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American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices

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Accredited Standards Committee C63®—Electromagnetic Compatibility

Accredited by the
American National Standards Institute

ANSI C63.10-2020
(Revision of ANSI C63.10-2013)

IEEE

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American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices

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: The procedures for testing the compliance of a wide variety of unlicensed wireless transmitters (also called intentional radiators and license-exempt transmitters) including, but not limited to, remote control and security unlicensed wireless devices, frequency hopping and direct sequence spread spectrum devices, antipilferage devices, cordless telephones, medical unlicensed wireless devices, Unlicensed National Information Infrastructure (U-NII) devices, intrusion detectors, unlicensed wireless devices operating on frequencies below 30 MHz, automatic vehicle identification systems, and other unlicensed wireless devices authorized by a radio regulatory authority are covered in this standard. Excluded by this standard are test procedures for unlicensed wireless devices already covered in other published standards (e.g., Unlicensed Personal Communication Services (UPCS) devices).

Keywords: ANSI C63.10, compliance testing, intentional radiators, license-exempt transmitters, spread spectrum devices, test procedures, Unlicensed National Information Infrastructure (U-NII), unlicensed wireless devices

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Introduction

This introduction is not part of ANSI C63.10-2020, American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices.

This standard provides procedures for testing the compliance of a wide variety of unlicensed wireless devices (transmitters). For information concerning those devices that are covered or not covered by this standard, see 1.2. Procedures for testing of some of these devices were previously provided in ANSI C63.4-2014,[1] but they will be removed in a future revision of that standard. The intention is to include all procedures in this standard for testing unlicensed wireless devices, except any devices excluded from the scope; for example, test procedures for Unlicensed Personal Communication Systems devices are addressed by ANSI C63.17-2013 [B5].[2]

[1] Information on references can be found in Clause 2.
[2] The numbers in brackets correspond to those of the bibliography in Annex N.

Contents

American National Standard of Procedures for Compliance Testing of Unlicensed Wireless Devices

1. Overview

1.1 Scope

This standard specifies U.S. consensus standard methods and instrumentation and test facilities requirements for measurement of radio frequency (RF) signals and noise emitted from unlicensed wireless devices (also called unlicensed transmitters, intentional radiators, and license-exempt transmitters) operating in the frequency range 9 kHz to 231 GHz. It does not include generic or product specific emission limits. It also does not cover measurement of radio emissions from unintentional radiators, as mentioned in 1.2. Where possible, the specifications herein are harmonized with other national and international standards used for similar purposes.

As described in 1.2 of this standard, measurement methods are provided for radiated and conducted emissions that can be generated by a variety of devices. For terms and phrases contained in the text that do not represent obvious or common usage, definitions are provided. In most cases, measurement instrumentation and calibration requirements, which should be used with this standard, are 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 and applications

Various unlicensed wireless devices (also known as unlicensed transmitters, intentional radiators, and license-exempt transmitters) are subject to certain 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 current wireless devices in wide use. It is not expected that all unlicensed wireless devices on the market will in fact be covered by this standard.

This standard does not consider test methods for unlicensed wireless devices already covered in other published standards, such as, but not limited to:

a) Unlicensed Personal Communications Services devices covered under ANSI C63.17-2013

b) Dynamic Frequency Selection (DFS) functionality required for U-NII devices in the United States

c) Industrial, Scientific and Medical equipment

d) RF exposure conformity assessment methods subject to standards such as IEEE Std 1528-2003

This document provides standard test methods for determining compliance with regulatory requirements for many types of unlicensed wireless devices. These unlicensed wireless devices include, but are not limited to, the following:

- Remote control and security unlicensed wireless devices
- Frequency hopping and direct sequence spread spectrum devices
- Digital transmission system devices
- Antipilferage devices
- Cordless telephones
- Radio frequency identification (RFID) tag readers
- Unlicensed National Information Infrastructure devices
- Intrusion detectors
- Unlicensed wireless devices operating below 30 MHz
- Wireless (garage) door openers
- Ultra-wideband (UWB) devices
- Automatic vehicle identification systems
- Inductive devices

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 the general requirements for all standard test methods. Clause 6 provides standard test methods required for most unlicensed wireless devices. Clause 7, Clause 8 (FM band devices), Clause 9 (millimeter-wave devices), Clause 10 (ultra-wideband devices), Clause 11 (DTS devices), Clause 12 (U-NII devices), Clause 13 (devices using antenna arrays), Clause 14 (devices with multiple outputs) identify additional tests or requirements for specific types of unlicensed wireless devices, and Clause 15 (Whitespace devices). Clause 17 specifies requirements for reporting test results.

All annexes in this edition are informative however if applied during testing to this standard the information becomes normative for that particular instance where the annex is applied. Annex A is a listing of the tests required to determine compliance of a specific unlicensed wireless device and gives examples of regulatory band-edge requirements for various unlicensed wireless devices. Because Annex A describes regulatory requirements for testing of unlicensed wireless devices, it serves as a key to use of this standard. Annex B is an example of the information to be included in a test report. Annex C is a discussion on instrumentation pulse desensitization considerations. Annex D provides information about detector types and functions used in EMC testing. Annex E provides information about measurements above 1 GHz from an instrumentation perspective. Annex F is a discussion on broadband measurements. Annex G provides guidelines for effective radiated power (ERP) and equivalent isotropic radiated power (EIRP) measurements. Annex H discusses the rationale for making radiated emission measurements using two different methods. Annex I discusses site considerations for measuring inductive-loop devices below 1 MHz. Annex J provides details of an alternative procedure for determining compliance of unlicensed FM transmitters. Annex K provides details and information on Dynamic Frequency Selection (DFS) testing. Annex L is a discussion on FMCW desensitization and sweep time considerations. Finally, Annex M and Annex N provide an informative glossary and a bibliography, respectively.

Use of the annexes and clauses applicable to an unlicensed wireless EUT allows users of this standard to determine compliance of a device with regulatory requirements. However, any test procedure identified for use by the national regulatory authority that differs from the provisions of this standard shall take precedence.

Not all clauses in this standard are applicable to all devices that can be measured with these methods. The nature of this standard is to specify general methods that can be applied to all devices within its scope and to supplement these methods with particular requirements for some types of devices. Device-specific requirements take precedence over general requirements. See Annex A for guidance in applying this standard to specific types of devices.

This document covers measurement methodologies but is not intended to describe regulatory limits.

As new measurement methods mature, this standard will be amended or a follow-up standard will be developed to present the new methods. It is also expected that the ASC C63® Committee that developed this standard will provide a forum for test laboratories, manufacturers, and government agencies to determine the need for additions and amendments of this standard to accommodate new wireless devices in the future.

1.3 Stating requirements and recommendations

For clarity in what is meant by the use of certain verbs in this standard, the following defines what each verb shown means:

- The word *shall* in this standard indicates a mandatory requirement that must be met to satisfy this standard. The word *shall* used in an informative annex indicates a mandatory requirement for the use of that annex (i.e., while the annex is not normative, if the user chooses to use it, then the mandatory requirements stated therein using the word *shall* must be observed).
- The word *should* is used to indicate recommendations.
- The word *may* is used to indicate that an action is permitted.
- The word *can* is used to express possibility.

NOTE—Use of these verbs follows the requirements in the IEEE Standards Board Operations and Style Manuals.

In addition, notes in this document are informative and are not part of the requirements. Notes are used in the text for emphasis or to offer informative suggestions about the technical content of the standard, and these notes provide additional information to assist the reader with a particular passage but do not include mandatory requirements.

Footnotes in text are included only for information, clarification, and/or as an aid applicable to the use of the standard, but mandatory requirements are not included in text footnotes.

In this standard the text takes precedence over the figures, when a figure is identified by inclusion of the word “example” in the figure caption, because the text is complete and the figures are an illustration of a typical application of the text.

Notes to tables and figures are informative; however, footnotes (i.e., superscript notation) to tables and figures are normative, as are numbered clauses between a figure and its caption (i.e., the list clauses in Figure 5 through Figure 7).

Numbered cross-references used throughout this standard refer to either a specific clause or subclause of this standard; for example, 6 refers to Clause 6, 6.2 refers to subclause 6.2, and B.2 refers to subclause B.2 of Annex B.

1.4 Measurement uncertainty

The results of measurements of emissions from an unlicensed wireless device shall include measurement instrumentation uncertainty considerations contained in ANSI C63.23. For tests not covered by ANSI C63.23, ETSI TR 100 028-2001 may be used. 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.

1.5 Dimensional tolerances

Normative maximum tolerances on dimensional requirements specified in this standard (e.g., EUT spacing, dimensions, and distances) shall be as stated in Table 1. Any commercial measurement devices (e.g., ruler, tape measure) may be used for the distance measurement. No calibration is required for these devices. Good engineering judgement should be made on any dimensional requirement not covered in Table 1.

Nominal dimensions are those dimensions that are stated without a specified tolerance. Nominal dimensions are, by definition, required to have tolerances that are consistent with good engineering practice. In particular, the tolerances selected by the user should be small in comparison to the dimension itself.

Table 1—EUT spacing, distances, and tolerances

Reference	Element	Spacing/ distances	Tolerance [a]	Measurement
5.10.2, 6.2.3.2.2, 8.3, Figure 6	Spacing between any two elements on the EUT support table.	10 cm	±1.0 cm	Conducted and radiated
6.2.2 Figure 6	Vertical conducting plane to rear of EUT/AE/support table. In case of protruding connectors on the rear face of the EUT/AE, the separation distance requirement applies for the rear face of the EUT/AE, not considering the protruding connector/cable end.	40 cm	±1.0 cm	Conducted
6.2.2, Figure 5	Spacing between LISN and EUT	≥80 cm	*	Conducted
6.2.2, Figure 5	Spacing between LISN and local peripherals.	≥80 cm	*	Conducted and radiated
6.2.2, 6.2.3.1, 6.3.1, 6.6.3.1, 6.6.3.3	Height to the top of EUT support table	80 cm (below 1 GHz) 1.5 m (above 1 GHz)	±1.0 cm	Conducted and radiated
6.2.2, 6.2.3.1, 6.3.1	Table size for tabletop measurements	1.0 m × 1.5 m	Nominal value (may be larger or smaller to accommodate various sized EUTs)	Conducted and radiated
6.3.1 Figure 6	Spacing between: table-top EUT/peripheral cables or bundled EUT/peripheral cables draped over the back of the table; and the RGP	40 cm above the RGP	±4.0 cm	Conducted and radiated
6.3.1	Cable bundles	30 cm to 40 cm	*	Conducted and radiated
5.3, 6.6.5.2	Measurement distance	3 m to 10 m	±0 m, 1 m	Radiated
6.4.6, 6.5.2, 6.6.3.2, 6.11.2	Lowest antenna height above reflecting plane	1 m	−5 cm, +0 cm	Radiated

Table 1—EUT spacing, distances, and tolerances[a] (continued)

Reference	Element	Spacing/ distances	Tolerance [a]	Measurement
6.5.2, 6.6.3.2	Highest antenna height above reflecting plane	4 m	−0 m, +5 cm	Radiated
6.2.3.3.1	insulating material thickness for cables that are normally insulated from the ground	>0 mm and ≤12 mm	*	Conducted and radiated
6.8, 9.5	Temperature settings during frequency stability testing	—	±2 °C	Conducted and radiated

[a] Where a one-sided range is specified, the tolerance is 0% below the *greater than* value, and 0% above the *less than* value, and no specified tolerance on the other end. Where a two-sided range is specified, there is no tolerance on the upper value and lower value. Both these cases are designated with asterisks in this table.

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.

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

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 C63.4a, 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—Amendment 1: Test Site Validation.

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

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

ANSI C63.14, 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.

ANSI C63.25.1, American National Standard Validation Methods for Radiated Emission Test Sites, 1 GHz to 18 GHz.

CISPR 16-1-1:2019, Specification for radio disturbance and immunity measuring apparatus and methods—Part 1-1: Radio disturbance and immunity measuring apparatus—Measuring apparatus.[4]

[3] C63® publications are available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/) and the American National Standards Institute (https://www.ansi.org/).
[4] CISPR documents are available from the International Electrotechnical Commission (http://www.iec.ch/) and in the United States from the American National Standards Institute (http://www.ansi.org/).

CISPR 16-1-4:2019, Specification for radio disturbance and immunity measuring apparatus and methods—Part 1-4: Radio disturbance and immunity measuring apparatus—Antennas and test sites for radiated disturbance measurements.

ETSI TR 100 028 V1.3.1 (2001-03), Electromagnetic compatibility and Radio spectrum Matters (ERM); Uncertainties in the measurement of mobile radio equipment characteristics—Part 1 and Part 2.[5]

IEEE Std 1309-2013, IEEE Standard for Calibration of Electromagnetic Field Sensors and Probes (Excluding Antennas) from 9 kHz to 40 GHz.[6, 7]

ISO 10012:2003, edition 1, Measurement management systems — Requirements for measurement and measuring equipment.[8]

RSS-210, Licence-Exempt Radio Apparatus: Category I Equipment, Innovation, Science and Economic Development Canada.[9]

RSS-220, Devices Using Ultra-Wideband (UWB) Technology, Innovation, Science and Economic Development Canada.

RSS-247, Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and Licence-Exempt Local Area Network (LE-LAN) Devices.

RSS-310, Licence-Exempt Radio Apparatus: Category II Equipment, Innovation, Science and Economic Development Canada.

RSS-Gen, General Requirements for Compliance of Radio Apparatus—Limits and Methods of Measurement.

U.S. Code of Federal Regulations Title 47—Telecommunication, Chapter I—Federal Communications Commission, Part 15—Radio Frequency Devices (47 CFR Part 15).[10]

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. ANSI C63.14 and the *IEEE Standards Dictionary Online* should be referenced for terms not defined in this clause.[11] Definitions in wireless device product standards or regulations shall take precedence where applicable. See also the Glossary provided in Annex M, which includes various terms relevant for wireless devices compiled from the FCC, ITU, and other documents.

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

calibration: Operation establishing the relation between quantity values provided by measurement standards and the corresponding indications of a measuring system, carried out under specified conditions including measurement uncertainty.

[5] ETSI publications are available from the European Telecommunications Standards Institute (http://www.etsi.org/).
[6] IEEE publications are available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/).
[7] The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.
[8] ISO publications are available from the ISO Central Secretariat (http://www.iso.org/). ISO publications are also available in the United States from the American National Standards Institute (http://www.ansi.org/).
[9] RSS publications are available from Innovation, Science and Economic Development Canada (http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06129.html).
[10] CFR publications are available from the U.S. Government Printing Office (http://www.gpo.gov/).
[11] The *IEEE Standards Dictionary Online* is available at https://dictionary.ieee.org. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

continuous transmit mode: A mode in which the unlicensed wireless device is continuously transmitting at a 100% duty cycle.

NOTE—Where specified by the test requirements, a duty cycle of greater than 98% may be acceptable.

emission bandwidth (EBW): An unlicensed wireless device parameter determined by measuring the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, which are 26 dB down relative to the maximum level of the modulated carrier based on the use of measurement instrumentation employing a peak detector function with an instrument resolution bandwidth approximately equal to 1.0% of the emission bandwidth of the device under measurement. [47 CFR §§ 15.303(c), 15.403(i) – MOD]

NOTE—See also the similar but distinct terms and concepts authorized bandwidth, necessary bandwidth, and occupied bandwidth in Annex M.

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

floor-standing equipment: 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).

inductive-loop device: A low frequency unlicensed wireless device used for low frequency radio frequency identification (RFID) devices, access control card readers, electronic article surveillance, and so on, consisting of a simple inductive single-loop coil or co-planar phase aiding loops for generating a magnetic field.

intentional radiator: A device that intentionally generates and emits radio frequency energy by radiation or induction and can be operated with or without an individual license. *Syn:* **license-exempt transmitter; unlicensed wireless device**.

license-exempt transmitter: A device that intentionally generates and emits radio frequency energy by radiation or induction and can be operated with or without an individual license. *Syn:* **intentional radiator; unlicensed wireless device**.

line impedance stabilization network (LISN): A network inserted in the power supply lead of equipment under test (EUT) to be tested that provides, in a given frequency range, a specified load impedance for each current-carrying conductor for the measurement of disturbance voltages and that isolates the apparatus from the power supply in that frequency range, and couples the EUT emissions to the measuring instrument.

NOTE—A LISN unit can contain one or more individual LISN circuits.[12]

occupied bandwidth: the bandwidth containing 99% of the total integrated power of the transmitted spectrum, centered on the assigned frequency.

peak power: Power measured with the peak detector using a filter with adequate bandwidth and shape to accept the signal bandwidth.

restricted-bands: Frequency bands in which fundamental emissions of an intentional radiator are not permitted.[13] *Syn:* **exclusion bands**.

spectral plot: A graphical representation of the emissions in the frequency-domain showing the full spectrum measured over any given frequency range

[12] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.
[13] See 47 CFR 15.205.

symbol rate: The rate at which the waveform changes per second using a digitally modulated signal. It is measured in baud or symbols per second for a modulated signal. Each symbol can represent or convey one or several bits of data. The reciprocal of the symbol rate is called the symbol period.

system: A configuration of interconnected devices, including accessories and peripherals, and their cables, which is designed to perform a particular function or functions.

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

test equipment: Equipment that is intended primarily for the purposes of performing measurements or scientific investigations. Such equipment includes, but is not limited to, field strength meters, spectrum analyzers, and modulation monitors.[14]

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

unintentional radiator: A device that intentionally generates radio frequency (RF) energy for use within the device or that sends radio frequency signals by conduction to associated equipment via connecting wiring but that is not intended to emit radio frequency energy by radiation or induction.[15]

Unlicensed National Information Infrastructure (U-NII) device: Intentional radiator operating in the frequency bands 5.15 GHz to 5.25 GHz, 5.25 GHz to 5.35 GHz, 5.470 GHz to 5.725 GHz, and 5.725 GHz to 5.85 GHz that use wideband digital modulation techniques and provide a wide array of high data rate mobile and fixed communications for individuals, businesses, and institutions.

NOTE—A high data rate is defined as a bit rate of 1 Mbps or more.

unlicensed wireless device: (A) A low power communication device that intentionally generates and emits radio frequency energy by radiation or induction. These devices or systems typically can be operated without an individual license in some countries, provided they comply with certain technical and administrative requirements. **(B)** Device that is permitted to emit radio frequency (RF) energy but requires no specific device licensing or user authorization.[16] *Syn:* **intentional radiator; license-exempt transmitter**.

NOTE—This term also is essentially the same as “short range device” used by various regulatory authorities.

3.2 Acronyms and abbreviations

ac	alternating current
AVG	average
dc	direct current
DFS	dynamic frequency selection
DTS	digital transmission system
EBW	emission bandwidth
EIRP	equivalent isotropically radiated power
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ERP	equivalent radiated power
EUT	equipment under test
FHSS	frequency hopping spread spectrum
GNSS	global navigation satellite system
GPR	ground-penetrating radar

[14] 47 CFR 15.3(dd).
[15] 47 CFR 15.3(z).
[16] FCC/DA 03 1758 [B27].

IF	intermediate frequency
LISN	line impedance stabilization network
LPDA	log periodic dipole array
MIMO	multiple-input multiple-output
NSA	normalized site attenuation
OATS	open-area test site
OBW	occupied bandwidth
OET	Office of Engineering and Technology (FCC)
PDA	personal digital assistant
PK	peak
PRF	pulse repetition frequency
PDCF	pulse desensitization correction factor
PPSD	peak power spectral density
PSD	power spectral density
QP	quasi-peak
RBW	resolution bandwidth
RF	radio frequency
RFID	radio frequency identification
SA	Sample
SISO	single input single output
SPL	sound pressure level
TVWS	television whitespace
Tx	transmit
U-NII	Unlicensed National Information Infrastructure
UWB	ultra-wideband
VBW	video bandwidth
WIR	wall-imaging radar
WPT	wireless power transfer

4. Measurement instrumentation

4.1 Emission measuring instrumentation

4.1.1 General considerations

Use of proper measurement instrumentation is critical to obtaining accurate, reproducible results. Various equipment accessories and settings can be needed depending on the particular measurements to be performed, as described in 4.1.2 through 4.1.7.

This standard recognizes that both spectrum analyzers and electromagnetic interference (EMI) receivers can be used for making emission measurements. Measurement instrumentation used for making radiated and alternating current (ac) power-line conducted radio-noise measurements include those that conform to the specifications contained in either:

— ANSI C63.2

— CISPR 16-1-1:2019 (for measurements up to and including 18 GHz)

NOTE—ANSI C63.2 normatively references CISPR 16-1-1 for frequencies up to 18 GHz.

Typically a spectrum analyzer does not meet all the requirements stated in ANSI C63.2 or CISPR 16-1-1:2019 without additional accessories. Appropriate accessories, such as preselection, quasi-peak detection, and specific intermediate frequency (IF) filters, can be used with a spectrum analyzer; this combination can be equivalent to a receiver, meeting the requirements in either specification.

4.1.2 Receiver

The receiver for measurements of radiated and ac power-line conducted radio-noise is an instrument conforming to 4.1.1. Automatic scanning receivers may be used, but the maximum scan speed shall be selected such that calibrated measurements can be performed (based on the IF bandwidth selection) and the signals are properly intercepted (e.g., based on the pulse repetition frequencies). Requirements for selecting the proper bandwidth are given in 4.1.5.

If the output of the quasi-peak or linear average detector is indicated in logarithmic units, then the logarithms shall be taken in the measuring instrument after the signal is detected and the detector function is fully realized. It shall be confirmed that the output indication represents the logarithm of the true quasi-peak or linear average value of the signal measured.

4.1.3 Spectrum analyzer

The use of spectrum analyzers for radiated and ac power-line conducted radio-noise compliance measurements are permissible only if they meet all specifications called out in the standards listed in 4.1.1.

To meet the requirements in 4.1.5, spectrum analyzers shall be equipped with proper quasi-peak and linear average detection. However, measurements with the positive peak detector of the instrument are permissible to demonstrate compliance of the EUT, as long as the required resolution bandwidth is used, because positive peak detection yields amplitudes equal to or greater than amplitudes measured with the quasi-peak or linear average detector. Thus, the data measured using the positive peak detector of a spectrum analyzer represents the worst-case results.

Nominal values for the resolution bandwidth shall be as specified in 4.1.5. Most spectrum analyzers implement a resolution bandwidth specification of −3 dB, with a Gaussian shape, which is acceptable because larger bandwidths are permissible. The resolution bandwidths cited in the standards listed in 4.1.1 do not have a Gaussian shape but are instead specified individually by their frequency response (i.e., “masks”). When using larger bandwidths than those specified, or filters with different transfer functions, different measurement results for broadband signals can be expected. In case of dispute, the test results measured with one of the reference receivers defined in 4.1.2 shall take precedence.

For a spectrum analyzer to meet the specifications of one of either of the two standards listed in 4.1.1, it shall provide adequate overload protection and system dynamic range, achieve proper weighting of pulses when using quasi-peak detection, and have the resolution bandwidths specified in either CISPR 16-1-1:2019 or ANSI C63.2. If a spectrum analyzer is to be used to make quasi-peak measurements of low-repetition-rate signals (i.e., pulse repetition rate of 20 Hz or less), then the use of a preselector is required to provide adequate dynamic range of the instrument.

When using spectrum analyzers for measurements, the following characteristics shall be addressed:

a) **Overload**—Most spectrum analyzers have no RF preselection in the frequency range up to 2 GHz; that is, the input signal is directly fed to the broadband input mixer. To avoid overload, to reduce the chance of damage, and to operate the spectrum analyzer linearly, the signal amplitude at the mixer shall be less than the manufacturer’s stated specification for the maximum input level for linear operation.[17] RF attenuation and/or additional RF preselection may be required to reduce the input signal to this level.

b) **Linearity test**—Linearity can be verified by measuring the level of the specific signal under investigation and repeating this measurement after a 6 dB or greater external attenuator has been inserted at the input of the measuring instrument, or, if used, of the preamplifier. The new reading of the measuring instrument display, plus the inserted attenuation, shall differ by not more than ± 0.5 dB from the first reading for deeming the measuring system is linear; see ANSI C63.4-2014

[17] The typical maximum input level for the linear operation of a spectrum analyzer is 150 mV peak; regardless, users should be aware of the actual maximum input level for the linear operation of their particular spectrum analyzer.

Annex H.3 for details. In case of broadband time-variant signals and spread-spectrum signals, the linearity test may be performed by setting the analyzer in maximum hold with positive peak detector function, separately, for each one of the two measurements.

c) Normal response to pulses—The response of a spectrum analyzer with quasi-peak detection shall be verified with the reference test pulses specified in CISPR 16-1-1:2019. The large peak voltage of the reference test pulses typically requires an insertion of RF attenuation of 40 dB or more to satisfy the linearity requirements. This decreases the instrumentation sensitivity and makes the measurement of low-repetition-rate and isolated test pulses impossible for CISPR bands B, C, and D.[18] If a preselecting filter is used at the input of the spectrum analyzer, then the RF attenuation can be decreased. The filter limits the spectrum width of the calibration test pulse as seen by the mixer.

d) **Signal interception**—The spectrum of intermittent and/or time varying emissions can be captured with positive peak detection and digital display storage (i.e., "max-hold" function). Multiple, fast frequency scans reduce the time to intercept an emission compared with a single, slow frequency scan. The starting time of the scans shall be varied to avoid any synchronism with the emission and thereby masking it. The total observation time for a given frequency range shall be longer than the time between the emissions. Depending on the type of emission being measured, the positive peak detection measurements can replace all or part of the measurements needed using quasi-peak or linear average detection. Retests using a quasi-peak or linear average detector shall then be made at frequencies where emission maxima have been found.

e) **Linear average detection**—For spectrum analyzers not equipped with a linear average detector as specified in 4.1.5.2, an alternate method of linear average detection with a spectrum analyzer can be obtained by setting the detector mode to positive peak and reducing the video bandwidth until no significant variations in the displayed signal are observed from trace to trace; see 4.1.5.2.3 for a basic measurement procedure. The sweep time shall be increased with reductions in video bandwidth to maintain amplitude calibration. For such measurements, the instrument shall be used in the linear mode of the detector, and maximum-hold processing of traces shall be employed to achieve a maximum reading. After linear detection is made, the signal can be processed logarithmically for display, in which case, the value is corrected even though it is the logarithm of the linearly detected signal.

f) Voltage average detection—For spectrum analyzers not equipped with a linear average detector as specified in 4.1.5.2, an alternative method of linear average detection for measurements with a spectrum analyzer can be obtained by setting the detector mode to peak and reducing the video bandwidth; see 4.1.5.2.3 for a basic measurement procedure.

NOTE 1—A logarithmic amplitude display mode may be used for investigation or exploratory purposes; for example, to distinguish more easily between narrowband and broadband signals. The displayed value is the average of the logarithmically distorted IF signal envelope. A logarithmic amplitude display mode results in a larger attenuation of broadband signals than in the linear detection mode without affecting the display of narrowband signals. Therefore, video filtering in the log display mode is especially useful for estimating the narrowband component in a spectrum containing both broadband and narrowband signals. *This technique is useful for troubleshooting but cannot be used for compliance measurements.*

When performing final compliance measurements, the video bandwidth shall be set to a value lower than the lowest pulse repetition frequency of the measured signal, but not lower than 1 Hz, in accordance with CISPR 16-1-1:2019, so that the proper integration time is realized; H.5 in Annex H of ANSI C63.4-2014 provides other details.

NOTE 2—Notwithstanding the video bandwidth requirements of 6.4 of CISPR 16-1-1:2019, the measurement procedure standards CISPR 16-2-1:2014/AMD1:2017 [B6] (i.e., Annex D therein) and CISPR 16-2-3:2016 [B7] (i.e., Annex C therein) allow the use of higher video bandwidths, at least for pre-scan measurements, when measuring slowly intermittent, unsteady, or drifting narrowband disturbance signals that have pulse repetition frequencies or modulation frequencies greater than 5 Hz. Also, because the measurand in 6.4 of CISPR 16-1-1:2019 is specified to be the peak reading, the larger amplitude fluctuations that occur with the use of a higher-than-specified video bandwidth provides a conservative measurement result (i.e., higher emission level).

[18] CISPR 16-1-1:2019 band B is 0.15 MHz to 30 MHz, and bands C and D are 30 MHz to 1000 MHz.

g) **Selection of display mode**—For measurements with peak detector (e.g., where the limit is specified for peak detection), the positive peak detector shall be selected, so that the highest emission amplitudes are displayed.

h) Bin size-When using a spectrum analyzer, its bin size shall be no larger than half the measurement (resolution) bandwidth when using anything other than peak detection.

NOTE—Bin size is specific to instruments having a digital display and describes the frequency resolution (horizontal resolution) of that instrument's display. The instrument determines the level to be displayed at each "trace point" by applying the selected detector function to all input signal samples within the "bin" corresponding to that "trace point". For example, positive peak detector function will select the input signal sample having the highest amplitude for display and discard all the other samples in that bin. As such, greater frequency accuracy is achieved by decreasing the span because the "bin" will include a larger number of samples. When using peak detection with a bin size >> RBW caution needs to be taken when determining the actual frequency of the emission and to ensure there are not multiple, high amplitude narrowband signals within a frequency bin by zooming in one the individual frequencies with span > 2 × bin size to more accurately determine frequency(ies) of signals in the original scan.

i) When using the auto OBW function of an analyzer, the span setting must be sufficiently wide to include the entire signal being measured plus at least 5%. If this is not done, the OBW data may be incorrect.

4.1.4 FFT-based measurement instrument

Spectrum analyzers or EMI receivers equipped with FFT capabilities shall be compliant with the requirements stated in 4.1.1 in order to be considered acceptable for use.

4.1.5 Detector functions and selection of bandwidth

4.1.5.1 General considerations

Unless otherwise specified, EMI receivers or spectrum analyzers shall have the detector functions and bandwidths specified in either ANSI C63.2 or CISPR 16-1-1:2019 for frequencies up to and including 18 GHz; above 18 GHz, the detector functions and bandwidths specified in ANSI C63.2 shall be used.

In the frequency range from 1 GHz to 18 GHz, the IF filter used in an EMI receiver or in a spectrum analyzer shall satisfy any one of the following requirements:

a) The IF filter shall comply with the selectivity criterion called out in Figure 9 of CISPR 16-1-1:2019; or

b) The IF filter shall have a 1 MHz impulse bandwidth; or

c) If the 1 MHz measurement bandwidth of the IF filter is not calibrated as the impulse bandwidth, a correction factor for broadband signal amplitudes shall be applied.

For EMI receivers or spectrum analyzers subject to the preceding condition c), the necessary correction factor shall be determined as follows:

— The impulse bandwidth, B_{imp}, of the 1 MHz IF filter shall be determined by measurements made in accordance with the method stated in E.7 of CISPR 16-1-1:2019.

— A bandwidth correction factor shall be applied ONLY when broadband signal amplitudes are measured. The broadband correction factor (in dB) shall be calculated using the equation:

$$C_{BB} = 20\log\left(B_{imp} / B_{meas}\right)$$

where B_{meas} equals the measurement bandwidth (i.e., 1 MHz). This correction factor is to be added algebraically to the broadband signal level measured using the available 1 MHz IF bandwidth.

In the frequency range from 18 GHz to 40 GHz, the IF filter used in an EMI receiver or in a spectrum analyzer shall satisfy the requirements stated under either the preceding item b) or item c).

Positive peak detector measured data may be substituted for the reference detector data to show compliance, as long as the required resolution bandwidth is maintained or exceeded, if the peak level obtained does not exceed the limit. The bandwidth used shall be equal to or greater than that specified in ANSI C63.2 or CISPR 16-1-1:2019. Use of bandwidths greater than those specified may produce higher readings for certain types of emissions. If bandwidths greater than those specified are used, the actual bandwidths used shall be recorded in the test report. In case of dispute, the reference receiver shall take precedence. More than one instrument may be needed to perform all of these functions and/or to cover the complete frequency range of interest.

The measuring instrument shall satisfy the following provisions:

- The quasi-peak detector shall have a linear response.
- The average detector shall have a linear response and shall meet the linear average specifications in ANSI C63.2 or CISPR 16-1-1:2019. This is a voltage average detector. A logarithmic average detector or CISPR rms detector shall not be used for making measurements in accordance with ANSI C63.4.
- When measuring an emission with a low duty cycle, the dynamic range of the measuring instrument shall be adequate to yield correct and calibrated results.

When using a spectrum analyzer or other instrument that allows access to the video bandwidth setting, for peak measurements, this bandwidth shall be set to a value at least three times greater than the IF bandwidth of the measuring instrument, to avoid the introduction of unwanted amplitude smoothing.

4.1.5.2 Specific detector functions and bandwidths for unlicensed wireless device measurements

Measurement of conducted and radiated emissions from unlicensed wireless devices is based on the following considerations (4.1.5.2.1 to 4.1.5.2.8), unless otherwise specified elsewhere in this standard.

4.1.5.2.1 Frequencies less than or equal to 1000 MHz

At any frequency or frequencies less than or equal to 1000 MHz, measurements shall be made with the CISPR quasi-peak detector and related measurement bandwidths, unless otherwise specified. The specifications for the measuring instrument using the CISPR quasi-peak detector are given in

CISPR 16-1-1:2019. Where average limits are specified, an average detector shall be used. Where peak limits are also specified, proper corrections for factors such as a pulse desensitization shall be applied to the peak emission measurements.[19] As an alternative to CISPR quasi-peak measurements or average measurements, a test laboratory may demonstrate compliance with the emission limits using measuring equipment employing a peak detector function as long as the equivalent or greater bandwidths as indicated for CISPR quasi-peak measurements or average measurements, as applicable, are employed.

Pulse-modulated devices with a pulse repetition frequency of 20 Hz or less have additional requirements.[20]

4.1.5.2.2 Frequencies above 1000 MHz

Unless otherwise stated, on any frequency or frequencies above 1000 MHz, measurements shall be made with measurement instrumentation employing an average detector function.[21] Unless otherwise specified,

[19] See 47 CFR 15.35(b).
[20] Clause 4 of ANSI C63.4, as referenced by 47 CFR 15.35(a), provides additional guidance for the measurement of signals with a pulse repetition frequency of 20 Hz or less when CISPR quasi-peak measurements are specified.

measurements above 1000 MHz shall be performed using a minimum resolution bandwidth of 1 MHz. Peak measurements can apply to the total peak emission level radiated by the device (i.e., the total peak power level) depending on the applicable regulatory requirement. Note that the use of a pulse desensitization correction factor might be needed to determine the total peak emission level. See 4.1.5.2.7 and Annex C for more information and methods for determining pulse desensitization factors.

See 4.1.5.2.8 and Annex L for more information and methods for determining FMCW desensitization factors and suitable instrument sweep times when measuring FMCW emissions.

4.1.5.2.3 Average voltage measurements using spectrum analyzer reduced video bandwidth

When the spectrum analyzer is not equipped with an average detector (4.1.5.1), the following alternative method may be used for average voltage measurements:

a) Tune the instrument to the signal of interest by setting its center frequency to the signal frequency. The resolution bandwidth shall be set according to the frequency of measurement.

b) Set the spectrum analyzer frequency span to capture fully the emission that is to be measured while keeping the peak value of the measured signal in the center of the display.

c) The display mode shall be set to a positive peak detector and the sweep time shall be auto-coupled.

d) Set the instrument to perform video filtering in a linear (voltage) mode. For many instruments, this will require setting the vertical scale to linear and amplitude units to voltage (µV or dBµV). If the analyzer can set the video filter averaging type independently of the display settings, the average type shall be voltage average.[22]

e) Set the reference level of the instrument, as required, to reduce the chance of the signal exceeding the maximum spectrum analyzer input mixer level for linear operation. In general, the peak of the spectral envelope shall be at least [10 log (OBW/RBW)] below the reference level (OBW is occupied bandwidth and RBW is resolution bandwidth). Specific guidance is given in 4.1.6.2.

f) Reduce the video bandwidth until no significant variations in the displayed signal are observed in subsequent traces, provided the video bandwidth is no less than 1 Hz. For regulatory requirements that specify averaging only over the transmit duration (e.g., digital transmission system [DTS] and Unlicensed National Information Infrastructure [U-NII]), the video bandwidth shall be greater than [1 / (minimum transmitter on time)] and no less than 1 Hz. EUTs shall be operated with a maximum duty cycle which is representative of normal worst-case operating conditions or measured using a peak detector corrected with a duty cycle correction factor.

g) Set the trace display for maximum hold until it is stabilized, then record the highest level.

This method yields the linear average value of signals at the input of a spectrum analyzer measured with a specified resolution bandwidth.

Additional details about the use of spectrum analyzers for average measurements are given for example in Linkwitz [B64].

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[21] If an average limit is specified for the EUT, then proper corrections for factors such as pulse desensitization and FMCW desensitization shall be applied to peak emission measurements, to demonstrate that the peak emission is less than 20 dB above the average limit per U.S./FCC regulations. [See 47 CFR 15.35(b).]

[22] If unsure of the analyzer capabilities, then a check that the correct averaging is being performed using the reduced video filtering method can be made by measuring the peak and average values of a pulse-modulated carrier set for a 50% duty cycle, a period of approximately 2 ms, and an amplitude at least 40 dB above the instrument noise floor. Both peak and average measurements are made using a 1 MHz resolution bandwidth and a peak detector. The average measurement shall be performed using a video bandwidth of 1 Hz. The peak measurement shall be performed using a video bandwidth of at least 3 MHz. The difference between peak and average values of the signal should be ~6 dB if a linear voltage average is being performed. The difference will be 20 dB or more between peak and log-average measurement results. The verification should be performed using the same measurement control software used for subsequent EUT measurements.

NOTE—A logarithmic amplitude display mode may be useful, for example, to distinguish more easily between narrowband and broadband signals. A logarithmic amplitude display mode results in a larger attenuation of broadband signals than in the linear display mode without affecting the display of narrowband signals (assuming a 100% duty cycle). Therefore, video filtering in the log display mode is especially useful for determining the narrowband component in a spectrum containing both broadband and narrowband signals.

4.1.5.2.4 Using an external preamplifier with a spectrum analyzer or EMI receiver

Spectrum analyzers or EMI receivers may lack the appropriate sensitivity to perform EMI measurements, because of a higher instrument noise figure. Adding an external preamplifier to the measuring instrument serves as a method to improve the measurement system sensitivity. However, the dynamic range of the measurement system is affected, as well as the amplitude accuracy. In addition, overload requirements for the measuring instrument shall be accounted for, to avoid possible erroneous measurement results. Subclause J.2 in Annex J of CISPR 16-1-1:2019 describes detailed considerations for the best design of an emission test system which includes a measuring instrument and an external preamplifier.

The performance of the system, i.e., system noise level and overload capability, will depend on the characteristics of both the preamplifier and the measuring receiver; therefore, it is necessary to properly understand the linearity specifications of both the measuring instrument and the preamplifier. The guidance given in J.3 of Annex J of CISPR 16-1-1:2019 shall be followed. Proper precautions to avoid overload or saturation conditions during the measurement shall be taken, i.e., in the form of linearity checks of the system, as defined in J.3 of CISPR 16-1-1:2019. If a measuring instrument with fast Fourier transform (FFT) technology is used, specific requirements for overload detection shall be accounted for, as documented in J.4 of Annex J of CISPR 16-1-1:2019.

4.1.5.2.5 Average value of pulsed emissions

Unless otherwise specified, when the radiated emission limits are expressed in terms of the average value of the emission and pulsed operation is employed, the average measurement shall be determined from the peak field strength after correcting for the worst-case duty cycle as described in 7.5. The exact method of calculating the average field strength shall be included in the test report.

As an alternative the average value may be measured directly provided that the device is operating at, or above, the maximum operational duty cycle and the operational duty cycle is fixed trough the protocol or device firmware. The averaging time shall be the period of the pulse train or 100 ms, whichever is the smaller.

Where required (e.g., some DTS and U-NII devices) the average value for devices with pulsed emissions must be measured over the on-time of the transmission. For these devices if the average value is measured with the device operating at a duty cycle of less than 100% the measured value must be corrected upwards based on the duty cycle during the measurement (refer to Clause 11 and Clause 12).

The average value may not be determined, except where explicitly allowed otherwise (e.g., for FHSS devices) by measuring the average value and then applying a duty factor correction to further reduce the measured value.

4.1.5.2.6 Measurement of power average (rms) emissions

For testing ultra-wideband systems and other systems that require average readings based on a power average (rms) value, a spectrum analyzer with a power average detector shall be used. The analyzer shall provide a means to record, store, and display the rms values across the desired band of operation. The analyzer bin size shall not exceed 50% of the measurement bandwidth.

4.1.5.2.7 Pulse desensitization

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

NOTE 1—PDCF typically applies only to peak emission measurements. As an example, where a requirement specifies that a minimum 1 MHz resolution bandwidth is employed for emission measurements above 1000 MHz, when pulse widths are narrower than the inverse of the resolution bandwidth 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).

NOTE 2—PDCF typically is not applicable for ultra-wideband (UWB) device measurements; regulatory authorities might specify other measurement procedures for determining compliance with UWB regulations.

4.1.5.2.8 FMCW desensitization and sweep time

Some unlicensed wireless devices utilize FMCW modulation. As with pulse modulation, FMCW modulation can impact instrumentation accuracy due to the response of the RBW filter to the modulation. Additionally, there are sweep time constraints when measuring FMCW signals.

NOTE 1—FMCW modulation is often selected for radiolocation and material characterization applications.

Compliance measurements are typically performed with a receiver or spectrum analyzer. Depending on various factors (resolution bandwidth, instrument sweep time, FMCW Chirp Bandwidth, FMCW Chirp Time, etc.), the instrument might not display the true peak value or the true average value of the emission.

For peak emissions with a valid sweep time, this effect, called “FMCW desensitization,” relates to the capabilities of the measuring instrument and to the characteristics of the emission.

For the measurement of the true peak of FMCW emissions it shall be determined whether to apply an FMCW desensitization factor to the measured value.

For the measurement of the true average of FMCW emissions it shall be determined whether to utilize a very slow instrument sweep time relative to the period of the modulation.

See Annex L for information and methods for determining FMCW desensitization factors and suitable instrument sweep times.

Where harmonics of the FMCW signal are observed the Chirp Time will be the same as for the fundamental, while the Chirp BW will be N times larger than for the fundamental, where N is the harmonic number. For example, the Chirp BW of the 3rd harmonic will be 3 times the Chirp BW of the fundamental.

NOTE 2—A common means of generating an FMCW signal is to apply the FMCW modulation at a relatively low frequency and multiply it up to the fundamental operating frequency.

Where subharmonics of the FMCW signal are observed, the Chirp Time will be the same as for the fundamental while the Chirp BW will be N times smaller than for the fundamental, where N is the subharmonic number. For example, the Chirp BW of the 4th subharmonic will be 0.25 times the Chirp BW of the fundamental.

Thus, the FMCW Desensitization Factor will be different for each subharmonic, the fundamental, and each harmonic.

As the Chirp Time is the same for subharmonics, the fundamental and harmonics, the required instrument sweep time will be the same for all these classes of emissions.

4.1.6 Reference level, attenuation, and headroom

4.1.6.1 General considerations

For measurements where the bandwidth of the emission is greater than the resolution bandwidth of the measuring instrument, care must be taken to ensure that the input mixer of the instrument is operating in its linear region and is not saturating or clipping the signal.

For measurements where the bandwidth of the emission is less than or equal to the resolution bandwidth of the measuring instrument, it is generally sufficient that the peak of the displayed signal be less than the reference level, as long as the instrument attenuation is set to AUTO.

4.1.6.2 Setting the proper reference level and input attenuation

a) Set attenuation to auto. (If finer control of attenuation is required to achieve a sufficiently low noise floor for out-of-band measurements, then manual setting of attenuation is permitted provided that the power level corresponding to the reference level setting specified below falls within the mixer level range recommended by the instrument manufacturer.)

b) Set the reference level based on power measurements of the signal or by ensuring that the “head room” between the maximum spectrum level and the reference level is at least [10 log (99% occupied bandwidth / RBW)]. The nominal channel bandwidth or the emission bandwidth may be substituted for 99% occupied bandwidth in this formula, if a measurement of occupied bandwidth is not available.

    1) Additional headroom (i.e., higher reference level) equal to [10 log (1 / duty cycle)] will be needed if the headroom calculation is based on power or spectrum measurements that are averaged across the ON/OFF cycle of the transmission. (For example, the reference level should be set 3 dB higher if the settings are based on power or spectrum measurements that are averaged across the ON/OFF cycles of a 50% duty cycle transmission.)

    2) For in-band measurements, the reference level is based on in-band power or maximum in-band spectrum level.

    3) The same reference level is also used for out-of-band measurements, unless a preselector attenuates the in-band signal sufficiently to justify a lower reference level.

4.1.7 RF power meter

A peak responding power meter and sensor, where permitted, may be used to measure the fundamental emission of the output power. When used, the video bandwidth of the combination of the power meter and sensor shall be greater than the occupied bandwidth of the unlicensed wireless device.

4.2 Line impedance stabilization network

A LISN having the impedance magnitude and phase angle listed in Table 2 and Table 3, and illustrated in Figure 1 and Figure 2 shall be used for ac power-line conducted emission measurements, except for in situ measurements (see 6.11.4) When the measuring instrument (receiver or spectrum analyzer) ports of the LISN are each terminated into an impedance of 50 Ω, the characteristic impedance in Table 2 or Table 3 or both (based on the measurement frequency range of conducted emissions from the EUT) shall be present at the EUT ports of the LISN.

Table 2—Impedance and tolerance specifications at LISN terminals (without extension cord), 50 µH and 250 µH LISN

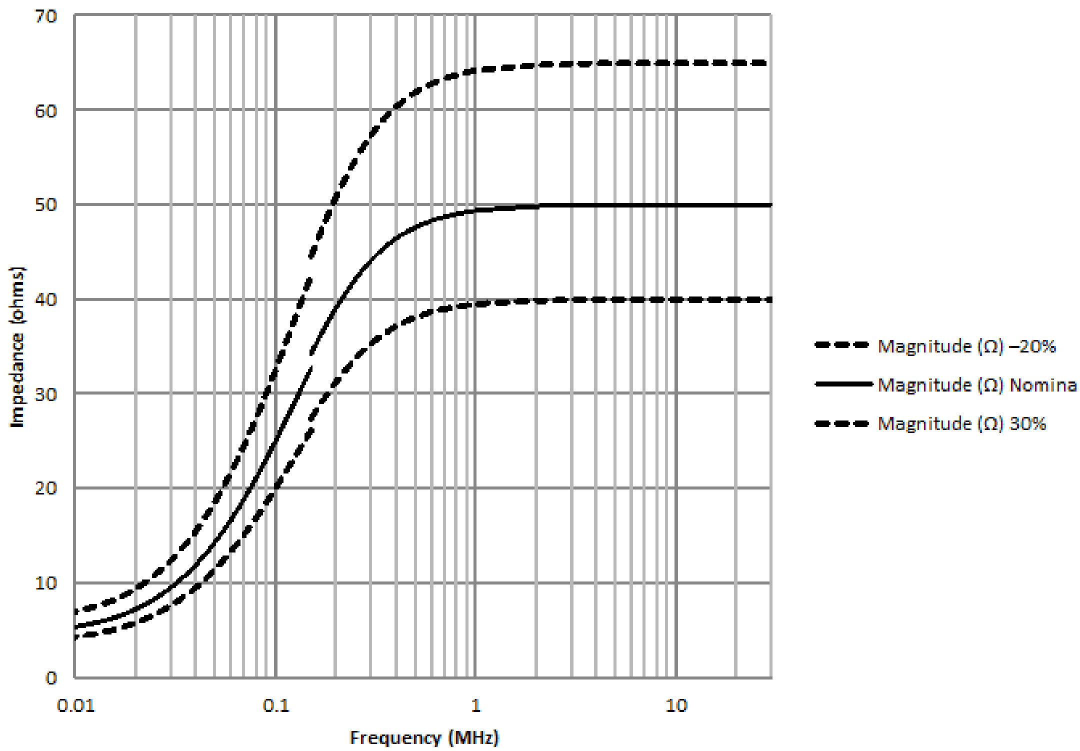
Frequency (kHz)	Magnitude (Ω)			Phase (degrees)		
	–20%	Nominal	+20%	–11.5°	Nominal	+11.5°
9	4.172	**5.215**	6.258	15.045	**26.545**	38.045
10	4.288	**5.359**	6.431	17.373	**28.873**	40.373
15	4.979	**6.223**	7.468	26.907	**38.407**	49.907
20	5.802	**7.253**	8.703	33.471	**44.971**	56.471
25	6.703	**8.379**	10.055	37.891	**49.391**	60.891
30	7.648	**9.560**	11.472	40.830	**52.330**	63.830
35	8.614	**10.768**	12.921	42.742	**54.242**	65.742
40	9.589	**11.986**	14.383	43.933	**55.433**	66.933
45	10.562	**13.203**	15.844	44.607	**56.107**	67.607
50	11.528	**14.410**	17.292	44.904	**56.404**	67.904
60	13.417	**16.771**	20.125	44.726	**56.226**	67.726
70	15.229	**19.037**	22.844	43.897	**55.397**	66.897
80	16.951	**21.188**	25.426	42.690	**54.190**	65.690
90	18.572	**23.215**	27.858	41.265	**52.765**	64.265
100	20.089	**25.112**	30.134	39.722	**51.222**	62.722
110	21.502	**26.878**	32.253	38.125	**49.625**	61.125
120	22.813	**28.516**	34.219	36.517	**48.017**	59.517
130	24.025	**30.031**	36.037	34.924	**46.424**	57.924
140	25.143	**31.428**	37.714	33.366	**44.866**	56.366
150	26.172	**32.715**	39.258	31.853	**43.353**	54.853

Table 3—Impedance and tolerance specifications at LISN terminals (without extension cord), 50 µH LISN

Frequency (MHz)	Magnitude (Ω)			Phase (degrees)		
	–20%	Nominal	+20%	–11.5°	Nominal	+11.5°
0.15	27.435	**34.293**	41.152	35.196	**46.696**	58.196
0.16	28.359	**35.449**	42.539	33.348	**44.848**	56.348
0.17	29.200	**36.500**	43.801	31.613	**43.113**	54.613
0.18	29.966	**37.458**	44.949	29.983	**41.483**	52.983
0.19	30.664	**38.329**	45.995	28.451	**39.951**	51.451
0.20	31.299	**39.124**	46.949	27.012	**38.512**	50.012
0.25	33.743	**42.178**	50.614	20.982	**32.482**	43.982
0.30	35.335	**44.169**	53.003	16.447	**27.947**	39.447
0.35	36.412	**45.515**	54.618	12.953	**24.453**	35.953
0.40	37.166	**46.458**	55.749	10.197	**21.697**	33.197
0.45	37.711	**47.139**	56.566	7.978	**19.478**	30.978
0.5	38.116	**47.645**	57.173	6.157	**17.657**	29.157
0.6	38.663	**48.329**	57.994	3.356	**14.856**	26.356
0.7	39.005	**48.756**	58.507	1.309	**12.809**	24.309
0.8	39.231	**49.039**	58.847	–0.248	**11.252**	22.752
0.9	39.389	**49.236**	59.083	–1.472	**10.028**	21.528
1	39.503	**49.379**	59.254	–2.457	**9.043**	20.543
2	39.874	**49.842**	59.811	–6.950	**4.550**	16.050

Table 3—Impedance and tolerance specifications at LISN terminals (without extension cord), 50 μH LISN *(continued)*

Frequency (MHz)	Magnitude (Ω)			Phase (degrees)		
	–20%	**Nominal**	**+20%**	**–11.5°**	**Nominal**	**+11.5°**
3	39.944	**49.930**	59.916	–8.463	**3.037**	14.537
4	39.968	**49.960**	59.953	–9.221	**2.279**	13.779
5	39.980	**49.975**	59.970	–9.677	**1.823**	13.323
6	39.986	**49.982**	59.979	–9.981	**1.519**	13.019
7	39.990	**49.987**	59.984	–10.198	**1.302**	12.802
8	39.992	**49.990**	59.988	–10.360	**1.140**	12.640
9	39.994	**49.992**	59.991	–10.487	**1.013**	12.513
10	39.995	**49.994**	59.992	–10.588	**0.912**	12.412
11	39.996	**49.995**	59.994	–10.671	**0.829**	12.329
12	39.996	**49.996**	59.995	–10.740	**0.760**	12.260
13	39.997	**49.996**	59.996	–10.799	**0.701**	12.201
14	39.997	**49.997**	59.996	–10.849	**0.651**	12.151
15	39.998	**49.997**	59.997	–10.892	**0.608**	12.108
16	39.998	**49.998**	59.997	–10.930	**0.570**	12.070
17	39.998	**49.998**	59.997	–10.964	**0.536**	12.036
18	39.998	**49.998**	59.998	–10.993	**0.507**	12.007
19	39.999	**49.998**	59.998	–11.020	**0.480**	11.980
20	39.999	**49.998**	59.998	–11.044	**0.456**	11.956
21	39.999	**49.999**	59.998	–11.066	**0.434**	11.934
22	39.999	**49.999**	59.998	–11.086	**0.414**	11.914
23	39.999	**49.999**	59.999	–11.104	**0.396**	11.896
24	39.999	**49.999**	59.999	–11.120	**0.380**	11.880
25	39.999	**49.999**	59.999	–11.135	**0.365**	11.865
26	39.999	**49.999**	59.999	–11.149	**0.351**	11.851
27	39.999	**49.999**	59.999	–11.162	**0.338**	11.838
28	39.999	**49.999**	59.999	–11.174	**0.326**	11.826
29	39.999	**49.999**	59.999	–11.186	**0.314**	11.814
30	39.999	**49.999**	59.999	–11.196	**0.304**	11.804



NOTE—The discontinuity in the curve is due to impedance values being derived from the two different circuits for the 9 kHz to 150 kHz and 150 kHz to 30 MHz frequency ranges.

Figure 1—Example impedance characteristics of LISN port 9 kHz to 30 MHz

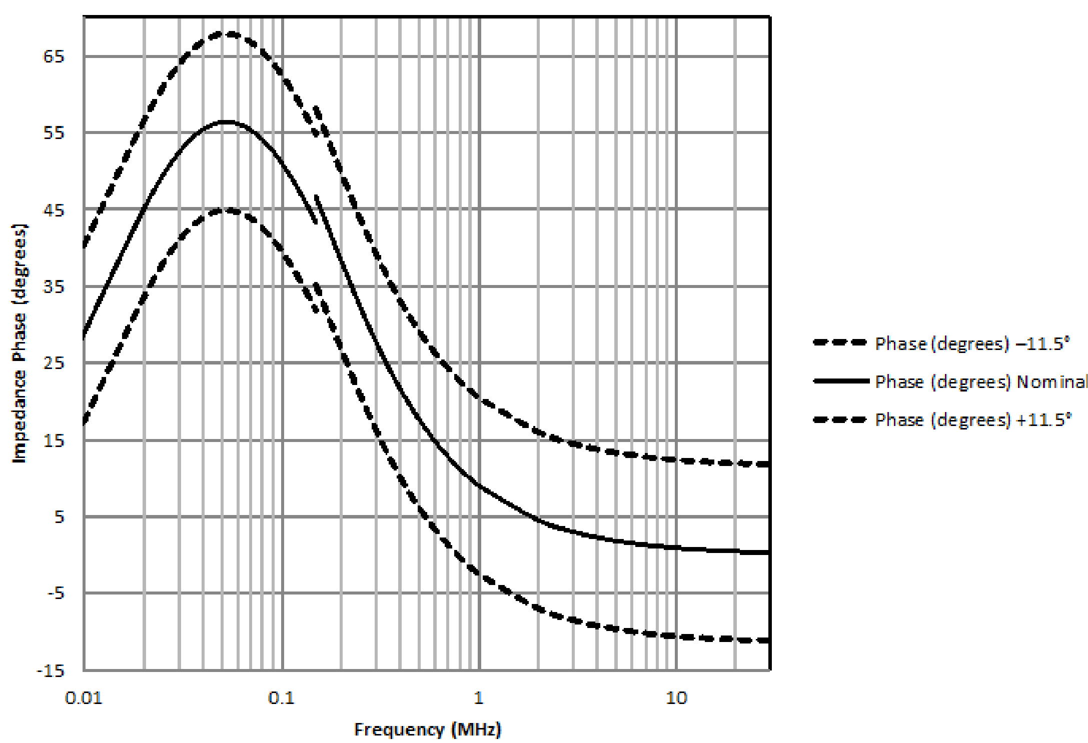
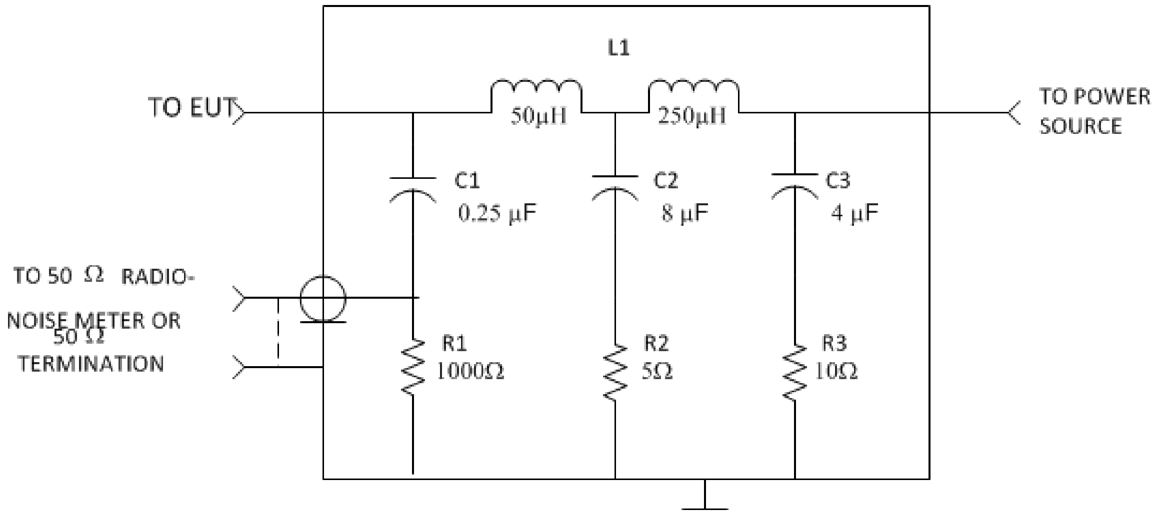


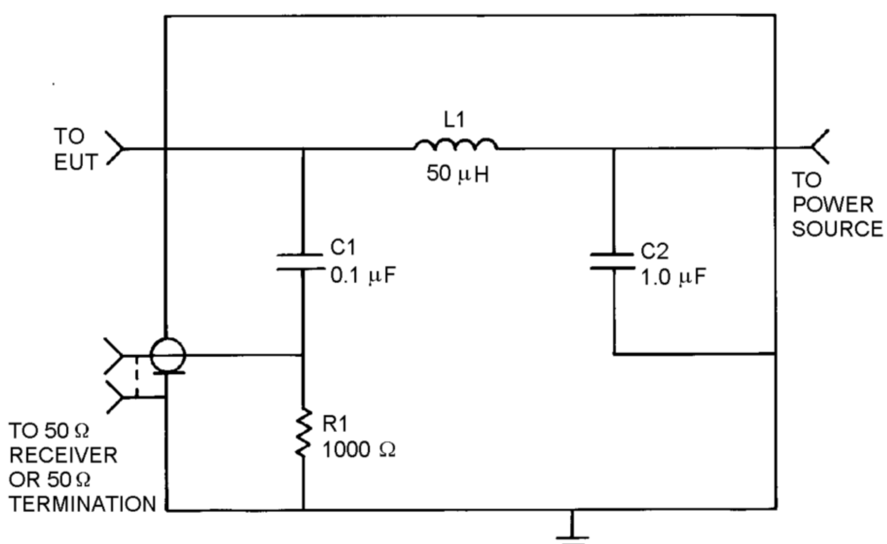
Figure 2—Example phase characteristics of LISN port 9 kHz to 30 MHz

The required nominal impedance values (magnitude and phase) were derived from idealized LISN circuits: 50 Ω in parallel with a series combination of 5 Ω and 50 µH, for the 9 kHz to 150 kHz frequency range, and 50 Ω in parallel with 50 µH, for the 150 kHz to 30 MHz frequency range. Figure 3 and Figure 4 illustrate two circuits that when carefully constructed can provide the impedance characteristics of Figure 1 and Figure 2.



*IF CAREFULLY CONSTRUCTED, THIS NETWORK CAN BE USED ABOVE 150 kHz TO AS HIGH AS 30 MHz

Figure 3—Example circuit diagram of LISN to provide impedance of Figure 1 for the 9 kHz to 150 kHz (30 MHz[23]) frequency range



*IN SOME LISNs, A SERIES RESISTANCE IS INCLUDED IN SERIES WITH CAPACITOR C2

Figure 4—Example circuit diagram of LISN to provide impedance of Figure 1 for the 150 kHz to 30 MHz frequency range

[23] Some LISN designs and implementations support use of the Figure 4 circuit up to 30 MHz without impedance resonances or anomalies.

The LISN impedance shall not deviate from the nominal values listed in Table 2 or Table 3 or both (and plotted in Figure 1 and Figure 2), as applicable, by more than ±20% (for the LISN impedance magnitude), and ±11.5 (for the LISN impedance phase), at the LISN's EUT terminals.

The insertion loss of the LISN (from its EUT port to the coaxial measurement port), taken from the calibration certificate of the LISN, shall be used for correcting the measurement result before comparing with the applicable limit at each frequency of measurement.

Where specific equipment requirements specify another LISN, the specified LISN shall be used.

4.3 Antennas

4.3.1 General requirements

The use of specific antennas depends on the frequency range and field type (electric or magnetic) being measured in performing radiated emissions measurements, as indicated in 4.3.2 through 4.3.4. Antennas shall be calibrated in accordance with ANSI C63.5.

NOTE—Users of ANSI C63.10 are especially recommended to pay careful attention to the scope and content of Table 4 through Table 9.

4.3.1.1 Antennas for exploratory and relative-comparison evaluation measurements

Table 4, Table 5, and Table 6 provide a summary listing of types of antennas that may be used in making *exploratory* radiated emissions measurements and/or for making *relative-comparison evaluation* measurements (e.g., A/B comparisons). Table 4, Table 5, and Table 6 identify the typical frequency ranges over which these antennas operate and provide normative footnotes regarding special considerations in their use. *Antenna types other than those specifically listed in Table 4, Table 5, and Table 6 may also be employed for making exploratory radiated emissions measurements and/or relative-comparison evaluation measurements, but users are cautioned to carefully consider the performance characteristics of those antennas as well as the applicable calibration procedures for those antennas prior to their use.*

Table 4—Radiated emissions antennas for exploratory and/or relative-comparison evaluation purposes (below 30 MHz)

#	Antenna types	Footnotes
3	Passive loop	
4	Active loop	a

[a] When an active antenna is used for exploratory or relative-comparison measurements, users are cautioned to verify whether the ambient and/or measured signals are causing the preamplifier portion of the active antenna to saturate (thus yielding unacceptable, erroneous measurements) and, if they are, to take corrective action (e.g., use of a notch filter, reorientation of the measurement axis) to eliminate the saturation condition. It is further recommended that only active antennas equipped with an operating saturation indicator are used, and the saturation indicator is monitored during the course of the testing to help ensure it does not indicate saturation.

Table 5—Radiated emissions antennas for exploratory and/or relative-comparison evaluation purposes (30 MHz to 1000 MHz)

#	Antenna types	Footnotes
1	Resonant tuned dipole (passive)	
2	Biconical dipole (50 Ω or 200 Ω balun)	
3	Log-periodic dipole array (LPDA)	
4	Hybrid (bicon/log)	
5	Double-ridged guide horn (passive)	a, b

[a] In general, tuned dipole, biconical dipole, and LPDA antennas operate within the 30 MHz to 1000 MHz frequency range, and waveguide/DRG horn antennas operate over portions of the 1 GHz to 40 GHz band. However, some designs of tuned dipole, biconical dipole, and LPDA antennas also operate within portions of the 1 GHz to 40 GHz range, and some designs of DRG horns operate at frequencies as low as 170 MHz.

[b] The largest aperture dimension, D, of these horn antennas (i.e., length or width; in meters) should be small enough so that the measurement distance (in meters) is equal to or greater than the Rayleigh distance (i.e., $R_m = D^2 / 2\lambda$), where λ is the free-space wavelength (in meters) at the frequency of measurement.

Table 6—Radiated emissions antennas for exploratory and/or relative-comparison evaluation purposes (1 GHz to 40 GHz)

#	Antenna types	Footnotes
1	Resonant tuned dipole (passive)	a, b
2	Biconical dipole (50 Ω or 200 Ω balun)	a, b
3	Precision broadband omnidirectional biconical dipole	c
4	Log-periodic dipole array (LPDA)	a, b
5	Hybrid (bicon/log)	
6	Waveguide horn	d
7	Double-ridged guide horn (passive)	a, d
8	Double-ridged guide horn (active)	a, d, e

[a] In general, tuned dipole, biconical dipole, and LPDA antennas operate within the 30 MHz to 1000 MHz frequency range, and waveguide/DRG horn antennas operate over portions of the 1 GHz to 40 GHz band. However, some designs of tuned dipole, biconical dipole, and LPDA antennas also operate within portions of the 1 GHz to 40 GHz range, and some designs of DRG horns operate at frequencies as low as 170 MHz.

[b] Users of biconical antennas, with 50 Ω or 200 Ω baluns, and LPDA antennas are cautioned that the required calibration methods for these antennas at frequencies up to and including 1 GHz are completely different from those required to be used at frequencies above 1 GHz. For further details, see the ANSI C63.5.

[c] Precision broadband omnidirectional (biconical) antennas should only be used if they comply with the constructional and pattern requirements specified in 7.4.2 of CISPR 16-1-4:2019.

[d] The largest aperture dimension, D, of these horn antennas (i.e., length or width; in meters) should be small enough so that the measurement distance (in meters) is equal to or greater than the Rayleigh distance (i.e., $R_m = D^2 / 2\lambda$), where λ is the free-space wavelength (in meters) at the frequency of measurement.

[e] When an active antenna is used for exploratory or relative-comparison measurements, users are cautioned to verify whether the ambient and/or measured signals are causing the preamplifier portion of the active antenna to saturate (thus yielding unacceptable, erroneous measurements) and, if they are, to take corrective action (e.g., use of a notch filter, reorientation of the measurement axis) to eliminate the saturation condition. It is further recommended that only active antennas equipped with an operating saturation indicator are used, and the saturation indicator is monitored during the course of the testing to help ensure it does not indicate saturation.

4.3.1.2 Antennas for final compliance measurements

Table 7, Table 8, and Table 9 contains the complete list of antennas that are permitted to be used for making *final compliance measurements (including emission maximization measurements)* for this standard and identify the frequency ranges over which those antennas are permitted to operate when making final compliance or emission maximization measurements. *Only the antenna types specifically listed in Table 7, Table 8, and Table 9 and used in the frequency ranges listed for their operation in Table 7, Table 8, and Table 9* (*and used in a manner consistent with the normative footnotes in Table 7, Table 8, and Table 9) shall be used for making emission maximization and final compliance measurements*.

Table 7—Radiated emissions antennas for use in making final compliance measurements on devices (9 kHz to 30 MHz)

#	Antenna types	Footnotes
3	Passive loop[a]	
4	Active loop[a]	[b]

[a] When E-field measurements are required to be made, antenna factors shall be converted to E-field values assuming a free-space impedance of 377 Ω.

[b] The use of an active antenna for final compliance measurements on devices is permitted ONLY if the active 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.

Table 8—Radiated emissions antennas for use in making final compliance measurements on devices (30 MHz to 1000 MHz)

#	Antenna types	Footnotes
1	Resonant tuned dipole (passive)	
2	Biconical dipole (50 Ω or 200 Ω balun)	
3	Log-periodic dipole array (LPDA)	
4	Hybrid (bicon/log)	[a, b]

[a] See Annex N of ANSI C63.4-2014 for the site-specific hybrid antenna qualifications that shall be met for a specific hybrid antenna to be used at a specific test site over the frequency range of 30 MHz to 1 GHz.

[b] If a hybrid antenna impedance matching pad (HAIMP) attenuator was used during the site-specific hybrid antenna qualification procedure detailed in Annex N of ANSI C63.4-2014, then an attenuator of the same insertion loss value and the same or greater frequency range of operation shall be used during all final compliance measurements made with that specific hybrid antenna on that specific test site.

Table 9—Radiated emissions antennas for use in making final compliance measurements on devices (1 GHz to 40 GHz)

#	Antenna types	Footnotes
1	Precision broadband omnidirectional biconical dipole	a
2	Log-periodic dipole array (LPDA)	b
3	Hybrid (bicon/log)	b, c, d
4	Waveguide horn	e
5	Double-ridged guide horn (passive)	e
6	Double-ridged guide horn (active)	e, f

[a] The use of precision broadband omnidirectional (biconical) antennas is permitted when making final compliance measurements on devices ONLY if they comply with the constructional and pattern requirements specified in 7.4.2 of CISPR 16-1-4:2019. No other types of biconical antennas shall be used above 1 GHz for making final compliance measurements.

[b] Users of LPDA and hybrid antennas are cautioned that the required calibration methods for these antennas at frequencies up to and including 1 GHz are completely different from those required to be used at frequencies above 1 GHz. Users are further cautioned that an LPDA or hybrid antenna whose operating frequency range extends above 1 GHz shall be acceptable for use in making final compliance measurements on devices ONLY if the calibration certificate/report for that antenna explicitly states the differences between the calibration methods used below 1 GHz and the calibration method used above 1 GHz and separately lists the antenna factors below and above 1 GHz.

[c] See Annex N of ANSI C63.4-2014 for the site-specific hybrid antenna qualifications that shall be met for a specific hybrid antenna to be used at a specific test site over the frequency range of 30 MHz to 1 GHz. A specific hybrid antenna that has been determined to be suitable for use on a specific test site from 30 MHz to 1 GHz by means of the procedures detailed in Annex N of ANSI C63.4-2014 is deemed to be suitable for use on that same test site from 1 GHz upwards to its highest frequency of operation.

[d] If a hybrid antenna impedance matching pad (HAIMP) attenuator was used during the site-specific hybrid antenna qualification procedure detailed in Annex N of ANSI C63.4-2014, then an attenuator of the same insertion loss value and the same or greater frequency range of operation shall be used during all final compliance measurements made with that specific hybrid antenna on that specific test site.

[e] The largest aperture dimension, D, of these horn antennas (i.e., length or width; in meters) shall be small enough so that the measurement distance (in meters) is equal to or greater than the Rayleigh distance (i.e., $R_m = D^2 / 2\lambda$), where λ is the free-space wavelength (in meters) at the frequency of measurement.

[f] The use of an active horn antenna is permitted for final compliance measurements on devices; however, users shall verify whether the ambient and/or EUT signals are causing the preamplifier portion of the active horn antenna to saturate (thus yielding unacceptable, erroneous measurements) and, if they are, to take corrective action (e.g., use of a notch filter, reorientation of the measurement axis) to eliminate the saturation condition.

4.3.2 Magnetic field measurements (9 kHz to 30 MHz)

Either passive loop antennas or active loop antennas, as specified in Table 4 and Table 7 and/or CISPR 16-1-4:2019 shall be used to measure magnetic fields in the frequency range of 9 kHz to 30 MHz. See Table 7 for applicable conditions of use of loop antennas.[24]

4.3.3 Electric field measurements (30 MHz to 1000 MHz)

Linearly polarized antennas, as specified in Table 5 and Table 8, shall be used to measure electric field strengths in the frequency range of 30 MHz to 1000 MHz (see also CISPR 16-1-4:2019). Specifically, tunable dipole antennas, biconical dipole antennas, log-periodic dipole array (LPDA) antennas, and hybrid antennas may be used. However, hybrid antennas can be used only if the requirements of either one of the two procedures specified in Annex N of ANSI C63.4-2014 are satisfied. See Table 5 and Table 8 for the applicable conditions of use for tunable dipole antennas, biconical dipole antennas, LPDA antennas, and hybrid antennas.

[24] For the United States, the regulatory limits below 30 MHz are in terms of μV/m. By convention, magnetic field strength is converted to an electric field strength based on free-space impedance [1 μV/m = (1 / 377 Ω) × 1 μA/m].

NOTE—Some regulatory and purchasing agencies may require the use of a reference antenna (i.e., tunable dipole as described in 6.2, Annex C, and Annex D of ANSI C63.5-2017) for measurements of radiated emissions.

4.3.4 Electric field measurements (above 1 GHz)

Linearly polarized antennas, as specified in Table 6 or Table 9, as applicable, and calibrated in accordance with ANSI C63.5, shall be used (see also CISPR 16-1-4:2019). These antennas include hybrid antennas, LPDAs, double-ridged waveguide horns, quadruple-ridged waveguide horns, rectangular waveguide horns, pyramidal horns, optimum-gain horns, octave-band horns, and standard-gain horns. The main “beam” or main lobe of the pattern for any antenna used, which shall be taken as the half-power (−3 dB) beamwidth of the antenna, shall be large enough to encompass the physical size of the EUT, or system arrangement, in both width and height, when located at the measuring distance, in each antenna polarization used for measurements, or otherwise the measurement procedure detailed in 6.6 shall be employed.

The aperture dimensions of these horn antennas shall be small enough so that the measurement distance in meters is equal to or greater than the Rayleigh distance (i.e., $R_m = D^2 / 2\lambda$), where D is the largest linear dimension (i.e., width or height) of the antenna aperture in m and λ is the free-space wavelength in meters at the frequency of measurement. The same requirement applies for the other types of antennas mentioned above, but in that case *D* is the largest dimension of the antenna elements active at the frequency of measurement. In case of dispute, measurements made with a standard-gain horn antenna shall take precedence.

4.4 Calibration of measuring equipment

4.4.1 General requirements

All measurement equipment, instruments, and corresponding ancillary equipment (e.g., cables), including all ancillary equipment within the signal path used for measurements made as specified in this standard shall be calibrated. A calibration records system shall be maintained, as part of a laboratory quality system, which monitors the calibration status of the test equipment and facilitates the traceability to national standards.

4.4.2 Confirmation interval

The calibration of all instruments, measurement equipment, and ancillary equipment shall be confirmed in the first year of deployment. The subsequent recalibration intervals may be longer (up to 3 years) or shorter based on review of calibration data relative to the recommendations of the instrument manufacturer and the required measurement accuracy. Other requirements may also apply, such as CISPR 16-1-1:2019 or ANSI C63.2 for the measurement instrument. All instruments, measurement equipment, and ancillary equipment in the measurement path 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.

Reference antennas that are used only for calibration or test site validation measurement purposes shall be constructed as specified in, and shall be checked using the methods in ANSI C63.5 methods at least every 3 years.

4.4.3 Antenna calibration

All antennas shall be calibrated in accordance with ANSI C63.5, including antennas used for performing NSA measurements for standard test site validation and alternative test site validation (see 5.2) and antennas used for performing S_{VSWR} measurements for test site validation above 1 GHz (see 5.2). Antennas shall be recalibrated at regular intervals (i.e., periodically recalibrated) as described in 4.4.2 and recalibrated after repair or when damage or deterioration is suspected or known to have occurred. Notwithstanding the provisions of the preceding sentence:

— Standard-gain horns need not be periodically recalibrated, unless damage or deterioration is suspected or known to have occurred. If a standard-gain horn is not periodically recalibrated, its critical dimensions (see IEEE Std 1309-2005) shall be verified and documented on an annual basis.

— Precision broadband omnidirectional (biconical) antennas used for S_{VSWR} site validation testing (see also 5.2) and complying with the constructional and pattern requirements specified in 7.4.2 of CISPR 16-1-4:2019 need not be periodically recalibrated, unless damage or deterioration is suspected or known to have occurred.

Loop antennas used for radiated emission measurements below 30 MHz shall be calibrated in accordance with Annex N of ANSI C63.5-2017 and their calibration shall be confirmed at regular intervals as described in 4.4.2.

NOTE—Annex N of ANSI C63.5-2017 is informative. However, that annex is made normative for calibrating the loop antenna for use in measurements according to ANSI C63.10, by the use of "shall" in the above paragraph.

To be acceptable, an antenna calibration certificate/report shall have been issued by an antenna calibration laboratory whose scope of accreditation includes the applicable antenna calibration method or methods, over the required frequency range, and the calibration certificate (report) shall include the calibration measurement uncertainty.

4.4.4 LISN impedance and insertion loss measurements

The attenuation (insertion loss) between the EUT receptacle and the measuring instrument port on the LISN shall be accounted for when calculating the EUT emission levels, at each frequency of measurement. The impedance and insertion loss of each LISN used in conducted emissions testing shall be measured over the frequency range of use. The LISN shall be measured in the configuration for which it is used for testing a product. Acceptable procedures for performing these measurements are given in ANSI C63.4-2014 Annex B, which also includes the requirements the LISN impedance shall comply with (nominal impedance magnitude and phase values and maximum tolerances).-The LISN shall be checked routinely to confirm acceptable performance; see 4.4.2.

NOTE—It is suggested that the insertion loss measurement be carried out after the completion of the impedance measurements.

4.4.5 Insertion loss of passive devices and preamplifier gain

The insertion loss of passive devices included in the measurement path (such as cables, attenuators, directional couplers, and filters), as well as the gain of preamplifiers used for connection of antennas or transducers to measuring instruments (e.g., EMI receivers, spectrum analyzers) shall be characterized over the used frequency range and the calibrated loss or gain factor shall be applied for correcting the measurement result before comparing with the applicable limit, at each frequency of measurement.

Passive components (such as cables, attenuators, filters, couplers, adapters) shall be checked frequently for deterioration caused by use and environmental exposure (e.g., variation due to change in temperature and damage). Published data[25] have shown that temperature variations of 15 °C or more result in 2 % or greater change in cable losses. Consequently, the temperatures present during initial loss characterization of the passive component and product testing shall be recorded. When the temperature change exceeds 15 °C, the passive device characterization(s) shall be repeated.

[25] For example, see http://www.gore.com/en_xx/products/cables/microwave/changes_insertion_loss_phase.html.

5. General measurement and setup considerations

5.1 General requirements

The information in this clause shall be used in conjunction with the standard test methods of Clause 6, and the device-specific test methods of Clause 7 through Clause 15, as applicable for a specific EUT. Users of this standard shall apply the information of this clause when testing unlicensed wireless devices, particularly those using new technologies.[26]

5.2 Radiated emission test site

Radiated emission test sites below 30 MHz shall be free from metal objects, buried pipes, and any objects that can affect radiated measurements. An alternative test site that can demonstrate equivalence to a test site as described in the preceding sentence shall be accepted for the purposes of this standard.

Field strength measurements from 30 MHz up to and including 1 GHz shall be made on a test site meeting the requirements for an acceptable site as defined in ANSI C63.4-2014 as modified by ANSI C63.4a-2017 or any later versions of ANSI C63.4 that incorporate the text of C63.4a-2017.[27, 28] Guidance for constructing a test site meeting these requirements is provided in ANSI C63.7.

For measurements from 1 GHz to 40 GHz, the test site shall conform to the site validation criteria called out in ANSI C63.25.1 over the frequency range 1 GHz to 18 GHz. Site validation measurements shall be made at heights that encompass the range of EUT heights to be evaluated.

NOTE 1—The requirements of ANSI C63.25.1 permit the use of CISPR 16-1-4:2019 as an acceptable methodology for validating at test site from 1 GHz to 18 GHz.

For measurements above 40 GHz, every attempt shall be made to reduce contributions from reflections to a minimum.

Site validation measurements shall be made at heights that encompass the range of EUT heights to be evaluated when tests are conducted on an alternative test site and volumetric NSA is required.

NOTE 2—In the case of an unlicensed wireless device for which measurements can be performed only at the installation site, such as perimeter protection systems, carrier current systems, and systems employing a “leaky” coaxial cable as an antenna, some regulatory or purchasing agencies might specify that measurements should be performed at a minimum of three installations that can be demonstrated to be representative of typical installation sites.

5.3 Radiated emission test distance

5.3.1 General requirements

To the extent practicable, the EUT shall be measured at the distance at which the limits applicable for the EUT are specified; the following subclauses provide other details. Only unlicensed wireless devices that physically cannot be tested at a test site that meets the criteria of ANSI C63.4, at the discretion of the regulatory authority, may be permitted to be tested in situ. The distance specified corresponds to the horizontal distance between the measurement reference point of the measurement antenna and the closest

[26] For the United States, many of the general requirements for unlicensed wireless devices in this clause are contained in 47 CFR 15.31.
[27] For the United States, an unlicensed wireless device might require special authorization for testing on an open field test site (see 47 CFR 2.805 [B71] and 47 CFR 5 subpart G [B72]).
[28] For the United States, see 47 CFR 15.31 for additional guidance regarding test sites.

point of the EUT, support equipment, or interconnecting cables, as determined by the boundary defined by an imaginary straight line periphery describing a simple geometric configuration enclosing the system containing the EUT. The EUT, support equipment, and any interconnecting cables shall be included within this boundary.

5.3.2 Test distance for frequencies below 30 MHz

Radiated emissions limits are usually defined at a specific distance from the EUT. Where possible, measurements shall be made at the distance specified in the limits. This might not be possible in all cases, however, due to the physical limitations of the test facility, physical access problems at the required distance (especially for measurements that must be made in situ or on-site), or levels of ambient noise or other radiated signals present at the time and location where measurements are made. See 6.4.3 for more information about antenna selection, location, and test distance. If measurements cannot practically be made at the EUT limit distance, then they may be made at a different distance (usually closer) and extrapolated to the limit distance using one of the procedures described in 6.4.4, 6.4.5, or 7.7, depending on the EUT source and size.[29] The test report shall specify the extrapolation method used to determine compliance of the EUT.

5.3.3 Test distance for frequencies at or above 30 MHz

Measurements may be performed at a distance other than the limit distance provided they are not performed in the near-field, and the emissions to be measured can be detected by the measurement equipment (see 4.3.4). Measurements shall not be performed at a distance greater than 30 m for frequencies above 30 MHz, unless it can be further demonstrated that measurements at a distance of 30 m or less are impractical. Measurements from 18 GHz to 40 GHz are typically made at distances significantly less than 3 m from the EUT. When performing measurements at a distance other than that specified, the results shall be extrapolated to the specified distance using an extrapolation factor of 20 dB/decade of distance (inverse of linear distance for field strength measurements or inverse of linear distance squared for power density measurements).

NOTE—Instrumentation capabilities can preclude preliminary scans at 3 m from 18 GHz to 40 GHz, but every attempt should be made to make final measurements at a 3 m distance in this frequency range. Measurements in the frequency range above 40 GHz are typically made at a closer distance because the instrumentation noise floor is typically close to the radiated emission limit.

5.4 Measurements around the EUT

Measurements shall be made at a test site that incorporates a turntable allowing EUT rotation of 0° through 360°, except where the EUT is so large that a suitable turntable is not readily available. A remotely controlled turntable shall be installed at the test site to support the EUT and facilitate determination of the direction of maximum radiation for each EUT emission frequency. Continuous azimuth searches shall be made. The maximum field strength at the frequency being measured shall be reported in the test report.[30] See ANSI C63.4 for details of the test site, turntable, and antenna positioner.

Where a continuous azimuth search cannot be made, as is the case for example where the EUT is so large that a suitable turntable is not readily available, frequency scans of the EUT field strength with both polarizations of the measuring antenna shall be made, starting with a minimum of 16 azimuth angles around the EUT, nominally spaced by 22.5°, in characterizing the EUT radio-noise profile. If directional EUT radiation patterns are suspected, especially above 1 GHz, then additional and smaller azimuth angles shall be examined.

NOTE—Some unlicensed wireless devices require specific azimuth increments, as described in the specific subclause in this standard for those unlicensed wireless devices (e.g., see 6.11.1, 7.7.3, and 8.4.3).

[29] The use of the procedures in 6.4.4, 6.4.5, and 7.7 are at the discretion of the regulatory authority.
[30] See 47 CFR 15.31(f)(5).

5.5 Frequency range of radiated emission measurements

Unless otherwise noted for a specific unlicensed wireless device, the spectrum shall be investigated from the lowest radio frequency signal generated in the device and up to at least the frequency shown in Table 10.[31] However, frequencies below 9 kHz do not need to be investigated.

If the unlicensed wireless device contains a digital device, regardless of whether this digital device controls the functions of the unlicensed wireless device or the digital device is used for additional control or function purposes other than to enable the operation of the unlicensed wireless device, unless otherwise specified by the regulatory agency, then the frequency range shall be investigated up to the range specified in Table 10 or the range applicable to the digital device as specified by the regulatory authority, whichever is the highest frequency range of investigation.

Particular attention shall be paid to harmonic and subharmonic emissions of the fundamental frequency, as well as to those frequencies removed from the fundamental by multiples of the oscillator frequency. Radiation at the frequencies of all oscillators and harmonics thereof shall also be checked.

Table 10 —Frequency range of measurements for unlicensed wireless device

Lowest frequency generated in the device	Upper frequency range of measurement
9 kHz to below 10 GHz	10th harmonic of highest fundamental frequency or to 40 GHz, whichever is lower
At or above 10 GHz to below 30 GHz	5th harmonic of highest fundamental frequency or to 100 GHz, whichever is lower
At or above 30 GHz	5th harmonic of highest fundamental frequency or to 200 GHz, whichever is lower, unless otherwise specified

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

5.6.1 General requirement

Measurements of unlicensed wireless devices shall be performed and, if required, reported for each band in which the EUT can be operated with the device operating at the number of frequencies in each band specified in Table 11.[32]

Table 11 —Number of frequencies to be tested

Frequency range in which device 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

5.6.2 Test channels and test modes (streamline test requirements)

Measurement of all modes and all channels is not always necessary to demonstrate compliance[33]. Subclauses 5.6.2.1 and 5.6.2.2 describe cases where testing can be reduced.[34] Reductions in the requirement to report test results found in Clause 17 do not constitute a reduction in the actual testing required by this subclause.

[31] See 47 CFR 15.33(a).
[32] See 47 CFR 15.31(m).
[33] Although this clause outlines test reductions for demonstrating compliance, it is the manufacturers' responsibility to ensure that the device under test complies with the regulatory requirements under all modes of operation.
[34] For tests on other than U-NII and DTS devices, use of the procedures in 0 is at the discretion of the regulatory authority.

5.6.2.1 Channel bandwidth

The number of channels tested can be reduced by measuring the center channel bandwidth first and then applying the following relaxations as appropriate, which only applies when a regulatory limit on the channel bandwidth is specified:

a) For each operating mode, if the measured channel bandwidth on the middle channel is at least 150% of the minimum permitted bandwidth, then it is not necessary to measure the bandwidth on the high and low channels.

b) For multiple-input multiple-output (MIMO) systems, if the measured channel bandwidth on the middle channel exceeds the minimum permitted bandwidth by more than 50% on one transmit chain, then it is not necessary to repeat testing on the other chains.

c) If the measured channel bandwidth on the middle channel is less than 50% of the maximum permitted bandwidth, then it is not necessary to measure the bandwidth on the high and low channels.

5.6.2.2 Determining worst-case mode for test parameters being evaluated

For devices with multiple operating modes, measurements on the middle channel can be used to determine the worst-case mode(s). The worst-case modes are as follows:

a) Band-edge requirements—Measurements on the mode with the widest bandwidth can be used to cover the same channel (center frequency) on modes with narrower bandwidth that have the same or lower output power for each modulation family (e.g., OFDM or direct sequence spread spectrum).

b) Spurious emissions—Measure the mode with the highest output power and the mode with the highest output power spectral density for each modulation family (e.g., OFDM or direct sequence spread spectrum).

c) In-band PSD—Measurements on the mode with the narrowest bandwidth can be used to cover all modes within the same modulation family of an equal or lower output power provided the result is less than 50% of the limit.

d) When testing Multiple Access technologies (e.g., OFDMA), consideration should be given to evaluate both full band mode and with different combinations of resource assignment. When these considerations are used to reduce testing they shall be documented in the test report.

5.6.3 Band-edge channels with reduced output power

In regards to testing the band-edge signals, if the lowest or highest channel frequency is not at the highest fundamental output power setting, the adjacent channel(s) up to the channel that has the highest fundamental output power setting shall, when appropriate, also be tested to demonstrate compliance with the appropriate limits.

5.6.4 AC power-line conducted emissions

AC power-line conducted emissions do not require measurements on the minimum number of channels outlined in 5.6.1. Measurements shall only be performed on the channel and mode with the highest output power.

The exception to this test reduction is for any measurements performed on fundamental emissions that occur within the frequency band covered by an ac power-line emission. For these frequency bands the transmitter shall follow the minimum channels outlined in 5.6.1.

5.7 Swept-frequency device measurements

For unlicensed wireless devices using swept-frequency modulation techniques, other than those employing FMCW modulation, measurements shall be made with the frequency sweep stopped at those frequencies chosen for the measurements to be reported.

5.8 EUT antenna requirements

In general, an unlicensed wireless device shall be tested with all antennas provided and recommended for use with the EUT; however, variations and exceptions to this requirement can apply. See also 5.10.4. The test report shall document the antenna(s) tested with the EUT to determine compliance.[35]

NOTE—Users of this standard are advised to refer to the latest applicable regulatory requirements and interpretations concerning requirements for evaluations of antennas used for unlicensed wireless devices.

5.9 Restricted frequency bands of operation

An unlicensed wireless device shall be tested to demonstrate that any emissions within restricted frequency bands specified by the regulatory authority are spurious emissions only. Unless otherwise specifically authorized, the spurious emission shall meet prescribed limits and the fundamental transmit signal shall not fall within these frequency bands.[36] Test reports shall provide measured data to demonstrate compliance with these regulatory requirements.

At frequencies less than or equal to 1000 MHz, compliance testing shall use measurement instrumentation employing a CISPR quasi-peak detector. Above 1000 MHz, compliance testing shall address both the peak and average values of the measured emissions. The considerations in 4.1.5.2 apply to these measurements.

5.10 General unlicensed wireless device configurations and test setups

This subclause addresses the general setup and operating requirements for evaluating unlicensed wireless devices, including stand-alone, modular, and embedded unlicensed wireless devices, external antenna considerations, and software requirements.

5.10.1 Stand-alone unlicensed wireless devices

Unlicensed wireless devices that are designed to operate as stand-alone systems (complete finished products), such as network access points, remote control unlicensed wireless devices, cordless phones, smart phones, tablets, and so on, shall be set up as such. A stand-alone unlicensed wireless device can contain a digital device whose functionality is only to control the unlicensed wireless device.

Products such as network access points, network bridges, or the equivalent shall be connected to a server or computer via control/data cable(s) to exercise the product. The controlling server or computer may be placed outside the test area.

A portable or small unlicensed wireless device shall be placed on a nonmetallic test fixture or other nonmetallic support during testing. The supporting fixture shall permit orientation of the EUT in each of three orthogonal axis positions such that emissions from the EUT are maximized.

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[35] See 47 CFR 15.203 and 15.204 and related interpretations in the FCC Knowledge Database (http://www.fcc.gov/labhelp).
[36] See 47 CFR 15.35, 15.205, and 15.209.

5.10.2 Modular unlicensed wireless devices

Modular unlicensed wireless devices shall be positioned for testing using a nonmetallic test fixture or other nonmetallic support(s), in accordance with applicable regulatory guidance.[37] Peripheral devices are not required to be connected to the host device that is operating the modular unlicensed wireless device within a test fixture. For module unlicensed wireless devices being tested on an extender-card/adaptor-connector from a host computer, the radio module itself shall be extended at least 10 cm from the host computer, if possible, but it shall be located outside the enclosure of the host computer.

5.10.3 Module-like unlicensed wireless device embedded in a host device

For an unlicensed wireless device embedded or integrated in a host device, such as a notebook computer or a personal digital assistant (PDA), the use of peripherals for the host device is not required except for the spurious emission tests. For unintentional spurious emissions from the host, the test setup shall be in accordance with ANSI C63.4 for such testing.

5.10.4 Unlicensed wireless transmission systems with external antennas

The EUT system shall be tested with the highest gain for each antenna type to be marketed with the EUT[38] (see also 5.8). Antenna(s) shall be supported on a nonmetallic structure to preclude direct contact with the support table. The antenna shall be connected with the minimum length cable needed to be compliant with the EIRP requirements where applicable. If additional cable longer than the minimum length is used, then this shall be recorded in the test report, and it may need to be recorded as an operating condition for the approval of the equipment if such minimum cable length is required to maintain compliance with the specific regulation.

The EUT and antenna configurations tested shall include at least one configuration that provides the highest conducted output power (e.g., to evaluate worst-case enclosure radiation).

5.10.5 Maximization of EUT controls

The EUT shall be configured, using those controls that are readily accessible to or are intended to be accessible to the end user, in such a manner as to maximize the level of the emissions. For those devices to which wire leads can be attached by the consumer, tests shall be performed with wire leads attached. The wire leads shall be of the length to be used with the equipment, if that length is known. Otherwise, wire leads 1 m in length shall be attached to the equipment. Longer wire leads may be employed if necessary to interconnect to associated equipment.

5.10.6 Composite systems

If the individual devices in a composite system are subject to different regulatory technical requirements, then each part of the system shall comply with its specific technical requirement. In no event shall the measured emissions of the composite system exceed the highest level permitted for an individual component.

For a composite system, testing for compliance shall be performed with all of the parts in the system functioning. If an unlicensed wireless device incorporates more than one antenna or other radiating source and these radiating sources are designed to emit at the same time, then measurements of conducted and radiated emissions shall be performed with all radiating sources emitting simultaneously.[39] If the composite system contains an unintentional radiator, then that part of the composite system shall be tested in accordance with the test procedures in the latest version of ANSI C63.4, as accepted by the appropriate regulatory agency.

[37] See FCC/DA 00 1407 [B24] and 47 CFR 15.212.
[38] Refer to the latest applicable regulatory requirements and interpretations concerning testing of antennas for unlicensed wireless devices.
[39] See 47 CFR 15.31(h) and 15.31(k).

5.10.7 External accessories

If the EUT allows for the connection of external accessories, including external electrical control signals, then the EUT shall be tested with the accessories attached. The EUT shall be fully exercised with these external accessories. The emission tests shall be performed with the device and accessories configured in a manner that tends to produce maximum emissions within the range of variations that can be expected under normal operating conditions. In the case of multiple accessory external ports, an external accessory shall be connected to one of each type of port. Only one test using external accessories that are representative of the devices that will be employed with the EUT is required; testing of all possible equipment combinations is not required. The accessories connected to the EUT shall be unmodified and commercially available equipment.

When testing RFID readers that interact with passive tags, they shall be tested with a representative tag and without the tags. Tags that can be used at a distance shall be tested at the minimum separation distance to avoid backscatter emissions to overcome the readers emissions.

The test report shall identify (1) the operating modes and accessories tested for both exploratory and final emission measurements and (2) the rationale for the modes and accessories used in the final measurement.

5.10.8 Central control units

If the EUT consists of a central control unit and external or internal accessory(ies), and the same party manufactures or assembles the central control unit and at least one of the accessory devices that can be used with that control unit, then testing of the control unit and/or the accessory(ies) shall be performed using the devices manufactured or assembled by that same party, in addition to any other needed devices that the same party does not manufacture or assemble. If the same party does not manufacture or assemble the central control unit and at least one of the accessory devices that can be used with that control unit, or if the same party can demonstrate that the central control unit or accessory(ies) normally would be marketed or used with equipment from a different entity, then testing of the central control unit and/or the accessory(ies) shall be performed using the specific combination of equipment that is intended to be marketed or used together. Only one test using peripherals or accessories that are representative of the devices that will be employed with the EUT is required; testing of all possible equipment combinations is not required. The accessories or peripherals connected to the device being tested shall be unmodified, commercially available equipment.

5.11 Operational requirements during testing

The operation of the EUT shall conform to the following provisions:

a) The unlicensed wireless device shall be configured to operate at 100% duty cycle. For systems incapable of supporting 100% duty cycle, the unlicensed wireless device shall be operated using the maximum possible duty cycle under normal operating conditions, and this information shall be noted as such in the test report.

b) The unlicensed wireless device shall be tested operating at the highest transmit power allowed for each antenna configuration.

c) The system shall be tested with each modulation to identify the worst-case modulation that produces the highest level of emissions. Where a single modulation scheme is used to demonstrate full EUT compliance, justification for the single modulation chosen shall be provided in the test report.

d) The system shall be tested using the data rate that yields the highest fundamental emission levels for each modulation type. The data rate and rationale or supporting test data shall be included in the test report.

e) For frequency hopping systems, the hopping sequence shall be stopped for certain test suites to allow for measurements on a single channel.

f) Where applicable, the device shall also be configured to transmit at the worst-case duty cycle under normal operating conditions to determine the average correction factor.

g) The software shall allow configuration and operation on all available unlicensed wireless device channels.

h) The software shall allow configuration and operation in the unmodulated carrier model, where applicable.

The test report shall include the date, version number, and storage location of the software used to exercise the unlicensed wireless device.

5.12 Applied modulation

Unless otherwise specified in the individual test requirements or in this subclause, typical modulation shall be applied during testing. The test results shall be documented in the test report for operation with any modulation, devices, or functions used for modifying the spectrum when such devices are optional at the discretion of the user or are adjusted for network conditions during end use operation.

a) When modulation is required in an individual test, devices modulated from internal sources shall be tested with all types of applied modulation. When a change in applied modulation yields a considerable difference in results, investigative measurements shall be carried out to establish the applied modulation, under foreseeable usage conditions, that will generate the worst-case results.

b) If a device is equipped with input connectors for external modulation, then typical modulating signals shall be applied at the maximum rated input level for the device (e.g., apply a 1000 Hz tone to an input for an external microphone), unless otherwise specified by the regulatory authority. Voice only modulated devices (200 Hz to 3000 Hz) for which it is not practical to apply an audio signal electrically shall have a 1000 Hz tone at 100 dB sound pressure level (SPL) applied 10 cm from the microphone (0 dB SPL is 20 µPa).

c) For systems deploying broadband wireless technologies or spread spectrum technology, the system shall be tested with the worst-case modulation(s) as determined by the engineering test. Devices employing digital modulation techniques shall be tested with the input modulation set to produce the maximum amplitude and symbol rate. The test results shall be reported for operation with any devices or functions used for modifying the spectrum when such devices are optional at the discretion of the user or are adjusted for network conditions during end use operation.

d) When testing systems using frequency hopping technology, the tests shall address the additional requirements for operation with modulation as specified in 7.8.

e) All modulations supported by the system shall described in the test report with justification provided for selecting specific modulation(s) for compliance testing.

5.13 Variations in supply voltage

When required for unlicensed wireless devices, measurements of the variation of the input power or the radiated signal level of the fundamental frequency component of the emission, as appropriate, shall be performed with the supply voltage varied between 85% and 115% of the nominal rated supply voltage.

a) Where the device is intended to be powered from an external power adapter, the voltage variations shall be applied to the input of the adapter provided with the device at the time of sale. If the device is not marketed or sold with a specific adapter, then a typical power adapter shall be used.

b) For devices where operating at a supply voltage deviating ±15% from the nominal rated value may cause damages or loss of intended function, test to minimum and maximum allowable voltage per manufacturer’s specification and document in the report.

c) For devices with wide range of rated supply voltage, test at 15% below the lowest and 15% above the highest declared nominal rated supply voltage.

d) For devices obtaining power from an input/output (I/O) port (USB, firewire, etc.), a test jig is necessary to apply voltage variation to the device from a support power supply, while maintaining the functionalities of the device.

For battery-operated equipment, the equipment tests shall be performed using a variable power supply.[40]

5.14 Special accessories

The EUT as marketed to a consumer shall comply with the applicable regulatory requirements in the configuration in which the equipment is marketed. Where special components or accessories, such as shielded cables and/or special connectors, are required to enable the equipment to comply with the applicable emission limits, the equipment shall be tested with those special accessories and components and documented as such in the test report.[41,42]

6. Standard test methods

6.1 General

This clause specifies standard test methods that are applicable to most unlicensed wireless devices covered under the scope of this standard. Additional test methods for specific devices are contained in Clause 7 through Clause 16. If conflicting test methods are found between Clause 6 and those in Clause 7 through Clause 16, the test methods in Clause 7 through 16 shall take precedence. The standard methods include tests for the following:

a) Power-line conducted emissions (6.2)

b) Radiated emissions—common requirements (6.3)

c) Radiated emissions below 30 MHz (6.4)

d) Radiated emissions above 30 MHz and below 1000 MHz (6.5)

e) Radiated emissions above 1000 MHz (6.6)

f) Antenna-port conducted signals (6.7)

g) Frequency stability (6.8)

h) Occupied bandwidth (6.9)

i) Band-edge (6.10)

j) In situ radiated emissions (6.11)

NOTE—For readability and continuity of the test procedure descriptions, accompanying figures are all grouped in 6.12.

[40] See 6.8 for testing of frequency stability due to variations in temperature and variations in supply voltage, as required per 47 CFR 15.225(e), 15.229(d), and 15.231(d).
[41] See 47 CFR 15.27.
[42] Regulatory authorities could specify additional labeling, instruction manual, and user requirements for devices and systems that require accessories for the operation or installation of certain unlicensed wireless devices.

6.2 Standard test method for ac power-line conducted emissions from unlicensed wireless devices

6.2.1 General considerations

AC power-line conducted emission measurements shall be made, unless otherwise specified, over the frequency range from 150 kHz to 30 MHz, to determine the line-to-ground radio-noise voltage that is conducted from all of the EUT current-carrying power input terminals that are directly (or indirectly via separate transformers or power supplies) connected to a public power network. These measurements can also be required between 9 kHz and 150 kHz.

If the EUT normally receives power from another device that in turn connects to the public utility ac power-lines, measurements shall be made on that device with the EUT in operation to demonstrate that the device continues to comply with the appropriate limits while providing the EUT with power. If the EUT is operated only from internal or dedicated batteries, with no provisions for connection to the public utility ac power-lines (600 V ac or less) to operate the EUT (such as an adapter), then ac power-line conducted measurements are not required.

For direct current (dc) powered devices where the ac power adapter is not supplied with the device, an "off the shelf" unmodified ac power adapter shall be used. If the device is supposed to be installed in a host (e.g., the device is a module or PC card), then it is tested in a typical compliant host (see also 5.10.3).

6.2.2 Measurement requirements

Measured levels of ac power-line conducted emission shall be the emission voltages from the voltage probe, where permitted, or across the 50 Ω LISN port (to which the EUT is connected), where permitted, terminated into a 50 Ω measuring instrument. All emission voltage and current measurements shall be made on each current-carrying conductor at the plug end of the EUT power cord by the use of mating plugs and receptacles on the LISN, if used. Equipment shall be tested with power cords that are normally supplied or recommended by the manufacturer and that have electrical and shielding characteristics that are the same as those cords normally supplied or recommended by the manufacturer. For those measurements using a LISN, the 50 Ω measuring port is terminated by a measuring instrument having 50 Ω input impedance. All other ports are terminated in 50 Ω loads. Figure 5 shows typical test setups of radiated measurements. Note the optional LISN in this figure. Figure 6 and Figure 7 show typical test setups for ac power-line conducted emissions testing. (Figures cited in Clause 6 are shown in 6.12.) For information about the use of an RF shielded (screened) room, vertical conducting plane, and voltage probe, see ANSI C63.4.

Tabletop devices shall be placed on a platform of nominal size 1 m by 1.5 m, raised 80 cm above the reference ground plane. The vertical conducting plane or wall of an RF shielded (screened) room shall be located 40 cm to the rear of the EUT. Floor-standing devices shall be placed either directly on the reference ground plane or on insulating material as described in ANSI C63.4. All other surfaces of tabletop or floor-standing EUTs shall be at least 80 cm from any other grounded conducting surface, including the case or cases of one or more LISNs.

Each current-carrying conductor of the EUT power cord(s), except the ground (safety) conductor(s), shall be connected individually through a LISN to the input power mains. All 50 Ω ports of the LISN shall be resistively terminated in 50 Ω loads when not connected to the measuring instrument. When the test configuration comprises multiple units that have their own power cords, ac power-line conducted emissions measurements shall be performed with the ac power-line cord of the particular unit under test connected to one LISN that is connected to the measuring instrument. Power cords not connected to the EUT shall be connected to separate LISN(s). This connection may be made using a multiple receptacle device.

Emissions from each current-carrying conductor of the EUT shall be measured individually. Where multiple portions of the EUT receive ac power from a common power strip, which is furnished by the manufacturer as part of the EUT, measurements need only be made on the current-carrying conductors of the common power strip. Adapters or extension cords connected between the EUT power cord plug and the LISN power receptacle shall be included in the LISN setup such that the calibration of the combined adapter or extension cord with an adapter and the LISN meets the requirements of 4.2.

If the EUT is composed of several devices that have their own separate ac power connections (e.g., a floor-standing frame with independent power cords for each shelf), which can connect directly to the ac power network, then each current-carrying conductor of one device is measured while the other devices are connected to a second (or more) LISN(s). All devices shall be measured separately.

If the EUT is normally operated with a ground (safety) connection, then the EUT shall be connected to the ground at the LISN through a conductor provided in the lead from the ac power to the LISN.

The excess length of the power cord between the EUT and the LISN receptacle (or ac power receptacle where a LISN cannot be used), or an adapter or extension cord connected to and measured with the LISN, shall be folded back and forth at the center of the lead to form a bundle not exceeding 40 cm in length; see Figure 5. If the EUT does not have a flexible power lead, then the EUT shall be placed at a distance of 80 cm from the LISN (or power receptacle where a LISN cannot be used) and connected thereto by a power lead or appropriate connection no more than 1 m long. The measurement shall be made at the LISN end of this power lead or connection.

The LISN housing, measuring instrument case, and reference ground plane or vertical conducting plane, if used, shall be bonded together (see ANSI C63.4).

6.2.3 Arrangement of EUT

6.2.3.1 General requirements

The emission tests shall be performed with the EUT and accessories arranged and configured in a manner that tends to produce maximum emissions within the range of variations that can be expected under normal operating conditions. Equipment that typically operates within a system made up of multiple interconnected units shall be tested as part of such a typical operational system. The guidance and consideration in 5.10 shall also be applied in the setup and operating requirements of the unlicensed wireless device.

The results of any such discussion and decision process shall be reported in the test report. A photograph or detailed drawing shall be used to document the equipment arrangement and shall be part of the test report.

To replicate emission measurements, it is important to document the arrangement of the system components, cables, wires, and ac power cords. Two general device classes and test arrangements are described: tabletop equipment (6.2.3.2) and floor-standing equipment (6.2.3.3).

6.2.3.2 Tabletop equipment testing

6.2.3.2.1 General requirements

Portable, small, lightweight, or modular devices that can be handheld, worn on the body, or placed on a table during operation shall be positioned at the center along the back edge of a nonconducting platform, the top of which is 80 cm above the reference ground plane, as shown in Figure 6. Ceiling and wall-mounted devices shall also be positioned at the center of a tabletop for conducted testing purposes. The preferred area occupied by the EUT arrangement is 1 m by 1.5 m, but it may be larger or smaller to accommodate various sized EUTs (see Figure 6).

6.2.3.2.2 Arrangement of tabletop EUTs

A stand-alone EUT shall be placed in the center along the back edge of the tabletop. For multiunit tabletop systems, the EUT shall be centered laterally (left to right facing the tabletop) on the tabletop and its rear shall be flush with the rear of the table.

Accessories that are part of an EUT system tested on a tabletop shall be placed in a test arrangement on one or both sides of the host with a 10 cm separation between the nearest points of the cabinets (see Figure 6). The rear of the host and accessories shall be flush with the back of the supporting tabletop unless that would not be typical of normal use. If more than two accessories are present, then an equipment test arrangement shall be chosen that maintains 10 cm spacing between cabinets unless the equipment is normally located closer together. Multiple accessories (more than two) may be distributed around the table as shown in Figure 6.

Accessories, such as ac power adapters, which are typically table mounted because of cable length, shall be mounted on the tabletop in a typical manner. Accessories, which are typically floor mounted, shall occupy a floor position directly below the portion of the EUT to which they are typically connected.

Power accessories, such as ac power adapters that power other devices, shall be tested in the following manner:

a) **Power accessories that are not the EUT:** If the EUT power cord to the power accessory is less than 80 cm in length, the EUT power cord shall be draped over the edge of the tabletop and the power accessory shall hang vertically in the air such that the EUT power cord, continued with the power accessory and the ac mains cable to the power accessory, take the shortest path to the floor.

   If the power accessory plugs directly into outlet (i.e., it is not equipped with an ac mains power cable) or if its ac mains power cable is too short to reach the test site mains outlet or the LISN, an extension cord shall be used from the power source (or LISN) to the power accessory (or the end of its ac mains cable). Any suitable gauge extension cord may be used. If required, a non-conductive support may be used for raising the power accessory at the necessary height above ground. In all other cases, the power accessory shall be placed directly on the floor immediately under the EUT connection point.

b) **Power accessories that are the EUT:** If the ac mains power cord of the power accessory has length 80 cm or greater, the power accessory shall be placed on the tabletop. If the power accessory has an ac mains power cord that is less than 80 cm or if the power accessory plugs directly into an outlet, the power accessory shall be tested on the tabletop using an extension cord between the source of power and the accessory. The extension cord shall be connected in a manner such that it takes the most direct path to the power accessory. Any suitable gauge extension cord may be used.

   In all cases where the power accessory is included in the EUT arrangement (i.e., placed on the tabletop), its location shall observe the 10 cm spacing requirement, as per 6.2.3.2.2.

6.2.3.2.3 Arrangement and manipulation of interconnect cabling (or wiring) for tabletop equipment

The system shall be arranged in one typical equipment arrangement for the test. In making any tests, involving several tabletop equipment components interconnected by cables or wires, it is essential to recognize that the measured levels can be critically dependent on the exact placement of the cables or wires. Thus, exploratory tests as specified in 6.2.4 shall be carried out while varying cable positions within typical arrangements to determine the maximum emission level. During manipulation, cables shall not be placed under or on top of the system units, unless such placement is required by the inherent equipment design.

Cables that are tied together over a length greater than 50 cm (see Table 1 in 1.5 for allowed tolerance), or run in a common jacket or conduit, or that are too stiff to bend do not have to be manipulated.

6.2.3.3 Floor-standing equipment tests

6.2.3.3.1 General requirements

Where a floor-standing EUT is typically installed with its base in direct electrical contact with, or connected to, a grounded metal floor or grid, the EUT shall be connected to, or placed directly on, the test site (or turntable) reference ground plane in a manner representative of this contact or connection.

Where floor-standing equipment is not typically installed with its base in direct electrical contact with, or connected to, a metal floor or grid, the EUT shall not be placed in direct electrical contact with the test site (or turntable) reference ground plane. If necessary to prevent direct metallic contact of the EUT and the reference ground plane, insulating material (up to 12 mm thick) shall be placed under the EUT.

To represent typical raised/false floor installation of EUTs more explicitly, the base of the EUT may be raised but in no case exceed 34 cm above the reference ground plane. If the EUT elevation that is not representative of a typical installation is used for testing, the reason for the variation shall be explained in the test report. However, the preferred method shall be measurements made at elevations that are representative of actual applications.

Floor-standing equipment can be interconnected with cabling either lying on the floor, under the floor (to simulate a raised floor installation), or overhead, according to typical installation. The material used to raise the test item or to support the cabling shall be nonconductive and shall not adversely affect the validation of the test site (for radiated emissions). Test arrangements for floor-standing equipment are shown in Figure 7. Normally, tests shall be performed with the equipment standing on the reference ground plane, with or without an insulating surface, as appropriate.

6.2.3.3.2 Arrangement of floor-standing accessories

Accessories that are part of a floor-standing system shall be placed in one typical arrangement with typical spacing between equipment cabinets or enclosures.

6.2.3.3.3 Arrangement and manipulation of interconnect cabling (or wiring) for floor-standing equipment

Interconnecting cables are not normally manipulated for floor-standing equipment of which the typical installation is known. Instead, the cables shall be laid out as shown in Figure 7. If the configuration of a typical installation is not known or changes with each installation, then the cables of floor-standing equipment shall be manipulated to the extent possible to produce the maximum level of emissions, within the range of typical installations. For large equipment interfacing with other large equipment normally placed at some distance away, cables may be attached to the EUT, extend away from the EUT in the horizontal direction for at least 1 m, and then return to another port of the EUT (which would normally receive the transmit signal from another equipment), but at an elevation sufficiently different than that of the outgoing direction so as not to cancel the emission potential of either portion (outgoing and incoming) of the cable in this loop back situation. Loop back for this purpose is characterized by a single cable leaving a connector of the EUT, extending a distance away, and then routed back to the EUT at another connector.

Cables that are tied together over a length greater than 50 cm (see Table 1 in 1.5 for allowed tolerance), or run in a common jacket or conduit, or that are too stiff to bend do not have to be manipulated.

6.2.4 Exploratory ac power-line conducted emission measurements

Exploratory tests shall be run with the modulating signal(s) specified in 5.12 applied to the EUT. Antenna(s) can be integral or detachable. If detachable, the antenna(s) shall be attached during the test. The EUT shall be operated on the mid channel and in the mode with highest output power unless the fundamental operates in the AC power-line emission test range then the EUT shall be operated in the range of typical modes of operation, cable positions, and with a typical system equipment configuration and arrangement. For each mode of operation and for each ac power current-carrying conductor, cable manipulation shall be performed within the range of likely configurations. For this measurement or series of measurements, the frequency spectrum of interest shall be monitored looking for the emission that has the highest amplitude relative to the limit. Once that emission is found for each current-carrying conductor of each power cord associated with the EUT (but not the cords associated with non EUT equipment in the overall system), the one configuration and arrangement and mode of operation that produces the emission closest to the limit over all of the measured conductors shall be recorded.

6.2.5 Final ac power-line conducted emission measurements

Based on the exploratory tests of the EUT performed in 6.2.4, the one EUT cable configuration and arrangement and mode as described in 5.6.4 that produced the emission with the highest amplitude relative to the limit is selected for the final measurement, while applying the appropriate modulating signal to the EUT. If the EUT is relocated from an exploratory test site to a final test site, the highest emissions shall be remaximized at the final test location before final ac power-line conducted emission measurements are performed. The final test on all current-carrying conductors of all of the power cords to the equipment that comprises the EUT (but not the cords associated with other non EUT equipment in the system) is then performed for the full frequency range for which the EUT is being tested for compliance without further variation of the EUT arrangement, cable positions, or EUT mode of operation. If the EUT is composed of equipment units that have their own separate ac power connections (e.g., floor-standing equipment with independent power cords for each shelf that are able to connect directly to the ac power network), then each current-carrying conductor of one unit is measured while the other units are connected to a second (or more) LISN(s). All units shall be measured separately. If a power strip is provided by the manufacturer, to supply all of the units making up the EUT, only the conductors in the power cord of the power strip shall be measured.

If the EUT operates above 30 MHz and uses a detachable antenna, then these measurements shall be made with a representative antenna connected to the antenna output terminals. These tests shall be made with the antenna connected and, if adjustable, fully extended.

When an EUT operates below 30 MHz it is acceptable to test the device with the antenna connected and if emissions at the fundamental frequency exceed the limit the antenna, detachable or non-detachable, may be replaced with a suitable dummy load and the test repeated in this configuration. Emissions must not exceed the regulatory limit with the dummy load in place.

For conducted power-line emission test data reporting, both spectral plots and tabular data shall be included. Tabulated data shall include the six highest EUT emissions relative to the limit of each of the current-carrying conductors of the power cords of the equipment that comprises the EUT over the frequency range specified by the procuring or regulatory agency. See Clause 17 for full reporting requirements.

6.3 Radiated emissions testing-common requirements

This subclause details requirements common to all radiated measurements. Specific requirements beyond those in this subclause for measurements below 30 MHz, from 30 MHz to 1000 MHz (inclusive), and above 1000 MHz are detailed in 6.4, 6.5, and 6.6, respectively.

6.3.1 Test arrangement

Figure 5 shows the typical arrangement of an unlicensed wireless device on a tabletop on a test site. Tabletop devices shall be placed on a nonconducting platform with nominal top surface dimensions 1 m by 1.5 m. For emissions testing at or below 1 GHz, the table height shall be 80 cm above the reference ground plane.[43] For emission measurements from 1 GHz to 40 GHz, the table height shall be 1.5 m (see 6.6.3.1). A method for evaluating the effects of the table on EUT radiated emissions is given in 6.11 of CISPR 16-1-4:2019 for frequencies up to 18 GHz. The EUT shall be set up in its typical configuration and arrangement and operated in its various modes as described in 5.10. An antenna shall be connected to the EUT in accordance with 5.8 and 5.10.4. The EUT and transmitting antenna shall be centered on the turntable. For devices with multiple antennas that are active simultaneously, the EUT shall be positioned, to the extent possible, with the antennas equally distributed around the center of the device. The exact setup shall be documented in the test report.

[43] For UWB devices (47 CFR Part 15 Subpart F), the table height shall be 80 cm for emission measurements at or below 960 MHz, and 1.5 m for emission measurements above 960 MHz.

Any controlling device (e.g., notebook, laptop, or desktop computer) shall be positioned such that it shall not significantly influence the measurement results. No other peripherals are required to be connected to the controlling device for this test unless the radio is being tested as part of the notebook or PDA qualifications.

External antenna(s) shall be positioned for maximum radiated emissions. If the EUT is equipped with or uses an adjustable antenna, then the EUT antenna shall be manipulated through typical positions and lengths during exploratory testing to maximize emission levels. For high gain antennas or antennas that are not structurally supported by the EUT, a nonmetallic supporting structure shall be used.

EUTs with integral antennas shall be evaluated in their normal orientation. Where EUTs are designed to be installed in one of two orientations (such as wireless access points that can be located horizontally on a table or mounted vertically to the wall), these devices shall be tested in both orientations. EUTs that can be operated in multiple orientations (such as handheld, portable, or modular devices) shall be tested in three orientations. However, in all cases, the antenna shall be adjusted and the EUT orientated to permit the measurement of the maximum emission from the EUT. For example, a device that is intended to radiate downward in normal operation shall be tested in an orientation that permits the measurement of the maximum level of the downward radiation; see Figure 9.

NOTE—Ground-penetrating UWB devices do not require any other orientation beyond the downward direction, see Clause 10 for method details.

When rotating the EUT, the maximum antenna coupling between the EUT and the measurement antenna must be achieved at some point during the rotation.

When testing tabletop equipment on a test site that meets the validation requirements of Figure 5 with the LISN in place, the LISN may remain in place; otherwise, the LISN shall be removed. Below 30 MHz, the LISN shall be removed, unless it is located below the ground plane. Unused LISN measuring port connector(s) shall be terminated in 50 Ω load(s).

A typical arrangement for floor-standing equipment is shown in Figure 7, except that the LISNs located above the ground plane shall be removed for radiated measurements. The applicable comments in 6.3 also apply to “floor-standing equipment.” Where possible, the antenna(s) of the EUT shall be located at a height of 1.5 m above the floor, and the intentional radiator circuitry shall be located within the system at a height of at least 0.8 m above the floor.

Interconnecting cables that hang closer than 40 cm to the ground plane shall be folded back and forth in the center, forming a bundle 30 cm to 40 cm long.

6.3.2 Operational Configurations

The EUT shall be tested while operating on the design frequency of the device. In the case of EUTs that can operate on more than one frequency, unless otherwise specified in the individual tests, measurements shall be made with the EUT set to a frequency or frequencies as provided in 5.5 and 5.6 for each frequency band of operation. The EUT controls shall be maximized pursuant to 5.10.5 and 5.11. The applied modulation shall follow the guidance given in 5.12. In addition, the following steps shall be performed, if appropriate:

a) Set the unlicensed wireless device to operate in continuous transmit mode. For unlicensed wireless devices unable to be configured for 100% duty cycle even in test mode, configure the system for the maximum duty cycle supported under normal operating conditions.

b) Testing shall be performed using the minimum required number of channels as specified in 5.5 and 5.6 for each allowable frequency band. Testing shall be performed on all channel sets allowed under applicable regulatory requirements.

c) Testing shall be performed for each frequency with every available modulation in the unlicensed wireless device that produces maximum emissions. Different data rates can also result in different emissions profiles. The test report shall show that the maximum emission levels have been collected and reported.

d) The highest gain of each antenna type shall be used for this test. Tests shall be repeated on lower gain antennas of the same type if the device has a higher output power when used with the lower gain antennas.

Measurements shall be made around the EUT as described in 5.4, and the orientation of the measurement antenna shall be investigated to determine the maximum radiated emission level. Cables or wires shall be manipulated within the range of likely arrangements to maximize the measured emission levels.

6.3.3 Radiated total peak emission level

Some wireless devices are subject to a peak limit based on the total peak emission level (i.e., rather than being based on a peak level over a specified bandwidth). Unless otherwise specified, radiated measurements of the fundamental signal peak field strength shall be made using instrumentation with a bandwidth equal to or greater than the 6 dB bandwidth of the emission.[44] For unlicensed wireless devices with fundamental signals subject to quasi-peak (QP) limits, when the QP detector bandwidth is less than the 6 dB bandwidth of the emission, a peak detector with a bandwidth equal to or greater than the 6 dB bandwidth of the emission shall be used.

6.3.4 Test report

For radiated emission test data reporting, both spectral plots and tabular data shall be included. When multiple operating modes are evaluated, only the worst-case spectral plots for each mode in each operating band need to be included in the report. A diagram or photograph of the test setup that was used shall also be included. Data content and format shall conform to the requirements specified in Clause 17.

6.4 Radiated emissions from unlicensed wireless devices below 30 MHz

6.4.1 General

This subclause contains procedures for compliance testing below 30 MHz. Unlicensed wireless devices that are too large for a test site shall be tested for compliance at the manufacturer's facility or in situ; see the procedures in 6.11.

6.4.2 Test arrangement

The test site shall meet the test site requirements of 5.2. The tests shall be made using the instrumentation specified in Clause 4, and following the general requirements in Clause 5 and 6.3. Measurements shall be performed around the EUT in accordance with the description in 5.4.

6.4.3 Measuring antenna selection, location, and test distance

Radiated emission tests shall be performed in the frequency range of 9 kHz to 30 MHz, using a calibrated loop antenna as specified in 4.3.2, at a suitable site and measurement distance as specified in 5.3. This method is applicable for measuring radiated RF emissions from all units, cables, power cords, and interconnect cabling or wiring of the EUT, by applying the guidance provided in 5.10 along with guidance provided subsequently.

At frequencies below 30 MHz, measurements may be performed at a distance closer than that specified in the requirements. When performing measurements at a closer distance than specified, the results shall be extrapolated to the specified distance by using one of the methods described in 6.4.4 or 6.4.5, unless

[44] See 47 CFR 15.35(b).

otherwise accepted by a regulatory authority. See Table 12 showing the relationship between frequency and wavelength.[45] For all measurements or calculations of extrapolation, if extrapolation is determined at a particular frequency, then the resultant extrapolation value may be presumed to apply to other frequencies within one octave of the frequency that was used for the measurement or calculation of extrapolation.

Table 12—Relationship of frequency and wavelength (informative)

Frequency (MHz)	λ (m)	0.625λ (m)	λ/2π
0.009	33333.3	20833.3	5305.2
0.1	3000.0	1875.0	477.5
0.3	1000.0	625.0	159.2
1	300.0	187.5	47.7
4.76	63.0	39.4	10.0
16	18.8	11.7	3.0
30	10.0	6.3	1.6

6.4.4 Extrapolation for devices with a maximum dimension ≤0.625λ

6.4.4.1 General requirements

If measurements are made of a device with a maximum antenna dimension of 0.625λ or less at the frequency being measured, then the results shall be extrapolated to the specified distance by conservatively presuming that the field strength decays at 40 dB/decade of distance in the region closer than λ in m divided by 2π (i.e., λ/2π), and at 20 dB/decade of distance beyond that, using the measurement of a single point at the radial angle that produces the maximum emission as described in 5.4, or by making measurements at a minimum of two distances on the radial for which the field strength at the closest point was the greatest, to determine the proper extrapolation factor. If a measurement is made at the specified limit distance, it is not necessary to do any extrapolation of that measurement result. The distances used to measure extrapolation should be spaced no closer than 3 m; or if there were reasons that the spacing of measurement points had to be less than 2 m, the test report shall explain those reasons.[46]

The λ/2π distance in m, $d_{\text{near-field}}$, shall be determined using Equation (1):

$$d_{\text{near field}} = 47.77 / f_{\text{MHz}} \tag{1}$$

where

f_{MHz} is the frequency of the emission being measured in MHz.

6.4.4.2 Extrapolation from the measurement of a single point

If field strength is measured at only a single point, then that point shall be at the radial from the EUT that produces the maximum emission at the frequency being measured, as described in 5.4. If that point is closer to the EUT than λ/2π and the limit distance is greater than λ/2π, the measurement shall be extrapolated to the limit distance by conservatively presuming that the field strength decreases at a 40 dB/decade of distance rate to the λ/2π distance, and at a 20 dB/decade of distance rate beyond λ/2π. This shall be accomplished using Equation (2):

[45] 0.625λ (λ is wavelength) is the size at which radiating antennas begin to develop a complex pattern that starts decreasing radiating energy in the direction of greatest directivity and putting more energy in other directions. This value was chosen for the purposes of this standard as a justifiable break point at which it is necessary to look at multiple radials at the various distances used for extrapolation calculation because of the complex nature of the radiating pattern of large radiators. See footnote 47 to 6.4.5.
[46] The 3 m distance was considered to be a reasonable minimum distance for which to determine an extrapolation factor. Other minimum distances may be used, provided a reasonable justification is provided.

$$FS_{\text{limit}} = FS_{\max} - 40\log\left(\frac{d_{\text{near field}}}{d_{\text{measure}}}\right) - 20\log\left(\frac{d_{\text{limit}}}{d_{\text{near field}}}\right) \tag{2}$$

where

FS_{limit} is the calculation of field strength at the limit distance, expressed in dBμV/m
$FS_{\max}$ is the measured field strength, expressed in dBμV/m
$d_{\text{near-field}}$ is the $\lambda/2\pi$ distance
d_{measure} is the distance of the measurement point from the EUT
d_{limit} is the reference limit distance

If the single point measured is at a distance greater than $\lambda/2\pi$, then extrapolation to the limit distance shall be calculated using Equation (3):

$$FS_{\text{limit}} = FS_{\max} - 20\log\left(\frac{d_{\text{limit}}}{d_{\text{measure}}}\right) \tag{3}$$

If both the single point and the limit distance are equal to or closer to the EUT than $\lambda/2\pi$, then extrapolation to the limit distance shall be calculated using Equation (4):

$$FS_{\text{limit}} = FS_{\max} - 40\log\left(\frac{d_{\text{limit}}}{d_{\text{measure}}}\right) \tag{4}$$

where

FS_{limit} is the calculation of field strength at the limit distance, expressed in dBμV/m
$FS_{\max}$ is the measured field strength, expressed in dBμV/m
d_{measure} is the distance of the measurement point from the EUT
d_{limit} is the reference limit distance

6.4.4.3 Calculation of extrapolation factor using measurements made at two or more points with multiple measurement points and limit distance ≥ λ/2π

If measurements of field strength are made at more than one measurement distance from the EUT and all measurement points and the limit distance are at a distance of $\lambda/2\pi$ or greater, then measurements of two or more points at different distances along the radial of maximum emissions shall be made. A calculation of the extrapolation factor from measurements may be made using the methods described in 6.4.4.4 or 6.4.4.5, depending on the number of points measured.

6.4.4.4 Calculation of extrapolation factor from two points

If two measurement points and the limit distance are all at a distance equal to or greater than $\lambda/2\pi$ and are used to determine the extrapolation value, or if the measurement points and the limit distance are within $\lambda/2\pi$, then Equation (5) shall be used to calculate the extrapolation factor in dB/decade of distance:

$$N = 20\frac{\log(E_1 / E_2)}{\log(d_1 / d_2)} \tag{5}$$

where

E_1 is the field strength at the measurement distance closest to the radiating source, expressed in μV/m
E_2 is the field strength at the measurement distance farthest from the radiating source, expressed in μV/m

d_1 is the measurement distance closest to the radiating source
d_2 is the measurement distance farthest from the radiating source
N is the distance extrapolation factor in dB/decade of distance. The field strength at the limit distance shall then be calculated using the methods and formula described in 6.4.4.7.

If measurements of two or more points at distances greater than λ/2π are made, then it is not necessary to evaluate the field strength at distances closer than λ/2π or to determine the rate of decay of the field strength within the λ/2π boundary.

6.4.4.5 Calculation of extrapolation factor from three or more points

If three or more measurement points at a distance equal to or greater than λ/2π are used to determine the extrapolation value, or if the measurement points and the limit distance are within λ/2π, then the slope of the decay of the line of best fit of those values in dB/decade of distance (N) shall be determined by calculating the first order linear regression of the three measurements versus distance. The values for the x-axis used for this calculation shall be expressed in terms of [log (d)], where d is the linear distance of the measurement point from the radiating source. The values for the y-axis shall be expressed in terms of [20 log (E)], where E is the field strength in V/m or A/m (or also μV/m or μA/m). This calculation may be done using the linear regression function available on many scientific calculators.

If the measurement result is obtained in dBμV/m, as is common practice, the [20 log] function has already been applied. The resultant value N represents the extrapolation factor in dB/decade of distance. The field strength at the limit distance shall then be calculated using the methods and formula described in 6.4.4.7.

6.4.4.6 Calculation of extrapolation factor if one or more measurement points are located <λ/2π

On frequencies for which all measurement points and the limit distance are equal to or closer than λ/2π, the methods described in 6.4.4.4 or 6.4.4.5 may be used.

It is recommended that measurements of field strength not be in the near-field at distances closer than λ/2π, unless near-field measurements cannot be avoided because of site limitations, ambient noise levels, or other necessary testing considerations. If measurements are made at distances closer than λ/2π, the test report shall indicate the reasons that it was necessary to make measurements in the near-field.

If a measurement at one or more points must be made closer than λ/2π to the EUT, then these measurement results shall be extrapolated to estimate field strength at the λ/2π boundary. This extrapolated value shall then be used as one of the points in the calculations described in 6.4.4.4 or 6.4.4.5.

If only one point is measured inside the λ/2π boundary, then this result shall be extrapolated to a distance of λ/2π using the assumption of a decay of 40 dB/decade of distance. This shall be determined using Equation (6):

$$FS_{\text{near field}} = FS_{\text{measure}} - 40\log\left(\frac{d_{\text{measure}}}{d_{\text{near field}}}\right) \tag{6}$$

where

$FS_{\text{near-field}}$ is the estimated field strength at the λ/2π boundary
FS_{measure} is the value measured at the measurement point
d_{measure} is the distance of the measurement point from the EUT
$d_{\text{near-field}}$ is the distance of the λ/2π boundary

If two points are measured inside the λ/2π boundary, then the measurement results shall be extrapolated to the λ/2π distance using Equation (7):

$$FS_{\text{near field}} = FS_{\text{measure}} - \left[20 \frac{\log(E_1 / E_2)}{\log(d_1 / d_2)} \log\left(\frac{d_{\text{near field}}}{d_{\text{measure}}} \right) \right] \tag{7}$$

where

$FS_{\text{near-field}}$	is the estimated field strength at the λ/2π boundary
FS_{measure}	is the value measured at the measured point
d_{measure}	is the distance of the measurement point from the EUT
$d_{\text{near-field}}$	is the distance of the λ/2π boundary

If three or more points are measured inside the λ/2π boundary, then the measurements shall be extrapolated to the λ/2π distance using the methods described in 6.4.4.5.

6.4.4.7 Calculating field strength at the limit distance

After a value of the extrapolation (*N*) is determined using the methods in 6.4.4.4 or 6.4.4.5, this value shall be used to estimate the value of field strength at a more distant point. This point shall generally be the reference distance specified in a regulation or standard, or it shall be the field strength at the λ/2π distance to be used for a second extrapolation to the reference distance. If two measurement points were used to calculate extrapolation, then either may be used to determine the field strength at the reference or λ/2π distance. If three or more points were used to determine extrapolation, then the point with the maximum field strength shall be used in Equation (8) to calculate the field strength at the reference or λ/2π distance:

$$FS_{\text{limit}} = FS_{\text{max}} - N \log\left(\frac{d_{\text{limit}}}{d_{\text{measure}}} \right) \tag{8}$$

where

N	is the value in dB/decade of distance determined using 6.4.4.4 or 6.4.4.5
FS_{limit}	is the estimate of field strength at the limit distance, expressed in dBμV/m
FS_{max}	is the maximum value of field strength, expressed in dBμV/m, measured during the measurement of the points used for extrapolation
d_{measure}	is the distance of the measurement point of FS_{max} from the radiating source
d_{limit}	is the limit reference distance

If Equation (8) is being used to calculate the value of field strength at the reference distance, starting with the calculated value of the field strength at the λ/2π point using the method described in 6.4.4.6, then d_1 is the distance of λ/2π and d_2 is the reference distance specified in measurement requirements or standards.

6.4.5 Extrapolation for devices with maximum dimension greater than 0.625λ[47]

If measurements are made of a device with a maximum dimension of more than 0.625λ at the frequency being measured, then the extrapolation methods described in 6.4.4 may still be used. However, the radiated emissions pattern from a physically large device is complex in the radiating near-field region bounded by $2D^2/\lambda$ (D is the maximum dimension of the EUT). If measurements are made at distances closer than $2D^2/\lambda$, then measurements made of multiple points along the radial of greatest emission shall include sufficient points such that the measurement is not being made of a null in the field strength pattern. This shall be accomplished by making measurements at each distance being measured at a minimum of eight radial angles surrounding the EUT, and then using the highest value at each distance in the calculations described in 6.4.4 for emitters whose maximum antenna dimensions are smaller than 0.625λ.

[47] Radiators that are larger than 0.625 λ develop complex patterns of radiation that diminish the amount of energy that is present in the main lobe of a smaller radiator, perpendicular to the radiator. For this reason, additional measurement points are necessary to establish the decay of emissions at close distances compared with the emission at greater distances. Several references validate this point: Jasik [B61] and Kraus [B63].

Figure 9 (see 6.12) shows an example of measurements made at eight different radials surrounding a device. In this example, the points indicated by stars represent the maximum emission measured at each distance along each radial; these maximum result points would be used to calculate the extrapolation value.

6.4.6 Exploratory radiated emission tests

The tests shall be performed in the frequency range specified in 5.5 and 5.6, using the procedures in

Clause 5, applying the appropriate modulating signal to the EUT, to determine cable or wire positions of the EUT system that produce the emission with the highest amplitude relative to the limit.

Exploratory measurements below 30 MHz are useful in determining the maximum level of emissions while manipulating and rotating the EUT; however, exploratory and final measurements may be made concurrently, provided care is taken to determine the maximum level of emissions for all configurations and orientations.

The test arrangement, measuring antenna guidelines and operational configurations in 6.3.1 and 6.3.2, shall be followed. The measurement antenna shall be positioned with its plane perpendicular to the ground at the specified distance. When perpendicular to the ground plane, the lowest height of the magnetic antenna shall be 1 m above the ground and shall be positioned at the specified distance from the EUT.[48] When the EUT contains a loop antenna that can only be placed in a vertical axis, normal measurements shall be made aligning the measurement antenna along the site axis, and then orthogonal to the axis. For each measurement antenna alignment, the EUT shall be rotated through 0° to 360° on a turntable. When the EUT contains a loop antenna that can be placed in a horizontal or vertical axis, normal measurements shall be made aligning the measurement antenna along the site axis, orthogonal to the axis, and then with the measurement antenna horizontal. For each measurement antenna alignment, the EUT shall be rotated through 0° to 360° on a turntable. The report shall list the six emissions with the smallest margin relative to the limit, for each of the three antenna orientations (parallel, perpendicular, and ground parallel) unless the margin is greater than 20 dB, then the following statement shall be made: “all emissions were greater than 20 dB below the limit.”

6.4.7 Final radiated emission tests

Using the orientation and equipment arrangement of the EUT determined in 6.4.6, and applying the appropriate modulating signal to the EUT, perform final radiated emission measurements on the fundamental and highest spurious emissions.

Unless otherwise specified by the regulatory authority, the instrumentation, detector functions, and bandwidths specified in 4.1.5.2.1 shall be used. For pulsed emissions, the procedure in 4.1.5.2.4 shall be used.

6.5 Radiated emissions from unlicensed wireless devices in the frequency range of 30 MHz to 1000 MHz

The following subclauses describe the procedures that shall be used for making exploratory and final radiated emission tests for frequencies between 30 MHz and 1000 MHz. Measurements may be performed at a distance closer than that specified in the requirements, provided the measuring antenna is beyond its near-field range as determined by the Rayleigh criteria.

6.5.1 Test arrangement

The test site shall meet the test site requirements of 5.2. The tests shall be made using the instrumentation specified in Clause 4 and following the general requirements in Clause 5 and 6.3.

[48] The 1 m antenna height requirement follows the procedure in CISPR 16-1-4:2019 for making magnetic field measurements.

6.5.2 Antenna selection, location, and test distance

Radiated measurements shall be made at the measurement distance as specified in 5.3 using antenna(s) as specified in 4.3.3. The measurement antenna shall be positioned at the specified distance from the periphery of the EUT. The specified distance is the distance between the horizontal projection onto the ground plane of the closest periphery of the EUT and the projection onto the ground plane of the calibration reference point of the measurement antenna.

Measurements shall be made with the antenna positioned in both horizontal and vertical polarizations. The measurement antenna shall be varied in height above the reference ground plane to obtain the maximum signal strength. The measurement antenna height shall be varied from 1 m to 4 m. These height scans apply for both horizontal and vertical polarizations, except that for vertical polarization, the minimum height of the center of the antenna shall be increased so that the lowest point of the bottom of the lowest antenna element clears the site reference ground plane by at least 25 cm. For a tuned dipole, the minimum heights as measured from the center of the antenna are those specified in the NSA measurement requirements (see ANSI C63.4a-2017 or any later versions of ANSI C63.4 that incorporate the text of C63.4a-2017).

Measurements shall be made around the EUT as described in 5.4, and the orientation of the measurement antenna shall be investigated to determine the maximum radiated emission level. Cables or wires greater than 1 m shall be bundled. Cables or wires that are not bundled shall be manipulated within the range of likely arrangements to maximize the measured emission levels. The EUT controls shall also be maximized pursuant to guidance provided in 5.10 and 5.11. The applied modulation shall follow the guidance provided in 5.12.

6.5.3 Exploratory radiated emission tests

Exploratory measurements are used to identify the frequencies and amplitudes of the emissions while manipulating and rotating the EUT.

Exploratory radiated measurements shall be performed at the measurement distance or at a closer distance than that specified for compliance to determine the emission characteristics of the EUT. At near distances, for EUTs of comparably small size, it is relatively easy to determine the spectrum signature of the EUT and, if applicable, the EUT configuration that produces the maximum level of emissions. Exploratory measurements shall be made on a test site per 5.2. Shielded rooms not treated with RF absorption material, shall not be used for exploratory measurements.

For each mode of operation required to be tested, the frequency spectrum shall be monitored. The highest signal levels relative to the limit shall be determined by rotating the EUT from 0° to 360° while varying the measurement antenna height between 1 m and 4 m in vertical and horizontal polarizations.

6.5.4 Final radiated emission tests

Using the orientation and equipment arrangement of the EUT, and based on the measurement results found during the exploratory measurement in 6.5.3, the EUT arrangement, appropriate modulation, and modes of operation that produce the emissions that have the highest amplitude relative to the limit shall be selected for the final measurement. The final measurement shall follow all the procedures in 6.3 with the EUT operating on frequencies per 5.6. For each mode selected, record the frequency and amplitude of the highest fundamental emission (if applicable) and the frequency and amplitude of the six highest spurious emissions relative to the limit; emissions more than 20 dB below the limit do not need to be reported.

Measurements are performed with the EUT rotated from 0° to 360°, the antenna height scanned between 1 m and 4 m, and the antenna rotated to repeat the measurements for both the horizontal and vertical antenna polarizations. Variations in cable or wire placement shall be explored to maximize the measured emissions.

Unless specified otherwise by the regulatory authority, the instrumentation, detector functions, and bandwidths specified in 4.1.5.2.1 and 4.1.5.2.2 shall be used. For pulsed emissions, the procedure in 4.1.5.2.5 shall be used.

6.6 Radiated emissions from unlicensed wireless devices from 1 GHz to 40 GHz

6.6.1 General requirements

This subclause specifies procedures for testing unlicensed wireless devices for radiated emissions on frequencies above 1 GHz. These procedures are in addition to the procedures in 6.3. General guidance for instrumentation and measurement issues from 1 GHz to 40 GHz is contained in Annex E.

6.6.2 Antenna selection, location, and measuring distance

Radiated emission measurements in the frequency range from 1 GHz to 40 GHz shall be made on a test site meeting the requirements in 5.2, and at a measurement distance specified in 5.3 (typically 3 m) using antenna(s) specified in 4.3.4. Because some EUTs can have an electrical size larger than the 3 dB beamwidth of the antenna at the specified measurement distance, and because the source of emissions is generally limited to relatively small angle cones of radiation, the measurement antenna beamwidth shall be known so that when emissions from EUTs are measured, the area of coverage across the EUT can be determined.

6.6.3 Equipment arrangement

6.6.3.1 Tabletop equipment

For emission measurements between 1 and 40 GHz, the EUT shall be placed at a height of 1.5 m above the floor on a support that is RF transparent for the frequencies of interest.[49] The 1.5 m height EUT support shall be constructed using a low permittivity and low loss tangent (tan δ) material with a height of 1.5 m, or a low permittivity and low loss tangent (tan δ) material may be placed on top of a typical table with a height of 0.8 m or 1 m to raise the total height to the 1.5 m specification. One typical low permittivity and low loss tangent material is styrene. Due to its dielectric properties for frequencies above 1 GHz, the use of styrene or building insulation foam is recommended, rather than, for example, wood. Support equipment shall be placed at least 50 cm away from the EUT, such that changes in relative position of the EUT and support equipment do not cause changes in measured values. Final measurements for the EUT require a measurement antenna height scan of 1 m to 4 m.

Where possible, the methods for portable, handheld, or body worn equipment detailed in 6.6.3.3 may be employed for smaller tabletop equipment to allow the use of shorter cabling between measurement antennas and measuring receiver/spectrum analyzer by restricting the upper height of the measurement antenna.

6.6.3.2 Floor-standing equipment

The common requirements of 6.3 apply. Final measurements for floor-standing equipment require a measurement antenna height scan of 1 m to 4 m.

6.6.3.3 Equipment that can used in multiple orientations

Devices that are portable or handheld, or devices that can be mounted in multiple orientations, shall be evaluated as detailed in 6.3.1. The device shall be placed at a height of 1.5 m above the floor on a support that is RF transparent for the frequencies of interest. The use of styrene or building insulation foam is recommended. Support equipment shall be placed far enough away from the EUT such that changes in relative position of the EUT and support equipment do not cause changes in measured values.

[49] The 1.5 m EUT height is consistent with the practice in ETSI documents of specifying a table height of 1.5 m for frequencies above 1 GHz to minimize the effect of the ground plane. This was first recommended by ETSI in 1995 for testing radio equipment operating above 1 GHz and was subsequently incorporated in a European Norm (see, e.g., EN 300 440 1 V1.6.1 (2010 08) [B9]. Elevating the EUT above the lowest height of the measurement antenna also allows for emissions directed below the horizontal plane of the EUT to be measured.

When the EUT is manipulated through three different orientations, the scan height upper range for the measurement antenna is limited to 2.5 m or 0.5 m above the top of the EUT, whichever is higher. The scan height lower range shall be set to 1 m. Alternatively, the measurement method of 6.6.5 may be used for devices smaller than the beamwidth of the measurement antenna.

6.6.4 Radiated emissions tests

6.6.4.1 General

Subclauses 6.6.4.2 and 6.6.4.3 describe the procedures that shall be used for making exploratory and final radiated emission tests for frequencies between 1 GHz and 40 GHz. Measurements may be performed at a distance closer than that specified in the requirements; however, an attempt shall be made to avoid making measurements in the near-field of both the measurement antenna and the EUT for final measurements. If far-field conditions cannot be realized then the appropriate regulator(s) shall be contacted for further guidance.

In performing these measurements, the sensitivity of the complete measurement system relative to the limit shall be determined before the test. If the overall measurement sensitivity does not provide a noise floor more than 6 dB below the limit, then low-noise preamplifiers, closer test distances, higher gain antennas, or narrower bandwidths might be required. If closer measurement distances are used, then the beamwidth of the measurement antenna versus the size of the EUT shall be taken into account. Also, measurement system overload protection shall be determined to be adequate when preamplifiers are used [see item a) of 4.1.3]. The effects of using bandwidths different from those specified shall also be determined (see also 6.3). Any changes from the specific measurement conditions shall be described in the report of the measurements (see also Annex E).

Install an appropriate filter at the input of the measurement system power amplifier. This filter shall attenuate the fundamental emission of the EUT and allow an accurate measurement of the associated harmonics and spurious emissions. The filter shall be characterized, and any attenuation/loss factors shall be accounted for in the measurement results.

Data shall be recorded in peak and average detection up to the highest measurement frequency required (unless stated otherwise in the applicable requirements).

6.6.4.2 Exploratory radiated emissions measurements

Exploratory radiated measurements shall be performed at the measurement distance or at a closer distance than that specified for compliance to determine the emission characteristics of the EUT and, if applicable, the EUT configuration that produces the maximum level of emissions. The frequencies of maximum emission may be determined by manually positioning the antenna close to the EUT, and then moving the antenna over all sides of the EUT while observing a spectral display. It is advantageous to have prior knowledge of the frequencies of emissions, although this may be determined from such a near-field scan. The near-field scan shall only be used to determine the frequency but not the amplitude of the emissions. Where exploratory measurements are not adequate to determine the worst-case operating modes and are used only to identify the frequencies of the highest emissions, additional preliminary tests can be required.

Preliminary tests shall be performed following the procedures in 6.3 on a site meeting the requirements of 5.2. For emissions from the EUT, the maximum level shall be determined by rotating the EUT and its antenna through 0° to 360°. For each mode of operation required to be tested, the frequency spectrum (based on findings from exploratory measurements) shall be monitored.

Broadband antennas and a spectrum analyzer or a radio-noise meter with a panoramic display are often useful in this type of test. If either antenna height or EUT azimuth are not fully measured during exploratory testing, then complete testing can be required at the OATS or semi-anechoic chamber when the final full spectrum testing is performed.

6.6.4.3 Final radiated emissions measurements

The final measurements are performed on a site meeting the requirements of 5.2. Using the orientation and equipment arrangement of the EUT based on the measurement results found during the preliminary (exploratory) measurements per 6.6.4.2, the EUT arrangement, appropriate modulation, and modes of operation that produce the emissions that have the highest amplitude relative to the limit shall be selected for the final measurement. The final measurement shall follow all the procedures in 6.3 with the EUT operating on frequencies per 5.6. For each mode selected, record the frequency and amplitude of the highest fundamental emission (if applicable), as well as the frequency and amplitude of the six highest spurious emissions relative to the limit. Emissions more than 20 dB below the limit do not need to be reported.

Measurements are performed with the EUT rotated from 0° to 360°; the antenna height scanned in accordance with 6.6.3.1, 6.6.3.2, or 6.6.3.3, as appropriate; and the antenna rotated to repeat the measurements for both the horizontal and vertical antenna polarizations. Variations in cable or wire placement shall be explored to maximize the measured emissions.

The emission signal shall be kept within the illumination area of the 3 dB beamwidth of the antenna so that the maximum emission from the EUT is measured. This may be achieved by either pointing the antenna at an angle toward the source of the emission or by testing the EUT as described in 6.6.3.3.

If the emission is pulsed, then refer to Annex C for guidelines on selecting bandwidth and determining pulse desensitization factors, as necessary.

For FMCW emissions, the procedures in 4.1.5.2.8 and Annex L shall be used.

As noted in 6.6.4.1, when performing these measurements, the sensitivity of the complete measurement system relative to the limit shall be determined before the test. If the overall measurement sensitivity is inadequate, then low-noise preamplifiers, closer measurement distances, higher gain antennas, or narrower bandwidths may be used. If closer measurement distances or higher gain antennas are used, then the beamwidth of the measurement antenna versus the physical size of the EUT shall be taken into account, so that the physical sizes of the EUT dimensions are encompassed by the beamwidth of the measurement antenna. Also, measurement system overload protection shall be determined to be adequate when preamplifiers are used. The effects on the measured emission value using bandwidths different from those specified shall be determined if such bandwidth changes are made. Any changes from the specific measurement conditions shall be described in the report of the measurements.

Unless specified otherwise by the regulatory authority, the instrumentation, detector functions, and bandwidths specified in 4.1.5.2.1 and 4.1.5.2.2 shall be used. For pulsed emissions, the procedure in 4.1.5.2.5 shall be used.

NOTE 1—Where limits are specified by regulations for both average and peak detection, if the maximized peak measured value complies with the average limit, then it is unnecessary to perform an average measurement.

NOTE 2—Use of waveguide and flexible waveguide might be necessary at frequencies above 10 GHz to achieve usable signal-to-noise ratios at required measurement distances. See Annex E for guidance.

NOTE 3—Most devices that cause emissions above 10 GHz are physically small compared with the beamwidths of typical horn antennas used for EMC measurements. For such EUTs and frequencies, it might be preferable to vary the height and polarization of the EUT, instead of the receiving antenna, to maximize the measured emissions.

6.6.5 Alternative procedure for an EUT used in any orientation[50]

6.6.5.1 General considerations

This alternative procedure may be used when testing devices that are portable, handheld, or can be installed in different orientations (see 6.6.3.3), in lieu of the procedures of 6.6.4.2 and 6.6.4.3. Typical devices include, but are not limited to, smart phones, tablets, laptops, access points, and so on, which can be wall or ceiling mounted, or can be used in other nonfixed orientation configurations.

Devices with any dimension larger than the beamwidth of the measurement antenna are not suitable for testing with this method; such devices shall be evaluated as tabletop equipment (i.e., 6.6.3.1) or using the method of 6.6.3.2.

6.6.5.2 General requirements for use of the alternative procedure

The general procedures in 6.3 shall be followed to the extent applicable for a device being tested at frequencies between 1 GHz and 40 GHz (i.e., as described in 6.6.1 and 6.6.2).

The antenna and EUT are initially set at the same height of 1.5 m to help reduce the effects from reflections from the ground plane and the RF absorbing material. Extra care needs to be taken where any preliminary measurements are performed at distances less than 3 m, as these measurements can be in the near-field and the extrapolation of results might not be accurate; when possible, final measurements shall be made at 3 m. The actual test distance shall be considered against the requirement to maintain the system noise floor being at least 6 dB, ideally 10 dB, below the lowest applicable emission limit. Final measurements shall be performed on a test site that meets the requirements of 5.2.

6.6.5.3 General description of alternative procedure

The required angular resolution of the turntable is ≤10° (i.e., the sweep time of the analyzer shall be faster than the time it takes for the table to rotate 10°). For fixed turntable angles, set the step size to 10° or less, and then investigate the required frequencies or frequency range. The sweep time and span of the spectrum analyzer, as well as the speed of the turntable, shall be set such that the full frequency range is investigated every 10° or less.

As depicted in Figure 11, x and z represent the "horizontal" axes (i.e., in the plane of the top of the turntable). The vertical y axis is at a point where the center of the turntable rotates about. For the purposes of this method, the "major axis" of the EUT (i.e., x') is taken to be aligned with the x axis of the reference system.

The procedure aligns the equipment, in 30º steps, over the x axis and y axis (from horizontal through to vertical) and continuing over toward the x' axis position (continuing from vertical back toward horizontal), representing the EUT being rotated from 0° (alignment with the x axis) to 150º (30° above the x' position).

The possible EUT usage orientations shall be described by the equipment manufacturer and shall be consistent with the EUT supporting documentation (installation guides, user's manuals, etc.).

6.6.5.4 Details of the alternative method for radiated emission tests

The following procedures are used to determine signals to be measured in the final scan. If exploratory measurements identified a small number of signals to be measured, then it can be more expedient to go directly to the final measurement stage using those signals.

a) Align the equipment such that it is flat to the turntable; Figure 12 shows a typical setup for a mobile device. When the equipment has a display screen, it shall be placed screen upward (if the device

[50] See Annex H for the rationale for making radiated emission measurements using the alternative method of 6.6.5 compared with a three axis orientation EUT test (i.e., 6.6.3.3).

has a number of screens, the larger shall be faced upward). With the measuring antenna in the first polarization, rotate the turntable through 0° to 360° and record any emissions within 10 dB of the limit. Change the measurement antenna polarization and repeat the preceding.

b) As shown in Figure 13, lift one end of the equipment such that it is raised at an angle of 30° to the turntable, one edge on the turntable, and the other is raised and supported by foamed polystyrene or an equivalent material to hold the equipment at 30°. It does not matter which side or end is raised, but the following steps shall continue with the same rotation axis. With the measuring antenna in the first polarization, rotate the turntable through 0° to 360° and record all emissions within 10 dB of the limit. Change the measurement antenna polarization and repeat the preceding.

c) Repeat step b) with the angle increased to 60°.

d) Repeat step b) with the angle increased to 90° (i.e., device vertical).

e) Repeat step b) with the angle increased to 120°. At this stage, the screen, which in step a) was face upward, will now be starting to face toward the tabletop.

f) Repeat step b) with the angle increased to 150°.

In total, six EUT elevation positions are measured (see Figure 14). As the turntable is rotated through 0° to 360° in each step, and both antenna polarizations are measured, the full spherical coverage spurious emission measurements are recorded. The fundamental and all emissions recorded during these preliminary measurements shall be subject to final measurements.

6.6.5.5 Final radiated emission test results using the alternative procedure

The preferred test distance for the final measurements below 40 GHz is 3 m. Final measurements on emissions from the preliminary wideband scan are measured using the same technique as detailed in 6.6.5.4, with the spectrum analyzer tuned to each emission frequency. Final measurements on emissions identified in the preliminary testing are measured discretely at the worst-case EUT orientation by rotating the turntable through 0° to 360°.

6.7 Antenna-port conducted emission measurements

This subclause specifies the procedure for measuring antenna-port conducted emissions from certain unlicensed wireless devices (e.g., frequency hopping spread spectrum systems and direct sequence spread spectrum systems).

Testing shall be done on a laboratory bench in a shielded room or in another suitable location. The active antenna port of the unlicensed wireless device shall be connected to the spectrum analyzer after applying appropriate precautions to protect the instrumentation. If a second antenna port is available, then it shall be tested at one operating frequency, with other port(s) appropriately terminated, to verify it has similar output characteristics as the fully tested port. (See also 7.8.8, 11.12.2, and 12.1.2.)

6.8 Frequency stability tests

Some unlicensed wireless device requirements specify frequency stability tests with variation of supply voltage and temperature; the requirements can be found in the regulatory specifications for each type of unlicensed wireless device. The procedures listed in 6.8.1 and 6.8.2 shall be used for frequency stability tests.

6.8.1 Frequency stability with respect to ambient temperature

a) Supply the EUT with a nominal ac voltage or install a new or fully charged battery in the EUT. If possible, a dummy load shall be connected to the EUT because an antenna near the metallic walls of an environmental test chamber could affect the output frequency of the EUT. If the EUT is equipped with a permanently attached, adjustable-length antenna, then the EUT shall be placed in the center of the chamber with the antenna adjusted to the shortest length possible. Turn ON the EUT and tune it to one of the number of frequencies shown in 5.6.

b) Couple the unlicensed wireless device output to the measuring instrument by connecting an antenna to the measuring instrument with a suitable length of coaxial cable and placing the measuring antenna near the EUT (e.g., 15 cm away), or by connecting a dummy load to the measuring instrument, through an attenuator if necessary.

   NOTE—An instrument that has an adequate level of accuracy as specified by the procuring or regulatory agency is the recommended measuring instrument.

c) Adjust the location of the measurement antenna and the controls on the measurement instrument to obtain a suitable signal level (i.e., a level that will not overload the measurement instrument but is strong enough to allow measurement of the operating or fundamental frequency of the EUT).

d) Turn the EUT OFF and place it inside the environmental temperature chamber. For devices that have oscillator heaters, energize only the heater circuit.

e) Set the temperature control on the chamber to the highest specified in the regulatory requirements for the type of device and allow the oscillator heater and the chamber temperature to stabilize.

f) While maintaining a constant temperature inside the environmental chamber, turn the EUT ON and record the operating frequency at startup, and at 2 min, 5 min, and 10 min after the EUT is energized. Four measurements in total are made.

g) Measure the frequency at each of frequencies specified in 5.6.

h) Switch OFF the EUT but do not switch OFF the oscillator heater.

i) Lower the chamber temperature by not more than 10 °C, and allow the temperature inside the chamber to stabilize.

j) Repeat step f) through step i) down to the lowest specified temperature.

6.8.2 Frequency stability when varying supply voltage

Unless otherwise specified, these tests shall be made at ambient room temperature (+15 °C to +25 °C). An antenna shall be connected to the antenna output terminals of the EUT if possible. If the EUT is equipped with or uses an adjustable-length antenna, then it shall be fully extended.

a) Supply the EUT with nominal voltage or install a new or fully charged battery in the EUT. Turn ON the EUT and couple its output to a frequency counter or other frequency measuring instrument.

   NOTE—An instrument that has an adequate level of accuracy as specified by the procuring or regulatory agency is the recommended measuring instrument.

b) Tune the EUT to one of the number of frequencies required in 5.6. Adjust the location of the measurement antenna and the controls on the measurement instrument to obtain a suitable signal level (i.e., a level that will not overload the measurement instrument but is strong enough to allow measurement of the operating or fundamental frequency of the EUT).

c) Measure the frequency at each of the frequencies specified in 5.6.

d) Repeat the above procedure at 85% and 115% of the nominal supply voltage as described in 5.13.

6.9 Occupied bandwidth tests

The following procedures shall be used for measuring the OBW of the fundamental frequencies of certain unlicensed wireless devices, when required.

6.9.1 General requirements

A spectrum analyzer or other instrument providing a spectral display is recommended for these measurements. When using a spectrum analyzer or other instrument providing a spectral display, the video bandwidth shall be set to a value at least three times greater than the IF bandwidth of the measuring instrument to avoid the introduction of unwanted amplitude smoothing. Video filtering is not used during occupied bandwidth tests.

6.9.2 Occupied bandwidth-relative measurement procedure

A dBc bandwidth is measured as the width of the spectral envelope of the modulated signal, at an amplitude level reduced from a reference value by a specified ratio (or in decibels, a specified number of dB down from the reference value). Typical ratios, expressed in dB, are −6 dB, −20 dB, and −26 dB, corresponding to 6 dB BW, 20 dB BW, and 26 dB BW, respectively. In this subclause, the ratio is designated by "−xx dB." The reference value is either the level of the unmodulated carrier or the highest level of the spectral envelope of the modulated signal, as stated by the applicable requirement. Some requirements might specify a specific maximum or minimum value for the "−xx dB" bandwidth; other requirements might specify that the "−xx dB" bandwidth be entirely contained within the authorized or designated frequency band.[51]

a) The spectrum analyzer center frequency is set to the nominal EUT channel center frequency. The span range for the EMI receiver or spectrum analyzer shall be between two times and five times the OBW.

b) The nominal IF filter bandwidth (3 dB RBW) shall be in the range of 1% to 5% of the OBW and video bandwidth (VBW) shall be at least three times RBW, unless otherwise specified by the applicable requirement.

c) Set the reference level of the instrument as required, keeping the signal from exceeding the maximum input mixer level for linear operation. In general, the peak of the spectral envelope shall be more than [10 log (OBW/RBW)] below the reference level. Specific guidance is given in 4.1.6.2.

d) Steps a) through c) might require iteration to adjust within the specified tolerances.

e) The dynamic range of the instrument at the selected RBW shall be more than 10 dB below the target "−xx dB down" requirement; that is, if the requirement calls for measuring the −20 dB OBW, the instrument noise floor at the selected RBW shall be at least 30 dB below the reference value.

f) Set detection mode to peak and trace mode to max-hold.

g) Determine the reference value: Set the EUT to transmit an unmodulated carrier or modulated signal, as applicable. Allow the trace to stabilize. Set the spectrum analyzer marker to the highest level of the displayed trace (this is the reference value).

h) Determine the "−xx dB down amplitude" using [(reference value) - xx]. Alternatively, this calculation may be made by using the marker-delta function of the instrument.

i) If the reference value is determined by an unmodulated carrier, then turn the EUT modulation ON, and either clear the existing trace or start a new trace on the spectrum analyzer and allow the new trace to stabilize. Otherwise, the trace from step g) shall be used for step j).

j) Place two markers, one at the lowest frequency and the other at the highest frequency of the envelope of the spectral display, such that each marker is at or slightly below the "−xx dB down amplitude" determined in step h). If a marker is below this "−xx dB down amplitude" value, then it shall be as close as possible to this value. The dBc bandwidth is the frequency difference between the two markers. Alternatively, set a marker at the lowest frequency of the envelope of the spectral

[51] See 47 CFR 15.215(c) and 8.11 of RSS Gen Issue 5.

display, such that the marker is at or slightly below the "−xx dB down amplitude" determined in step h). Reset the marker-delta function and move the marker to the other side of the emission until the delta marker amplitude is at the same level as the reference marker amplitude. The marker-delta frequency reading at this point is the specified emission bandwidth.

k) The dBc bandwidth shall be reported by providing spectral plot(s) of the measuring instrument display; the plot axes and the scale units per division shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

6.9.3 Occupied bandwidth-power bandwidth (99%) measurement procedure

The occupied bandwidth is the frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers are each equal to 0.5% of the total mean power of the given emission. The following procedure shall be used for measuring 99% power bandwidth:

a) The instrument center frequency is set to the nominal EUT channel center frequency. The frequency span for the spectrum analyzer shall be between 1.5 times and 5.0 times the OBW.

b) The nominal IF filter bandwidth (3 dB RBW) shall be in the range of 1% to 5% of the OBW, and VBW shall be at least three times the RBW, unless otherwise specified by the applicable requirement.

c) Set the reference level of the instrument as required, keeping the signal from exceeding the maximum input mixer level for linear operation. In general, the peak of the spectral envelope shall be more than [10 log (OBW/RBW)] below the reference level. Specific guidance is given in 4.1.6.2.

d) Step a) through step c) might require iteration to adjust within the specified range.

e) Video averaging is not permitted. Where practical, a sample detection and single sweep mode shall be used. Otherwise, peak detection and max-hold mode (until the trace stabilizes) shall be used.

f) Use the 99% power bandwidth function of the instrument (if available) and report the measured bandwidth.

g) If the instrument does not have a 99% power bandwidth function, then the trace data points are recovered and directly summed in linear power terms. The recovered amplitude data points, beginning at the lowest frequency, are placed in a running sum until 0.5% of the total is reached; that frequency is recorded as the lower frequency. The process is repeated until 99.5% of the total is reached; that frequency is recorded as the upper frequency. The 99% power bandwidth is the difference between these two frequencies.

h) The occupied bandwidth shall be reported by providing spectral plot(s) of the measuring instrument display; the plot axes and the scale units per division shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

6.10 Band-edge testing

The following procedure shall be used when band-edge measurements are required. Table A.2, presented in Annex A, gives a useful guide for determining which band-edge procedure shall be used for each type of unlicensed wireless device.

6.10.1 Band-edge data reporting requirements

These reporting requirements are applicable to all devices for which band-edge measurements are required.

On each operating frequency measured, band-edge emissions shall be reported by providing spectral plots of the measuring instrument display. The axes, the scale units per division, and the limit shall be clearly labeled in the test report. Tabular data are not suitable for reporting band-edge emissions.

6.10.2 Band-edge testing—Applicability of procedures

Procedures in this subclause are not applicable to millimeter-wave devices or UWB devices; see specific procedures for such devices in Clause 9 and Clause 10.

6.10.3 Unlicensed wireless device operational configuration

Set the EUT to operate at 100% duty cycle or equivalent “normal mode of operation.”[52] Testing shall be performed at the lowest frequency channel and highest frequency channel within the allowed operating band.[53] Testing shall be performed for each frequency with every applicable unlicensed wireless device configuration. If more than one power output level is available, then testing shall be done with the appropriate maximum power output for each antenna combination or modulation, as recorded in the unlicensed wireless device conducted power measurement results. The highest gain of each antenna type shall be used for this test.

6.10.4 Authorized-band band-edge measurements (relative method)

These procedures are applicable for determining compliance at authorized band edges where the requirements are expressed as a value relative to the in-band signal level. Procedures for determining compliance with field strength limits at or close to the band-edges are given in 6.10.6 (see also Table A.2).

Band-edge tests are typically performed as a conducted test but may be performed as radiated measurements on a test site meeting the specifications in 5.2, at the measurement distances specified in 5.3. The instrumentation shall meet the requirements in 4.1.1 using the bandwidths and detectors specified in 4.1.5.2.

When performing radiated measurements, the measurement antenna(s) shall meet the specifications in 4.3. The EUT shall be connected to an antenna and operated at the highest power settings following procedures in 6.3.

For other than frequency hopping devices, this test sequence shall be performed once. For devices that support frequency hopping, this test sequence shall be performed twice: once with the hopping function turned OFF and then repeated with the hopping function turned ON. The purpose of the test with the hopping function turned on is to confirm that the RF power remains OFF while the device is changing frequencies, and that the oscillator stabilizes at the new frequency before RF power is turned back ON. Overshoot of any oscillator, including phase-lock-loop stabilized oscillators, can cause the device to be temporarily tuned to frequencies outside the authorized band, and it is important that no transmissions occur during such temporary periods. Particular attention to the hopping sequence requirements specified below is needed in the case of adaptive frequency hopping devices:

a) Connect the EMI receiver or spectrum analyzer to the EUT using an appropriate RF cable connected to the EUT output. Configure the spectrum analyzer settings as described in step e) (be sure to enter all losses between the unlicensed wireless device output and the spectrum analyzer).

b) Set the EUT to the lowest frequency channel (for the hopping on test, the hopping sequence shall include the lowest frequency channel).

c) Set the EUT to operate at maximum output power and 100% duty cycle, or equivalent “normal mode of operation” as specified in 6.10.3.

d) If using the radiated method, then use the applicable procedure(s) of 6.4, 6.5, or 6.6, and orient the EUT and measurement antenna positions to produce the highest emission level.

[52] For unlicensed wireless devices unable to be configured for 100% duty cycle even in test mode, configure the system for the longest duration duty cycle supported under normal operating conditions.

[53] Some radios operating, for example, in the 2.4 GHz band, have hardware capability to operate at frequencies outside the band permitted by the regulatory authority. Testing shall only be done at the lowest and highest frequencies within the allowed frequency band (see Annex A for examples of regulatory requirements and frequency ranges).

e) Perform the test as follows:

   1) Span: Wide enough to capture the peak level of the emission operating on the channel closest to the band-edge, as well as any modulation products that fall outside of the authorized band of operation.

   2) Reference level: As required to keep the signal from exceeding the maximum instrument input mixer level for linear operation. In general, the peak of the spectral envelope shall be more than [10 log (OBW/RBW)] below the reference level. Specific guidance is given in 4.1.6.2.

   3) Attenuation: Auto (at least 10 dB preferred).

   4) Sweep time: No faster than coupled (auto) time.

   5) Resolution bandwidth: 100 kHz.[54]

   6) Video bandwidth: 300 kHz.

   7) Detector: Peak.

   8) Trace: Max-hold.

f) Allow the trace to stabilize. For the test with the hopping function turned ON, this can take several minutes to achieve a reasonable probability of intercepting any emissions due to oscillator overshoot.

g) Set the marker on the emission at the band-edge, or on the highest modulation product outside of the band, if this level is greater than that at the band-edge. Enable the marker-delta function, and then use the marker-to-peak function to move the marker to the peak of the in-band emission.

h) Repeat step c) through step e) for every applicable modulation.

i) Set the EUT to the highest frequency channel (for the hopping on test, the hopping sequence shall include the highest frequency channel) and repeat step c) through step d).

j) The band-edge measurement shall be reported by providing spectral plot(s) of the measuring instrument display; the plot axes and the scale units per division shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

6.10.5 Restricted-band band-edge measurements

These procedures are applicable for determining compliance when restricted-bands are adjacent to the authorized band-edges.

6.10.5.1 Test setup

Restricted band-edge tests shall be performed as radiated measurements, on a test site meeting the specifications in 5.2 at the measurement distances specified in 5.3.[55]

The instrumentation shall meet the requirements in 4.1.1 using the bandwidths and detectors specified in 4.1.5.2. Considering the requirements of 5.8, the antenna(s) shall be connected to the antenna ports. When performing radiated measurements, the measurement antenna(s) shall meet the specifications in 4.3. The EUT shall be connected to an antenna and operated at the highest power settings following procedures in 6.3, and the relevant procedure in 6.4, 6.5, or 6.6.

6.10.5.2 Test methodology

The following test methodology shall be used for the restricted-band band-edge measurements:

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[54] See specification for spread spectrum device operation under 47 CFR 15.247 and RSS-247; otherwise, per applicable regulation.

[55] Conducted testing may be an acceptable alternative to radiated testing for devices operating under certain regulatory requirements: examples include 47 CFR 15.247 and 47 CFR 15.407, as well as RSS-247. See FCC/KDB 789033 [B34] and FCC/KDB 558074 [B32].

a) For frequency hopping systems, the hopping shall be turned OFF during this test.

b) Configure the spectrum analyzer settings as described in step e) (be sure to enter all losses between the unlicensed wireless device output and the spectrum analyzer).

c) Set the unlicensed wireless device to the lowest frequency channel.

d) Set the unlicensed wireless device to operate at maximum output power and 100% duty cycle, or equivalent "normal mode of operation" as specified in 6.10.3.

e) Perform the test as follows:

   1) Span: Wide enough to capture the peak level of the emission operating on the channel closest to the band-edge, as well as any modulation products that fall outside of the authorized band of operation.

   2) Reference level offset: Adjusted for gains and losses of measurement antenna factor, preamp gain and cable loss, so as to indicate field strength, in units of dBμV/m at 3 m, directly on the instrument display. Alternatively, the reference level offset may be set to zero and calculations shall be provided showing the conversion of raw measured data to the field strength in dBμV/m at 3 m.

   3) Reference level: As required to keep the signal from exceeding the maximum spectrum analyzer input mixer level for linear operation. In general, the peak of the spectral envelope shall be more than [10 log (OBW/RBW)] below the reference level. Specific guidance is given in 4.1.6.2.

   4) Attenuation: Auto (at least 10 dB preferred).

   5) Sweep time: No faster than coupled (auto) time.

   6) Resolution bandwidth:

      i) Below 150 kHz: 300 Hz or CISPR 200 Hz (CISPR 200 Hz required if using QP detector)

      ii) 150 kHz to 30 MHz: 10 kHz or CISPR 9 kHz, (CISPR 9 kHz required if using QP detector)

      iii) 30 MHz to 1000 MHz: 100 kHz or CISPR 120 kHz, (CISPR 120 kHz required if using QP detector)

      iv) Above 1 GHz: 1 MHz

   7) Video bandwidth:

      i) VBW for Peak, Quasi-peak, or Average Detector Function: 3 × RBW

      ii) VBW for alternative average measurements using peak detector function; refer to 4.1.5.2.3

   8) Detector (unless specified otherwise):

      i) QP below 1 GHz (however, peak detector measurements may be used to determine compliance with QP requirements).

      ii) Peak and average above 1 GHz

   9) Trace: Max-hold for final measurement; a combination of two traces, clear-write and max-hold, is recommended for maximizing the emission.

f) Using the applicable procedure(s) of 6.4, 6.5, or 6.6, orient the EUT and measurement antenna positions to produce the highest emission level.

g) Set the marker on the emission at the restricted band-edge, or on the highest modulation product within the restricted-band, if this level is greater than that at the band-edge.

h) Repeat step d) through step g) for every applicable modulation.

i) Repeat step d) through step h) for the highest gain of each type of antenna to be used with the EUT.

j) Set the EUT to the highest frequency channel and repeat step d) through step i).

k) The band-edge measurement shall be reported by providing spectral plot(s) of the measuring instrument display; the axes and the scale units per division shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

6.10.6 Marker-delta method

6.10.6.1 General requirements

In making radiated band-edge measurements, there can be a problem obtaining meaningful data because a measurement instrument that is tuned to a band-edge frequency might also capture some in-band signals when using the specified RBW. In an effort to compensate for this problem, the following technique has been developed for determining band-edge compliance.

This method may be used only when the edge of the occupied bandwidth of the emission falls within two “standard bandwidths” of the restricted-band band-edge frequency, where “standard bandwidth” is the RBW required by the measurement procedure (generally, the “standard bandwidth,” i.e., reference bandwidth, is 10 kHz for measurements below 30 MHz, 100 kHz for measurements between 30 MHz and 1000 MHz, and 1 MHz for measurements above 1 GHz). For this purpose, the occupied bandwidth is based on the 99% power bandwidth. Detailed explanations and examples of these constraints are given subsequently.

For example, for band-edge measurements in the restricted-band that begins at 2483.5 MHz, a measurement bandwidth of 1 MHz is required. Therefore the “delta” technique may be used if the upper frequency edge of the occupied bandwidth of the fundamental emission is greater than or equal to 2481.5 MHz (2 MHz removed from the band-edge). If the upper frequency edge of the occupied bandwidth is less than 2481.5 MHz, then radiated emissions within the restricted-band shall be measured in the conventional manner. The report shall include photographs or spectral plots of the measuring instrument display, with the lower and/or upper frequency limit(s), as applicable, clearly labeled.

Additionally this method may be used only when the emission being measured falls within two “standard bandwidths” of the restricted-band band-edge frequency. For example, for band-edge measurements in the restricted-band that begins at 2483.5 MHz, a measurement bandwidth of 1 MHz is required. Therefore the “delta” technique may be used if the restricted-band emission is between 2483.5 MHz and 2485.5 MHz. If the restricted-band emission is at a frequency greater than 2485.5 MHz, then radiated emissions within the restricted-band shall be measured in the conventional manner.

6.10.6.2 Marker-delta procedure

The following procedure shall be used for the marker-delta method:

a) Perform an in-band field strength measurement of the fundamental emission using the RBW and detector function required for the frequency being measured. For example, for a device operating in the 902 MHz to 928 MHz band, use a 120 kHz RBW with a CISPR QP detector (a peak detector with 100 kHz RBW alternatively may be used). For transmitters operating above 1 GHz, use a 1 MHz RBW, a 3 MHz VBW, and a peak detector, as required.[56] Repeat the measurement with an average detector (or alternatively, a peak detector and reduced VBW). For pulsed emissions, other factors shall be included; see 4.1.5.2.7.

b) Choose an EMI receiver or spectrum analyzer span that encompasses both the peak of the fundamental emission and the band-edge emission under investigation. Set the instrument RBW to 1% of the total span (but never less than 30 kHz), with a VBW equal to or greater than three times the RBW. Record the peak levels of the fundamental emission and the relevant band-edge emission (i.e., run several sweeps in peak hold mode). Observe the stored trace and measure the amplitude delta between the peak of the fundamental and the peak of the band-edge emission. This is not an

[56] See 47 CFR 15.35.

absolute field strength measurement; it is only a relative measurement to determine the amount by which the emission drops at the band-edge relative to the highest fundamental emission level.

c) Subtract the delta measured in step b) from the field strengths measured in step a). The resulting field strengths (CISPR QP, average, or peak, as appropriate) are then used to determine band-edge emissions compliance, where required.[57]

6.11 On-site (in situ) radiated emission measurements

6.11.1 General requirements

If an EUT cannot be set up on a test site as defined in 5.2, then testing is permitted at the end user's or manufacturer's premises. In this case, both the EUT and its location are considered to be integral components. Radiated emission test data shall be unique to the installation site because the site affects the measured results. The ac power-line conducted emission test results also might be unique to the installation. However, where testing of a given system has been accomplished at three or more representative locations, the results may be considered representative of all sites with similar EUT configurations, for the purposes of determining compliance with emission requirements (if allowed by the procuring agent or regulatory authority).

When radiated emission measurements cannot be made on a standard test site, instead tests may be performed at the user installation (in situ) by adapting the basic parameters of 5.2 and 5.3. The EUT shall be installed in accordance with the installation instructions of the product. Measurements shall be performed around the EUT in accordance with the procedure in 5.4, to the extent possible, at a sufficient number of radials to determine the radial at which the field strength values of the radiated emissions are maximized. The EUT azimuth, antenna height, orientation, and polarization shall be investigated so that the maximum radiated emissions levels are measured and recorded. In the tests, the height of the antenna and its polarization are to be varied in accordance with the requirements of this subclause. The standard procedures in 6.3, 6.4, 6.5, and 6.6 shall be used to the extent possible.

The measurements shall be performed using the instrumentation specified in Clause 4, the general considerations in Clause 5, and the additions, specific clarifications, and exceptions described in this subclause. Radiated emissions measurements shall be made over the frequency range specified in 5.5 and 5.6.

A detailed description of the test setups, procedures, and any rationale for variations from the standard measurement procedures (e.g., nonstandard measurement distances) shall be included in the test report. For a comparison of the measured radiated emissions with the prescribed limits, unit conversions and/or distance extrapolations (see 5.3) can be necessary. All conversion calculations, applicable assumptions, and results shall be documented in the final test report.

6.11.2 In situ measurements for frequencies below 30 MHz

For radiated emission measurements performed on an EUT operating on frequencies below 30 MHz, a calibrated loop antenna as specified in 4.3.2 shall be positioned with its plane vertical at the specified distance from the EUT and rotated about its vertical axis for maximum response at each azimuth position around the EUT. For certain applications, the loop antenna might also need to be positioned with its plane horizontal at the specified distance from the EUT. The loop shall be 1 m above the ground.

6.11.3 In situ measurements for frequencies above 30 MHz

For measurements at frequencies above 30 MHz, the antenna(s) specified in 4.3.3 shall be used at the measurement distance specified in 5.3, to the extent possible. A calibrated, linearly polarized antenna shall be positioned at the specified distance from the periphery of the EUT. The specified distance is the distance between the horizontal projection onto the ground of the closest periphery of the EUT and the projection onto the ground of the center of the axis of the elements of the receiving antenna. However, if the receiving

[57] See 47 CFR 15.205 or RSS Gen.

antenna is a log periodic array, then the specified distance shall be the distance between the closest periphery of the EUT and the calibrated phase center of the array of elements.

6.11.4 On-site ac power-line conducted measurements

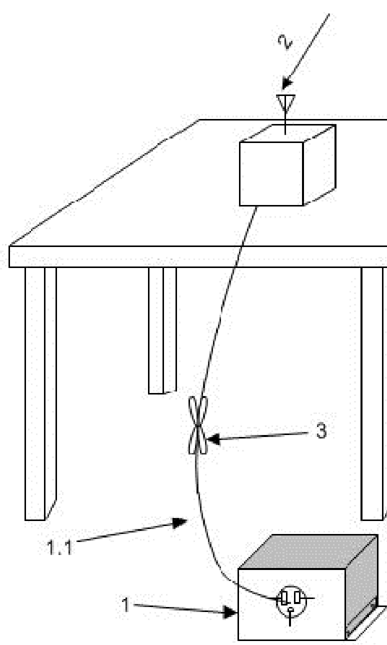
When measurements are performed at the user's installations, the EUT shall be installed as normally used. A LISN shall not be used for testing at the user's installation, unless the LISN is a part of the typical installation, so that the measured radio-noise is representative of the specific site. The voltage probe, as described in Clause 4 of ANSI C63.4-2014, shall be used for ac power-line conducted emission measurements. Neither a ground plane nor a LISN shall be installed for the user's installation testing unless one or both are to be a permanent part of the installation.

6.11.5 Other on-site measurements

Other on-site measurements such as frequency stability, occupied bandwidth and band-edge, output power, peak power spectral density, power spectral density at f < 40 GHz, and power spectral density at f > 40 GHz shall be performed in accordance with 6.7, 6.8, 6.9, 7.8, Clause 9, and Clause 11, respectively.

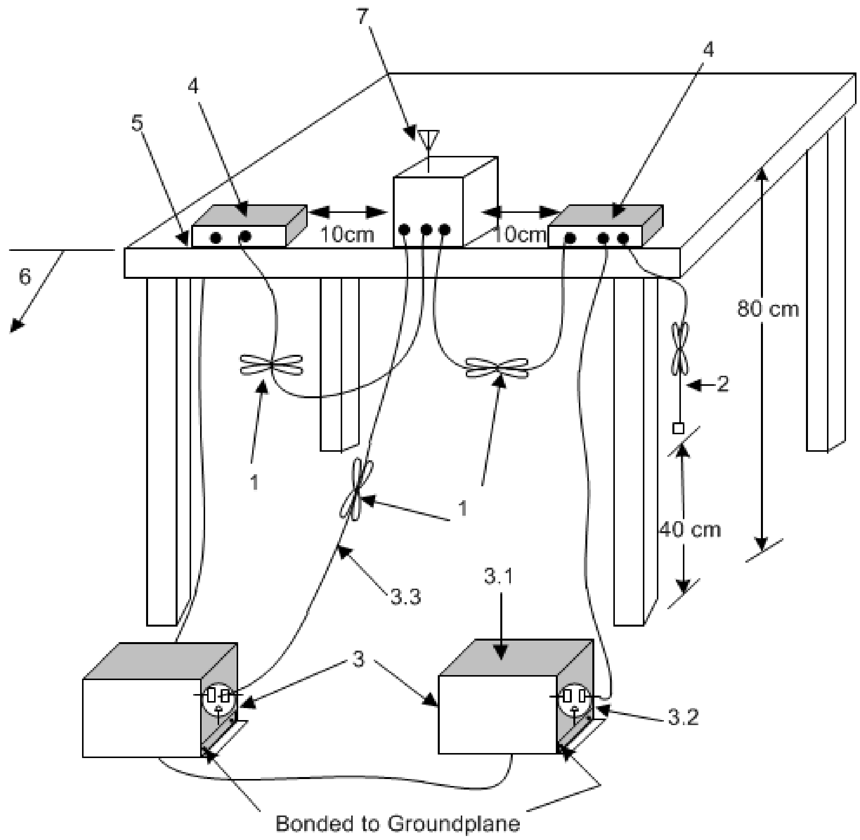
6.12 Figures for Clause 6

All figures (i.e., Figure 5 through Figure 14) accompanying the text of Clause 6 are grouped in this subclause.



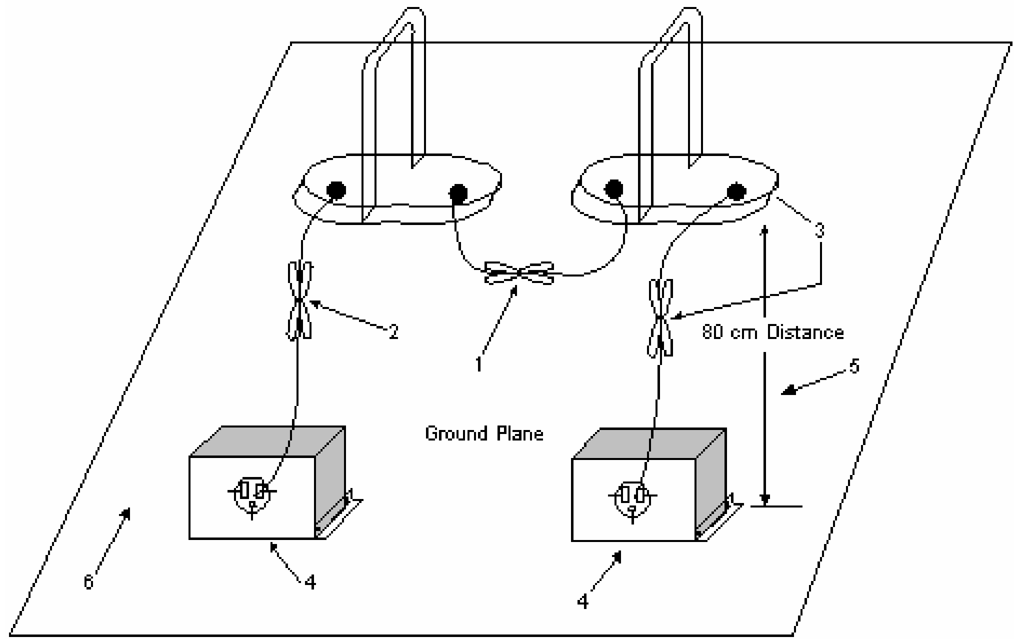
1—A LISN is optional for radiated measurements between 30 MHz and 1000 MHz but not allowed for measurements below 30 MHz and above 1000 MHz (see 6.3.1). If used, then connect EUT to one LISN. Unused LISN measuring port connectors shall be terminated in 50 Ω loads. The LISN may be placed on top of, or immediately beneath, the reference ground plane (see 6.2.2 and 6.2.3.2).
1.1—LISN spaced at least 80 cm from the nearest part of the EUT chassis.
2—Antenna can be integral or detachable, depending on the EUT (see 6.3.1).
3—Interconnecting cables that hang closer than 40 cm to the ground plane shall be folded back and forth in the center forming a bundle 30 cm to 40 cm long (see 6.3.1).
4—For emission measurements at or below 1 GHz, the table height shall be 80 cm. For emission measurements above 1 GHz, the table height shall be 1.5 m for measurements, except as otherwise specified (see 6.3.1 and 6.6.3.1).

Figure 5—Example of a test arrangement for radiated emissions (tabletop product)



1—Interconnecting cables that hang closer than 40 cm to the ground plane shall be folded back and forth in the center forming a bundle 30 cm to 40 cm long see (see 6.2.3.2).
2—The I/O cables that are not connected to an accessory shall be bundled in the center. The end of the cable may be terminated, if required, using the correct terminating impedance. The overall length shall not exceed 1 m (see 6.2.2).
3—EUT connected to one LISN. Unused LISN measuring port connectors shall be terminated in 50 Ω loads. LISN may be placed on top of, or immediately beneath, reference ground plane (see 6.2.2 and 6.2.3).
3.1—All other equipment powered from additional LISN(s).
3.2—A multiple outlet strip may be used for multiple power cords of non EUT equipment.
3.3—LISN at least 80 cm from nearest part of EUT chassis.
4—Non EUT components of EUT system being tested.
5—Rear of EUT, including peripherals, shall all be aligned and flush with edge of tabletop (see 6.2.3.2).
6—Edge of tabletop shall be 40 cm removed from a vertical conducting plane that is bonded to the ground plane (see 6.2.2 for options).
7—Antenna can be integral or detachable. If detachable, then the antenna shall be attached for this test.

Figure 6—Example of a test arrangement for power-line conducted emissions (product with accessories)



1—Excess I/O cables shall be bundled in the center. If bundling is not possible, then the cables shall be arranged in serpentine fashion. Bundling shall not exceed 40 cm in length (see 6.2.3.3).
2—Excess power cords shall be bundled in the center or shortened to an appropriate length (see 6.2.1).
3—EUT and all cables shall be insulated, if required, from the ground plane by up to 12 mm of insulating material (see 6.2.3.3).
4—EUT connected to one LISN. LISN may be placed on top of, or immediately beneath, the ground plane.
i All other equipment powered from a second LISN or additional LISN(s) (see 6.2.3 and 6.2.3.3).
ii A multiple outlet strip may be used for multiple power cords of non EUT equipment.
5—Horizontal projection from the closest point of EUT to the nearest point of the LISN (see 6.2.3.3). For radiated emission testing, the LISNs shall be removed (see 6.3.1).
6—Ground reference plane.

Figure 7—Example of a test arrangement for radiated and conducted emissions for floor-standing unlicensed wireless devices

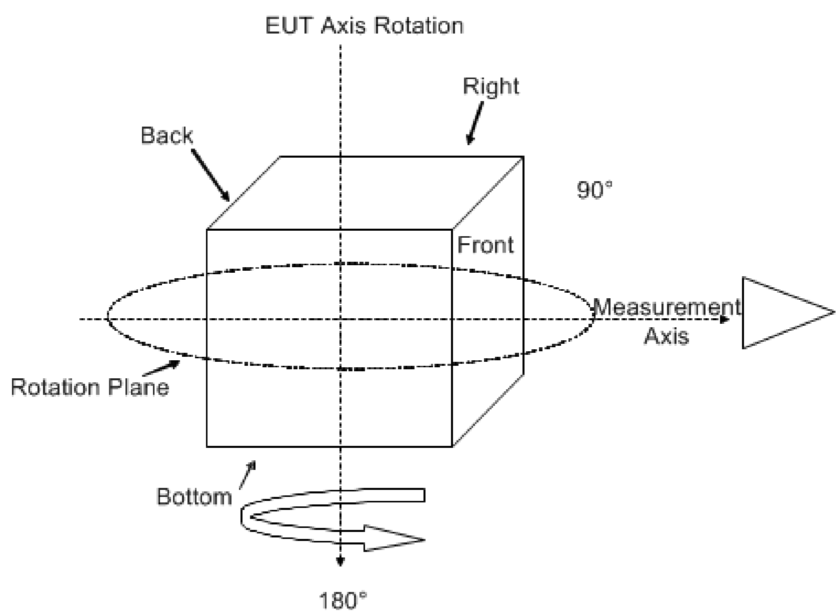


Figure 8—EUT faces identified relative to view from receiving antenna (see 6.3.1)

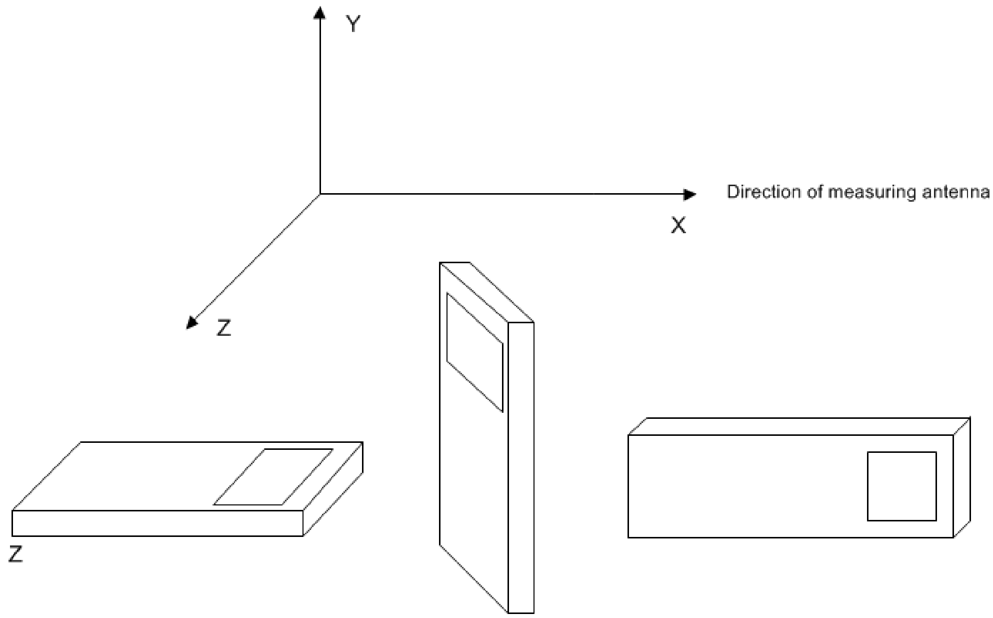


Figure 9—Example of the EUT configuration positions (see 6.3.1)

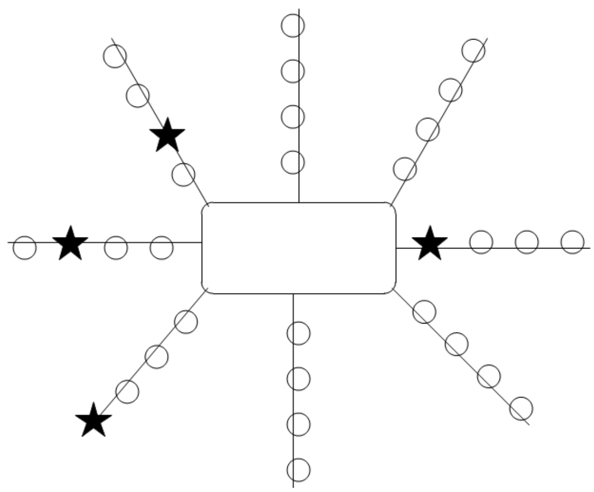


Figure 10—Example of the field strength measurement points at various distances from EUT along eight radials (see 6.4.5)

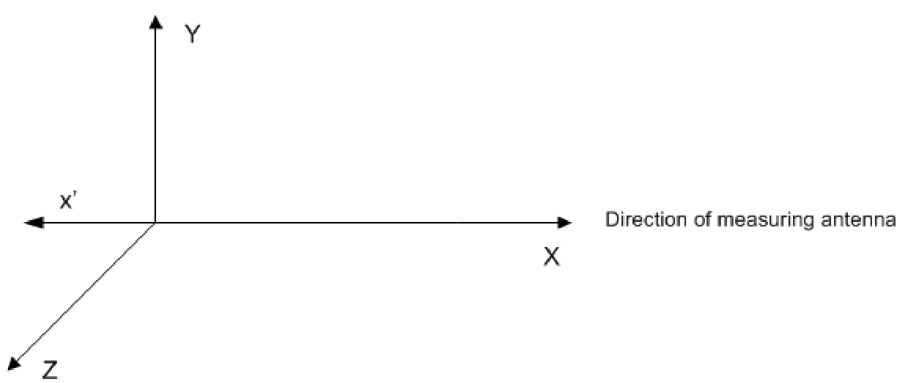


Figure 11—Example of the axis of the EUT with addition of *x′* (see 6.6.5.3)

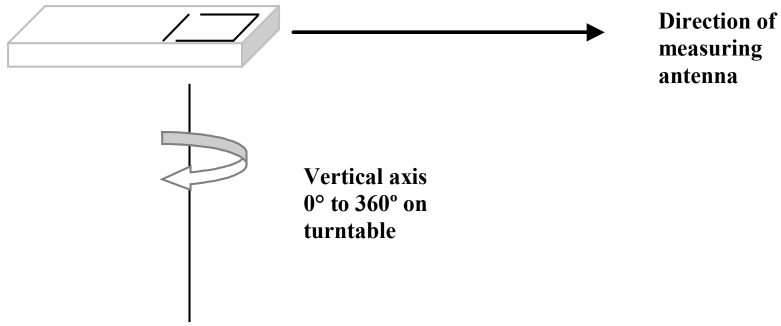


Figure 12—Example of the typical setup for a mobile device (see 6.6.5.4)

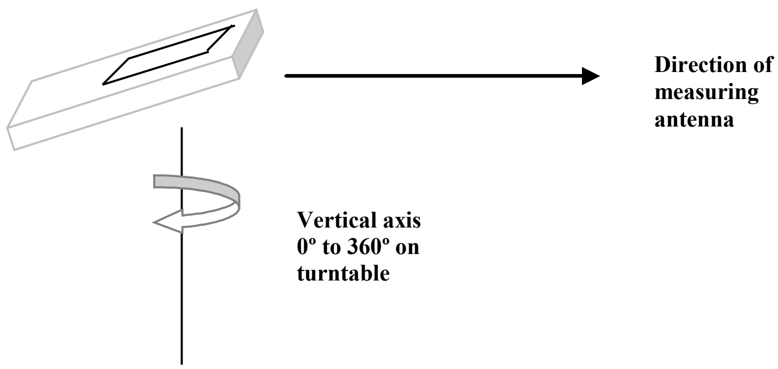


Figure 13—Example of the elevation of EUT *y* axis to *z* axis, 0° to 150° end over end, at 30° (see 6.6.5.4)

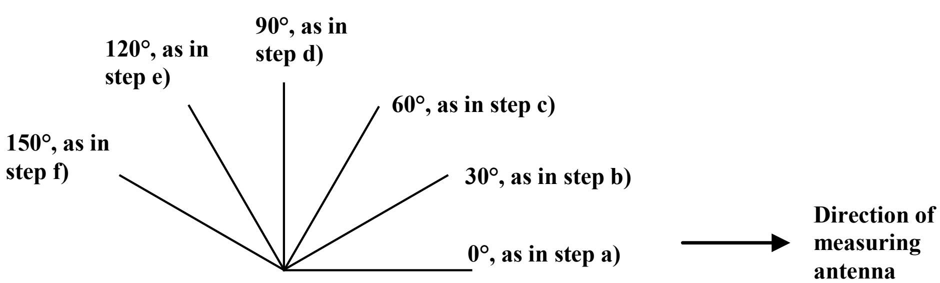


Figure 14—Total number of measurement positions (see 6.6.5.4)

7. Additional tests and requirements for specific devices

This clause covers the additional test methods and requirements for the following specific unlicensed wireless devices:

a) Cordless phone security code (7.1)

b) Cordless phone frequency pairing (7.2)

c) Input power testing (7.3)

d) Demonstration of periodic operation (7.4)

e) Evaluation of average values of pulsed emissions (7.5)

f) Evaluation of compliance for devices with periodic emissions (7.6)

g) Low frequency inductive-loop devices (7.7)

h) Evaluation of frequency hopping device parameters (7.8)

See also the following clauses for additional tests or requirements for specific types of unlicensed wireless devices: Clause 8 (FM band devices), Clause 9 (millimeter-wave devices), Clause 10 (ultra-wideband devices), Clause 11 (DTS devices), Clause 12 (U-NII devices), Clause 13 (devices using antenna arrays), Clause 14 (devices with multiple outputs) and Clause 15 (whitespace device testing).

7.1 Test method for determining compliance of cordless telephone handset security code

This procedure is for evaluating the handset security requirements to reduce the chance of unauthorized access to the public switched telephone network.[58]

Any of the three following methods, or a combination thereof, may be used by the manufacturer to evaluate this cordless phone handset requirement:

a) The first method is to allow the end user to select manually one of a minimum of 256 codes before the handset can be used. The manufacturer shall provide to the end user a description of how to select from among these codes, and the test laboratory shall verify that the system does not transmit until correct codes are selected. If the first method is used in conjunction with the second method described in item b), then the handset may transmit prior to the end user selecting a different code

b) The second method uses a fixed code that is varied randomly, sequentially, or by some other systematic means at the time of manufacture. The manufacturer shall supply a description of the means for varying the code in the operational description section of the test report.

c) The third method is for the manufacturer to use a handset that automatically selects a different code each time it is activated. A description of how the code is selected shall be placed in the operational description of the test report.

A short description of compliance to the requirements shall be included in the test report. The description shall include the number of digital security codes provided and the means by which they are varied.

[58] See 47 CFR 15.214(d).

7.2 Frequency pairing of cordless phones

This is an attestation procedure to demonstrate that the frequency pairing for cordless phones is compliant with the applicable requirements.[59]

7.2.1 Requirements

The manufacturer shall provide the complete list of frequencies for both the handset and the base station in a tabulated form. This frequency chart shall be compared with the frequency chart of the paired frequencies as referenced in the requirements. In comparing the frequency charts, note that the base station channels 1 to 15 can be paired with any handset channel 1 to 15 per the requirements.

7.2.2 Reporting

The channels pairing list as well as a statement verifying compliance with the requirements is required for the test report.

7.3 Input power to final RF stage for certain types of unlicensed wireless devices

For unlicensed wireless devices subject to a limit on total input power to the final radio frequency stage (exclusive of filament power or heater power),[60] the following procedure shall be used.

The total input power shall be determined by first identifying and reporting the circuit elements and details that constitute the final output stage. The current and voltage of the bus power to the output stage shall be measured and the net dc power shall be computed for the final stage.

The final radio frequency stage shall be the dc bus power that is supplied to the final RF amplifier components, inclusive of all bias, transistor, module, and circuit portions that provide the final radio frequency excitation energy to the radiating element.

a) Identify the final radio frequency stage and all passive and active components associated therewith.
b) Measure the dc voltage applied to the final radio frequency stage.
c) Measure the dc current into the final radio frequency stage; if the net voltage and currents cannot be measured directly, then it is permissible to sum up the total power supplied by the battery or power supply.
d) Compute the total dc power by multiplying the dc voltage times the dc current according to Equation (9):

$$P_{\text{final}} = \sum V_n I_n \tag{9}$$

where

V_n and I_n are the individual components to the final stage

If bias voltage is provided for the heater or filament in a vacuum-tube circuit, then that power shall not be part of the measurement result.

[59] See 47 CFR 15.233(b)(2).
[60] For example, 47 CFR 15.217, 15.219.

7.4 Procedure for determining compliance of unlicensed wireless devices having periodic operation

This procedure specifies a method for determining compliance with regulatory requirements of certain unlicensed wireless devices that are subject to a limit on the transmission period.[61] For example, certain unlicensed wireless devices operating in the band 40.66 MHz to 40.70 MHz and above 70 MHz are restricted to periodic operation. These operating condition requirements may be satisfied by an attestation provided by the manufacturer, as described herein. Such an attestation shall be supported with a thorough description of the operational details.

The equipment manufacturer and/or responsible party shall confirm that the equipment is not a radio control device or toy, and is not capable of generating continuous transmissions, voice, or video transmissions. Data shall be sent only along with a control signal.

For evaluation of periodic operation characteristics, the following procedure may be used:

a) Trigger the spectrum analyzer sweep on the RF waveform of the unlicensed wireless device.
b) Set the spectrum analyzer sweep time greater than the specified time for periodic operation.
c) Manually activate and deactivate the unlicensed wireless device and confirm that it ceases transmission within the specified time of deactivation.
d) Document the test results.
e) Verify and document that periodic transmissions at regular predetermined intervals do not exist, except where regulatory requirements allow polling or supervision transmissions, including data, to determine system integrity. Compliance is addressed by an attestation supported by the equipment theory of operation.

7.5 Procedure for determining the average value of pulsed emissions

Unless otherwise specified, when the radiated emission limits are expressed in terms of the average value of the emission, and pulsed operation is employed, the measurement field strength shall be determined by averaging over one complete pulse train, including blanking intervals, as long as the pulse train does not exceed 0.1 s (100 ms). In cases where the pulse train exceeds 0.1 s, the measured field strength shall be determined during a 0.1 s interval.[62] The following procedure is an example of how the average value may be determined. The average field strength may be found by measuring the peak pulse amplitude (in log equivalent units) and determining the duty cycle correction factor (in dB) associated with the pulse modulation as shown in Equation (10):

$$\delta(\text{dB}) = 20\log(\Delta) \tag{10}$$

where

δ is the duty cycle correction factor (dB)
Δ is the duty cycle (dimensionless)

This correction factor may then be subtracted from the peak pulse amplitude (in dB) to find the average emission. This correction may be applied to all emissions that demonstrate the same pulse timing characteristics as the fundamental emission (e.g., the fundamental and harmonic emissions). In cases where the pulse train is truly random or pseudo random, some regulatory agencies might accept a declaration by the manufacturer of the worst-case value of t_{ON}. The duty cycle correction is determined as follows:

[61] See 47 CFR 15.231 and 15.240(b).
[62] See 47 CFR 15.35(c).

a) Adjust and configure any EUT switches, controls, or input data streams to ensure that the EUT is transmitting or encoded to obtain the "worst-case" pulse ON time.

b) Couple the final radio frequency output signal to the input of a spectrum analyzer. This may be performed by a radiated, direct connection (i.e., conducted) or by a "near-field" coupling method. The signal received shall be of sufficient level to trigger adequately the spectrum analyzer sweep display.

NOTE—If the bandwidth of the pulse is greater than the RBW of the spectrum analyzer, then a similar measurement may be performed using a wideband digital storage oscilloscope (DSO).

c) Adjust the center frequency of the spectrum analyzer to the center of the RF signal.

d) Set the spectrum analyzer for ZERO SPAN.

e) Adjust the SWEEP TIME to obtain at least a 100 ms period of time on the horizontal display axis of the spectrum analyzer.

f) If the pulse train is periodic (i.e., consists of a series of pulses that repeat in a characteristic pattern over a constant time period), and the period (T) is less than or equal to 100 ms, then:

   1) Set the TRIGGER on the spectrum analyzer to capture at least one period of the pulse train, including any blanking intervals.

   2) Determine the total maximum pulse "ON time" (t_{ON}) over one period of the pulse train. An example of a periodic pulse train and the associated period is shown in Figure 15. If the pulse train contains pulses of different widths, then t_{ON} is determined by summing the duration of all of the pulses within the pulse train [i.e., $t_{ON} = \Sigma(t_1 + t_2 + \ldots t_n)$].

   3) The duty cycle is then determined by dividing the total maximum "ON time" by the period of the pulse train (t_{ON}/T).

g) If the pulse train is nonperiodic or is periodic with a period that exceeds 100 ms, or as an alternative to step f), then:

   1) Set the TRIGGER on the spectrum analyzer to capture the greatest amount of pulse "ON time" over 100 ms.

   2) Find the 100 ms period that contains the maximum "on time"; this could require summing the duration of multiple pulses as described in step f2).

   3) Determine the duty cycle by dividing the total maximum "ON time" by 100 ms (t_{ON}/100 ms).

h) Determine the duty cycle correction factor by applying Equation (10) to the duty cycle determined in the preceding steps.

Figure 15 shows an example of a ZERO SPAN spectrum analyzer display of a representative pulse train. The center frequency is set to the maximum of the emission, and the triggering is set to capture a single sweep over 100 ms. The pulse train is composed of two different duration pulses, t_1 and t_2. Using the delta marker function, the times t_1 and t_2 are measured and recorded. The total number of times that the two pulses occur over the period (i.e., time interval T) is counted. The duty cycle correction factor is calculated from the sum of the individual ON times, per Equation (11):

$$\delta(\text{dB}) = 20\log\left[\sum\left(nt_1 + mt_2 + \ldots + \xi t_x\right)/T\right] \quad (11)$$

where

n	is the number of pulses of duration t_1
m	is the number of pulses of duration t_2
ξ	is the number of pulses of duration t_x
T	is the period of the pulse train, or 100 ms if the pulse train length is greater than 100 ms

7.6 Evaluation of certain unlicensed wireless devices with periodic emissions against limits

An unlicensed wireless device operating with periodic emissions shall address compliance with the applicable regulatory requirements for both the fundamental and spurious radiated emissions. This subclause provides a method for comparing the emissions from the device with the appropriate limits.[63]

7.6.1 Determination of spurious and fundamental emissions

To determine compliance, the limits for both the fundamental and the spurious emissions of the unlicensed wireless device are calculated based on the unlicensed wireless device fundamental. Hence, the radiated electric field from the unlicensed wireless device shall determine compliance for both the fundamental frequency and spurious emissions. The conformity assessment process is as follows:

a) Identify the unlicensed wireless device fundamental frequency.

b) Verify that the fundamental does not fall in any restricted frequency bands (see 5.9).

c) Note the field strength limit at 3 m, from the appropriate regulatory requirement for the fundamental frequency of the device.

d) Note the spurious emission limits at 3 m, from the appropriate regulatory requirement for spurious emissions from the device.

e) Measure the fundamental frequency of the device, and compute the average value of the emission using the appropriate duty cycle correction. Do the same for spurious emissions from the device.

f) Record the result.

7.6.2 Calculation of the effective limit

The effective limit at the frequency of interest is found by linearly interpolating using the familiar slope intercept formula, $y = mx + b$, rewritten as in Equation (12):

$$\text{Limit}[\mu\text{V/m}] = \text{Lim}_{\text{lower}} + \Delta F\left[\left(\text{Lim}_{\text{upper}} - \text{Lim}_{\text{lower}}\right)/\left(f_{\text{upper}} - f_{\text{lower}}\right)\right] \qquad (12)$$

where

$\text{Lim}_{\text{lower}}$	is the limit at the lower frequency of the intended band of operation
$\text{Lim}_{\text{upper}}$	is the limit at the upper frequency of the intended band of operation
f_{lower}	is the lower frequency of the intended band of operation
f_{upper}	is the upper frequency of the intended band of operation
ΔF	equals $f_c - f_{\text{lower}}$
f_c	is the center frequency of the emission signal

The effective limit in dBµV/m is found using [20 log (Limit [µV/m])].

7.6.3 Example of calculation of emission from a pulse-modulated unlicensed wireless device

Consider a pulse-modulated unlicensed wireless device operating at 315 MHz. Radiated electric field data were collected at the following frequencies and amplitudes. The data in Table 13 have been corrected for all measurement/calibration factors (antenna factors, cable losses, amplifier gains, pulse desensitization, etc.).

[63] See 47 CFR 15.231(b).

Table 13—Example data for an unlicensed wireless device operating at 315 MHz

Frequency	Antenna polarization	EUT orientation	Peak pulse amplitude dBµV/m
315	H	x	70
315	V	x	50
630	H	x	55
630	V	x	35
945	H	x	45
945	V	x	25
1260	H	x	40
1260	V	x	20

Using Figure 15, the pulse characteristics at the center frequency of the device are as follows:

t_1 = 5 ms
t_2 = 15 ms
T = 70 ms

The ON time during T is calculated using Equation (11) in a template as shown in Table 14.

Table 14—Example of calculation of correction factor

Subpulse	Duration (ms)	Number of pulses	Subpulse “ON time”
1	5	2	10
2	15	1	15
		Total ON time:	25

The correction is found from the ON time divided by T, as shown in Equation (13):

$$\delta = \left(n_1 t_1 + n_2 t_2\right) / T \tag{13}$$

$$\delta = 25 / 70 = 0.36$$

$$\delta\left(\text{dB}\right) = 20 \log\left(0.36\right) = -8.9 \text{ dB}$$

where

T is the pulse width
t_1 is the pulse width of pulse 1
t_2 is the pulse width of pulse 2
n_1 is the number of t_1 pulses
n_2 is the number of t_2 pulses

Table 15 shows emissions results from Table 13 with the duty cycle correction factor now included.

Table 15—Example of emissions with correction factor applied

Frequency	Antenna polarization	EUT orientation	E-field dBµV/m	δ dB	Corrected E-field dBµV/m
315	H	x	70	−8.9	61.1
315	V	x	50	−8.9	41.1
630	H	x	55	−8.9	46.1
630	V	x	35	−8.9	26.1
945	H	x	45	−8.9	36.1
945	V	x	25	−8.9	16.1
1260	H	x	40	−8.9	31.1
1260	V	x	20	−8.9	11.1

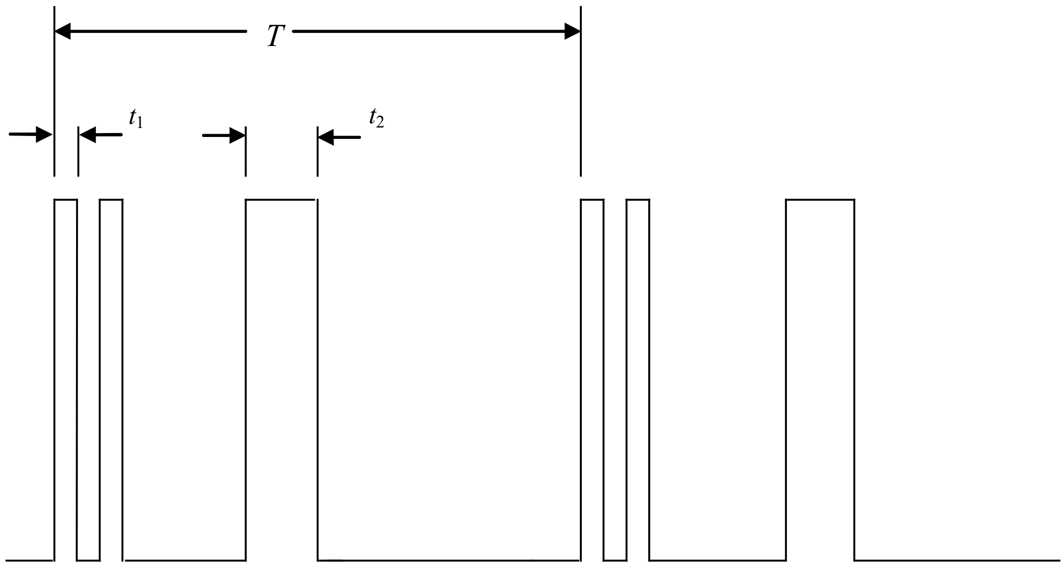


Figure 15—Example of pulse emissions with two different pulse durations

7.7 Procedure for determining compliance of inductive-loop devices

7.7.1 General considerations

This procedure addresses low frequency, inductive-loop devices, such as low frequency RFID, access control card readers, electronic article surveillance, and so on. Additionally, this procedure addresses inductive-loop devices where the loop coil windings are oriented in the same plane. This procedure applies to frequencies for which the ratio of wavelength to two times π ($\lambda/2\pi$) is greater than the regulatory specified measurement distance, and loop sizes are less than 10 m^2. This procedure assumes sufficient documentation is available to establish whether the device is planar or three dimensional (i.e., coils wound in different planes).

At a test site as described in Annex I, the EUT antenna shall be set up in the orientation specified by the product's installation guide. Optionally, the EUT antenna can be oriented in the vertical orientation (i.e., a conservative condition). If the EUT antenna can be oriented and normally used in either the horizontal or the vertical plane, then set up the antenna in the vertical plane. For floor mounted devices, place the EUT antenna on the ground. For countertop mounted or tabletop mounted devices, place the EUT antenna on a nonconductive surface at 0.8 m above the ground. For wall-mounted devices, secure the antenna to a vertical nonconductive surface, with the EUT antenna at 1 m above the ground.[64]

If the antenna consists of a remote resonating circuit, then bundle the excess cable between the remote resonating circuit and the antenna loop coil in a serpentine shape or in the shape of a figure eight. If excess cable is left in a coiled loop, then the excess cable will act as an antenna as magnified by the number of turns in the coil.

An inductive-loop antenna has gain compared with cables, the transmitter, and ancillary devices (i.e., proportional to the amps-turns-aperture product). Because the gain of the antenna will overwhelm the contribution of other elements of the EUT for measurements below 30 MHz, it is only necessary to include the EUT antenna footprint in the determination of distance from the measurement antenna. The distance specified corresponds to the horizontal distance between the measurement antenna and the closest point of the loop antenna. If the resonance capacitors are remote from the coil loop, then the antenna boundary

[64] Recommendations for nonconductive surface include cardboard box, foamed polystyrene block, wood frame, and so on.

consists of the loop structure, interconnecting cables, and equipment containing the capacitors for resonance; the boundary is defined by an imaginary straight line periphery describing a simple geometric configuration enclosing the antenna components.

7.7.2 Inductive-loop devices without phase-opposed characteristics

Using a shielded magnetic loop measurement antenna, place the measurement antenna at 10 m distance from the EUT antenna.[65] Arrange the measurement loop so that the plane of its coil is parallel with the plane of the EUT inductive-loop antenna coil, and axially aligned horizontally, with the center of the measurement loop set at 1 m above ground. For a vertically installed EUT, the measurement antenna shall be oriented in the plane of the loop vertically polarized. For a horizontally installed EUT, the measurement antenna shall be horizontally polarized. This parallel orientation produces the maximum measured signal of the EUT, for devices that can be installed in either a horizontal or a vertical orientation for both the EUT and measurement antennas.

Below 30 MHz, the limit distance is usually at a distance greater than 10 m. In that case, the measured value shall be extrapolated to the limit distance and then compared with the limit.

To determine compliance, where the measurement point and the limit distance are within the λ/2π boundary,[66] the measured value may be extrapolated to the limit distance by conservatively presuming that the field strength decreases at a 60 dB/decade of distance rate to the limit distance.[67] This shall be accomplished using Equation (14):

$$FS_{\text{limit}} = FS_{\text{max}} - 60\log\left(\frac{d_{\text{limit}}}{d_{\text{measure}}}\right) \tag{14}$$

where

FS_{limit}	is the calculation of field strength at the limit distance, expressed in dBμV/m
FS_{max}	is the measured field strength, expressed in dBμV/m
d_{measure}	is the distance of the measurement point from the EUT
d_{limit}	is the reference distance or the distance of the λ/2π point

One example regulatory limit is at 300 m for f < 490 kHz.[68] At or below 159 kHz, the limit distance of 300 m is within the λ/2π boundary, the limit is expressed as a magnetic field strength, and a measurement of magnetic field strength is being made, so a 60 dB/decade of distance extrapolation (third-order) may be used.

If the limit distance is different from 300 m, then Equation (14) may be used on all frequencies for which the limit distance and the measurement point are within the λ/2π boundary. See 6.4.3 for the methods used to determine the distance of the λ/2π boundary. Alternatively, it is permissible to make measurements of the actual value of extrapolation using the two point or three or more point extrapolation methods described in 6.4.4.4 and 6.4.4.5.

For measurements made below 159 kHz, if the measurement point is at a distance of 10 m from the EUT and the limit distance is 300 m, then the measurement result may be reduced by 88.6 dB for comparison with the emissions limit. If the measurement point is at a distance of 30 m from the EUT, then the measurement value may be reduced by 60 dB.

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[65] For weak signal small aperture devices, a closer distance might be required.
[66] For frequencies below 159 kHz and a limit distance of 300 m, the limit distance and all points closer are within λ/2π
[67] At the time of publication of this standard, the 60 dB/decade of distance extrapolation factor does not agree with current FCC Rules in 47 CFR 15.31(f)(2). The 60 dB/decade of distance factor is based on measurements made on simple emitters in the inductive field, where the wavelength of the source is less than λ/2π. Measurements at frequencies below ~500 kHz have been shown to have an extrapolation factor of 60 dB/decade of distance. See Annex I, European Radiocommunications Committee [B14] and ETSI EN 300 330 2 V1.5.1 (2010 02) [B9] for additional information regarding roll-off. Acceptance of this procedure is at the discretion of the regulatory authority.
[68] See 47 CFR 15.209.

To determine compliance for frequencies between 159 kHz and 490 kHz, the magnetic field strength may be presumed to decay at a rate of 60 dB/decade of distance within the λ/2π boundary and at a rate of

40 dB/decade of distance beyond λ/2π. For a measurement made within the λ/2π boundary, where the limit distance is outside of the λ/2π boundary, Equation (15) may be used to calculate the field strength at the limit distance:

$$FS_{\text{limit}} = FS_{\text{max}} - 60\log\left(\frac{d_{\text{near field}}}{d_{\text{measure}}}\right) - 40\log\left(\frac{d_{\text{limit}}}{d_{\text{near field}}}\right) \quad (15)$$

where

FS_{limit}	is the calculation of field strength at the limit distance, expressed in dBμV/m
FS_{max}	is the measured field strength, expressed in dBμV/m
$d_{\text{near-field}}$	is the λ/2π distance
d_{measure}	is the distance of the measurement point from the EUT
d_{limit}	is the reference limit distance

If the single point measured is at a distance greater than λ/2π, then extrapolation to the limit distance shall be calculated using Equation (16):

$$FS_{\text{limit}} = FS_{\text{max}} - 40\log\left(\frac{d_{\text{limit}}}{d_{\text{measure}}}\right) \quad (16)$$

7.7.3 Inductive-loop devices with phase-opposed characteristics

For devices that exhibit phase-canceling characteristics with distance, it is advantageous to make measurements as far as practical from the EUT; however, the phase-canceling nature decreases the distance where signals can be detected and measured. Phase-canceling devices can be measured using the methods of non-canceling devices, to obtain conservative results, as described in 7.7.2. If the full benefit of the phase-canceling is desired for determining compliance, then measurement of multiple points may be used, as described in 6.4.4.4 and 6.4.4.5. Because of the impact of the phase-canceling characteristics of the field generated, use of the full procedure of measuring radials at 22.5°, and rotation of the measurement loop about its planar vertical or horizontal axis (axis matching the orientation of the EUT loop), is necessary. Phase-canceling approaching the fourth-order term has been seen in certificated products.

Measurements shall be performed at a sufficient number of radials around the EUT to determine the radial at which the field strength values of the radiated emissions are maximized. The maximum field strength at the frequency being measured shall be reported in the test report. Symmetry may be used to minimize the test positions:

a) Using a shielded magnetic loop measurement antenna, arrange the measurement loop so that the plane of its coil is parallel with the plane of the EUT inductive-loop antenna coil, and axially aligned horizontally, with the measurement loop set at 1 m above ground for the first measurement. This parallel orientation establishes the first radial of the 22.5° radial increments for vertically polarized EUT antennas. For devices that can be installed in either the horizontal or the vertical orientation, testing shall be carried out in the vertical orientation.

b) With the measurement loop antenna set per step a), rotate the EUT antenna in the plane of its coil about its vertical axis, identifying the maximum emission.

c) With EUT loop antenna set per step b), rotate the measurement antenna in the plane of its coil about its vertical axis, identifying the maximum emission. Record this value.

d) Repeat step a) through step c) for each 22.5° radial, until the symmetry coverage has been completed.

e) Move the measurement antenna to another convenient measurement distance. Repeat step a) through step d) for the new distance.

f) Calculate the roll-off with Equation (17) and Equation (18):

$$\text{Roll-off factor, } P = \left(\text{level}_{\text{near distance}} - \text{level}_{\text{far distance}}\right) / 20\log\left(d_{\text{far}} / d_{\text{near}}\right) \tag{17}$$

$$\text{DCF} = 20\log\left(d_{\text{test}} / d_{\text{limit}}\right)^{P} = 20P\log\left(d_{\text{test}} / d_{\text{limit}}\right) \tag{18}$$

where

distance is in meters
DCF (distance correction factor) is in dB
level is in decibels

The distance specified corresponds to the horizontal distance between the measurement antenna and the closest point of the loop antenna defined in 7.7.2. If the resonance capacitors are remote from the coil loop, then the antenna boundary consists of the loop structure, interconnecting cables, and equipment containing the capacitors for resonance; the boundary is defined by an imaginary straight line periphery describing a simple geometric configuration enclosing the antenna components.

7.8 Evaluation of frequency-hopping device parameters

An unlicensed wireless device using frequency hopping techniques shall use the following procedures for determining compliance with the applicable frequency hopping regulatory requirements.[69] Information about the number of hopping channels, dwell time per channel, signal bandwidth and related frequency hopping parameters for each operating mode shall be provided to the lab prior to testing to assist in configuring the test equipment for each measurement.

7.8.1 Test setup

Timing, bandwidth, power, and band-edge measurements with a relative limit, (e.g., −20 dB relative to the in-band level) are typically made by connecting the spectrum analyzer to the active antenna port using a suitable RF attenuator, but could be made using radiated measurement methods. Direct measurements require verification that the antenna port selected and connected to the spectrum analyzer is the active antenna port if the system has more than one antenna.

Testing shall be done using the maximum power output. Some measurements require that the system be operating with the hopping feature enabled while other measurements require that the hopping feature be disabled and the device be transmitting continuously on a single channel. For tests with the hopping feature enabled the system shall be configured for normal operation using a pseudorandom hopping pattern (see also 7.8.6 and 7.8.8). Measurements made with frequency hopping disabled shall be performed on the required number of channels (refer to 5.6, typically three channels as the frequency range is greater than 10MHz) unless stated otherwise.

7.8.2 Carrier frequency separation

The EUT shall have its hopping function enabled. Use the following spectrum analyzer settings:

a) Span: Wide enough to capture the peaks of two adjacent channels.

b) RBW: Start with the RBW set to approximately 30% of the channel spacing; adjust as necessary to best identify the center of each individual channel.

c) Video (or average) bandwidth (VBW) ≥ RBW.

[69] See 47 CFR 15.247.

d) Sweep: No faster than coupled (auto) time.

e) Detector function: Peak.

f) Trace: Max-hold.

g) Allow the trace to stabilize.

Use the marker-delta function to determine the separation between the peaks of the adjacent channels. Compliance of an EUT with the appropriate regulatory limit shall be determined. A spectral plot of the data shall be included in the test report.

Where the device shares the same channel plan (carrier frequencies and number of channels) across multiple data rates or modulation schemes then the carrier separation need only be measured for one of those modulation schemes or data rates.

7.8.3 Number of hopping frequencies

The EUT shall have its hopping function enabled. Use the following spectrum analyzer settings:

a) Span: The frequency band of operation. Depending on the number of channels the device supports, it could be necessary to divide the frequency range of operation across multiple spans, to allow the individual channels to be clearly seen.

b) RBW: To identify clearly the individual channels, set the RBW to less than 30% of the channel spacing or the 20 dB bandwidth, whichever is smaller.

c) VBW ≥ RBW.

d) Sweep: No faster than coupled (auto) time.

e) Detector function: Peak.

f) Trace: Max-hold.

g) Allow the trace to stabilize.

It might prove necessary to break the span up into subranges to show clearly all of the hopping frequencies. Compliance of an EUT with the appropriate regulatory limit shall be determined for the number of hopping channels. A spectral plot of the data shall be included in the test report.

Where the device shares the same channel plan (carrier frequencies and number of channels) across multiple data rates or modulation schemes then the number of channels need only be measured for one of those modulation schemes or data rates.

7.8.4 Time of occupancy (dwell time)

The dwell time per hop on a channel is the time from the start of the first transmission to the end of the last transmission for that hop. If the device has a single transmission per hop then the dwell time is the duration of that transmission. If the device has a multiple transmissions per hop then the dwell time is measured from the start of the first transmission to the end of the last transmission.

The time of occupancy is the total time that the device dwells on a channel over an observation period specified in the regulatory requirement. To determine the time of occupancy the spectrum analyzer will be configured to measure both the dwell time per hop and the number of times the device transmits on a specific channel in a given period.

The EUT shall have its hopping function enabled. Compliance with the requirements shall be made with the minimum and with the maximum number of channels enabled. If the dwell time per channel does not vary with the number of channels than compliance with the requirements may be based on the minimum number of channels. If the device supports different dwell times per channel (example Bluetooth devices can dwell on a channel for 1, 3 or 5 time slots) then measurements can be limited to the longest dwell time with the minimum number of channels.

Use the following spectrum analyzer settings to determine the dwell time per hop:

a) Span: Zero span, centered on a hopping channel.
b) RBW shall be ≤ channel spacing and where possible RBW should be set >> 1 / T, where T is the expected transmission time per hop.
c) Sweep time: Set so that the start of the first transmission and end of the last transmission for the hop are clearly captured. Setting the sweep time to be slightly longer than the hopping period per channel (hopping period = 1/hopping rate) should achieve this.
d) Use a video trigger, where possible with a trigger delay, so that the start of the transmission is clearly observed. The trigger level might need adjustment to reduce the chance of triggering when the system hops on an adjacent channel.
e) Detector function: Peak.
f) Trace: Clear-write, single sweep.
g) Place markers at the start of the first transmission on the channel and at the end of the last transmission. The dwell time per hop is the time between these two markers.

To determine the number of hops on a channel in the regulatory observation period repeat the measurement using a longer sweep time. When the device uses a single hopping sequence the period of measurement should be sufficient to capture at least 2 hops. When the device uses a dynamic hopping sequence, or the sequence varies, the period of measurement may need to capture multiple hops to better determine the average time of occupancy. Count the number of hops on the channel across the sweep time.

The average number of hops on the same channel within the regulatory observation period is calculated from the number of hops on the channel divided by the spectrum analyzer sweep time multiplied by the regulatory observation period. For example, if three hops are counted with an analyzer sweep time of 500 ms and the regulatory observation period is 10 s, then the number of hops in that ten seconds is 3 / 0.5 × 10, or 60 hops.

The average time of occupancy is calculated by multiplying the dwell time per hop by the number of hops in the observation period.

Where the device shares the same hopping algorithms (dwell time, channel selection) across multiple data rates or modulation schemes then the time of occupancy need only be measured for one of those modulation schemes or data rates. If the dwell time value varies with different modes of operation (data rate, modulation format, number of hopping channels, etc.), then repeat this test for each variation in dwell time.

Spectral plots of the channel occupancy shall be included in the report.

7.8.5 Output power test procedure for frequency-hopping spread-spectrum (FHSS) devices

This is an RF-conducted test to evaluate maximum peak output power. Use a direct connection between the antenna port of the unlicensed wireless device and the spectrum analyzer, through suitable attenuation. Frequency hopping shall be disabled for this test. Use the following spectrum analyzer settings:

a) Span: Approximately five times the 20 dB bandwidth, centered on a hopping channel.
b) RBW > 20 dB bandwidth of the emission being measured.
c) VBW ≥ RBW.
d) Sweep: No faster than coupled (auto) time.

e) Detector function: Peak.

f) Trace: Max-hold.

g) Allow trace to stabilize.

h) Use the marker-to-peak function to set the marker to the peak of the emission.

i) The indicated level is the peak output power, after any corrections for external attenuators and cables.

j) A spectral plot of the test results and setup description shall be included in the test report.

NOTE—A peak responding power meter may be used, where the power meter and sensor system video bandwidth is greater than the occupied bandwidth of the unlicensed wireless device, rather than a spectrum analyzer.

7.8.6 Occupied bandwidth

For occupied bandwidth measurements, use the procedure in 6.9.3. Frequency hopping shall be disabled for this test.

7.8.7 Conducted spurious emissions test methodology

7.8.7.1 General considerations

To demonstrate compliance with the relative out-of-band emissions requirements conducted spurious emissions shall be measured for the transmit frequencies, per 5.5 and 5.6, and at the maximum transmit powers. Frequency hopping shall be disabled for this test with the exception of measurements at the allocated band-edges which shall be repeated with hopping enabled.

Connect the primary antenna port through an attenuator to the spectrum analyzer input; in the results, account for all losses between the unlicensed wireless device output and the spectrum analyzer. The frequency range of testing shall span 30 MHz to 10 times the operating frequency and this may be done in a single sweep or, to aid resolution, across a number of sweeps. The resolution bandwidth shall be 100 kHz, video bandwidth 300 kHz, and a coupled sweep time with a peak detector.

The limit is based on the highest in-band level across all channels measured using the same instrument settings (resolution bandwidth of 100 kHz, video bandwidth of 300 kHz, and a coupled sweep time with a peak detector). To help clearly demonstrate compliance a display line may be set at the required offset (typically 20 dB) below the highest in-band level. Where the highest in-band level is not clearly identified in the out-of-band measurements a separate spectral plot showing the in-band level shall be provided.

When conducted measurements cannot be made (for example a device with integrated, non-removable antenna) radiated measurements shall be used. The reference level for determining the limit shall be established by maximizing the field strength from the highest power channel and measuring using the resolution and video bandwidth settings and peak detector as described above. The field strength limit for spurious emissions outside of restricted-bands shall then be set at the required offset (typically 20 dB) below the highest in-band level. Radiated measurements will follow the standards measurement procedures described in Clause 6 with the exception that the resolution bandwidth shall be 100 kHz, video bandwidth 300 kHz, and a coupled sweep time with a peak detector. Note that use of wider measurement bandwidths are acceptable for measuring the spurious emissions provided that the peak detector is used and that the measured value of spurious emissions are compared to the highest in-band level measured with the 100 kHz / 300 kHz bandwidth settings to determine compliance.

7.8.7.2 Band-edges

Compliance with a relative limit at the band-edges (e.g., −20 dBc) shall be made on the lowest and on the highest channels with frequency hopping disabled and repeated with frequency hopping enabled. For the latter test the hopping sequence shall include the lowest and highest channels.

For measurements with the hopping disabled the analyzer screen shall clearly show compliance with the requirement within 10 MHz of the allocated band-edge.

For measurements with the hopping enabled the analyzer screen shall clearly show compliance with the requirement within 10 MHz of both of the allocated band-edges. This could require separate spectral plots for each band-edge.

7.8.8 Radiated emissions

7.8.8.1 General considerations

Radiated emissions measurements shall be made with frequency hopping disabled.

7.8.8.2 Average measurements

Where average measurements of an emission are required it is permitted to determine the average value over 100 ms after accounting for the maximum dwell time per 1 MHz in any 100 ms period. The dwell time in any 100 ms period can include multiple hops on that frequency for devices which have a short dwell time.

The maximum dwell time per 1 MHz does need to account for cases where the channel spacing is less than the 1 MHz measurement bandwidth and for cases where the occupied bandwidth exceeds the channel spacing and the channels overlap. The maximum dwell time per 1 MHz is determined as follows:

Maximum dwell time per 1 MHz = dwell time per 100 ms per channel × (channel separation correction + overlapping channel correction) where:

— Channel separation correction = [1 / channel separation (MHz)] for channel separation < 1 MHz, and = 1 for channel separation ≥ 1 MHz, as determined using the procedures of 7.8.2. If the average measurements are performed on the N^{th} harmonic, the channel separation value is N times the separation at the fundamental frequency.

— Overlapping channel correction = 0 when the 20 dB channel bandwidth < channel separation and = 1 for when the 20 dB channel bandwidth > channel separation.

The average value may be determined as follows:

a) From the peak value of the emission: The measured peak value in dBuV/m is corrected by 20log(maximum dwell time in 100 ms / 100).

b) From the average value of the emission: When the average value has been measured with the device continuously transmitting (100% duty cycle) the measured average value in dBuV/m is corrected by Xlog(maximum dwell time in 100 ms / 100) where X = 10 if using an rms-average power detector (with output data in power terms) and X = 20 if using a linear voltage average detector (with output data in voltage terms).

When the average value has been measured with the device operating with a duty cycle, equivalent to the maximum dwell time the measured average value is used. The averaging period shall be set to 100 ms.

When measuring the average value using rms or voltage average detectors the resolution bandwidth is set according to the frequency of measurement (e.g., 1 MHz for measurements above 1 GHz – refer to 4.1.5.2.2), the video bandwidth is set to at least 3 times the resolution bandwidth and the measurement time is set to 100 ms. When the device is transmitting continuously or the period of the duty cycle is << 100 ms the measurement time can be reduced to enable faster measurements but should always be equal to or greater than the period of the duty cycle and at least ten times the symbol rate to ensure averaging over multiple symbols. When using a spectrum analyser the measurement time is the sweep time divided by the number of display points, or if using trace averaging, the number of sweeps multiplied by the number of points divided by the sweep time. Refer also to 4.1.3 for additional considerations related to setting reference level, average detection modes and bin size.

When using the reduced video bandwidth method to make an average measurement the resolution and video bandwidths shall be set as detailed in 4.1.5.2.3.

Application of a correction factor based on the dwell time per 1 MHz per 100 ms is based on current regulatory guidance but can be modified or removed in a future addition of guidance on testing FHSS. In this case the duty cycle factor to be applied would be the overall transmit duty cycle and not the duty cycle per channel.

7.8.8.3 Measurements in restricted-bands adjacent to the allocated band

Compliance with radiated field strength limits in restricted-bands adjacent or close to the allocated band shall be performed on the lowest and highest channels with hopping disabled. Note that where the low and high channels operate at lower power levels than their adjacent channels it can be necessary to repeat the band-edge measurements on those adjacent channels.

The procedures described in 6.10.4 also apply.

7.8.8.4 Alternate method[70]

In lieu of measurements of radiated emissions with each different antenna type the manufacturer may demonstrate compliance with the radiated spurious emissions requirements by performing a conducted emissions test using the same measurement bandwidths and detector functions as required for radiated tests. For emissions falling into restricted-bands the conducted measurements shall be converted to a radiated field strength using the equations in 11.12.2.2 (General procedure for conducted measurements in restricted-bands) after taking into account the EUT antenna gain considerations of 11.12.2.6.

For emissions outside of the restricted-bands the conducted measurements procedures of 7.8.7 are used to demonstrate compliance with the the applicable dBc limit.

In addition, radiated emissions tests as described in 11.12.2.7 shall be performed.

8. Procedures for determining emissions from FM transmitters designed for use in vehicles

8.1 General

For all measurements in this subclause, the general measurement considerations regarding instrumentation in Clause 4 of this document, the general requirements of Clause 5, and the standard methods of Clause 6 shall be followed, to the extent practical.

FM modulated signals might be coupled to vehicle head units in many ways, including but not limited to the following:

a) Wireless transmission between the FM source and the vehicle antenna.

b) Injection into a vehicle’s wiring system via the cigarette lighter adapter (CLA) socket.

c) Capacitive coupling to a vehicle FM whip antenna, rooftop antenna, or embedded glass antenna.

[70] Regulatory bodies may not accept this alternative method. Users of the method should check to validate that the relevant regulatory body allows this method.

This subclause describes the appropriate test procedures for measuring emissions for each type of coupling method.

NOTE—For readability and continuity of test procedure descriptions, the accompanying figures are all grouped in 8.8.

8.2 Wireless transmission between FM source and vehicle antenna

When the radiating mechanism is internal to the EUT, and when the EUT can be installed by the end user in multiple orientations, the EUT shall be measured independently on three axes to determine the orientation that produces the maximum emissions. After the orientation is found that produces the maximum emissions, final radiated measurements may be made. This procedure shall be followed for each antenna polarization.

When the radiating mechanism is a leaky coaxial cable, or an external radiating element, the cable or radiating element shall be placed on the test tabletop in a random fashion, followed by optimization of the element or cable placement for maximum emissions during prescans. After the position is found that results in maximum emissions, the cable or radiating element need not be moved again while final measurements are performed. This procedure shall be followed for each measurement antenna polarization.

For all measurements, the EUT settings that can be controlled by the end user, and that can affect the FM modulated signal, shall be adjusted to their maximum.

The measurements shall be repeated such that data are obtained with the device transmitting at the center of the transmitting band and at both band-edges.

8.3 Injection into a vehicle’s wiring system via the CLA socket

The following procedure shall be used for measuring radiated emissions when an FM signal is injected into the CLA socket:

a) For tabletop measurements of radiated emissions from a device that directly injects an FM signal into a vehicle’s wiring system through the CLA socket, the EUT arrangement shall be as depicted in Figure 16.
b) A representative sample of the transmitting CLA (EUT) shall be placed on an approved test tabletop 80 cm above the OATS or semi-anechoic chamber ground plane floor, along with a vehicle battery, the FM source device, and all associated peripherals and interconnecting cables.
c) The EUT shall be connected to the vehicle battery with a 12 AWG or 14 AWG diameter twisted pair cable of 1 m in length. The twisted pair cable shall have a minimum of 12 turns, and care shall be taken to confirm that the twists go all the way to both ends of the cable.
d) A socket may be attached to the CLA side of the twisted pair for easier connection to the EUT, or the wires may be connected directly to the CLA positive and negative terminals.
e) All peripherals and devices shall be spaced 10 cm apart along the back edge of the table surface. The EUT shall be placed next to the vehicle battery, and the twisted pair cable shall be draped off the back of the test tabletop, i.e., not placed on the tabletop. All other cables used to connect the EUT to the peripherals and to the FM source device shall be placed on the test tabletop in a random fashion.
f) For measurements of FM transmitters, it is important that the prescan and final measurement procedures described in 6.5.3 and 6.5.4 are followed to find maximum emissions.
g) For all measurements, the EUT settings that can be controlled by the end user, and that can affect the FM modulated signal, shall be adjusted to maximum settings.
h) The tabletop setup radiated emissions measurement shall be repeated with the device transmitting at the center of the transmitting band and at both band-edges.

8.4 In situ measurement procedure for vehicles

8.4.1 General

For in situ measurements of radiated emissions from all types FM transmitters in vehicles, a minimum of three vehicles shall be used. The vehicles chosen shall be representative of typical small, medium, and large vehicles. The vehicles chosen shall have an FM antenna, which may be an embedded glass, roof mount, or whip style antenna, connected to the head unit.

When installing the EUT, a reasonable effort shall be made to locate the transmit antenna or capacitive coupler, as well as the interconnect cabling, to achieve maximum radiated emissions within the parameters of the EUT installation guide.

For all measurements, the EUT settings that can be controlled by the end user, and that can affect the FM modulated signal, shall be adjusted to their maximum.

The in situ radiated emissions measurement shall be repeated with the device transmitting at the center of the transmitting band and at both band-edges. The chosen transmitting frequencies within the FM band shall be free of strong ambient signals.

8.4.2 In situ measurement procedure with vehicle on a turntable

The following procedure shall be used for measuring radiated emissions when using a vehicle turntable:

a) Radiated emissions measurements of FM modulators that inject a signal directly into a vehicle's wiring system through the CLA socket may be performed on a traditional turntable, if available.

b) For this procedure, exploratory measurements may be used to determine the radiated emissions of interest, as well as the worst-case azimuth for each emission.

c) The receive antenna shall be placed on a suitable mast that allows measurements to be made in both horizontal and vertical polarizations and allows for height scans of 1 m to 4 m.

d) Each representative vehicle shall be centered on the turntable, and the receive antenna shall be placed at a 3 m distance, as measured from the center of one of the sides of the vehicle. This establishes that the measurement distance is never greater than 3 m; however, as the vehicle rotates through 0° to 360°, the circumference created by the vehicle's perimeter will reduce the measurement distance to less than 3 m through most of the rotation. This is acceptable for the purposes of exploratory measurements; however, final measurements shall be made at 3 m. Figure 17 depicts the test setup for exploratory measurements.

e) While monitoring the received level of the chosen transmitting frequency or spurious emission in one polarization, the turntable shall be rotated through 0° to 360°. The azimuth and antenna polarization that is determined to produce the highest amplitude for each emission shall be recorded.

f) For final measurements, the turntable shall be returned to the azimuth that produced the highest amplitude of each of the radiated emissions recorded in the appropriate antenna polarization.

g) The receive antenna measurement distance shall be adjusted to 3 m. A height scan of 1 m to 4 m shall be performed to determine the antenna height that produces the highest amplitude of the emission. This orientation of the EUT and antenna represents the maximized emission level of the emission being measured.

h) Using the appropriate detector, a formal measurement can be made. The measurement result, azimuth position, antenna polarization, and antenna height shall be recorded.

i) This shall be repeated for each emission recorded during the exploratory measurements.

8.4.3 In situ measurement procedure without the vehicle on a turntable

If a traditional turntable is not available, radiated emissions measurements of FM modulators that inject a signal directly into a vehicle's wiring system through the CLA socket may still be made in situ, using the test method described in this subclause.

Figure 18 depicts the test setup for making in situ measurements at a test site that does not have a traditional turntable capable of rotating a vehicle.

While monitoring the received level of the chosen transmitting frequency, the receive antenna shall be moved horizontally along the vehicle sides at a distance of 3 m; at the same time, the antenna on the mast is raised between 1 m and 4 m at a sufficient number of discrete points to find the maximum emissions. This procedure shall be repeated for each of the four sides of the vehicle. Alternatively, if the mast is not easily moved along the perimeter of the vehicle, then the mast may be placed at eight positions around the vehicle at a 3 m distance from the nearest point of the vehicle at each of the positions or the vehicle itself may be moved into the required positions to achieve the same measurement azimuths and measurement distances.

8.5 Conducted power measurement

The following procedure shall be used when conducted power measurements of the fundamental frequency from FM transmitters that inject a signal directly into a vehicle's wiring system through the CLA socket are required. The test setup and procedure shall be as described subsequently and as shown in Figure 19.

The CLA shall be connected to the spectrum analyzer or EMI receiver input through a "bias-tee" (bias-T) circuit, which provides the necessary dc voltage to the CLA for normal operation but blocks the dc voltage from appearing at the instrument input; see Figure 19. The bias-T circuit shall not attenuate the FM signal. An impedance matching transformer, or a minimum loss impedance matching pad attenuator, may be inserted ahead of the bias-T to match the impedance of the EUT to the measuring equipment. The insertion loss of the impedance matching device shall be accounted for.

Any loss between the EUT and the spectrum analyzer or EMI receiver shall be added to the instrument reading to obtain the power level at the EUT output.

Measurements of the conducted power of the fundamental frequency shall be made with an instrument configured with the following setting:

a) Detector: Average.

b) Resolution bandwidth (RBW): 120 kHz.

c) Video bandwidth (VBW): 300 kHz.

d) Reference level: 10 dB above the peak emission (to provide sufficient dynamic range to the measurement system noise floor).

e) Span: Wide enough to capture the entire emission in the display screen and narrow enough to provide adequate measurement resolution of the peak.

NOTE 1—For fundamental FM frequency emissions, the measured field strength at a 3 m measurement distance may be related to EIRP by using the equation: E0[dBμV/m] = EIRP[dBm] + 100. For in situ measurements, to the extent that the measured field strength does not match the predicted value from this equation (as a result of vehicle shielding, nonisotropic radiation, and other factors), a correction factor (CF) may be inserted. The equation can then be rearranged to be in the form of a transfer function (TF). An analysis of the field strengths recorded for multiple in situ measurements used in recent FM transmitter certifications, and of the associated conducted power from the same units used for those certifications, has yielded a TF value of 77 dB. This value represents the mean value plus two standard deviations. If the field strength limit, as dictated by a regulatory agency, is substituted into the equation, and the empirically found TF value is used, then a conducted power effective limit for the FM fundamental emission can be determined, which would then be the equivalent of the radiated field strength limit for the radiator. For a more complete description of the measurements performed on a variety of vehicles and the development of the transfer function, see Annex J and O'Brien et al. [B67].

NOTE 2—Conducted power measurements have been performed on several FM transmitters and compared with the results of compliant FM transmitters measured in accordance with 8.4. Based on these empirical measurement results, and with standard deviations taken into account, a transfer function value of 77 dB has been determined, which relates conducted power to in situ radiated field strength.

8.6 Capacitive coupling to a vehicle FM antenna

The following procedure shall be used for measuring radiated emissions when the FM signal is capacitive coupled to a vehicle FM antenna:

a) For tabletop measurements of radiated emissions from a device that capacitively couples an FM signal to a vehicle FM receiver through the vehicle's FM embedded glass antenna, whip antenna, or roof mount antenna, the EUT arrangement shall be as described in this subclause and as shown in Figure 20.

b) A representative sample of a vehicle whip antenna shall be placed on a 1 m by 1.5 m metallic ground plane, on a suitable test tabletop, 80 cm above the OATS or anechoic chamber ground plane floor. When installing the EUT, a reasonable effort shall be made to maximize the location of the capacitive coupler, as well as the interconnect cabling, to achieve maximum radiated emissions within the parameters of the installation guide. The 1 m by 1.5 m small tabletop ground plane shall be connected to the EUT system ground.

c) For measurements of FM transmitters, it is important that the prescan and final measurement procedures described in 6.5.3 and 6.5.4 are followed, to find maximum emissions.

d) For all measurements, the EUT settings that can be controlled by the end user, and that can affect the FM modulated signal, shall be adjusted to their maximum.

e) The tabletop radiated emissions measurement shall be repeated with the device transmitting at the center of the transmitting band and at both band-edges.

f) Note that it can also be required to perform in situ tests for this type of coupling method, in which case the procedure in 8.4.2 or 8.4.3 shall be followed.

8.7 Procedure for determining occupied bandwidth of FM transmitter

For occupied bandwidth measurements of intentional radiators operating in the band 88 MHz to 108 MHz, the general considerations of 6.9 shall be followed. In addition, the method described as follows shall also be applied:

a) For the purposes of occupied bandwidth measurements, the input signal shall be a 2.5 kHz tone. The level of the tone shall be 16 dB higher than that required to produce a frequency deviation of 75 kHz, or 50% of the manufacturer's rated deviation, whichever is less.

b) Alternatively, in the event that a 16 dB increase cannot be achieved, the level of the tone shall be set to the manufacturer's maximum rated input to the modulator.

c) For FM modulators where only digital inputs are used, the manufacturer's maximum rated input is defined as the maximum digital input, which is 0 dB. The input shall be injected such that any filtering, emphasis, or other gain enhancements or reductions in front of the modulator are exercised in the same way that they will be when the device is operated by an end user.

d) For all measurements, the EUT settings that can be controlled by the end user, and that can affect the FM modulated signal, shall be adjusted to their maximum.

e) In addition to the graphical representations of the occupied bandwidth measurement results, the manufacturer's maximum rated input to the modulator shall be included in the test report.

f) The occupied bandwidth shall be recorded as the 20 dB bandwidth and tested at the low, middle, and high channels, and it shall be wholly contained in the band 88 MHz to 108 MHz. For bandwidth measurements, a peak detector shall be used, except that a sample detector may be used when the modulating audio signal is of a digital audio encoding format. Examples of digital audio encoding formats are shown below:

1) Advanced audio coding (AAC).
2) Spectral band replication (SBR) audio compression encoding.
3) CT (Coding Technologies)-aacPlus audio compression encoding (a combination of AAC and SBR compression encoding).
4) High efficiency AAC (HE-AAC), a compression scheme for digital audio. It is an extension of low-complexity AAC (AAC LC) optimized for low-bit-rate applications such as streaming audio.
5) HE AAC version 1 (HE-AAC v1): Uses SBR to enhance the compression efficiency in the frequency-domain.

8.8 Figures for Clause 8

All figures (i.e., Figure 16 through Figure 20) accompanying the text of Clause 8 are grouped in this subclause.

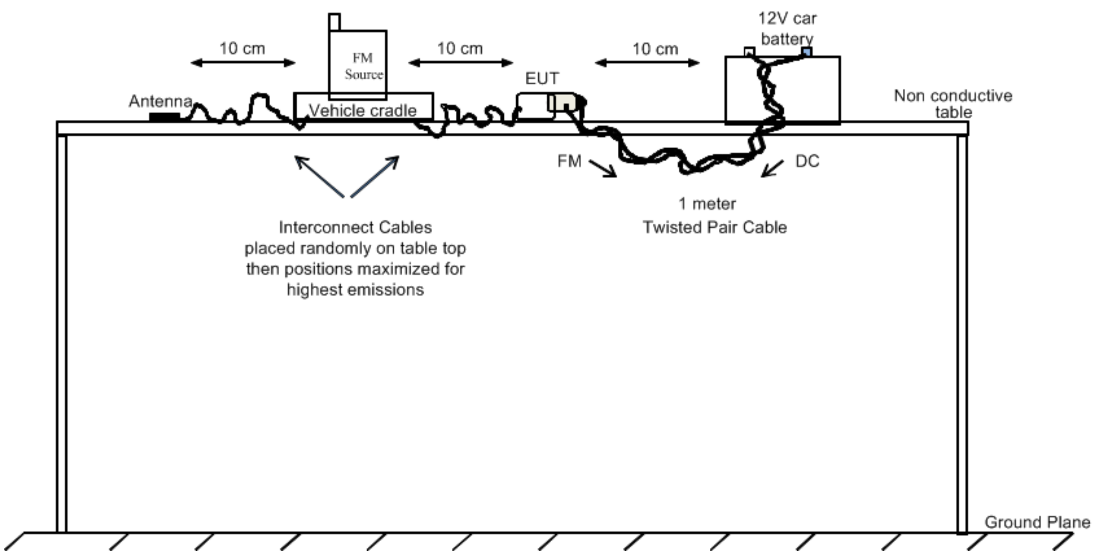


Figure 16—Example tabletop configuration for CLA (see 8.2 and 8.3)

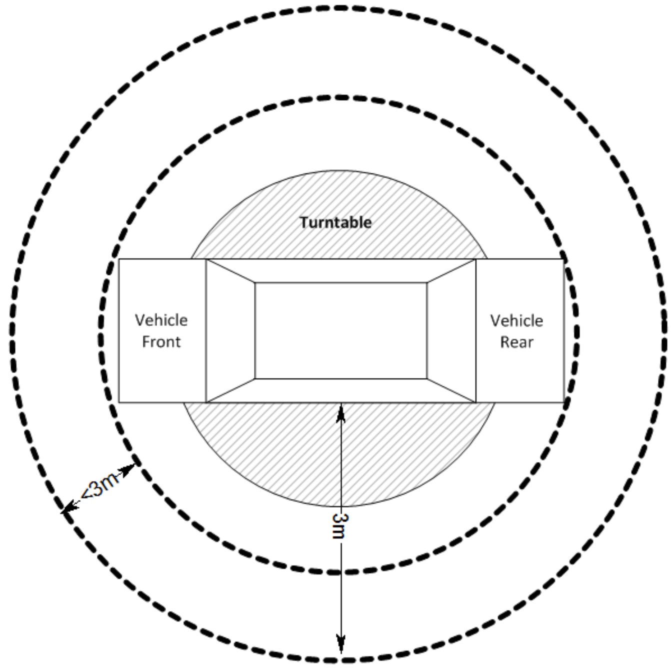


Figure 17—Example test setup for exploratory measurements using a turntable (dimensions not to scale) (see 8.4.2)

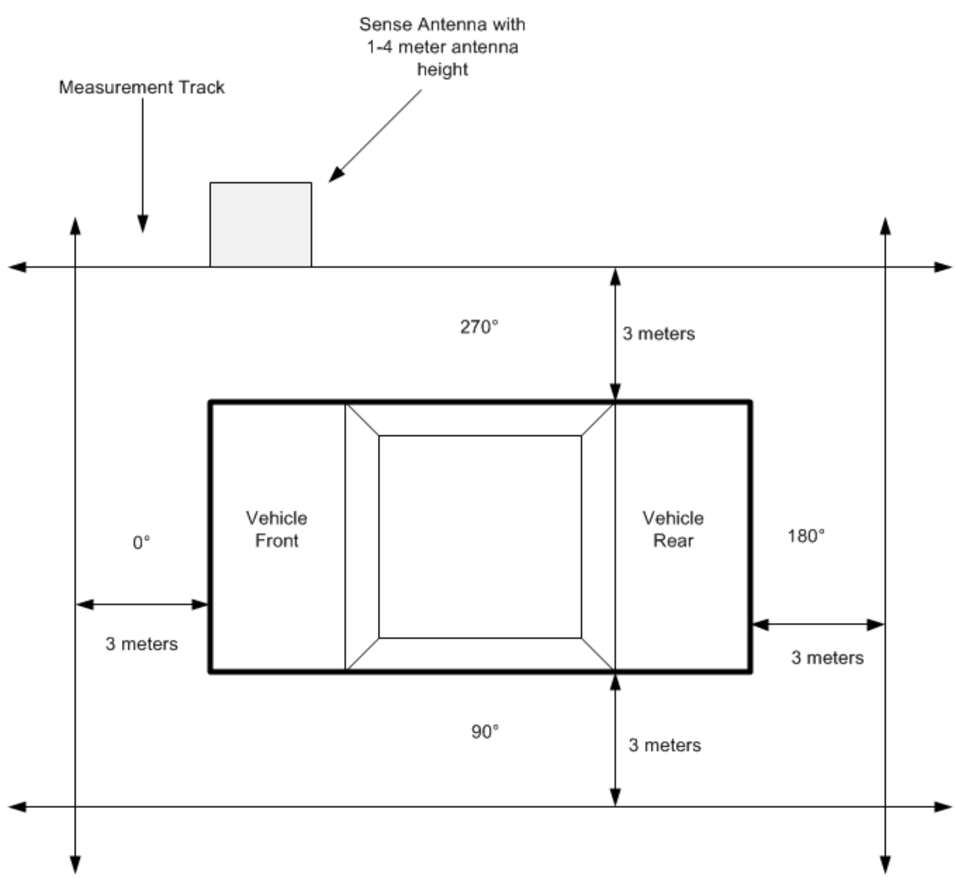


Figure 18—Example top view in situ vehicle measurement setup (see 8.4.2 and 8.4.3)

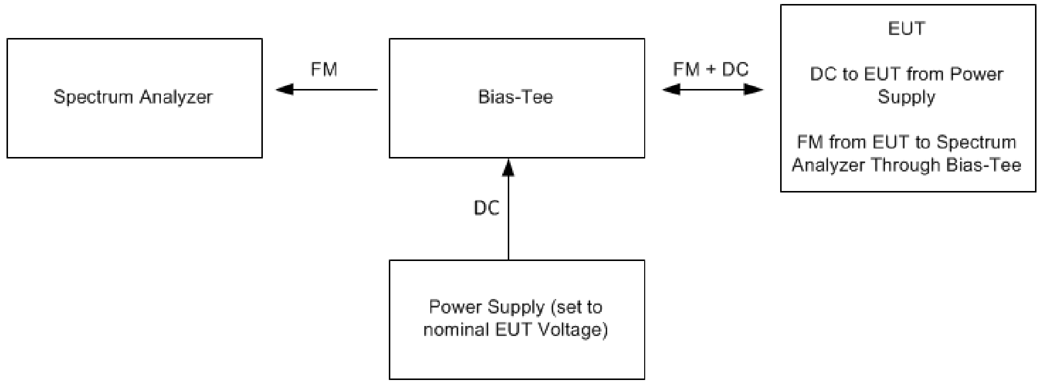


Figure 19—Example conducted power measurement setup for FM transmitters (see 8.5)

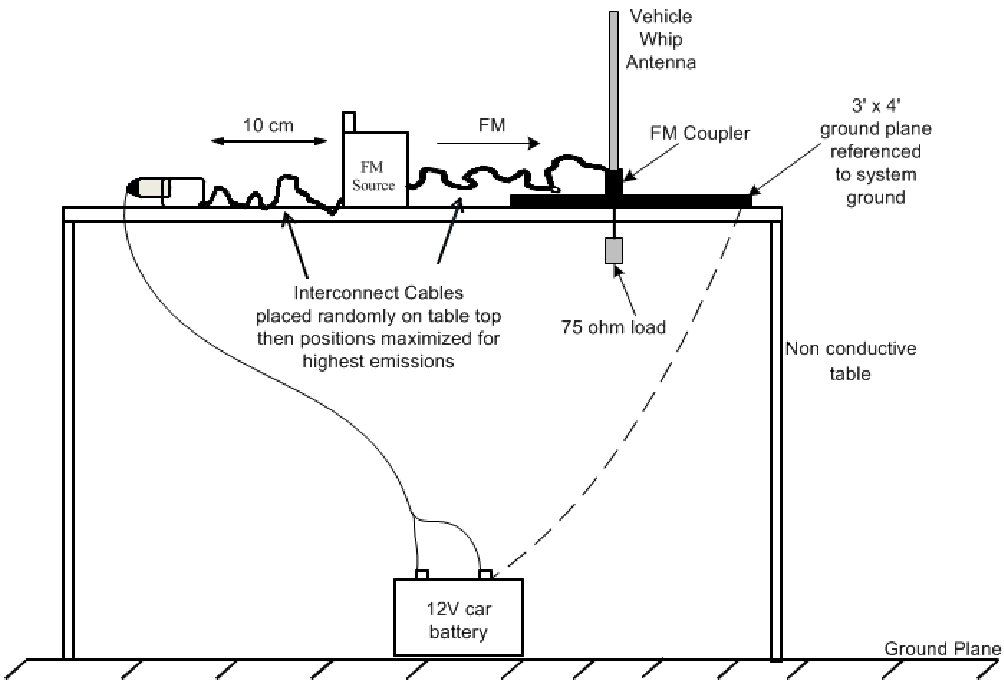


Figure 20—Example EUT arrangement for capacitive coupling to a vehicle FM antenna

9. Procedures for testing millimeter-wave systems

This clause describes the procedures for testing millimeter-wave (mm-wave) unlicensed wireless device systems with the applicable radio regulations.[71]

9.1 Instrument and test sites

9.1.1 General

A radiated method of measurements to demonstrate compliance with the various regulatory requirements has been chosen in consideration of test equipment availability, that many millimeter-wave EUTs utilize integrated antenna array elements and therefore do not have a coaxial or waveguide antenna port, and certain regulatory requirements. A conducted method of measurement could be employed for certain tests if EUT and mixer waveguides both are accessible and of the same type (waveguide number) and if waveguide sections and transitions can be found. Another potential problem is that the peak power output of devices operating under the applicable radio regulations might exceed the rated power limit of many commercially available mixers. For these reasons, a radiated method is preferred.

All measurements shall be made in the far-field of the measurement antenna.

Special care shall be used when measuring emissions from millimeter-wave devices, with consideration of the following issues.

The beamwidths associated with both the EUT and measurement antennas can be extremely narrow; thus, very small adjustments to the position of the measurement antenna might be required such that the maximum emission level is measured.

Tracking preselectors are rarely available with external mixers. This can result in the display of the signal and one or more image frequencies, requiring confirmation that emissions displayed on the spectrum analyzer originate from the EUT. Most spectrum analyzers have a signal identification feature that can be used if there is any question as to the source of the emission under investigation (i.e., to confirm it is not a false mixer image signal).These signal identification functions are applicable to harmonic mixers and downconverters operating in a swept mode where the LO drive is generated by the spectrum analyzer and the downconverter IF output feeds the spectrum analyzer external mixer input, but generally not applicable to downconverters operating in a block mode where the LO drive is generated by a separate, fixed signal generator and the downconverter IF output feeds the spectrum analyzer RF input.

The lack of tracking preselectors also increases the risk for the fundamental emission to overload the front end of the mixer, downconverter or spectrum analyzer. This condition is likely to produce harmonic distortion and intermodulation products. In such a case, a low-pass, high-pass or band-reject filter shall be used to attenuate the fundamental power so as to reduce the chance of inaccurate amplitude measurements. Waveguide components have inherent high-pass filter characteristics, significantly attenuating signals at frequencies below the waveguide cutoff frequency. The cutoff frequency for rectangular waveguides is approximately 0.8 times the lower operating frequency of the waveguide band. Therefore, while measuring the harmonics, the fundamental emissions in the millimeter-wave range will generally not overload the front end of the measurement system.

9.1.2 Measurement instrumentation

Typical equipment used for making millimeter-wave measurements includes:

a) Spectrum analyzer

b) External harmonic mixers and/or fundamental-mixing downconverters covering the necessary frequency ranges

[71] See 47 CFR 15.255, 15.256, and 15.257.

NOTE 1—Harmonic mixers typically have significantly higher conversion loss than downconverters therefore they might not provide adequate system sensitivity to make measurements in the far-field.

c) Standard-gain horns covering the necessary frequency ranges
d) Diplexer for analyzer, if required
e) External local-oscillator amplifier, if required
f) Signal generator for millimeter-wave source and/or external local-oscillator drive
g) Variable voltage supply
h) Temperature chamber
i) Non-conductive antenna positioning structure
j) Non-conductive EUT positioning structure
k) High-pass, band-pass and band-reject filters
l) RF detector
m) Millimeter-wave isolator, if required
n) Low-noise amplifier, if required
o) Digital storage oscilloscope (DSO)
p) 10 MHz low pass RF filter
q) Millimeter-wave source
r) Variable waveguide attenuator
s) Millimeter-wave power sensor
t) Open-ended rectangular waveguide aperture antennas as described in 5.5.1.1.3 of ANSI C95.3-2002, covering the necessary frequency ranges, if required
u) Video amplifier, 50 Ω input and output impedance, bandwidth dc to >10 MHz, if required

NOTE 2—Accredited calibration of equipment operating at the frequencies under investigation could be a challenge at present; however, manufacturer’s calibration services are generally available. Where accredited calibration services are not available, a manufacturer’s calibration of mm-wave instruments on a routine basis might be considered sufficient by the regulatory body.

9.1.3 Test sites

Pending the development of suitable validation criteria and procedures for the measurement frequency range, the test site should be a fully anechoic chamber with suitably rated absorbers. Every attempt shall be made to reduce contributions from reflections to a minimum.

The test object is mounted on a positioner at a height of 1.5 m. The measurement antenna is placed at a height of 1.5 m with a measurement distance in the far-field as described below. An appropriate band reject filter can be used to protect the measurement receiver from the in-band signal. The LNA can be used to increase the dynamic range for the measurement receiver. See Figure 21 and Figure 22.

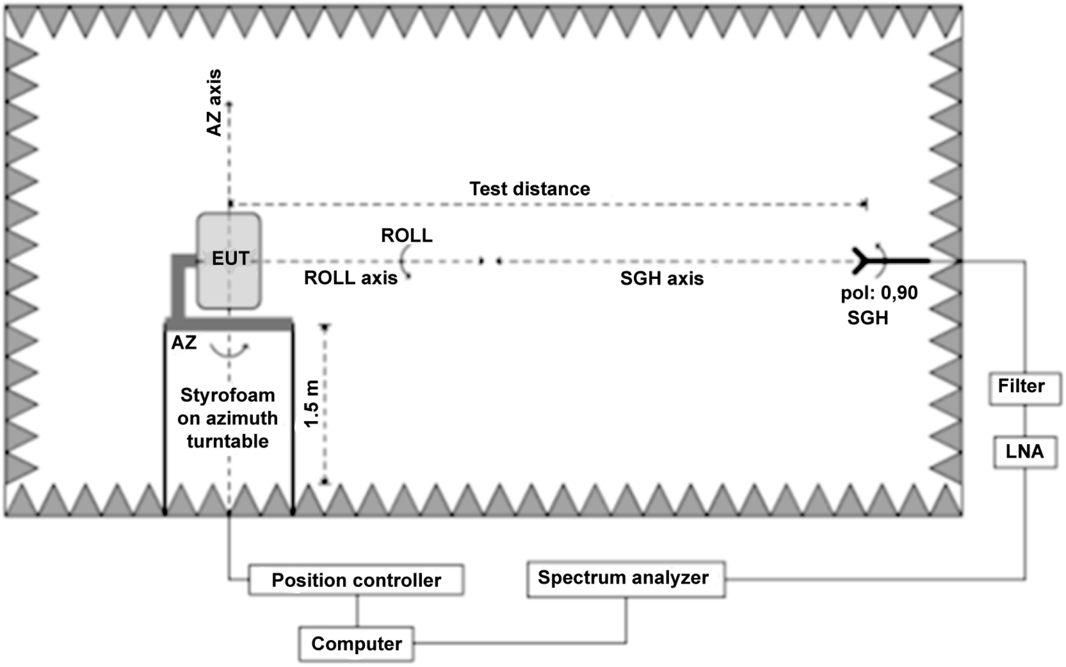


Figure 21—Example of a typical shielded anechoic chamber and positioner setup. The roll axis positioner is optional. This setup shows instrumentation where the frequency of the emissions is within the fundamental operating range of the spectrum analyzer.

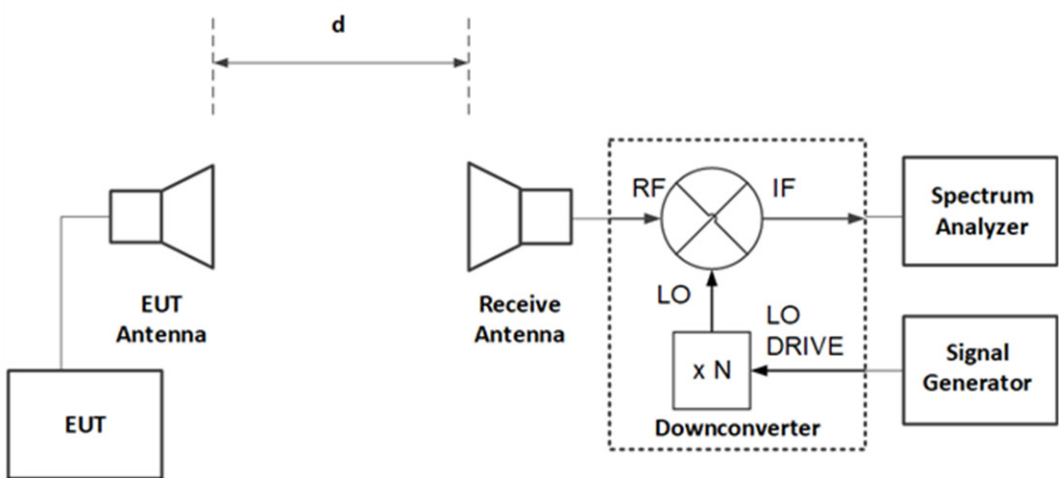


Figure 22—Example of a typical instrumentation setup with downconverter, generally operating at frequencies above the spectrum analyzer's fundamental operating range.

9.1.4 Measurement distance for all final radiated measurements

All measurements shall be made in the far-field of the measurement antenna. The far-field boundary for mm-wave antennas is $2D^2/\lambda$.

For fundamental or out-of-band emissions the far-field boundary distance of the EUT antenna or measurement antenna, whichever is largest, shall be used. For spurious and harmonic emissions the far-field boundary distance shall be based on the measurement antenna.

Consult the regulatory authority for guidance when far-field measurements are not practical due to the dimensions of the EUT antenna or radiating seams/slots

When the selected far-field measurement distance is different than the distance at which the applicable limit is specified, a linear inverse distance attenuation factor (20 dB/decade of distance change) shall be applied.

Note: A near-field measurement method may be used providing the regulatory authority has accepted its use. After regulatory acceptance, the procedures and measurements deviating from far-field measurement conditions shall be clearly identified and thoroughly described in the test report.

All measurements shall be made at a distance that provides a system sensitivity (noise floor) that is at least 6 dB below the applicable limit.

9.2 Equations

9.2.1 Equations to calculate and extrapolate field strength

Calculate the field strength from the radiated measurement in the far-field using Equation (19):

$$E = 126.8 - 20\log(\lambda) + P - G \tag{19}$$

where

- E is the field strength of the emission at the measurement distance, in dBuV/m
- λ is the wavelength of the emission under investigation [300/f(MHz)], in m
- P is the power measured at the output of the measurement antenna, in dBm
- G is the gain of the measurement antenna, in dBi

NOTE—The measured power P includes all applicable instrument correction factors up to the connection to the measurement antenna.

For field strength measurements made at other than the distance specified by the limit, extrapolate the measured field strength to the field strength at the distance specified by the limit using an inverse distance correction factor (20 dB/decade of distance). The inverse-distance equation is given by Equation (20):

$$E_{SpecLimit} = E_{Meas} + 20\log\left(\frac{D_{Meas}}{D_{SpecLimit}}\right)$$

$$E_{\mathrm{SpecLimit}} = E_{\mathrm{Meas}} + 20\ log\left(\frac{D_{\mathrm{Meas}}}{D_{\mathrm{SpecLimit}}}\right) \tag{20}$$

where

- $E_{\mathrm{SpecLimit}}$ is the field strength of the emission at the distance specified by the limit, in dBuV/m
- E_{Meas} is the field strength of the emission at the measurement distance, in dBuV/m
- D_{Meas} is the measurement distance, in m
- $D_{\mathrm{SpecLimit}}$ is the distance specified by the limit, in m

Calculate the field strength in V/m from the field strength in dBuV/m using Equation (21):

$$E_{Linear} = 10^{\left[\left(E_{Log} - 120\right)/20\right]} \tag{21}$$

where

- E_{Linear} is the field strength of the emission, in V/m
- E_{Log} is the field strength of the emission, in dBuV/m

9.2.2 Equations to calculate EIRP

Calculate the EIRP from the radiated measurement in the far-field using Equation (22):

$$EIRP = 21.98 - 20\log(\lambda) + 20\log(d_{Meas}) + P - G \quad (22)$$

where

$EIRP$	is the equivalent isotropic radiated power, in dBm
λ	is the wavelength of the emission under investigation [300/f(MHz)], in m
d_{Meas}	is the measurement distance, in m
P	is the power measured at the output of the measurement antenna, in dBm
G	is the gain of the measurement antenna, in dBi

NOTE—The measured power P includes all applicable instrument correction factors up to the connection to the measurement antenna.

Calculate the EIRP from the conducted power using Equation (23):

$$EIRP = P_{Cond} + G_{EUT} \quad (23)$$

where

$EIRP$	is the equivalent isotropic radiated power, in dBm
P_{Cond}	is the measured power at feedpoint of the EUT antenna, in dBm
G_{EUT}	is the gain of the EUT radiating element (antenna), in dBi

Convert the EIRP in dBm to the EIRP in Watts using Equation (24):

$$EIRP_{Linear} = 10^{[(EIRP_{LOG} - 30)/10]} \quad (24)$$

where

$EIRP_{\mathrm{Linear}}$	is the equivalent isotropic radiated power, in Watts
$EIRP_{\mathrm{Log}}$	is the equivalent isotropic radiated power, in dBm

9.2.3 Equations to calculate power density

Calculate the power density at the distance specified by the limit from the equivalent isotropic radiated power in Watts using Equation (25):

$$PD = \frac{EIRP_{Linear}}{\left(4\pi d^2\right)} \quad (25)$$

where

PD	is the power density at the distance specified by the limit, in W/m^2
$EIRP_{\mathrm{Linear}}$	is the equivalent isotropic radiated power, in watts
d	is the distance at which the power density limit is specified, in m

Calculate the power density at the distance specified by the limit from the field strength at the distance specified by the limit using Equation (26):

$$PD = \frac{E_{SpecLimit}^2}{377} \quad (26)$$

where

377	is free-space impedance
PD	is the power density at the distance specified by the limit, in W/m^2
$E_{\text{SpecLimit}}$	is the field strength at the distance specified by the limit, in V/m

9.2.4 Equation to calculate conducted power output

Calculate the conducted output power (in watts) from the equivalent isotropic radiated power (in watts) using Equation (27):

$$P_{Cond} = \frac{EIRP_{Linear}}{G_{EUT}} \tag{27}$$

where

P_{cond}	is the conducted output power, in W
$EIRP_{\text{Linear}}$	is the equivalent isotropic radiated power, in W
G_{EUT}	is numeric gain of the EUT radiating element (antenna)

9.3 Emission bandwidth - relative measurement procedure

The emission bandwidth (EBW) is defined as the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, outside of which all emissions are attenuated at least the specified amount below the maximum level of the modulated carrier.

The following procedure shall be used for measurement of the bandwidth for millimeter-wave devices. (See Figure 21):

a) Use the following spectrum analyzer settings:
    1) Span equal to approximately 1.5 times the EBW, centered on the carrier frequency
    2) RBW, prefer 1% to 5% of EBW, or a minimum of 1 MHz if this is not possible due to a large EBW, unless otherwise specified by the applicable rule
    3) VBW approximately 3 × RBW
    4) Set the reference level of the instrument as required to reduce the chance of the signal amplitude exceeding the maximum spectrum analyzer input mixer level for linear operation. See guidance provided in 4.1.6.
    5) Sweep = No faster than coupled (auto) time.
    6) Detector function = peak.
    7) Trace = max-hold.
b) The EUT shall be transmitting at its maximum data rate. Allow the trace to stabilize.
c) Use the marker-to-peak function to set the marker to the peak of the emission. Use the marker-delta function to measure the specified dB down one side of the emission.
d) Reset the marker-delta function, and move the marker to the other side of the emission, until the delta marker amplitude is at the same level as the reference marker amplitude. The marker-delta frequency reading at this point is the specified emission bandwidth. The spectral envelope can cross the “−X dB amplitude” at multiple points. The lowest or highest frequency shall be selected as the frequencies that are the farthest away from the center frequency at which the spectral envelope crosses the “−X dB amplitude.”

e) The EBW shall be reported by providing plot(s) of the measuring instrument display, to include markers depicting the relevant frequency and amplitude information (e.g., marker table). The frequency and amplitude axis and scale shall be clearly labeled. Tabular data may be reported in addition to the plot(s).

f) Repeat this test for each modulation scheme using the guidance of 5.6.2.1.

9.4 Occupied bandwidth—Power bandwidth (99%) measurement procedure

The occupied bandwidth (OBW) is the frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers are each equal to 0.5% of the total mean power of the given emission.

a) The following procedure shall be used for measuring 99% power bandwidth: Use the following spectrum analyzer settings:
   1) Span equal to approximately 1.5 times the OBW, centered on the carrier frequency
   2) RBW, prefer 1% to 5% of OBW, or a minimum of 1 MHz if this is not possible due to a large OBW
   3) VBW approximately 3 × RBW
   4) Set the reference level of the instrument as required to reduce the chance of the signal amplitude exceeding the maximum spectrum analyzer input mixer level for linear operation. See guidance provided in 4.1.6.
   5) Sweep = No faster than coupled (auto) time.
   6) Detector function = peak.
   7) Trace = max-hold.

b) The EUT shall be transmitting at its maximum data rate. Allow the trace to stabilize.

c) If the instrument does not have a 99% OBW function, recover the trace data points and sum directly in linear power terms. Place the recovered amplitude data points, beginning at the lowest frequency, in a running sum until 0.5% of the total is reached. Record that frequency as the lower OBW frequency. Repeat the process until 99.5% of the total is reached and record that frequency as the upper OBW frequency. The 99% power OBW can be determined by computing the difference these two frequencies.

d) The OBW shall be reported and plot(s) of the measuring instrument display shall be provided with the test report. The frequency and amplitude axis and scale shall be clearly labeled. Tabular data can be reported in addition to the plot(s).

e) Repeat this test for each modulation scheme using the guidance of 5.6.2.1.

9.5 Frequency stability measurement procedure

The following procedure shall be used for determining frequency stability of millimeter-wave systems:

a) Arrange EUT and test equipment as shown in Figure 23. Suitable temperature chambers have a window or other opening that permits locating the receive antenna and instrumentation outside the chamber.

b) Install an RF transparent foam plug in the chamber opening.

c) As applicable, install RF absorber sheets on the inside walls of the chamber, particularly in any areas illuminated by the EUT antenna beam.

d) With the EUT at ambient temperature (approximately 25 °C) and voltage source set to the EUT nominal operating voltage (100%), record the frequency excursion of the spectrum mask of the EUT emission on the spectrum analyzer. Alternatively, if the EUT has a test mode to transmit a CW frequency, the frequency can be measured using the spectrum analyzer’s internal frequency count function.

e) Follow the test methods of 6.8

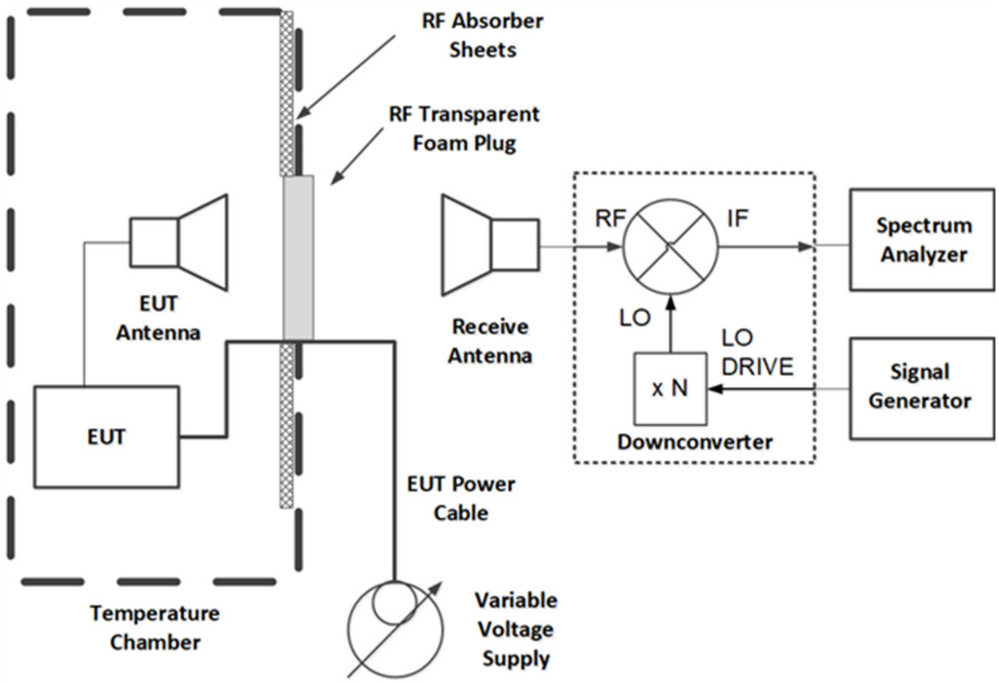


Figure 23—Example of a frequency stability setup configuration

9.6 Exploratory radiated measurements

a) Connect the measurement antenna to the instrumentation system.

b) Place the EUT in a continuous transmission mode.

c) Set the instruments to the proper values.

d) Perform an exploratory search for emissions, and determine the approximate direction and measurement antenna polarization at which each observed emission emanates from the EUT, using one of the following methods:

   1) Subclause 6.6.4.2

   2) Subclauses 6.6.5

   3) Annex H

   4) Hand-held exploratory scan

      i) This method is generally suitable when using harmonic mixers that can be readily held by hand and manually manipulated to scan around all surfaces of the EUT.

      ii) This method is not suitable for final emissions measurements.

      iii) It is suggested that exploratory measurements be made at a closer distance than the intended final measurement distance. However, exercise care not to overload the measurement system when the measurement antenna is directed toward the main beam(s) of the EUT antenna. Also exercise care that the system sensitivity is at least 6 dB below the applicable limit, considering that the gain of the measurement antenna at measurement distances within the near-field will be less than the published far-field gain value.

      iv) Hold the measurement antenna by the waveguide flange to preclude any obstructions of, or impact on, the antenna aperture.

v) Scan the measurement antenna around all surfaces of the EUT, keeping the measurement antenna at a separation distance approximately equal to the selected measurement distance, except increase the distance as needed to reduce the chance of a measurement system overload when the measurement antenna is directed to the main beam(s) of the EUT antenna.

vi) As the surfaces of the EUT are scanned, keep the measurement antenna pointed toward the EUT.

vii) As the surfaces of the EUT are scanned, vary the measurement antenna polarization by rotating through at least 0° to 180° to cover all possible polarizations of the emission.

viii) For each observed emission note the approximate measurement antenna position and antenna polarization at which the maximum level occurs.

ix) Where applicable, using two active traces on a spectrum analyzer (one set to clear-write, the second to max-hold) can aid the process.

9.7 Maximizing procedure for measurements

Maximize emissions as follows:

a) Connect the measurement antenna to the instrumentation system.

b) Place the EUT in a continuous transmission mode.

c) Support the EUT and the measurement antenna with stable holders to help ensure repeatability and remove additional uncertainty(for example, that would be associated with holding either or both by hand).

d) Set the instruments to the proper values.

e) For each emission observed in the exploratory scan as specified in 9.6, perform a final measurement as follows:

   1) Begin with the EUT and measurement antenna at the approximate orientation where the maximum level occurred during the exploratory scan.

   2) Place the measurement antenna at a measurement distance that meets the measurement distance requirements for final radiated measurements as specified in 9.1.4.

   3) Slowly scan the measurement antenna position and/or the EUT position around this initial orientation, and slowly vary the measurement antenna polarization by rotating through at least 0° to 180°, to find the final position, polarization and orientation at which the maximum level of the emission is observed.

f) Record the measured reading with the measurement antenna fixed at this maximized position, polarization and orientation. Record the measurement distance.

9.8 Measurement of the fundamental emission using spectrum analyzer[72]

Where applicable, the following procedure shall be used for measuring the field strength from millimeter-wave systems:

a) Set up the test as follows:

   1) For conducted measurements, connect the external mixer or spectrum analyzer, with appropriate attenuation as needed to reduce the chance of damage or overload to the measurement instrumentation, to the output port of the EUT.

[72] This procedure applies to devices subject to 47 CFR 15.256.

2) For radiated measurements, connect the measurement antenna for the fundamental frequency band to a spectrum analyzer via an external mixer, or directly to the spectrum analyzer if the instrument supports the required frequency range.

b) For all measurements

1) For pulsed emissions, the procedures in 4.1.5.2.4 and Annex C shall be used.

2) For FMCW emissions, the procedures in 4.1.5.2.8 and Annex L shall be used.

3) For any other emission, set spectrum analyzer RBW, VBW, detector, span, and so on, to the proper values.

c) For radiated measurements:

1) Place the measurement antenna at a measurement distance that is in the far-field of the measurement antenna, in the far-field of the EUT antenna, and meets the measurement distance requirements for final radiated measurements as specified in 9.1.4.

2) Place the measurement antenna in the main beam of the EUT then maximize the fundamental emission using the procedures of 9.7, noting that multiple peaks can be found at different beam orientations and/or polarizations.

3) Correct the power reading from the spectrum analyzer for any external gain and/or attenuation between the measurement antenna and the spectrum analyzer. This is the power at the output of the measurement antenna

4) Calculate the EIRP from the power at the output of the measurement antenna using Equation (22), and then convert to linear form using Equation (24).

5) Where applicable, calculate conducted output power from the EIRP using Equation (27).

d) For conducted measurements:

1) Correct the power reading from the spectrum analyzer for any external gain and/or attenuation between the EUT and the spectrum analyzer. This is the conducted output power of the EUT.

2) Calculate the EIRP from the conducted output power of the EUT using Equation (23), and then convert to linear form using Equation (24).

e) Repeat the preceding sequence to determine the EIRP and where applicable, conducted power for each detector (peak and average) as required.

f) Repeat the preceding sequence for every operating configuration supported by the EUT.

9.9 Measurement of the fundamental emission using an RF detector[73]

The following procedure shall be used for measuring the fundamental emission using an RF detector:

a) Set up the test as follows:

1) The measurement instrument shall be either a mm-wave RF detector that has an RF bandwidth encompassing the entire authorized frequency band or a mm-wave downconverter connected to a microwave RF detector, such that the RF input of the downconverter encompasses the entire authorized frequency band and both the IF output of the downconverter and the RF input of the detector encompass the entire downconverted authorized frequency band.

2) The input VSWR of the mm-wave detector or mm-wave downconverter shall be less than 3:1. If the detector or downconverter as a stand-alone device does not meet this requirement, then a mm-wave isolator shall be connected to the input RF port, and the input VSWR of the combination of isolator plus detector, or isolator plus downconverter, shall be less than 3:1.

[73] This procedure applies to devices subject to 47 CFR 15.255 and 15.257.

3) Connect the video output of the detector to the 50 Ω input of a DSO. The video bandwidth of the combination of the detector and DSO must be greater than 10 MHz. When connected to the 50 Ω input of the DSO, the video bandwidth will typically be greater than 10 MHz, in which case a low-pass filter (LPF) with a cutoff frequency of at least 10 MHz may be inserted between the output of the detector and the input of the DSO. Due to the input capacitance of the DSO, the video bandwidth will normally be less than 10 MHz when the output of the detector is connected to the high impedance (e.g., 1 MΩ) input of the DSO.

4) If the detected voltage is near the noise floor of the DSO, insert a video amplifier at the input of the DSO. The input and output impedance of the video amplifier shall be 50 ohms. The bandwidth of the video amplifier must extend from DC to at least 10 MHz; the video bandwidth of the combination of the detector, low pass filter (if used), video amplifier and DSO must be greater than 10 MHz. A gain of 40 dB is suggested. Placing the video amplifier after the 10 MHz filter, if used, will reduce the input noise to the video amplifier.

5) Set the sampling rate of the DSO to at least twice the cutoff frequency of any LPF used or to at least twice the signal bandwidth without a LPF. Adjust the memory depth, the triggering, and the sweep speed to obtain a display that is representative of the signal considering the type of modulation. If the signal is noncontinuous, then identify the segment of the signal that has the highest amplitude, and then adjust the triggering and the sweep speed to capture that segment. If the emission consists of RF bursts, then identify the highest level burst and adjust the triggering and sweep rate of the DSO to display the entire burst without blanking intervals.

b) For conducted measurements of transmitter output power, connect the mm-wave RF detector or the downconverter, with appropriate attenuation as needed to reduce the chance of damage or overload to the measurement instrumentation, to the output port of the EUT.

c) For radiated measurements:

1) Connect the measurement antenna for the fundamental frequency band to the mm-wave RF detector or the downconverter. Place the measurement antenna at a test distance that is in the far-field of the measurement antenna, in the far-field of the EUT antenna, and meets the measurement distance requirements for final radiated measurements as specified in 9.1.4.

2) Place the measurement antenna in the main beam of the EUT then maximize the fundamental emission using maximizing procedures 9.7, noting that multiple peaks can be found at different beam orientations and/or polarizations.

d) For all measurements, measure the level of the emission using substitution as follows:

1) Record the peak voltage from the DSO and record the average voltage during the ON time of the EUT from the DSO.

2) Disconnect the measurement antenna or EUT (as applicable for radiated or conducted tests, respectively) from the RF input port of the instrumentation system.

3) Connect a mm-wave source to the RF input port of the instrumentation system via a waveguide variable attenuator.

4) The mm-wave source shall be unmodulated.

5) Adjust the frequency of the mm-wave source to the center of the frequency range occupied by the transmitter.

6) Adjust the amplitude of the mm-wave source and/or the variable attenuator such that the DSO indicates a voltage equal to the peak voltage recorded in step d)1)

7) Disconnect the waveguide variable attenuator from the RF input port of the instrumentation system.

8) Without changing any settings, connect the waveguide variable attenuator to a wideband mm-wave power meter with a thermocouple detector or equivalent.

9) Measure and note the power.

10) Repeat steps d)3) through d)9) for the average voltage recorded in step d)1) .

e) For radiated measurements:

   1) Correct the peak and average substitution power at the input to the measurement instrument, as recorded in step d), for any external gain and/or attenuation between the measurement antenna and the measurement instrument that was not included in the substitution power measurement. This is the peak and average (respectively) substitution power at the output of the measurement antenna.

   2) Calculate the peak and average EIRP from the peak and average (respectively) substitution power at the output of the measurement antenna using Equation (22), and then convert to linear form using Equation (24)

   3) Calculate the peak conducted output power from the peak EIRP using Equation (27).

   4) Where applicable, calculate the peak and average power density at the distance at which the limit is specified from the peak and average (respectively) EIRP using Equation (25).

f) For conducted measurements:

   1) Correct the peak and average substitution power at the input to the measurement instrument, as recorded in step d), for any external gain and/or attenuation between the EUT and the measurement instrument that was not included in the substitution power measurement. This is the peak and average (respectively) conducted output power of the EUT.

   2) Calculate the peak and average EIRP from the peak and average (respectively) conducted output power of the EUT using Equation (23), and then convert to linear form using Equation (24).

   3) Where applicable, calculate the peak and average power density at the distance at which the limit is specified from the peak and average (respectively) EIRP using Equation (25).

g) For all measurements, repeat the preceding sequence for every operating configuration of which the EUT is capable.

9.10 Measurement of unwanted emissions above 40 GHz

The following procedure shall be used for measuring harmonic and spurious emissions for frequencies above 40 GHz:

a) Connect the measurement antenna covering the appropriate frequency range to a spectrum analyzer via an external mixer or directly to the spectrum analyzer if the instrument supports the required frequency range.

b) Set spectrum analyzer as follows:

   1) For pulsed emissions, the procedures in 4.1.5.2.7 and Annex C shall be used.

   2) For FMCW emissions, the procedures in 4.1.5.2.8 and Annex L shall be used.

   NOTE—Some devices that utilize FMCW modulation generate the modulation at a relatively low frequency and multiply it up to the fundamental operating frequency. Adjustments to instrument settings must be considered when measuring FMCW emissions at subharmonics.

   3) For all other emissions, RBW = 1 MHz, VBW = 1 MHz or 3 MHz (as specified in the requirements), average detector, span as required, and so on.

c) Place the measurement antenna at a measurement distance that is in the far-field of the measurement antenna and meets the distance requirements for final radiated measurements as specified in 9.1.4.

d) Search for emissions over the mixer band as specified in 9.6 and maximize all observed emissions as specified in 9.7.

e) Note the maximum power indicated on the spectrum analyzer. Correct this reading, if necessary, by the conversion loss of the external mixer, any external gain and/or attenuation due to low-noise amplifiers, filters and other RF components used at the frequency under investigation, by the external mixer IF cable loss and by the IF amplifier gain if used. This is the power at the output of the measurement antenna.

f) Where applicable, calculate the maximum field strength of the emission at the measurement distance from the power at the output of the measurement antenna using Equation (19). If measurements were made at any distance other than the distance specified by the limit, then extrapolate the calculated field strength to the field strength at the distance specified by the limit using Equation (20). Where applicable, convert the field strength to linear form using Equation (21).

g) Where applicable, calculate the EIRP from the power at the output of the measurement antenna using Equation (22) and then convert to the linear form using Equation (24).

h) Where applicable, calculate power density at the distance specified by the limit from the EIRP using Equation (25).

i) Where applicable, repeat the preceding sequence with peak detection.

j) Repeat the preceding sequence for every emission observed in the frequency band under investigation.

k) Repeat the preceding sequence for every external mixer band as needed to encompass the required frequency range of investigation (as specified by the regulatory requirements to which compliance is being tested).

l) Repeat the preceding sequence in all operating configurations supported by the EUT.

9.11 Measurement of unwanted emissions at or below 40 GHz

Use the standard test methods described in 6.3 through 6.6.

Where applicable, calculate EIRP from the power at the output of the measurement antenna using Equation (22) and then convert to the linear form using Equation (24).

10. Procedures for measuring ultra-wideband devices

The following procedures (10.1, 10.2, and 10.3) shall be used for measuring UWB devices.

10.1 Evaluation of −10 dB bandwidth

A UWB transmitter is defined as "an intentional radiator that, at any point in time, has a fractional bandwidth equal to or greater than 0.20 or has a UWB bandwidth equal to or great than 500 MHz, regardless of the fractional bandwidth."[74]

The frequency at which the maximum power level is measured with the peak detector is designated f_M. The peak power measurements shall be made using a spectrum analyzer or EMI receiver with a 1 MHz resolution bandwidth and a video bandwidth of 1 MHz or greater. The instrument shall be set to peak detection using the maximum-hold trace mode. The outermost 1 MHz segments above and below f_M, where the peak power falls by 10 dB relative to the level at f_M, are designated as f_H and f_L, respectively:

a) For the lowest frequency bound f_L, the emission is searched from a frequency lower than f_M that has, by inspection, a peak power much lower than 10 dB less than the power at f_M and increased toward f_M until the peak power indicates 10 dB less than the power at f_M. The frequency of that segment is recorded.

[74] See the ultra-wideband device rules in 47 CFR Part 15 Subpart F.

b) This process is repeated for the highest frequency bound f_H, beginning at a frequency higher than f_M that has, by inspection, a peak power much lower than 10 dB below the power at f_M. The frequency of that segment is recorded.

c) The two recorded frequencies represent the highest f_H and lowest f_L bounds of the UWB transmission, and the −10 dB bandwidth ($B - 10$) is defined as ($f_H - f_L$).[75] The center frequency (f_c) is mathematically determined from ($f_H - f_L$) / 2.

d) The fractional bandwidth is defined as $2(f_H - f_L) / (f_H + f_L)$.

e) Determine whether the −10 dB bandwidth ($f_H - f_L$) is ≥500 MHz, or whether the fractional bandwidth $2(f_H - f_L) / (f_H + f_L)$ is ≥0.2.

10.2 Radiated measurement procedure below 960 MHz

10.2.1 General

The procedures for measuring emissions below 960 MHz to determine compliance to the limits are those of Clause 6 with but one exception, as noted in 10.2.2. Note also that when measuring UWB emissions below 960 MHz, the spectrum shall be examined in small enough frequency segments such that reflections and measurement system gains and losses do not vary significantly over each segment.

10.2.2 In situ compliance measurements for UWB ground-penetrating radar and wall-imaging radar

Ground-penetrating radar (GPR) devices are field disturbance sensors designed to operate while in contact with, or in close proximity to, the ground. Wall-imaging radar (WIR) devices perform a similar function as GPRs, but instead of their emissions being directed into the ground, WIRs might radiate in other than a downward direction (the walls or ceiling of a mine or tunnel, concrete structures such as bridge supports, etc.). In both cases, most of the radiated energy is absorbed within the medium, and thus, the directly radiated emissions from these devices pose an insignificant interference potential to other spectrum users. This characteristic introduces a unique complexity in that a measurement methodology is required that shall discriminate between the UWB RF energy radiating directly from the transmit antenna and any leakage, diffracted, or scattered RF energy present under normal (in situ) operating conditions.

In an effort to devise a measurement procedure that provides adequate isolation between the directly radiated and the scattered or leaked emissions, an option exists to test these types of UWB devices while they are radiating into a bed of dry sand with 50 cm depth. The area of the sand bed shall be large enough to accommodate the GPR or WIR transducer/radiating antenna in its entirety. Measurements are then performed at an adequate number of radials and antenna height steps to determine the maximum radiated emission level (see 5.4 and 6.11). Anechoic material may be used as an alternative to a bed of sand if it can be shown to provide similar attenuation with respect to the directly radiated UWB emissions. However, if either of these methods precludes the use of a reference ground plane, then a ground reflection factor (i.e., 6 dB for $f \leq 30$ MHz and 4.7 dB for 30 MHz $< f \leq 960$ MHz) shall be added to the measured levels.

10.3 Radiated measurement procedure above 960 MHz

10.3.1 General

Above 960 MHz, the emissions limits for UWB devices are specified in terms of the EIRP relative to the device. Because the radiated power is the parameter of interest, a free-space propagation path is assumed. Thus, there is no requirement to perform this measurement with the EUT above a reference ground plane.

[75] The bandwidth of a UWB emission is defined by the points on the emission spectra where the amplitude is 10 dB below the maximum emission amplitude (i.e., the –10 dB points). In those cases where the measured emission spectrum contains multiple (more than two) –10 dB points, the outermost points define the UWB bandwidth (i.e., the widest bandwidth is reported).

10.3.2 Measurement distance

Because the emission limits are specified in terms of EIRP, there is no specified distance for performing these measurements; however, whenever possible, a separation distance of 3 m shall be used. In some cases, it might be necessary to measure the UWB device radiated emissions at a closer distance to obtain enough signal and margin to overcome the measurement system noise floor. When closer distances are used, care shall be taken to maintain antenna far-field conditions.

10.3.3 Measurement antennas

Measurement antennas are typically optimized over specific frequency ranges. When measuring the complete UWB spectral envelope, several measurement antennas shall be required, each optimized over a distinct frequency range.

10.3.4 Measurement receiver and detectors

The measurement receiver may be one of the following: a spectrum analyzer, an EMI test receiver, a vector signal analyzer, or an oscilloscope. Two signal detectors are specified for measuring UWB device emissions above 960 MHz. A power averaging (rms) detector is required for measuring the average UWB device emissions, and a peak detector is required for determining the peak power associated with UWB device emissions.

10.3.5 Peak power measurement

The spectral characterization of a UWB device shall begin with a peak detected radiated measurement because the results obtained from this measurement could preclude the need for subsequent average measurements. For example, if the data collected from the peak power measurement show that the radiated emissions levels are equal to, or less than, the applicable emissions limit, then these data are adequate to determine compliance. This is predicated on the fact that the average levels are typically less than, or equal to, the peak signal level.

The peak detector of the instrument is selected and the maximum hold feature activated. The RBW is set to 1 MHz and the VBW is set to at least 1 MHz (3 MHz is recommended).

10.3.6 Bandwidth conversion of peak power measurements

It is acceptable to employ an RBW of less than 50 MHz (but no less than 1 MHz) when performing the required peak power measurements. When this approach is employed, the peak emissions EIRP limit (0 dBm / 50 MHz) is converted to a limit commensurate with the RBW by employing a [20 log (RBW/50 MHz)] relationship. For example, the peak power limit could be expressed in a 1 MHz bandwidth as follows in Equation (28):

$$EIRP_{1\text{ MHz}} = EIRP_{50\text{ MHz}} + 20\log\left(1\text{ MHz} / 50\text{ MHz}\right) = 0\text{ dBm} + \left(-34\text{ dB}\right) = -34\text{ dBm} \tag{28}$$

When a resolution bandwidth of less than 50 MHz is used, this measurement shall be performed over a 50 MHz span centered on the frequency associated with the highest detected average emission level.

10.3.7 Evaluating rms-average power spectral density

The following procedure shall be used for evaluating rms-average power spectral density:

a) Set the RBW to 1 MHz.

b) Set the VBW to be at least 1 MHz (a VBW of 3 MHz is desirable).

c) Set the frequency span to examine the spectrum across a convenient frequency segment (e.g., 600 MHz).

d) Select the power averaging (rms) detector.

e) Set the sweep time so that there is no more than a 1 ms integration period over each measurement bin.

Many older instruments use a default value of approximately 600 bins per scan. Assuming this value, a sweep time of 600 ms provides the required 1 ms integration period within each measurement bin. The number of measurement bins can be specified with many modern instruments, providing many other possible combinations of sweep time and number of measurement bins that also result in adherence to the 1 ms maximum integration time requirement. The rms-average power spectral density is the highest integrated power detected within a 1 MHz RBW over a 1 ms integration period.

10.3.8 Required corrections to the measured signal amplitude levels

The signal amplitude levels shall be corrected for measurement system influences. In particular, any gains introduced by the measurement antenna and preamplifier shall be deducted and any losses in the interconnecting cables and connectors shall be added to the displayed amplitude.

For example, to determine the power spectral density at the measurement antenna, Equation (29) may be used:

$$PSD_{EIRP} = A + F_C - G_A - G_{PA} \tag{29}$$

where

PSD_{EIRP}	is the power spectral density in dBm/MHz (1 MHz RBW)
A	is the signal amplitude (as displayed by the instrument) in dBm/MHz
F_C	is the cable and connector attenuation factor in dB
G_A	is the measurement antenna gain (at measurement distance) in dBi
G_{PA}	is the preamplifier gain (at measurement frequency) in dB

Similarly, the corrected field strength may be determined from Equation (30):

$$E = A + F_C + F_A - G_{PA} \tag{30}$$

where

E	is the field strength (at measurement distance) in dBμV/m
A	is the signal amplitude (as displayed by the instrument) in dBμV
F_A	is the antenna factor (at measurement distance) in dB/m

and all other parameters are as previously defined.

10.3.9 Determination of EIRP

The UWB emissions limits are expressed as an EIRP, which effectively restricts both the maximum device output power and the directivity (gain) of the radiating antenna, assuming basic free-space propagation path loss. The EIRP may be determined from the power spectral density as described in Equation (31):

$$\mathrm{EIRP} = \mathrm{PSD} + F_{fs} \tag{31}$$

where

EIRP	is the equivalent isotropically radiated power in dBm/MHz
PSD	is the power spectral density (in a bandwidth specified by applicable regulatory authority) in dBm/MHz
F_{fs}	is the free-space path loss in dB

The basic free-space path loss may be calculated from Equation (32):

$$F_{\text{fs}} = 20\log f + 20\log d - 27.56 \quad (32)$$

where

f is the frequency in MHz
d is the distance of measurement in m

Alternatively, when an isotropic transmitting antenna is assumed, the following relationships in

Equation (33) and Equation (34) may be employed to relate EIRP to field strength at a specified measurement distance of 3 m:

$$E(\text{dB}\mu\text{V/m}) = \text{EIRP}(\text{dBm}) + 95.3 \quad (33)$$

or conversely,

$$\text{EIRP}(\text{dBm}) = E(\text{dB}\mu\text{V/m}) - 95.3 \quad (34)$$

10.3.10 Spectral line measurements

Another test required for these types of devices involves the measurement of the maximum of the average power contained in any spectral lines present within the 1164 MHz to 1240 MHz and 1559 MHz to 1610 MHz frequency ranges. The measurement setup is similar to that described in 10.3.7. The rms detector is selected, and the sweep time and number of measurement bins are set to provide the requisite 1 ms integration time. In this test, the RBW may be reduced to a minimum of 1 kHz (30 kHz is recommended) to enhance the resolution of the individual spectral lines. A ratio of VBW / RBW > 3 shall be maintained when possible.

11. Procedures for testing DTS devices

11.1 General

The measurement procedures provided in this clause are applicable only to DTS devices operating in the 902 MHz to 928 MHz, 2400 MHz to 2483.5 MHz, and/or 5725 MHz to 5850 MHz[76] bands under the applicable regulations of the regulatory authority.[77] This procedure is not applicable to FHSS that are not hybrid systems, authorized under the same regulatory requirement. For measurements of non-hybrid FHSS devices, see the procedure in 7.8 of this standard. It should be noted that whenever a device utilizes combined technologies (e.g., DTS and U-NII), compliance with the applicable regulatory requirements shall be determined for each component separately.

11.2 Power limits, definitions, and device configuration

The following list of items provides definitions, power limit specifications, and device configurations for DTS devices:

a) The output power limit for DTS devices considered in this clause is specified by the regulatory authority and is expressed in terms of either maximum peak conducted output power or maximum conducted output power.[78]

[76] For RLAN devices operating in the 5.7 GHz band, these are to be tested in accordance with the U-NII procedures.
[77] See, for example, 47 CFR 15.247.
[78] See, for example, 47 CFR 15.247(b)(3).

1) The maximum peak conducted output power is defined as the maximum power level measured with a peak detector using a filter with bandwidth and shape of which is sufficient to accept the signal bandwidth. However, when a filter with adequate bandwidth is not available, a peak power meter is acceptable.
2) The maximum conducted output power is defined as the total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level.
3) The term “maximum power control level” is intended to distinguish between the operational power levels of the EUT and those power levels associated with individual symbols.

b) Within this clause, the minimum required 6 dB bandwidth is referred to as the DTS bandwidth. The procedures provided herein for measuring the maximum peak conducted output power assumes the use of the DTS bandwidth (see 11.8 for guidance pertaining to the measurement of the DTS bandwidth).

c) The procedures provided herein for measuring the maximum conducted (average) output power assume the use of the OBW. See 6.9.3 for guidance pertaining to the definition and measurement of OBW.

11.3 Acceptable measurement configurations

The measurement procedures described herein are based on the use of an antenna-port conducted test configuration. However, if antenna-port conducted tests cannot be performed on an EUT, then radiated tests are acceptable for determining compliance with the various conducted emission requirements. The guidance provided herein is applicable to either antenna-port conducted or radiated compliance measurements.

If a radiated test configuration is used, then the measured power or field strength levels shall be converted to equivalent conducted power levels for comparison with the applicable output power limit. This may be accomplished by first measuring the radiated field strength or power levels using a methodology from 11.9 for maximum peak conducted power or maximum conducted (average) power as applicable and from 11.10 for peak or average power spectral density as applicable. The radiated field strength or power level is converted to EIRP (see Annex G for guidance). The equivalent conducted output power or power spectral density is then determined by subtracting the EUT transmit antenna gain (guidance applicable to devices using MIMO or beamforming technologies is provided in Clause 13 or Clause 14, respectively) from the EIRP (assuming logarithmic representation). All calculations and parameter assumptions shall be provided in the test report.

Antenna-port conducted measurements shall be performed using test equipment that matches the nominal impedance of the antenna assembly to be used with the EUT. Additional attenuation might be required in the conducted RF path to reduce the chance of overloading the measurement instrument. The measured power levels shall be corrected to account for all losses or gains introduced into the conducted RF path, including cable loss, external attenuation, or amplification. These corrections shall be recorded in the test report.

Radiated measurements shall use the procedures specified in 6.3, as applicable.

Averaging over the symbol alphabet is permitted when measuring the maximum conducted (average) output power; however, time intervals when the transmitter is OFF or transmitting at reduced power levels are not to be considered. This implies that whenever possible, the EUT shall be configured to transmit continuously (i.e., with a duty cycle of greater than or equal to 98%) at the maximum power control level over a random symbol set. Alternatively, sweep triggering/signal gating may be employed so that all measurements are performed while the EUT is transmitting at its maximum power control level.

The duty cycle may be considered when determining the average value of unwanted emissions (including spurious emissions) when average measurements are specified, when the maximum duty cycle used in determining the reduction factor is “hardwired” such that under no condition can it be changed or modified by either the device or the end user. The regulatory body could require that justification for use of cycle allowance, including the measurements used to determine the worst-case duty cycle, be included in the test report. The average value may be either calculated by applying the duty factor correction detailed in 7.6.3

to the measured peak value or the average value may be measured directly provided that the device is operating at or above the maximum duty cycle during testing. When measuring the average value directly the procedures detailed in 11.12.2.5, and 11.12.3.2 can be employed without applying the duty cycle correction factor described therein.

The DTS maximum conducted output power shall include the total transmit power delivered to all antennas and antenna elements (see Clause 13 and Clause 14 for additional guidance).

11.4 Test suite considerations

Depending on the operational frequency range used by a particular DTS EUT, compliance measurements can be required on multiple frequencies or channels. Subclause 5.6 specifies the number of frequencies/channels that shall be tested as a function of the frequency range over which the EUT operates.

Many DTS EUTs use wireless protocols that provide for operation in multiple transmission modes, where the data rate, bandwidth, modulation, coding rate, and number of data streams are often variable. When such multiple modes of operation are possible, then compliance to the applicable technical requirements shall be confirmed for any and all realizable operational modes.

In some cases, it might be possible to identify one or more specific operational modes that produce the "worst-case" test results with respect to all the required technical limits (e.g., output power, power spectral density, unwanted emission power at the band-edge and in all spurious emissions, and for each possible output data stream), and then reduce the testing to just these modes on each of the frequencies/channels required per 5.6. Whenever this type of test reduction is used, a complete and detailed technical justification shall be provided, to include measurement data where applicable.

11.5 Reference level/attenuation/headroom

Refer to 4.1.6 for guidance.

11.6 Duty cycle (D), transmission duration (T), and maximum power control level

Preferably, all measurements of maximum conducted (average) output power will be performed with the EUT transmitting continuously (i.e., with a duty cycle of greater than or equal to 98%). When continuous operation cannot be realized, then the use of sweep triggering/signal gating techniques can be used to help ensure that measurements are made only during transmissions at the maximum power control level. Such sweep triggering/signal gating techniques will require knowledge of the minimum transmission duration (T) over which the transmitter is on and is transmitting at its maximum power control level for the tested mode of operation. Sweep triggering/signal gating techniques can then be used if the measurement/sweep time of the analyzer can be set such that it does not exceed T at any time that data are being acquired (i.e., no transmitter OFF-time is to be considered).

When continuous transmission cannot be achieved and sweep triggering/signal gating cannot be implemented, alternative procedures are provided that can be used to measure the average power; however, they will require an additional measurement of the transmitter duty cycle (D). Within this subclause, the duty cycle refers to the fraction of time over which the transmitter is ON and is transmitting at its maximum power control level. The duty cycle is considered to be constant if variations are less than ±2%; otherwise, the duty cycle is considered to be nonconstant.

The term "maximum power control level" is intended to distinguish between operating power levels of the EUT and differences in power levels of individual symbols that occur with some modulation types such as quadrature amplitude modulation (QAM). During testing, the EUT is not required to transmit continuously its highest possible symbol power level. Rather, it should transmit all the symbols and should do so at the highest power control level (i.e., highest operating power level) of the EUT.

Measurements of duty cycle and transmission duration shall be performed using one of the following techniques:

a) A diode detector and an oscilloscope that together have a sufficiently short response time to permit accurate measurements of the ON and OFF times of the transmitted signal.

b) The zero-span mode on a spectrum analyzer or EMI receiver 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:

   1) Set the center frequency of the instrument to the center frequency of the transmission.

   2) Set RBW ≥ OBW if possible; otherwise, set RBW to the largest available value.

   3) Set VBW ≥ RBW. Set detector = peak or average.

   4) The zero-span measurement method shall not be used unless both RBW and VBW are > 50/T and the number of sweep points across duration T exceeds 100. (For example, if VBW and/or RBW are limited to 3 MHz, then the zero-span method of measuring the duty cycle shall not be used if $T \leq 16.7$ µs.)

11.7 Transmit antenna performance considerations

The conducted output power limits for DTS EUTs are based on the use of transmit antennas with directional gains that do not exceed 6 dBi. If transmit antennas with an effective directional gain greater than 6 dBi are used, then the conducted output power from the EUT shall be reduced, as specified in the applicable requirements for DTS.[79]

For those cases where it is specified that the conducted output power be reduced by the amount in dB that the directional gain of the transmitting antenna exceeds 6 dBi, the output power effective limit shall be calculated as follows in Equation (35):

$$P_{\mathrm{Out}} = P_{\mathrm{Limit}} - \left(G_{\mathrm{Tx}} - 6\right) \tag{35}$$

where

P_{Out}	is the maximum conducted output power in dBm
P_{Limit}	is the output power limit in dBm
G_{Tx}	is the maximum transmitting antenna directional gain in dBi

For those cases where it is specified that the conducted output power be reduced by 1 dB for every 3 dB that the directional gain of the transmitting antenna exceeds 6 dBi, the output power effective limit shall be calculated as follows in Equation (36):

$$P_{\mathrm{Out}} = P_{\mathrm{Limit}} - \mathrm{Floor}\left[\left(G_{\mathrm{Tx}} - 6\right)/3\right] \tag{36}$$

where

P_{Out}	is the maximum conducted output power in dBm
P_{Limit}	is the output power limit in dBm
G_{Tx}	is the maximum transmitting antenna directional gain in dBi
Floor[z]	is the largest integer not greater than z (i.e., neglect all fractional portions of the real number, retaining only the least integer value of the operation)

[79] See for example, 47 CFR 15.247(b) and 15.247(c).

Additional guidance for determining the effective antenna gain of EUTs that use multiple transmit antennas simultaneously or sequentially (e.g., MIMO or beamforming technologies) is provided in Clause 13 and Clause 14, respectively.

11.8 DTS bandwidth

One of the following procedures may be used to determine the modulated DTS bandwidth.

11.8.1 Option 1

The steps for the first option are as follows:

a) Set RBW = shall be in the range of 1% to 5% of the OBW but not less than 100 kHz.

b) Set the VBW ≥ [3 × RBW].

c) Detector = peak.

d) Trace mode = max-hold.

e) Sweep = No faster than coupled (auto) time.

f) Allow the trace to stabilize.

g) Measure the maximum width of the emission by placing two markers, one at the lowest frequency and the other at the highest frequency of the envelope of the spectral display, such that each marker is at or slightly below the "−6 dB down amplitude". If a marker is below this "−6 dB down amplitude" value, then it shall be as close as possible to this value.

11.8.2 Option 2

The automatic bandwidth measurement capability of an instrument may be employed using the X dB bandwidth mode with X set to 6 dB, if the functionality described in 11.8.1 (i.e., RBW = 100 kHz,

VBW ≥ 3 × RBW, and peak detector with maximum hold) is implemented by the instrumentation function. When using this capability, care shall be taken so that the bandwidth measurement is not influenced by any intermediate power nulls in the fundamental emission that might be ≥ 6 dB.

11.9 Fundamental emission output power

11.9.1 Maximum peak conducted output power

One of the following procedures may be used to determine the maximum peak conducted output power of a DTS EUT.

11.9.1.1 RBW ≥ DTS bandwidth

The following procedure shall be used when an instrument with a resolution bandwidth that is greater than the DTS bandwidth is available to perform the measurement:

a) Set the RBW ≥ DTS bandwidth.

b) Set VBW ≥ [3 × RBW].

c) Set span ≥ [3 × RBW].

d) Sweep time = No faster than coupled (auto) time.

e) Detector = peak.

f) Trace mode = max-hold.

g) Allow trace to fully stabilize.

h) Use peak marker function to determine the peak amplitude level.

11.9.1.2 PKPM1 Peak power meter method

The maximum peak conducted output power may 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 DTS bandwidth and shall use a fast responding diode detector. See Figure 24.

11.9.2 Maximum conducted (average) output power

11.9.2.1 General

Some regulatory agencies permit the maximum conducted (average) output power to be measured as an alternative to the maximum peak conducted output power for determining compliance to the limit. When this option is exercised, the measured power is to be referenced to the OBW rather than to the DTS bandwidth (see 11.2 for definitions and 6.9.2 for measurement guidance).

When using a spectrum analyzer or EMI receiver (see Figure 25) to perform these measurements, it shall be capable of utilizing a number of measurement points in each sweep that is greater than or equal to twice the

span / RBW, to set a bin-to-bin spacing of ≤ RBW / 2 so that narrowband signals are not lost between frequency bins. If possible, configure or modify the operation of the EUT so that it transmits continuously at its maximum power control level (see 11.6).

The intent is to test at 100% duty cycle; however, a small reduction in duty cycle (to no lower than 98%) is permitted, if required by the EUT for amplitude control purposes. Manufacturers are expected to provide software to the test laboratory to permit such continuous operation.

If continuous transmission (or at least 98% duty cycle) cannot be achieved because of hardware limitations (e.g., overheating), the EUT shall be operated at its maximum power control level, with the transmit duration as long as possible, and the duty cycle as high as possible during which sweep triggering/signal gating techniques may be used to perform the measurement over the transmission duration.

11.9.2.2 Measurement using a spectrum analyzer (SA)

11.9.2.2.1 Selection of test method

The proper test method is selected based on the following criteria:

a) **Method AVGSA-1 or method AVGSA-1A (alternative)** shall be applied if either of the following conditions can be satisfied:

   1) The EUT transmits continuously (with a D ≥ 98%); or

   2) Triggering methods when the device is not continuously transmitting (D≤ 98%)

      i) Sweep triggering can be implemented in such a way that the device transmits at the maximum power control level throughout the duration of each of the instrument sweeps to be averaged. This condition can generally be achieved by triggering the instrument's sweep if the duration of the sweep (with the instrument configured as in method AVGSA-1) is equal to or shorter than the duration T of each transmission from the EUT, and if those transmissions exhibit full power throughout their durations; or

ii) Gate triggering can be implemented in such a way that the sweep of the instrument is only active during the burst period of the device. Any Gate triggering shall be performed on the full power portion of the pulses and care must be taken to ensure that static portions of the pulse are not included in the measurement (ensuring that the trace is averaged over the entire symbol range). All Gate triggered measurements shall be accompanied by a Gate setup plot in the test report.

b) **Method AVGSA-2 or method AVGSA-2A (alternative)** shall be applied if the conditions of the preceding item a) cannot be achieved and the transmissions exhibit a constant duty cycle during the measurement duration. Duty cycle will be considered to be constant if variations are less than ±2%.

c) **Method AVGSA-3 or method AVGSA-3A (alternative)** shall be applied if the conditions of the preceding item a) and item b) cannot be achieved.

11.9.2.2.2 Method AVGSA-1

Method AVGSA-1 uses trace averaging with the EUT transmitting at full power throughout each sweep. The procedure for this method is as follows:

a) Set span to >1.5 times the OBW.

b) Set RBW = 1% to 5% of the OBW, but do not exceed 1 MHz.

c) Set VBW ≥ [3 × RBW].

d) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

e) Sweep time = auto.

f) Detector = power averaging (rms), if available. Otherwise, use sample detector mode.

g) If transmit duty cycle < 98%, use a sweep trigger with the level set to enable triggering only on full power pulses. The transmitter shall operate at the maximum power control level for the entire duration of every sweep. If the EUT transmits continuously (i.e., with no OFF intervals) or at duty cycle ≥ 98%, and if each transmission is entirely at the maximum power control level, then the trigger shall be set to "free run."

h) Trace average at least 100 traces in power averaging (rms) mode.

i) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band power measurement function, with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

11.9.2.2.3 Method AVGSA-1A (alternative)

Method AVGSA-1A uses rms detection with slow sweep and EUT transmitting continuously at full power. The procedure for this method is as follows:

a) Set span to > 1.5 times the OBW.

b) Set RBW = 1% to 5% of the OBW, but do not exceed 1 MHz.

c) Set VBW ≥ [3 × RBW].

d) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

e) Manually set sweep time ≥ [10 × (number of points in sweep) × (transmission symbol period)], but not less than the automatic default sweep time.

NOTE—The transmission symbol period (in seconds) is the reciprocal of the symbol rate (in baud or symbols per second). Note that each symbol can represent one or several data bits, and thus, the symbol rate should not be confused with the gross bit rate (expressed in bits/second). In no case should the sweep time be set less than the auto sweep time.

f) Set detector = Power averaging (rms).

g) The EUT shall be operated at ≥98% duty cycle or sweep triggering/signal gating shall be employed such that the sweep time is less than or equal to the transmission duration *T*.

h) Gate triggering can be implemented in such a way that the sweep of the instrument is only active during the burst period of the device. Any Gate triggering shall be performed on the full power portion of the pulses and care must be taken to ensure that static portions of the pulse are not included in the measurement (ensuring that the trace is averaged over the entire symbol range). All Gate triggered measurements shall be accompanied by a Gate setup plot in the test report

i) Perform a single sweep.

j) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band-power measurement function, with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

11.9.2.2.4 Method AVGSA-2

Method AVGSA-2 uses trace averaging across ON and OFF times of the EUT transmissions, followed by duty cycle correction. The procedure for this method is as follows:

a) Measure the duty cycle *D* of the transmitter output signal as described in 11.6.

b) Set span to >1.5 times the OBW.

c) Set RBW = 1% to 5% of the OBW, but do not exceed 1 MHz.

d) Set VBW ≥ [3 × RBW].

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time = auto.

g) Detector = Power averaging (rms), if available. Otherwise, use the sample detector mode.

h) Do not use sweep triggering. Allow the sweep to "free run."

i) Trace average at least 100 traces in power averaging (rms) mode; however, the number of traces to be averaged shall be increased above 100 until trace is stabilized so that the average accurately represents the true average over the ON and OFF periods of the transmitter.

j) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band-power measurement function with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW of the spectrum.

k) Add [10 log (1 / *D*)], where *D* is the duty cycle, to the measured power to compute the average power during the actual transmission times (because the measurement represents an average over both the ON and OFF times of the transmission). For example, add [10 log (1/0.25)] = 6 dB if the duty cycle is 25%.

11.9.2.2.5 Method AVGSA-2A (alternative)

Method AVGSA-2A uses rms detection with slow sweep with spectrum bin averaging across ON and OFF times of the EUT transmissions, followed by duty cycle correction. The procedure for this method is as follows:

a) Measure the duty cycle *D* of the transmitter output signal as described in 11.6.

b) Set span to >1.5 times the OBW.

c) Set RBW = 1% to 5% of the OBW, but do not exceed 1 MHz.

d) Set VBW ≥ [3 × RBW].

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Manually set sweep time ≥ [10 × (number of points in sweep) × (total ON/OFF period of the transmitted signal)].

g) Set detector = Power averaging (rms).

h) Perform a single sweep.

i) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band-power measurement function with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW.

j) Add [10 log (1 / *D*)], where *D* is the duty cycle, to the measured power to compute the average power during the actual transmission times.

11.9.2.2.6 AVGSA-3

Method AVGSA-3 uses rms detection across ON and OFF times of the EUT with max-hold. The procedure for this method is as follows:

a) Set span to > 1.5 times the OBW.

b) Set sweep trigger to "free run."

c) Set RBW = 1% to 5% of the OBW, but do not exceed 1 MHz.

d) Set VBW ≥ [3 × RBW].

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time ≤ (number of points in sweep) × *T*, where *T* is defined in 11.6. If this gives a sweep time less than the auto sweep time of the instrument, then method AVGSA-3 shall not be used (use AVGSA-3A). The purpose of this step is so that the averaging time in each bin is less than or equal to the minimum time of a transmission.

g) Detector = Power averaging (rms).

h) Trace mode = max-hold.

i) Allow max-hold to run for at least 60 s or longer as needed to allow the trace to stabilize.

j) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band-power measurement function with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW.

11.9.2.2.7 AVGSA-3A (alternative)

Method AVGSA-3A uses reduced VBW averaging across ON and OFF times of the EUT with max-hold. The procedure for this method is as follows:

a) Set span to at > 1.5 times the OBW.

b) Set sweep trigger to "free run."

c) Set RBW = 1% to 5% of the OBW, but do not exceed 1 MHz.

d) Set VBW ≥ 1 / *T*, where *T* is defined in 11.6.

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time = No faster than coupled (auto) time.

g) Detector = peak.

h) Video filtering shall be applied to a voltage squared or power signal (i.e., rms mode), if possible. Otherwise, it shall be set to operate on a linear voltage signal (which can require use of linear display mode). Log mode shall not be used.

    1) The preferred voltage squared (i.e., power or rms) mode is selected on some instruments by setting the "average-VBW type" to power or rms.

    2) If rms mode is not available, then linear voltage mode is selected on some instruments by setting the display mode to linear. Other instruments have a setting for "Average-VBW Type" that can be set to "voltage" regardless of the display mode.

i) Trace mode = max-hold.

j) Allow max-hold to run for at least 60 s or longer as needed to allow the trace to stabilize.

k) Compute power by integrating the spectrum across the OBW of the signal using the instrument's band-power measurement function with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, sum the spectrum levels (in power units) at intervals equal to the RBW extending across the entire OBW.

l) If linear mode was used in step h), then add 1 dB to the final result to compensate for the difference between linear averaging and power averaging.

11.9.2.3 Measurement using a power meter (PM)

11.9.2.3.1 Method AVGPM

Method AVGPM is a measurement using an RF average power meter, as follows:

a) As an alternative to spectrum analyzer or EMI receiver measurements, measurements may be performed using a wideband RF power meter with a thermocouple detector or equivalent (see Figure 24) if all of the conditions listed below are satisfied:

    1) The EUT is configured to transmit continuously, or to transmit with a constant duty cycle.

    2) At all times when the EUT is transmitting, it shall be transmitting at its maximum power control level.

    3) The integration period of the power meter exceeds the repetition period of the transmitted signal by at least a factor of five.

b) If the transmitter does not transmit continuously, measure the duty cycle, *D*, of the transmitter output signal as described in 11.6.

c) Measure the average power of the transmitter. This measurement is an average over both the ON and OFF periods of the transmitter.

d) Correct the measurement in dBm by adding [10 log (1 / *D*)], where *D* is the duty cycle.

11.9.2.3.2 Method AVGPM-G

Method AVGPM-G is a measurement using a gated RF average power meter.

Alternatively, measurements may be performed using a wideband gated RF power meter provided that the gate parameters are adjusted such that the power is measured only when the EUT is transmitting at its maximum power control level. Because the measurement is made only during the ON time of the transmitter, no duty cycle correction factor is required.

Gate triggering can be implemented in such a way that the sweep of the instrument is only active during the burst period of the device. Any Gate triggering shall be performed on the full power portion of the pulses and care must be taken to ensure that static portions of the pulse are not included in the measurement (ensuring that the trace is averaged over the entire symbol range). All Gate triggered measurements shall be accompanied by a Gate setup plot in the test report.

11.9.3 Figures for the test methods of 11.9

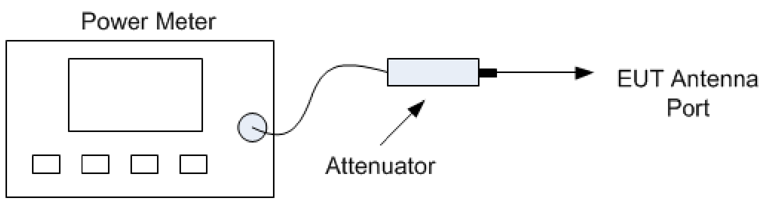


Figure 24—Example of a power meter conducted test setup

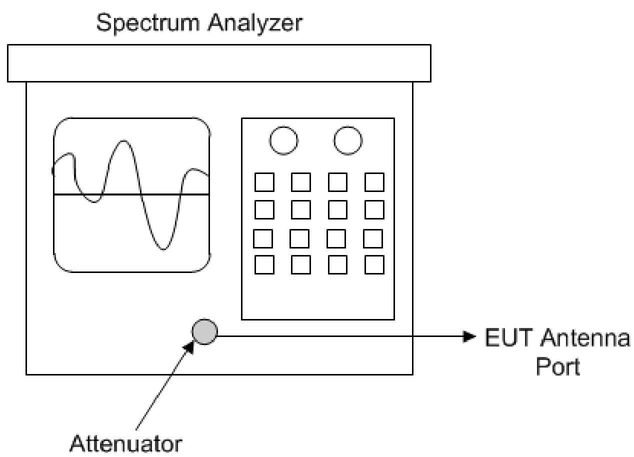


Figure 25—Example of a spectrum analyzer or EMI receiver output power test configuration

11.10 Maximum power spectral density level in the fundamental emission

11.10.1 Selection of applicable test method

Some regulatory requirements specify a conducted PSD limit within the DTS bandwidth during any time interval of continuous transmission.[80] Such specifications require that the same method as used to determine the conducted output power shall be used to determine the power spectral density. If maximum peak conducted output power was measured, then the peak PSD procedure 11.10.2 (method PKPSD) shall be used. If maximum conducted output power was measured, then one of the average PSD procedures shall be used, as applicable based on the following criteria (the peak PSD procedure is also an acceptable option):

[80] See, for example, 47 CFR 15.247(e).

a) **Method AVGPSD-1 or method AVGPSD-1A (alternative)** shall be applied if either of the following conditions can be satisfied:

   1) The EUT transmits continuously (or with a D ≥ 98%); or

   2) Triggering methods when the device is not continuously transmitting (D≤ 98%)

      i) Sweep triggering can be implemented in such a way that the device transmits at the maximum power control level throughout the duration of each of the instrument sweeps to be averaged. This condition can generally be achieved by triggering the instrument's sweep if the duration of the sweep is equal to or shorter than the duration T of each transmission from the EUT, and if those transmissions exhibit full power throughout these durations; or

      ii) Gate triggering can be implemented to allow that the sweep instrument to only be active during the burst period of the device. Any Gate triggering shall be performed on the full power portion of the pulses and care must be taken to ensure that static portions of the pulse are not included in the measurement (ensuring that the trace is averaged over the entire symbol range). All Gate triggered measurements shall be accompanied by a Gate setup plot in the test report.

b) **Method AVGPSD-2 or method AVGPSD-2A (alternative)** shall be applied if the conditions of the preceding item a) cannot be achieved, and the transmissions exhibit a constant duty cycle during the measurement duration. Duty cycle will be considered to be constant if variations are less than ±2%.

c) **Method AVGPSD-3 or method AVGPSD-3A (alternative)** shall be applied if the conditions of the preceding items a) and b) cannot be achieved.

If the average PSD is measured with a power averaging (rms) detector or a sample detector, then the instrument shall be capable of using several measurement points in each sweep that is greater than or equal to twice the span / RBW, to set a bin-to-bin spacing of ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.

Where the measured power (peak conducted output power or maximum conducted output power) complies with the regulatory requirement for the PSD, then measurement of PSD is not required, provided that the PSD level is reported as being equal to the measured output power.

11.10.2 Method PKPSD (peak PSD)

The following procedure shall be used if maximum peak conducted output power was used to determine compliance, and it is optional if the maximum conducted (average) output power was used to determine compliance:

a) Set analyzer center frequency to DTS channel center frequency.

b) Set the span >1.5 times the DTS bandwidth.

c) Set the RBW to 3 kHz ≤ RBW ≤ 100 kHz.

d) Set the VBW ≥ [3 × RBW].

e) Detector = peak.

f) Sweep time = No faster than coupled (auto) time.

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 RBW.

j) If measured value exceeds requirement, then reduce RBW (but no less than 3 kHz) and repeat.

11.10.3 Method AVGPSD-1

Method AVGPSD-1 uses trace averaging with EUT transmitting at full power throughout each sweep.

The following procedure may be used when the maximum (average) conducted output power was used to determine compliance to the fundamental output power limit. This is the baseline method for determining the maximum (average) conducted PSD level. If the instrument has a power averaging (rms) detector, then it must be used; otherwise, use the sample detector. The EUT must be configured to transmit continuously ($D \geq 98\%$), or else sweep triggering/signal gating must be implemented to help ensure that measurements are made only when the EUT is transmitting at its maximum power control level (no transmitter OFF time to be considered):

a) Set instrument center frequency to DTS channel center frequency.
b) Set span to > 1.5 times the OBW.
c) Set RBW to: 3 kHz ≤ RBW ≤ 100 kHz.
d) Set VBW ≥ [3 × RBW].
e) Detector = power averaging (rms) or sample detector (when rms not available).
f) Ensure that the number of measurement points in the sweep ≥ [2 × span / RBW].
g) Sweep time = auto couple.
h) Employ trace averaging (rms) mode over a minimum of 100 traces.
i) Use the peak marker function to determine the maximum amplitude level.
j) If the measured value exceeds requirement, then reduce RBW (but no less than 3 kHz) and repeat (note that this might require zooming in on the emission of interest and reducing the span to meet the minimum measurement point requirement as the RBW is reduced).

11.10.4 Method AVGPSD-1A (alternative)

Method AVGPSD-1A uses rms detection with slow sweep speed and EUT transmitting continuously at full power.

The following procedure may be used as an alternative to 11.10.3 when the maximum (average) conducted output power was used to determine compliance to the fundamental output power limit and the EUT can be configured to transmit continuously ($D \geq 98\%$), or when sweep triggering and/or signal gating can be implemented to help ensure that measurements are made only when the EUT is transmitting at its maximum power control level (no transmitter OFF time to be considered):

a) Set instrument center frequency to DTS channel center frequency.
b) Set the instrument span to > 1.5 times the OBW.
c) Set the RBW to: 3 kHz ≤ RBW ≤ 100 kHz.
d) Set the VBW ≥ [3 × RBW].
e) Detector = power average (rms).
f) Ensure that the number of measurement points in the sweep ≥ [2 × span / RBW].
g) Manually set the sweep time to: ≥ [10 × (number of measurement points in sweep) × (transmission symbol period)], but no less than the auto sweep time.

NOTE—The transmission symbol period (in seconds) is the reciprocal of the symbol rate (in baud or symbols per second). Note that each symbol can represent one or several data bits, and thus, the symbol rate should not be confused with the gross bit rate (expressed in bits/second). In no case should the sweep time be set less than the auto sweep time.

h) Perform the measurement over a single sweep.

i) Use the peak marker function to determine the maximum amplitude level.

j) If measured value exceeds requirement, then reduce RBW (but no less than 3 kHz) and repeat (note that this might require zooming in on the emission of interest and reducing the span to meet the minimum measurement point requirement as the RBW is reduced).

11.10.5 Method AVGPSD-2

Method AVGPSD-2 uses trace averaging across ON and OFF times of the EUT transmissions, followed by duty cycle correction.

The following procedure is applicable when the EUT cannot be configured to transmit continuously (i.e.,

D < 98%), when sweep triggering/signal gating cannot be used to measure only when the EUT is transmitting at its maximum power control level, and when the transmission duty cycle is constant (i.e., duty cycle variations are less than ±2%):

a) Measure the duty cycle (D) of the transmitter output signal as described in 11.6.

b) Set instrument center frequency to DTS channel center frequency.

c) Set span to > 1.5 times the OBW.

d) Set RBW to: 3 kHz ≤ RBW ≤ 100 kHz.

e) Set VBW ≥ [3 × RBW].

f) Detector = power averaging (rms) or sample detector (when rms not available).

g) Ensure that the number of measurement points in the sweep ≥ [2 × span / RBW].

h) Sweep time = auto couple.

i) Do not use sweep triggering; allow sweep to "free run."

j) Employ trace averaging (rms) mode over a minimum of 100 traces.

k) Use the peak marker function to determine the maximum amplitude level.

l) Add [10 log (1 / D)], where D is the duty cycle measured in step a), to the measured PSD to compute the average PSD during the actual transmission time.

m) If measured value exceeds requirement specified by regulatory agency, then reduce RBW (but no less than 3 kHz) and repeat (note that this might require zooming in on the emission of interest and reducing the span to meet the minimum measurement point requirement as the RBW is reduced).

11.10.6 Method AVGPSD-2A (alternative)

Method AVGPSD-2A uses rms detection with slow sweep speed with spectrum bin averaging across ON and OFF times of the EUT transmissions, followed by duty cycle correction.

The following procedure is applicable as an alternative to 11.10.5 when the EUT cannot be configured to transmit continuously (i.e., D < 98%), when sweep triggering/signal gating cannot be used to measure only when the EUT is transmitting at its maximum power control level, and when the transmission duty cycle is constant (i.e., duty cycle variations are less than ±2%):

a) Measure the duty cycle (D) of the transmitter output signal as described in 11.6.

b) Set instrument center frequency to DTS channel center frequency.

c) Set the span to > 1.5 times the OBW.

d) Set the RBW to: 3 kHz ≤ RBW ≤ 100 kHz.

e) Set the VBW ≥ 3 × RBW.

f) Detector = power average (rms).

g) Ensure that the number of measurement points in the sweep ≥ [2 × span / RBW].

h) Manually set the sweep time to: ≥ [10 × (number of measurement points in sweep) × (total ON/OFF period of the transmitted signal)].

i) Do not use sweep triggering. Allow sweep to “free run.”

j) Perform the measurement over a single sweep.

k) Use the peak marker function to determine the maximum amplitude level.

l) Add [10 log (1 / D)], where D is the duty cycle measured in step a), to the measured PSD to compute the average PSD during the actual transmission time.

m) If the measured value exceeds requirement, then reduce RBW (but no less than 3 kHz) and repeat (note that this might require zooming in on the emission of interest and reducing the span to meet the minimum measurement point requirement as the RBW is reduced).

11.10.7 Method AVGPSD-3

Method AVGPSD-3 uses rms detection across ON and OFF times of the EUT with max-hold.

The following procedure is applicable when the EUT cannot be configured to transmit continuously (i.e.,

D < 98%), when sweep triggering/signal gating cannot be used to measure only when the EUT is transmitting at its maximum power control level, and when the transmission duty cycle is not constant (i.e., duty cycle variations exceed ±2%):

a) Set the instrument span to > 1.5 times the OBW.

b) Set sweep trigger to “free run.”

c) Set RBW to: 3 kHz ≤ RBW ≤ 100 kHz.

d) Set VBW ≥ [3 × RBW].

e) Number of points in sweep ≥ [2 × span / RBW]. (This ensures that bin-to-bin spacing is

f) ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

g) Sweep time ≤ [(number of points in sweep) × T], where T is defined in 11.6.

NOTE—If this results in a sweep time less than the auto sweep time of the instrument, then this method shall not be used (use AVGPSD-2A instead). The purpose of this step is to ensure that averaging time in each bin is less than or equal to the minimum time of a transmission.

h) Detector = Power averaging (rms).

i) Trace mode = max-hold.

j) Allow max-hold to run for at least 60 s or longer as needed to allow the trace to stabilize.

k) Use the peak marker function to determine the maximum PSD level.

l) If the measured value exceeds requirement, then reduce RBW (but no less than 3 kHz) and repeat (note that this might require zooming in on the emission of interest and reducing the span to meet the minimum measurement point requirement as the RBW is reduced).

11.10.8 Method AVGPSD-3A (alternative)

Method AVGPSD-3A uses reduced VBW averaging across ON and OFF times of the EUT with max-hold.

The following procedure is applicable as an alternative to 11.10.7 when the EUT cannot be configured to transmit continuously (i.e., D < 98%), when sweep triggering/signal gating cannot be used to measure only when the EUT is transmitting at its maximum power control level, and when the transmission duty cycle is not constant (i.e., duty cycle variations exceed ±2%):

a) Set the instrument span to > 1.5 times the OBW.

b) Set sweep trigger to "free run."

c) Set RBW to: 3 kHz ≤ RBW ≤ 100 kHz.

d) Set VBW ≥ 1/ T, where T is defined in 11.6.

e) Number of points in sweep ≥ [2 × span / RBW]. (This ensures that bin-to-bin spacing is ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time = No faster than coupled (auto) time.

g) Detector = peak.

h) Video filtering shall be applied to a voltage squared or power signal (i.e., rms mode), if possible. Otherwise, it shall be set to operate on a linear voltage signal (which can require use of linear display mode). Log mode shall not be used:

   1) The preferred voltage squared (i.e., power or rms) mode is selected on some instruments by setting the "average-VBW type" to power or rms.

   2) If rms mode is not available, then linear voltage mode is selected on some analyzers by setting the display mode to linear. Other instruments have a setting for "average-VBW type" that can be set to "voltage" regardless of the display mode.

i) Trace mode = max-hold.

j) Allow max-hold to run for at least 60 s or longer as needed to allow the trace to stabilize.

k) Use the peak marker function to determine the maximum PSD level.

l) If linear mode was used in step h), then add 1 dB to the final result to compensate for the difference between linear averaging and power averaging.

m) If the measured value exceeds requirement, then reduce RBW (but no less than 3 kHz) and repeat (note that this might require zooming in on the emission of interest and reducing the span to meet the minimum measurement point requirement as the RBW is reduced).

11.11 Emissions in non-restricted frequency bands

11.11.1 General

Typical regulatory requirements specify that in any 100 kHz bandwidth outside of the authorized frequency band, the power shall be attenuated by an amount specified by the regulator.[81]

NOTE—The regulatory requirements may change based on the method used for the measurement of output power.

The following procedures shall be used to determine compliance to these requirements. Note that these procedures can be used in either an antenna-port conducted or a radiated test setup. Radiated tests must

[81] Based on 47 CFR 15.247(d).

conform to the test site requirements and use the maximization procedures defined herein (see 6.3, 6.4, 6.5 and 6.6 as applicable).

11.11.2 Reference level measurement

Establish a reference level by using the following procedure:

a) Set instrument center frequency to DTS channel center frequency.

b) Set the span to ≥ 1.5 times the DTS bandwidth.

c) Set the RBW = 100 kHz.

d) Set the VBW ≥ [3 × RBW].

e) Detector = peak.

f) Sweep time = No faster than coupled (auto) time.

g) Trace mode = max-hold.

h) Allow trace to fully stabilize.

i) Use the peak marker function to determine the maximum PSD level.

Note that the channel found to contain the maximum PSD level can be used to establish the reference level

11.11.3 Emission level measurement

Establish an emission level by using the following procedure:

a) Set the center frequency and span to encompass frequency range to be measured. Note that the frequency range might need to be divided into multiple frequency ranges to retain frequency resolution.

NOTE—the number of points can also be increased for large spans to retain frequency resolution

b) Set the RBW = 100 kHz.

c) Set the VBW ≥ [3 × RBW].

d) Detector = peak.

e) Sweep time = No faster than coupled (auto) time.

f) Trace mode = max-hold.

g) Allow trace to fully stabilize.

h) Use the peak marker function to determine the maximum amplitude level.

Ensure that the amplitude of all unwanted emissions outside of the authorized frequency band (excluding restricted frequency bands) is attenuated by at least the minimum requirements specified in 11.11. Report the three highest emissions relative to the limit.

11.12 Emissions in restricted frequency bands

Typical regulatory requirements for DTS specify that emissions that fall into restricted frequency bands shall comply with the general radiated emission limits.[82]

[82] See, for example, 15 CFR 15.247(d).

11.12.1 Radiated emission measurements

Because the typical emission requirements are specified in terms of radiated field strength levels, measurements performed to determine compliance have traditionally relied on a radiated test configuration.[83] Radiated measurements remain the principal method for determining compliance to the specified requirements; however antenna-port conducted measurements are also now acceptable to determine compliance (see 11.12.2 for details). When radiated measurements are utilized, test site requirements and procedures for maximizing and measuring radiated emissions that are described in 6.3, 6.5, and 6.6 shall be followed.

In cases where antenna arrays or MIMO systems are under test, refer to Clause 13 for testing these systems.

11.12.2 Antenna-port measurements

11.12.2.1 General

Antenna-port conducted measurements may also be used as an alternative to radiated measurements for determining compliance in the restricted frequency bands requirements. If conducted measurements are performed, then proper impedance matching must be ensured and an additional radiated test for cabinet/case emissions is required.

The measurement procedures described herein are based on the use of an antenna-port conducted test configuration. However radiated tests are acceptable for determining compliance with the various emission requirements. The guidance provided herein is applicable to either antenna-port conducted or radiated compliance measurements.

11.12.2.2 General procedure for conducted measurements in restricted-bands

The general procedure for conducted measurements in restricted-bands is as follows:

a) Measure the conducted output power (in dBm) using the detector specified by the appropriate regulatory agency (see 11.12.2.3 through 11.12.2.5 for guidance regarding measurement procedures for determining quasi-peak, peak, and average conducted output power, respectively).

b) Add the maximum transmit antenna gain (in dBi) to the measured output power level to determine the EIRP (see 11.12.2.6 for guidance on determining the applicable antenna gain).

c) Add the appropriate maximum ground reflection factor to the EIRP (6 dB for frequencies ≤ 30 MHz; 4.7 dB for frequencies between 30 MHz and 1000 MHz, inclusive; and 0 dB for frequencies > 1000 MHz).

d) For MIMO devices, measure the power of each chain and sum the EIRP of all chains in linear terms (i.e., watts and mW).

e) Convert the resultant EIRP to an equivalent electric field strength using the following relationship:

$$E = EIRP - 20 \log d + 104.8$$

where

E	is the electric field strength in dBμV/m
EIRP	is the equivalent isotropically radiated power in dBm
d	is the specified measurement distance in m

f) Compare the resultant electric field strength level with the applicable regulatory limit.

g) Perform the radiated spurious emission test in accordance with 11.12.1.

[83] See, for example, 47 CFR 15.209(a).

11.12.2.3 Quasi-peak measurement procedure

The specifications for measurements using the CISPR quasi-peak detector can be found in ANSI C63.2.

As an alternative to CISPR quasi-peak measurement, compliance can be determined for the applicable emission requirements using a peak detector.

11.12.2.4 Peak measurement procedure

Peak emission levels are measured by setting the instrument as follows:

a) RBW = as specified in Table 16
b) VBW ≥ [3 × RBW].
c) Detector = peak.
d) Sweep time = No faster than coupled (auto) time.
e) Trace mode = max-hold.
f) Allow sweeps to continue until the trace stabilizes. (Note that the required measurement time and number of sweep points may be lengthened for low duty cycle applications.)

Table 16—RBW as a function of frequency

Frequency	RBW
9 kHz to 150 kHz	200 Hz to 300 Hz
0.15 MHz to 30 MHz	9 kHz to 10 kHz
30 MHz to 1000 MHz	100 kHz to 120 kHz
>1000 MHz	1 MHz

If the peak detected amplitude can be shown to comply with the average limit, then it is not necessary to perform a separate average measurement.

11.12.2.5 Average measurement procedures

Three conditional procedures are provided in 11.12.2.5.1 through 11.12.2.5.2 for performing average power or field strength measurements. Use the appropriate procedure for which the EUT qualifies.

The average value for emissions is based on emission levels occurring during transmission and shall not be based on an average across ON and OFF times of the transmitter except where the duty cycle is protocol limited.

11.12.2.5.1 Trace average with continuous EUT transmission at full power

If the EUT can be configured or modified to transmit continuously (D ≥ 98%), then the average emission levels shall be measured using the following method (with EUT transmitting continuously):

a) RBW = 1 MHz (unless otherwise specified).
b) VBW ≥ [3 × RBW].
c) Detector = Power averaging (rms), if [span / (# of points in sweep)] ≤ (RBW / 2). Satisfying this condition might require increasing the number of points in the sweep or reducing the span. If this condition cannot be satisfied, then the detector mode shall be set to peak.
d) Averaging type = power (i.e., rms):

1) As an alternative, the detector and averaging type may be set for linear voltage averaging.

2) Some instruments require linear display mode to use linear voltage averaging. Log or dB averaging shall not be used.

e) Sweep time = auto.

f) Perform a trace average of at least 100 traces.

11.12.2.5.2 Trace averaging across ON and OFF times of the EUT transmissions followed by duty cycle correction

11.12.2.5.2.1 Average detector

If continuous transmission of the EUT ($D \geq 98\%$) cannot be achieved and the duty cycle is constant (duty cycle variations are less than ±2%), then the following procedure shall be used:

a) The EUT shall be configured to operate at the maximum achievable duty cycle.

b) Measure the duty cycle D of the transmitter output signal as described in 11.6.

c) RBW = 1 MHz (unless otherwise specified).

d) VBW ≥ [3 × RBW].

e) Detector = Power averaging (rms), if span / (# of points in sweep) ≤ (RBW / 2). Satisfying this condition might require increasing the number of points in the sweep or reducing the span. If this condition cannot be satisfied, then the detector mode shall be set to peak.

f) Averaging type = power (i.e., rms):

1) As an alternative, the detector and averaging type may be set for linear voltage averaging.

2) Some instruments require linear display mode to use linear voltage averaging. Log or dB averaging shall not be used.

g) Sweep time = auto.

h) Perform a trace average of at least 100 traces.

i) A correction factor shall be added to the measurement results prior to comparing with the emission limit to compute the emission level that would have been measured had the test been performed at 100% duty cycle. The correction factor is computed as follows:

1) If power averaging (rms) mode was used in step f), then the applicable correction factor is [10 log (1 / D)], where D is the duty cycle.

2) If linear voltage averaging mode was used in step f), then the applicable correction factor is [20 log (1 / D)], where D is the duty cycle.

3) If a specific emission is demonstrated to be continuous ($D \geq 98\%$) rather than turning ON and OFF with the transmit cycle, then no duty cycle correction is required for that emission.

Determining compliance is based on emission levels occurring during transmission; it is not based on an average across ON and OFF times of the transmitter except where the duty cycle is protocol limited. Reduction of the measured emission amplitude levels to account for operational duty cycle is only permitted when the transmitter has a protocol-limited duty-cycle and the emission is temporally related to the transmitter duty cycle (i.e., has the same duty cycle as the transmitted signal). In this case the measured value does not need the correction detailed in (i) above provided that the device is operating at or above the maximum operational duty cycle.

11.12.2.5.2.2 Peak detector

When the radiated emission limits are expressed in terms of the average value of the emission, and pulsed operation is employed, the measurement field strength may be determined by the duty cycle correction factor subtracted from the peak pulse amplitude (in dB) to find the average emission level. This correction may be applied to all emissions that demonstrate the same pulse timing characteristics as the fundamental emission (e.g., the fundamental and harmonic emissions).

a) The EUT shall be configured to operate at the maximum achievable duty cycle.
b) Measure the duty cycle D of the transmitter output signal as described in 11.6.
c) RBW = 1 MHz (unless otherwise specified).
d) VBW ≥ [3 × RBW].
e) Detector = peak max-hold.
f) Sweep time = No faster than coupled (auto) time.
g) A correction factor shall be subtracted from the measurement results prior to comparing with the emission limit to compute the average emission level. The correction factor is computed as follows:
    1) If linear voltage averaging mode was used in step f), then the applicable correction factor is [20 log (1 / D)], where D is the duty cycle.
    2) If a specific emission does not demonstrate the same ON and OFF characteristics as the fundamental, then no duty cycle correction is permitted for that emission.

11.12.2.5.2.3 Reduced VBW averaging across ON and OFF times of the EUT transmission with max-hold

If continuous transmission of the EUT ($D \geq 98\%$) cannot be achieved and the duty cycle is not constant (duty cycle variations exceed ±2%), then the following procedure shall be used:

a) RBW = 1 MHz.
b) VBW ≥ 1 / *T,* where *T* is defined in 11.6. When the device operates with a protocol-limited duty factor the average value may be measured using VBW=1Hz provided that the device is being exercised at or above the maximum operational duty cycle during the measurement.
c) Video bandwidth mode or display mode:
    1) The instrument shall be set so that video filtering is applied in the power domain. Typically, this requires setting the detector mode to Power averaging (rms) and setting the average-VBW type to power (rms).
    2) As an alternative, the instrument may be set to linear detector mode. Ensure that video filtering is applied in linear voltage domain (rather than in a log or dB domain). Some instruments require linear display mode to accomplish this. Others have a setting for average-VBW type, which can be set to "voltage" regardless of the display mode.
d) Detector = peak.
e) Sweep time = No faster than coupled (auto) time.
f) Trace mode = max-hold.
g) Allow max-hold to run for at least [50 × (1 / *D*)] traces.

11.12.2.6 Determining the applicable transmit antenna gain

A conducted power measurement will determine the maximum output power associated with a restricted-band emission; however, to determine the associated EIRP, the gain of the transmitting antenna (in dBi) must be added to the measured output power (in dBm).

Because the out-of-band characteristics of the EUT transmit antenna will often be unknown, the use of a conservative antenna gain value is necessary. Thus, when determining the EIRP based on the measured conducted power, the upper bound on antenna gain for a device with a single RF output shall be selected as the maximum in-band gain of the antenna across all operating bands, or 2 dBi, whichever is greater. However, for devices that operate in multiple frequency bands while using the same transmit antenna, the highest gain of the antenna within the operating band nearest in frequency to the restricted-band emission being measured may be used in lieu of the overall highest gain when the emission is at a frequency that is within 20% of the nearest band-edge frequency, but in no case shall a value less than 2 dBi be used.

See Clause 13 and Clause 14, respectively, for guidance on calculating the additional array gain term when determining the effective antenna gain for an EUT with multiple outputs occupying the same or overlapping frequency ranges in the same band (e.g., MIMO or beamforming antennas).

11.12.2.7 Radiated spurious emission test

An additional consideration when performing conducted measurements of restricted-band emissions is that unwanted emissions radiating from the EUT cabinet, control circuits, power leads, or intermediate circuit elements will likely go undetected in a conducted measurement configuration. To address this concern, a radiated test shall be performed to help ensure that emissions emanating from the EUT cabinet (rather than from the antenna port) also comply with the applicable limits.

For these cabinet radiated spurious emission measurements, the EUT transmit antenna may be replaced with a termination matching the nominal impedance of the antenna. Procedures for performing radiated measurements are specified in 6.3, 6.5, and 6.6. All detected emissions shall comply with the applicable requirements.

11.12.3 Measurements when within 2 MHz of the band-edge

Emissions within a restricted-band and within 2 MHz of an authorized band-edge may be measured using either the marker-delta method, described in 11.12.3.1, or the integration method, which is described in 11.12.3.2, provided that the DTS bandwidth (or EBW) edge falls within 2 MHz of the band-edge. Otherwise, all unwanted emissions measurements shall be performed using the standard methods.

11.12.3.1 Marker-delta method

The marker-delta method, as described in 6.10.6, can be used to perform measurements of the unwanted emissions level at the band-edges.

11.12.3.2 Integration method

11.12.3.2.1 General

The following procedures may be used to determine the average field strength or power of an unwanted emission that is within 2 MHz of the authorized band-edge. Use the procedure described in 11.12.3.2.2 when using an average detector and the EUT can be configured to transmit continuously (i.e., $D \geq 98\%$). Use the procedure described in 11.12.3.2.3 when using an average detector and the EUT cannot be configured to transmit continuously but the duty cycle is constant (i.e., duty cycle variations are less than ±2%). Use the procedure described in 11.12.3.2.4 when using an average detector for those cases where the EUT cannot be configured to transmit continuously and the duty cycle is not constant (duty cycle variations equal or exceed 2%).

11.12.3.2.2 Trace averaging with continuous EUT transmission at full power

If the EUT can be configured or modified to transmit continuously ($D \geq 98\%$), then the average emission levels within 2 MHz of the authorized band-edge may be measured using the following method (with EUT transmitting continuously):

a) Set instrument center frequency to the frequency of the emission to be measured (must be within 2 MHz of the authorized band-edge).

b) Set span to 2 MHz.

c) RBW = 100 kHz.

d) VBW ≥ [3 × RBW].

e) Detector = Power averaging (rms), if [span / (# of points in sweep)] ≤ (RBW / 2).

f) Averaging type = power (i.e., rms):

   1) As an alternative, the detector and averaging type may be set for linear voltage averaging.

   2) Some instruments require linear display mode to use linear voltage averaging. Log or dB averaging shall not be used.

g) Sweep time = auto.

h) Perform a trace average of at least 100 traces.

i) Compute the power by integrating the spectrum over 1 MHz using the analyzer's band-power measurement function with band limits set equal to the emission frequency (f_{emission}) ± 0.5 MHz. If the instrument does not have a band-power function, then sum the amplitude levels (in power units) at 100 kHz intervals extending across the 1 MHz spectrum defined by f_{emission} ± 0.5 MHz.

11.12.3.2.3 Trace averaging across ON and OFF times of the EUT transmissions following duty cycle correction

If continuous transmission of the EUT ($D \geq 98\%$) cannot be achieved and the duty cycle is constant (duty cycle variations are less ±2%), then the following procedure may be used to measure the average power of unwanted emissions within 2 MHz of the authorized band-edge:

a) The EUT shall be configured to operate at the maximum achievable duty cycle.

b) Measure the duty cycle D of the transmitter output signal as described in 11.6.

c) Set instrument center frequency to the frequency of the emission to be measured.

d) Set span to 2 MHz.

e) RBW = 100 kHz.

f) VBW ≥ 3 × RBW.

g) Detector = Power averaging (rms), if [span / (# of points in sweep)] ≤ (RBW / 2). Satisfying this condition might require increasing the number of points in the sweep or reducing the span. If this condition cannot be satisfied, then the detector mode shall be set to peak.

h) Averaging type = power (i.e., rms):

   1) As an alternative, the detector and averaging type may be set for linear voltage averaging.

   2) Some instruments require linear display mode to use linear voltage averaging. Log or dB averaging shall not be used.

i) Sweep time = auto.

j) Perform a trace average of at least 100 traces.

k) Compute the power by integrating the spectrum over 1 MHz using the instrument's band-power measurement function with band limits set equal to the emission frequency ($f_{emission}$) ± 0.5 MHz. If the spectrum analyzer does not have a band-power function, then sum the amplitude levels (in power units) at 100 kHz intervals extending across the 1 MHz spectrum defined by $f_{emission}$ ± 0.5 MHz.

l) A correction factor shall be added to the measurement results prior to comparing with the emission limit to compute the emission level that would have been measured had the test been performed at 100% duty cycle. The correction factor is computed as follows:

   1) If power averaging (rms) mode was used in step f), then the applicable correction factor is [10 log (1 / *D*)], where *D* is the duty cycle.

   2) If linear voltage averaging mode was used in step f), then the applicable correction factor is [20 log (1 / *D*)], where *D* is the duty cycle.

   3) If a specific emission is demonstrated to be continuous ($D \geq 98\%$) rather than turning ON and OFF with the transmit cycle, then no duty cycle correction is required for that emission.

Reduction of the measured emission amplitude levels to account for operational duty cycle is not permitted. Determining compliance is based on emission levels occurring during transmission—it is not based on an average across ON and OFF times of the transmitter.

11.12.3.2.4 Reduced VBW averaging across ON and OFF times of the EUT transmissions with max-hold

If continuous transmission of the EUT (D ≥ 98%) cannot be achieved then the following procedure may be used to measure unwanted emissions within 2 MHz of the authorized band-edge:

a) Set analyzer center frequency to the frequency of the emission to be measured.

b) Set span to 2 MHz.

c) RBW = 100 kHz.

d) VBW ≥ 1 / *T*.

e) Video bandwidth mode or display mode:

   1) The analyzer shall be set so that video filtering is applied in the power domain. Typically, this requires setting the detector mode to Power averaging (rms) and setting the average-VBW type to power (rms).

   2) As an alternative, the analyzer may be set to linear detector mode. Ensure that video filtering is applied in linear voltage domain (rather than in a log or dB domain). Some analyzers require linear display mode to accomplish this. Others have a setting for average-VBW type, which can be set to "voltage" regardless of the display mode.

f) Detector = peak.

g) Sweep time = No faster than coupled (auto) time.

h) Trace mode = max-hold.

i) Allow max-hold to run for at least [50 × (1 / *D*)] traces.

j) Compute the power by integrating the spectrum over 1 MHz using the analyzer's band-power measurement function with band limits set equal to the emission frequency ($f_{emission}$) ± 0.5 MHz. If the spectrum analyzer does not have a band-power function, then sum the amplitude levels (in power units) at 100 kHz intervals extending across the 1 MHz spectrum defined by $f_{emission}$ ± 0.5 MHz.

12. Testing of Unlicensed National Information Infrastructure (U-NII) devices

12.1 General considerations

12.1.1 General

This clause includes acceptable procedures for measuring maximum conducted transmit power, peak power spectral density, emission bandwidth, peak excursion, and unwanted emissions both in and out of restricted-bands. Procedures for evaluating DFS functionality are not covered in this standard. For EUTs that transmit on multiple outputs simultaneously (e.g., beamforming or MIMO devices), refer to Clause 13 and Clause 14 for additional guidance.

All operating modes and data rates of the EUT shall satisfy all requirements. Be aware that the operating mode and data rate that are the worst-case for one test might not be the worst-case for another test, and be aware that data rate settings can have a significant effect on test results.

Note that average emission measurements in restricted-bands are based on continuous transmission by the U-NII device during the measurement interval. There is no downward correction of results based on the actual operational duty cycle of the device.

12.1.2 Antenna-port conducted versus radiated testing

All in-band measurements in 12.2 through 12.6 are based on antenna-port conducted measurements. However, if antenna-port conducted tests cannot be performed on an EUT, then radiated tests are acceptable for determining compliance with the various conducted emission requirements. The guidance provided herein is applicable to either antenna-port conducted or radiated compliance measurements.

If a radiated test configuration is used, then the measured power or field strength levels shall be converted to equivalent conducted power levels for comparison with the applicable output power limit. This may be accomplished by first measuring the radiated field strength or power levels using an applicable methodology from 12.3 for maximum conducted power and from 12.5 for power spectral density. The radiated field strength or power level is converted to EIRP (see Annex G for guidance). The equivalent conducted output power or power spectral density is then determined by subtracting the EUT transmit antenna gain (guidance applicable to devices using MIMO or beamforming technologies is provided in Clause 13 or Clause 14, respectively) from the EIRP (assuming logarithmic representation). All calculations and parameter assumptions shall be provided in the test report.

12.1.3 Reference level/attenuation

Refer to 4.1.6 for guidance.

12.2 Duty cycle (*D*), transmission duration (*T*), and maximum power control level

The following procedure shall be used for determining duty cycle, transmission duration, and maximum power control level for U-NII devices:

a) All measurements are to be performed with the EUT transmitting at 100% duty cycle at its maximum power control level; however, if 100% duty cycle cannot be achieved, measurements of duty cycle, *D*, and maximum-power transmission duration, *T*, are required for each tested mode of operation:

1) T refers to the minimum transmission duration over which the transmitter is ON and is transmitting at its maximum power control level for the tested mode of operation.

2) Duty cycle (D), as used in this clause, refers to the fraction of time over which the transmitter is ON and is transmitting at its maximum power control level.

3) The term "maximum power control level" is intended to distinguish between operating power levels of the EUT and differences in power levels of individual symbols that occur with some modulation types, such as quadrature amplitude modulation (QAM). During testing, the EUT is not required to transmit continuously with its highest possible symbol power level. Rather, it shall transmit all of the symbols, and shall do so at the highest power control level (i.e., highest operating power level) of the EUT.

b) Measurements of duty cycle and transmission duration shall be performed using one of the following techniques:

1) A diode detector and an oscilloscope that together have sufficiently short response time to permit accurate measurements of the ON and OFF times of the transmitted signal.

2) The zero-span mode on a spectrum analyzer or EMI receiver, 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:

i) Set the center frequency of the instrument to the center frequency of the transmission.

ii) Set RBW ≥ EBW if possible; otherwise, set RBW to the largest available value.

iii) Set VBW ≥ RBW.

iv) Set detector = peak.

v) The zero-span measurement method shall not be used unless both RBW and VBW are $> 50/T$, where T is defined in item a1) of 12.2, and the number of sweep points across duration T exceeds 100.

For example, if VBW and/or RBW are limited to 3 MHz, then the zero-span method of measuring duty cycle shall not be used if $T \leq 16.7$ µs.

12.3 Addressing wide band signal measurement issues

12.3.1 Signals where transmit power is equally distributed between the bands

For signals where the transmit power is equally distributed between the two bands, the lower power must be maintained in both bands and the lower PSD must be used. As such the measurement would be uniform across both bands and one would not need to do a separate power measurement in each bands the lower limits would apply to both bands.

Referencing signals that cross the boundary between two adjacent U-NII bands, the described procedure to measure EBW, power, and PSD in each U-NII band. For the case of a 160MHz signal equally distributed between U-NII-1 and U-NII-2a, the following parameters can be used

From 0:

— The half of the signal in U-NII-1 should be measured against the lower band-power and PSD limits

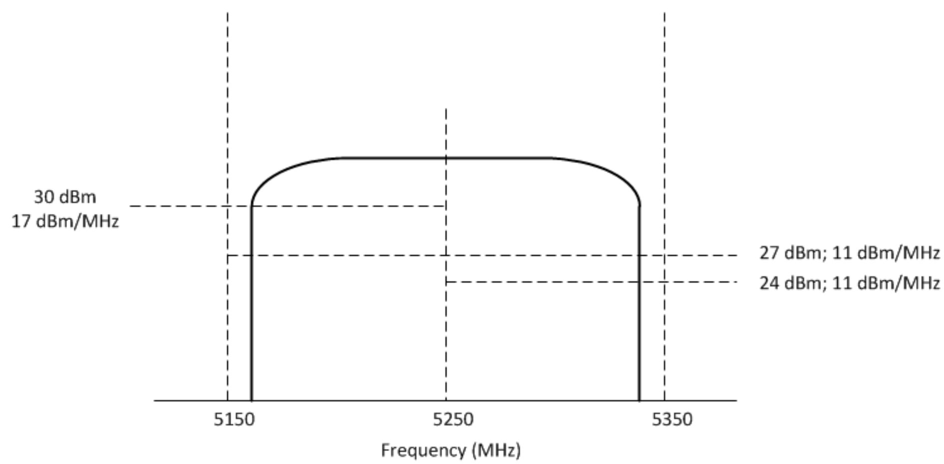
— The half of the signal in U-NII-2a should be measured against their power / PSD limits of upper band

Given the fact that in most cases the 160 MHz signal would have the same transmit power and PSD across all 160 MHz bandwidth, then testing to the 2 separate limits is not necessary. In these case to fully comply with both band would require the power and PSD to be based on the lowest maximum allowed for the more restrictive band.

Therefore, if a 160MHz signal (which is equally distributed between the two bands) produces a total power of xdBm across the entire EBW, the total power in each band would be half of the total, or (which meets both frequency band limits), and would have a PSD no greater than that allowed in the more restrictive sub band.

This would allow to a measurement of this complete EBW (across both sub-bands) if the equal amount of band width is used in each band, and the power is based on the tighter limit., rather than individual sub band measurements.

NOTE—If the total power across the entire signal complies with the lowest limit for total power in each band and the highest power spectral density across the entire emission complies with the lower of the psd limits in each band then no additional test would be required, regardless of how power is distributed.



NOTE—Limit shown above is for example only, see specific regulations for actual applicable limit.

Figure 26—Example of equally distributed signal across multiple regulatory bands

12.3.2 For channels where the distribution is unequal between the bands

Where the signal is not equally distributed between the two bands, for example

— Where 2/3 of the signal is in lower band should be measured against the lower power of and PSD limits

— The 1/3 of the signal is in second band it should be measured against the 2nd band-power and PSD limits

a) The EBW of each non-contiguous segment is measured at points that are 26 dB below the maximum for that segment.

b) Band-crossing emissions: For an emission that crosses the boundary between two adjacent U-NII bands, the boundary frequency between the bands serves as one edge for defining the portion of the EBW that falls within a particular U-NII band. See Figure 27.

c) However, the −26 dB points are measured relative to the highest point on the contiguous segment—regardless of which band contains that highest point

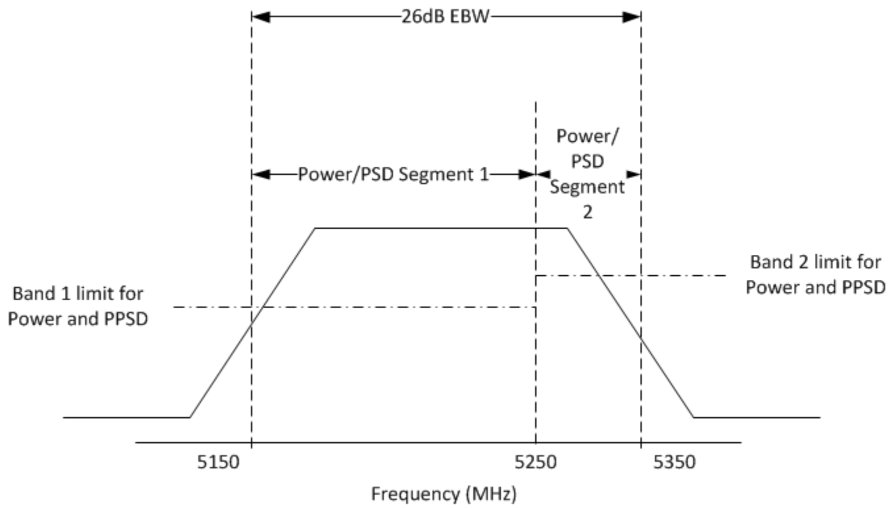


Figure 27—Example of a signal not equally distributed over multiple bands

12.4 Maximum conducted output power

12.4.1 General considerations

Some general considerations are as follows:

a) If possible, configure or modify the operation of the EUT so that it transmits continuously at its maximum power control level (see 12.2).

b) The intent is to test at 100% duty cycle; however a small reduction in duty cycle (to no lower than 98%) is permitted, if required by the EUT for amplitude control purposes. Manufacturers are expected to provide software to the test lab to permit such a continuous operation.

c) If continuous transmission (or at least 98% duty cycle) cannot be achieved due to hardware limitations (e.g., overheating), the EUT shall be operated at its maximum power control level, with the transmit duration as long as possible, and the duty cycle as high as possible.

d) Maximum conducted output power may be measured using a spectrum analyzer, an EMI receiver, or an RF power meter.

e) Measurement of maximum conducted output power using a spectrum analyzer requires integrating the spectrum across a frequency span that encompasses, at a minimum, either the the 99% occupied bandwidth.[84]

12.4.2 Maximum conducted output power measurement using spectrum analyzer (SA) or EMI receiver

12.4.2.1 Selection of test method

The proper test method is selected based on the following criteria:

a) **Method SA-1** or **method SA-1A (alternative)** shall be applied if either of the following conditions can be satisfied:

[84] The option of using 99% occupied bandwidth to determine the frequency span for integration provides flexibility to test labs. However, for determining compliance in accordance with 47 CFR 15.407(a), the 26 dB emission bandwidth must be used to determine the bandwidth-dependent limits on maximum conducted output power.

1) The EUT transmits continuously (or with a $D \geq 98\%$).

2) Sweep triggering or gating can be implemented in such a way that the device transmits at the maximum power control level throughout the duration of each of the instrument sweeps to be averaged. This condition can generally be achieved by triggering the spectrum analyzer's sweep if the duration of the sweep (with the instrument configured as in Method SA-1; i.e., see next list item) is equal to or shorter than the duration T of each transmission from the EUT, and if those transmissions exhibit full power throughout their durations.

b) **Method SA-2** or **method SA-2A (alternative)** shall be applied if the conditions of the preceding item a) cannot be achieved, and the transmissions exhibit a constant duty cycle during the measurement duration. Duty cycle will be considered to be constant if variations are less than ± 2%.

c) **Method SA-3** or **method SA-3A (alternative)** shall be applied if the conditions of the preceding item a) and item b) cannot be achieved.

12.4.2.2 Method SA-1

Method SA-1 uses trace averaging with the EUT transmitting at full power throughout each sweep. The procedure for this method is as follows:

a) Set span to encompass the entire 99% OBW of the signal.

b) Set RBW = 1 MHz.

c) Set VBW ≥ 3 MHz.

d) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

e) Sweep time = auto.

f) Detector = Power averaging (rms), if available. Otherwise, use sample detector mode.

g) If transmit duty cycle < 98%, use a video trigger with the trigger level set to enable triggering only on full power pulses. The transmitter shall operate at maximum power control level for the entire duration of every sweep. If the EUT transmits continuously (i.e., with no OFF intervals) or at duty cycle ≥ 98%, and if each transmission is entirely at the maximum power control level, then the trigger shall be set to "free run."

h) Trace average at least 100 traces in power averaging (rms) mode.

i) Compute power by integrating the spectrum across the 99% OBW of the signal using the instrument's band-power measurement function, with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at 1 MHz intervals extending across the 99% OBW of the spectrum.

12.4.2.3 Method SA-1A (alternative)

Method SA-1A uses rms detection with slow sweep and EUT transmitting continuously at full power. The procedure for this method is as follows:

a) Set span to encompass the entire 99% OBW of the signal.

b) Set RBW = 1 MHz.

c) Set VBW ≥ 3 MHz.

d) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

e) Manually set sweep time ≥ [10 × (number of points in sweep) × (symbol period of the transmitted signal)], but not less than the automatic default sweep time.

f) Set detector = Power averaging (rms).

g) The EUT shall be operated at 100% duty cycle.

h) Perform a single sweep.

i) Compute power by integrating the spectrum across the 99% OBW of the signal using the instrument's band-power measurement function, with band limits set equal to the EBW or OBW band-edges. If the instrument does not have a band-power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the 99% OBW of the spectrum.

12.4.2.4 Method SA-2

Method SA-2 uses trace averaging across ON and OFF times of the EUT transmissions, followed by duty cycle correction. The procedure for this method is as follows:

a) Measure the duty cycle *D* of the transmitter output signal as described in 12.2.

b) Set span to encompass the entire 99% OBW of the signal.

c) Set RBW = 1 MHz.

d) Set VBW ≥ 3 MHz.

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time = auto.

g) Detector = Power averaging (rms), if available. Otherwise, use sample detector mode.

h) Do not use sweep triggering. Allow the sweep to "free run."

i) Trace average at least 100 traces in power averaging (rms) mode; however, the number of traces to be averaged shall be increased above 100 as needed such that the average accurately represents the true average over the ON and OFF periods of the transmitter.

j) Compute power by integrating the spectrum across the 99% OBW of the signal using the instrument's band-power measurement function with band limits set equal to the EBW or OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at 1 MHz intervals extending across the 99% OBW of the spectrum.

k) Add [10 log (1 / *D*)], where *D* is the duty cycle, to the measured power to compute the average power during the actual transmission times (because the measurement represents an average over both the ON and OFF times of the transmission). For example, add [10 log (1 / 0.25)] = 6 dB if the duty cycle is 25%.

12.4.2.5 Method SA-2A (alternative)

Method SA-2A uses rms detection with slow sweep with each spectrum bin averaging across ON and OFF times of the EUT transmissions, followed by duty cycle correction. The procedure for this method is as follows:

a) Measure the duty cycle *D* of the transmitter output signal as described in 12.2.

b) Set span to encompass the entire 99% OBW of the signal.

c) Set RBW = 1 MHz.

d) Set VBW ≥ 3 MHz.

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Manually set sweep time ≥ [10 × (number of points in sweep) × (total ON/OFF period of the transmitted signal)].

g) Set detector = Power averaging (rms).

h) Perform a single sweep.

i) Compute power by integrating the spectrum across the 99% OBW of the signal using the instrument's band-power measurement function with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at 1 MHz intervals extending across the 99% OBW of the spectrum.

j) Add [10 log (1 / *D*)], where *D* is the duty cycle, to the measured power to compute the average power during the actual transmission times (because the measurement represents an average over both the ON and OFF times of the transmission). For example, add [10 log (1 / 0.25)] = 6 dB if the duty cycle is 25%.

12.4.2.6 Method SA-3

Method SA-3 uses rms detection with max-hold. The procedure for this method is as follows:

a) Set span to encompass the entire 99% OBW of the signal.

b) Set sweep trigger to "free run."

c) Set RBW = 1 MHz.

d) Set VBW ≥ 3 MHz

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time ≤ [(number of points in sweep) × *T*], where *T* is defined in 12.2. If this gives a sweep time less than the auto sweep time of the instrument, then method SA-3A shall not be used. (The purpose of this step is so that averaging time in each bin is less than or equal to the minimum time of a transmission.)

g) Detector = Power averaging (rms).

h) Trace mode = max-hold.

i) Allow max-hold to run for at least 60 s or longer as needed to allow the trace to stabilize.

j) Compute power by integrating the spectrum across the 99% OBW of the signal using the instrument's band-power measurement function with band limits set equal to the EBW or OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at 1 MHz intervals extending across the 99% OBW of the spectrum.

12.4.2.7 Method SA-3A (alternative)

Method SA-3A uses reduced VBW with max-hold. The procedure for this method is as follows:

a) Set span to encompass the entire 99% OBW of the signal.

b) Set sweep trigger to "free run."

c) Set RBW = 1 MHz.

d) Set VBW ≥ 1 / *T*, where *T* is defined in item a1) in 12.2.

e) Number of points in sweep ≥ [2 × span / RBW]. (This gives bin-to-bin spacing ≤ RBW / 2, so that narrowband signals are not lost between frequency bins.)

f) Sweep time = No faster than coupled (auto) time.

g) Detector = peak.

h) Video filtering shall be applied to a voltage-squared or power signal (i.e., rms mode), if possible. Otherwise, it shall be set to operate on a linear voltage signal (which can require use of linear display mode). Log mode shall not be used:

   1) The preferred voltage-squared (i.e., power or rms) mode is selected on some instruments by setting the "average-VBW type" to power or rms.

   2) If RMS mode is not available, then linear voltage mode is selected on some analyzers by setting the display mode to linear. Other instruments have a setting for "average-VBW type" that can be set to "voltage" regardless of the display mode.

i) Trace mode = max-hold.

j) Allow max-hold to run for at least 60 s or longer as needed to allow the trace to stabilize.

k) Compute power by integrating the spectrum across the 99 %OBW of the signal using the instrument's band-power measurement function with band limits set equal to the OBW band-edges. If the instrument does not have a band-power function, then sum the spectrum levels (in power units) at 1 MHz intervals extending across the 99% OBW of the spectrum.

l) If linear mode was used in step h) in 12.4.2.7, then add 1 dB to the final result to compensate for the difference between linear averaging and power averaging.

12.4.3 Maximum conducted output power using a power meter

12.4.3.1 Method PM

Method PM is Measurement using an RF average power meter. The procedure for this method is as follows:

a) Measurements may be performed using a wideband RF power meter with a thermocouple detector or equivalent if all of the following conditions are satisfied:

   1) The EUT is configured to transmit continuously, or to transmit with a constant duty cycle.

   2) At all times when the EUT is transmitting, it shall be transmitting at its maximum power control level.

   3) The integration period of the power meter exceeds the repetition period of the transmitted signal by at least a factor of five.

b) If the transmitter does not transmit continuously, measure the duty cycle *D* of the transmitter output signal as described in 12.2.

c) Measure the average power of the transmitter. This measurement is an average over both the ON and OFF periods of the transmitter.

d) Correct the measurement in dBm by adding [10 log (1 / *D*)], where *D* is the duty cycle {e.g., [10 log (1 / 0.25)], if the duty cycle is 25%}.

12.4.3.2 Method PM-G

Method PM-G is measurement using a gated RF average power meter.

Measurements may be performed using a wideband gated RF power meter provided that the gate parameters are adjusted such that the power is measured only when the EUT is transmitting at its maximum power control level. Because the measurement is made only during the ON time of the transmitter, no duty cycle correction factor is required.

12.5 Emission bandwidth and occupied bandwidth

12.5.1 Emission bandwidth for the band 5.725 GHz to 5.85 GHz

The following procedure shall be used for measuring this bandwidth:

a) Set RBW = 100 kHz.

b) Set the video bandwidth (VBW) ≥ 3 × RBW.

c) Detector = Peak.

d) Trace mode = max-hold.

e) Sweep = No faster than coupled (auto) time.

f) Allow the trace to stabilize.

g) Measure the maximum width of the emission that is constrained by the frequencies associated with the two outermost amplitude points (upper and lower frequencies) that are attenuated by 6 dB relative to the maximum level measured in the fundamental emission.

NOTE—The automatic bandwidth measurement capability of a spectrum analyzer or EMI receiver may be employed if it implements the functionality described above.

12.5.2 Emission bandwidth for all other bands

The procedure for this method is as follows:

a) Set RBW = shall be in the range of 1% to 5% of the emission bandwidth.

b) Set the VBW > RBW.

c) Detector = peak.

d) Trace mode = max-hold.

e) Measure the maximum width of the emission that is 26 dB down from the peak of the emission. Compare this with the RBW setting of the instrument. Readjust RBW and repeat measurement as needed until the RBW/EBW ratio is in the range of 1% to 5%.

NOTE—The automatic bandwidth measurement capability of a spectrum analyzer or an EMI receiver may be employed if it implements the functionality described in the preceding items.

12.5.3 Occupied bandwidth

See 6.9.3 for the measurement procedure for OBW.

12.6 Peak power spectral density

Notwithstanding that some regulatory requirements refer to peak power spectral density (PPSD), in some cases the intent is to measure the maximum value of the time average of the power spectral density during a period of continuous transmission. The procedure for this method is as follows:

a) Create an average power spectrum for the EUT operating mode being tested by following the instructions in 12.4.2 for measuring maximum conducted output power using a spectrum analyzer or EMI receiver; that is, select the appropriate test method (SA-1, SA-2, SA-3, or their respective alternatives) and apply it up to, but not including, the step labeled, "Compute power…." (This procedure is required even if the maximum conducted output power measurement was performed using the power meter method PM.)

b) Use the peak search function on the instrument to find the peak of the spectrum.

c) Make the following corrections to the peak value of the spectrum, if applicable:

   1) If method SA-2 or SA-2A was used, then add [10 log (1 / *D*)], where *D* is the duty cycle, to the peak of the spectrum.

   2) If method SA-3A was used and the linear mode was used in step h) of 12.4.2.7, add 1 dB to the final result to compensate for the difference between linear averaging and power averaging.

d) The result is the PPSD.

e) The procedure in item a) through item c) requires the use of 1 MHz resolution bandwidth to satisfy the 1 MHz measurement bandwidth specified by some regulatory authorities.[85] This requirement also permits use of resolution bandwidths less than 1 MHz "provided that the measured power is integrated to show the total power over the measurement bandwidth" (i.e., 1 MHz). If measurements are performed using a reduced resolution bandwidth and integrated over 1 MHz bandwidth, the following adjustments to the procedures apply:

   1) Set RBW $\geq 1 / T$, where T is defined in 12.2 a).

   2) Set VBW $\geq [3 \times \text{RBW}]$.

   3) Care shall be taken such that the measurements are performed during a period of continuous transmission or are corrected upward for duty cycle.

12.7 Unwanted emissions measurement

12.7.1 General

Subclauses 12.7.2 and 12.7.3 cover measurements in the restricted and non-restricted-bands, respectively. However, these subclauses are not self-contained. Rather, they reference the general unwanted emissions measurement requirements in 12.7.4 and the specific measurement procedures in 12.7.4.4 through 12.7.7.

12.7.2 Unwanted emissions in the restricted-bands

The requirements for unwanted emissions in the restricted-bands are as follows:

a) For all measurements, follow the requirements in 12.7.4.

b) At frequencies below 1000 MHz, use the procedure described in 12.7.5.

c) At frequencies above 1000 MHz, the measurement results from the peak and average measurement procedures described in 12.7.6 and 12.7.7, respectively, shall satisfy the respective peak and average limits; if all peak measurement results satisfy the average limit, then average measurements are not required.

d) For conducted measurements above 1000 MHz, EIRP shall be computed as specified in 12.7.4.2, and then field strength shall be computed as follows (see also Annex G):

   1) $E[\text{dB}\mu\text{V/m}] = \text{EIRP}[\text{dBm}] - 20 \log (d[\text{m}]) + 104.77$, where E is field strength and d is distance at which the field strength limit is specified in the applicable requirements.

[85] See 47 CFR 15.407(a)(5).

2) E[dBμV/m] = EIRP[dBm] + 95.2, for d = 3 m.

e) For conducted measurements below 1000 MHz, the field strength shall be computed as specified in item d), and then an additional 4.7 dB shall be added as an upper bound on the field strength that would be observed on a test range with a ground plane for frequencies between 30 MHz and 1000 MHz, or an additional 6 dB shall be added for frequencies below 30 MHz.

12.7.3 Unwanted emissions that fall outside of the restricted-bands

The requirements for unwanted emissions that fall outside of the restricted-bands are as follows:

a) For all measurements, follow the requirements in 12.7.4.

b) At frequencies below 1000 MHz, use the procedure described in 12.7.5.

c) At frequencies above 1000 MHz, use the procedure for peak emissions described in 12.7.6.

d) If radiated measurements are performed, then field strength is then converted to EIRP as follows in Equation (37):

$$\mathrm{EIRP} = (Ed)^2 / 30 \qquad (37)$$

where

E is the field strength in V/m
d is the measurement distance in m
EIRP is the equivalent isotropically radiated power in W

Working in dB units, Equation (37) is equivalent to Equation (38):

$$\mathrm{EIRP}[\mathrm{dBm}] = E[\mathrm{dB}\mu\mathrm{V/m}] + 20\log(d[\mathrm{m}]) - 104.77 \qquad (38)$$

Or, if d is 3 m as in Equation (39):

$$\mathrm{EIRP}[\mathrm{dBm}] = E[\mathrm{dB}\mu\mathrm{V/m}] - 95.2 \qquad (39)$$

12.7.4 General requirements for unwanted emissions measurements

The requirements in 12.7.4.1 through 12.7.4.4 apply to all unwanted emissions measurements, both inside and outside of the restricted-bands.

12.7.4.1 EUT duty cycle

The requirements for unwanted emissions in the EUT duty cycle are as follows:

a) The EUT shall be configured or modified to transmit continuously except as stated in the following step b). The intent is to test at 100% duty cycle; however, a small reduction in duty cycle (to no lower than 98%) is permitted if required by the EUT for amplitude control purposes. Manufacturers are expected to provide software to the test lab to permit such continuous operation.

b) If continuous transmission (or at least 98% duty cycle) cannot be achieved due to hardware limitations of the EUT (e.g., overheating), the following additions to the measurement and reporting procedures are required:

   1) The EUT shall be configured to operate at the maximum achievable duty cycle.

   2) Measure the duty cycle D of the transmitter output signal as described in 12.2.

3) Adjustments to measurement procedures (e.g., increasing test time and number of traces averaged) shall be performed as described in the procedures in 12.7.5 through 12.7.7.

4) The test report shall include the following additional information:

   i) The reason for the duty cycle limitation.

   ii) The duty cycle achieved for testing and the associated transmit duration and interval between transmissions.

   iii) The sweep time and the amount of time used for trace stabilization during max-hold measurements for peak emission measurements.

c) Reduction of the measured emission amplitude levels to account for operational duty cycle is not permitted. Determining compliance is based on emission levels occurring during transmission; that is, it is not based on an average across ON and OFF times of the transmitter.

12.7.4.2 Radiated versus conducted measurements

The unwanted emission limits in both the restricted and non-restricted-bands are based on radiated measurements; however, as an alternative, antenna-port conducted measurements in conjunction with cabinet emissions tests are permitted to determine compliance provided that the following steps are performed:

a) Cabinet emissions measurements—A radiated test shall be performed to confirm that cabinet emissions are below the emission limits. For the cabinet-emission measurements the antenna may be replaced by a termination matching the nominal impedance of the antenna.

b) Impedance matching—Conducted tests shall be performed using equipment that matches the nominal impedance of the antenna assembly used with the EUT.

c) EIRP calculation—A value representative of an upper bound on out-of-band antenna gain (in dBi) shall be added to the measured antenna-port conducted emission power to compute EIRP within the specified measurement bandwidth. (For emissions in the restricted-bands, additional calculations are required to convert EIRP to field strength at the specified distance.) The upper bound on antenna gain for a device with a single RF output shall be selected as the maximum in-band gain of the antenna across all operating bands, or 2 dBi, whichever is greater.[86] However, for devices that operate in multiple bands using the same transmit antenna, the highest gain of the antenna within the operating band nearest to the out-of-band frequency being measured may be used, in lieu of the overall highest gain, when measuring emissions at frequencies within 20% of the absolute frequency at the nearest edge of that band, but in no case shall a value less than 2 dBi be selected.

d) EIRP corrections for multiple outputs—For devices with multiple outputs occupying the same or overlapping frequency ranges in the same band (e.g., MIMO or beamforming devices), compute the total EIRP as follows:

   1) Compute EIRP for each output, as described in step c).

   2) Follow the procedures specified in Clause 14 for summing emissions across the outputs, or correcting emission levels measured on individual outputs by [10 log (N_{ANT})], where N_{ANT} is the number of outputs.

Add the array gain term specified in 14.6.4 for out-of-band and spurious signals.[87]

[86] If an EUT uses an "electrically short antenna" (i.e., an antenna shorter than its resonant length of λ/4 or λ/2), then the in-band antenna gain may be low—perhaps even less than 0 dBi—but the gain may be higher at an out-of-band frequency where the antenna is resonant. In such a case, the gain is not expected to exceed that of a resonant λ/2 dipole (i.e., 2.15 dBi, here rounded to 2 dBi).

[87] Although out-of-band signals are not intentionally correlated between outputs and are not intended to exhibit array gain, the FCC noted the following: 1) if the in-band signals on two outputs are correlated, out-of-band intermodulation products and harmonics are also expected to be correlated; and 2) narrowband signals originating from the same source are also expected to exhibit correlation between channels. See FCC/KDB-662911 [B33].

12.7.4.3 Maximization of emissions

For all radiated emissions tests, measurements shall correspond to the direction of maximum emission level for each measured emission (see Clause 6 for guidance).

12.7.4.4 Band-edge measurements

12.7.4.4.1 General

Unwanted emissions within 2 MHz of the band-edge may be measured using either the marker-delta, as described in 12.7.4.4.2, or integration methods, as described in 11.12.3.2, provided that the 99% occupied bandwidth edge falls within 2 MHz of the band-edge. Otherwise, all unwanted emissions measurements shall be performed using the standard methods.

12.7.4.4.2 Marker-delta method (for band-edge measurements)

When the conditions described in 6.10.6 are satisfied, the marker-delta method, as described in 6.10.6, can be used to perform measurements of the unwanted emissions level at the band-edges.

12.7.5 Procedures for unwanted emissions measurements below 1000 MHz

The procedure for unwanted emissions measurements below 1000 MHz is as follows:

a) Follow the requirements in 12.7.4.
b) Compliance shall be determined using CISPR quasi-peak detection; however, peak detection is permitted as an alternative to quasi-peak detection.

12.7.6 Procedure for peak unwanted emissions measurements above 1000 MHz

The procedure for peak unwanted emissions measurements above 1000 MHz is as follows:

a) Follow the requirements in 12.7.4.
b) Peak emission levels are measured by setting the instrument as follows:
   1) RBW = 1 MHz.
   2) VBW ≥ [3 × RBW].[88]
   3) Detector = peak.
   4) Sweep time = No faster than coupled (auto) time.
   5) Trace mode = max-hold.
   6) Allow sweeps to continue until the trace stabilizes. Note that if the transmission is not continuous, then the time required for the trace to stabilize will increase by a factor of approximately 1 / *D*, where *D* is the duty cycle. For example, at 50% duty cycle, the measurement time will increase by a factor of two, relative to measurement time for continuous transmission.

[88] VBW is specified here as 3 × RBW rather than as 3 MHz to accommodate the use of reduced RBW for the band-edge measurement method described in 12.7.4.4.

12.7.7 Procedures for average unwanted emissions measurements above 1000 MHz

12.7.7.1 General requirements

Follow the requirements in 12.7.4. Average emission levels shall be measured using one of two methods presented in 12.7.7.2 and 12.7.7.3.

12.7.7.2 Method AD (average detection)-primary method

The procedure for method AD is as follows:

a) RBW = 1 MHz.

b) VBW ≥ [3 × RBW].

c) Detector = Power averaging (rms), if [span / (# of points in sweep)] ≤ RBW / 2. Satisfying this condition can require increasing the number of points in the sweep or reducing the span. If the condition is not satisfied, then the detector mode shall be set to peak.

d) Averaging type = power (i.e., rms) (As an alternative, the detector and averaging type may be set for linear voltage averaging. Some instruments require linear display mode to use linear voltage averaging. Log or dB averaging shall not be used.)

e) Sweep time = auto.

f) Perform a trace average of at least 100 traces if the transmission is continuous. If the transmission is not continuous, then the number of traces shall be increased by a factor of 1 / *D*, where *D* is the duty cycle. For example, with 50% duty cycle, at least 200 traces shall be averaged. (If a specific emission is demonstrated to be continuous—i.e., 100% duty cycle—then rather than turning ON and OFF with the transmit cycle, at least 100 traces shall be averaged.)

g) If tests are performed with the EUT transmitting at a duty cycle less than 98%, then a correction factor shall be added to the measurement results prior to comparing with the emission limit, to compute the emission level that would have been measured had the test been performed at 100% duty cycle. The correction factor is computed as follows:

    1) If power averaging (rms) mode was used in the preceding step e), then the correction factor is [10 log (1 / *D*)], where *D* is the duty cycle. For example, if the transmit duty cycle was 50%, then 3 dB shall be added to the measured emission levels.

    2) If linear voltage averaging mode was used in the preceding step e), then the correction factor is [20 log (1 / *D*)], where *D* is the duty cycle. For example, if the transmit duty cycle was 50%, then 6 dB shall be added to the measured emission levels.

If a specific emission is demonstrated to be continuous (100% duty cycle) rather than turning ON and OFF with the transmit cycle, then no duty cycle correction is required for that emission.

12.7.7.3 Method VB-A (alternative)

Method VB-A is averaging using reduced video bandwidth. The procedure for this method is as follows:

a) RBW = 1 MHz.

b) Video bandwidth:

    1) If the EUT is configured to transmit with *D* ≥ 98%, then set VBW ≤ RBW / 100 (i.e., 10 kHz), but not less than 10 Hz.

    2) If the EUT *D* is < 98%, then set VBW ≥ 1 / *T*, where *T* is defined in item a1) of 12.2.

c) Video bandwidth mode or display mode:

1) The instrument shall be set with video filtering applied in the power domain. Typically, this requires setting the detector mode to Power averaging (rms) and setting the average-VBW type to power (rms).
2) As an alternative, the instrument may be set to linear detector mode. Video filtering shall be applied in linear voltage domain (rather than in a log or dB domain). Some instruments require linear display mode to accomplish this. Others have a setting for average-VBW type, which can be set to "voltage" regardless of the display mode.

d) Detector = peak.
e) Sweep time = No faster than coupled (auto) time.
f) Trace mode = max-hold.

Allow max-hold to run for at least 50 traces if the transmitted signal is continuous or has at least 98% duty cycle. For lower duty cycles, increase the minimum number of traces by a factor of $1/x$, where D is the duty cycle. For example, use at least 200 traces if the duty cycle is 25%. (If a specific emission is demonstrated to be continuous—i.e., 100% duty cycle—then rather than turning ON and OFF with the transmit cycle, at least 50 traces should be averaged.)

12.8 Elevation mask procedures

12.8.1 General

Depending on the regulatory agency, outdoor devices might require measurements of the elevation pattern of the transmit antenna. Elevation masks are relative to the horizon and any lobe radiated outside of the permitted area of the mask must be controlled, either mechanically or electrically to reduce RF energy from transmitting in an upward direction.

For the purposes of compliance, information for all the antenna types must be included in the filing. In order for antennas to be considered of similar type, the antenna patterns must also be similar as well as other characteristics of the antenna

Within the following clauses, the elevation angle of 0° is the horizon and 90° is straight-up.

When evaluating any antenna configuration, the manufacturer recommended installation must be taken into account. For those antennas that are required, by the manufacturer, to be installed with a tilt, this tilt must be taken into account during the assessment of the elevation pattern.

12.8.2 Fixed infrastructure, not electrically or mechanically steerable beam antennas[89]

There are two methods available for evaluating the elevation of fixed infrastructure antennas. The method depends on the information available at the time of assessment. Subclause 12.8.2.1 may be used if the manufacturer provides a detailed antenna pattern data sheet showing the elevation characteristics of the antenna. Subclause 12.8.2.2 shall be used if no data sheets are provided or the information in the data sheet is insufficient to demonstrate compliance.

12.8.2.1 Detailed antenna pattern

If the elevation plane pattern is available in the supplied antenna data sheet, perform the following steps to evaluate compliance:

[89] Fixed infrastructure antennas are typically dipole omnidirectional, yagi, parabolic dish, or sector antennas.

a) Determine the device intended mounting elevation and define 0° reference angle on the elevation plane radiated pattern.

b) Calculate the required EIRP level. This can be different depending on the limit being assessed. Some regulatory agencies require the total EIRP while others require a PSD EIRP level. This can require the addition of multiple antennas for MIMO devices, the guidance in Clause 14 shall be used for calculating maximum directional gain.

c) Evaluate all lobes of the antenna pattern against their respective regulatory limits.

12.8.2.2 Elevation pattern measurements

If the elevation plane data is not provided the antenna pattern can be determined using the following measurement procedure:

a) Set the antenna to be evaluated on a test site as described in 5.2.

b) The antenna under test shall be rotated 90° around the main beam axis in the horizontal position to transform the measurement in elevation angle into azimuth. (i.e., rotating the turntable will result in a scan of the elevation pattern of the antenna under test)

c) Determine the position of 0° relative to the horizon based on the manufacturer supplied installation instructions.

d) Configure the EUT to transmit at the maximum power or maximum power spectral density, depending on the regulatory requirement being assessed. If the antenna is detachable, the EUT may be replaced with a signal generator set to produce the equivalent power.

e) Configure the measurement equipment using the appropriate measurement method of either 12.4.2 for output power or 12.6 for power spectral density. This method shall match the method used in determining compliance with the aforementioned requirements. If the EUT has been replaced by a signal generator, set the RBW to 1 MHz and the VBW to 3 MHz with a Peak detector.

f) Rotate the turntable 360° recording the output power at each step. Through the main beam of the antenna, the step size shall be kept to a maximum of 1°. Once outside the main beam of the antenna, the maximum step size shall be:

    1) Between 0° and 8°, maximum step size of 2°

    2) Between 8° and 40°, maximum step size of 3°

    3) Between 40° and 45°, maximum step size of 1°

    4) Between 45° and 90°, maximum step size of 3°

    The main beam of the antenna is defined as the 3 dB bandwidth of the antenna.

g) Convert the measured values to EIRP using the formulas in Annex G.

h) Compare the EIRP values with the applicable regulatory limits

i) Repeat a) to h) in both receive antenna polarizations. This can also require a change to the transmit antenna as some fixed infrastructure antennas can transmit in different polarizations depending on their configuration

12.8.3 All other antenna types

For all other types of antenna[90] which have any combination of following characteristics:

— Asymmetrical, complex radiation patterns

[90] patch antenna, array antenna, antennas with irregular shape of radiators, etc.

— 2-D or 3-D steerable beam

— Portable/mobile, not fixed infrastructure device

12.8.3.1 Provide following information in the report

a) Describe what type of antenna is used.

b) Determine by calculation, measurement or simulation, all radiation lobes/beams, which have EIRP higher than allowed for the elevation beamwidth.[91]

c) Provide an explanation of how those antenna beams are controlled to be kept below 30° elevation angle. The explanation should include installation instruction of the device, mechanical control, electro-mechanical control or software algorithm, if the beams are electrically controlled by software.

12.8.3.2 Alternate methods to demonstrate compliance of antennas under 12.8.3

Test data provided from a qualified CTIA chamber or antenna range where the full pattern is reported is also acceptable to demonstrate the fulfillment of requirements of 12.8.3.

Information on the test chamber or antenna test site must be included in the report.

[91] In regards to this requirement, only applicable in regards to FCC regulations – see FCC Part 15.407.

13. Procedures for measuring device operating using antenna arrays with beam-steering and/or beamforming capability

13.1 Definitions specific to this clause

Several definitions specific to Clause 13 are listed as follows:

a) Orientation of beam lobe relative to a fixed (non–beam steering) receive measurement antenna:
   1) Specified by two angles (γ, ξ), where ξ = 0° is coincident with the main lobe of the antenna.
   2) ξ = 0° is at right angles to γ = 0°. γ = 0° corresponds to traditional vertical polarization and ξ = 90° corresponds to traditional horizontal polarization.
b) **Spherical coordinate system for measurements**: Given a horizontal *xy* plane, a measurement point is specified by three coordinates (*R*, θ, ϕ), where:
   1) *R* is the radial distance of a point from the origin.
   2) θ is the elevation angle from the *x*y plane to the point.
   3) ϕ is the azimuth angle from the positive *x* axis to the orthogonal projection of the point in the *xy* plane.
c) **Antenna axis**: The reference for the positive *x* axis of the spherical coordinate system is defined by the device manufacturer. It is suggested that for a panel antenna, the line that is normal to the plane of the antenna is coincident with the positive *x* axis (γ = 0°). The point at *R* = 0 is at the center of the antenna. It is suggested that for a dish antenna, the line that is normal to the plane that is tangent to the dish, and that is coincident with the feed point, is coincident with the positive *x* axis (γ = 0°). The point at *R* = 0 is at the intersection of the tangential plane and the dish.
d) **Circular beamforming pattern**: Beam is steered in azimuth only, over a circle or a portion of a circle.
e) **Spherical beamforming pattern**: Beam is steered in both azimuth and elevation, over a sphere or a portion of a sphere.

13.2 Baseline scan methodologies

13.2.1 Baseline scan methodology-circular beamforming pattern

The procedure for employing the circular beamforming pattern is as follows:

a) Perform a baseline test over a circle (or portion of a circle encompassing the steerable range of the beam) with the receive antenna placed at a constant distance *R* from the EUT antenna and located at various settings of ϕ. The angular distance between any two adjacent ϕ points shall be less than or equal to 15°.
b) At each beam orientation, scan the receive antenna in small increments of θ and ϕ relative to the EUT antenna and vary the orientation of the receive antenna in small increments of (γ) relative to the receive antenna at ξ = 0° and 90° to maximize the emission. The receive antenna scan along θ is needed in case the peak of the beam lobe is not at an elevation of exactly 0°. If the transmit beam orientation is polarized at something other than vertical or horizontal, then vary the receive antenna ξ to find the worst-case polarization.

c) Starting from the ϕ orientation that produces the highest received level, perform additional investigative tests around this orientation using smaller increments of ϕ as required finding the worst-case ϕ orientation.

13.2.2 Baseline scan methodology-spherical beamforming pattern

The procedure for employing the spherical beamforming pattern is as follows:

a) Perform a baseline test over a sphere (or portion of a sphere encompassing the steerable range of the beam) with the receive antenna placed at a constant distance *R* from the EUT antenna and located at various combinations of (θ, ϕ). The arc length between any two adjacent (θ, ϕ) points shall be less than or equal to $R \times (\pi/4 \text{ radians}) = R \times (45°)$. For the three points ($\theta$, ϕ) = (0°, 0°), (0°, 30°), and (30°, 30°), the arc length between any two of these points satisfies this condition.

b) For an antenna that has a steerable range of a half sphere:

   1) With θ set to 0°, ϕ is set to −90°, −60°, −30°, 0°, +30°, +60°, and +90°

   2) With θ set to +30°, ϕ is set to −90°, −60°, −30°, 0°, +30°, +60°, and +90°

   3) With θ set to −30°, ϕ is set to −90°, −60°, −30°, 0°, +30°, +60°, and +90°

   4) With θ set to +60°, ϕ is set to −90°, −45°, 0°, +45°, and +90°

   5) With θ set to −60°, ϕ is set to −90°, −45°, 0°, +45°, and +90°

   6) With θ set to +90°, ϕ is set to either an arbitrary angle or 0°

   7) With θ set to −90°, ϕ is set to either an arbitrary angle or 0°

c) At each beam orientation, scan the receive antenna in small increments of θ and ϕ relative to the EUT antenna and vary the orientation of the receive antenna in small increments of (γ) relative to the receive antenna, at ξ = 0° and 90° to maximize the emission. If the transmit beam orientation is polarized at something other than vertical or horizontal, then vary the receive antenna ξ to find the worst-case polarization.

d) Starting from the (θ, ϕ) orientation that produces the highest received level, perform additional investigative tests around this orientation using smaller increments of (θ, ϕ) as required to find the worst-case (θ, ϕ) orientation.

13.2.3 Baseline scan-antenna systems with lockable beam

For beam steering arrays that have a mode (either test or operational) whereby the beam can be locked in a user selectable orientation, perform the baseline scan with the beam locked to the orientations specified 13.2.1 and 13.2.2 in the applicable circular or spherical baseline scan methodology.

13.2.4 Baseline scan-antenna systems with nonlockable scanning beam

For beam steering arrays that sweep the beam in a predictable pattern but do not have a mode whereby the beam can be locked into and cannot be locked in user selectable orientations, perform the baseline scan with the measurement receive antenna placed at the orientations specified above in the applicable circular or spherical baseline scan methodology. The instrument shall be set to peak detection, and the sweep time of the instrument shall be slow enough to capture the transmit beam as it sweeps across the orientation of the measuring antenna.

13.2.5 Baseline scan-antenna systems with adaptive scanning beam

For beam steering arrays that automatically steer the beam to take advantage of the natural multipaths between radios in the network, a user adjustable beam locking function shall be provided for test purposes. Use the procedures for the lockable beam version.

13.3 Final tests

13.3.1 Final test-antenna systems with lockable beam

Perform final tests with the beam locked at the worst-case orientation determined in the baseline scan and the measurement antenna located and orientated for the maximum received level. Where peak and average limits is specified, separate peak and average measurements may be made using applicable instrument settings.

13.3.2 Final test-antenna systems with nonlockable scanning beam

Perform final tests with the measurement antenna located and orientated for the maximum received level as determined in the baseline scan. Only peak measurements (peak detection and max-hold) may be made. The sweep time of the instrument shall be slow enough so that the antenna beam passes across the receive antenna during each sampling bin on the instrument. Where peak and average limits are specified, peak measurements shall meet both peak and average limits.

Alternatively, if a conducted test of the time-domain duty cycle of the RF signal can be made, then the average value may be determined by the peak measurement corrected for the time-domain duty cycle only. No corrections for the spatial duty cycle due to the scanning of the beam over the aperture area of the receive antenna shall be made.

13.4 Occupied bandwidth, power density, output power, and band-edge tests

Perform final tests, using the applicable lockable or nonlockable beam procedure of 13.3, at the worst-case orientation determined in the baseline scan (i.e., 13.2).

13.5 Spurious emissions tests

Perform final tests, using the applicable lockable or nonlockable beam procedure of 13.3, at the worst-case orientation determined in the baseline scan (i.e., 13.2).

Also perform the final tests of cabinet radiated emissions over the entire required frequency range, with the beamforming antenna set to the normal operational mode, using traditional emissions maximizing procedures as applicable for fixed-beam antenna systems (i.e., see Clause 6).

14. Procedures for combining emissions and computing directional gain from devices with multiple outputs[92]

14.1 Scope

This clause provides procedures for measurement of conducted output emissions from devices or composite systems that employ a transmitter with multiple outputs in the same band or multiple transmitters operating in the same band, with the outputs occupying the same or overlapping frequency ranges. It applies to EMC compliance measurements on devices and systems that transmit on multiple antennas simultaneously in the same or overlapping frequency ranges through a coordinated process. Examples include, but are not limited to, devices and systems employing beamforming or MIMO. This clause applies wherever the regulatory requirements call for conducted output measurements, or where conducted output measurements are combined with directional antenna gain to determine compliance with a radiated limit. Procedures are provided for in-band, out-of-band, and spurious emission measurements.

14.2 Purpose

These procedures address two issues associated with conducted testing of emissions from transmitters with multiple outputs in the same band. These issues are summarized as follows:

a) Summing emissions. FCC emission limits, for example, apply to the total of emissions from all outputs of the transmitter. Thus, emissions from the transmitter outputs must be summed before comparing measured emissions with the emission limit. (An exception exists for devices having two outputs driving a cross-polarized pair of antennas and operating under a rule part that specifies radiated rather than conducted limits. See 14.7 for more information.)

b) Accounting for array gain. Correlation between signals transmitted from different antennas can lead to array gain, which increases the directional gain of the device and leads to higher radiated levels in some directions. The contribution of array gain to the directional gain of the transmitter must be considered for requirements where conducted in-band emission limits vary with directional gain or in situations in which conducted measurements are combined with directional antenna gain to determine compliance with in-band radiated limits.

These issues are unique to conducted emissions measurements. In most cases, radiated measurements automatically combine the power emitted from multiple outputs and include the effects of directional gain if the measurements are performed in the direction of maximum response of the transmitter. However, for a device driving cross-polarized antennas, special considerations apply, as described in 14.7.

14.3 Limitations

The procedures described in this clause apply to summing of emissions from multiple outputs and performing directional gain computations. This clause makes no change in other aspects of measurements and compliance, such as the type of power or power spectral density measurement to be made (e.g., peak or average) or the methods for making those measurements (e.g., instrument setup parameters).

14.4 Methodologies for combining emissions from multiple outputs

The procedure in this clause employs the measure and sum approach, and the conducted emission level (e.g., transmit power or power in a specified bandwidth) is measured at each antenna port. The measured

[92] Procedure taken and modified from FCC/KDB 662911 D01 v02r01 [B33].

results at the various antenna ports are then summed mathematically to determine the total emission level from the device. Summing is performed in linear power units (e.g., mW, not dBm).

14.5 Guidance for combining emissions from multiple outputs of a transmitter of from multiple transmitters

Acceptable methodologies for combining emissions from multiple transmitter outputs depend on the type of emission measurement being performed. Three types of emission measurements are considered: in-band power measurements, in-band power spectral density measurements, and out-of-band and spurious emissions measurements.

14.5.1 In-band power measurements

The measure and sum technique should be used for measuring the in-band transmit power of a device. Total power is the sum of the conducted power levels measured at the various output ports.

In case all transmit port outputs have equal power levels, then it is sufficient to measure one of the randomly selected transmit port and report total MIMO power using following equation:

Total MIMO power (dBm) = Single antenna port power Measurement (dBm) + 10 $\log_{10}$ (maximum number of participating ports in beaming)

Maximum total power level of largest number of participating MIMO for each BW shall be reported.

14.5.2 In-band power spectral density measurements

14.5.2.1 General

When performing measurements for determining compliance with PSD limits within the band of operation of a transmitter, any of the three techniques below may be used to combine the emissions from multiple outputs prior to comparing with the emission limit. The procedures in 14.5.2.2 (the first) are the most accurate method. The procedure in 14.5.2.3 and 14.5.2.4 are offered as simpler alternatives but can lead to an overestimate of the total PSD when emission levels differ between outputs; consequently, if measurements performed using the method of 14.5.2.3 and 14.5.2.4 exceed the emission limit, the test lab might wish to retest using the method of 14.5.2.2 before declaring that the device fails the emission limit.

With any of the methods, existing requirements and guidance should be applied in performing the measurements on the individual outputs and in determining the maximum permitted PSD for the device.

14.5.2.2 Measure and sum the spectra across the outputs

With this technique, spectra are measured at each output of the device at the required resolution bandwidth. The individual spectra are then summed mathematically in linear power units. Unlike in-band power measurements, in which the sum involves a single measured value (output power) from each output, measurements for determining compliance with PSD limits involve summing the entire spectra across corresponding frequency bins on the various outputs. This will likely require transferring the measured spectra to a computer, where the bin by bin summing can be performed. For a device with N_{OUT} transmitter outputs, if the spectrum measurements of the individual outputs are all performed with the same span and number of points, the spectrum value (in watts or milliwatts) in the first spectral bin of output 1 is summed with that in the first spectral bin of output 2 and that from the first spectral bin of output 3, and so on up to the N_{OUT}-th output to obtain the value for the first frequency bin of the summed spectrum. The summed spectrum value for each of the other frequency bins is computed in the same way.

14.5.2.3 Measure and sum spectral maxima across the outputs

With this technique, spectra are measured at each output of the device at the required resolution bandwidth. The maximum value (peak) of each spectrum is determined. These maximum values are then summed mathematically in linear power units across the outputs. These operations shall be performed separately over frequency spans that have different out-of-band or spurious emission limits.

14.5.2.4 Measure and add [10 log (N_{OUT})] dB

With this technique, spectrum measurements are again performed at each output of the device, but rather than summing the spectra across the outputs, the quantity [10 log (N_{OUT})] dB (N_{OUT} is the number of outputs in the EUT) is added to each spectrum value before comparing with the emission limit. The addition of [10 log (N_{OUT})] dB serves to apportion the emission limit among the N_{OUT} outputs so that each output is permitted to contribute no more than $1/N_{OUT}$-th of the PSD limit specified.

14.5.3 Out-of-band and spurious emissions measurements

14.5.3.1 Absolute limits

When testing for determining compliance with absolute (rather than with relative) emission limits, emissions measured on individual channels must either be summed across the outputs or corrected by [10 log (N_{OUT})] before comparison with the emission limit.

When performing measurements outside of the band of operation of a transmitter (i.e., out-of-band and spurious emissions), any of the methods described in 14.5.2.2, 14.5.2.3 or 14.5.2.4 may be used to combine the emissions from multiple outputs prior to comparing with the emission limit. The method in 14.5.2.2 is the most accurate method. The methods in 14.5.2.3 and 14.5.2.4 are offered as potentially simpler alternatives, but it can lead to overestimates of the total PSD when emission levels differ between outputs. Consequently, if measurements performed using the method described in 14.5.2.3 or 14.5.2.4 exceed the emission limit, then the test lab might wish to retest using the method described in 14.5.2.2 before declaring that the device fails the emission limit.

14.5.3.2 Relative limits

When testing out-of-band and spurious emissions against relative emission limits, tests may be performed on each output individually without summing or adding [10 log (N_{OUT})] if the measurements are made relative to the in-band emissions on the individual outputs. Alternatively, tests may be performed on the combined out-of-band emission by summing or adding [10 log (N_{OUT})] and comparing to the maximum total in-band power spectral density, as determined by the “measure and sum the spectra” technique.

Emission limits specified as X + 10 log(P) dB below the transmit power (where P is the transmit power) are absolute limits and are not considered “relative limits” for purposes of this guidance. Out-of-band and spurious emissions must be tested against absolute limits using techniques described in 14.5.3.1.

14.6 Directional gain calculations

14.6.1 General

The directional gain of the antenna system affects emissions measurements in either of the following situations:

1) When regulatory requirements define a limit on output power or power spectral density that is a function of the directional gain of the antenna system

2) When conducted measurements are combined with directional antenna gain to determine compliance with in-band radiated limits

In such cases, the effect of array gain must be included in the calculation of overall directional antenna gain for devices that transmit on multiple outputs simultaneously in the same band, in the same or in overlapping frequency ranges.

Array gain results when the signals transmitted on different antennas are positively correlated when viewed from a specific direction. In most cases, beamforming systems attempt to achieve 100% correlation between the transmitted signals when viewed from the intended beam direction, although actual correlation can be slightly lower. A transmitter that transmits correlated signals from its multiple antennas has the potential to create array gain even when that is not the intent.

14.6.2 Categorization as correlated or completely uncorrelated

14.6.2.1 General

Transmission characteristics can be considered as correlated (i.e., correlation exists between the signals on at least two antennas) or as completely uncorrelated. Unless the transmitted signals are categorized as completely uncorrelated based on the guidance provided in 14.6.2.3, the signals must be considered correlated for the purposes of computing directional gain. In the case of correlated signals, array gain will be computed based on 100% correlation even if the actual correlation is lower except in certain cases involving cyclic delay diversity or multiple spatial streams.

14.6.2.2 Transmission characteristics-correlated

The following transmission characteristics are considered correlated:

a) For the purposes of this clause, transmitter output signals are considered correlated if any of the following are true:

   1) The same digital data are transmitted from two or more antennas in a given symbol period, even with different coding or phase shifts.

   2) Correlation between two transmitted signals exists at any frequency and time delay.

   3) Multiple transmitter outputs serve to focus energy in a given direction or to a given receiver.

   4) The operating mode combines correlated techniques with uncorrelated techniques.

   Otherwise, the output signals are considered completely uncorrelated.

b) Correlated signals include, but are not limited to, signals transmitted in any of the following modes:

   1) Any transmit beamforming mode, whether fixed or adaptive (e.g., phased array modes, closed-loop MIMO modes, transmitter adaptive antenna modes, maximum ratio transmission modes, and statistical Eigen beamforming modes).

   2) Cyclic delay diversity (CDD) modes, also known as cyclic shift diversity (including modes for IEEE 802.11n and later devices to communicate with legacy IEEE 802.11 devices).[93] In CDD modes, the same digital data are carried by each transmit antenna but with different cyclic delays. The signals are highly correlated at any one frequency, although not necessarily at zero time delay. In particular, correlations tend to be high over the bandwidths specified for in-band PSD measurements where it is required that the PSD is reduced when the directional antenna gain exceeds a threshold.

[93] "IEEE 802.11n" and "IEEE 802.11" are shorthand notations for devices operating per IEEE Std 802.11 2012 [B44].

14.6.2.3 Transmission characteristics-completely uncorrelated

Completely uncorrelated signals include those transmitted in the following modes, if they are not combined with any correlated modes, such as beamforming:

a) Space time block codes or space time codes for which different digital data are carried by each transmit antenna during any symbol period (e.g., IEEE Std 802.16™-2012, matrix A (Alamouti coding) [B45]).

b) Spatial multiplexing MIMO, for which independent data streams are sent to each transmit antenna (e.g., IEEE Std 802.16-2012, matrix B [B45]). IEEE Std 802.16-2012, matrix C [B45], which adds diversity, also produces uncorrelated transmit signals.[94]

14.6.3 Directional gain calculations for in-band measurements

14.6.3.1 Directional gain in commonly occurring cases

In the commonly occurring case of N_{ANT} transmit antennas, each with the same directional gain G_{ANT} dBi, being driven by N_{OUT} transmitter outputs of equal power, directional gain shall be computed as follows:

a) If any transmit signals are correlated with each other:

$$\text{Directional gain} = G_{\mathrm{ANT}} + 10 \log (N_{\mathrm{ANT}}) \text{ dBi}$$

b) If all transmit signals are completely uncorrelated with each other:

$$\text{Directional gain} = G_{\mathrm{ANT}}$$

14.6.3.2 Directional gain-special cases

In special cases for sectorized antenna systems, cross-polarized antennas, antennas with unequal gains and equal transmit powers, spatial multiplexing, and cyclic delay diversity, the directional gain can be computed as specified in 14.6.3.2.1 through 14.6.3.2.6.

14.6.3.2.1 Sectorized antenna systems

In sectorized antenna systems in which each antenna is used to transmit different data in a different direction from the other antennas, directional gain is equal to the gain of an individual sector antenna.

14.6.3.2.2 Cross-polarized antennas with N_{ANT} = 2

In the case of a transmitter with only two outputs driving antennas that are cross-polarized (e.g., vertical and horizontal, or left-circular and right-circular), directional gain is the gain of an individual antenna.

14.6.3.2.3 Multiple antenna, each of which has one of two (or three) polarizations that are orthogonal to one another (i.e., cross-polarized)

(If three polarizations are used, all three polarizations must be mutually orthogonal.) The total gain, including array gain, is computed separately for each of the two (or three) polarizations using the procedures presented in this document. The highest of the total gains shall apply.

14.6.3.2.4 Unequal antenna gains with equal transmit powers

Let the antenna gains be designated by G_1, G_2, …, G_N dBi:

[94] Regulatory authorities may consider adjustments to these procedures as new modes of operation that should be brought to their attention.

a) If transmit signals are correlated, then:

$$\text{Directional gain} = 10\log\left[\left(10^{G_1/20} + 10^{G_2/20} + \ldots + 10^{G_N/20}\right)^2 / N_{\text{ANT}}\right] \text{ dBi} \tag{40}$$

NOTE— the purpose of the factor 20 in the denominator of each exponent and the square of the sum of terms is to combine the signal levels coherently.

b) If all transmit signals are completely uncorrelated, then:

$$\text{Directional Gain} = 10\log\left[\left(10^{G_1/10} + 10^{G_2/10} + \ldots + 10^{G_N/10}\right) / N_{\text{ANT}}\right] \text{ dBi} \tag{41}$$

14.6.3.2.5 Spatial multiplexing

In some cases, spatial multiplexing is combined with techniques that produce correlated signals, such as beamforming or cyclic delay diversity. This is common when the number of transmit antennas exceeds the number of independent data streams (i.e., the number of “spatial streams”) to be transmitted. For cyclic delay diversity, see 14.6.3.2.6. In all other cases directional gain is calculated as follows:

a) If all antennas have the same gain, G_{ANT}:

$$\text{Directional gain} = G_{\text{ANT}} + 10\log\left(N_{\text{ANT}} / N_{\text{ss}}\right) \text{ dBi} \tag{42}$$

where N_{ss} is the number of independent spatial streams of data.

NOTE— This formula can also be applied when antennas have different gains if the highest antenna gain is substituted for G_{ANT}.

b) If antenna gains are not equal and each transmit antenna is driven by only one spatial stream: Directional gain may be calculated by using Equation (42) with G_{ANT} set equal to the gain of the antenna having the highest gain; or as in Equation (43):

$$\text{Directional gain} = 10\log\left[\sum_{j=1}^{N_{\text{ss}}}\left\{\sum_{k=1}^{N_{ANT}} g_{j,k}\right\}^2 / N_{\text{ANT}}\right] \tag{43}$$

where each antenna is driven by no more than one spatial stream, and

N_{ss}	is the number of independent spatial streams of data
N_{ANT}	is the total number of antennas
$g_{j,k}$	is if the *k*th antenna is being fed by spatial stream *j*, or zero if it is not
G_k	is the gain in dBi of the *k*th antenna

c) If antenna gains are not equal and each transmit antenna can be driven by more than one spatial stream, then directional gain may be calculated by using Equation (44) with G_{ANT} set equal to the gain of the antenna having the highest gain; or:

$$\text{Directional gain} = 10\log\left[\sum_{j=1}^{N_{\text{ss}}}\left\{\sum_{k=1}^{N_{\text{ANT}}} g_{j,k}\sqrt{P_{j,k}}\right\}^2 / N_{\text{ANT}}\right] \tag{44}$$

where

N_{ss}	is the number of independent spatial streams of data

N_{ANT} is the total number of antennas

$g_{j,k}$ is $10^{G_k/20}$ if the kth antenna is being fed by spatial stream j, or zero if it is not

G_k is the gain in dBi of the kth antenna

$P_{j,k}$ is the relative normalized power (in linear terms, not decibels) of spatial stream j feeding the kth antenna

$P_{j,k}$ is normalized such that:

$$\sum_{j=1}^{N_{ss}}\left\{\sum_{k=1}^{N_{ANT}} P_{j,k}\right\} = N_{ANT} \tag{45}$$

NOTE—$P_{j,k}$ is zero if spatial stream j does not feed the kth antenna.

CAUTION

Most devices can operate with one spatial stream (N_{ss} = 1) even if they also are capable of more spatial streams. The worst-case directional gain will occur when N_{ss} = 1; therefore, it is especially important that the device complies with all emission limits for the case of N_{ss} = 1 (or with the lowest possible value of N_{ss}, if the device always uses spatial multiplexing).

The test report must clearly include proper justification for the lowest value of N_{ss} used.

14.6.3.2.6 Cyclic delay diversity (also known as cyclic shift diversity)

CDD signals are correlated and create unintended array gain that varies with signal bandwidth, antenna geometry, and cyclic delay values. Consequently, depending on system parameters, it might be appropriate to use different values of array gain for determining compliance with power limits versus determining compliance with power spectral density limits. In all formulas, N_{ANT} is the number of transmit antennas and N_{SS} is the number of spatial streams. (Assume N_{SS} = 1, unless specific information to the contrary is documented.)

The CAUTION statement shown in 14.6.3.2.5 shall be applied in the use of all of the following formulas:

a) For CDD transmissions where all antennas have the same gain (G_{ANT}), directional gain is calculated as follows in Equation (46):

$$\text{Directional gain} = G_{ANT} + \text{array gain} \tag{46}$$

The quantity Array gain is as follows.

1) For power spectral density (PSD) measurements on all devices:

Array gain = 10 log (N_{ANT} / N_{ss}) dB

2) For power measurements on IEEE 802.11 devices[95]:

[95] This guidance is based on modeling by the FCC of array gain as documented in a subsequent FCC technical report (Stephen Martin, "Directional Gain of IEEE 802.11 MIMO Devices Employing Cyclic Delay Diversity", FCC/OET 13TR1003, April 5, 2013). The technical report analysis is for the case where no spatial multiplexing is performed (*i.e.*, N_{SS} = 1). N_{ANT} in formulas in the technical report is replaced here by N_{ANT}/N_{SS} because spatial multiplexing effectively reduces the number of correlated streams that are transmitted. The model in the technical report sets broadband array gain = 3 dB for the case of 20-MHz channel widths with $N_{ANT} \geq 5$. Here we replace this with the formula 5 log(N_{ANT}/N_{SS}) or 3 dB, whichever is less, to accommodate multiple spatial streams. The revised formula was selected to yield a broadband array gain of 3 dB (matching the value in the technical report) when N_{SS} = 1, but to permit the value to drop to fixed fraction of the narrowband array gain value of 10 log(N_{ANT}/N_{SS}) with spatial processing, based on the shapes of the upper three curves in Figure 18 of the technical report. We wanted broadband array gain to be no less than 3 dB with

i) Array gain = 0 dB (i.e., no array gain) for $N_{ANT} \leq 4$

ii) Array gain = 0 dB (i.e., no array gain) for channel widths ≥ 40 MHz for any N_{ANT}

iii) Array gain = 5 log (N_{ANT}/N_{ss}) dB or 3 dB, whichever is less for 20 MHz channel bandwidths with $N_{ANT} \geq 5$

3) For power measurements on all other devices:

Array gain = 10 log (N_{ANT}/N_{ss}) dB

NOTE—Regulatory authorities can permit a lower array gain value based on analysis involving the specific cyclic delays, signal bandwidths, channelization, and antenna configurations used by the device. [96]

b) For CDD transmissions where antenna gains are not equal and each antenna is driven by only one spatial stream, the directional gain may be calculated (1) as described in item a) of this subclause, but with G_{ANT} set equal to the gain of the antenna with the highest gain, or (2) by calculating the directional gain using Equation (47):

$$\text{Directional gain} = 10\log\left[\sum_{j=1}^{N_{ss}}\left\{\sum_{k=1}^{N_{ANT}} g_{j,k}\right\}^2 / N_{ANT}\right] \tag{47}$$

where

N_{ss} is the number of independent spatial streams of data
N_{ANT} is the total number of antennas
$g_{j,k}$ is $10^{G_k/20}$ if the kth antenna is being fed by spatial stream j or zero if it is not
G_k is the gain in dBi of the kth antenna

c) For CDD transmissions where antenna gains are not equal and transmit the transmit antenna can be driven by more than one spatial stream, the direction gain may be calculated (1) as described in item a), but with G_{ANT} set equal to the gain of the antenna with the highest gain, or (2) by calculating the directional gain using Equation (48):

$$\text{Directional gain} = 10\log\left[\sum_{j=1}^{N_{ss}}\left\{\sum_{k=1}^{N_{ANT}} g_{j,k}\sqrt{P_{j,k}}\right\}^2 / N_{ANT}\right] \tag{48}$$

where

N_{ss} is the number of independent spatial streams of data
N_{ANT} is the total number of antennas
$g_{j,k}$ is $10^{G_k/20}$ if the kth antenna is being fed by spatial stream j or zero if it is not
G_k is the gain in dBi of the kth antenna
$P_{j,k}$ is the relative normalized power (in linear terms, not decibels) of spatial stream j feeding the kth antenna

$P_{j,k}$ is normalized such that, as in Equation (49):

N_{SS} = 1, which a required that the multiplier of the log(N_{ANT}/N_{SS}) be reduced from 10 by a factor of at least 3 dB / 7 dB or 4.3 to accommodate the case of N_{ANT} = 5, so we selected the next higher integer value of 5.

[96] Contact the regulatory authority through the appropriate avenues (regulatory authority dependent) for more information.

$$\sum_{j=1}^{N_{ss}}\left\{\sum_{k=1}^{N_{ANT}} P_{j,k}\right\} = N_{ANT} \tag{49}$$

NOTE—$P_{j,k}$ is zero if spatial stream j does not feed the kth antenna.[97]

14.6.4 Directional gain calculations for conducted out-of-band and spurious measurements

When out-of-band and spurious emissions compliance is demonstrated exclusively by radiated measurement, correction for directional antenna gain is not required. When out-of-band and spurious emissions limits are specified as absolute conducted power levels at the antenna ports (rather than EIRP) in a given bandwidth with no required reduction based on directional gain[98], correction for directional antenna gain is not required. If conducted measurements are permitted to determine compliance with a relative out-of-band limit (e.g., a requirement that out-of-band emissions be attenuated by X dB relative to in-band emissions), then correction for directional gain is generally not necessary because the directionality applies to both the in-band and the out-of-band emissions.

In some cases,[99] however, a combination of conducted measurements and cabinet radiated measurements are permitted to determine compliance with radiated out-of-band and spurious limits that are absolute rather than relative. In those cases, the conducted measurements must be combined with directional gain to compute the radiated levels of the out-of-band and spurious emissions. The directional gain in such cases is the sum of the individual antenna gain (in dBi) and the array gain resulting from possible correlation of the out-of-band and spurious signals (in dB).

Follow the procedures in Clause 11 or Clause 12 as required regarding the out-of-band gain of the individual antennas, along with the following.

The array gain term to be added to the individual antenna gain is computed as follows[100]:

Gain of each antenna shall be based on the guidance in the relevant subclause of this standard. (e.g., the guidance might not permit use of a gain value less than 2 dBi in the formulas)

a) [10 log (N_{ANT})] for narrowband lines such as those that might originate from a clock or local-oscillator (including harmonics thereof).

b) The value applicable for in-band power spectral density measurements, at all other frequencies. (In most cases this will be [10 log (N_{ANT})] when transmitting correlated signals and 0 dB when transmitting uncorrelated signals.)

The methodology described in this subclause can overestimate array gain, thereby resulting in apparent failures to satisfy the out-of-band limits even if the device is actually compliant. In such cases, compliance may be determined by performing radiated tests around the frequencies at which the apparent failures occurred.

[97] Contact the regulatory authority for more information.

[98] Many licensed rule parts express out-of-band emission limits as an attenuation below the in-band power level of X + 10 log P dB, where P is the transmit power. Such limits correspond to absolute out-of-band limits. For example, if the out-of-band emissions must be attenuated by at least 43 + 10 log P dB below the transmit power, the limit corresponds to an absolute limit of -43 dBW or -13 dBm. When the attenuation levels are expressed relative to transmit power (rather than relative to EIRP or ERP), the absolute emission limit corresponds to an absolute conducted power level. In such a case, there is no need to add the effect of directional gain. If the limit specifies a minimum attenuation below the in-band EIRP or ERP, then the out-of-band limit corresponds to an absolute EIRP or ERP and directional gain must be added to the conducted measurements.

[99] For example, FCC/KDB 558074 [B32] for DTS and FCC/KDB 789033 [B34] for U-NII.

[100] Although out of band signals are not intentionally correlated between outputs and are not intended to exhibit array gain, it is noted that (1) if the in band signals on two outputs are correlated, out of band intermodulation products and harmonics are also expected to be correlated; and (2) narrowband signals originating from the same source are also expected to exhibit correlation between channels.

14.7 MIMO with cross-polarized antenna

In the special case of a MIMO system with two outputs driving a cross-polarized pair of linearly polarized antennas, radiated measurements will yield a result that differs from that of conducted measurements because a linearly polarized measurement antenna aligned with one of the transmit antenna polarizations will see only the emissions from that antenna. Given that a radiated emission measurement might respond to only one output at a time in that case, the following procedure shall be used.

Where radiated measurements are used for determining compliance with conducted limits, the following steps are required to help ensure that the total emission power or PSD is determined for equipment driving cross-polarized antennas:

a) Measure radiated emissions with vertical and horizontal polarizations of the measurement antenna

b) Convert each radiated measurement to transmit power or PSD based on the antenna gain

c) Sum the powers or PSDs across the two polarizations

14.8 Transmitters with non-detachable antennas for MIMO operation

Expected antenna radiation field pattern and beam tilt of EUT must be known.

If the transmitter employs antenna tilt, then, either the EUT or the measurement antenna shall be placed in a particular tilt angle to help ensure that measurements are performed on the bore-sight of the antenna and the maximum radiated power is measured.

14.8.1 MIMO system with equal antenna port power, BW and frequency range and the EUT can be configured any single antenna energized

14.8.1.1 Antenna port power

The test set-up should be similar to Single Input Single Output (SISO) system. Turn on any one of the randomly selected antennas with RF full power. RF power to other antennas either should be switched off or reduced to lowest possible levels. The levels should be at least 30 dB below the fully energized antenna. Alternatively un-energized antenna power shall be below the allowed channel edge power. Measurement must be performed in the far-field. Additional measurement at different distances might be necessary to make sure that measurements are made in the far-field. The measurement antenna with smaller aperture may be used so that measurements are made within a reason distance within the measurement chamber. The antenna radiated power shall be reported in EIRP at the legal measurement distance and at the EUT antenna port using the Friis equation.

14.8.1.2 Measurement of antenna spurious and harmonic power

The test set-up should be similar to SISO system. Turn on any one of the randomly selected antennas with full RF power. RF power to other antennas either should be switched off or reduced to low possible levels. The levels should be at least 30 dB below the fully energized antenna. Measurement must be performed at the legally permitted measurement distance. If the detected levels are lower than the spectrum analyzer noise level, the measurements could be performed at closer far-field distance. Additional measurement at different distances might be necessary to prove measurements are made in the far-field and the final measurement data shall be calculated at the legally permitted measurement distance using the Friis equation. The total radiated power for maximum number of participating MIMO antennas for each EUT BW shall be reported. It should be recognized that high Gain antennas have high aperture dimensions and their far-field occur at larger distance from the EUT. To avoid loading of the analyzer or preamplifier, the transmit power can be notched without notching spurious and harmonics. The notch filter must be installed in the signal path of the measurement antenna and the spectrum analyzer. Alternatively, low/high-pass filters can be used instead of notch filters.

14.8.2 MIMO power where the EUT cannot be configured any single antenna port

14.8.2.1 Antenna port power

Only one antenna port of EUT alone cannot be energized, then follow the following steps:

a) Test setup shall be similar to SISO system.

b) Energize all participating antenna ports of the MIMO beamforming system.

c) Configure the system all participating antennas radiate a maximum EIRP so that major radiation lobe could be identified separately within the chamber measurement distance.

d) Alternatively, configure the system so that each participating MIMO antenna system radiate at a maximum EIRP and their composite beams occur within the chamber measurement distance.

e) Measure EIRP of each of the major lobes at the far-field.

f) In the case of c), calculate the composite EIRP and report the EIRP at the measurement distance and the EUT antenna port using Friis equation.

g) In the case of d), report highest composite EIRP at the measurement distance and the EUT antenna port using Friis equation.

14.8.2.2 Measurement of antenna spurious and harmonic power

a) Test setup shall be similar to SISO system.

b) Energize all participating antenna ports of the MIMO system.

c) Configure the system all antennas radiate a maximum EIRP so that major radiation lobe of each antenna could be identified separately within the chamber measurement distance.

d) Alternatively, configure the system so that each participating MIMO antenna system radiate at a maximum EIRP and their composite beams occur within the chamber measurement distance.

e) Install a notch filter at the measurement to minimize the radiated power on the fundamental transmitting frequency.

f) Measure harmonic and spurious emissions at the legal measurement distance. A preamplifier can be used so that the analyzer noise level is at least 6 dB below the specification limits. Measurement can be made at the shorter distances provided measurements are in the far-field.

g) In the case of c), calculate the composite EIRP and report radiated power at the EUT using Friis equation.

h) In the case of d), report highest composite EIRP and report radiated power at the EUT using Friis equation.

14.8.2.3 EIRP and power levels calculations at the EUT

EIRP/RBW at EUT = Analyzer reading + Free-space propagation loss for the measurement distance from the antenna + Cable loss – Measurement antenna G.

Friis Free-space propagation loss (L) = 20 log10 (slant distance from EUT to measurement antenna in meters) + 20 log10 (Frequency in MHz) – 27.56 dB.

14.8.2.4 Far-field verification

Measure power levels increasing the measurement distance at an incremental value of 0.5 m for three distances. EIRP/RBW shall not change more than 0.5 dB. If change is more than 0.5 dB, then measurement should be performed at additional distances

For spurious and harmonics EIRP/RBW shall not change more than 1 dB.

14.8.3 MIMO system with unequal antenna port power, BW, and frequency range

Measurement procedures are similar to EUT with equal antenna port power. Energize each antenna or each MIMO system. Measure maximum radiated power and calculate composite EIRP and power level at the EUT.

14.8.4 MIMO TDD measurements

In order to accurately measure TDD radiated power, the analyzer should get reference signal and a trigger. In an advanced system, the reference signal typically obtained from a GNSS receiver and the trigger is obtained from the transmitter. For consumer products trigger along with pulse width information are sent as data from the base station. It is recognized that separate procedures for TDD and FDD is not necessary.

15. Whitespace device testing

15.1 Test configuration requirements

a) The ability to compel the equipment-under-test (EUT) to operate on a TV channel selectable by the test personnel.

b) The ability to vary the output power from the minimum to the maximum realizable levels and set it to a desired level.

c) The ability to continuously transmit a modulated signal (i.e., with no time bursting or signal gating applied).

15.2 Permissible channels of operation

a) Verify that the EUT cannot be tuned to operate on unauthorized TV channels, based upon device type: fixed, Mode or Mode II, or frequencies outside of the authorized band(s).

b) Note that the lockout of unauthorized channels might not be totally implemented in the EUT but rather, must be reliant upon limitations provided to the EUT by the database (e.g., channels 36 and 38).

15.3 Fixed TVBDs Power measurements

The power limits for fixed TVBDs are specified in terms of conducted PSD; therefore, the recommended compliance verification measurement should utilize a conducted test configuration. The following step a) through step g) provide recommended settings and procedures for using a spectrum analyzer (with signal-processing capability) to perform the measurement:

a) Connect a patch cable of known attenuation (at the specific frequencies under consideration) between the antenna port of the EUT and a spectrum analyzer. For a fixed TVBD, it might be necessary to insert an external attenuator in the signal path to reduce the chance of overload damage to the analyzer.

b) Select the analyzer's power averaging (rms) detector, a span of 10 MHz, a resolution bandwidth (RBW) of 100 kHz, a video bandwidth of 300 kHz and a sweep speed that provides one millisecond per trace point integration time.

c) Activate the EUT test mode that provides continuous transmission of the output signal (no time bursting or signal gating) on the operating channel under investigation (low, middle, and high channels within tuning range must be examined).

d) Employ the trace averaging analyzer function over a minimum of 10 traces.

e) Use the integrated band/channel power analyzer function to determine the average power within the 6 MHz channel bandwidth.

f) Use the peak marker function to determine the maximum power in any 100 kHz band segment.

g) Make the necessary corrections to the measured amplitude levels to account for externalities inserted into the signal path (e.g., signal attenuation in patch cable and/or external attenuator). Record the corrected amplitude levels as the power levels measured in the 6 MHz channel bandwidth and 100 kHz frequency segment, respectively.

h) Check that the reported EUT transmit antenna gain is in compliance with regulatory requirements.[101] If necessary, reduce the PSD limits by the amount in dB that the transmit antenna gain exceeds 6 dBi.

i) Compare the recorded power levels to the applicable PSD limits to assess compliance.

j) Repeat until data is accumulated for the low, middle and high channels in the EUT tuning range.

15.4 Personal/Portable TVBDs

The power limits specified for personal/portable TVBDs are mixed in that the limit within the 6 MHz channel is specified as an EIRP whereas, the limit in any 100 kHz band segment is specified in terms of conducted power provided to the transmit antenna.

15.4.1 Conducted measurements

The following recommended spectrum analyzer settings and procedures assume access to a 50-Ω RF output port incorporated within the EUT.

a) Connect a patch cable of known attenuation (at the specific frequencies under consideration) between the antenna port of the EUT and a spectrum analyzer.

b) Select the analyzer's power averaging (rms) detector, a span of 10 MHz, a resolution bandwidth (RBW) of 100 kHz, a video bandwidth of 300 kHz and a sweep speed that provides one millisecond per trace point integration time.

c) Activate the EUT test mode that provides continuous transmission of the output signal (no time bursting or signal gating) on the operating channel under investigation (low, middle, and high channels within tuning range must be examined).

d) Employ the trace averaging analyzer function over a minimum of 10 traces.

e) Use the integrated band/channel power analyzer function to determine the average power within the 6 MHz channel bandwidth.

f) Use the peak marker function to determine the maximum amplitude in any 100 kHz band segment.

g) Make the necessary corrections to the measured amplitude levels to account for externalities inserted into the signal path (e.g., signal attenuation in patch cable and/or external attenuator). Record the corrected amplitude levels as the power levels measured in the 6 MHz channel bandwidth and 100 kHz frequency segment, respectively.

h) Determine the associated EIRP levels using guidance provided in Annex G.

i) Compare the EIRP levels to the applicable EIRP limits to assess compliance.

j) Repeat until data is accumulated for the low, middle and high channels in the EUT tuning range.

15.5 Band-edge measurement

The band-edge measurements must be performed relative to both the lower (f_L) and upper (f_U) channel edge frequencies. The PSD is to be measured within a 100 kHz band segment relative to the channel edge (i.e., $f_L -$ 100 kHz and f_U + 100 kHz). The following spectrum analyzer settings and procedures are recommended for this measurement:

a) Select the power averaging (rms) detector, a start frequency of $f_L -$ 100 kHz and a stop frequency of f_L (where f_L is the lower edge frequency of the operating channel), a resolution bandwidth (RBW)

[101] See §15.709(a)(1)

of 10 kHz, a minimum video bandwidth of 30 kHz and a sweep speed that provides one millisecond per trace point integration time.

b) Activate the EUT test mode that provides continuous transmission of the output signal (no time bursting or signal gating) on the operating channel to be investigated (low, middle and high channels of tuning range must be tested).

c) Employ the trace averaging feature of the analyzer over a minimum of 10 traces.

d) Use the integrated band/channel power function of the analyzer to determine the maximum average power spectral density over the 100 kHz frequency span.

e) Correct the measured amplitude level to account for externalities in the signal path (e.g., attenuation in the patch cable for conducted measurements; to include measurement antenna gain for radiated tests).

f) Repeat procedure with the analyzer start frequency set to f_U and the stop frequency set to f_U + 100 kHz.

g) Repeat the entire procedure until data is accumulated for the lower, middle and upper channels in the EUT tuning range.

15.6 Adjacent-channel measurement

The adjacent channel emission limit applies in any 100 kHz band segment within either the lower- or upper-adjacent 6 MHz channels relative to the operating channel (N±1, where N represents the channel of operation).

The following spectrum analyzer settings and procedures are recommended for this measurement:

a) Select the power averaging (rms) detector, a start frequency of f_L − 6 MHz and a stop frequency of f_L − 100 kHz (where f_L is the lower edge frequency of the operating channel), a resolution bandwidth (RBW) of 100 kHz, a minimum video bandwidth of 300 kHz and a sweep speed that provides one millisecond per trace point integration time.

b) Activate the EUT test mode that provides continuous transmission of the output signal (no time bursting or signal gating) on the operating channel to be investigated (low, middle and high channels of tuning range must be tested).

c) Employ the trace averaging feature of the analyzer over a minimum of 10 traces.

d) Use the peak marker function of the analyzer to determine the maximum power spectral density in any 100 kHz segment within the frequency span.

e) Correct the measured amplitude level to account for externalities in the signal path (e.g., attenuation in the patch cable for conducted measurements; to include measurement antenna gain for radiated tests).

f) Repeat the procedure with the analyzer start frequency set to f_U + 100 kHz and the stop frequency set to f_U + 6 MHz.

g) Repeat the entire procedure until data is accumulated for the lower, middle and upper channels in the EUT tuning range.

16. Procedures for measuring devices equipped with wireless power transfer functionality

16.1 Definitions specific to Clause 16

load modulation: Limited communication technique between wireless power transfer (WPT) source and client devices where the WPT source does not transmit any data communication, though it can change its transmitted power level based on detected changes in the amount of power drawn by the WPT client device(s).[102]

secondary frequency: Frequency or channel on which a WPT device intentionally transmits radiated electromagnetic energy for purposes other than WPT.

NOTE—Secondary frequencies are essentially the transmit frequencies of intentional radiators used for radiocommunication. This includes transmit frequencies used for WPT power transfer management in some WPT technologies (e.g., A4WP), but not the wireless power transfer frequency itself.

separation distance: Distance over which wireless power is transferred from a WPT source to a WPT client, measured from the surface of the WPT source that is used for wireless power transfer (i.e., its "WPT zone", usually on the top of the WPT source) to the surface of the WPT client that is designed to be placed on or oriented towards the WPT source (usually the bottom of the WPT client), measured between the corresponding surfaces of the WPT zones of the source and client devices, at the surface of their enclosures.

NOTE—This usually is not the same as the distance between the WPT transducers (e.g., coils) of the source and client devices.

wireless subassembly or module: Subcomponent of a device equipped with WPT functionality that is an intentional radiator on one or more secondary frequencies.

NOTE 1—Wireless subassemblies or wireless modules are radio devices and, as such, are subject to the provisions of ANSI C63.10 or ANSI C63.26, as applicable.

NOTE 2—Radio functionality can be implemented in the device either by means of a module or by means of a subassembly or circuit on a PCB within the device.

wireless power transfer (WPT): Transfer of energy from a source to one or more client devices through radio waves, with no electrical contact between the source and client devices, for the purpose of powering and/or charging client devices wirelessly.

WPT client: device capable of receiving power wirelessly from a WPT source.

NOTE 1—A WPT client is not designed to transmit power wirelessly, but only to receive it. However, it can include intentional radiators other than for power transfer (on secondary frequencies), e.g., for power management signaling to the WPT source.

NOTE 2—WPT client devices have, in general, some other primary function (or operation mode), e.g., cell phone, electric toothbrush, kitchen appliance, electric vehicle.

[102] WPT systems that use load modulation in the form of load impedance changes on the client device at the fundamental WPT frequency, with limited communication for the sole purpose of load management, are currently classified as ISM equipment in both the U.S. and Canada (see FCC KDB 680106 D03 and RSS-216 Issue 2, respectively), subject to the additional requirement that their operation is in close proximity (i.e., short separation distance between the WPT source and client devices).

WPT device: WPT source, WPT client, or system comprising one WPT source and one or more WPT clients.

NOTE 1—A WPT device can also include other subassemblies for additional functionality beyond wireless power transfer. These can include, for example, wireless radio modules for IEEE 802.11 communication (which can be an integral part of the specific WPT technology used in the device, e.g., in case of A4WP devices, or can serve other functions, like transfer of digital data between the source and client devices, or both) or circuitry for processing digital information.

NOTE 2—Wireless modules are radio apparatus and, as such, are subject to the provisions of ANSI C63.10 or ANSI C63.26, as applicable.

WPT source: Device directly connected (i.e., through a wired connection) to, or incorporating, a power source (e.g., ac mains, a battery or some other source of internal or external electrical power) and which is capable of wireless power transfer to one or more WPT client devices.

WPT source subassembly: Part (component) of a WPT source that generates, conditions and operates the wireless power transfer function of the device, including any signaling and modulation circuitry if the device is capable of transmitting information by modulating the intentional radiating signal on the WPT frequency, but excluding any wireless modules, even if used for WPT power transfer management.

16.2 Scope

16.2.1 Primary function

Devices equipped with wireless power transfer (WPT) functionality can be divided in two major categories: WPT source (or WPT primary) devices and WPT client (or WPT secondary) devices. Typically, the WPT client device has some other principal function (such as a cell phone, a kitchen appliance, or an electric vehicle), while the WPT source device has no other function than wireless power transfer. This clause only applies to the WPT function; non-WPT functionality is covered elsewhere in this document or in other standards (e.g., digital or information technology functionality is covered by ANSI C63.4).

NOTE—Nonetheless, some WPT client devices have no other function than WPT (e.g., a wireless charging receiver equipped with a male USB port for providing WPT charging to a cell phone that is not equipped with WPT client functionality) and some WPT source devices can have other functions (e.g., a cell phone charging pad that also allows downloading of files from/to the cell phone while providing it with wireless charging, or a table lamp equipped with a cell phone WPT charging pad in its base).

16.2.2 Intentional radiators

Usually, the WPT subassembly is classified as ISM equipment (industrial, scientific, or medical equipment), including the WPT source device (which is an intentional radiator), in which case the measurement procedures of this standard are not applicable. However, the WPT subassembly of a WPT source device, if it transmits any intelligent information (communication) on its WPT frequency, will be classified as a radio apparatus, in which case this clause shall apply.

Clause 16 and other clauses in this document, based on the specific wireless technology, shall also apply for the compliance evaluation measurements of any wireless modules incorporated into devices equipped with WPT functionality.

16.3 Test procedures

16.3.1 EUT type

16.3.1.1 General

Depending on the type of the EUT and how it is marketed, this subclause differentiates between three types of EUT, as follows:

- WPT source device (see 16.3.1.2)
- WPT client device (see 16.3.1.3)
- WPT system (see 16.3.1.4)

The EUT, in most cases (some WPT source devices and most WPT client devices), will include other subcomponents, e.g., an electric vehicle, a cell phone, or a home appliance can be equipped with WPT functionality, but their main function is of a different nature. The main function of the EUT is usually subject to other specification or standard. The differentiation based on the EUT's WPT function performed in this subclause is only for the purpose of defining the specific procedures for testing the EUT's unlicensed radio function according to this standard.

16.3.1.2 EUT is a WPT source

If the WPT source is marketed independently, without WPT client devices, then the EUT consists of the WPT source alone.

For evaluating the compliance of the WPT subassembly, where this is classified as radio apparatus (i.e., it transmits data communication on its WPT frequency), the EUT shall be configured to produce the worst-case emissions, which can include variation to the alignment and space between the source and the client, and operated such that it continuously transmits maximum power on its WPT frequency for the entire duration of the test.

For evaluating the compliance of the wireless subassemblies or modules (transmitting on secondary frequencies) that are included in the EUT, it shall be tested together with one or more WPT client device(s), as applicable, selected and configured such that the EUT transmits on all its secondary frequency transmitters all throughout the duration of the tests, while each one of these transmitters is operated according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency (based on the specific wireless technology). However, the inclusion of WPT client devices in the test setup is not required if the EUT can be configured to transmit on all its secondary frequencies by other means.

If the EUT cannot be configured to transmit simultaneously on all its secondary frequencies, a number of separate configurations shall be tested, such that each secondary frequency transmitter in the EUT operates according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency (based on the specific wireless technology) in at least one of these tests. The EUT might need to be modified using special software, firmware, and/or hardware, as applicable, in order to help ensure continuous transmission at the required parameters for the duration of the test. The modifications should be the minimum necessary to achieve this, and they shall be described in the test report.

In case the EUT includes wireless modules intended for radiocommunication with other than WPT client devices, it shall also be exercised by the use of such devices, used as support equipment during the test, for the purpose of evaluating the compliance of all its secondary frequency transmitters with the applicable limit. If the EUT's wireless modules that are not intended for radiocommunication with WPT client devices are tested in a separate test, then the presence of WPT client(s) is only required if their absence impacts the ability of the EUT to transmit at the required parameters on these corresponding secondary frequencies.

The measurements shall be performed according to the specific test procedures applicable to the wireless technology used in the EUT, in accordance to this standard.

16.3.1.3 EUT is a WPT client

If the WPT client is marketed independently, without its corresponding WPT source device, then the EUT consists of the WPT client alone.

For evaluating the compliance of the wireless subassemblies or modules included in the EUT, it shall be tested together with a typical WPT source, which is designed for use with the EUT, selected such that the EUT transmits on all its secondary frequency transmitters for the entire duration of that test, while each one of these transmitters is operated according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency (based on the specific wireless technology). However, the inclusion of a WPT source in the test setup is not required if the EUT can be configured to transmit on all its secondary frequencies by other means.

If the EUT cannot be configured to transmit simultaneously on all its secondary frequencies, a number of separate configurations shall be tested for evaluating the compliance of its wireless modules, such that each secondary frequency transmitter in the EUT operates according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency (based on the specific wireless technology) in at least one of these tests. The EUT might need to be modified using special software, firmware, and/or hardware, as applicable, in order to help ensure continuous transmission at required parameters for the duration of the test. The modifications should be the minimum necessary to achieve this, and they shall be described in the test report.

In case the EUT includes wireless modules intended for radiocommunication with other than WPT source devices, it shall also be exercised by the use of such devices, used as support equipment during the test, for the purpose of evaluating the compliance of all its secondary frequency transmitters with the applicable limit. If the EUT’s wireless modules that are not intended for radiocommunication with WPT source devices are tested in a separate test, then the presence of a WPT source is only required if its absence impacts the ability of the EUT to transmit at the required parameters on these corresponding secondary frequencies.

The measurements shall be performed according to the specific test procedures applicable to the wireless technology used in the EUT, in accordance to this standard.

16.3.1.4 EUT is a WPT system

If one WPT source and one or more WPT client devices are marketed together as a system and neither the source nor the clients can operate with other types of WPT devices, then the EUT consists of the WPT source and the WPT client(s) together.

If either the source or at least one client device of a WPT system can also operate with other types of WPT devices, of models not included in the WPT system, then the units may be tested either separately (i.e., WPT source and each type/model of WPT client tested separately, as per 16.3.1.2 and 16.3.1.3, respectively) or as a system (as per this subclause). However, in the latter case, if:

— The WPT source is classified as radio device but it cannot be fully exercised by the WPT client device(s) included in the EUT to transmit at maximum power on the WPT frequency; or

— The WPT source or at least one WPT client included in the EUT cannot be fully exercised to transmit on all its secondary frequency transmitters for the entire duration of the test, while each one of these transmitters is operated according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency (based on the specific wireless technology) then additional test cases shall be performed, using other models of WPT client devices (i.e., not included in the EUT) and/or other support equipment, as necessary, such that the WPT subassembly in the WPT source (if this is classified as radio apparatus) and all wireless transmitters in both the WPT source and in all WPT client devices included in the EUT are evaluated for compliance with the applicable limits.

For evaluating the compliance of the WPT subassembly in the WPT source device, where this is classified as radio apparatus (i.e., it transmits data communication on its WPT frequency), the EUT shall be configured according to the procedure in the applicable ISM standard and operated such that it continuously transmits maximum power on its WPT frequency for the entire duration of the test.

For evaluating the compliance of the wireless subassemblies or modules (transmitting on secondary frequencies) that are included in the EUT, it shall be tested while configured with one or more WPT client device(s), as applicable, based on the EUT design. The selection of WPT client devices for testing shall be based on the following criteria:

a) In case all models of WPT client devices included in the EUT are receive-only (i.e., with no secondary frequency transmitters), any or none of these may be included in the EUT test configuration. However, the test configuration shall ensure the EUT's WPT source transmits on all its secondary frequency transmitters at the required parameters (i.e., according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency, based on the specific wireless technology) all throughout the duration of the test.

b) In case all models of WPT client devices included in the EUT are equipped with secondary frequency transmitters, at least one of each model of WPT client device shall be included in the test configuration(s).

c) If the EUT includes a mix of receive-only WPT client device(s) and WPT client device(s) with secondary frequency transmitters, at least one of each model of the latter shall be included in the test configuration(s).

The EUT shall be configured and operated such that it transmits on all its secondary frequency transmitters, in both its WPT source and WPT client devices, all throughout the duration of the tests, while each one of these transmitters is operated according to this standard and to the specific requirements specified by the regulatory authority or purchasing agency (based on the specific wireless technology). Alternatively, subject to the purchasing authority or regulatory agency approval, the various EUT components (WPT source and WPT clients) may be tested separately if each can be configured to transmit at the required parameters on all its secondary frequencies by other means, without requiring the presence of the other EUT components.

If the EUT cannot be configured to transmit simultaneously on all its secondary frequencies, a number of separate configurations shall be tested for evaluating the compliance of its wireless modules, such that each secondary frequency transmitter in the EUT, in both its WPT source and all its WPT client models, operates at the required parameters in at least one of these tests.

In case the EUT includes wireless modules intended for radiocommunication with other than WPT source or WPT client devices, it shall also be exercised by the use of such devices, used as support equipment during the test, for the purpose of evaluating the compliance of all its secondary frequency transmitters with the applicable limit. For this type of wireless modules, if they are evaluated for compliance in a separate test, then:

— If the wireless module is in the EUT's WPT source device, then the presence of WPT client(s) is only required if their absence impacts the ability of the EUT to transmit at the required parameters on these corresponding secondary frequencies.

— If the wireless module is in one of the EUT's WPT client devices, then the presence of a WPT source is only required if its absence impacts the ability of the EUT to transmit at the required parameters on these corresponding secondary frequencies.

The measurements shall be performed according to the specific test procedures applicable to the wireless technology used in the EUT, in accordance to this standard and to the specific requirements specified by the regulatory authority or purchasing agency.

16.3.2 Orientation

WPT source devices shall be tested in their typical setup configuration, as per the manufacturer's instructions in the user manual, while observing the procedures in this standard applicable to the WPT source under test.

WPT source devices that are normally used on a table or are intended for wall-mount or ceiling applications shall be tested as tabletop EUT.

For radiated emissions, wall-mount EUTs shall be set up in a vertical position on the test table, as in their typical application. When testing for conducted emissions on AC mains power cable, wall-mount WPT source devices shall be placed on the test table such that their side that typically faces the wall is parallel to and 40 cm away from the vertical reference plane.

EUTs that are typically ceiling mounted shall be tested for radiated emissions twice, once configured with their base (EUT side that normally faces the ceiling) on the table and then flipped 180 degrees, configured with their base facing up.

WPT source devices that are intended to be mounted on a pole shall be tested as tabletop EUT, without the pole.

WPT source devices that are typically used in floor-standing installation mode shall be tested as floor-standing EUT.

WPT source devices that can be operated in various orientations shall be tested for radiated emissions in each orientation. Any support used to hold the EUT in the various positions/orientations during tests shall be made of insulating materials that are transparent to and not reflective of the electromagnetic energy at all frequencies within the tested frequency range.

17. Test reports

The results of each test or series of tests shall be reported accurately, clearly, unambiguously, and objectively.

This clause includes additional information that shall be documented in the test report in addition to other reporting requirements specified in applicable subclauses.

When reporting test results for the purpose of submitting an application to a regulatory authority (see the FCC and Innovation, Science and Economic Development Canada requirements listed in Clause 2), the test report shall comply with the reporting requirements set forth in this standard as well as with any additional reporting requirements imposed by the authority from which product certification is sought.

The test report shall contain at a minimum the following items:

a) Title (such as "Test Report for EUT XYZ").

b) A date (i.e., day, month, and year).

c) The name and address of the laboratory and the location where the tests were carried out, if different from the address of the laboratory.

d) The name and address of the applicant or customer.

e) The name(s), function(s), and signature(s) or equivalent identification of person(s) responsible for the test report.

f) Unique identification of the test report (such as a serial number).

g) A table of contents, and on every page an apparent identification, so that a page can be recognized as a part of the test report. In addition, a clear identification of the end of the test report shall be included.

h) A description as well as unambiguous identification of the EUT(s) tested. Where more than one sample is required for technical reasons (such as the use of connected units for the purpose of conducted output power testing where the product units will have integral antennas), each specific test shall identify which unit was tested.

i) A summary of all the tests listed in Clause 6 and Clause 7 through Clause 15 of this document, as applicable for a specific EUT, with a notation of whether the EUT passed or not. Alternatively, a general statement addressing the outcome (e.g., compliant/noncompliant) of the compliance testing is also acceptable.[103]

j) Photographs of the EUT and any manufacturer supplied accessories to be used with the EUT under normal operating conditions that are relevant for the purpose of performing the testing of the EUT.

k) Any tune up or adjustment procedures that were employed during the testing of the EUT. Identification and description of any operating software/firmware for both the normal operating mode and special test modes for compliance testing.

l) A statement to the effect that the results relate only to the items tested.

m) The measurement uncertainty of the instrumentation as specified in 1.4.

n) The following information for each test provision deemed applicable:

   1) The requirements to which the device is tested.

[103] The applicable regulatory requirements should also be stated in the test report; or at minimum, cross-references to specific versions, sections, and dates of regulatory limits should be in the test report. See item n1).

Deviations or modifications (if any) to the test methods defined in Clause 6 and Clause 7 through Clause 16 (as applicable), with the reasons for such deviations.

2) Operating conditions for the EUT (including firmware, specific software settings, and input/output signal levels to the EUT).

3) Modifications made to the device (if any).

4) The results of the test in the form of tables, spectrum analyzer plots, charts, sample calculations and procedures as appropriate for each test.

   Except where the regulatory agency mandates plots and tabular data would not be an appropriate result, test results provided in the test report may be reduced to tabular data demonstrating compliance to the applicable test in all modes of operation, and the plots provided may only cover those demonstrating compliance of the worst-case test results, when practical. Regulatory requirements can supersede any of these reductions. Test data must still be acquired for all modes of operation in line with test streamline guidance.

5) The test equipment used identified by type, manufacturer, serial number, or other identification and the date on which the next calibration or service check is due.

6) Description of the firmware or software used to operate EUT for testing purposes.

7) A description and a block diagram of the test setup.

8) Photographs of the test setup where this is relevant for the repeatability of the test results. These photographs may be included in a separate document.

9) The name of the person(s) who has(have) performed the testing.

An example of a test report layout is shown in Annex B.

In the case of tests performed for internal customers or in the case of a written agreement with a customer, the test results may be reported in a simplified manner. Examples of circumstances under which a simplified test report may be used include testing done for diagnostic purposes, precompliance assessments, and engineering evaluations. When the use of a simplified report is deemed acceptable, the test laboratory or responsible party shall make sure that any information required to comply with the applicable reporting requirements set forth in this standard shall be readily available, so that a full test report can be generated at any point in time. However, a simplified report shall not be used for the purpose of submitting an application to a regulatory authority.

Annex A

(informative)

Cross-references between regulatory requirements and ANSI C63.10 test methods

This annex specifies the procedures that should be performed to determine compliance of unlicensed wireless devices subject to Part 15 of the FCC Rules and Regulations (47 CFR Part 15).

Users of this standard should be aware of the fact that the FCC rules change frequently and that this table should only be used as a GUIDE. The listings in this annex are not intended to be exhaustive nor to identify all testing procedures and policies applicable for a specific product. Users should consult FCC rules and procedures documents directly for any additional requirements and to confirm that this table is up-to-date. See the “Electronic Code of Federal Regulations” (e-CFR) for the latest FCC Rules.[104]

Table A.1 summarizes the basic test requirements specified in FCC 47 CFR Part 15 rule sections for all unlicensed wireless devices, unless otherwise specified, and the corresponding subclauses of ANSI C63.10.

Table A.2 provides a mapping for FCC 47 CFR Part 15 rule sections to ANSI C63.10 test methods for unlicensed wireless devices. For some rule sections, Table A.2 also gives examples of regulatory band-edge requirements and provides guidance for the determining band-edge requirements for various unlicensed wireless devices subject to Part 15. Band-edge requirements vary depending on the rule section under which the device is intended to operate. Band-edge requirements are in terms “occupied bandwidth,” “relative measurement,” and “absolute field strength,” respectively. The procedures for determining bandwidth compliance are provided in 6.9 and 6.10 of this standard. Finally, restricted-band frequencies are listed for convenience for some rule sections in Table A.2, where those are adjacent to specific intentional radiator bands.

Similar regulatory standards administered by Innovation, Science and Economic Development Canada, including various related Innovation, Science and Economic Development Canada (ISED) Spectrum Management and Telecommunications publications, are available online.[105] The IC publications include:

— RSS-Gen: General Requirements for Compliance of Radio Apparatus—Limits and Methods of Measurement
— RSS-210: Licence-exempt Radio Apparatus (All Frequency Bands): Category I Equipment
— RSS-220: Devices Using Ultra-Wideband (UWB) Technology
— RSS-247: Digital Transmission Systems (DTSs), Frequency Hopping Systems (FHSs) and Licence-Exempt Local Area Network (LE-LAN) Devices
— RSS-310: Licence-exempt Radio Apparatus All Frequency Bands): Category II Equipment.

[104] http://www.ecfr.gov/cgi bin/text idx?&c=ecfr&tpl=/ecfrbrowse/Title47/47tab_02.tpl.
[105] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06129.html.

Table A.1—Mapping of FCC 47 CFR Part 15 sections to ANSI C63.10 basic testing requirements for all devices

#	FCC rule section(s)	Selected requirement(s)	ANSI C63.10 subclause(s)	Remarks
01	15.31(c)	Measurement setup for swept-frequency devices.	5.7; 6.11.1; Annex M item 95)	—
02	15.31(e)	Input power or the radiated signal level of the fundamental frequency component of the emission variations versus supply voltage.	5.13	Variation of radiated signal level is measured for all devices subject to field strength limits. Variation of input power is measured for devices subject to §§15.217, 15.219, and 15.235(c).
03	15.31(f)	Distance in rules generally to be used for radiated emissions testing.	5.3.1	—
04	15.31(f)(1)	$f \geq 30$ MHz, extrapolation factor of 20 dB/decade of distance.	5.3.3	Results are extrapolated (converted), not the limits.
05	15.31(f)(2)	$f < 30$ MHz, extrapolation factor of 40 dB/decade of distance.	5.3.2	Results are extrapolated (converted), not the limits.
06	15.31(f)(6)	Measurements performed at a sufficient number of radials.	5.4; 6.6.4.2; 6.6.4.3; 6.11.1; 6.11.2; 8.4.2; 8.4.3; 7.7.3	—
07	15.31(g)	EUT adjusted to maximize output/emissions.	5.10.5; 5.11; 6.3.2; 6.5.4; 6.11.1; 13.2.1; 13.2.2; 8.4.1	Test setup and exploratory measurements.
08	15.31(h)	For composite system devices, all components must be functioning.	5.10.6; Clause 14; Annex M item 15)	—
09	15.31(h)	For devices incorporating more than one antenna or other radiating source, measure with all radiating sources emitting.	5.10.6; 6.3.1; Clause 14	Conducted and radiated emissions shall be performed with all radiating sources emitting simultaneously.
10	15.31(i)	Device shall be tested with the accessories attached.	3.1 System; 5.10.8; 5.14; 6.2.3.1; 6.2.3.2.2; 6.2.3.3.2; B.2.2	The EUT shall be tested in the configuration in which it is marketed.
11	15.31(j)	Selection of accessories for device consisting of a central control unit and an external or internal accessory(ies) (peripheral).	3.1 System; 5.10.8; 6.2.3.1; 6.2.3.2.2; 6.2.3.3.2; B.2.2	The EUT shall be fully exercised. with these external accessories.
12	15.31(l)	LISN specification.	4.2; 4.4.4	—
13	15.31(m)	Number of test frequencies for fundamental emissions.	5.6	—
14	15.31(o)	Reporting of spurious emissions.	5.9; 6.4.6; 6.5.4; 6.6.4.3; B.2.8.3; B.2.8.4	Six highest emissions; no need to report emissions that are more than 20 dB below the limit.
15	15.33(a)	Frequency range for radiated emissions.	5.5	Table 10 for the unlicensed wireless device. Table 1 for the digital device portion.
16	15.33(c)	Frequency range for conducted emissions.	6.2.1	150 kHz to 30 MHz.
17	15.33(d)	Attention paid to harmonics and subharmonics of fundamental frequencies; multiples of oscillator frequencies; multiplier stage frequencies.	5.5	—

Table A.1—Mapping of FCC 47 CFR Part 15 sections to ANSI C63.10 basic testing requirements for all devices *(continued)*

#	FCC rule section(s)	Selected requirement(s)	ANSI C63.10 subclause(s)	Remarks
18	15.35(a)	≤1000 MHz, the limits shown are based on CISPR quasi-peak detector function and related measurement bandwidths, unless otherwise specified. (CISPR 16). As an alternative to CISPR, quasi-peak compliance with the emission limits may be determined using peak detector, with measurements properly corrected for such factors as pulse desensitization. For pulse-modulated devices with a pulse repetition frequency of 20 Hz or less and for which CISPR quasi-peak measurements are specified, use a peak detector, properly correcting measurements for such factors as pulse desensitization.	4.1.5.2.1; 4.1.5.2.7; Annex C	—
19	15.35(b)	>1000 MHz, the radiated emission limits are based on use of an average detector. Unless otherwise specified, use a minimum resolution bandwidth of 1 MHz. Peak level of emissions (20 dB above the maximum average emission limit for both above and below 1000 MHz). Applies to the total peak emission level radiated by the device, for example, the total peak power level. Note that the use of a pulse desensitization correction factor may be needed to determine the total peak emission level.	4.1.5.2.2; 4.1.5.2.7; Annex C	—
20	15.35(c)	Average radiated emissions and pulsed operation is employed, the measurement field strength shall be determined by averaging over one complete pulse train, including blanking intervals, as long as the pulse train does not exceed 0.1 s. For pulse train exceeding 0.1 s, the measured field strength shall be determined from the average absolute voltage during a 0.1 s interval during which the field strength is at its maximum value.	4.1.5.2.5; 7.5	—
21	15.101(b)	Receivers that are contained within a transceiver, which operate (tune) within the frequency range of 30 MHz to 960 MHz, are subject to receiver testing requirements. For example, aside from the transmitter provisions of this standard, receiver requirements remain applicable when a 902 MHz to 928 MHz modular transceiver (15.212 transmitter with receiver) is installed in a final product.	1.2; 5.10.6	This standard does not cover measurement of emissions from radio receivers, receiver portion of a transceiver, and other types of unintentional radiators, which are covered by other standards.
22	15.202	Master devices that operate in a master/client network must be limited to operation on permissible frequencies under 47 CFR Part 15.	N/A	In other words, transmission on 15.205 frequencies must be precluded, as well as transmissions outside of bands specified under 15.217 through 15.257 and/or 15 subpart E, as applicable.
23	15.204	Test highest gain with highest conducted output.	5.8; 5.10.1; 5.10.4; 6.3.2 d); 6.10.3; 6.10.5.2 i); 11.12.2.6; 12.7.4.2	—

Table A.1—Mapping of FCC 47 CFR Part 15 sections to ANSI C63.10 basic testing requirements for all devices *(continued)*

#	FCC rule section(s)	Selected requirement(s)	ANSI C63.10 subclause(s)	Remarks
24	15.205(a)	Prohibited transmit frequencies (i.e., frequency bands in which only device spurious emissions are permitted).	5.9	*Syn.:* exclusion bands.
25	15.205(b)	For $f \leq 1000$ MHz, use CISPR quasi-peak detector. For $f > 1000$ MHz, use average value.	4.1.5.2.1; 4.1.5.2.2; 6.3	Measurand is field strength.
26	15.207(a)	Conducted emissions 150 kHz to 30 MHz.	6.2	Class A and Class B digital device categories of part 15 subpart A and B are not applicable for intentional radiators; 15.207 remains applicable for any intentional radiator device portion of composite system with a Class A or Class B digital device.
27	15.207(c)	Devices with battery chargers that permit operating while charging, and so on require 15.207(a) testing.	6.2; 6.2.3.2.2	—
28	15.209(a)	General field strength limits for intentional radiators.	6.3	Measurand is field strength.
29	15.209(d)	Frequency bands 9 kHz to 90 kHz, 110 kHz to 490 kHz, and above 1000 MHz, use average detector; otherwise, use CISPR quasi-peak detector.	4.1.5.2.1 (for QP); 4.1.5.2.2 (for Av)	—
30	15.209(e)	15.31 (other distances), 15.33 (frequency range), and 15.35 (limiting peak emissions) apply for 15.209(a) measurements.	5.3; 5.5; 7.5; Annex C	—
31	15.212	A modular transmitter (intentional radiator) is a completely self-contained device that is typically incorporated into another product or host.	5.10.2; Annex M	—
32	15.212(a)(1)(ii)	Modular transmitter excessive data rates or overmodulation.	N/A	—
33	15.212(a)(1)(v)	Modular transmitter stand-alone configuration testing.	N/A	—
34	15.212(a)(1)(v)	Modular transmitter ac line-conducted testing (unless a device will only be used in battery powered host).	N/A	—
35	15.212(a)(1)(vii)	A modular transmitter must comply with any specific rules or operating requirements that ordinarily apply to a complete transmitter.	N/A	See ANSI C63.10 subclauses corresponding to the applicable intentional radiator operations part 15 section(s).
36	15.215(b)	Unwanted emissions, for devices under §§15.217 through 15.257.	6.3 through 6.6; Table A.2	—
37	15.215(c)	20 dB bandwidth for devices under §§15.217 through 15.257.	6.9	—
38	15.215(c)	Frequency stability for devices under §§15.217 through 15.257.	6.8	—
39	15.225(e), 15.229(d), 15.231(d), 15.233(g)	Frequency stability versus temperature, and frequency stability versus supply voltage.	6.8	—

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
01	15.205	Swept-frequency field disturbance sensors in 1.705 MHz to 37 MHz	Only spurious emissions are permitted in the restricted-bands per 15.205(a). The frequency sweep must never stop such that the fundamental emission is in the 15.205 bands. The fundamental emission must be outside of the 15.205(a) bands more than 99% of the time the device is actively transmitting, without compensation for duty cycle.	N/A	—
02	15.209 f < 30 MHz	General radiated emissions	Field strength of radiated emissions below 30 MHz. Average detector for 9 kHz to 90 kHz and 110 kHz to 490 kHz [15.209(d)].	4.1.5; 5.2; 5.3.2; 6.3; 6.4	The FCC does not allow the use of a rod antenna to determine compliance with these limits.
03	15.209 30 ≤ f f ≤ 1000	do	Field strength of radiated emissions from 30 MHz to 1000 MHz.	4.1.5; 6.3; 6.5; 6.11.3	—
04	15.209 f > 1 GHz	do	Field strength of radiated emissions above 1 GHz; average detector.	4.1.5; 6.3; 6.6	—
05	15.211(c)	Tunnel radio systems	Total electromagnetic field from a tunnel radio system appearing outside of the tunnel, mine, or other structure.	N/A	See applicable testing procedures in 15.211 and the ANSI C63.10 subclauses corresponding to the applicable intentional radiator operations part 15 section(s).
06	15.211(d)	do	RF voltage on public utility power-lines.	N/A	—
07	15.212	Modular transmitters		N/A	See Table A.1
08	15.213	Cable locating equipment	Peak output power is measured for 9 kHz to 490 kHz; depending on EUT, ac power-line conducted testing might apply.	N/A	Peak power method; matching network needed for conducted measurement. 15.205 is not applicable [15.205(d)(3)].
09	15.214(d)	Cordless telephones	Security provisions.	7.1	One of three methods described can be used; a short description of compliance to the requirements shall be included in the test report.
10	15.217(a)	160 kHz to 190 kHz operations	Total input power.	7.3	—
11	15.217(c)	do	Out-of-band-emissions (OOBE); decibel level relative to unmodulated carrier.	6.3, 6.4; 6.7, 6.10.5/6.10.6	Width of specified band: 30 kHz. Measurand: RF voltage at antenna output terminal or field strength for EUT with permanently attached antenna.
12	15.219(a)	510 kHz to 1705 kHz operations	Total input power.	7.3	—

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
13	15.219(c)	do	OOBE; decibel level relative to unmodulated carrier; band-edge relative measurement.	6.3, 6.4; 6.7	Width of specified band: 1195 kHz. Measurand: RF voltage at antenna output terminal or field strength for EUT with permanently-attached antenna.
14	15.221(a)	525 kHz to 1705 kHz operations	In-band and OOB emissions. Carrier current systems, transmitters with leaky coax, antenna.	6.10.5/6.10.6	Width of specified band: 1180 kHz. Measurand: field strength at specified distance from the electric power-line or coaxial cable. 15.209 apply for OOB.
15	15.221(b)	do	Alternative “on-site test.”	6.4	Measurand: a) OOB field strength on campus b) In-band and OOB field strength at campus perimeter c) Conducted emissions on public utility power-lines off campus
16	15.223(a)	1.705 MHz to 10 MHz operations	Field strength, 6 dB bandwidth.	6.3, 6.4; 6.9, 6.9.2	—
17	15.223(b)	do	OOBE field strength.	6.3, 6.4; 6.5; 6.6, 6.10.5/6.10.6	Width of specified band: 8.295 MHz. 15.209 apply for OOB.
18	15.225(a)-(c)	13.110 MHz to 14.010 MHz operations	Field strength.	6.3, 6.4	QP detector. Band-edge occupied bandwidth: There is a field strength “mask” within the specified band. 15.205 is not applicable for 13.36 MHz to 13.41 MHz band only [15.205(d)(7)].
19	15.225(d)	do	OOBE field strength.	6.3, 6.4; 6.5; 6.6, 6.10.5/6.10.6	Width of specified band: 900 kHz. 15.209 applies for OOB.
20	15.225(e)	do	Frequency stability.	6.8	Frequency stability: If device is battery-operated, then testing is to be conducted with a new battery.
21	15.225(f)	do	Testing for RF powered tags certified with the device.	N/A	Tag may be approved with the device or be considered as a separate device subject to its own authorization.
22	15.227(a)	26.96 MHz to 27.28 MHz operations	Field strength.	6.3, 6.4	Peak-to-average ratio less than 20 dB, average detector.
23	15.227(b)	do	OOBE.	6.3, 6.4; 6.5; 6.6; 6.10.5/6.10.6	Width of specified band: 320 kHz. 15.209 apply for OOB.
24	15.229(a)	40.66 MHz to 40.70 MHz operations	Field strength.	6.3; 6.5	—
25	15.229(b)	do	Field strength using average detector for perimeter protection systems.	N/A	—

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
26	15.229(c)	Do	OOBE.	6.3, 6.4; 6.5; 6.6, 6.10.5/6.10.6	Width of specified band: 40 kHz. 15.209 apply for OOB.
27	15.229(d)	do	Frequency stability.	6.8	—
28	15.231(a)	40.66 MHz to 40.70 MHz and above 70 MHz periodic operations	Demonstrate that transmission is a control signal, and so on.	N/A	Refer to device documentation, user manual, and operational description.
29	15.231(a)(1)	do	Deactivation time.	7.4	Use this section as general guidance on capturing TX time in zero span mode. Adjust the sweep time as needed to show data needed.
30	15.231(a)(2)	do	Deactivation time.	7.4	Set the sweep time to more than 5 s and perform single activation of device.
31	15.231(a)(3)	do	Demonstrate nonperiodic; transmit time per hour.	N/A	Refer to operational description and perform measurements as needed.
32	15.231(a)(5)	do	Transmit time, and so on.	7.4	Refer to operational description and perform measurements as needed.
33	15.231(b)	do	Field strength.	5.6, 6.3; 6.4.7, 6.5, 6.6, 7.4, 7.5, 7.6	Av value; see also 15.205 provisions, instrumentation.
34	15.231(c)	do	Bandwidth, determined at the points 20 dB down from the modulated carrier.	6.9.2	Width of specified band: Varies with frequency. • 40.66 MHz to 40.77 MHz shall remain in-band. • 70 MHz to 900 MHz: <0.25% of center frequency. • >900 MHz: <0.5% of center frequency. 15.209 apply for OOB.
35	15.231(d)	do	Frequency stability.	6.8	Frequency stability—If device is battery-operated testing is to be conducted with a fresh battery.
36	15.231(e)	do	Transmit time, and so on.	7.4	Refer to operational description.
37	15.233(b)	Cordless phones in 43.71 MHz to 44.49 MHz, 46.60 MHz to 46.98 MHz, 48.75 MHz to 49.51 MHz, and 49.66 MHz to 50.0 MHz	Demonstrate frequency pairing, and so on.	7.2	Attestation procedure to demonstrate that the frequency pairing for cordless phones is compliant to the applicable requirements.
38	15.233(c)	do	Field strength.	5.6, 6.3; 6.5	Average detector.

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
39	15.233(d)	do	Measure "mask," and so on. Modulation products outside of 20 kHz band shall be attenuated at least 26 dB below the level of the unmodulated carrier or to 15.209 levels, whichever permits higher.	5.12; 6.9; 6.10; 6.10.5/6.10.6	15.235(d) "…Tests to determine compliance with these requirements shall be performed using an appropriate input signal as prescribed in §2.989 of this chapter." Erratum: 2.989 is now 2.1049. 15.209 applies for OOB. Band-edge: Emissions on any frequency removed from the center frequency by more than the EBW must be solely unwanted emissions. 20 kHz channel bandwidth.
40	15.233(g)	do	Frequency stability.	6.8	—
41	15.235(a)	49.82 MHz to 49.90 MHz operations	Field strength.	5.6, 6.3; 6.5	Peak-to-average ratio less than 20 dB, average detector.
42	15.235(b)	do	Measure "mask." Band-edge relative measurement: Field strength of any emissions appearing between the band-edges and up to 10 kHz above and below the band-edges shall be attenuated at least 26 dB below the level of the unmodulated carrier or to the 15.209 levels, whichever permits higher.	6.9; 6.10; 6.10.4 or 6.10.5/6.10.6	Width of specified band: 80 kHz. 15.209 apply for OOBE (more than 10 kHz from the band-edges).
43	15.235(c)	do	Home-built devices.	6.3; 6.9	See applicable testing procedures in 15.235(c).
44	15.237(b)	Auditory assistance devices in 72.0 MHz to 73.0 MHz, 74.6 MHz to 74.8 MHz, and 75.2 MHz to 76.0 MHz	Band-limited band-edge occupied bandwidth. Restricted-band(s) adjacent: 73 MHz to 74.6 MHz, 74.8 MHz to 75.2 MHz.	6.9; 6.10; 6.10.4 and 6.10.5	Average detector. 200 kHz channel bandwidth. Field strength μV/m (average) at 3 m outside of the 200 kHz channel bandwidth. The 200 kHz channel shall lie wholly within the specified frequency ranges.
45	15.237(c)	do	Field strength.	5.6, 6.3; 6.5	Average detector; peak-to-average ratio less than 20 dB.
46	15.239(a)	88 MHz to 108 MHz operations	Band limited. 15.209 outside of the 200 kHz channel; the 200 kHz channel shall remain within the band; band-edge occupied bandwidth.	6.9.2, 8.7	20 dB occupied bandwidth per 15.215.
47	15.239(b)	do	Field strength.	5.6, 6.3; 6.5; 6.6; 8.1; 8.2; 8.3; 8.4; 8.6	Average detector. The method in 8.5 may be employed at the discretion of the regulatory authority.

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
48	15.239(c)	do	OOBE.	6.3 through 6.6; 6.10.4; 8.1; 8.2; 8.3; 8.4; 8.6	Width of specified band: 10 MHz. 15.209 applies for OOB.
49	15.240(b)	Commercial RFID devices in 433.5 MHz to 434.5 MHz	Field strength.	6.3; 6.5	Average detector.
50	15.240(b)	do	Transmit time, and so on.	7.4; 6.10.5/6.10.6	Measurement of both transmission time and silent time required.
51	15.240(c)	do	OOBE.	6.3 through 6.6	Width of specified band: 1 MHz. 15.209 apply for OOB.
52	15.240(d)	do	Testing for RF-powered tags certified with the device.	N/A	Tag may be approved with the device or be considered as a separate device subject to its own authorization.
53	15.241	Biomedical telemetry devices in 174 MHz to 216 MHz	Not applicable; not available for new devices [see 15.37(b)].	6.10.4	Per 15.37(b), new device certifications are not available for §15.241 operations.
54	15.242	Biomedical telemetry devices in health care facilities in 174 MHz to 216 MHz, 470 MHz to 668 MHz	Not applicable; not available for new devices [see 15.37(b)].	N/A	Per 15.37(b), new device certifications are not available for §15.242 operations.
55	15.243(b)	RF measuring devices in 890 MHz to 940 MHz	Field strength.	6.3; 6.5	Average detector; peak-to-average ratio less than 20 dB.
56	15.243(c)	do	OOBE.	6.3; 6.5; 6.6, 6.10.5/6.10.6	Width of specified band: 50 MHz. 15.209 apply for OOB.
57	15.245(b)(2)	Field disturbance sensors in 902 MHz to 928 MHz, 2435 MHz to 2465 MHz, 5785 MHz to 5815 MHz, 10 500 MHz to 10 550 MHz, and 24 075 MHz to 24 175 MHz	Field strength.	6.3 through 6.6	Average detector; peak-to-average ratio less than 20 dB. Perimeter protection systems not permitted. For 24.075 GHz to 24.175 GHz band devices, 15.205 is not applicable for 48.15 GHz to 48.35 GHz and 72.225 GHz to 72.525 GHz bands only [15.205(d)(8)].

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
58	15.245(b)(3)	do	OOBE; band-edge absolute field strength.	6.3 through 6.6, 6.10.4 or 6.10.5/6.10.6	Width of specified band: Varies with frequency. Band-edge relative measurement: –50 dB (or 15.209, whichever is less). For field disturbance sensors, harmonic emissions in restricted-bands above 17.7 GHz are subject to 15.245(b) limits [15.205(e)].
59	15.247	Frequency hopping and digitally modulated devices in 902 MHz to 928 MHz, 2400 MHz to 2483.5 MHz, and 5725 MHz to 5850 MHz	DTS procedure, multioutput devices, beamforming, and so on.	7.7, Clause 11; Clause 13; Clause 14, 6.10.5/6.10.6 for 2400 MHz to 2483.5 MHz band	Band-edge occupied BW: Minimum 6 dB BW is 500 kHz for DTS devices. Band-edge attenuation: –20 dB or –30 dB in a 100 kHz BW relative to highest fundamental channel PSD in 100 kHz (based on power measurement method used). Band-edge: 15.209 applies to adjacent and nearby restricted-bands for 2400 MHz to 2483.5 MHz band operations.
60	15.249(a)	902 MHz to 928 MHz, 2400 MHz to 2483.5 MHz, 5725 MHz to 5875 MHz, and 24.0 GHz to 24.25 GHz operations	Field strength. Restricted-band(s) adjacent: 2.4835 GHz to 2.5 GHz, 23.6 GHz to 24 GHz.	6.3; 6.5; 6.6, 6.10.4 or 6.10.5/6.10.6	Width of specified band: Varies with frequency. Band-edge attenuation decibel level (or 15.209, whichever is less). BW not specified. For 24.0 GHz to 24.25 GHz band devices, 15.205 is not applicable for 48.0 GHz to 48.5 GHz and 72.0 GHz to 72.75 GHz bands only [15.205(d)(9)].
61	15.249(e)	do	Peak field strength for each modulation.	4.1.5.2.2; 6.5, 6.6	—
62	15.250(a)	Wideband systems operations in 5925 MHz to 7250 MHz	–10 dB bandwidth contained in allowed band, including frequency stability and modulation effects. Restricted-band(s) adjacent: 7.25 GHz to 7.75 GHz.	6.8; 6.10.4, 10.1	Width of specified band: 1325 MHz.
63	15.250(b)	do	Minimum span of –10 dB bandwidth.	10.1	Band-edge occupied BW: The –10 dB bandwidth of the fundamental emission shall be at least 50 MHz.
64	15.250(d)	do	EIRP.	6.6; 10.3; Annex G	RMS-Av (4.1.4.2.5).
65	15.250(e)	do	Measurement procedures.	6.5	—

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
66	15.251(b)	Automatic vehicle identification systems in 2.9 GHz to 3.26 GHz, 3.267 GHz to 3.332 GHz, 3.339 GHz to 3.3458 GHz, and 3.358 GHz to 3.6 GHz	Field strength; also at within ±10° from horizontal. Restricted-band(s) adjacent: 2.69 GHz to 2.9 GHz, 3.26 GHz to 3.267 GHz, 3.332 GHz to 3.339 GHz, 3.3458 GHz to 3.358 GHz, 3.6 GHz to 4.4 GHz.	6.6, 6.10.5/6.10.6	Width of specified band: Varies with frequency. Swept-frequency range must lie within authorized band. In addition to the provisions of 15.205, the field strength of radiated emissions outside the frequency range swept by the signal shall be limited to a maximum μV/m/MHz level at 3 m.
67	15.251(c)	do	Demonstrate device sweep rate(s).	N/A	—
68	15.251(e)	do	Demonstrate "sense vehicle presence before transmit."	N/A	—
69	15.251(g)(2)	do	Off-axis field strength reduction (radiation pattern).	N/A	—
70	15.252(a)(1)	Wideband vehicular radar systems operations in 16.2 GHz to 17.7 GHz and 23.12 GHz to 29.0 GHz	–10 dB bandwidth contained in allowed band, including freq. stability and modulation effects. Restricted-band(s) adjacent: 15.35 GHz to 16.2 GHz, 17.7 GHz to 21.4 GHz, 22.01 GHz to 23.12 GHz, 23.6 GHz to 24 GHz.	6.8; 10.1	Width of specified band: Varies with frequency. Notch for 23.6 GHz to 24.0 GHz restricted-band.
71	15.252(a)(2)	do	Minimum span of –10 dB bandwidth.	10.1	Band-edge occupied BW: The –10 dB bandwidth of the fundamental emission shall be 10 MHz or greater.
72	15.252(b)	do	EIRP.	6.6, 6.10.5/6.10.6; Annex G	RMS-Av (4.1.4.2.5). Band-edge absolute field strength, dBm/MHz EIRP.
73	15.252(c)	do	Measurement procedures.	6.5	—
74	15.255(c)	57 GHz to 71 GHz operations	In-band radiated emissions	9.9	15.205 is not applicable [15.205(d)(4)].
75	15.255(d)	do	Spurious emissions, field strength below 40 GHz, average spatial power density from 40 GHz to 200 GHz	9.10, 9.11	Average spatial power density limit expressed in units of pW/cm^2 at 3 m.
76	15.255(e)	do	Peak transmitter output power.	9.9	—
77	15.255(f)	do	Frequency stability.	9.5	—
78	15.256(f); 15.215(c)	Level Probing Radars within 75 GHz to 85 GHz band	Fundamental bandwidth	9.3, 9.5	Also see FCC/KDB 890966 [B35]
79	15.256(g)	do	Fundamental emissions	9.8	Also see FCC/KDB 890966 [B35]
80	15.256(h)	do	Unwanted emissions	9.10, 9.11	Also see FCC/KDB 890966 [B35]
81	15.257(c)	Indoor-only devices in 92 GHz to 95 GHz	In-band radiated emissions, average and peak spatial power density.	9.9	15.205 is not applicable [15.205(d)(4)]. Spatial power density limits expressed in units of μW/cm^2 at 3 m.
82	15.257(d)	do	Spurious emissions, field strength below 40 GHz, average spatial power density from 40 GHz to 200 GHz	9.10, 9.11	Average spatial power density limit expressed in units of pW/cm2 at 3 m.
83	15.257(e)	do	Peak transmitter output power.	9.9	—

Table A.2—Mapping of FCC rule sections into ANSI C63.10 test methods *(continued)*

#	FCC rule section(s)	Description/application (do = ditto)	Selected requirement(s) and/or measurand(s)	ANSI C63.10 subclause(s)	Remarks
84	15.257(f)	do	Frequency stability.	9.5	—
85	15 subpart D	Unlicensed personal communications service devices		N/A	Outside scope of ANSI C63.10. See ANSI C63.17-2006 [B5]. 15.205 is not applicable [15.205(d)(6)].
86	15 subpart E	Unlicensed national information infrastructure devices		Clause 12	Field strength limits outside of specified bands expressed as EIRP or field strength (for emissions outside restricted-bands), field strength for emissions inside restricted-bands. All are covered under Clause 12.
87	15 subpart F	Ultrawideband devices		Clause 10	15.205 is not applicable [15.205(d)(6)].
88	15 subpart H	Television band devices		Clause 15	See FCC/KDB-416721 [B31].

Annex B

(informative)

Example test report contents

B.1 General

Test reports are the means of presenting the test results to the appropriate procuring or regulatory agency or for archiving the data in the permanent files of the testing organization. As such, test reports should be clearly written in unambiguous language. A practical guide to follow is contained in 5.10 of ISO/IEC 17025:2017 [B50].

B.2 Test report content

The conditions relating to the tests listed in B.2.1 through B.2.8 should be described in the test report for the test results to be documented properly.

B.2.1 Applicable standards

In addition to this standard, any other standards or test procedures to which the EUT was tested should be described clearly in the test report. Where referenced standards have more than one measurement procedure or where the referenced measurement procedure has options, the test report should state which procedures or options were used. The test report should also state the issue or year of the referenced standard(s) used.

B.2.2 Equipment units tested

The test report should list all equipment tested, including product type and marketing designations, where applicable. Serial numbers and any other distinguishing identification features should also be included in the test report. Identification or a detailed description should also be made of interconnecting cables. The rationale for selecting the EUT, comprising the equipment units needed to be functionally complete, as well as the necessary cabling, antennas, or accessories should be noted in the test report.

B.2.3 Equipment, antenna, and cable arrangement

The setup of the equipment and cable or wire placement on the test site that produces the highest radiated and the highest ac power-line conducted emissions should be shown clearly and described. Information on the orientation of portable equipment during testing should be included. Drawings or photographs may be used for this purpose.

B.2.4 List of test equipment

A complete list of all test equipment used should be included with the test report. The manufacturer's model and serial numbers, and date of last calibration, and calibration interval should be included. Measurement cable loss, measuring instrument bandwidth and detector function, video bandwidth, if appropriate, and antenna factors should also be included where applicable.

B.2.5 Units of measurement

Unless noted otherwise in the referenced standard, the measurements of ac power-line conducted emissions and conducted power output should be reported in units of dBµV. Unless noted otherwise in the referenced standard, the measurements of radiated emissions should be reported in units of decibels, referenced to one microvolt per meter (dBµV/m) for electric fields, or to one ampere per meter (dBA/m) for magnetic fields, at the distance specified in the appropriate standards or requirements. The measurements of antenna conducted power for receivers may be reported in units of dBµV if the impedance of the measuring instrument is also reported. Otherwise, antenna conducted power should be reported in units of decibels referenced to one milliwatt (dBm). All formulas for data conversions and conversion factors, if used, should be included in the measurement report.

B.2.6 Location of test facility

The location of the test site should be identified in the test report. Facilities that have received recognition or listing from various accreditation bodies should use the same site address information as was included in their original application for recognition or listing.

B.2.7 Measurement procedures

The sequence of testing followed to determine the emissions included in the test report should be documented in sufficient detail to allow replication of the test results by procuring or regulatory agencies, or if required to perform additional tests and ongoing compliance checks. Any measurements that use special test software should be indicated and referenced in the test report.

B.2.8 Reporting measurement data

B.2.8.1 General requirements

The measurement results, along with the appropriate limits for comparison, should be presented in tabular or graphical form. Alternatively, recorded charts, spectral plots from the spectrum analyzer, or printouts of receiver screen contents may be used if the information is presented clearly showing a comparison with the limits, and all data conversions are explained. In addition, any variation in the measurement environment should be reported (e.g., a significant change of temperature will affect the cable loss and amplifier response).

B.2.8.2 Measurement uncertainty

The results of measurements of emissions from transmitters should reference the measurement instrumentation uncertainty considerations contained in ETSI TR 100 028; see also CISPR 16-4-2:2011 [B8] for other EMC measurement uncertainty considerations. Determining compliance should be based on the results of the compliance measurement, not taking into account measurement instrumentation uncertainty. Hence, the measurement uncertainty of the measurement instrumentation and its associated connections between the various instruments in the measurement chain should be calculated, and both the measurement results and the calculated uncertainty should be given in the test report.

B.2.8.3 AC Power-line conducted emissions data

The frequency and amplitude of the six highest ac power-line conducted emissions relative to the limit, measured over all the current-carrying conductors of the EUT power cords, and the operating frequency or frequency to which the EUT is tuned (if appropriate), should be reported, unless such emissions are more than 20 dB below the limit. AC power-line conducted emissions measurements are to be separately carried out only on each of the phase (“hot”) line(s) and (if used) on the neutral line(s), but not on the ground [protective earth] line(s). If less than six emission frequencies are within 20 dB of the limit, then the noise level of the measuring instrument at representative frequencies should be reported. The specific conductor of the power-line cord for each of the reported emissions should be identified. Measure the six highest emissions with respect to the limit on each current-carrying conductor of each power cord associated with the EUT (but not the power cords of associated or peripheral equipment that are part of the test configuration). Then, report the six highest emissions with respect to the limit from among all the measurements identifying the frequency and specific current-carrying conductor identified with the emission. The six highest emissions should be reported for each of the current-carrying conductors, or the six highest emissions may be reported over all the current-carrying conductors.

B.2.8.4 Radiated emissions data

For each of the frequencies to which the device is tuned, the frequency and amplitude of the six highest radiated emissions relative to the limit and the operating frequency, or frequency to which the EUT is tuned (if appropriate), should be reported unless such emissions are more than 20 dB below the limit. If less than the specified number (less than six) emissions are within 20 dB of the limit, then the noise level of the measuring instrument at representative frequencies should be reported.

The polarization of the measurement antenna (horizontal or vertical) should be identified for each of the reported emissions, as should the orientation of the EUT (for devices that can be positioned in multiple orientations). Radiated emissions measurements taken at alternative distances are to be converted to the limit distance using the inverse distance relationship, unless data can be presented to validate a different conversion. At a reported frequency, the polarization with the highest level should be reported.

B.2.8.5 Output and spurious conducted data

For each of the frequencies to which the transmitter or receiver is tuned, if antenna conducted power measurements are performed, then the frequency to which the EUT is tuned, the frequency and level harmonic and spurious emissions, relative to the appropriate limit, and the impedance of the measuring instrument should be reported. If less than six emissions are within 10 dB of the limit, then the noise level of the measuring instrument at representative frequencies should be reported.

Annex C

(informative)

Pulse desensitization considerations for emission measurements using a spectrum analyzer or EMI receiver (Schaefer [B69])

C.1 Narrowband emission

C.1.1 General

A narrowband emission is defined as a signal for which the instrument displays a "line" spectrum. This occurs when the 3 dB bandwidth of a spectrum analyzer or EMI receiver is narrow compared with the frequency spacing of the spectral components of the signal to be measured. A line spectrum will occur when the resolution bandwidth (RBW) of the filter used for measurement is smaller than the pulse repetition frequency (PRF) of the signal, as described by Equation (C.1):

$$\mathrm{RBW} << \mathrm{PRF} \tag{C.1}$$

The following rule of thumb shown in Equation (C.2) provides the display of a line spectrum (narrowband emission):

$$\mathrm{RBW} < 0.3 \times \mathrm{PRF}\left(\mathrm{RBW} < 0.1 \times \mathrm{PRF}_{\mathrm{preferred}}\right) \tag{C.2}$$

If Equation (C.2) is satisfied, then all individual spectral components of the signal to be measured can be resolved and displayed. Only one spectral component is within the IF filter pass band at any one time. Therefore, the instrument display shows the frequency-domain representation of the actual Fourier components of the input signal.

The presence of narrowband emissions can be verified by the following:

- Varying the sweep time of the instrument while observing the actual spacing of the displayed signal components—the spacing will not change if the emissions are narrowband.
- Changing the RBW of the instrument while observing the amplitude of the displayed spectral components—the amplitudes will not change, if the emissions are narrowband [i.e., Equation (C.1) is met].

When a line spectrum is displayed on the instrument, the main pulse parameters can be determined as follows:

a) The difference between two adjacent spectral components represents the PRF.

b) The spacing of two adjacent side lobe minima represents $1/\tau$ and thus can be used to determine the pulse width.

c) The spacing of the two main lobe minima represents $2/\tau$ and can also be used to determine the pulse width.

d) The duty cycle of the pulse can be determined by using the two parameters determined previously: $\alpha = \tau \times \mathrm{PRF}$.

It can also be observed that the amplitude of the carrier signal (which is the highest amplitude in the spectrum envelope) of a pulse-modulated signal is considerably lower than the continuous wave amplitude of the unmodulated carrier—this effect is called “pulse desensitization.”

C.1.2 Pulse desensitization factor α_L for line spectrum display

The reduction in the display of the carrier amplitude is due to the pulse modulation of the carrier. The carrier power is distributed over several spectral components, and each one of these components (i.e., carrier and sidebands) contains only a fraction of the total power.

For a line spectrum presentation (i.e., narrowband case), the desensitization is directly (and only) related to the pulse duty cycle, per Equation (C.3) and Equation (C.4):

$$\alpha_{\mathrm{L}}(\mathrm{dB}) = 20\log\left(\frac{\tau}{T}\right) \tag{C.3}$$

$$\alpha_{\mathrm{L}}(\mathrm{dB}) = 20\log(\tau \times \mathrm{PRF}) \tag{C.4}$$

The average power P_{AVG} of the signal is also dependent on the duty cycle shown in Equation (C.5) and Equation (C.6):

$$P_{\mathrm{AVG}} = P_{\mathrm{PEAK}}\frac{\tau}{T} \tag{C.5}$$

$$P_{\mathrm{AVG}} = P_{\mathrm{PEAK}}(\tau \times \mathrm{PRF}) \tag{C.6}$$

This can be expressed as a logarithmic ratio (dB) as shown in Equation (C.7):

$$P_{\mathrm{AVG}} / P_{\mathrm{PEAK}}(\mathrm{dB}) = 10\log(\tau \times \mathrm{PRF}) \tag{C.7}$$

Table C.1 summarizes the range of numerical values.

Table C.1—Pulse desensitization (line spectrum)

Pulse desensitization (dB)	Duty cycle	$P_{\mathrm{AVG}}/P_{\mathrm{PEAK}}$ (dB)
0	1	0
−20	0.1	−10
−40	0.01	−20
−60	0.001	−30
−80	0.0001	−40

It can be seen that for low duty cycles, the desensitization factor becomes very large and that the sensitivity of the spectrum analyzer or EMI receiver, along with the maximum signal level at the broadband input mixer, become important factors.

C.2 Broadband emission

C.2.1 General

A "pulse" spectrum is displayed by the instrument when the RBW of the instrument is equal to or greater than the PRF. Under this condition, the emission is considered to be "broadband." The analyzer or receiver cannot resolve each spectral component of the input signal because multiple spectral lines are within the pass band of the IF filter at any given time. However, if the RBW is narrow compared with the spectrum envelope, then the envelope can still be resolved. The resultant display on a spectrum analyzer or swept-frequency EMI receiver is not a true frequency-domain display, but it is a combination of time and frequency-domain displays. It is a time-domain display of pulse lines because each line is displayed when a pulse occurs, regardless of the frequency within the pulse spectrum to which the instrument is tuned to at a given instant. It is, however, also a frequency-domain display because it depicts the spectrum envelope.

The presence of a pulse display can be verified for example by the following:

— Varying the sweep time of the instrument while observing the actual spacing of the displayed signal components—the spacing and number of lines will change on the display. The lines are spaced in real time by 1/PRF. The spectrum envelope will remain the same when changing the sweep time.

— Varying the frequency span will not affect the spacing of the displayed responses. However, the spectrum envelope will change horizontally.

— The amplitude of the displayed envelope will increase linearly as the RBW is increased. This means an amplitude increase of 6 dB for doubling the RBW. This change can be observed as long as the RBW does not exceed 0.2/τ. When the RBW equals 1/τ (or half of the main lobe width), the display amplitude is practically the peak amplitude of the signal. At this point, all the significant spectral components of the signal are within the pass band of the IF filter. At this point, the spectrum envelope cannot be resolved any longer.

Some rules of thumb are of importance for the proper operation of the measuring instrument and the correct interpretation of pulse spectra:

a) For sufficient resolution of the spectrum envelope, the RBW should be less than 5% of the main lobe width as shown in Equation (C.8):

$$\mathrm{RBW} < \frac{0.1}{\tau} \tag{C.8}$$

For better resolution of lobe minima (20 dB to 30 dB), Equation (C.9) should be satisfied:

$$\mathrm{RBW} < \frac{0.03}{\tau} \tag{C.9}$$

b) The instrument should respond to each pulse independently to avoid measuring the result of overlapping pulses. This means that the effects of one pulse should decay before the next pulse occurs. The normalized IF amplifier decay time constant is approximately 0.3/RBW. A decay of the pulse response of the IF amplifier to 1% (i.e., 40 dB) requires five time constants. This fact leads to the following rule shown in Equation (C.10):

$$\mathrm{RBW} > 1.5 \times \mathrm{PRF} \tag{C.10}$$

The range between RBW < 0.3 PRF (line spectrum) and B < 1.5 PRF (pulse spectrum) shows the properties of both response types and should be avoided.

c) The number of pulse lines from which the spectrum envelope display is determined by the PRF and the sweep time. For a display with useful resolution, meaning, sufficient number of lines, the sweep time should be selected as follows in Equation (C.11):

$$t_{\text{sweep}} = \frac{100}{\text{PRF (Hz)}} \tag{C.11}$$

This assures that more than 100 lines are used to form the spectrum envelope; therefore, the main lobe peak is then displayed on each scan.

The response of the instrument to each RF pulse is in essence the pulse response of the IF amplifier when displaying a pulse spectrum. The peak pulse response should be relatively independent of the pulse shape and PRF (for RBW > PRF). However, the actual implementation of the IF filter will determine the impact of these signal parameters on the displayed test result.

C.2.2 Pulse desensitization factor α_P for pulse spectrum display

The expression relating the peak pulse response to a continuous wave signal response is the pulse desensitization factor α_P. This parameter for the pulse spectrum depends on physical parameters different from those for the line spectrum parameter α_L, namely:

$$\alpha_{\text{P}}\left(\text{dB}\right) = 20\log\left(\tau \times B_{\text{imp}}\right) \tag{C.12}$$

This equation includes the factor B_{imp}, which represents the effective impulse bandwidth of the IF filter. The impulse bandwidth of a filter is defined as the bandwidth of an ideal rectangular shaped filter with a pulse response equivalent to the actual filter with a 3 dB bandwidth equal to the RBW of the IF filter. The impulse bandwidth specification of a filter is different from its 3 dB or 6 dB bandwidth specification. Various methods are available and described in the literature to determine the impulse bandwidth of a filter (Schaefer [B70]). As indicated by Equation (C.12), the desensitization factor becomes very high for short pulses, even for the widest bandwidths. It should also be noted that the peak pulse amplitude at the input mixer should stay below the 1 dB compression point to reduce the chance of compression and erroneous test results. These two parameters, pulse desensitization and the 1 dB compression point of the input mixer, effectively limit the usable display range for proper pulse parameter analysis.

C.3 Application procedure

The following steps should be taken to address pulse desensitization issues:

a) Determination of narrowband versus broadband display of the signals of interest should be done.

b) The pulse parameters (i.e., pulse width, pulse period, or PRF) should be determined.

c) The impulse bandwidth of the measurement instrument should be determined (for broadband emission only).

d) The displayed carrier amplitude should be corrected, using the factor for the applicable display signal.

A general process chart is shown in Figure C.1.

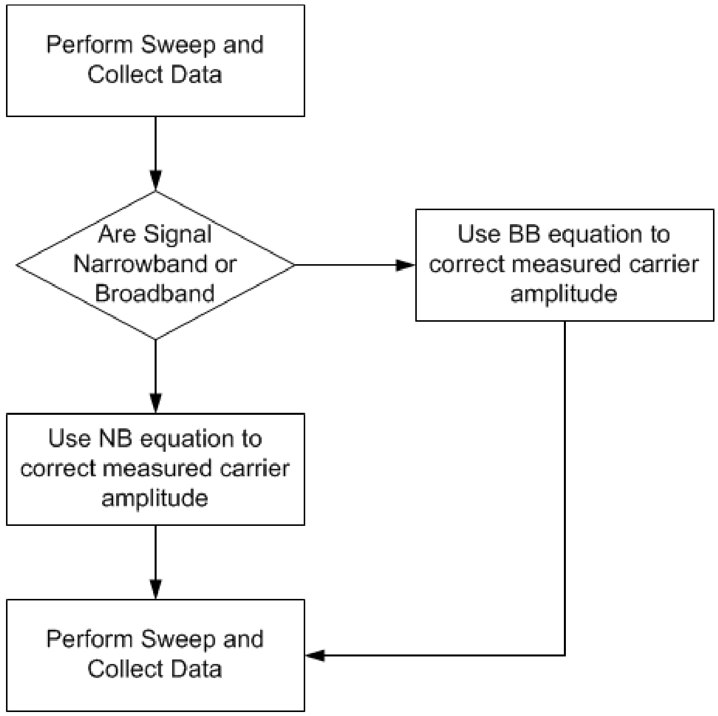


Figure C.1—Pulse desensitization correction process

Annex D

(informative)

Detector functions

D.1 Introduction

The following four distinguishable types of envelope detectors are available for use with emission measurement systems:

a) RMS voltage
b) Quasi-peak voltage
c) Peak voltage
d) Average voltage

The choice of detector should be based on some knowledge of the signal environment, the ultimate application of the emission data, and the database available for reference and trend analyses. Of the four types, the rms voltage detector offers the most flexible measure of the radiated signal environment; the resulting measure of average power is of fundamental importance in all radio systems work. The remaining three detectors possess more limited applicability. It should be noted that quasi-peak and peak-voltage detectors have had extensive use in certain site survey applications, principally those conducted by the electric power and automotive industries and by the military. Consequently, extensive databases have been assembled for both detectors. Quasi-peak detectors have been employed in the measurement of am broadcast signal environments; here, it has been demonstrated that the quantitative derived noise data are highly correlated with subjective annoyance effects. Peak detectors are particularly useful in measuring interference environments consisting of low-repetition-rate impulses that can produce errors on digital data transmission links.

The average voltage detector has been employed much less frequently in site survey studies than either peak or quasi-peak detectors; consequently, only a limited database exists. The utility of this detector type is principally confined to the measurement of continuous wave modulated signals and the voltage deviation V_d, which is a measure of the impulsiveness of random signals, defined as the ratio of the root mean squared envelope voltage to the average envelope voltage of a signal expressed in decibels.

Much of the information describing the four detector types was drawn from ANSI C63.2, and is summarized in this annex for ready reference.

D.2 Detector types

D.2.1 RMS voltage detector

The rms detector should provide true rms measurement for all types of modulated signals and random waveforms. A selectable integrating time constant ranging from 0.1 s to 100 s is recommended. A minimum linear dynamic range of 100 dB is necessary for the detection of impulsive noise. The detector bandwidth should equal or slightly exceed the intermediate frequency bandwidth of the receiver. The rms detector should be capable of measuring all types of modulated signals or noise that have a crest factor of up to 10 (20 dB).

D.2.2 Quasi-peak voltage detector

D.2.2.1 General

The linear range of the quasi-peak detector as measured between the receiver noise floor and the 1 dB gain compression point should be as given in Table D.1.

Table D.1—Linear range of quasi-peak detector

Frequency range (MHz)	Predetection (dB)	Postdetection (dB)
0.01 to 0.15	24.0	12
0.15 to 30.00	30.0	12
30.00 to 1000.00	43.5	6

The quasi-peak detector circuit should have the characteristics shown in Table D.2 for the frequency ranges indicated.[106]

Table D.2—Quasi-peak voltage detector nominal characteristics

Frequency range (MHz)	Charge time constant (ms)	Discharge time constant (ms)	Optional discharge time constant (ms)
0.01 to 0.15	45	500 ± 20%	
0.15 to 30.00	1	160 ± 20%	600 ± 20% [a]
30.00 to 1000.00	1	550 ± 20%	

[a] This discharge time constant is required for interference measurements in the U.S. electric power industry.

The charge time constant is the time needed, after the instantaneous application of a constant sine-wave voltage for the output voltage to reach 63% of its final value.

The discharge time constant is the time needed, after the instantaneous removal of a constant sine-wave voltage applied to the input of the measuring set, for the output voltage to fall to 37% of its initial value.

In the special case of interference measurements associated with electrical power apparatus, interference meters with quasi-peak detector time constants of 1 ms charge and 600 ms discharge, and having 6 dB bandwidths of approximately 4.5 kHz, may be used at frequencies near 1 MHz. The use of these meters is acceptable because it has been established that, for the types of electrical discharges, they will read essentially the same as the CISPR meter with 1 ms charge and 160 ms discharge time constants and 9 kHz, 6 dB bandwidth (ANSI C63.2).

D.2.2.2 Pulse amplitude response

The pulse amplitude response of the measuring set with a quasi-peak detector, throughout the frequency, amplitude, and pulse repetition rate range specified in Table D.3 (with a uniform spectrum throughout the frequency range), should be equal to the response of an unmodulated sine-wave signal of 2 mV rms produced by a signal generator of equal impedance. When the output impedance of the generator is equal to the input impedance of the measuring set, the rms sine-wave signal at the input to the measuring set will be 1 mV.

[106] The parameters of the quasi-peak detector agree with CISPR (International Special Committee on Radio Interference).

Table D.3—Pulse amplitude response

Frequency range (MHz)	Pulse amplitude (µV)	Pulse amplitude dB(µV/MHz)	Repetition rate (Hz)
0.015 to 0.15	13.5	139.5	25
0.150 to 30.00	0.316	107.0	100
30.000 to 1000.00	0.044	90.0	100

D.2.2.3 Pulse repetition rate response

The response of the measuring set with a quasi-peak detector to repeated impulses should be such that, for a constant indication on the measuring set, the relationship between amplitude and repetition frequency should be between the limits shown in Table D.4.

Table D.4—Amplitude versus repetition frequency limits

Repetition frequency (Hz)	Relative equivalent level of pulse (dB)		
	(MHz) 0.01 to 0.15	(MHz) 0.15 to 30	(MHz) 30 to 1000
1000	[a]	−4.5 ± 1.0	−8.0 ± 1.0
100	−4.0 ± 1.0	0	0
60	−3.0 ± 1.0	[a]	[a]
25	0	[a]	[a]
20	[a]	6.5 ± 1.0	9.0 ± 1.0
10	4.0 ± 1.0	10.0 ±1.5	14.0 ± 1.5
5	7.5 ± 1.5	[a]	[a]
2	13.0 ± 2.0	20.5 ± 2.0	26.0 ± 2.0
1	17.0 ± 2.0	22.5 ± 2.0	28.5 ± 2.0
Isolated pulse	19.0 ± 2.0	23.5 ± 2.0	31.5 ± 2.0

[a] Indicates level is not specified for this frequency range.

D.2.3 Peak-voltage detector

D.2.3.1 General

The linear dynamic range of the peak-voltage detector as measured between the receiver noise floor and the 1 dB gain compression point should be 60 dB and have an accompanying spurious response rejection of at least 60 dB.

D.2.3.2 Direct peak

The direct peak detector should have a charging circuit with a time constant in seconds that is short compared to the reciprocal of the receiver bandwidth in hertz. The discharge time constant (that is, peak hold) should be a minimum of five times the time constant of the output indicating device. A peak hold circuit with a dump circuit is recommended. Manual control of the discharge or dump time constant by either a step function or a continuous variable is recommended.

D.2.3.3 Manual slideback peak

The manual slideback peak detector can be designed as either a back bias circuit or a comparator circuit for determining the peak of the noise envelope. Either an aural or a visual indication of the threshold point may be employed. The bias or comparator signal should be used to control the output indication of the signal level.

The peak detector should provide a reading within 2 dB of peak at a pulse rate of 1/s for impulse noise with a uniform spectrum across the bandwidth of the receiver.

D.2.4 Average envelope-voltage detector

The detector should provide an average measurement for all types of modulation envelopes and statistically random signals. The linear dynamic range, as measured between the receiver noise floor and the 1 dB gain compression point, should equal or exceed 70 dB. This yields an error of measurement of less than 1 dB for impulsive noise signals. A selectable integration time constant ranging from 0.1 s to 100 s is recommended.

D.3 Detector accuracy

The amplitude accuracy should be ±2 dB.

D.4 Associated output/display devices

D.4.1 General

Each detector should be fitted with an output indicator that provides a continuous, real time indication of the measured parameter. The indicator may be a panel meter, a digital display, a CRT, or an oscilloscope.

D.4.2 RMS-voltage detector output

Two output indicators should be provided for simultaneous indication of rms voltage and voltage deviation V_d. The rms indicator should have a logarithmic scale with a minimum range of 40 dB. The V_d indicator should have a logarithmic scale with a minimum range of 0 dB to 40 dB.

D.4.3 Quasi-peak voltage detector output

The indicator scale should have a minimum linear deflection range of 4 to 1. In addition, a logarithmic scale is recommended.

The indicator should be critically damped with time constants of 160 ms for the 0.01 MHz to 30 MHz range and 100 ms for the 30 MHz to 1000 MHz range. The mechanical time constant assumes that the mechanical deflection of the indicator is linear with the input current. The use of an indicator having a different relationship between input current and deflection is not precluded.

The time constant of the indicator can also be defined as being equal to the duration of a rectangular pulse of constant amplitude that produces a deflection equal to 35% of the steady deflection produced by a direct current having the same amplitude as that of the rectangular pulse.

D.4.4 Peak-voltage detector output

The output indicator for the peak-voltage detector should have a range of 0 to 100 and a logarithmic scale with a minimum range of 0 dB to 40 dB.

D.4.5 Average-voltage detector output

The indicator scale may be either linear with a range of 0 to 100 or a logarithmic function of the impressed voltage with a 0 dB to 40 dB minimum range.

D.4.6 V_d Output

The indicator scale may be linear with a range of 0 to 100 or a logarithmic function of impressed voltage with a 0 dB to 40 dB minimum range.

D.5 Comparison of detector functions

Table D.5 has been included to provide a direct comparison among the performance of the four types of detectors in typical electromagnetic signal environments. The responses of the four detector functions to several types of signals are shown and certain differences in response (Geselowitz [B37], Haber [B39], Magrab and Blomquist [B65]).

Table D.5—Comparison of detector functions

Waveform	RMS responding meter indicates	Average responding meter indicates	Peak responding meter indicates	Quasi-peak responding meter indicates	Differences (dB)		
					Average RMS	Peak RMS	Quasi-peak RMS
Sine-wave	0.707	0.707	0.707	0.707	0.0	0.0	0.0
Gaussian noise	1σ	0.887σ	NOTE 1	1.83σ	−1.04	—	5.25
Pulse train – $\alpha = 0$ $d_\alpha = 0.1$	0.316	0.1	0.707	—	−10.0	6.99	—
Pulse train – $\alpha = 0$ $d_\alpha = 0.01$	0.10	0.01	0.707	—	−20.0	16.99	—
Recurrent – NOTE 2, Impulses with $f_p = 100$	1.0	0.10	13.5	6.08	−20.0	22.3	15.7
Recurrent – NOTE 2, Impulses with $f_p = 1000$	1.0	0.316	4.27	3.62	−10.0	12.3	11.2

NOTE 1—A peak reading has limited meaning for random noise unless a sufficient observation time is allowed to assure that the maximum likely impulse has been sensed.
NOTE 2—For these two examples, B (radio-noise bandwidth) = 10 kHz, Δf_{imp} (impulse bandwidth) = 1.35 × 10 kHz, Δf_{6dB} (6 dB bandwidth) = 1.07 × 10 kHz, R_d/R_c = 600 f_p = impulse repetition rate, and $p(\alpha) = 0.45$ for f_p = 100 and $p(\alpha) = 0.85$ for f_p = 1000 (Haber [B39]).

Annex E

(informative)

Measurements above 1 GHz-instrumentation perspective

E.1 Introduction

Radiated field strength measurements at frequencies above 1 GHz present some challenges due to the relatively high values of cable loss and antenna factor. These high factors tend to necessitate the use of a preamplifier to make a measurement at the typical measurement distance of 3 m. To avoid issues with gain compression and harmonic distortion created by overloading the preamplifier, the need for high-pass or band reject filters becomes necessary when making measurements on high EIRP systems when the fundamental signal falls in the frequency range of the measurement antenna.

These filters provide significant attenuation across a frequency band wider than the allocated band of operation of the unlicensed wireless device. Measurements at the allocated band-edges, where compliance with the general limits of 54 dBμV/m for average and 74 dBμV/m peak has to be demonstrated, are not possible with the filter in place. Either an alternative method should be used (i.e., reference marker-delta method) or the filter needs to be replaced with a fixed attenuator, or a lower gain preamplifier with a higher dynamic range might need to be used.

Above 40 GHz, it is often necessary to use external mixers. The inherent losses of interface cables or waveguides, the conversion loss of the mixers and the high antenna factors of antennas make field strength measurements at 3 m impractical. Extrapolation of measured data from a measurement distance closer than the limit distance is addressed elsewhere in this standard.

E.2 Test equipment

E.2.1 General

The typical configuration for the test equipment when making measurements from 1 GHz to 40 GHz is shown in Figure E.1. Each element is described in E.2.2 through E.2.7. As stated in 6.6.4.1, the measurement chain (filter, amplifier, and cables) should be characterized and any attenuation/loss factors should be accounted for in the measurement. The goal is to achieve a system noise floor 6 dB below a 500 μV/m (54 dBμV/m) average limit at a test distance of 3 m.

Note that preliminary measurements using a peak detector (comparing values to the average limit) to allow for wide frequency scans at faster sweep speeds might necessitate the use of test distances less than 3 m.

Many options are available for each piece of test and measurement equipment, with important issues discussed in E.2.2 through E.2.7.

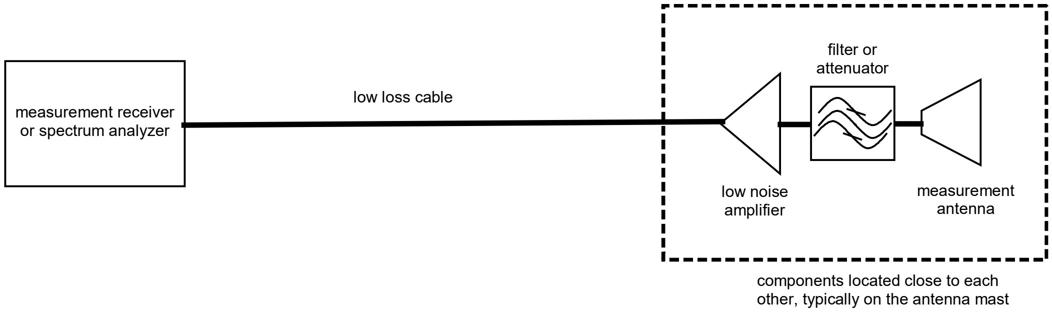


Figure E.1—Typical instrumentation arrangement above 1 GHz

E.2.2 Measurement antenna

E.2.2.1 Antenna types

Testing will require the use of different antennas to cover different frequency bands between 1 GHz and 40 GHz. Several options are available for each band, as described in E.2.2.1.1 through E.2.2.1.3.

E.2.2.1.1 Standard-gain horn antennas

Standard-gain horn antennas operate over a small range of frequencies and have a constant gain (antenna factor varies with frequency) over their operating range. Multiple antennas would be required to cover the complete frequency range (based on standard waveguide bands, nine antennas to cover the complete 1 GHz to 40 GHz range).

Their advantages are that they typically have the lowest antenna factor versus the wideband antennas and that their limitation in frequency range allows them to act as a band-pass filter, reducing the need for filters in the measurement chain.

E.2.2.1.2 Double-ridged guide horn antenna

Double-ridged guide horn antennas have the advantage of a very wide frequency range, typically 0.8 GHz to 18 GHz and 18 GHz to 40 GHz. Their advantage is that two antennas can cover the complete frequency range versus the standard-gain antennas. The disadvantage is that they typically have a larger antenna factor and their wideband operating range requires the use of filters to block out intentionally transmitted signals to avoid overloading a preamplifier.

Some older models of double-ridged horns have issues with a split main lobe in the radiation pattern above 12 GHz and are not recommended for use above 12 GHz, even though their specification might state use from 1 GHz to 18 GHz.

E.2.2.1.3 Log periodic dipole array antennas

Log periodic dipole array antennas are typically limited to an upper frequency of 6 GHz, with lower frequencies as low as 30 MHz. They can be useful when measuring the spurious emissions from transmitters operating between 30 MHz and 6000 MHz because the one antenna can be used to cover the entire measurement frequency range of interest, when combined with appropriate preamplifiers and filters, where necessary.

E.2.2.2 Antenna parameters

The key parameters related to a measurement antenna are the antenna factor and the antenna beamwidth.

E.2.2.2.1 Antenna beamwidth

The antenna beamwidth is typically expressed as the angle of the 3 dB points of the antenna pattern. The wider the beamwidth, the more of the EUT the antenna will illuminate. The beamwidth might not be the same in the E plane and H plane (i.e., the illuminated area might be an ellipse rather than a circle), so both horizontal and vertical beamwidths should be taken into consideration when determining how to confirm the EUT falls in the illuminated area of the measurement antenna. The dimension of the illuminated area (sometimes referred to as spot size) can be calculated from the beamwidth and test distance using:

$$\text{Spot size}[m] = 2 \times \text{test distance}[m] \times \tan(beamwidth / 2)$$

Typical 3 dB beamwidths and spot sizes for standard-gain and double-ridged guide horn antennas are listed in the following table:

Antenna type	3 dB Beamwidth	Spot size at 3 m
Standard-gain horn	~28° to 30°	1.6 m
Double-ridged guide horn (1 GHz to 18 GHz)	85° at 1 GHz 30° at 10 GHz 20° at 18 GHz	5.5 m 1.6 m 1.1 m
Double-ridged guide horn (18 GHz to 40 GHz)	30° at 18 GHz 20° at 40 GHz	1.6 m 1.1 m

E.2.2.2.2 Antenna factor

The antenna factor (AF) is the transducer correction applied to convert the measured voltage (dBμV) to a field strength result at the measurement antenna (dBμV/m). Lower antenna factors give more sensitive system performance (i.e., lower field strength levels can be measured).

Typical antenna factors for the antennas described in E.2.2.1 are provided in shown in Figure E.2.

E.2.2.3 Antenna connectors

The coaxial RF connectors and any associated adapters should be suitable for the frequency range of the measurement equipment. The higher frequency horn antennas typically have a waveguide connector to the horn and are provided with a waveguide to coaxial adapter integrated into the assembly. Lower frequency antennas are typically provided with a standard or precision N connector, depending on their frequency range.

E.2.3 Filter

A filter is required when the intentional signal(s) from the EUT are at a level that could cause overload of the amplifier, for example when the intentional signal falls within the frequency range of the measurement antenna. If the filter response inhibits the measurement of the signal under investigation, then it may be replaced with an attenuator, or the filter and low-noise amplifier may have to be removed from the configuration.

The filter and amplifier, when used, should be located as close as possible to the measurement antenna, ideally via direct connections.

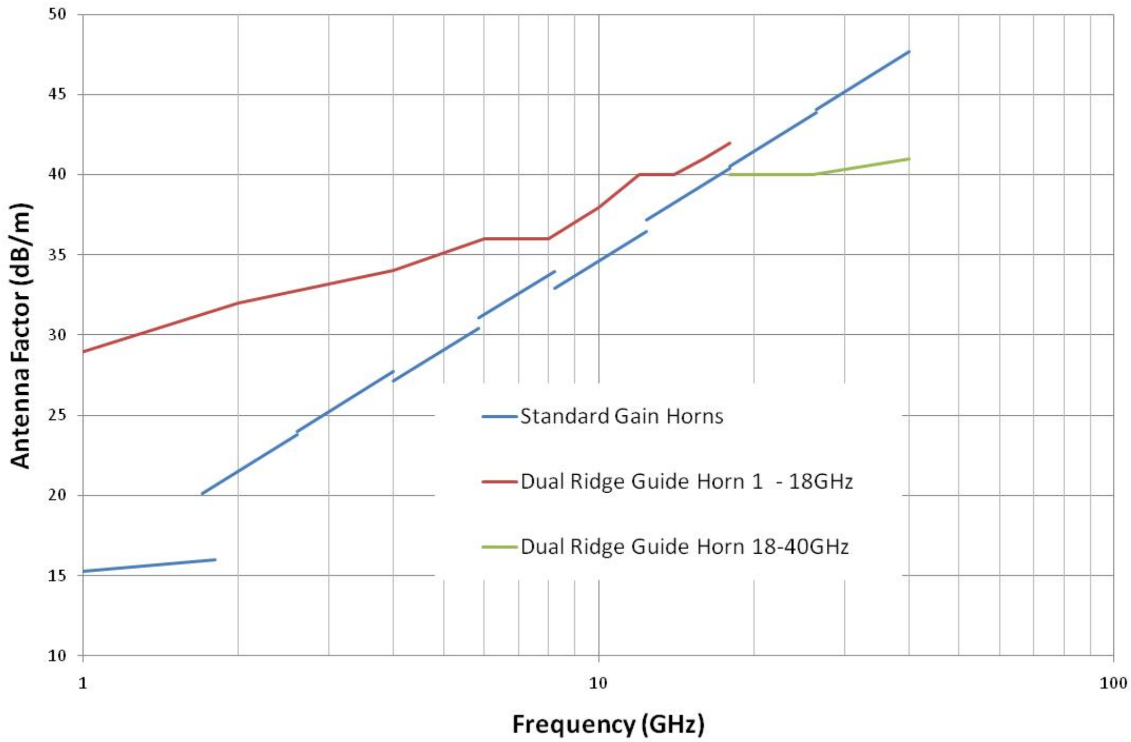


Figure E.2—Typical antenna factors for antennas described in E.2.2.1

E.2.4 Preamplifier

The low-noise preamplifier is required to overcome the losses in the cable and noise floor of the test instrument when making measurements of low-level signals. It should be located as close as possible to the measurement antenna.

Low-noise amplifiers can easily become susceptible to overload conditions (hence the need for the filter described in E.2.3). Overload leads to effects such as gain compression and distortion that create signals for example at harmonics of the overloading signal(s). Gain compression will lead to a measurement that underestimates the level of signal being measured, whereas the creation of harmonics or intermodulation distortion products can lead to making measurements of signals not created by the EUT. Higher gain amplifiers will increase the system sensitivity but often have higher noise figures or more likely to overload at lower input levels (lower 1 dB compression point). It is also important to consider the noise figure of the amplifier—the higher the noise figure, the lower the overall reduction in the effective noise floor of the test system and the corresponding reduction in the dynamic range of the measurement system.

The amplifier gain required to provide the overall system performance will depend on the cable loss, antenna factor, amplifier noise figure, and average noise level as displayed on the measurement instrument. Chapter 5 of the Agilent Application Note 150, “Spectrum Analysis Basics” [B1], contains a detailed description of the trade-offs in amplifier gain, noise figure, and 1 dB compression point.

Linearity tests to determine whether an overload condition exists are explained in 6.6.4.1; however, if trying to determine the linearity of a measurement setup, the 6 dB attenuator needs to be placed between the measuring antenna and the preamplifier.

E.2.5 Cables

The selection of a high-quality, low-loss coaxial cable is essential. The cable length needs to be as short as possible while allowing the antenna to be moved up and down the mast as required while connected to the measurement instrumentation.

Common cable types include LMR400 for applications to 6 GHz, and TBJ141 to 40 GHz. These cables require correct handling and installation to be sure appropriate strain relief is provided to reduce the chance of bends beyond their allowed bend radius and stress at the connector. Cables should be visually inspected prior to use and verification checks (at the cable level or with a radiated source, such as a comb generator) performed at regular intervals

E.2.6 Measurement receiver

The specifications for the measurement instrumentation are detailed elsewhere in this standard or in referenced standards. When measurements are being made below 1 GHz, the receiver is typically located away from the test site. For measurements above 1 GHz, the instrument may need to be located nearby the antenna mast to reduce cable losses by allowing the use of short cables.

E.2.7 Considerations for coaxial connectors

The coaxial RF connectors for each piece of equipment in the measurement chain, and any associated adapters, should be suitable for the frequency of the measurements being taken with that particular set of equipment. The frequency range for the more commonly available connectors used for RF measurements are as follows:

- Standard N to 11 GHz
- Precision N to 18 GHz
- SMA to 18 GHz
- K to 40 GHz

These connectors are delicate, and appropriate handling and maintenance procedures should be followed. Connectors cross thread easily and can be damaged by excessive torque. N connectors should only be hand tight, and the use of appropriate torque wrenches for SMA and K connectors is strongly recommended. When using the torque wrench with multiple stacked connectors, special care is needed not to overtighten the connections. Connectors might become contaminated with metal particles, so regular cleaning with compressed air and alcohol is advisable.

Additional information on RF coaxial connectors can be found via an Internet search. See the following, for example:

- Overview of RF connectors and their applications[107]
- 3.5 mm versus SMA[108]
- Connector usage and care[109]
- General information[110]

[107] http://www.wa1mba.org/rfconn.htm.
[108] http://www.microwaves101.com/encyclopedia/connectortrashed.cfm.
[109] http://www.microwaves101.com/encyclopedia/connectorcare.cfm.
[110] http://www.microwaves101.com.

Annex F

(informative)

Broadband measurement discussion

F.1 Introduction[111]

The first step for a broadband measurement discussion is to define a broadband signal. The International Telecommunications Union-Radio and the Federal Communications Commission each have their own view on what is a broadband signal. The IEEE defines a broadband signal as a signal that is wider than the measuring receiver bandwidth.

In the context of regulatory requirements, using 47 CFR 15.247 as an example, a broadband system is defined as any radio with a bandwidth of 500 kHz or greater. In the licensed radio services, each specific radio service rule part may have its own definition.[112] Other documents have used a 1 MHz bandwidth as the threshold for being classified as a broadband signal. However, for this discussion, although the definition of broadband or wideband signals can vary, for measurement purposes, a signal can be considered broadband when the bandwidth of the signal that is being measured is equal to or greater than the resolution bandwidth of the measuring instrument, even though the signal bandwidth might be less than what would normally be defined as "broadband."

The actual test parameters for broadband devices for transmitter power output, band-edge emissions, radiated emissions, and so on are described in the corresponding subclauses of this document. Therefore, specific test requirements for an unlicensed wireless device are not addressed in this annex, but instead a technical discussion is given about broadband signals and the considerations that should be kept in mind when measuring them.

F.2 General discussion

As an example, a 5 MHz bandwidth broadband signal is considered to be a wideband emission, but if the RBW of the measuring instrument is 20 MHz, then the measurement bandwidth is larger than the bandwidth of the 5 MHz signal. Therefore, using a peak detector will yield a fairly accurate result in most cases.

However, if the same instrument is used to measure the power of an IEEE 802.11 [B44] device with 40 MHz channel, the bandwidth of the transmitter signal is greater than the RBW of the instrument, which will affect the peak measurement, unless other steps are taken to account for the measurement bandwidth being smaller than the signal bandwidth.

Most regulatory requirements for unlicensed wireless devices specify determining compliance based on peak power. However, where a device is near or exceeds the RBW of the measuring device, the true peak cannot be measured.

Therefore, test procedures are provided in the applicable parts of this standard that allow measurements of broadband signals using an average or "rms" detector. However, as in the case of some regulatory

[111] This discussion will not be focused on issues involving the U.S. National Broadband Plan or determination of what services fall under the National Broadband Plan (http://www.broadband.gov/). Also, this is not meant to serve as a test method; it is only an informational discussion about broadband emissions and measurements of those emissions.
[112] For example, 47 CFR part 24 subpart D specifically states it applies to specific narrowband systems, whereas 47 CFR part 24 subpart E does not call out any reference and leaves it to the discretion of an equipment manufacturer to decide whether it is a broadband signal.

requirements, additional measurements using a peak-to-average ratio (also called peak excursion) are required to determine maximum power.

For performing broadband or wideband measurements, it is recommended that the instrumentation selected be capable of measuring such signals. However, as the bandwidth of signals increases to 20 MHz, 40 MHz or more, these wideband signals will exceed the RBW of the measurement instrument in most cases. Therefore, it is recommended that the operator select the widest available RBW, as well as the widest VBW, to perform the measurements.

Furthermore, it is crucial that Clause 4 on instrumentation be applied when performing such tests.

When measuring a broadband signal, it is important to keep in mind the relative bandwidth of the measurement instrument that is being used, when compared with the bandwidth of the signal being measured. When the bandwidth of the instrument is large compared with the bandwidth of the signal being measured, the entire emission bandwidth is captured by the measurement instrument, and a true peak power measurement can be made. This is the narrowband scenario. As instrumentation evolves, the bandwidth capabilities are increasing, allowing wider and wider emissions to be measured directly. However, there are situations where an instrument does not have sufficient resolution bandwidth to encompass the bandwidth of the signal being measured. This occurs when the signal bandwidth starts to become approximately equal to or greater than the instrumentation resolution bandwidth because the instrument can no longer capture the full power of the emission. Most spectrum analyzers use 3 dB RBW specifications, whereas most EMI receivers use 6 dB RBW specifications. This means that specified resolution bandwidth is the width of the IF filter response (i.e., 3 dB or 6 dB). For example, a 120 kHz resolution bandwidth filter will give approximately 0 dB attenuation to signals at the center of the frequency being measured, but the amplitude response will attenuate to 3 dB or 6 dB of attenuation at 60 kHz above and below the frequency being measured. shows the 6 dB response at the D2 points. The filter response further attenuates as the frequency offset increases, quickly rising to 26 dB, and then 90 dB of attenuation outside of the filter bandwidth.

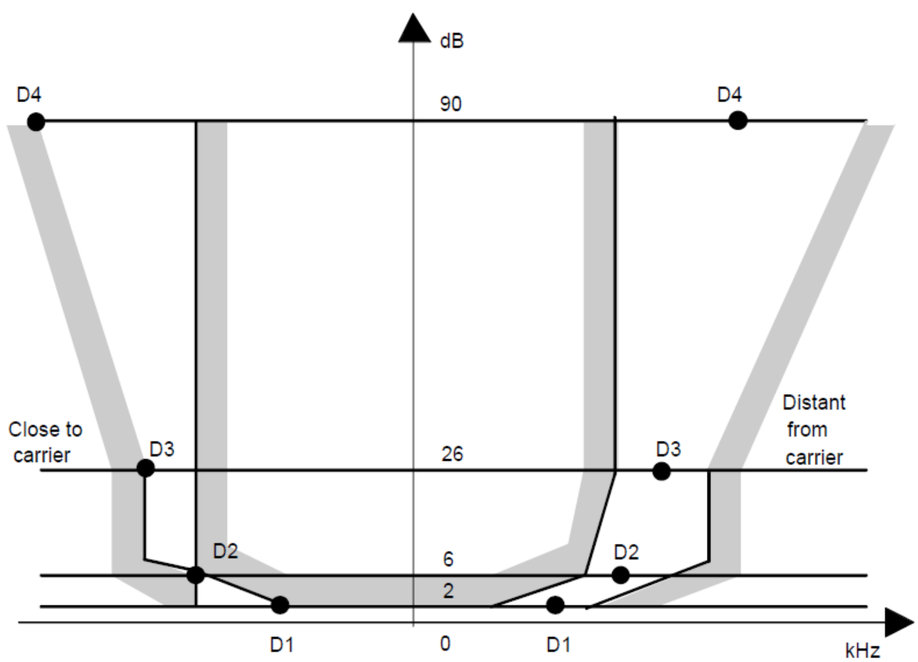


Figure F.1—Example of 120 kHz bandwidth filter response

Because it is not possible to measure accurately an emission that exceeds the bandwidth of the filter being used, other methods are needed. One way is to measure smaller parts of the emission and sum them by integrating the results over the emission bandwidth. For example, a 20 MHz signal can be measured using a 100 kHz resolution bandwidth by taking 300 or more nonoverlapping measurements and summing the results. In practice, it is actually necessary to take enough measurements so that the entire emission bandwidth is captured.

Many instruments have signal power integration functions built in, which take care of most measurement considerations automatically. These measurements include corrections for the equivalent noise bandwidth of the RBW filter and the number of measurement points across the span of the emission. It is still useful to understand the measurement process and the possible errors that can be made while performing the measurements.

The user should determine whether the instrument being used has a 3 dB or 6 dB RBW specification and which detector because these parameters influence the selection of test frequencies. If test frequencies are too far apart, then portions of the emission will not be measured, but if the test frequencies are too close together, then portions of the emission will be measured twice, and the overall power of the emission will be overestimated. Furthermore, detector selection becomes important. Receivers and spectrum analyzers typically will sweep across a selected span using the selected resolution bandwidth, and while the display can have a finite number of pixels, each pixel actually comprises multiple submeasurements. The value displayed for each pixel depends on the detector selected. A positive peak detector will display the highest value for all the measurements made in each pixel, whereas an average detector will display the average value and an rms detector will display the rms-average of all the submeasurements for a pixel. Some instruments have a sample detector that will display the center value for each pixel, regardless of amplitude.

The rms detector is best suited for the integration method of measuring broadband emissions. As an alternative, the sample detector can be used in conjunction with trace averaging (set to power averaging mode). Because a peak detector will present the worst-case for each measurement, it can be used as a conservative method for estimating the output power using the integration method where the rms or sample detector might not provide the right resolution bandwidth overlap for the span selected. RMS or sample detectors should be used only when the resolution bandwidth is greater than twice the bin width (i.e., spectrum analyzer span/number of points in spectrum display).[113]

Broadband signals are typically noise-like, and so using a peak detector with a max-hold can also introduce error by overestimating the emission power. A max-hold function will capture the worst-case value over time at each frequency. However, the noise is random and is never at worst-case at every frequency at any given instant in time. For this reason, if the signal being measured is continuous and does not have a duty cycle that would affect the results, then sweep averaging or video averaging can be used to “smooth out” the noise of the emission. This yields a stable, repeatable average measurement on systems that have been configured to operate continuously. If the signal being measured has a duty cycle, however, then a peak detector or a triggered trace mode should be used, so that the full spectrum is captured while the transmitter being measured is ON, unless the spectrum analyzer can be gated to sweep only when the transmitter is ON.

NOTE—The type of averaging (video averaging, power averaging, or voltage averaging) of the individual sweep data could give different results.

Due to the noise-like nature of digital modulation for a broadband signal, another error is introduced when the entire signal cannot be measured at once. This is because the modulation amplitude at any frequency for a broadband signal is complex and depends on the data being transmitted. Therefore, if a direct measurement can be performed, then an accurate peak measurement of the emission can be obtained because the entire measurement was performed simultaneously, with the modulation waveform for the entire emission captured essentially instantaneously, including all modulation variations within the signal. This result is representative of the peak power at a given instant in time. However, if it becomes necessary

[113] See FCC/KDB 558074 [B32].

to make several individual smaller measurements and then sum those together, using either integration or an instrument power integration function, then these individual measurements will by necessity occur in some sequence. Given that the measurements do not occur at the same time, each slice of the emission that is measured will be based on a different modulation state, which may or may not be the worst-case for that frequency range. Therefore, it is possible to get a sequence of worst-case measurements, a sequence of best case measurements, or a mixture of both, leading to the possibility of overestimation or underestimation of the true peak signal level at any given instant in time. It might be possible to evaluate statistically a series of results to determine what a typical result should be, but the best solution is to measure the entire emission simultaneously across the whole emission bandwidth, if possible.

To achieve accurate peak measurements across the entire emission bandwidth, some analyzers include a cumulative complementary density function (CCDF). These analyzers use an array of detectors to monitor the entirety of a wide span simultaneously rather than sweeping across the selected span. Therefore, these analyzers will measure the instantaneous peak at each frequency across the emission bandwidth simultaneously, yielding a true peak measurement that represents the actual power of the emission at a given instant in time. The CCDF is a tool that analyzes the noise-like behavior of a signal and determines the actual peak-to-average ratio (PAR) for the noise observed, allowing peak and average measurements to be made accurately and to be correlated with each other.

Peak power measurements of wideband signals can also be made with peak power sensors such as a peak power meter (not a continuous wave sensor or an average sensor), as long as (1) the sensor video bandwidth is greater than the emission bandwidth and (2) consideration is made that if the bandwidth is much larger than the emission bandwidth, the peak power might be higher than the actual peak due to the instrument capturing additional signals such as intermodulations, spurious emissions, and harmonics.

In other cases, such as UWB signals, where the emission bandwidth is typically 500 MHz wide or greater, the power of the emission can be quantified for regulatory requirements as the power of the highest amplitude 50 MHz span of emissions spectrum. At the time the regulations were written, no commercial measurement instrument existed with a 50 MHz resolution bandwidth, and given that a UWB emission can be considered somewhat “flat” across large segments of frequency, the regulatory requirements have specified that measurement results using a lower resolution bandwidth can be “adjusted upward” to simulate a 50 MHz bandwidth by mathematically converting results to the higher bandwidth.[114] This method is best suited to emissions that can be considered to be “flat” across their bandwidth, where measurement of one small segment of the noise can be readily extrapolated to represent a larger range of spectrum.

The preceding considerations in this annex are useful and necessary when making broadband measurements to avoid common measurement problems and yield more accurate test results.

[114] “If a resolution bandwidth other than 50 MHz is employed, then the peak EIRP limit shall be adjusted by 20 log (RBW/50) dBm where RBW is the resolution bandwidth in megahertz that is employed” (see 10.3.6) [FCC 47 CFR, part 15 subpart F, 15.521(g)].

Annex G

(informative)

Basic relationships among field strength, power, effective radiated power, and equivalent isotropically radiated power

G.1 Introduction

Many FCC rule parts specify power and/or emission limits in terms of the transmitter system (transmitter, radiating antenna, and cable connector) effective radiated power (ERP) or its equivalent (or effective) isotropically radiated power (EIRP). These guidelines are intended to demonstrate how to determine the EIRP or ERP from the results of a power measurement.[115]

EIRP and ERP are similarly defined as the product of the power supplied to the antenna and the antenna gain (when the power and gain are represented in linear terms). The primary difference between them is that for ERP the antenna gain is expressed relative to an ideal half wave dipole antenna, whereas for EIRP, the antenna gain is expressed relative to an ideal (theoretical) isotropic antenna. The EIRP and ERP may be expressed mathematically as follows.

Subclauses G.2, G.3, and G.4 are applicable only in the far-field.

G.2 Field strength approach (linear terms)

$$\mathrm{EIRP} = p_t \times g_t = \left(E \times d\right)^2 / 30 \qquad \text{(G.1)}$$

where

p_t	is the transmitter output power in watts
g_t	is the numeric gain of the transmitting antenna (dimensionless)
E	is the electric field strength in V/m
d	is the measurement distance in meters (m)

$$\mathrm{ERP} = \mathrm{EIRP} / 1.64 = (E \times d)^2 / \left(30 \times 1.64\right) = \left(E \times d\right)^2 / 49.2 \qquad \text{(G.2)}$$

where all terms are as previously defined.

G.3 Power approach (logarithmic terms)

$$\mathrm{ERP/EIRP} = P_T + G_T - L_C \qquad \text{(G.3)}$$

where

ERP/EIRP	is the equivalent (or effective) radiated power [in same units as P_T, typically dBW, dBm, or power spectral density (psd)], relative to either a dipole antenna (ERP) or an isotropic antenna (EIRP)
P_T	is the transmitter output power, in dBW, dBm, or psd (power over a specified reference bandwidth)

[115] Derivations of the equations presented herein are not provided in this document. Readers interested in how these equations are derived are referred to NTIA Technical Memorandum TM 10 469 [B66].

G_T is the gain of the transmitting antenna, in dBd (ERP) or dBi (EIRP)
L_C is the signal attenuation in the connecting cable between the transmitter and the antenna, in dB.

NOTE—In personal/portable radios using an integral antenna, this factor is typically negligible. However, in a fixed station transmit system that uses a long cable run between the transmitter and the transmitting antenna, this factor can be significant. The minimum cable loss should be used in this equation.

G.4 Relationship between ERP and EIRP

The numeric gain of an ideal half wave dipole antenna is 1.64, and the numeric gain of an ideal isotropic antenna is 1.0. The gain of an ideal half wave dipole antenna relative to an ideal isotropic antenna is [10 log (1.64)] or 2.15 dBi. Therefore, if the antenna gain in dBd is unknown, it may be determined from the gain in dBi via the following relationship in Equation (G.4):

$$G_T\left(\text{dBd}\right) = G_T\left(\text{dBi}\right) - 2.15\ \text{dB} \qquad \text{(G.4)}$$

Alternatively, the EIRP may be determined from Equation (G.3) and then converted to ERP based on the maximum antenna gain relationship by applying Equation (G.5):

$$\text{ERP} = \text{EIRP} - 2.15\ \text{dB} \qquad \text{(G.5)}$$

Similarly, the EIRP may be determined from the ERP as follows in Equation (G.6):

$$\text{EIRP} = \text{ERP} + 2.15\ \text{dB} \qquad \text{(G.6)}$$

G.5 Applications

Subclauses G.5.1 through subclause G.5.3 discuss the appropriate methods for applying Equation (G.1) through Equation (G.6) depending on the power measurement configuration used.

G.5.1 EUT power measured in a conducted test configuration

When the EUT power is measured using a direct impedance matched connection between the transmitter antenna port and the measurement instrumentation via a coaxial cable (conducted test), and the transmit antenna gain is a known quantity, then the ERP/EIRP may be calculated by direct application of Equation (G.3) and using the relationships defined in Equation (G.4), Equation (G.5), or Equation (G.6), as appropriate.

The value to be used for P_T in these equations is the measured power level (in dBm, dBW, or psd), corrected to account for external test peripherals (cable loss, external attenuation, and/or external amplification).

The value to be used for GT is the gain associated with the EUT transmit antenna, expressed in either dBd (i.e., ERP) or dBi (i.e., EIRP).

G.5.2 Direct calculation from the EUT power measured in a radiated test configuration [i.e., signal (antenna) substitution techniques not used]

When the EUT power is measured using a radiated test configuration, the EIRP may be directly determined using the power (logarithmic) approach as follows in Equation (G.7):

$$\text{EIRP} = P_R + L_P \qquad \text{(G.7)}$$

where

EIRP	is the equivalent (or effective) isotropically radiated power (in same units as P_R)
P_R	is the corrected received power level, in dBW, dBm, or psd
L_P	is the basic free-space propagation path loss, in dB

The received power level is the measured power corrected for measurement antenna gain, connecting cable loss, and any external signal amplification or attenuation used in the test configuration. Mathematically, as in Equation (G.8):

$$P_R = P_{\text{meas}} - G_R + L_C + L_{\text{atten}} - G_{\text{amp}} \quad \text{(G.8)}$$

where

P_{meas}	is the measured power level, in dBW, dBm, or psd
G_R	is the gain of the receive (measurement) antenna, in dBi
L_C	is the signal loss in the measurement cable, in dB
L_{atten}	is the value of external attenuation (if used), in dB
G_{amp}	is the value of external amplification (if used), in dB

The free-space propagation path loss is determined from Equation (G.9):

$$L_P = 20\log F + 20\log d - 27.5 \quad \text{(G.9)}$$

where

L_P	is the basic free-space propagation path loss, in dB
F	is the center frequency of radiated EUT signal, in MHz
d	is the measurement distance, in meters

The ERP may then be determined from the EIRP by applying Equation (G.5).

When the EUT power is measured using a radiated test configuration, the EIRP may be directly determined using the field strength (linear) approach by applying Equation (G.1) and the ERP may be determined directly by applying Equation (G.2).

G.5.3 EUT power measured in a radiated test configuration using the signal (antenna) substitution techniques[116]

The ERP/EIRP may be determined from the power setting of a signal generator used in the signal (antenna) substitution test configuration as follows in Equation (G.10):

$$\text{ERP/EIRP} = P_{SG} + G_T - L_C \quad \text{(G.10)}$$

where

P_{SG}	is the power setting of the signal generator that produces the same received power reading as the EUT, in dBm, dBW, or psd
G_T	is the gain of the substitute antenna, in dBd (i.e., ERP) or dBi (i.e., EIRP)
L_C	is the signal loss in the cable connecting the signal generator to the substitute antenna, in dB

[116] The signal (antenna) substitution technique is not accepted by some radio regulatory agencies for measurement of unlicensed devices.

Annex H

(informative)

Rationale for making radiated emission measurements using two different methods

H.1 Introduction

This informative annex is needed to clarify the requirements of 6.6.5. Unless the device is expected to have a very high peak-to-average ratio (greater than 15 dB), the VBW used for exploratory scans may be less than the resolution bandwidth to reduce the noise floor—the rationale being that the peak limit is 20 dB higher than the average limit, so unless the device signal has a high peak-to-average ratio, the average value will be closer to the average limit than the peak value would be to the peak limit.

This primarily affects the measurement of emissions above 1 GHz. In the frequency range 30 MHz to 1000 MHz, the measurements are made with (1) a ground plane beneath the EUT, and (2) between the EUT and the measurement antenna, which effectively allows the measurement antenna to see the emissions radiated both above and below the plane of the EUT.

H.2 Conventional (single EUT orientation) and three-axis method rationale

H.2.1 General considerations

This subclause considers the conventional 0.8 m table height for the EUT and a 1 m to 4 m antenna height search test method compared with the methods of 6.6.3.3 and 6.6.5. The conventional method for apparatus that can be used in any axis has a small but repeatable concern for emissions testing above 1 GHz where there is RF absorbing material on the floor of the test site. This concern is that emissions in one direction from the equipment are not scanned. The methods of both 6.6.3.3 and 6.6.5 overcome this shortcoming of the conventional method.

Assumption: The spurious emissions rarely come from a highly tuned PCB track or similar, and the spurious emission might have limited directivity but can be considered to have a beamwidth greater than 10°. The calculations below have not included the beamwidth of the spurious emission.

NOTE—York University (Yorkshire, U.K.) considered this matter some years ago and concluded that “theoretically” narrow beam emissions are possible. The study was based on the complete EUT being a resonant enclosure at the same frequency of the spurious emission, with no other material in the enclosure, such as a PCB, which would “spoil” the resonant cavity.

In practice, emissions typically are seen from random directions at a lower level early during prescans, and then the antenna position is optimized for the maximum reading during the final scans.

H.2.2 Stage 1

Take the area of a sphere ($4\pi R^2$) at $R = 3$ m as in Equation (H.1):

$$4\pi R^2 = 4 \times 3.14159 \times 3 \times 3 = 113.1 \text{ m}^2 \qquad \text{(H.1)}$$

This area should be swept to cover emissions from all angles from a small EUT.

H.2.3 Stage 2

Take the area of a "cylinder around a sphere" at $R = 3$ m (y axis).

To visualize, consider the red color band in Figure H.1(a).

Now, taking a "typical" broadband antenna at mid frequency band (around 10 GHz), it has a beamwidth of approximately 30°. Any emissions outside of this beamwidth will be measured lower than required. Assume the EUT has a similar, or larger, emission beamwidth to the measurement antenna.

Taking the y axis as a first axis (say a mobile phone vertical), the table is rotated and to a rough approximation measures emissions from a cylindrical band, circumference $2\pi R$, with a "height" h of about 1.6 m.

Therefore, the swept area of this cylindrical band is as follows in Equation (H.2):

$$2\pi Rh = 2\times 3.14159\times 3\times 1.6 = 28.3 \text{ m}^2 \tag{H.2}$$

To visualize, consider the area covered by the red bands in Figure H.1(a), although this band is slightly narrower than expected in a test situation.

H.2.4 Stage 3

Now, add the area of a second "cylinder" around a sphere at $R = 3$ m (x axis) after rotating the EUT to the second x axis (say a mobile phone face up). This is orthogonal to the first axis; however, at two positions, the cylinders should overlap, which means common areas with the stage 1 sweep are measured. These areas are 1.6 m by 1.6 m, or approximately 2.6 m^2.

So for the two orthogonal planes, the swept area is as follows in Equation (H.3):

$$2\times 28.3-\left(2\times 2.6\right) = 51.2 \text{ m}^2 \tag{H.3}$$

To visualize, consider the area covered by the red and blue bands in Figure H.1(b), which shows one of the two overlapping areas.

H.2.5 Stage 4

Now add the area of a third "cylinder" around a sphere at $R = 3$ m (z axis) after rotating the EUT onto its third axis, z (say a mobile phone on the thin side). In this case, the new cylinder should cross the previous two cylinders at two areas for each cylinder, so the common swept area is now 2 × 2.6 m^2 or 5.2 m^2, in addition to that previously considered, or as in Equation (H.4):

$$51.2+28.3-5.2 = 74.6 \text{ m}^2 \tag{H.4}$$

So without height search, the three axes x, y, and z cover approximately (74.6 / 113.1) or 66% of the area of the sphere. To visualize, consider the red, green, and blue bands in Figure H.1(c).

H.2.6 Stage 5

To improve the coverage over the EUT from this 66%, a new measurement antenna height is added such that the measurement antenna is now 45° above the EUT. Add antenna at a fixed height (45°) as well as table/EUT at equal heights to each "cylinder around a sphere at $R = 3$ m."

The math becomes much more complex, in simple terms, if a fixed height of 45° is added and just over half (approximately) of the remaining unswept area for the hemisphere is covered (the height is only above the *x*, *y*, and *z* hemispheres, and it does not cover the area below each respective hemisphere); another 10% coverage is probably added when considering the overlapping cylinders—estimated at around 76%, or higher, coverage—see Figure H.1(d).

H.2.7 Stage 6

Adding a third antenna fixed height (22.5°) to each "cylinder" around a sphere at $R = 3$ m, or performing a continuous height search, "most" of the gaps are filled in, but not all—see Figure H.1(e).

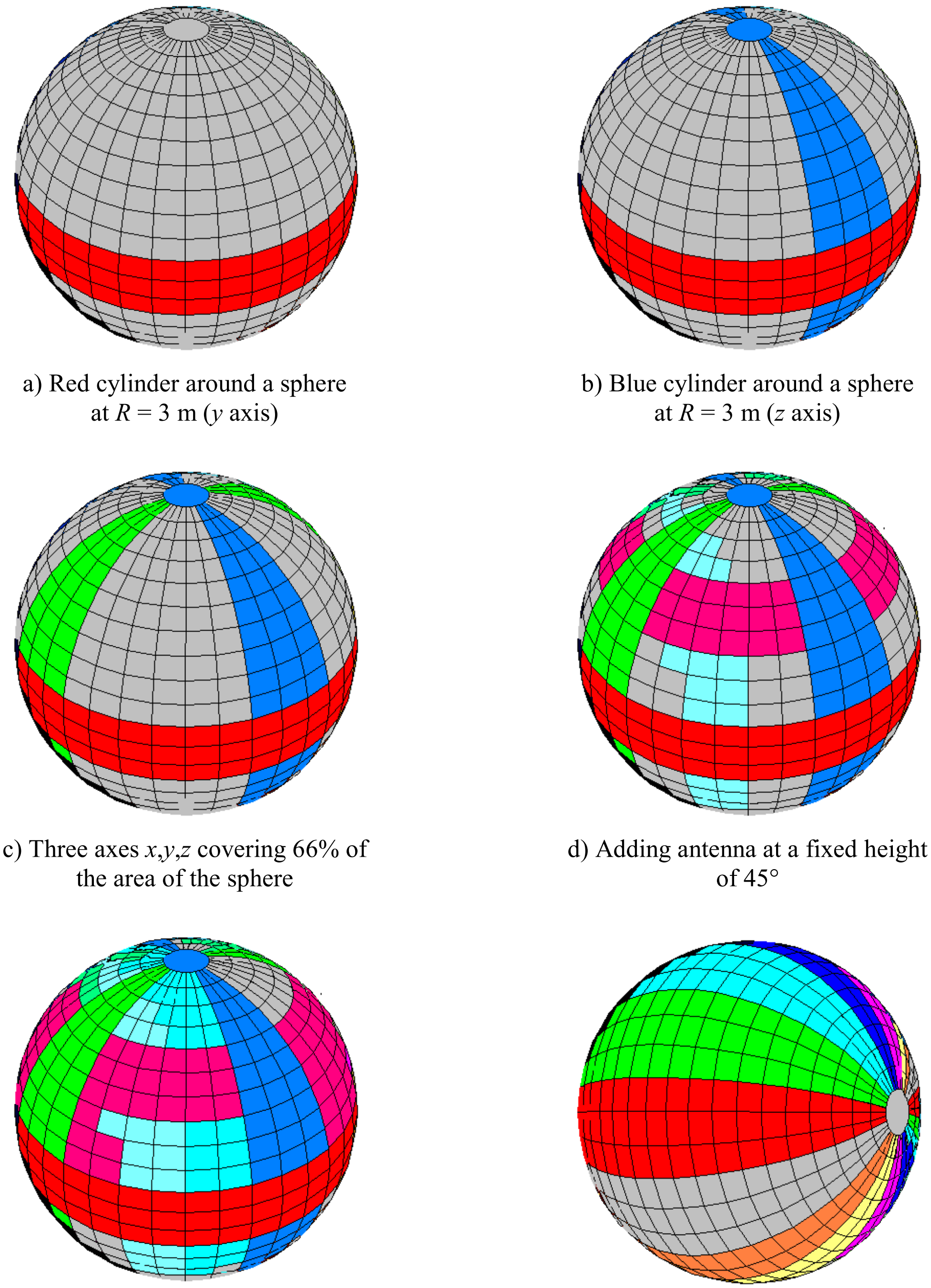
The "holes" are left as the height search covers only one hemisphere of each of the three axes. The only way around this is to then repeat all measurements with the EUT flipped 180° in each of the three axes, giving rise to a total of six full scans (*x* axis, *y* axis, *z* axis, *x* axis flipped 180°, *y* axis flipped 180°, and *z* axis flipped 180°).

H.3 Rationale for method of 6.6.5

For small equipment that can be used in any orientation, there is a more complete solution that achieves improved coverage in the same number of EUT orientations, but without the need to change the height of the measurement antenna (at least for the preliminary measurements, to determine the worst-case EUT orientation for a specific frequency).

The proposed method tilts the EUT in "small" angular steps, performing a full 0° to 360° table rotation at each angular adjustment of the EUT, for both vertical and horizontal measurement antenna polarization. The EUT would need to rotate through 0° to 180° with a "step" angle less than the HPBW of the EUT emission, which is assumed to be 30°.

In Figure H.1(f), red is showing the first "slice" with the EUT in the vertical position, green the second position with the EUT angled at a 30° offset from the vertical, light blue the third with a 60° offset from the vertical, dark blue the fourth with a 90° offset from the vertical, etc. In six "segment" sweeps, the sphere is completely enclosed (assuming a 30° EUT HPBW, and 0°, 30°, 60°, 90°, 120°, and 150° EUT angles), with no antenna height search. Added to this is the fact that the separation distances from EUT to measurement antenna remains constant (when the antenna is moved up/down, the distance from EUT to antenna changes). Styrofoam wedges, precut to the 30°, 60°, and 90° angles, would be used to support the EUT in the different orientations (the 30° wedge would support the EUT in the 30° and 150° orientations, the 60° wedge for the 60° and 120° angles).



a) Red cylinder around a sphere at R = 3 m (y axis)

b) Blue cylinder around a sphere at R = 3 m (z axis)

c) Three axes x,y,z covering 66% of the area of the sphere

d) Adding antenna at a fixed height of 45°

e) Adding antenna at a fixed height of 45° and 22.5°

f) Method of 6.6.5 - six step angles of search

Figure H.1—Illustration of coverage by the scan methods of a virtual sphere enclosing an EUT

Annex I

(informative)

Site considerations for measuring inductive-loop devices in the near-field

I.1 Introduction

The ideal site is an open-area site meeting the classic OATS requirements with additional underground requirements. The site should be free of metallic structures, such as underground utilities, rebar, and so on. Structures such as fire mains, iron or steel reinforced drainage tiles, and underground electric utilities for parking lot lighting have been known to affect site calibration. An OATS for electric field strength testing with a rebar slab or galvanized wire mesh will not produce the full third-order field roll-off expected for simple inductive-loops when measuring at distances of 20 m and greater. Where underground utilities cannot be avoided, sometimes knowing their location and aligning the measurement setup perpendicular to the utility direction will allow the expected results.

I.2 Site Considerations

Site characteristics may be determined by performing a distance calibration. Identify the area for which the measurements are intended to be taken using the following guidelines:

a) Using a reference loop source antenna[117] and shielded antenna measurement loop, set up the reference source antenna in the intended area.

b) The reference source should be oriented in the vertical plane.

c) The center of the measurement antenna should be at 1 m from the ground, oriented in the vertical plane.

d) To minimize complications with ambient, use a narrow resolution bandwidth on measurement instrumentation.

e) To minimize coupling between source instrumentation and measurement instrumentation, a gas-powered electric generator for each is useful. Maximize the distance between source power cords and measurement power cords.

f) Set up the measurement antenna 5 m away from the source antenna in the intended measurement area, oriented parallel to the source antenna. Take a measurement at 5 m and record the value.

g) Set up the measurement antenna 10 m away from the source antenna as done in step f). Record the value. The value should be 18 dB lower than the 5 m reading.

h) Set up the measurement antenna 20 m away from the source antenna as done in step f). Record the value. The value should be 18 dB lower than the 10 m reading.

i) If 18 dB is not realized, then try the measurement in a perpendicular orientation in the field (e.g., north-south instead of east-west).

j) If 17 dB to 18 dB is not realized, then the site is less than ideal, probably containing metallic structures coupling signals to the measurement structure by means other than reference loop to measurement loop coupling. Either find a more suitable site or accept that measurements taken on this site will over report levels compared to the limit (i.e., provide conservative measurements).

[117] The reference source can be any inductive-loop device that produces the desired measurement frequency signal that is amplitude and frequency stable throughout the temperature and humidity range of the site location. The device will produce a constant level for a relative measurement at different distances.

The above distances were recommended for simple assessment of a test site. Other distances may be used to ascertain the characteristics of the site for the measurement distances desired. The following formulations in Equation (I.1) and Equation (I.2) may be used in place of 18 dB for distance doubling:

$$\text{Roll-off factor, } P = \left(\text{Level}_{\text{near-distance}} - \text{Level}_{\text{far-distance}}\right) / 20\log\left(d_{\text{far}} / d_{\text{near}}\right) \tag{I.1}$$

$$\text{DCF} = 20\log\left(d_{\text{test}} / d_{\text{limit}}\right)^{P} = 20P\log\left(d_{\text{test}} / d_{\text{limit}}\right) \tag{I.2}$$

where

distance is in meters
DCF is the distance correction factor in dB
Level is in dB

Performing a volume calibration can identify the bounds of the site suitable for measurements. It is recommended to measure on either side of the above test setup to determine whether there are any underground structures nearby that could couple with and corrupt the measured signal.

I.3 Manufacturer's test site data

Data were taken at Tyco (Boca Raton, FL) and confirmed 60 dB per decade roll-off. Measurements were taken on both an open field and in a parking lot where locations of underground utilities were known (Figure I.1 and Figure I.2).

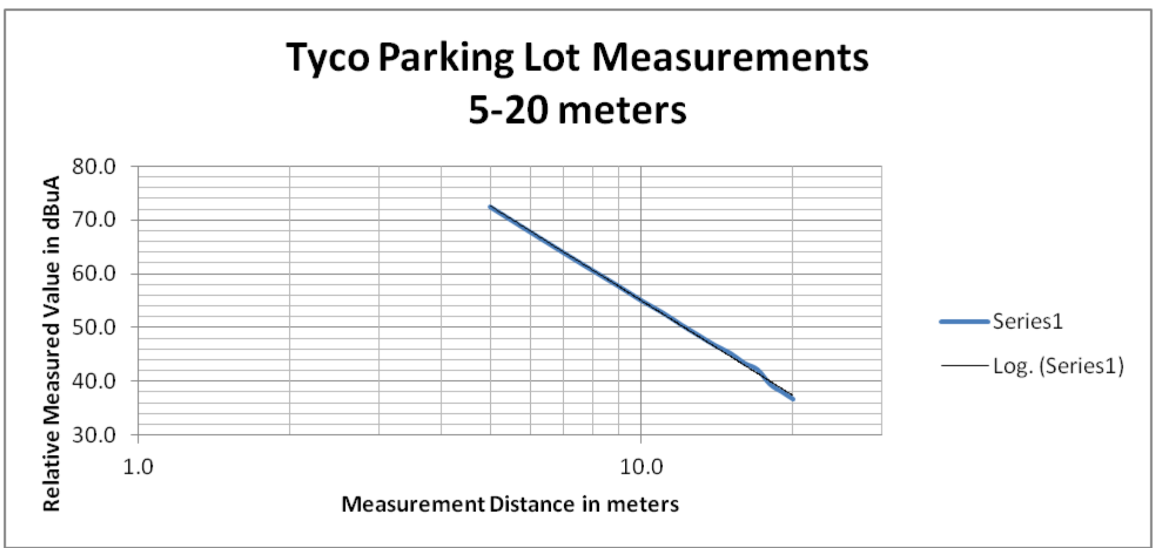


Figure I.1—Tyco parking lot measurements 5 m to 20 m

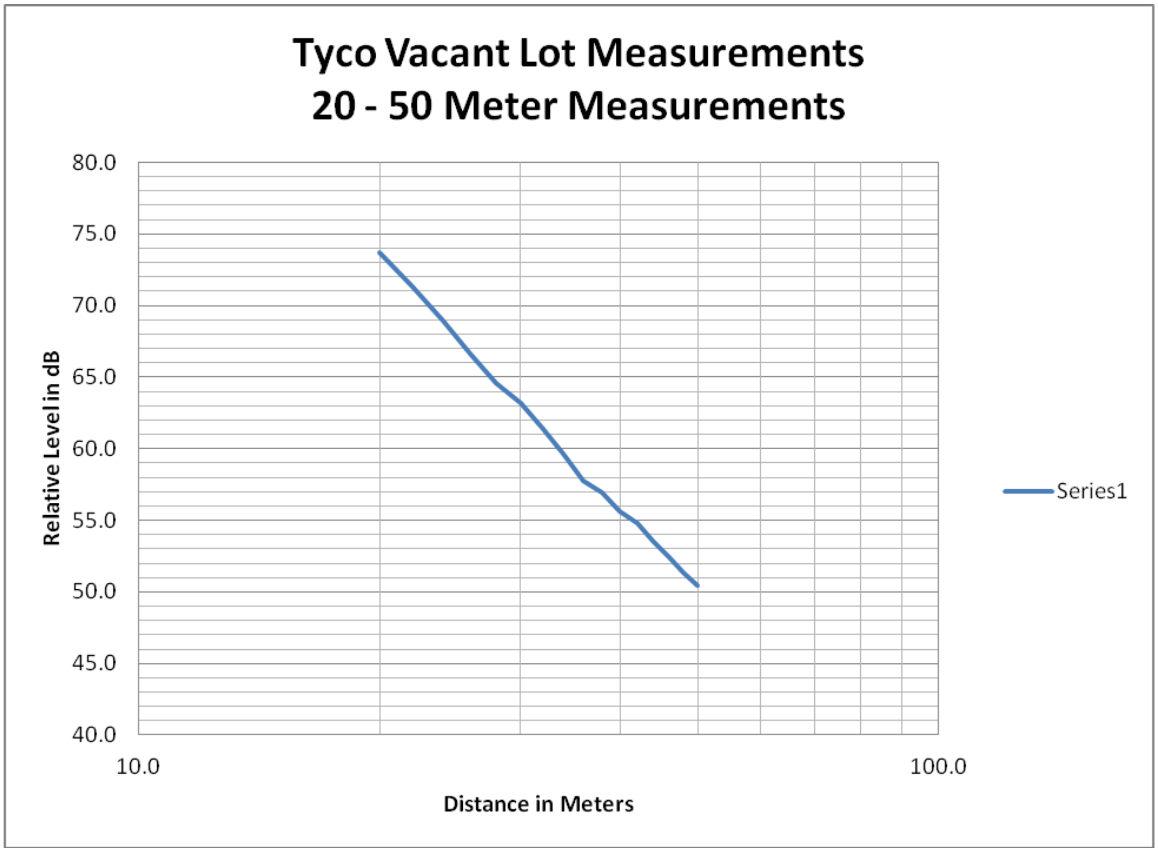


Figure I.2—Tyco vacant lot measurements 20 m to 50 m

I.3.1 Test item

The test item shall be set up as follows:

a) The EUT was a Sensormatic Ultra Post antitheft pedestal (manufactured by Tyco)

b) Operating frequency: 58 kHz

c) Loop size: ~0.33 m^2, contained in a single plane

d) Transmitter and antenna self-contained in pedestal enclosure

e) 120 V, 60 Hz power

I.3.2 Tyco test conditions

a) Measurements <20 m were performed in a parking lot, utilities around the perimeter of the measurement area.

b) Measurements >20 m were taken in a vacant lot, utilities around the perimeter of the measurement area.

1) Dry sandy soil, vegetation ~3 in to 8 in high

2) No rain for the previous few days

3) Temperature ~93 °C, humidity ~65%

c) EUT and instrumentation powered by separate gas-driven generators

I.3.3 Orientation of maximum measurement

a) The measurement antenna was rotated 22.5° about the vertical axis and horizontal axis for each radial of the EUT orientation over a range from 0° to ±90°.

b) The EUT was rotated 22.5° in a range from 0° to ±90° about its vertical axis (specified installation orientation).

c) This process was executed at 5 m, 10 m, and 15 m prior to collecting data to determine orientation of highest emission.

d) Result: The maximum level was at 0°—measurement antenna parallel to EUT.

I.4 Other sources on the basis of 60 dB per decade roll-off

The following two reports document a 60 dB roll-off in the LF band:

a) ERC Report 44 [B14] by the European Radiocommunications Committee (ERC) within the European Conference of Postal and Telecommunications Administrations (CEPT) established that a 60 dB roll-off occurred in the LF band. See Clause 4 and 4.1 of that report.

b) ETSI EN 300 330-2 V 1.5.1 (2010 02) (see Annex F.1 in that report) [B10].

Annex J

(informative)

Developing a transfer function for FM transmitters (alternative procedure for determining compliance of unlicensed FM transmitters)

J.1 Introduction

Low power, unlicensed FM transmitters are used in vehicles to transmit a weak signal onto a vacant channel in the FM broadcast band (88 MHz to 108 MHz) for the purpose of receiving satellite broadcasts on the vehicle's FM radio. The only method for determining compliance of these transmitters according to the FCC Rules and Regulations is to measure the field strength from the transmitter installed in three typical vehicles. This annex describes an alternative method for determining compliance by measuring conducted RF power output and using a transfer function derived by measuring the radiated field strength from transmitters installed in several vehicles.[118] Compliance may then be determined by applying the empirically derived transfer function to the conducted power and comparing the result with the FCC limit. This annex also shows the validity of using a proposed tabletop measurement procedure that can achieve the same result for the fundamental emissions but that could also be used for out-of-band and spurious emissions.

J.2 Background

A low power transmitter may be operated without an individual license, provided it is certified to comply with §15.239 of the FCC Rules and Regulations (47 CFR §15.239). For these devices, the FCC field strength limit is 250 μV/m at a 3 m measurement distance. Typically, field strength measurements are made with the EUT on a tabletop at an OATS or other approved facility. However, because there is uncertainty concerning the validity of tabletop measurements for certain types of FM transmitters, and because radiated emissions may be significantly attenuated when the transmitter is installed in a vehicle, the FCC requires measurements to be made at a minimum of three installations (vehicles) that can be demonstrated to be representative of typical installation sites. In other words, compliance is determined by making in situ measurements on three typical vehicles. Performing these in situ measurements is a difficult, expensive, and time consuming process. Furthermore, the vehicle-to-vehicle variation that is inherent in these types of measurements make them poorly suited in terms of their ability to determine compliance to FCC limits. Yet this is the only procedure currently permitted by the FCC. The paper by O'Brien et al. [B67] analyzes certification results for multiple products that have been tested at accredited laboratories over the past two years, and for which the radiated data can be found on the FCC OET Website. It compares those results with conducted RF power measurements for the same devices that were made separately but at accredited laboratories. As a result of the analysis, a transfer function value that takes the associated standard deviation into account is proposed. Additionally, measurements from a proposed tabletop method are also shown to be valid for the purposes of determining compliance to FCC limits.

J.3 Derivation of a transfer function

For an isotropic radiator, Equation (J.1) defines the relationship between conducted power in dBm and radiated field strength in dBμV/m, for frequencies less than 1000 MHz:

[118] This procedure and the associated paper (O'Brien et al. [B67]) were developed and written by Tom O'Brien with the assistance of Jean Tezil and Syed Murad of Sirius XM Satellite Radio, Inc., and with the backing and support of the Wireless Working Group of C63®.

$$E[\text{dB}\mu\text{V/m}] = \text{EIRP}[\text{dBm}] - 20\log d[\text{m}] + 109.5 \quad \text{(J.1)}$$

where E(dBμV/m) is the electric field strength, d is the reference measurement distance, and the value of 109.5 includes a factor of 4.7 dB to account for reflections from the ground plane.

To the extent that the actual measured field strength is lower than the theoretical value, it means that additional losses are present that are not accounted for in the equation. These losses can be due to shielding provided by the vehicle itself, nonisotropic radiation from the radiator, or other factors.

To account for these variations when analyzing empirical measurements, a correction factor (CF) may be added into the equation. If a statistically significant number of measurements is made and if the variations are random, then the CF measurements may be expected to form a normal distribution around the mean. For the case where the measurement distance is 3 m, and with the term for the CF added, Equation (J.1) can be modified as follows in Equation (J.2):

$$E[\text{dB}\mu\text{V/m}] = \text{EIRP}[\text{dBm}] - 9.54 - \text{CF} + 109.5 \quad \text{(J.2)}$$

Combining like terms gives Equation (J.3):

$$E(\text{dB}\mu\text{V/m}) = \text{EIRP}(\text{dBm}) - \text{CF} + 100 \quad \text{(J.3)}$$

Now, rearranging to put the equation into the conventional form of a transfer function (TF), i.e., [Output (dB) − Input (dB)], Equation (J.4) results:

$$E[\text{dB}\mu\text{V/m}] - \text{EIRP}[\text{dBm}] = [100 - \text{CF}] = \text{TF} \quad \text{(J.4)}$$

This can be visualized as in Figure J.1.

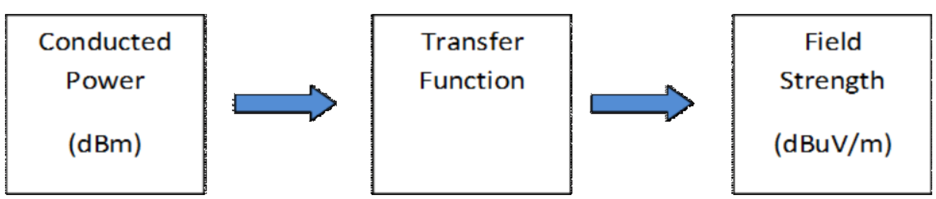


Figure J.1—Visualization of transfer function

From Equation (J.4), it can be seen that the correction factor is inversely related to the TF with an offset of 100 dB. After the TF is determined, it can be used for the purposes of determining a conducted power effective limit. By rearranging Equation (J.4) and substituting the 47 CFR 15.239 limit at FM frequencies for the output, Equation (J.5) results:

$$\text{EIRP}_{\text{LIMIT}}[\text{dBm}] = 48[\text{dB}\mu\text{V/m}] - \text{TF} \quad \text{(J.5)}$$

Or if using a correction factor instead, Equation (J.6) results:

$$\text{EIRP}_{\text{LIMIT}}[\text{dBm}] = 48[\text{dB}\mu\text{V/m}] - 100 + \text{CF} \quad \text{(J.6)}$$

From these equations, it can be seen that a higher TF yields a lower conducted power limit and that a higher CF yields a higher conducted power limit.

As mentioned previously, for in situ measurements of FM transmitters, a high CF means that either the vehicle body provides high attenuation or the radiation pattern is non-isotropic such that the field strength measured at the receive antenna is lower than it would be if the pattern were isotropic. Of course, it is also possible that a nonisotropic radiator can increase the gain in the direction of the receive antenna as well. Because of the variability of vehicle shielding and the potential for nonisotropic radiation, in situ measurements of FM transmitters have an inherently high degree of variability.

J.4 Measurement data

The initial arrangement used for measuring radiated field strength emissions from transmitters installed in a vehicle is shown in Figure 17. The general procedures for measuring radiated emissions in situ are contained in 6.11. For certification of the SiriusXM Satellite Radio FM transmitters subject to 47 CFR §15.239, measurements were made of transmitters installed on three vehicles and at three frequencies in the high, low, and mid band of 88 MHz to 108 MHz. Currently, tabletop emissions measurements are also being requested by the FCC in addition to the in situ measurements. Sirius XM Satellite Radio Inc. has received certifications for eight products with FM transmitters since August 2009. The data for these certifications were taken by eight different accredited test laboratories in Virginia, Maryland, Georgia, and Florida. All the in situ and tabletop data in the paper by O'Brien et al. [B67] were taken from the certification data and can be found on the FCC Office of Engineering and Technology Website. After being certified, conducted FM power measurements were made at accredited laboratories using the same products at the same FM frequencies that were used for the certifications. Because many of the in situ measurements were made at an OATS, only frequencies that were relatively free of strong ambient signals could be used. Thus, in some cases, different frequencies were used for different products.

Because in situ measurements have high variability, for the purposes of finding the appropriate TF and the associated conducted power effective limit, it was thought that a useful approach might be to minimize the effects of that variation by looking at only the worst-case measurements. Worst-case is defined as those measurements that yielded the highest TF because those measurements correspond to the lowest conducted power effective limits. The results from the frequency and vehicle combinations that met those criteria are plotted in the histogram in Figure J.2.

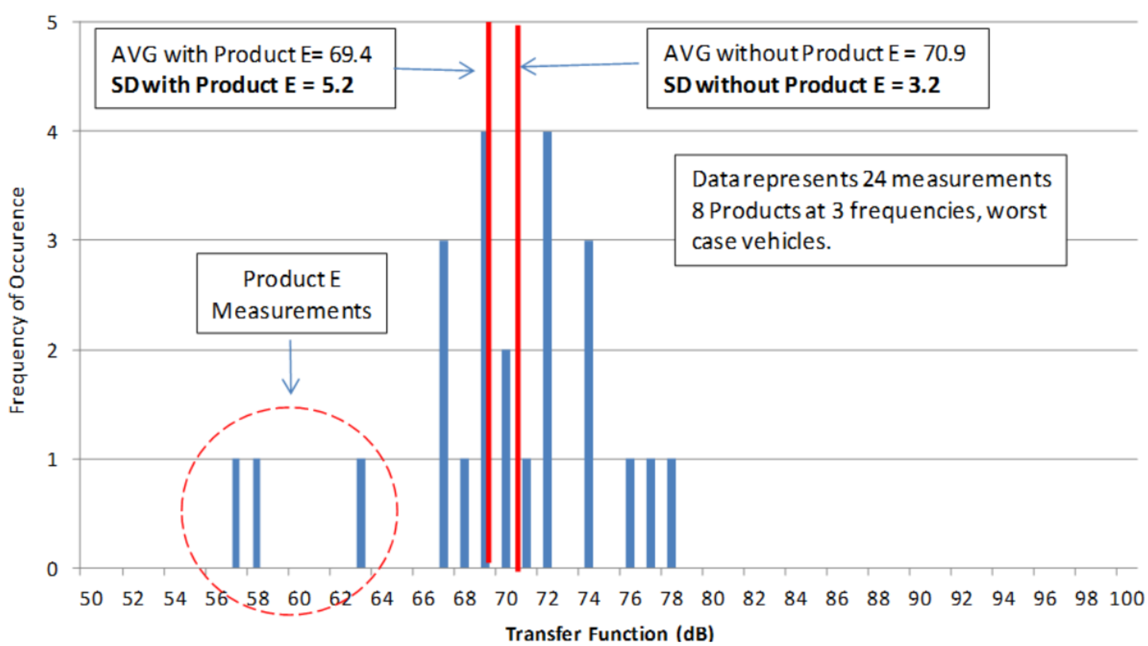


Figure J.2—Histogram using worst-case in situ measurements

Note from this plot that Product E seems to be an outlier. Initially, it was suspected that the data for that product could be in error, so TF averages and standard deviations were calculated both with and without the data from that product included. Using Equation (J.5), it can be seen that the average TF values of 69.4 dB (with Product E) and 70.9 dB (without Product E) would correspond to conducted power level effective limits of −21.4 dBm and −22.9 dBm, respectively. The standard deviation (σ) was 5.2 dB and 3.2 dB, respectively, for those measurements.

From statistics, it is known that for a normal distribution, approximately 68.3% of the values lie within ±1σ of the mean, approximately 95.4% of the values lie within ±2σ of the mean, and approximately 99.7% of the values lie within ±3σ of the mean. If it is assumed that the Product E measurements were not part of the normal distribution, then the mean is 70.9 dB, and adding 3σ (3 × 3.2) yields a TF limit of 80.5 dB, which corresponds to a conducted power effective limit of −32.5 dBm. If only 2σ are used, then the TF limit is 77.3 dB, which corresponds to a conducted power effective limit of −29.3 dBm.

It is instructive here to compare these limits with the actual measured conducted power for those certificated devices. For the eight products measured, the conducted power average, minimum, and maximum, are shown in Table J.1.

Table J.1—Conducted average, minimum, and maximum power

Average	−28.9 dBm
Minimum measured conducted power	−33.1 dBm
Maximum measured conducted power	−26.1 dBm

From the data in Table J.1 it can be observed that if the conducted power limit of −29.3 dBm is used, based on worst-case measurements, with Product E results removed, using 2σ from the mean, and assuming that the distribution is truly normal, then about half of the products that have previously been certified would not pass. A plot of conducted power levels for the eight products that are the subject of this investigation makes it easy to see that that limit would not be valid; see Figure J.3. Yet as shown in Figure J.4, those same products when tested in situ, despite the wide variation, all fall below the FCC limit for radiated emissions. Tabletop emissions, measured as per this standard, pass as well, but with a tighter distribution; see Figure J.5. A complete table of measured conducted power, along with all in situ data and the associated transfer function and correction factor values, is shown in Table J.2.

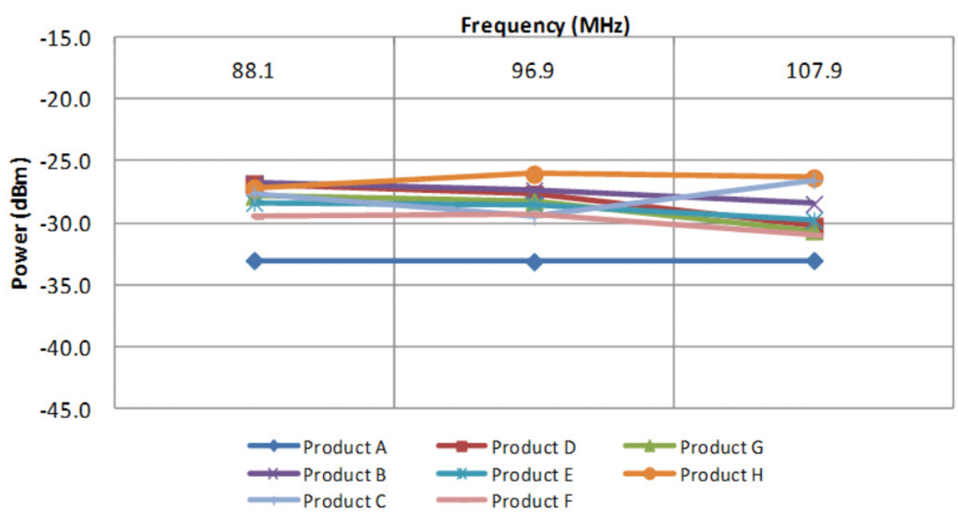


Figure J.3—Certified products conducted output power

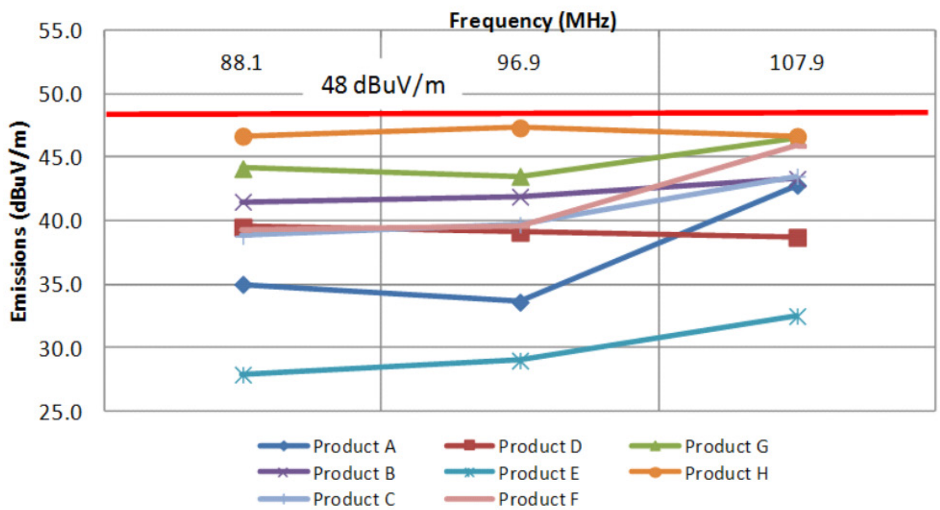


Figure J.4—Certified products in situ radiated emissions level

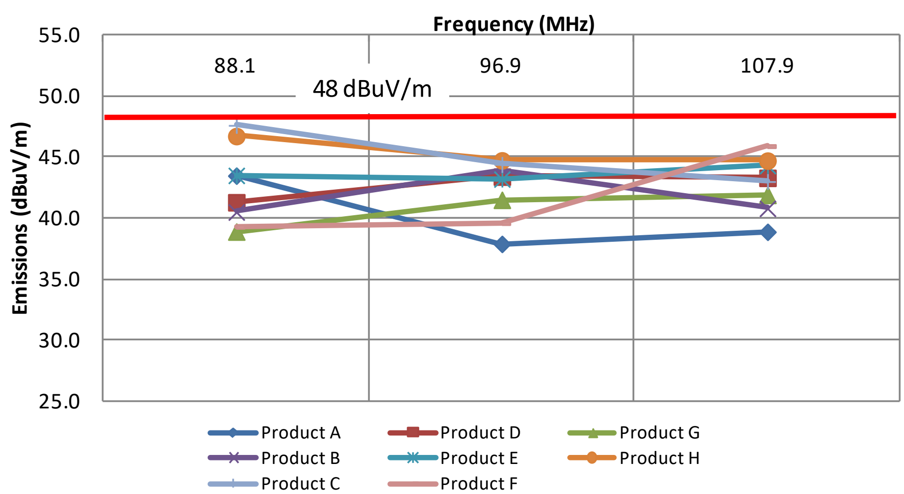


Figure J.5—Certified products tabletop radiated emissions level

Table J.2—Table of measured conducted with in situ and transfer functions

EUT	Frequency (MHz)	Measured power (conducted) (dBm)	Corresponding Eo @ 3m (dBμV/m)	In situ measured Eo @ 3m (dBμV/m)	Δ (dB) Correction factor	Δ (dB) Transfer function
Product A small car	88.1	−33.0	67.0	35.0	32	68
	96.9	−33.1	66.9	38.6	28.3	71.7
	107.9	−33.0	67.0	42.8	24.2	75.8
Product A midsize	88.1	−33.0	67.0	29.3	37.7	62.3
	96.9	−33.1	66.9	35.1	31.8	68.2
	107.9	−33.0	67.0	37.1	29.9	70.1
Product A large	88.1	−33.0	67.0	28.7	38.3	61.7
	96.9	−33.1	66.9	33.2	33.7	66.3
	107.9	−33.0	67.0	32.1	34.9	65.1
Product G small car	89.1	−27.8	72.2	44.1	28.1	71.9
	97.7	−28.3	71.7	43.5	28.2	71.8
	106.3	−30.6	69.4	46.5	22.9	77.1
Product G midsize	89.1	−27.8	72.2	39.0	33.2	66.8
	97.7	−28.3	71.7	34.8	36.9	63.1
	106.3	−30.6	69.4	32.2	37.2	62.8
Product G large	89.1	−27.8	72.2	33.1	39.1	60.9
	97.7	−28.3	71.7	35.5	36.2	63.8
	106.3	−30.6	69.4	35.5	33.9	66.1
Product E small	89.1	−28.4	71.6	27.9	43.7	56.3
	97.7	−28.5	71.5	29.0	42.5	57.5
	106.3	−29.8	70.2	31.1	39.1	60.9
Product E midsize	89.1	−28.4	71.6	24.7	46.9	53.1
	97.7	−28.5	71.5	27.0	44.5	55.5
	106.3	−29.8	70.2	31.7	38.5	61.5
Product E large	89.1	−28.4	71.6	26.7	44.9	55.1
	97.7	−28.5	71.5	26.7	44.8	55.2
	106.3	−29.8	70.2	32.5	37.7	62.3
Product B small car	89.1	−26.8	73.2	41.5	31.7	68.3
	97.7	−27.4	72.6	41.9	30.7	69.3
	106.3	−28.5	71.5	43.3	28.2	71.8
Product B midsize	89.1	−26.8	73.2	30.6	42.6	57.4
	97.7	−27.4	72.6	33.7	38.9	61.1
	106.3	−28.5	71.5	33.0	38.5	61.5
Product B large	89.1	−26.8	73.2	28.7	44.5	55.5
	97.7	−27.4	72.6	30.5	42.1	57.9
	106.3	−28.5	71.5	32.8	38.7	61.3
Product H small	91.7	−27.2	72.8	46.1	26.7	73.3
	98.3	−26.1	73.9	47.4	26.6	73.45
	105.3	−26.4	73.6	42.9	30.7	69.28
Product H midsize	91.7	−27.2	72.8	44.5	28.3	71.7
	98.3	−26.1	73.9	45.6	28.4	71.65
	105.3	−26.4	73.6	46.7	26.9	73.08
Product H large	91.7	−27.2	72.8	46.7	26.1	73.9
	98.3	−26.1	73.9	44.6	29.4	70.65
	105.3	−26.4	73.6	46.6	27.0	73
Product D small	89.1	−26.9	73.1	39.5	33.6	66.4
	97.7	−27.7	72.3	39.1	33.2	66.8
	106.3	−30.3	69.7	38.7	31.0	69
Product D midsize	89.1	−26.9	73.1	30.6	42.5	57.5
	97.7	−27.7	72.3	24.3	48.0	52
	106.3	−30.3	69.7	32.2	37.5	62.5
Product D large	89.1	−26.9	73.1	33.4	39.7	60.3
	97.7	−27.7	72.3	38.9	33.4	66.6
	106.3	−30.3	69.7	35.6	34.1	65.9

Table J.2—Table of measured conducted with in situ and transfer functions *(continued)*

EUT	Frequency (MHz)	Measured power (conducted) (dBm)	Corresponding Eo @ 3m (dBµV/m)	In situ measured Eo @ 3m (dBµV/m)	Δ (dB) Correction factor	Δ (dB) Transfer function
Product F small	88.1	−29.5	70.5	38.0	32.5	67.5
	96.9	−29.3	70.7	39.6	31.1	68.9
	107.9	−30.9	69.1	45.9	23.2	76.8
Product F midsize	88.1	−29.5	70.5	39.3	31.2	68.8
	96.9	−29.3	70.7	34.6	36.1	63.9
	107.9	−30.9	69.1	33.6	35.5	64.5
Product F large	88.1	−29.5	70.5	38.6	31.9	68.1
	96.9	−29.3	70.7	36.2	34.5	65.5
	107.9	−30.9	69.1	33.6	35.5	64.5
Product C small	88.1	−27.7	72.3	38.8	33.5	66.5
	96.9	−29.5	70.5	39.7	30.8	69.2
	107.9	−26.6	73.4	43.5	29.9	70.1
Product C midsize	88.1	−27.7	72.3	37.8	34.5	65.5
	96.9	−29.5	70.5	38.7	31.8	68.2
	107.9	−26.6	73.4	40.4	33.0	67.0
Product C large	88.1	−27.7	72.3	35.4	36.9	63.1
	96.9	−29.5	70.5	30.8	39.7	60.3
	107.9	−26.6	73.4	32.1	41.3	58.7

J.5 Using all in situ measurement results

When all measurement results are used, instead of worst-case only, the range of measurement values increases, as expected. As mentioned, this likely reflects the fact that some vehicles provide significantly more attenuation than others or that the radiation from within the vehicle structures is not isotropic.

Note too that when all measurement results are used, it can be observed that the Product E measurements are encompassed by the wider distribution, and in fact, legitimate values seem to exist in what appears to be a normal distribution.

The in situ measurements, which represent eight products measured at three frequencies and in three vehicles, are plotted in the histogram in Figure J.6.

The average TF value is 66.5 dB without Product E and 65.4 dB with Product E. The standard deviation (σ) was 5.3 dB and 5.9 dB, respectively, for those measurements. Considering that Product E appears to be part of the normal distribution, it does not make sense to remove it from the data set, so it is believed that a conducted power effective limit should only be calculated with it included. Thus, with Product E included and using the same formulas and calculations as described, if 2σ are used, the TF mean would be 65.4 dB and the associated conducted power effective limit would be −29.2 dBm.

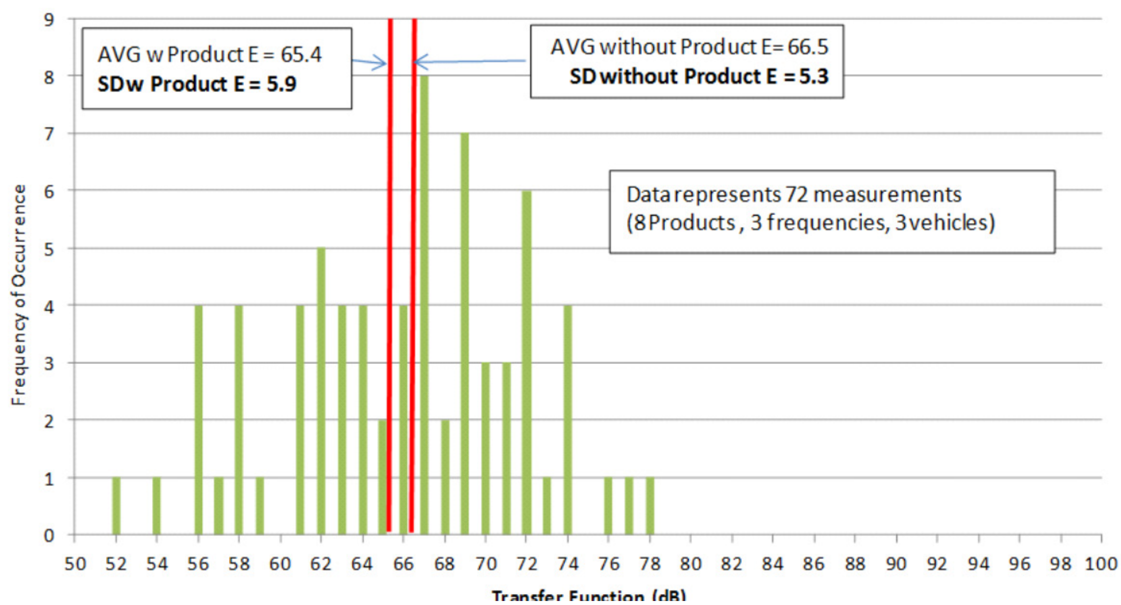


Figure J.6—Histogram using all in situ measurements

J.6 Using tabletop measurements

The arrangement used for making tabletop measurements of radiated emissions from a device that directly injects an FM signal into a vehicle's wiring system through the CLA socket is shown in Figure 16. The proposed method is the same method that was used to collect the tabletop data for the certifications that are described in this paper. All of the products used a method of directly injecting the FM signal into the vehicle wiring system through the CLA socket. Thus, a standard FM injection procedure for those types of transmitters was followed as closely as was possible by all the test laboratories.

The transfer function and various other equations described for in situ measurements may also be applied to tabletop measurements. However, it can be seen from the data that for these measurements, the distribution is tighter and the mean is higher. This likely reflects the fact that there is no opportunity for vehicle shielding and, thus, less opportunity for a higher CF (lower TF).

The certification data for eight products, measured at three frequencies, are represented in the histogram in Figure J.7. The average TF value is 71.8 dB and σ is 2.6 dB. Using the same formulas and calculations as described, if 2σ is used, then the TF value would be 77 dB and the associated conducted power effective limit would be −29.0 dBm. A complete set of radiated tabletop measurement results, with the associated transfer functions, is shown in Table J.3.

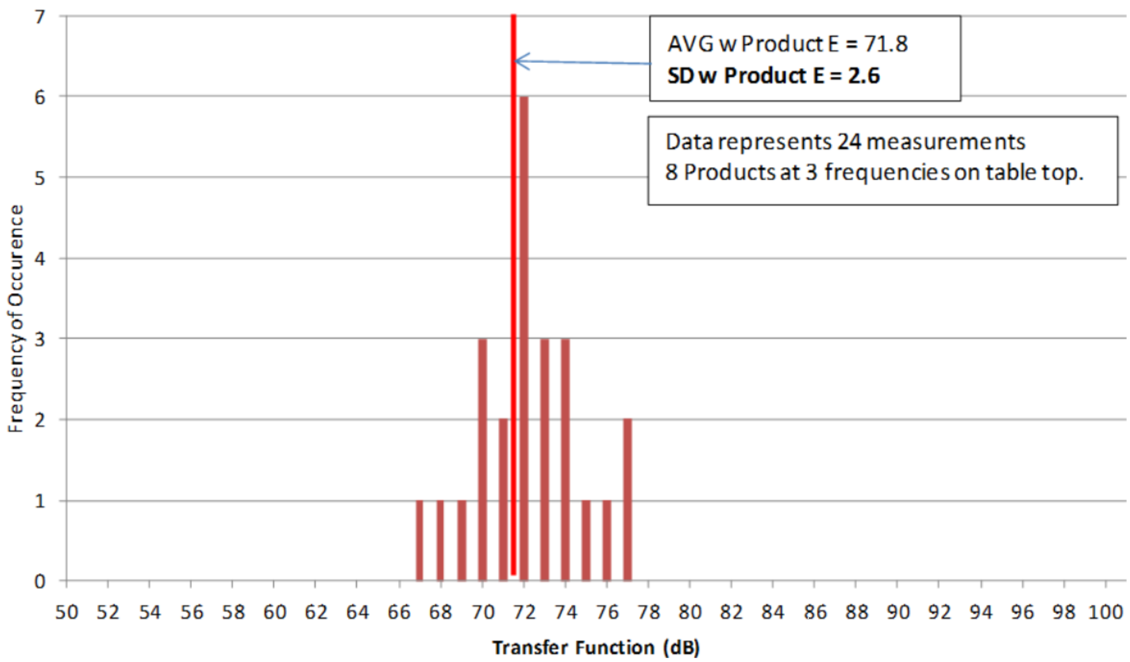


Figure J.7—Histogram of all tabletop measurements

Table J.3—Complete table of radiated tabletop measurements with transfer functions

EUT	Frequency (MHz)	Measured power (conducted) (dBm)	Conducted power (converted to dBµV/m)	Corresponding Eo @ 3 m (dBµV/m)	Tabletop (dBµV/m)	Δ (dB) Tabletop
Product A	88.1	−33.0	74.0	67.0	43.5	76.5
	96.9	−33.1	73.9	66.9	37.9	71.0
	107.9	−33.0	74.0	67.0	38.9	71.9
Product G	89.1	−27.8	79.2	72.2	38.9	66.7
	97.7	−28.3	78.7	71.7	41.5	69.8
	106.3	−30.6	76.4	69.4	41.9	72.5
Product E	89.1	−28.4	78.6	71.6	43.5	71.9
	97.7	−28.5	78.5	71.5	43.2	71.7
	106.3	−29.8	77.2	70.2	44.3	74.1
Product B	91.7	−26.8	80.2	73.2	40.5	67.3
	98.3	−27.4	79.6	72.6	43.9	71.3
	105.3	−28.5	78.5	71.5	40.8	69.3
Product H	89.1	−27.2	79.8	72.8	46.7	73.9
	97.7	−26.2	80.9	73.9	44.7	70.8
	106.3	−26.4	80.6	73.6	44.7	71.1
Product D	88.1	−26.9	80.1	73.1	41.3	68.2
	96.9	−27.7	79.3	72.3	43.4	71.1
	107.9	−30.3	76.7	69.7	43.3	73.6
Product F	88.1	−29.5	77.5	70.5	43.1	72.6
	96.9	−29.3	77.7	70.7	43.2	72.5
	107.9	−30.9	76.1	69.1	45.6	76.5
Product C	88.1	−27.7	79.3	72.3	47.6	75.3
	96.9	−29.5	77.5	70.5	44.4	73.9
	107.9	−26.6	80.4	73.4	43.0	69.6

J.7 A comparison of all in situ and tabletop measurements

When all the data are overlaid on one plot, as in Figure J.8, it can be seen that in situ measurements have the widest variation. Worst-case in situ measurements have a slightly lower σ and are distributed nearer to the highest TF values, but they can still include outliers. Tabletop measurements have the lowest σ and are distributed most closely to the highest TF values.

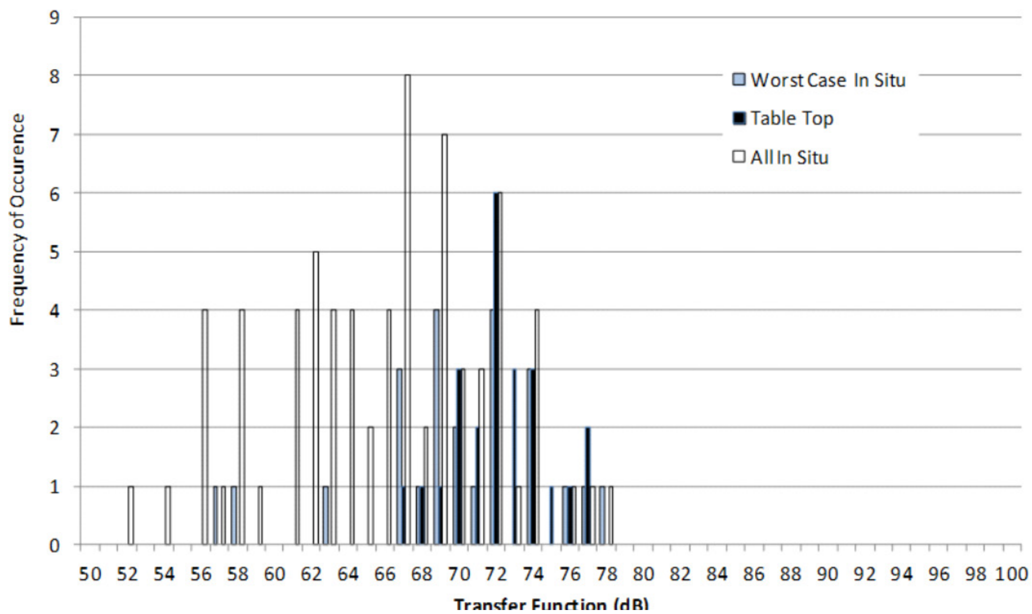


Figure J.8—Histogram of all measurements in situ and tabletop

J.8 Summary and conclusion

A summary of the measurements, with transfer functions, and associated conducted power effective limits for 1σ, 2σ, and 3σ, is shown in Table J.4. Previously, it was noted that for a normal distribution, approximately 95.4% of the values lie within ±2σ of the mean. From the histograms, it does appear that the data are distributed normally about the mean. If this supposition is accepted, then a conducted power effective limit based on the TF calculated using the tabletop method, plus 2σ, would mean that 95.4% of the products that meet the conducted power effective limit would also pass on the tabletop. For those products that are outside the 95.4%, only half of them would be on the high side of the distribution; the other half would be on the low side of the distribution. Furthermore, a diminishing percentage of those products would reach even one additional σ of 2.6 dB.

Thus, a transfer function value of 77 dB is proposed for the purpose of determining radiated emissions levels from conducted power levels at FM frequencies, yielding an effective conducted power limit of −29 dBm for the fundamental emissions. Furthermore, it is proposed that the tabletop method as described in this standard be used to determine compliance of the out-of-band and spurious emissions to FCC limits, so that in situ measurements are no longer required.

Table J.4—Summary of measurement results and transfer functions (TF)

Test description	**Size of data set**	**TF mean**	**TF Standard deviation (σ)**	**TF mean + 1 σ**	**Conducted power effective limit for TF + 1 σ (dBm)**	**TF mean + 2 σ**	**Conducted power effective limit for TF + 2 σ (dBm)**	**TF mean + 3 σ**	**Conducted power effective limit for TF + 3 σ (dBm)**
Worst-case in situ results with NO Product E	7 products 3 frequencies = 21 measurements	70.9	3.2	74.1	−28.1	77.3	−29.3	80.5	−32.5
Worst-case in situ results with Product E	8 products 3 frequencies = 24 measurements	69.4	5.2	74.6	−28.8	79.8	−31.8	85.0	−37.0
All in situ results with NO Product E	7 products 3 frequencies 3 vehicles = 63 measurements	66.5	5.3	71.8	−23.8	77.1	−29.1	82.4	−34.4
All in situ results with Product E	8 products 3 frequencies 3 vehicles = 72 measurements	65.4	5.9	71.3	−23.3	77.2	−29.2	83.1	−35.1
Results from proposed tabletop method all products	8 products 3 frequencies = 24 measurements	71.8	2.6	74.4	−26.4	77.0	−29.0	79.6	−31.6

Annex K

(informative)

Discussion on Dynamic Frequency Selection (DFS) for Operation in the 5250 MHz to 5350 MHz and 5470 MHz to 5725 MHz bands[119]

K.1 General

In 2003, the International Telecommunications Union – Radio adopted Resolution 229, which allocated globally parts of the 5 GHz band for use by Mobile Services including Wireless access services that include RLAN devices.

As these bands are allocated to Radio Location (Radar) and Satellite services on a primary basis, sharing mechanisms were developed and adopted as part of this international allocation in order for the mobile services to be allowed to share the band on a noninterference basis with incumbent services.

In order to share with radar systems operating in the band, a methodology that was proposed by the ETSI group working on 5 GHz and was agreed upon by the various participants at WRC2003. This requirement is called Dynamic Frequency Selection (DFS) and requires mobile service device operating in the 5250 MHz to 5350 MHz and 5470 MHz to 5725 MHz bands to detect specific radar wave forms and move off channel to avoid causing interference to radars. Further depending on if the device is a Client or a Master device, specific DFS requirements were developed for each device. ITU-R Res 229 as adopted leaves open further revisions and discussions on these parameters at future World Radio Conferences.

Concerning operation, the device must perform a 60 s Channel Availability Check (CAC) prior to using any channels in the 5250 MHz to 5350 MHz and 5470 MHz to 5725 MHz bands. If the channel is clear then the device may start transmitting. If it detects a radar signal it must move off channel and lock out that channel for a period of 30 min. Further while operating on the channel, the device must also do In Service Monitoring to continue to determine the band is still not in use by a radar device. Upon detecting a radar signal, the device must move off channel and lock out that channel for 30 min before it can be looked at again via CAC to see if it is none occupied.

The detection criteria as listed below was agreed and adopted at the World Radio Conference 2003 and has been adopted by numerous countries including US and Canada.

In the US operation under Part 15 of the FCC rules is permitted on a noninterference basis, and in Canada under RSS-247. Because these bands are shared with various government services such as FAA Terminal Doppler Radar, Defense Department Radars and various Navigation radars, the RLAN works with the various government agencies concerning development of the test procedures and technical parameters. As such in the US, both federal and non-federal test radar signals and the specific files that must be transmitted for the testing in the US are provided in part by the National Telecommunications and Information Agency, which represents FAA, DOD, NASA and others in this process.

Concerning the basic DFS technical requirements, information can be found in ITU-R M.16512-1. These parameters are incorporated into a number of country regulations including the UU, Japan, Australia, U.S., and Canada.

[119] Additional info can be found at www.fcc.gov, www.itu.int, and www.ntia.doc.gov.

Table K.1—DFS Response requirement values

Parameter	Value
Non-occupancy period	30 min
Channel Availability Check Time	60 s
Channel Move Time	10 s
Channel Closing Transmission Time	200 ms + approx. 60 ms over remaining 10 s period

K.2 Detection threshold values

Table K.2 gives the DFS thresholds for Master devices and for Client devices.

Table K.2—Interference Detection Threshold values

Maximum Transmit Power	Value (see note)
≥ 200 mW	−64 dBm
< 200 mW	−62 dBm
NOTE—This is the level at the input of the receiver assuming a 0 dBi receive antenna.	

Further since 2003 new radar systems have been deployed in these bands and as such there have been ongoing discussions with both national administrations as well as in the ITU-R SG 5 Terrestrial Service Workgroups on updating these radar parameters to address newer radar systems and updated the DFS detection Algorithms.

In 2014, the FCC adopted changes to its DFS test procedure based on recommendations from the U.S. Workgroup including NTIA, DOD, FAA, and industry for adding a new sub-millisecond short pulse to detect the FAA Terminal Doppler Weather Radar operating in the 5600 MHz to 5650 MHz band.

Concerning future uses of DFS in other bands, the World Radio Conference 2019 has an agenda item looking at expansion of the 5 GHz bands. As part of this band allocation discussions in the ITU-R study groups working on issues for WRC19, they are looking at DFS as one possible sharing mechanism.

Annex L

(informative)

Desensitization factor and sweep time considerations for measurements of FMCW signals

L.1 Desensitization for peak detection

Decreased sensitivity and resolution results when a CW signal is swept by the spectrum analyzer IF amplifier at a high rate compared to the resolution bandwidth squared.

Keysight Technologies Application Note 5952-1039 "Spectrum and Signal Analysis Pulsed RF" [B62], in Appendix B "IF Amplifier Response and Distortion," provides the derivation of the desensitization due to a Gaussian-shaped RBW filter in response to a linearly-swept FMCW signal.

For the purposes of this Standard two parameters in the above-referenced application note, Fs = sweep width and T_s = sweep time, are designated as BW_{chirp} = Chirp Bandwidth (or Chirp BW) and T_{chirp} = Chirp Time, respectively. This serves to maintain consistency with the historic terminology related to FMCW modulation and to mitigate potential confusion between (signal) sweep width and (instrument) span, or between (signal) sweep time and (instrument) sweep time. See Figure L.1.

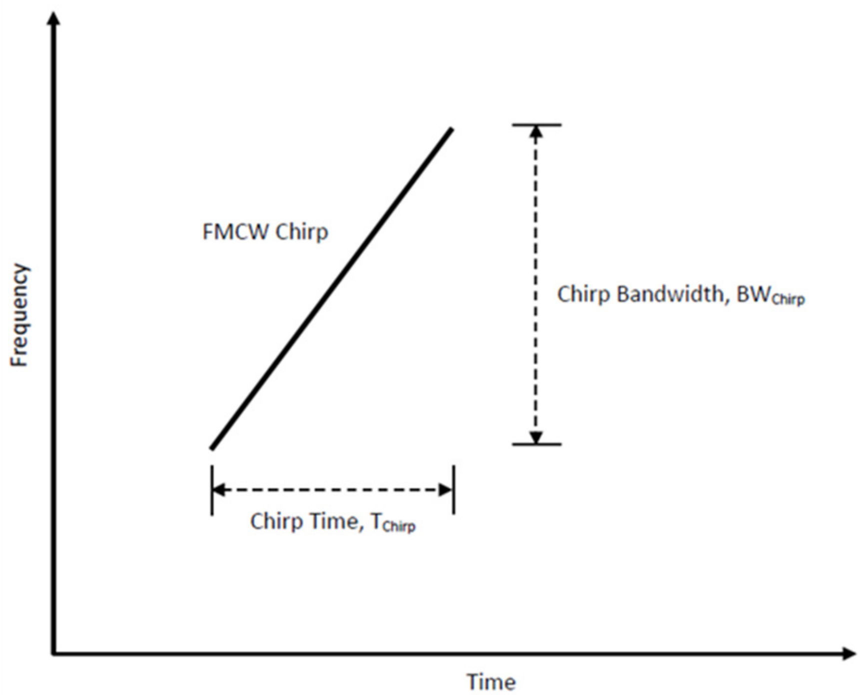


Figure L.1—Frequency-time characteristics of an FMCW chirp with linear sweep

The desensitization when the above signal passes through a Gaussian RBW filter is calculated by Equation (L.1):

$$\alpha = \frac{1}{\sqrt{1+\left(\frac{2\ln(2)}{\pi}\right)^2\left(\frac{BW_{\text{Chirp}}}{T_{\text{Chirp}}B^2}\right)^2}} \quad \text{(L.1)}$$

where

α	is the reduction in amplitude
BW_{Chirp}	is the FMCW Chirp Bandwidth
T_{Chirp}	is the FMCW Chirp Time
B	is the 3 dB IF Bandwidth = RBW

NOTE—This assumes that the analyzer sweep time is negligible (i.e., Sweep Time >> T_{Chirp}) or that the analyzer is in the zero span mode.

Normalized Sweep Rate is defined as BW_{Chirp} / (T_{Chirp} B^2); Figure L.2 shows the Desensitization as a function of Normalized Sweep Rate.

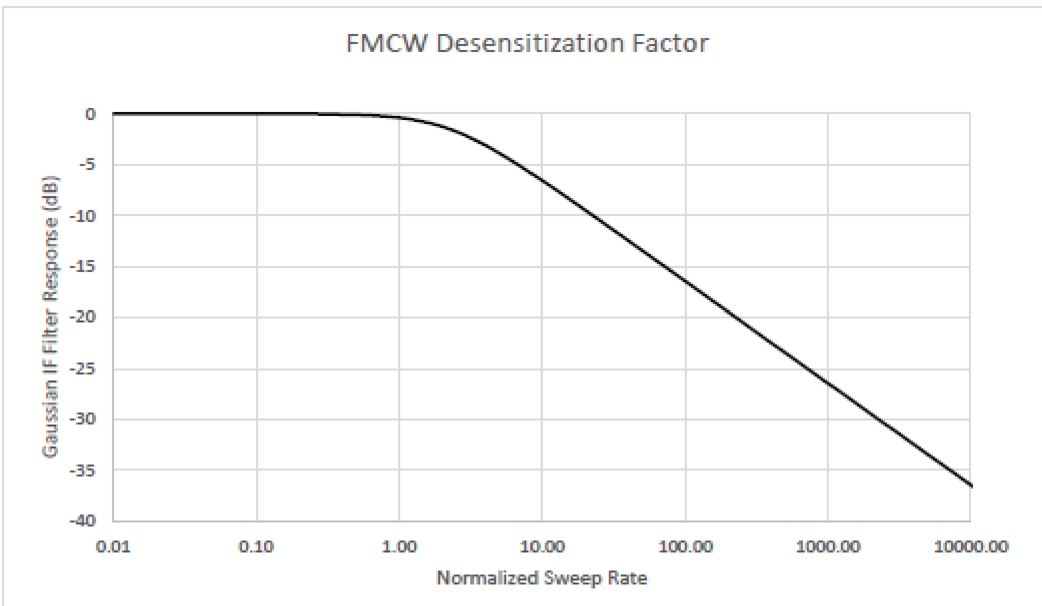


Figure L.2—FMCW desensitization as a function of normalized sweep rate

For non-linear FMCW sweeps use the highest chirp rate, where Chirp Rate is the Instantaneous BW_{Chirp} / T_{Chirp} as the time segment approaches 0.

For non-Gaussian RBW filters consult the instrument manufacturer.

Table L.1 provides calculations of the FMCW Desensitization Factor for selected FMCW Signal Characteristics and a 1 MHz Gaussian RBW.

Table L.1—FMCW desensitization factor for selected signal parameters

FMCW Chirp Width (MHz)	FMCW Chirp Time (µs)	Chirp Rate (MHz/µs)	Chirp Rate (Hz/S)	RBW (MHz)	RBW (Hz)	Normalized Sweep Rate (lin)	Peak Amplitude Response (lin)	Desensitization Factor (dB)
1000	1000	1.0	1.00E+12	1	1.00E+06	1.0	0.956	0.39
1000	100	10.0	1.00E+13	1	1.00E+06	10.0	0.470	6.56
1000	10	100.0	1.00E+14	1	1.00E+06	100.0	0.150	16.45
1000	1	1000.0	1.00E+15	1	1.00E+06	1000.0	0.048	26.45
1000	0.1	10000.0	1.00E+16	1	1.00E+06	10000.0	0.015	36.45
5000	1000	5.0	5.00E+12	1	1.00E+06	5.0	0.642	3.84
5000	100	50.0	5.00E+13	1	1.00E+06	50.0	0.213	13.44
5000	10	500.0	5.00E+14	1	1.00E+06	500.0	0.067	23.44
5000	1	5000.0	5.00E+15	1	1.00E+06	5000.0	0.021	33.44
5000	0.1	50000.0	5.00E+16	1	1.00E+06	50000.0	0.007	43.44

L.2 Desensitization for average detection

There is no desensitization for average detection.

The IF filter in the instrument does not respond instantaneously to the rising signal envelope; similarly, the IF filter does not respond instantaneously to the falling signal envelope. The result is that the response curve is distorted (lower peak level and longer time duration), however the integrated area under the IF filter response envelope is the same as the integrated area under the envelope of the actual signal.

L.3 Sweep time for peak detection

Theoretically if the analyzer sweep time is adjusted to a minimum of (Signal Period) × (Span) / (RBW), therefore the instrument is essentially (within ± 0.5 RBW) tuned to any particular frequency for at least one entire period of the signal, a 100% probability of detection will be achieved.

However practical considerations such as the lack of synchronization between the timing of the FMCW Chirp and the analyzer sweep/sampling, FMCW Chirp stability, analyzer sweep time accuracy and stability, analyzer sampling rate accuracy and stability, etc. indicate that a sweep time of exactly one signal period is insufficient. A nominal sweep time of 2 × (Signal Period) × (Span) / (RBW) ought to be sufficient, and may be necessary for signals where the duty cycle approaches 100%. Nevertheless, a suitable sweep time can be determined by increasing the sweep time until the displayed signal amplitude no longer increases.

L.4 Sweep time for average detection

Theoretically if the analyzer sweep time is adjusted to N × (Signal Period) × (Span) / (RBW), where N is a positive integer, the instrument will correctly measure the average value at any given frequency.

Due to the same practical considerations discussed above for the probability of detection, averaging is subject to additional errors. These are particularly evident when N is not an integer. The sweep time of the analyzer must be slow enough that analyzer dwells at each horizontal bin point for multiple EUT periods to help ensure a reasonable measurement accuracy.

The following analysis supports this conclusion.

Assume one horizontal bin point per RBW, that the RBW is an impulse bandwidth (thus a brick-wall filter shape) and define the dwell time as the length of time the instrument is tuned to the frequency associated with one RBW or one bin point.

NOTE 1—For effective averaging the instrument internal sampling rate must be much greater than the inverse of the dwell time per bin.

Consider an FMCW signal with the following characteristics:

FMCW Chirp Time = 10% of the Signal Period

FMCW Chirp Width = 100 times the RBW

The dwell time is 1 signal period per RBW. During the dwell time the signal level over one RBW within the Chirp Frequency Range consists of:

1 FMCW signal of duration 0.001 periods when the chirp frequency is within the RBW

+ 0.099 periods of effective OFF time when the chirp frequency is outside the RBW

+ 0.900 periods of actual OFF time

This yields an average value of 0.001 / 1 = 0.001 times the peak value.

Suppose it is intended to measure one period, and the analyzer sweep time is 1% less than the period. The dwell time is 0.99 periods per RBW. Depending on the relative timing, any given analyzer bin might capture 0 or 1 FMCW signals. Next assume the analyzer sweep time is 1% greater than the period. The dwell time is 1.01 periods per RBW. Depending on the relative timing, any given analyzer bin might capture 1 or 2 FMCW signals.

Now suppose that it is intended to measure 2 periods, and the analyzer sweep time is 1% less than the period. The dwell time is 1.99 periods per RBW. Depending on the relative timing, any given analyzer bin might capture 1 or 2 FMCW signals. Finally assume the analyzer sweep time is 1% greater than the period. The dwell well time is 2.01 periods per RBW. Depending on the relative timing, any given analyzer bin might capture 2 or 3 FMCW signals.

Consider this last instance, where the dwell time is 2.01 periods per RBW and 3 FMCW signals are detected. Depending on the relative phase synchronization between the signal and the instrument, during the dwell time the signal level over one RBW within the Chirp Frequency Range consists of:

3 FMCW signals of total duration 0.003 periods when the chirp frequency is within the RBW

+ as much as 0.207 periods of effective OFF time when the chirp frequency is outside the RBW

+ as little as 1.800 periods of actual OFF time

or

3 FMCW signals of total duration 0.003 periods when the chirp frequency is within the RBW

+ as little as 0.198 periods of effective OFF time when the chirp frequency is outside the RBW

+ as much as 1.809 periods of actual OFF time

No matter the phase synchronization this yields a measured average of 0.003 / 2.01 = 0.00149 times the peak value, which is different than the actual average of 0.001 times the peak value. This yields a measurement error of +49%.

NOTE 2—Phase synchronization outside the boundaries of the above range will result in the detection of only 2 FMCW signals.

This analysis can be extended to any number of intended periods to measure and applicable number of detected FMCW signals, for any relative error between the analyzer sweep time and the signal period.

Table L.2 provides error calculations for various intended numbers of signal periods to measure, given a 1% relative difference between the analyzer sweep time and the signal period. These calculations show the reduction in error that results by averaging over multiple periods of the signal.

Table L.2—Averaging error as a function of the intended number of periods to measure

Intended number of signal periods to measure (N)	Analyzer sweep time difference related to signal period (%)	Dwell time or averaging time per RBW (periods)	Number of chirp segements detected within RBW (N)	Total aggregate signal duration within RBW (periods)	Measured average value (fraction of peak)	Measurement error (%)	Maximum measurement error (%)	Maximum measurement error (dB)
1	−1	0.99	0	0.000	0.000000	−100	+98/−100	+5.9/−Undefined
			1	0.001	0.001010	1.01		
	1	1.01	1	0.001	0.000990	−0.99		
			2	0.002	0.001980	98		
2	−1	1.99	1	0.001	0.000503	−50	+49/−50	+3.5/−6.0
			2	0.002	0.001005	0.50		
	1	2.01	2	0.002	0.000995	−0.50		
			3	0.003	0.001493	49		
5	−1	4.99	4	0.004	0.000802	−20	±20	+1.6/−1.9
			5	0.005	0.001002	0.20		
	1	5.01	5	0.005	0.000998	−0.20		
			6	0.006	0.001198	20		
10	−1	9.99	9	0.009	0.000901	−10	±10	+0.8/−0.9
			10	0.010	0.001001	0.10		
	1	10.01	10	0.010	0.001000	−0.10		
			11	0.011	0.001049	10		
20	−1	19.99	19	0.019	0.000950	−5	±5	±0.4
			20	0.020	0.001001	0.05		
	1	20.01	20	0.020	0.001000	−0.05		
			21	0.021	0.001049	5		
50	−1	49.99	49	0.049	0.000980	−2	±2	±0.2
			50	0.050	0.001000	0.02		
	1	50.01	50	0.050	0.001000	−0.02		
			51	0.051	0.001020	2		
100	−1	99.99	99	0.099	0.000990	−1	±1%	±0.1
			100	0.100	0.001000	0.01		
	1	100.01	100	0.100	0.001000	−0.01		
			101	0.101	0.001010	1		

Annex M

(informative)

Glossary

This annex provides an informative compilation of terms used in various radio regulations and associated documents concerning unlicensed wireless devices, radio parameters, and wireless devices.

1) **access broadband over power-line (access BPL):** A carrier current system installed and operated on an electric utility service as an unintentional radiator that sends radio frequency energy on frequencies between 1.705 MHz and 80 MHz over medium-voltage lines or over low-voltage lines to provide broadband communications and is located on the supply side of the utility service's points of interconnection with customer premises. [47 CFR 15.3(ff)]

   NOTE—Access BPL does not include power-line carrier systems as defined in 15.3(t) or in house BPL as defined in 15.3(gg).

2) **access point (AP):** A U-NII transceiver that operates either as a bridge in a peer-to-peer connection or as a connector between the wired and wireless segments of the network. [47 CFR 15.403(a)]

3) **assigned frequency band:** The frequency band in which the center coincides with the frequency assigned to the station and the width equals the necessary bandwidth plus twice the absolute value of the frequency tolerance.

4) **auditory assistance device:** An intentional radiator used to provide auditory assistance to a handicapped person or persons. Such a device may be used for auricular training in an educational institution; for auditory assistance at places of public gatherings, such as a church, theater, or auditorium; and for auditory assistance to handicapped individuals, only, in other locations. [47 CFR 15.3(a)]

5) **authorized bandwidth:** The frequency band, specified in kilohertz and centered on the carrier frequency containing those frequencies upon which a total of 99% of the radiated power appears, extended to include any discrete frequency upon which the power is at least 0.25% of the total radiated power. (47 CFR 90.7)

6) **average symbol envelope power:** The average, taken over all symbols in the signaling alphabet, of the envelope power for each symbol. [47 CFR 15.403(c)]

7) **biomedical telemetry device:** An intentional radiator used to transmit measurements of either human or animal biomedical phenomena to a receiver. [47 CFR 15.3(b)]

8) **broadband over power-line (BPL):** *See:* **access broadband over power-line; in house broadband over power-line**.

9) **cable locating equipment:** An intentional radiator used intermittently by trained operators to locate buried cables, lines, pipes and similar structures, or elements. This operation entails coupling a radio frequency signal onto the cable, pipe, and so on, as well as using a receiver to detect the location of that structure or element. [47 CFR 15.3(d)]

10) **carrier current system:** A system, or part of a system, that transmits radio frequency energy by conduction over the electric power-lines. A carrier current system can be designed such that the signals are received by conduction directly from connection to the electric power-lines (unintentional radiator) or the signals are received over the air due to radiation of the radio

frequency signals from the electric power-lines (intentional radiator). [47 CFR 15.3(f)] *See also:* **broadband over power-line; power-line carrier systems**.

11) **chip rate:** The rate at which the successive bits of the spreading sequence are applied to the signal information. (ITU-R Rec. SM.1055)

12) **chirp:** A form of pulse compression that uses frequency modulation (usually linear) during the pulse. (IEEE Std 686™ 1997)

13) **combined equipment:** Any equipment made of two or more individual products or functions.

NOTE—At least one of the individual products or functions falls within the scope of intentional radiator regulations. The result of this combination provides additional control and/or functionality to the combined equipment. (ETSI TR 102 070-1 MOD)

14) **component part:** Part of the combined equipment that provides a (additional) function to the combined equipment but cannot operate individually. (ETSI TR 102 070-1)

15) **composite system:** A system that incorporates different devices contained either in a single enclosure or in separate enclosures connected by wire or cable, each of which device may be subject to different technical requirements. [47 CFR 15.31(k)]

16) **conformity assessment:** Demonstration that specified requirements relating to a product, process, system, person, or body are fulfilled. *Syn:* **certification**. (ISO 17000 2.1 MOD)

NOTE—The subject field of conformity assessment includes activities such as testing, inspection, and certification, as well as the accreditation of conformity assessment bodies.

17) **cordless telephone:** A device consisting of two transceivers, one a base station that connects to the public switched telephone network and the other a mobile handset unit that communicates directly with the base station. Transmissions from the mobile unit are received by the base station and then placed on the public switched telephone network. Information received from the switched telephone network is transmitted by the base station to the mobile unit. [47 CFR 15.3(j)]

18) **damped wave:** Generally defined as a wave in which, at every point, the amplitude of each sinusoidal component is a decreasing function of time.

NOTE—Some radio regulations [e.g., FCC 47 CFR 2.201(f) and 15.5(d)] prohibit the use of damped wave emissions.

19) **detector, peak:** *See:* **peak detector**.

20) **detector, root mean square (rms):** *See:* **root-mean-square (rms) detector**.

21) **digital modulation: (A)** The process by which the characteristics of a carrier wave are varied among a set of predetermined discrete values in accordance with a digital modulating function as specified in ANSI C63.17-2006 [B5]. [47 CFR 15.403(f) MOD] **(B)** The process by which the characteristics of a carrier wave are varied among a set of predetermined discrete values in accordance with a digital modulating function. (3.1.13 of ANSI C63.17-2006 [B5])

22) **digital transmission system:** A transmission system in which (a) all circuits carry digital signals and (b) the signals are combined into one or more serial bit streams that include all framing and supervisory signals. (ANSI/ATIS T1.523-2001) *See also:* **transmission system**.

NOTE—A-D/D-A conversion, if required, is accomplished external to the system.

23) **direct sequence system: (A)** A spread spectrum system in which the carrier has been modulated by a high-speed spreading code and an information data stream. The high-speed code sequence dominates the "modulating function" and is the direct cause of the wide spreading of the

transmitted signal. [47 CFR 2.1(c)] **(B)** Direct sequence spread spectrum is a signal structuring technique using a digital code spreading sequence having a chip rate $1 / T_{s,in}$ much higher than the information signal bit rate $1 / T_s$. Each information bit of the digital signal is transmitted as a pseudo random sequence of chips, which produces a broad noise-like spectrum with a bandwidth (distance between first nulls) of $2B_{s,in} = 2 / T_{s,in}$. The receiver correlates the RF input signal with a local copy of the spreading sequence to recover the narrow band data information at a rate $1 / T_s$. (ITU-R Rec. SM.1055)

24) **duty cycle, for pulsed emissions:** The ratio of the sum of all pulse durations to the total period, during a specified period of operation. The duty cycle is determined on the basis of one complete pulse train for pulse trains not exceeding 100 milliseconds. Where the pulse train exceeds 100 milliseconds, the duty cycle is determined on the basis of the 100 millisecond interval with the highest average value of emission. (FCC GEN. Docket No. 89-117-1989, NPRM, 1.2.1)

25) **emission:** Radiation produced, or the production of radiation, by a radio transmitting station. [47 CFR 2.1(c)]

NOTE—For example, the energy radiated by the local-oscillator of a radio receiver would not be an emission but a radiation.

26) **emission, out-of-band:** *See:* **out-of-band emission**.

27) **emission, spurious:** *See:* **spurious emission**.

28) **emission bandwidth:** Determined by measuring the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, which are 26 dB down relative to the maximum level of the modulated carrier; based on the use of measurement instrumentation employing a peak detector function with an instrument resolution bandwidth approximately equal to 1.0% of the emission bandwidth of the device under measurement. [47 CFR §§ 15.303(c), 15.403(i) – MOD]

29) **equivalent sine-wave:** A sine-wave that has the same frequency and the same rms value as the actual wave. (AIEE 1917)

30) **field disturbance sensor:** A device that establishes a radio frequency field in its vicinity and detects changes in that field resulting from the movement of persons or objects within its range. [47 FR 15.3(l)]

31) **frequency hopping system: (A)** A spread spectrum system in which the carrier is modulated with the coded information in a conventional manner causing a conventional spreading of the RF energy about the frequency carrier. The frequency of the carrier is not fixed but changes at fixed intervals under the direction of a coded sequence. The wide RF bandwidth needed by such a system is not required by spreading of the RF energy about the carrier but rather to accommodate the range of frequencies to which the carrier frequency can hop. The test of a frequency hopping system is that the near term distribution of hops appears random, the long-term distribution appears evenly distributed over the hop set, and sequential hops are randomly distributed in both direction and magnitude of change in the hop set. [47 CFR 2.1(c)] **(B)** The frequency-hopping spread spectrum is a signal structuring technique employing automatic switching of the transmitted frequency. Selection of the frequency to be transmitted is typically made in a pseudo-random manner from a set of frequencies covering a band wider than the information bandwidth. The intended receiver frequency hops in synchronization with the transmitter to retrieve the desired information. (ITU-R Rec. SM.1055)

32) **Global Information Infrastructure:** A collection of networks, end user equipment, information, and human resources that can be used to access valuable information, communicate with each other, work, learn, and receive entertainment from it at any time and from any place, with affordable cost on a global scale. (ITU-T Rec. Y.101:03/2000, 33)

33) **ground-penetrating radar system: (A)** Emits short pulses of radio frequency electromagnetic energy into the subsurface from a transmitting antenna. The energy passes through the ground, and some is reflected back to the receiving antenna. A computer processes the reflected signal, measures the strength and time between emission and reception, and produces a visual representation of the subsurface. **(B)** A field disturbance sensor that is designed to operate only when in contact with, or within 1 m of, the ground for the purpose of detecting or obtaining the images of buried objects or determining the physical properties within the ground. The energy from the GPR is intentionally directed down into the ground for this purpose. [47 CFR 15.503(f)]

34) **hybrid spread spectrum system:** A spread spectrum system that uses combinations of two or more types of direct sequence, frequency hopping, time hopping, and pulsed FM modulation to achieve its wide occupied bandwidth. [47 CFR 2.1(c)]

35) **imaging system:** A general category of devices consisting of ground-penetrating radar systems, medical imaging systems, wall-imaging systems, through-wall imaging systems, and surveillance systems. [47 CFR 15.503(e) MOD]

    NOTE—In the context of certain UWB device regulations, this category does not include systems designed to detect the location of tags or systems used to transfer voice or data information.

36) **industrial, scientific, and medical (ISM) equipment:** Equipment or appliance designed to generate and use locally RF energy for industrial, scientific, medical, domestic, or similar purposes, excluding applications in the field of telecommunication. Typical ISM applications are the production of physical, biological, or chemical effects such as heating, ionization of gases, mechanical vibrations, hair removal, and acceleration of charged particles. [47 CFR 18.107(c)]

37) **industrial, scientific, and medical (ISM) frequency:** A frequency assigned by 47 CFR part 18 for the use of ISM equipment. A specified tolerance (frequency delta) is associated with each ISM frequency—see 47 CFR 18.301. [47 CFR 18.107(h)]

38) **in-house broadband over power line (in-house BPL):** A carrier current system, operating as an unintentional radiator, that sends radio frequency energy by conduction over electric power lines that are not owned, operated, or controlled by an electric service provider. The electric power lines may be aerial (overhead), underground, or inside the walls, floors, or ceilings of user premises. In-house BPL devices may establish closed networks within a user's premises or provide connections to access BPL networks, or both. [47 CFR 15.3(gg)]

39) **learned-mode device:** A device typically sold as a universal replacement or as a duplicate for garage door opener controls, keyless entry systems, security alarm systems, remote switches, and similar types of radio-controlled devices. These transmitters are designed to recognize and replicate the operating frequency, duty cycle, and coding scheme of the targeted radio system. They accomplish this only when operated in very close proximity to a system's receiver to prevent use for theft. (FCC/DA-02-2850) *Syn:* **learned-mode transmitter; trainable transmitters**.

40) **line spectrum:** The individual Fourier frequency components of a signal. To observe a line spectrum, the resolution bandwidth of the measuring instrument must be less than the frequency spacing of the components. (FCC GEN. Docket No. 89-117-1989, NPRM, 1.2.3)

41) **low-power communication device:** (deprecated) A restricted radiation device, exclusive of those employing conducted or guided radio frequency techniques, used for the transmission of signs, signals (including control signals), writing, images, and sounds or intelligence of any nature by radiation of electromagnetic energy. [47 CFR 15.4(f) e.g., 1963 MOD]

42) **maximum conducted output power:** The total transmit power delivered to all antennas and antenna elements averaged across all symbols in the signaling alphabet when the transmitter is operating at its maximum power control level. Power must be summed across all antennas and antenna elements. The average must not include any time intervals during which the transmitter is

OFF or is transmitting at a reduced power level. If multiple modes of operation are possible (e.g., alternative modulation methods), then the maximum conducted output power is the highest total transmit power occurring in any mode. [47 CFR 15.403(n)]

43) **measurement bandwidth:** The bandwidth that is technically appropriate for the measurement of a specific system. In common spectrum analyzers, this is generally referred to as the resolution bandwidth. (ITU-R SM.1541-2:2006, 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.

44) **medical imaging system:** A field disturbance sensor that is designed to detect the location or movement of objects within the body of a person or animal. [47 CFR 15.503(g)]

45) **modular transmitter:** A completely self-contained radio frequency transmitter device that is typically incorporated into another product, host, or device. (15.212)

46) **module-like device:** A transmitter peripheral to a host product that is typically plugged into an externally accessible standard bus on such hosts. Examples of industry-defined standard bus interfaces are PCMCIA (Cardbus), SDIO, or CompactFlash slots on notebook computers or personal digital assistance devices. Module-like transmitters are tested in appropriate host platform configurations. (FCC-07-56)

47) **multiradio equipment:** Radio equipment containing two or more radio transmitters and/or receivers using different technologies that may operate simultaneously. (ETSI TR 102 070-1)

48) **National Information Infrastructure (NII):** A group of networks, including the public switched telecommunications network, radio and television networks, private communications networks, and other networks not yet built, which together will serve the communications and information processing needs of the people of the United States in the future. (FCC-96-193) *See:* **Global Information Infrastructure**.

NOTE—FCC U-NII rules were established to further the creation of the Global Information Infrastructure (GII).

49) **necessary bandwidth:** For a given class of emission, the width of the frequency band that is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions. (RR) (47 CFR 2.1)

50) **occupied bandwidth:** 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. (RR) (47 CFR 2.1)

NOTE—Unless otherwise specified by ITU-R for the appropriate class of emission, the value of Beta/2 should be taken as 0.5%.

51) **out-of-band emission:** Emission on a frequency or frequencies immediately outside the necessary bandwidth that results from the modulation process but excluding spurious emissions. (RR) (47 CFR 2.1)

52) **peak detector:** A detector, the output voltage of which is the true peak value of an applied signal or noise. (4.357 of ANSI C63.14-2014)

53) **peak power: (A)** Power measured with the peak detector using a filter, the width and shape of which is sufficient to accept the signal bandwidth. (1.11 of ITU-R SM.1541-2:2006 [B56]) **(B)** The peak power output as measured over an interval of time equal to the frame rate or transmission burst of the device under all conditions of modulation. *Syn:* **peak transmit power**. [47 CFR 15.303(f) MOD]

54) **peak power spectral density (PPSD):** Maximum power spectral density, within the specified measurement bandwidth, within the U-NII device operating band. [47 CFR 15.403(m)]

55) **perimeter protection system:** A field disturbance sensor that employs RF transmission lines as the radiating source. These RF transmission lines are installed in such a manner that allows the system to detect movement within the protected area. [47 CFR 15.3(q)]

56) **peripheral device:** An input/output unit of a system that feeds data into and/or receives data from the central processing unit of a digital device. Peripherals to a digital device include any device that is connected external to the digital device, any device internal to the digital device that connects the digital device to an external device by wire or cable, and any circuit board designed for interchangeable mounting, internally or externally, that increases the operating or processing speed of a digital device (e.g., "turbo" cards and "enhancement" boards). Examples of peripheral devices include terminals, printers, external floppy disk drives and other data storage devices, video monitors, keyboards, interface boards, external memory expansion cards, and other input/output devices that may or may not contain digital circuitry. This definition does not include CPU boards, as defined in 15.3(bb), even though a CPU board may connect to an external keyboard or other components. [47 CFR 15.3(r)]

57) **periodic transmitter:** An intentional radiator that intermittently transmits pulsed signals on a single frequency. The use of pulsed transmissions permits such devices to operate at a higher peak signal level under certain radio regulations than devices that use transmission techniques that continuously emit nonpulsed signals such as conventional FM transmission systems. The higher signal level is permissible because the signal levels, in times the pulses are ON and OFF, average to a level that is acceptable under the radio regulations. Examples of periodic emitters include, but are not limited to, devices for burglar, security, fire, or other emergency alarm; remote control of a door opener; and remote control of a switch. (FCC 89 155 MOD)

NOTE—A periodic emitter is a transmitter that uses pulse modulation techniques.

58) **personal communications services (PCS):** Radio communications that encompass mobile and ancillary fixed communication that provide services to individuals and businesses and can be integrated with a variety of competing networks. (47 CFR 24.5)

59) **personal communications services (PCS) device, unlicensed:** *See:* **unlicensed personal communications services (PCS) device**.

60) **port:** A place of access to a device or network where energy may be supplied or withdrawn or where the device or network variables may be observed or measured. (*IEEE Standards Dictionary Online*)

NOTE 1—In any particular case, the ports are determined by the way the device is used and not by its structure alone.

NOTE 2—The terminal pair is a special case of a port.

NOTE 3—In the case of a waveguide or transmission line, a port is characterized by a specified mode of propagation and a specified reference plane.

NOTE 4—At each place of access, a separate port is assigned to each significant independent mode of propagation.

NOTE 5—In frequency changing systems, a separate port is also assigned to each significant independent frequency response

61) **power, average symbol envelope:** *See:* **average symbol envelope power**.

62) **power line carrier systems:** An unintentional radiator employed as a carrier current system used by an electric power utility entity on transmission lines for protective relaying, telemetry, and so on for general supervision of the power system. The system operates by the transmission of radio

frequency energy by conduction over the electric power transmission lines of the system. The system does not include those electric lines that connect the distribution substation to the customer or house wiring. [47 CFR 15.3(t)]

63) **power, maximum conducted output:** *See:* **maximum conducted output power**.

64) **power, peak:** *See:* **peak power**.

65) **power, rms:** *See:* **root mean square (rms) power**.

66) **power, rms-average:** *See:* **root-mean-square (rms)-average emission**.

67) **power spectral density (PSD):** The total energy output per unit bandwidth from a pulse or sequence of pulses for which the transmit power is at its peak or maximum level, divided by the total duration of the pulses. This total time does not include the time between pulses during which the transmit power is OFF or below its maximum level. [47 CFR 15.403(o)]

68) **power spectral density, peak:** *See:* **peak power spectral density**.

69) **power-line communication network:** An electronic communication network using the mains distribution network infrastructure for communication. (ETSI TR 102 324)

70) **pulse:** A continuous transmission of a sequence of modulation symbols, during which the average symbol envelope power is constant. [47 CFR 15.403(p)]

71) **pulse code modulation:** A modulation process involving the conversion of a waveform from analog to digital form by means of coding. (*IEEE Standards Dictionary Online*)

NOTE 1—This is a generic term, and additional specification is required for a specific purpose.

NOTE 2—The term is commonly used to signify that form of pulse modulation in which a code is used to represent quantized values of instantaneous samples of the signal wave.]

72) **pulse compression:** A method for obtaining the resolution of a short pulse with the energy of a long pulse of width T by internally modulating the phase or frequency of a long pulse so as to increase its bandwidth B >> 1 / *T*, and using a matched filter (also called a pulse compression filter) on reception to compress the pulse of width T to a width of approximately 1/*B*. Used to obtain high-range resolution when peak power limited. (IEEE Std 686-1997)

73) **pulse desensitization:** The apparent reduction in peak amplitude of a pulsed continuous wave signal as viewed on a measuring instrument caused by the distribution of its energy over many spectral components. The manufacturer of the measuring instrument should be consulted for more information on pulse desensitization and effects on measurements. (FCC GEN. Docket No. 89-117, NPRM, 1.2.4 MOD)

74) **pulse spectrum:** A combination time and frequency-domain representation of a signal where the individual frequency components cannot be resolved, but the envelope of the signal can be seen. To observe a pulse spectrum, the resolution bandwidth of the measuring instrument must be greater than the frequency spacing of the individual Fourier components, but narrow compared with the width of the envelope of the signal. (FCC GEN. Docket No. 89 117, NPRM, 1.2.5)

75) **pulsed FM system:** A spread spectrum system in which an RF carrier is modulated with a fixed period and fixed duty-cycle sequence. At the beginning of each transmitted pulse, the carrier frequency is frequency modulated causing an additional spreading of the carrier. The pattern of the frequency modulation will depend on the spreading function that is chosen. In some systems, the spreading function is a linear FM chirp sweep, sweeping either up or down in frequency. [47 CFR 2.1(c)] *Syn:* **chirped modulation; pulsed frequency modulation; swept frequency modulation**.

76) **radiocommunication:** Telecommunication by means of radio waves. (ITU-R Rec. V.573-4, A01)

77) **radio frequency device:** Any device that in its operation can emit radio frequency energy by radiation, conduction, or other means. Radio frequency devices include, but are not limited to, (a) various types of radio communication transmitting devices; (b) incidental, unintentional, and intentional radiators; (c) industrial, scientific, and medical equipment; (d) any part or component thereof that in use emits radio frequency energy by radiation, conduction, or other means. (47 CFR 2.801 MOD) *Syn:* (deprecated) **radiofrequency device**.

78) **radio frequency identification (RFID) system: (A)** Any electronic identification system composed of a reader/scanner/interrogator and a transponder (tag) that can read or write data content using a specified radio frequency. **(B)** A wireless remote tracking system comprising a small transponder (tag) with encoded information, an antenna, and a transceiver equipped with a decoder. The antenna emits a radio signal to read or write data from or to the tags attached to the items to be tracked. (FCC/DA-03-1758-2003 [B27])

79) **radio service:** An administrative subdivision of the field of radiocommunication. In an engineering sense, the subdivisions may be made according to the method of operation, as, for example, mobile service and fixed service. In a regulatory sense, the subdivisions may be descriptive of particular groups of licensees, as, for example, the groups of persons licensed under this part. (47 CFR 5.5)

80) **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. For radar systems, the reference bandwidth should be selected in line with Recommendation ITU-R M.1177. (1.6 of ITU-R SM.1541-2:2006 [B56]). *See also:* **measurement bandwidth**.

81) **restricted band:** A frequency band in which intentional radiators are permitted to radiate only spurious emissions but not fundamental signals.

82) **restricted radiation device:** (deprecated) A device in which the generation of radio frequency energy is intentionally incorporated into the design and in which the radio frequency energy is conducted along wires or is radiated, exclusive of transmitters that require licensing under applicable radio regulations and exclusive of devices in which the radio frequency energy is used to produce physical, chemical, or biological effects in materials and which generally are regulated under provisions for industrial, scientific, and medical equipment. [47 CFR 15.4(d) (e.g., 1963) MOD]

83) **RMS:** *See:* **root-mean-square**.

84) **RMS detector:** *See:* **root-mean-square (rms) detector**.

85) **RMS power:** *See:* **root-mean-square (rms) power**.

86) **RMS-average power:** *See:* **root-mean-square (rms)-average emission**.

87) **root-mean-square (rms), true:** Refers to the use of a meter that displays an rms value calculated from the average of instantaneous readings rather than an rms value that is calculated from an average reading. The difference is that the instantaneous method allows the meter to display the correct rms value for waveforms that are not sinusoidal shaped while the other does not. The square root of the mean value of the square of the voltage values during a complete cycle. (IEEE Std 1560™-2005)

88) **root-mean-square (rms) detector:** A detector, the output voltage of which approximates the root mean square value of an applied signal or noise. (4.432 of ANSI C63.14-2014)

NOTE—The rms value should be taken over a specified time interval. [IEC 60050-161 (1990 09)]

89) **root-mean-square (rms) detector, true:** A detector that contains a circuit component that performs the mathematical operation:

$$\sqrt{\frac{1}{T}\int_{0}^{T}\left[v\left(t\right)^{2}\,dt\right]}$$

to a periodic signal $v(t)$, where

T is the period of the signal

NOTE—If there are harmonics in the field and $v(t)$ is proportional to the time derivative of the field, then the detector circuit should also contain a stage of integration prior to the rms operation to avoid error.

This type of detector gives the true rms value of a field containing harmonics provided that the frequency response of the detector is flat over the frequency range of interest. If significant levels of harmonics are present in $v(t)$, then particular attention should be given to the possibility of amplifier saturation effects if the integration follows one or more stages of amplification. *See also:* **average sensing rms detector**. [*IEEE Standards Dictionary Online*]

90) **root-mean-square (rms) power:** (deprecated) The apparent power of an ac power that is calculated by multiplying root-mean-square (rms) current by the root-mean-square voltage. [ETSI EN 302 245-1 V1.1.1 (2005 01)]

NOTE 1—In a purely resistive circuit, rms power is held to be the equivalent heating effect of a dc power and can be deemed to be true power. In a circuit that consists of reactance as well as resistance, the apparent power is greater than the true power (the vector difference between true power and apparent power is called reactive power).

$$\text{True power} = V_{\text{rms}} \times \left(I_{\text{rms}} \Delta \cos\phi\right)$$

where

$\Delta\cos\varphi$ is the phase difference between voltage and current introduced by the reactance of the load

NOTE 2—From the above definition, it becomes clear that unless any measuring system can be completely devoid of reactance, the measured power cannot be considered to be rms power. It therefore becomes apparent that this parameter would be difficult to measure with any degree of accuracy at RF frequencies.

91) **root-mean-square (rms) average emission:** Power (conducted or radiated) or field strength measured using a spectrum analyzer with a resolution bandwidth of 1 MHz, an rms detector, and a 1 ms or less averaging time (integration time period for each spectrum analyzer bin; spectrum analyzer sweep-time/number-of-bins not exceeding 1 millisecond). *Syn:* **root-mean-square (rms) average power**. (47 CFR 15.521 MOD)

NOTE—Spectrum analyzer measurements using trace averaging do not constitute rms-average emission measurements.

92) **spread spectrum system:** An information bearing communications system in which (1) information is conveyed by modulation of a carrier by some conventional means and (2) the bandwidth is deliberately widened by means of a spreading function over that which would be needed to transmit the information alone. In some spread spectrum systems, a portion of the information being conveyed by the system may be contained in the spreading function. [47 CFR 2.1(c) MOD]

93) **spurious emission:** Emission on a frequency or frequencies that are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions,

intermodulation products, and frequency conversion products, but exclude out-of-band emissions. (RR) (47 CFR 2.1)

94) **subassembly:** A chassis or other essentially completed device that requires the addition of cabinets, knobs, speakers, or other similar minor attachments to complete the device for marketing. Subassembly shall not encompass individual components, such as coils, condensers, intermediate frequency strips, tubes, and so on, that are used as replacements or that require considerable fabrication to produce a device subject to radio frequency device marketing regulations. (FCC/75 1352 1976)

95) **swept-frequency device:** A pulsed FM device.

96) **system:** Any organized assembly of resources and procedures united and regulated by interaction or interdependence to accomplish a set of specific functions. (ANSI/ATIS T1.523-2001)

97) **telecommunication:** Any transmission, emission, or reception of signs, signals, writings, images and sounds, or intelligence of any nature by wire, radio, optical, or other electromagnetic systems. [(CS) 1.3 of ITU-RR1-1-2004]

98) **telemetry:** The use of telecommunication for automatically indicating or recording measurements at a distance from the measuring instrument. (RR) (47 CFR 2.1)

99) **transmission system: (A)** A system consisting of a transmitter, an antenna, and with or without an external radio frequency power amplifier, approved as a system by a regulatory authority and marketed as a system. [47 CFR 15.204(b)] **(B)** Part of a communication system organized to accomplish the transfer of information from one point to one or more other points by means of signals. (ANSI/ATIS T1.523-2001)

NOTE—Examples of NATO owned transmission systems are SATCOM, ACE HIGH, and CIP 67.

100) **transmission system, digital:** *See:* **digital transmission system**.

101) **transmitter, radio:** Apparatus producing radio frequency energy for the purpose of radio communication. (D01 of ITU-R Rec. V.573-4-2000)

102) **ultra-wideband (UWB) transmitter: (A)** An intentional radiator that, at any point in time, has a fractional bandwidth equal to or greater than 0.20 or has a UWB bandwidth equal to or greater than 500 MHz, regardless of the fractional bandwidth. [47 CFR 15.503(d) MOD]

NOTE 1—Bandwidth refers to −10 dB attenuation levels.

(B) Any device whose emissions have a fractional bandwidth greater than 0.25 or occupy greater than 1.5 GHz of spectrum. [IEEE Std 1672™-2006 MOD]

NOTE 2—Bandwidth refers to −20 dB attenuation levels.

103) **ultra-wideband technology:** Technology for short-range radiocommunication, involving the intentional generation and transmission of radio frequency energy that spreads over a very large frequency range, which may overlap several frequency bands allocated to radiocommunication services. Devices using UWB technology typically have intentional radiation from the antenna with either a −10 dB bandwidth of at least 500 MHz or a −10 dB fractional bandwidth greater than 0.2. (Annex 1 of ITU-R SM.1755-2006)*Syn:* **ultra-wideband device**.

104) **unlicensed personal communications services (PCS) device:** Intentional radiator operating in the frequency band 1920 MHz to 1930 MHz to provide a wide array of mobile and ancillary fixed communication services to individuals and businesses. [47 CFR 15.303(g) MOD]

105) **unlicensed wireless service:** The offering of telecommunications services using duly authorized devices that do not require individual licenses. [U.S. Telecommunications Act of 1996, 47 U.S.C. 332(c)(7)(C)(iii), MOD]

106) **Unlicensed National Information Infrastructure (U-NII):** *See:* **National Information Infrastructure**.

107) **Unlicensed National Information Infrastructure (U-NII) device:** **(A)** Intentional radiator operating in any or all of the frequency bands 5.15 GHz to 5.25 GHz, 5.25 GHz to 5.35 GHz, 5.470 GHz to 5.725 GHz, and 5.725 GHz to 5.85 GHz that uses wideband digital modulation techniques to provide a wide array of high-data-rate mobile and fixed communications for individuals, businesses, and institutions. [47 CFR 15.403(s) MOD]

NOTE—A high data rate is defined as a bit rate of 1 Mbps or more.

(B) A type of radio device enabled under FCC Part 15 intended to provide short-range, high-speed wireless digital communications such as W-LANs and to facilitate wireless access to the National Information Infrastructure. (FCC/DA-03-1758-2003 [B27])

108) **wire:** A slender rod or filament of drawn metal. [*IEEE Standards Dictionary Online*]

Annex N

(informative)

Bibliography

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

[B1] Agilent Application Note 150, "Spectrum Analysis Basics."

[B2] Agilent Technologies, Inc., Agilent Spectrum Analyzer Series, Application Note 150-2, Spectrum Analysis…Pulsed RF, 2009.

[B3] AIEE, "Standardization rules of the American Institute of Electrical Engineers," *Transactions of the American Institute of Electrical Engineers*, vol. 34, pp. 1551–1661, 1917.[120]

[B4] ANSI/ATIS T1.523-2001, Telecom Glossary 2000.[121]

[B5] ANSI C63.17-2013, American National Standard Methods of Measurement of the Electromagnetic and Operational Compatibility of Unlicensed Personal Communications Services (UPCS) Devices.[122]

[B6] CISPR 16-2-1:2014/AMD1:2017, Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods—Part 2-1: Methods of Measurement of Disturbances and Immunity—Conducted Disturbance Measurements.[123]

[B7] CISPR 16-2-3:2016, Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods—Part 2-3: Methods of Measurement of Disturbances and Immunity—Radiated Disturbance Measurements.

[B8] CISPR 16-4-2:2011+AMD1:2014+AMD2:2018, Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods—Part 4-2: Uncertainties, Statistics and Limit Modeling—Measurement Instrumentation Uncertainty.

[B9] EN 300 440-1 V1.6.1 (2010-08), Electromagnetic Compatibility and Radio Spectrum Matters ERM); Short Range Devices; Radio Equipment to be Used in the 1 GHz to 40 GHz Frequency Range—Part 1: Technical Characteristics and Test Methods.[124]

[B10] ETSI EN 300 330-2 V1.5.1 (2010-02), Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Short Range Devices (SRD); Radio Equipment in the Frequency Range 9 kHz to 25 MHz and Inductive-loop Systems in the Frequency Range 9 kHz to 30 MHz; Part 2: Harmonized EN Covering the Essential Requirements of Article 3.2 of the R&TTE Directive.[125]

[B11] ETSI EN 302 245-1, Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Transmitting Equipment for the Digital Radio Mondiale (DRM) Broadcasting Service; Part 1: Technical Characteristics and Test Methods, V1.1.1 (2005-01).[126]

[B12] ETSI TR 102 070-1, Electromagnetic Compatibility and Radio Spectrum Matters (ERM); Guide to the Application of Harmonized Standards to Multi Radio and Combined Radio and Non Radio Equipment; Part 1: ElectroMagnetic Compatibility, V1.1.1 (2002-07).

[120] AIEE publications are available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/).
[121] ANSI publications are available from the American National Standards Institute (http://www.ansi.org/).
[122] C63® publications are available from the Institute of Electrical and Electronics Engineers (http://standards.ieee.org/) and the American National Standards Institute (https://www.ansi.org/).
[123] CISPR documents are available from the International Electrotechnical Commission (http://www.iec.ch/) and in the U.S. from the American National Standards Institute (http://www.ansi.org/).
[124] EN publications are available from the European Committee for Standardization (CEN) (http://www.cen.eu/).
[125] ETSI publications are available from the European Telecommunications Standards Institute (http://www.etsi.org/).
[126] ETSI publications are available from the European Telecommunications Standards Institute (http://www.etsi.org/).

[B13] ETSI TR 102 324, PowerLine Telecommunications (PLT); Radiated emissions' characteristics and measurement method of state of the art powerline communication networks, V1.1.1 (2004-05).

[B14] European Radiocommunications Committee (ERC) within the European Conference of Postal and Telecommunications Administrations (CEPT), ERC Report 44, Sharing Between Inductive Systems And Radiocommunication Systems In The Band 9–135 kHz, Sesimbra, Jan. 1997.

[B15] FCC/02-48, *Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems*, First Report and Order, FCC ET Docket 98-153, Apr. 22, 2002.

[B16] FCC/06-96, *Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) devices in the 5 GHz band*, Memorandum Opinion and Order, FCC ET Docket No. 03-122, June 30, 2006.

[B17] FCC/07-56, Modifications of Parts 2 and 15 of the Commission's Rules for unlicensed devices and equipment approval, Second Report and Order, FCC ET Docket No. 03 201, Apr. 23, 2007.[127]

[B18] FCC/75-1352, Amendment of Part 2 With Respect to Importation of Certain Electronic Equipment, Report and Order, Docket No. 20194, June 21, 1976.

[B19] FCC/89-155, FCC Procedure For Measuring RF Emissions from Intentional Radiators with Periodic Operation and Associated Super regenerative Receivers, Notice Of Proposed Rule Making, FCC GEN. Docket No. 89–117, June 29, 1989.

[B20] FCC/93-451, *Amendment of the Commission's Rules to Establish New Personal Communications Services*, Second Report and Order, FCC GEN Docket No. 90-314, Oct. 22, 1993.[128]

[B21] FCC/94-144, *Amendment of the Commission's Rules to Establish New Personal Communications Services*, Memorandum Opinion and Order, FCC GEN Docket No. 90-314, June 13, 1994.

[B22] FCC/96-193, Amendment of the Commission's Rules to Provide for Unlicensed NII/SUPERNet Operations in the 5 GHz Frequency Range, Notice of Proposed Rule Making, FCC ET Docket No. 96–102, May 6, 1996.

[B23] FCC/97-114, *Amendment of Parts 2 and 15 of the Commission's Rules Regarding Spread Spectrum Transmitters*, Memorandum Opinion and Order, FCC ET Docket No. 96-8, Apr. 10, 1997.

[B24] FCC/DA-00-1407, *Part 15 Unlicensed Modular Transmitter Approval*, June 26, 2000.

[B25] FCC/DA-02-2138, *Measurement Procedure Updated for Peak Transmit Power in the Unlicensed National Information Infrastructure (U-NII) Bands*, Aug. 30, 2002.

[B26] FCC/DA-02-2850, *FCC Clarifies Equipment Certification Procedures for "Learned Mode" or "Trainable" Transmitters*, Oct. 28, 2002.

[B27] FCC/DA-03-1758, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, K. R. Carter, A. Lahjouji, and N. McNeil, May 2003.

[B28] FCC/DA-04-3496, *OET Clarifies Equipment Authorization Policy for Measurement of Broadband Emissions*, Dec. 17, 2004.

[B29] FCC/KDB-174176, *Keyword:* "Section 15.207, C63.4, Suitable Dummy Load, AC Power-line Conducted Measurement," June 3, 2015.

[B30] FCC/KDB-393764, *Keyword:* "UWB Compliance Measurements," Jan. 29, 2018.

[B31] FCC/KDB-416721, Certification Test Procedures for TV Band (White Space) Devices Authorized Under Subpart H of the Part 15 Rules, Dec. 22, 2015.

[B32] FCC/KDB-558074, *Keyword:* Digital Transmission Systems, Measurements and Procedures, Apr. 2, 2019.

[127] FCC publications are available from the Federal Communications Commission (http://www.fcc.gov/).
[128] FCC publications are available from the Federal Communications Commission (http://www.fcc.gov/).

[B33] FCC/KDB-662911 D01 v02r01: Emission Testing of Transmitters with Multiple Outputs in the Same Band, October 31, 2013.

[B34] FCC/KDB-789033 D02 v02r01, Guidelines for Compliance Testing of Unlicensed National Information Infrastructure (U-NII) Devices—Part 15, Subpart E, Dec. 14, 2017.

[B35] FCC/KDB 890966, Keyword: "MEASUREMENT PROCEDURE FOR LEVEL PROBING RADARS"

[B36] FCC/OET Bulletin No. 70 (July 1997), Millimeter-wave Propagation: Spectrum Management Implications.

[B37] Geselowitz, D. B., "Response of ideal radio-noise meter to continuous sine-wave, recurrent impulses, and random noise," *IRE Transactions on Radio-Frequency Interference*, vol. RFI-3, no. 1, pp. 2–11, May 1961.

[B38] Gorin, J., "Detector selection for spectrum analyzer measurements," *RF Design*, pp. 32, 34, 36, 38, Feb. 2003.[129]

[B39] Haber, F., "Response of quasi-peak detector to periodic impulses with random amplitudes," *IEEE Transactions on Electromagnetic Compatibility*, vol. EMC-9, no. 1, pp. 1–5, Mar. 1967.

[B40] IEC 60050-161, International Electrotechnical Vocabulary—Chapter 161: Electromagnetic Compatibility.[130]

[B41] IEEE Std 473™-1985, IEEE Recommended Practice for an Electromagnetic Site Survey (10 kHz to 10 GHz).[131,132]

[B42] IEEE Std 686™-1997, IEEE Standard Radar Definitions.

[B43] IEEE Std 802.11ac-2013, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications—Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz.

[B44] IEEE Std 802.11™-2012, IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

[B45] IEEE Std 802.16™-2012, IEEE Standard for Air Interface for Broadband Wireless Access Systems.

[B46] IEEE Std 1528™-2003, IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques.

[B47] IEEE Std 1560™-2005, IEEE Standard for Methods of Measurement of Radio Frequency Power-line Interference Filter in the Range of 100 Hz to 10 GHz.

[B48] IEEE Std 1672™-2006, IEEE Standard for Ultrawideband Radar Definitions.

[B49] ISO 17000 2.1 MOD.[133]

[B50] ISO/IEC 17025:2017, General Requirements for the Competence of Testing and Calibration Laboratories.[134]

[B51] ITU-RR1, Radio Regulations, Volume 1 Articles, 2004.[135]

[129] This publication is available online at http://rfdesign.com/mag/radio_detector_selection_spectrum/ and at http://rfdesign.com/images/archive/302Gorin32(1).pdf.
[130] IEC publications are available from the International Electrotechnical Commission (http://www.iec.ch/). IEC publications are also available in the United States from the American National Standards Institute (http://www.ansi.org/).
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[133] ISO publications are available from the International Organization for Standardization (http://www.iso.org/). ISO publications are also available in the United States from the American National Standards Institute (http://www.ansi.org/).
[134] ISO/IEC publications are available from the ISO Central Secretariat (http://www.iso.org/). ISO publications are also available in the United States from the American National Standards Institute (http://www.ansi.org/).
[135] ITU publications are available from the International Telecommunication Union (http://www.itu.int/).

[B52] ITU-R Rec. SM.328-11:2006, *Spectra and Bandwidth of Emissions.*[136]

[B53] ITU-R Rec. SM.329-10:2003, Unwanted Emissions in the Spurious Domain.

[B54] ITU-R Rec. SM.443-3:2005, Bandwidth Measurement at Monitoring Stations.

[B55] ITU-R Rec. SM.1055:1994, The Use of Spread Spectrum Techniques.

[B56] ITU-R Rec. SM.1541-2:2006, Unwanted Emissions in the Out-of-Band Domain.

[B57] ITU-R Rec. SM.1754:2006, Measurement Techniques of Ultra-Wideband Transmissions.

[B58] ITU-R Rec. SM.1755, Characteristics of Ultra-wideband Technology, 2006.

[B59] ITU-R Rec. V.573-4, Radiocommunication Vocabulary, 2000.

[B60] ITU-T Rec. Y.101, Global Information Infrastructure Terminology: Terms and Definitions, 2000.

[B61] Jasik, H., "Characteristics of linear antenna elements," in *Antenna Engineering Handbook*, 1st ed. New York: McGraw-Hill, 1961, ch. 3, sec. 3.1, pp. 3.8–3.9.

[B62] Keysight Technologies Application Note 5952-1039 "Spectrum and Signal Analysis Pulsed RF"

[B63] Kraus, J. D., "Arrays of dipoles and of apertures," in *Antennas*, 2d ed. New York: McGraw-Hill, 1988, ch. 11, sec. 11.8, pp. 474–475.

[B64] Linkwitz, S., "Average measurements using a spectrum analyzer," *EMC Test & Design*, pp. 34, 35, 37, 38, May/June 1991.

[B65] Magrab, E. B., and D. S. Blomquist, *The Measurement of Time Varying Phenomenon*. Washington, DC: Wiley Interscience, 1971.

[B66] NTIA Technical Memorandum TM-10-469, Derivations of Relationships among Field Strength, Power in Transmitter-Receiver Circuits and Radiation Hazard Limits, by F. H. Sanders, Institute for Telecommunication Sciences, National Telecommunications & Information Administration, U.S. Department of Commerce, June 2010.[137]

[B67] O'Brien, T., J. Tezil, and S. Murad, "Developing a transfer function for the purpose of selecting a conducted power limit for fm band transmitters," *In Compliance Magazine*, July 2012.[138]

[B68] Rohde & Schwarz GmbH & Co. KG, *Power Measurement on Pulsed Signals with Spectrum Analyzers*, Application Note. München, Germany: Rohde & Schwarz GmbH & Co. KG, 2003.

[B69] Schaefer, W., "Measurement of impulsive signals with a spectrum analyzer or EMI receiver," *IEEE International Symposium on Electromagnetic Compatibility*, pp. 267–271, Aug. 2005.

[B70] Schaefer, W., "Understanding impulse bandwidth specifications of EMI receivers," *IEEE International Symposium on Electromagnetic Compatibility*, pp. 958–961, Aug. 1999.

[B71] U.S. Code of Federal Regulations Title 47—Telecommunication, Chapter I—Federal Communications Commission, Part 2—Frequency Allocations and Radio Treaty Matters; General Rules and Regulations (47 CFR Part 2).[139]

[B72] U.S. Code of Federal Regulations Title 47—Telecommunication, Chapter I—Federal Communications Commission, Part 5—Experimental Radio Service (Other Than Broadcast) (47 CFR Part 5).

[B73] U.S. Code of Federal Regulations Title 47—Telecommunication, Chapter I—Federal Communications Commission, Part 18—Industrial, Scientific, and Medical Equipment (47 CFR Part 18).

[B74] U.S. Code of Federal Regulations Title 47—Telecommunication, Chapter I—Federal Communications Commission, Part 24—Personal Communications Services (47 CFR Part 24).

[136] ITU-R publications are available from the International Telecommunication Union (http://www.itu.int/).
[137] This publication is available online at http://www.its.bldrdoc.gov/publications/2507.aspx.
[138] This publication is available online at http://www.incompliancemag.com/DigEd/inc1207 and at http://www.incompliancemag.com/DigEd/inc1207/offline/download.pdf.
[139] CFR publications are available from the U.S. Government Printing Office (http://www.gpo.gov/).

[B75] U.S. Code of Federal Regulations Title 47—Telecommunication, Chapter I—Federal Communications Commission, Part 90—Private Land Mobile Radio Services (47 CFR Part 90).

[B76] U.S. Telecommunications Act of 1996, Pub. L. No. 104 104, 110 Stat. 56 (1996).

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