Federal Communications Commission
Office of Engineering and Technology
Laboratory Division

April 20, 2021

BASIC CERTIFICATION REQUIREMENTS AND MEASUREMENT PROCEDURES FOR UPPER MICROWAVE FLEXIBLE USE SERVICE (UMFUS) DEVICES

1 INTRODUCTION

In the Report and Order document FCC 16-89, the Commission adopted new technical and service rules (effective December 14, 2016) for millimeter-wave band (mmWave) devices that operate under Part 30 of the FCC rules.[1] Part 30 equipment authorization is available for the following type of devices:[2]

- Base stations
- Mobile stations (*e.g.*, cell phones)
- Transportable stations – these devices are defined as being stationary while operating (*e.g.*, customer premise equipment, local hubs, etc.)[3]

2 GENERAL GUIDANCE FOR EQUIPMENT AUTHORIZATION

The following lists general policies that apply to new equipment authorizations for devices operating under Part 30.

a) *Equipment certification*

1) The following equipment classes shall be used for all filings under Part 30.[4]

---

[1] 47 CFR Part 30 includes frequencies falling in the centimeter-wave band (3 GHz to 30 GHz) and the millimeter-wave band (30 GHz to 300 GHz) as specified in 47 CFR § 2.101. This KDB publication uses the general term "mmWave" to refer to all bands presently in Part 30, and the procedures apply for all Part 30 centimeter-wave band and millimeter-wave band transmitting equipment.

[2] Adding a new equipment class to current grants may be accomplished via a permissive change application. For further guidance refer to the slide 12 of the FCC presentation 4.1, Equipment Authorization Admin, presented during the April 2014 TCB Council workshop: (https://transition.fcc.gov/bureaus/oet/ea/presentations/files/apr14/41-Equipment-Authorization-Admin-MN-GT-update.pdf) .

[3] Transmitters installed in vehicles do not fall under this type of devices.

[4] As discussed in 2 b), some devices are only subject to Supplier's Declaration of Conformity procedures and not required to file for a certification.

- 5GB – Part 30 Fixed Transmitter
- 5GM – Part 30 Mobile Transmitter
- 5GT – Part 30 Transportable Transmitter

2) Test reports, at a minimum, should include the following (specifically as related to mmWave measurements):

   i) Clearly list and identify, *i.e.*, by manufacturer and model number, all harmonic mixers, waveguides, standard gain horn antennas, signal generators, downconvertors, frequency extension modules, and spectrum analyzers used for mmWave measurements.

   ii) Clearly identify correction factors and how they were derived for mmWave measurement results. For instance, for radiated spurious emission measurements results, clearly identify how the measured raw amplitude is corrected to derive the true amplitude (include formulas).

   iii) Provide accredited calibration of equipment operating at frequencies under investigation. Where accredited calibration services are not available, a manufacturer's calibration of mm-wave instruments on a routine basis may be sufficient. Include manufacturer's antenna gain curves for standard gain horn antennas as an appendix to the test report. Standard gain horns need not be periodically calibrated, unless damage or deterioration is suspected or known to have occurred. The connector shall be checked periodically for damage. If a standard gain horn is not periodically calibrated, its critical dimensions (see Annex A of IEEE Std 1309™-2013) shall be verified and documented on an annual basis.

   iv) Copy of the test laboratory accreditation scope showing that the laboratory is accredited to make the measurements (include this as an appendix to the test report). The scope must show that the test laboratory is accredited and capable of performing measurements up to the highest frequency required by the rules (see Section 2.1057).[5] For example, a transmitter operating at 28 GHz requires spurious emissions to be investigated up to 100 GHz. In this case, the test laboratory scope should reflect that it has capability to measure up to 100 GHz or higher.

   v) Where applicable, clearly list and identify all measurement distances. Additionally, verify that all measurement distances are greater than or equal to the far-field distances of the applicable antennas (as described in 3.8) under all test scenarios.

   vi) Radiated emissions data shall be in the form of plots (tabular only data is not sufficient). The plots, at a minimum, shall show the following parameters and configurations of the measurement receiver:

      - RBW & VBW
      - Start / Stop frequencies or Center frequency & frequency span
      - Number of measurement points.
      - Sweep count

[5] See 47 CFR § 2.1057.

- Reference level and Offset
- Detector function shall be identified on the plot or in the Plot Title.

vii) Configuration of product under test

b) *Equipment operating under Section 30.201*[6]

1) The following devices operating under Section 30.201 may be authorized using the SDoC procedure:
   - Fixed point-to-point stations
   - Fixed point-to-multipoint hub stations
   - Fixed point-to-multipoint user stations
2) The manufacturer is required to perform all the necessary tests and shall retain the report including items listed in 2 a) 2) and submit to the Commission upon request.

3 GENERAL GUIDANCE FOR MMWAVE DEVICE EVALUATION

3.1 General

Subparts C and E of 47 CFR Part 30 establish specific requirements and set limits on in-band RF power level, out of band (emission) level, maximum authorized bandwidth (applicable to devices subject to subpart E), frequency tolerance (applicable to devices subject to subpart E), and antenna gain (main lobe and sidelobe) characteristics (applicable to devices subject to subpart E). RF power limits and out of band emission limits are expressed in terms of maximum radiated power (EIRP or EIRP density) and Total Radiated Power (TRP) or conductive power, respectively.

Procedures for compliance measurements on digitally-modulated licensed devices are included in ANSI C63.26-2015, *American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services*, which serves as an acceptable measurement procedure.[7] When applicable to Part 30 devices, appropriate compliance measurement procedures, as recommended in ANSI C63.26-2015 (licensed devices) are referenced in this document. In all other instances, measurement procedures specific to Part 30 devices have been developed and added to this document.[8]

[6] See 47 CFR § 30.201.

[7] ANSI C63.26-2015 was developed by ANSI-Accredited Standards Committee (ASC) C63® to provide equipment authorization applicants, manufacturers, and test laboratories with uniform, reliable, and consistent measurement procedures necessary to demonstrate that transmitters used in licensed radio services comply with FCC's technical requirements. ASC C63® is a standards development organization that includes participants from the wireless industry, test laboratories, and regulators.

[8] The guidance contained in this document is based on the test procedures developed by the ASC C63® Subcommittee 4 mmWave Joint Task Group (JTG) and are provided on an interim basis while the procedures are being finalized.

3.2 Definitions

Beam: Main lobe of the radiation pattern of an antenna or antenna system.

Multiple beams: Multiple peaks (major lobes) of the radiation pattern of an antenna or antenna system.

Total Radiated Power (TRP): Cellular Telecommunications and Internet Association (CTIA) defines TRP in "Test Plan for Wireless Device Over-the-Air Performance" document. The TRP definition in Section E.2 of that document is adopted for mmWave technologies as it is applicable for unwanted emission TRP measurement at each individual emission frequency [5].

The EIRP of an emission, at a given frequency f_n, is expressed as follows, where subscripts *a* and *b* denote orthogonal polarization measurements.

$$\mathrm{EIRP}(\theta, \phi, f_n) = \mathrm{EIRP}_a(\theta, \phi, f_n) + \mathrm{EIRP}_b(\theta, \phi, f_n)$$

The Max. EIRP of a highest emission at its measured frequency f_n is the maximum EIRP with respect to all angular directions.

The TRP of an emission at the frequency, f_n, is expressed [6] per the following equation:

$$\mathrm{TRP}(f_n) = \frac{1}{4\pi} \iint \mathrm{EIRP}(\theta, \phi, f_n) |\sin\theta| \mathrm{d}\theta \mathrm{d}\phi$$

In the preceding expressions, f_n represents the frequency of each unwanted emission, ($n = 1, 2, \ldots, N$), from a list of total N identified significant emission frequencies.

The EIRP values used in the preceding equations must be in linear units and expressed as power spectral density.

Measurement shall be made using both horizontal and vertical polarizations of the measurement antenna.

3.3 Basic Considerations

A radiated measurement method to demonstrate compliance has been selected in consideration of test equipment availability, and that many mmWave EUTs utilize integrated antenna array elements therefore do not have coaxial or waveguide antenna ports. A conducted method of measurement could be employed for certain tests if EUT antenna ports are accessible and connectable to spectrum analyzers, and EUT and analyzer 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 might exceed the rated power limit of many commercially available mixers. For these reasons, a radiated measurement method may be used.

The beamwidths associated with both the EUT antenna and the measurement antenna can be extremely narrow; thus, very small adjustments to the position of the test antenna might be required such that the maximum emission level is detected and measured.

Tracking pre-selectors may not be 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 regarding the displayed signal (*i.e.*, to confirm it is not a mixer image signal). These signal identification functions are applicable to harmonic mixers but generally not applicable to fundamental downconverters.[9] The lack of tracking pre-selectors also increases the risk of the fundamental emission to overload 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 to prevent inaccurate amplitude measurements. Waveguides have significant attenuation below a cutoff frequency, thus provide inherent high-pass characteristics. For example, WR15 waveguide used for the 50-75 GHz band has a cutoff frequency of 39.87 GHz and essentially will not propagate signals below this frequency. The low end of the waveguide band is about 1.2 times the cutoff frequency and the high end of the waveguide band is about 1.8 times the cutoff frequency. Thus, the fundamental frequency will always be below the cutoff frequency of the waveguide band that covers any harmonic of the fundamental. The waveguide below cutoff characteristic does not apply to broadband transmission lines such as strip line, coaxial cable or micro strip. Most standard gain antennas, that operate at frequency ranges higher than the fundamental transmission, act as high pass filters. Therefore, while measuring the harmonics of the transmitter with waveguide components, the fundamental transmission in the mmWave range below the waveguide cutoff frequency will not overload the analyzer.

In-band and out of band power measurements can be expressed in terms of peak or average values. When average measurements are used to demonstrate compliance, the averaging is to be performed only over durations of active transmissions at maximum output power level. In other words, average measurements for compliance demonstrations shall not include averaging over periods when the transmitter is quiescent or when operating at reduced power levels (*i.e.*, no duty cycle or duty factor reduction is permitted).

3.4 Equipment Required

a) Spectrum analyzer

b) External harmonic mixers and/or fundamental-mixing downconverters covering the necessary frequency ranges

c) Standard gain horns covering the necessary frequency ranges

d) Diplexer for analyzer, if required

e) External local oscillator amplifier, if required. The LO amplitude shall be within the operating range of mixer input.

f) Signal generator for mmWave 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

[9] See FCC technical report TR 14-1001, TR 14-1001 MMW Measurements with Harmonic Mixers [8].

l) RF detector

m) mmWave isolator, if required

n) Low Noise Amplifier, if required

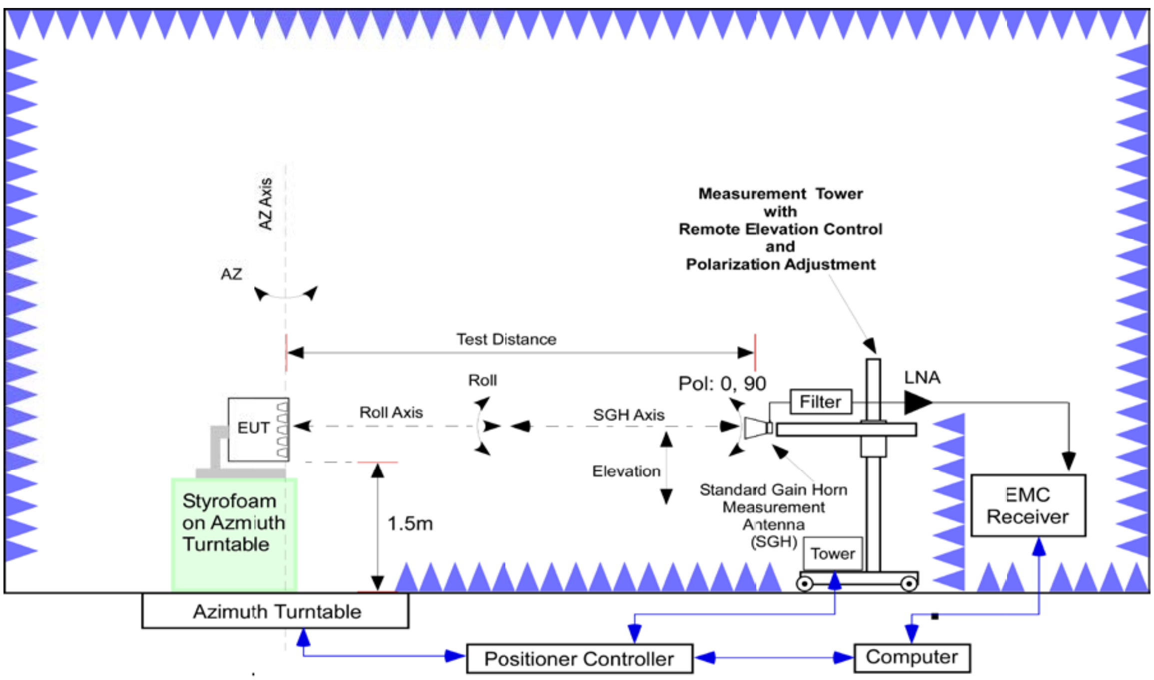
o) mmWave source if required

p) Variable waveguide attenuator if required

q) mmWave power sensor if required

3.5 General Test Setup in the Test Chamber

Radiated measurement test sites shall conform to the site validation criteria called out in CISPR 16-1-4:2019 over the frequency range 1 GHz to 18 GHz. The test object is mounted on a positioner; see Figure 1. The positioner is used to move the test object according to the sampling grid. A measurement antenna is placed in the chamber at a suitable measurement antenna far-field distance as shown in Figure 1. The measured quantity is the EIRP. Two partial values of EIRP for horizontal and vertical polarizations of the measurement antenna shall be recorded and summed at each angular point of the EUT for each frequency. 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.



NOTE: The roll axis positioner is optional, and if absent then TRP measurements can be made by manually reorienting the EUT on the EUT Styrofoam support structure and using the azimuth turntable for angular sweeps.

For example, 3 orthogonal orientations can be used to perform the 3 cut TRP method.

Figure 1 – Shielded anechoic chamber and positioner setup

3.6 General Test Setup in the Test Chamber

Antenna calibrations considerations for measurements in the frequency range of 30 MHz to 40 GHz shall be as per ANSI C63.26. For measurements above 40 GHz, standard gain horn antennas shall be used. The antenna factors may be calculated, or manufacturer provided factors may be used.

3.7 Test Configurations

Testing for unwanted emissions shall be performed with EUT operating in the mode that represents the worst case, *i.e.*, the mode or modes that result in the highest amplitude unwanted emissions. For technologically complex devices, the EUT worst case mode can be determined by the OEM or the device manufacturer.[10] The EUT shall be evaluated for at least one of the beam configurations listed below:

a) EUT configured to transmit a single beam at a rated maximum EIRP.

b) EUT is configured to transmit at rated maximum EIRP with several beams with equal power levels.

c) EUT is configured to transmit at rated maximum EIRP with several beams with unequal power levels.

It is advantageous during testing to have prior knowledge of transmitting power levels, number of beams configured to radiate, their approximate beamwidth, and their radiation pattern. See Appendix F for general guidance on how to perform exploratory scan. It is also recommended to lock the beam(s) during testing, especially when testing RF output power or OOBE.

3.8 Minimum Measurement Distance for Final Radiated Measurements

All measurements of the fundamental emission, out of band, harmonics and spurious emissions shall be made in the far field of the measurement antenna. The far-field boundary for mmWave antennas is greater than or equal to $\frac{2D^2}{\lambda}$ (with D being the largest dimension of the antenna, and λ the wavelength of the emission). 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 for field strength) shall be applied.

For fundamental and out-of-band emissions the largest far-field distance of either the EUT antenna or measurement antenna shall be used. For spurious emissions the far-field distance is based only on the measurement antenna.

3.9 Maximum Measurement Distance for Final Radiated Measurements

All measurements shall be made such that measurement noise floor is at least 6 dB below the applicable emissions limit.

---

[10] Test reports shall contain supporting documentation that forms the basis for determining the worst case. Additional details regarding worst case determination, including relevant assumptions and scenarios, can be provided in the Operations Description.

4 SPECIFIC MMWAVE DEVICE COMPLIANCE MEASUREMENT PROCEDURES

4.1 General

Compliance measurement procedures pertaining to Radiated RF output power, occupied bandwidth, unwanted radiated emissions, and frequency tolerance measurements are provided in 4.2 through 4.5.

4.2 Radiated RF Output Power (or RF Output Power Spectral Density) Measurements

Subclauses 5.5.3 (substitution method) and 5.5.4 (field strength method) of ANSI C63.26-2015 are also applicable to radiated RF output power and power spectral density measurements of Part 30 devices. The fundamental emission must be maximized, as described in Appendix G, when a radiated method of measurement is selected. If the measurement (resolution) bandwidth of the signal analyzer (or measurement device) is less than the bandwidth of the transmitted signal then power integration method may be used to integrate power over the occupied bandwidth of the transmitted signal (in case of power measurement) or over the reference bandwidth (in case of power spectral density measurement).
Note that a reference bandwidth of 100 MHz is chosen for all power spectral density measurements.

Three distinct scenarios are possible where radiated power spectral density (EIRP density) is subject to the limit. The scenarios and their corresponding measurement procedures are described below:

a) **The channel bandwidth is 100 MHz.** In this case, the total power (power contained in the 99% occupied bandwidth of the signal) is subject to the limit. If the overall transmission contains multi-carrier (contiguous or noncontiguous) 100 MHz channel BW signals (also known as component carriers) then the component carrier with maximum total power is subject to the limit.

b) **The channel bandwidth is less than 100 MHz.** In this case, the limit must be reduced proportionally and linearly based on the bandwidth relative to 100 megahertz. The total power (power contained in the 99% occupied bandwidth of the signal) is subject to the new limit. If two or more component carriers are contiguously aggregated to make a 100 MHz-wide signal, then the total power of the aggregated signal is subject to the limit. If two or more component carriers (that are each less than 100 MHz wide) are noncontiguously aggregated, then the total power of each component carrier is individually subject to the limit

c) **The channel bandwidth is greater than 100 MHz.** In this case, maximum EIRP density (radiated power per 100 MHz) is subject to the limit..

   A peak search with a given RBW (1 MHz as an example) can be performed, then add $10\log\left(\frac{Reference\ Bandwidth}{Resolution\ Bandwidth}\right)$ to the measurement . This value is an upper bound of the power density over the reference bandwidth, that is the highest power / 100 MHz cannot have a value that exceeds this bound. If this value meets the limit, then the transmission is compliant.

   In scenarios where the channel bandwidth of the signal is greater than or equal to 100 MHz, the total channel power may be measured and compared to the limit. If the measured total EIRP is less than the EIRP density limit, the device is compliant since the total power is always greater than the partial power.

Note: Both of the above methods upper bound the power density. If a more accurate measurement is desired see the "rolling integration method" below.

Rolling integration method:

Take a Power Density measurement over a span that is large enough to encompass the EBW of the signal, with the number of points such that Frequency Resolution is much smaller than the Reference BW,

- in particular such that
    - (Reference BW) = N * (Frequency Resolution), where N is an integer
    - Frequency Resolution = RBW setting of the spectrum analyzer

Using the applicable detectors, power averaging, and other instrument settings.

After the measurement is completed, download the trace data and

- correct for measurement system frequency response (if not already performed internally by the instrument)
- convert to the specified regulatory units of Power Density EIRP
- convert to linear units if not previously done

Calculate the Power Density over the Reference BW:
Using linear values, sum the first N converted data values, store this as the first amplitude element in a new data array.
Using the frequency associated with the midpoint of the first N bins, store this as the first frequency element in the new data array.
This is the Power Density EIRP over the Reference BW at the Frequency associated with the midpoint of the first N bins.

Starting with the second converted data value, sum the next N converted data values, store this as the second amplitude element in the new data array.
Using the frequency associated with the midpoint of these same N bins, store this as the second frequency element in the new data array.
This is the Power Density EIRP over the Reference BW at the Frequency associated with the midpoint of these N bins.

Repeat this process until: Sum the last N converted data values, store this as the last amplitude element in the new data array.
Using the frequency associated with the midpoint of these same N bins, store this as the last frequency element in the new data array.
This is the Power Density EIRP over the Reference BW at the Frequency associated with the midpoint of these last N bins.

Convert the amplitude values in the new data array to logarithmic units as required.
Find the maximum amplitude value in the new data array, and the associated frequency in the new data array.

This is the highest Power Density EIRP / (Reference BW) of the emission.

The Frequency Resolution can be smaller than the RBW, however in this case each sum of N converted data values will need to be divided by a factor equal to (RBW) / (Frequency Resolution).

4.3 Occupied Bandwidth Measurements

Subclause 5.4 of ANSI C63.26-2015 is applicable to occupied bandwidth measurements of Part 30 devices. [11]

4.4 Unwanted Emission Measurements

4.4.1 General

Subclauses 4.4.2 and 4.4.3 describe unwanted emission measurement procedures. Subclauses 4.4.2 and 4.4.3 also introduce an alternative approach to TRP (or conducted power) measurement, herein referred to as an "early exit" condition. It is acceptable to perform maximum EIRP measurements, over the required frequency range, and compare the measurements to the limit to verify compliance. If the measured EIRP levels are below the TRP limit the early exit condition is met and the device is compliant[12]. If the device does not meet the emission limit at one or some frequencies, then TRP measurements need be performed only at those frequencies.

According to Section 30.203(a),[13] the conductive power or the total radiated power of any emission outside a licensee's frequency block shall be −13 dBm/MHz or lower. However, in the bands immediately outside and adjacent to the licensee's frequency block, having a bandwidth equal to 10% of the channel bandwidth, the conductive power or the total radiated power of any emission shall be −5 dBm/MHz or lower. For the purpose of compliance measurements in the OOB region, "channel bandwidth" is assumed to be the same as transmitted signal bandwidth. In cases where transmitted signal can be configured to contain more than one carrier (for example in carrier aggregation scenarios), all configurations shall be tested.

4.4.2 Procedure for Assessing TRP for Emissions in Out of Band (OOB) Domain

4.4.2.1 General

a) Perform maximum EIRP measurement as described in 5.5.3 of ANSI C63.26 (substitution method) or 5.5.4 of ANSI C63.26 (field strength method). Note: EIRP measurements are performed using linearly polarized antenna. Both horizontal and vertical polarizations are measured separately and not summed. The highest amplitude signal measured from horizontal or vertical polarization is used for determining compliance to the unwanted emission limit.

b) Compare the measured maximum EIRP at each frequency with the applicable TRP limit.

---

[11] Subpart C of Part 30 does not explicitly set requirements on occupied bandwidth of transmitted signals. However, such measurements may be required to verify occupied bandwidth of transmissions fall within authorized bands.

[12] For isotropic and low gain radiators, EIRP (based on single linear polarization measurement) can be lower than TRP, however in practice for devices within the scope of this standard the gain will be high enough that EIRP will be greater than TRP.

[13] See 47 CFR § 30.203(a).

c) If the maximum EIRP is less than TRP limit then early exit condition is met, and no further measurements are required for that frequency.

d) Otherwise follow TRP measurement procedures using one of the methods described in 4.4.2.2 through 4.4.2.4.

4.4.2.2 Two or Three Cut Method When Pattern Multiplication Is Not Applicable

Use this method if the antenna cardinal cuts are known, *i.e.*, the angular cuts comprising the highest sidelobes. An exploratory scan as described in Appendix F to identify the cardinal cuts may be needed. Note that for arbitrary electrically steered beams the cardinal cuts may be curved with respect to the coordinate system angles. In this case a more advanced angular control is needed, additional consultation with the FCC through KDB inquiry will be needed. The measurement difficulties could be reduced by testing under non-steering (stationary) conditions.

a) Align the cardinal cuts with the xy-plane and the xz-plane of the antenna measurement coordinate system, thus the main beam of the EUT emission will point along the x-axis, and the intersection of the cardinal cuts will be along the x-axis.

b) Measure the antenna dimensions, *i.e.*, depth (d), width (w), and height (h). If the antenna dimensions are not accessible use the mechanical dimensions of the entire device.

c) Calculate the spherical and cylindrical diameters (D and Dcyl) using Equations (A.1) and (A.2) (see Appendix A).

d) For the highest frequency (smallest wavelength) of the frequency band measured, calculate the reference angular steps $\Delta\theta$ref and $\Delta\phi$ref using Equations (A.3) and (A.4).

e) Set the grid spatial sampling step $\Delta\theta \leq \Delta\theta$ref for the vertical cut and $\Delta\phi \leq \Delta\phi$ref for the horizontal cut.

f) For each emission frequency, measure the EIRP (as a sum of vertical and horizontal polarizations) at each spatial sampling step on the selected two- or three-cut grid.

g) For each emission frequency, first calculate the average EIRP in the two cuts, then take the average of these two average values. This averaged value is the estimated TRP to be compared against the OOB emission TRP limit.

h) If the TRP limit is exceeded, a third orthogonal cut in the yz-plane and using the $\Delta\theta$ angular step, can be added. Now, calculate the average values in all three cuts, and then take the average value of these three values. This value is the estimated TRP. Note that a maximum reduction by 2/3 (approximately 2 dB) may be achieved by using an additional third cut.

i) Evaluate the pass/fail decision by comparing estimated TRP from step g) or step h) against the applicable TRP limit.

4.4.2.3 Two Cut Method When Pattern Multiplication is Applicable

Beam pattern of co-located multiple arrays can be derived from the beam pattern of the individual participating antenna beam arrays (pattern multiplication). Therefore, worst case radiation pattern must be identified for final OOB evaluation. This method requires declared information about the antenna array geometry from the EUT vendor. The following conditions must be met:

- The antenna element positions form a rectangular grid
- The rectangular grid has symmetry planes that are vertical and horizontal.
- The vertical cardinal plane is in the xz-plane, *i.e.*, the main beam direction is in the xz-plane. See Appendix A and B figures A.1 and B.2 respectively for illustration of the planes
    - If the main beam is not in the xz plane additional consultation through KDB inquiry may be needed.

Note that pattern symmetries can be exploited for other (non-rectangular) grids as well. Only rectangular grid case is considered here.

a) Follow steps a) through g) of the two-cut methods described in 4.4.2.2 to get TRP data for two cuts.

b) Apply pattern multiplication described in Appendix E.

c) Compare the measured TRP with applicable TRP limit to make a pass/fail decision.

4.4.2.4 Spherical Grid Method

a) Measure the antenna dimensions, *i.e.*, depth (d), width (w), and height (h) (see Figure A.1 in Appendix A). If the antenna dimensions are not accessible use the mechanical dimensions of the entire device.

b) Calculate the spherical and cylindrical diameters (D and Dcyl) using Equations (A.1) and (A.2) in Appendix A.

c) For the highest frequency (smallest wavelength) of the frequency band measured, calculate the reference angular steps $\Delta\theta$ref and $\Delta\phi$ref using Equations (A.3) and (A.4) in Appendix A.

d) Set the grid spatial sampling step $\Delta\theta \leq \Delta\theta$ref for the vertical angle and $\Delta\phi \leq \Delta\phi$ref for the horizontal angle.

e) For each emission frequency, measure the total EIRP (sum of two orthogonal polarizations) on the selected grid.

f) For each emission frequency, calculate the TRP using weighted angular average value using numerical integration as described in Appendix B.

g) Compare measured TRP with the applicable TRP limit to make a pass/fail decision.

4.4.2.5 EIRP to Conducted Power Conversion in Band Edge Using Antenna Gain

The following procedure shall be used only for band edge measurements and only when realized gain of EUT antenna is known in a given polarization as a function of frequency over the out- of-band emissions / measurement range that covers both band-edges and block-edges of the device. The realized gain accounts for the impedance mismatch of the antenna input to required impedance. The Gain of the EUT antenna has to be properly measured or simulated over the above-mentioned frequency range. If the device can generate and radiate multiple beams simultaneously the number of beams at any bandwidth and their radiating power (EIRP) level need to be identified. All measurements shall be made in the far-field of the EUT antenna and measurement antenna.

Calculate antenna port conducted power level using following equations:

- Conducted Power level (dBm/BW) = Measured EIRP level (dBm/BW) – EUT antenna Gain (dBi)

- Measured EIRP (dBm/BW) = level at the measurement antenna connector (dBm/BW) – Measurement antenna Gain (dBi) + path loss (dB)

- Path loss (dB) = 20 log (frequency in MHz) + 20 log (measurement distance m) – 27.56

a) EUT Radiating a Single Beam operating at Rated EIRP:

  1) Maximize emissions using the procedure described in Appendix G. If necessary, align measurement antenna with EUT antenna to maximize emissions that use other linearly polarized transmission as described in Appendix G.

  2) Measure and record radiated emissions in band/block edge using the methods described in 5.5.3 of ANSI C63.26 (substitution method) or 5.5.4 of ANSI C63.26 (field strength method).

  3) Convert each radiated measurement to conducted Power Spectral Density using above equations.

  4) Sum the measured radiated PSD across two orthogonal polarizations to calculate total PSD.

  5) Evaluate the pass/fail decision by comparing total PSD against the applicable limit.

b) EUT radiating multiple beams, from different antenna array panels, operating at rated EIRP:

  1) Measurement can be performed for each of the beams with other beams turned off. In this case the measured levels from all beams must be summed in the linear units on each of the OOB frequencies and then convert them into decibels (dB or dBm). The EUT antenna Gain of the participating elements only can be accounted. The measured or simulated antenna Gain can be used. If an EUT transmits equal beams (equal power and the same beam geometry and characteristics), evaluation on only one beam is sufficient. Total power at each of the OOB frequencies is then calculated by adding 10 log(number of beams) dB.

  2) Repeat steps a) 1) and a) 2) of the above procedure for each beam and polarization. Determine maximum radiated power density (max. EIRP).

  3) Convert maximum radiated power density (max. EIRP density) to conducted power spectral density using above equations. Note that gain of the EUT antenna in Equation (D.9) (see Appendix D) may be different for each beam.

  4) If EUT employs multiple cross-polarized transmissions, then sum the power spectral densities across the polarizations to determine the total power spectral densities being delivered to the antennas to calculate total PSD.

  5) Evaluate the pass/fail decision by comparing total PSD against the applicable limit.

4.4.3 Measurement Procedures for Emissions in Spurious Domain

4.4.3.1 General

The measurement procedure for emissions in spurious domain consists of a three-step approach. The first step is initial exploratory scan with the purpose of optimizing test time by identifying a set of frequencies that need further EIRP/TRP measurements. The second step is to perform EIRP measurements based on first step results and determine which frequencies meet early exit conditions (based on EIRP measurements) and which frequencies need TRP measurements. The third step is to perform TRP measurements based on second step results using any of the various methods proposed in Clause 3.

4.4.3.2 Initial Exploratory Scan Procedure

Set the EUT in a test configuration mode as per 3.7 and follow the procedures as described below:

a) Perform initial exploratory scan while maximizing emissions per the procedures presented in Appendix F.

b) Additionally, use the general guidance presented in Appendix G to maximize the emissions being observed on a spectrum analyzer.

c) Record the list of spurious emission frequencies and corresponding power levels as observed on a spectrum analyzer.

d) Analyze the recorded results. The magnitude of spurious emissions which are attenuated by more than 20 dB below the specified spurious emission limit need not be further analyzed or specified in the test report.

e) For all other spurious emissions that are found to be within 20 dB of the applicable limit, further EIRP measurement, as described in 5.5.3 of ANSI C63.26 (substitution method) or 5.5.4 of ANSI C63.26 (field strength method) and analysis of the EIRP and/or TRP (using the measurement procedures specified in 4.4.3.3) shall be performed.

The test report shall thoroughly describe the antenna configuration(s), the EUT operating modes tested to maximize emissions, and provide appropriate technical justification to support the initial exploratory scan results.

4.4.3.3 TRP Based Measurement Procedure

4.4.3.3.1 General

a) Perform maximum EIRP measurement as described in 5.5.3 of ANSI C63.26 (substitution method) or 5.5.4 of ANSI C63.26 (field strength method). Note: EIRP measurements are performed using linearly polarized antenna. Both horizontal and vertical polarizations are measured separately and not summed. The highest amplitude signal from horizontal or vertical polarization is used for compliance to the unwanted emissions limit.

b) Compare the measured maximum EIRP at each frequency with the applicable TRP limit.

c) s

4.4.3.3.2 Two or Three Cut Method

a) Align the EUT with a chosen xy-plane and the xz-plane of the antenna measurement coordinate system.

   NOTE 1: For harmonics and spurious emission frequencies which are beamformed as identified in exploratory scan, it may be required to align the orthogonal cuts to include the peak based on exploratory scans.

b) Measure the EUT dimensions, *i.e.*, depth (d), width (w), and height (h); see Figure A.1 in Appendix A.

c) Calculate the spherical and cylindrical diameters (D and Dcyl) using Equations (A.1) and (A.2) (see Appendix A).

d) For the highest frequency (smallest wavelength) of the frequency band measured, calculate the reference angular steps $\Delta\theta$ref and $\Delta\phi$ref using Equations (A.3) and (A.4).

e) Set the grid spatial sampling step $\Delta\theta \leq \Delta\theta$ref for the vertical angle and $\Delta\phi \leq \Delta\phi$ref for the horizontal cut.

f) For each emission frequency, measure the EIRP (as a sum of two orthogonal polarizations) at each spatial sampling step on the selected grid.

g) For each emission frequency, calculate the average EIRP for both the cuts separately, and then take the average of these two average values.

h) Add 2 dB as a correction factor to the averaged value computed in step g).

i) If the TRP limit is exceeded, a third orthogonal cut in the yz-plane and using the $\Delta\theta$ angular step, can be added. Now, calculate the average values in all three cuts separately, and then take the average value of these three average values.

j) Add 1.5 dB as a correction factor to the averaged value computed in step i).

k) Evaluate the pass/fail decision by comparing TRP from step h) or step j) against the applicable TRP limit.

NOTE 2: The 2 dB correction factor for two cut and 1.5 dB correction factor for three cuts is derived from [4].

4.4.3.3.3 Equal Sector Method

The equal sector cuts based TRP method allows accounting for additional EIRP levels of the next strongest beams and averaging them for calculating the TRP. Four measurement segments for frequencies up to 18 GHz and eight measurements above 18 GHz is recommended for EUT Sizes up to 60 cm (2 ft) for measurement distances up to 3 m. For measurements above 18 GHz, the power input, control and back-haul cables need not be considered for measuring the size of the EUT. Either the width or height of the EUT should be less than 60 cm (2 ft). Alternatively, longer test distances may be used for large size EUTs provided analyzer has sufficient dynamic range.

The EIRP at the EUT (dBm/MHz) = Pr (dBm/MHz) + cable loss between antenna and analyzer (dB) – measurement antenna gain (dBi) + path loss (dB).

The path loss = 20 log10 (Fc) + 20 log 10 (d) – 27.56 dB.

where:

Pr = measured power level at the Analyzer

Fc = center frequency of spurious emission, MHz,

d = measurement distance between EUT and measurement antenna, m

a) Measurement shall be made in both vertical and horizontal polarizations of measurement antenna. The total EIRP on the measured beam is sum of Horizontal and Vertical polarization EIRP levels in linear units (mW).

b) If the largest horizontal or vertical dimensions of the EUT is less than 60 cm, then EIRP measurements shall be made in each 45° sector of the sphere (resulting in total of eight equal sectors) around the EUT by rotating EUT or turntable for measurement frequencies above 18 GHz. Below 18 GHz, it is sufficient to make measurements in each 90° sector of the sphere (resulting in total of four equal sectors)

c) Either measurement antenna or EUT may be tilted (see ANSI C63.4, ANSI C63.26, or ANSI C63.10) for maximizing the measured levels in each of the measurement sector (45° or 90°).

d) Measured power levels in each of the segments may be considered for meeting the TRP limits. If strongest measured beam did not meet the TRP limit, measured power levels in other segments (in descending order) may be used. Averaging must be performed in linear units.

For example, measurements performed for eight sectors from each half quadrant:

- TRP = 1/n (mW1 + mW2 + … mW8), where n = 8
- mW1 = sum of Horizontal and Vertical polarization EIRP levels in linear units (mW) of the strongest beam in each measurement sector
- mW1 + mW2 + … mW8 = sum of the EIRP arranged in descending order
- n= number of sectors (max beam in each sector is measured) for averaging (n= 1, 2…. 8)

Details of exploratory scan and final measurement procedure for equal sector cut method is presented in Appendix C.

4.4.3.3.4 Spherical Grid Method

The procedure to determine the step size for constant step spherical grid type is described in detail in 4.4.2.4.

a) Measure the EUT dimensions, *i.e.*, depth (d), width (w), and height (h); see Figure A.1 in Appendix A.

b) Calculate the spherical and cylindrical diameters (D and Dcyl) using Equations (A.1) and (A.2) in Appendix A.

c) For the highest frequency (smallest wavelength) of the frequency band measured, calculate the reference angular steps $\Delta\theta$ref and $\Delta\phi$ref using Equations (A.3) and (A.4) in Appendix A.

d) Set the grid spatial sampling step $\Delta\theta\text{ref} \leq \Delta\theta \leq 15°$ for the vertical angle and $\Delta\phi\text{ref} \leq \Delta\phi \leq 15°$ for the horizontal angle, and calculate the Sparsity factor (SF) using Equation (A.5).

e) For each emission frequency, measure the total EIRP (sum of two orthogonal polarizations) *on each of the non-redundant points of* the spherical grid.

f) For each emission frequency, calculate the weighted angular average value using numerical integration as described in Appendix B.

g) Add a correction factor to account for measurement uncertainty due to use of sparse grid by following the procedure [4]:

    1) Calculate the maximum sparsity factor SFmax by using $\Delta\theta = \Delta\phi = 15°$ in Equation (A.5).

    2) Calculate the correction factor as ΔTRP = (SF-1)/(SFmax-1) dB.

h) Add the correction factor ΔTRP from g) 2) to the emission value obtained in step f). If the total TRP value is not satisfactory and SF > 1. Repeat steps d) through g) after choosing a new lower SF value (resulting in denser sampling grid).

i) Compare measured TRP with the applicable TRP limit to make pass/fail decision.

4.5 Frequency Tolerance Measurements

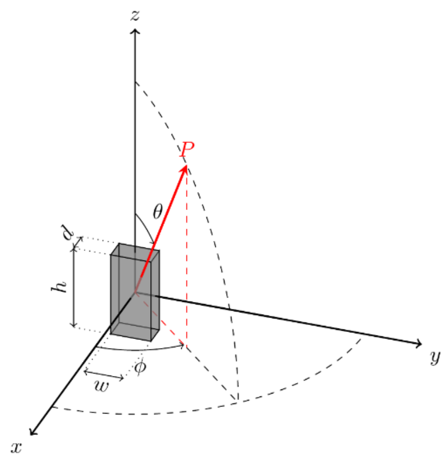
Subclause 5.6 of ANSI C63.26-2015 is applicable.

APPENDIX A

COORDINATES AND SAMPLING GRID

This Appendix covers the reference angular sampling which is required for error-free calculation of TRP on a spherical grid, as well as the definition of the Sparsity Factor (SF) which is used to characterize sparse sampling grids in comparison to the dense grid with reference angular sampling.

The device dimensions, depth (d), width (w) and height (h) are defined as in Figure A.1.



NOTE These dimensions refer either to only the antenna dimensions (out-of-band emissions) or the entire mechanical dimensions of the EUT (spurious emissions).

Figure A.1 – Spherical coordinates [1] and device dimensions, depth (d), width(w) and height (h).

The spherical and cylindrical diameters (D and D_{cyl}) are calculated as

$$\boldsymbol{D} = \sqrt{\boldsymbol{d}^2 + \boldsymbol{w}^2 + \boldsymbol{h}^2} \qquad \text{(A.1)}$$

$$\boldsymbol{D}_{\text{cyl}} = \sqrt{\boldsymbol{d}^2 + \boldsymbol{w}^2} \qquad \text{(A.2)}$$

For each emission frequency, the reference angular step for each emission frequency is calculated using Equations (A.2), (A.3) and the wavelength as

$$\boldsymbol{\Delta\theta}_{\text{ref}} = \mathbf{min}\left(\mathbf{15}^\circ, \mathbf{180}^\circ/(\boldsymbol{\pi D}/\boldsymbol{\lambda})\right) \qquad \text{(A.3)}$$

$$\boldsymbol{\Delta\phi}_{\text{ref}} = \mathbf{min}\left(\mathbf{15}^\circ, \mathbf{180}^\circ/(\boldsymbol{\pi D}_{\text{cyl}}/\boldsymbol{\lambda})\right) \qquad \text{(A.4)}$$

$\Delta\theta_{ref}$ and $\Delta\phi_{ref}$ are defined as the minimum of 15° and the value calculated based on the device dimensions. This is to ensure that the sampling step is not larger than 15° (see [2]). These reference values are the required angular steps for accurate TRP assessment with no grid-dependent error.

For any pair of used angular steps Δθ and Δϕ, SF is defined as

$$\mathbf{SF} = \mathbf{max}\left(\frac{\Delta\theta}{\Delta\theta_{\mathrm{ref}}}, \frac{\Delta\phi}{\Delta\phi_{\mathrm{ref}}}\right) \quad \text{(A.5)}$$

The measurement points for the EIRP values are either taken on a full-sphere grid or a two-cut or three-cut grid on a spherical surface. The choice of measurement grid is left as an option, bearing in mind that a dense full sphere will use the most points, *i.e.*, maximize the measurement time, but yield the most accurate result. As the method is designed to over-estimate the TRP result, using any other grid or a sparse sampling, for spurious emissions, will result in a faster measurement on the cost of a larger systematic correction factor for the TRP value.

In cases when an OEM uses a reference step larger than the values calculated by Equations (A.3) and (A.4), *i.e.*, corresponding to source dimensions smaller than the entire EUT, then an OEM needs to provide thorough analysis and/or empirical data to support their choice, and the corresponding correction factors ΔTRP may be used after obtaining regulatory acceptance. Any other theoretical or empirical methods used to determine the applicable spatial sampling grid size, requires the FCC Laboratory Division's approval, and may be used after obtaining regulatory acceptance.

Examples of sampling grid calculations for **base station (BS) enclosure:**

Base station (BS) enclosure Example 1	
d (cm)	10
w (cm)	20
h (cm)	40
Frequency (MHz)	17500
Wavelength (cm)	1.71
Vertical sampling	**Horizontal sampling**
$D = 45.8$	$D_{\mathrm{cyl}} = 22.4$
$D/\lambda = 26.7$	$D_{\mathrm{cyl}}/\lambda = 13.1$
$\Delta\theta_{\mathrm{ref}} = 2.1^{\circ}$	$\Delta\phi_{\mathrm{ref}} = 4.4^{\circ}$
$\Delta\theta = 5^{\circ}$	$\Delta\phi = 10^{\circ}$

Examples of sampling grid calculations for **user equipment (UE):**

User equipment example 1		**User equipment example 2**	
d (cm)	1	d (cm)	1
w (cm)	7	w (cm)	7
h (cm)	14	h (cm)	14
Frequency (MHz)	17500	Frequency (MHz)	90000
Wavelength (cm)	1.71	Wavelength (cm)	0.33
Vertical sampling	**Horizontal sampling**	**Vertical sampling**	**Horizontal sampling**
$D = 15.7$	$D_{\text{cyl}} = 7.1$	$D = 15.7$	$D_{\text{cyl}} = 7.1$
$D/\lambda = 9.2$	$D_{\text{cyl}}/\lambda = 4.1$	$D/\lambda = 47$	$D_{\text{cyl}}/\lambda = 21.5$
$\Delta\theta_{\text{ref}} = 6.3^{\circ}$	$\Delta\phi_{\text{ref}} = 13.8^{\circ}$	$\Delta\theta_{\text{ref}} = 1.2^{\circ}$	$\Delta\phi_{\text{ref}} = 2.6^{\circ}$
$\Delta\theta = 6^{\circ}$	$\Delta\phi = 12^{\circ}$	$\Delta\theta = 6^{\circ}$	$\Delta\phi = 12^{\circ}$
$\Delta\theta\ max = 15^{\circ}$	$\Delta\phi\ max = 15^{\circ}$	$\Delta\theta\ max = 15^{\circ}$	$\Delta\phi\ max = 15^{\circ}$
SF = Max of (6/6.3, 12/13.8) = 1		SF = Max of (6/1.2, 6/2.6) = 5	
SFmax = Max of (15/6.3, 12/13.8) = 2		SFmax = Max of (15/1.2, 12/2.6) = 12	
$\Delta\text{TRP} = \frac{\text{SF} - 1}{\text{SFmax} - 1} = 0\text{dB}$		$\Delta\text{TRP} = \frac{\text{SF} - 1}{\text{SFmax} - 1} = 0.36\text{dB}$	
Note: Choosing max sampling grid step size ($\Delta\theta = \Delta\theta\_\text{max} = 15°$ & $\Delta\phi = \Delta\phi\_\text{max} = 15°$), means SF = SFmax, which results in TRP correction of 1 dB (when SFmax > 1) to the actual measurement.			

APPENDIX B

TRP CALCULATIONS

When a spherical grid is used, as shown in Figure B.1, the TRP of the emissions is calculated using multiple EIRP measurements as

$$\text{TRP}_{\mathbf{grid},\boldsymbol{f_n}} \approx \frac{\mathbf{1}}{\mathbf{4\pi}} \iint_{\mathbf{4\pi}} \text{EIRP}(\boldsymbol{\theta}, \boldsymbol{\phi})_{\boldsymbol{f_n}} \sin\boldsymbol{\theta} \mathrm{d}\boldsymbol{\theta} \mathrm{d}\boldsymbol{\phi} \approx \frac{\mathbf{\Delta\theta\Delta\phi}}{\mathbf{4\pi}} \sum_{\boldsymbol{m},\boldsymbol{n}} \text{EIRP}(\boldsymbol{\theta_m}, \boldsymbol{\phi_n})_{\boldsymbol{f_n}} |\sin\boldsymbol{\theta_m}|$$

Here, the angular steps $\Delta\theta$ and $\Delta\phi$ are the angular steps between EIRP measurement points.

NOTE Select angular ranges which cover a whole sphere, e.g. $0° \leq \theta \leq 180°$, $-180° \leq \phi \leq 180°$ or alternatively $-180° \leq \theta \leq 180°$, $0° \leq \phi \leq 180°$ However, $-90° \leq \theta \leq 90°$, $-180° \leq \phi \leq 180°$ will only cover the upper hemisphere twice.

Instead of choosing measurement points on a rectilinear grid, another way to measure a full sphere is to use continuously sliding θ and ϕ angles to trace out a spiral on the spherical measurement sphere. The angular speeds must then be adjusted to give correct angular steps in both directions. In this case appropriate averaging weights must be applied to calculate the TRP [2, p. 126].

The total EIRP is measured on the two orthogonal cuts, shown in Figure B.2, and the TRP is then calculated as follows:

$$\boldsymbol{TRP_{grid}} = \frac{\mathbf{1}}{\mathbf{2}}\left(\overline{\text{EIRP}^{(\mathbf{1})}} + \overline{\text{EIRP}^{(\mathbf{2})}}\right)$$

Where $\text{EIRP}^{(\boldsymbol{n})} = \text{EIRP}_{\mathbf{0}}^{(\boldsymbol{n})} + \text{EIRP}_{\mathbf{90}}^{(\boldsymbol{n})}$ for $\boldsymbol{n} = \mathbf{1}, \mathbf{2}, (\mathbf{3})$ are the total EIRP in each cut, and the bar denotes angular average value calculated from each cut. Note that when orthogonal cuts are measured, the intersection points are measured multiple times and the repeated values can be removed from the samples before averaging. If a third cut is used the TRP calculation is

$$\mathbf{TRP_{grid}} = \frac{\mathbf{1}}{\mathbf{3}}\left(\overline{\text{EIRP}^{(\mathbf{1})}} + \overline{\text{EIRP}^{(\mathbf{2})}} + \overline{\text{EIRP}^{(\mathbf{3})}}\right)$$

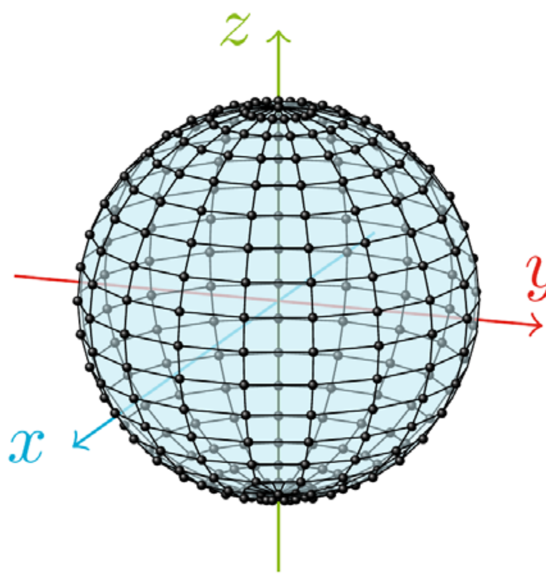
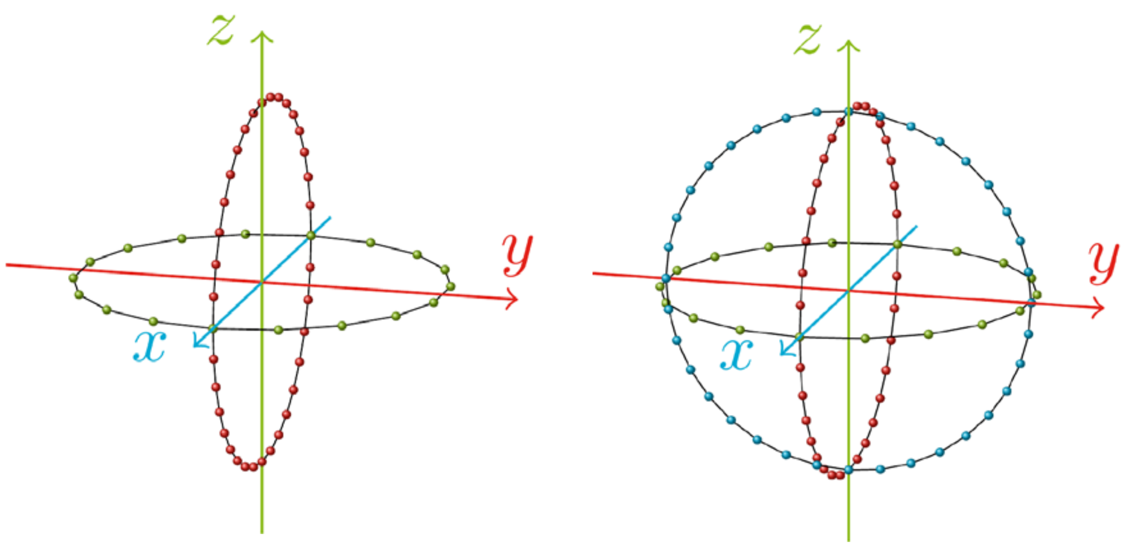


Figure B.1 – Full sphere grid using fixed steps in θ and ϕ and a weighting factor $|sin\theta|$ in the TRP calculation to compensate for denser sampling near the z-axis



NOTE The first two cuts are generated by rotating the EUT around its z-axis and y-axis, respectively, and the optional third cut is generated by rotating the EUT around its x-axis.

Figure B.2 – Orthogonal cuts geometry for spurious emissions or a broadside beam in the OOB region. Two mandatory cuts grid (left) and the optional added third cut (right)

APPENDIX C

EQUAL SECTOR METHOD

C.1 Equal sector exploratory scan

a) Connect the test antenna to the instrumentation system.

b) Evaluate the EUT transmitter antenna system and determine all radiating beamforming configurations supported with frequency range, BW, and power levels.

c) Identify the number of beams (N) supported at any BW and their EIRP levels.

d) Configure the EUT transmitter such that the antenna system radiates maximum power levels on one of the configurations listed in 3.7 a) through c).

e) EUT shall be placed on a 1.5 m high table.

f) Set the spectrum analyzer resolution BW to 1 MHz (lower resolution BW may be used for identifying narrow band signals and measurements below 1 GHz) and select peak detector with sufficient dwell time to capture the maximum emissions.

g) Make sure measurements are made during the transmitting period using the analyzer gated functions. In most cases GPS timing for referencing the analyzer and frame triggering from EUT are required.

h) The channel edge emissions are typically (but not necessarily) radiated through the EUT antenna. Notch filter may be necessary for suppressing carrier power to increase the measurement dynamic range during channel edge measurements.

i) During the harmonic and out of band spurious emissions measurements, additional low pass or high filters may be inserted in the measurement path for increasing the measurement dynamic range.

j) Measurement shall be made on all required channel BWs and channels as specified in the test standards.

k) Separate measurements are required for each channel edge and out of band spurious emissions.

   NOTE For channel edge measurements, the limit shall be applied to: from center frequency – (½ RBW + ½ BW + 10% BW), and from center frequency + (½ RBW + ½ BW+ 10% BW). However, the measurement frequency span should be approximately 15% BW instead of 10% BW. Additional 5% BW is recommended to identify all spurious emissions that may fall exactly at the edge of the required measurement frequency range.

l) The measurement should be made at the specified distance in the test standard. However, a closer distance may be used for identifying the sources of emissions. Place the measurement antenna at an appropriate distance (preferably at the far-field of measurement antenna) so that emissions frequencies closer to the limit can be measured.

m) For frequencies above 18 GHz, identify radiated frequencies by rotating the turntable at least 45°. For each 45° sector, the antenna shall be height scanned from 1 m to 4 m by rotating the roll axis positioner. For frequencies below 18 GHz, identify radiated frequencies by rotating the turntable at least 90°. For each 90° sector, the antenna shall be height scanned from 1 m to 4 m by rotating the roll axis positioner. List at least six strongest radiating frequencies for each test antenna polarities. The list shall also include appropriate sector and height at which maximum amplitude was measured.

n) mmWave standard gain antennas approximately have 20 dBi to 24 dBi gain and the 3 dB beamwidth will cover approximately 60 cm (24") wide EUT located at 3 m distance. While measuring mmWave frequencies, the 3 dB beamwidth need not cover the power and low frequency cables. If measurements are made at closer distances, the EUT width coverage will be reduced. Therefore, measurement shall be made with l turntable rotation angles of less than 45° (above 18 GHz) and less than 90° (below 18 GHz).

o) Measurement shall be made for both vertical and horizontal polarization of measurement antenna.

C.2 Equal sector final measurement procedure

The final radiated emissions test procedure is as follows:

a) For each segment of measurement, arrange all emission levels in descending order. Select six highest emissions for each polarization of measurement antenna. If number of recordable emissions are lower than six, then select all recorded emissions.

b) Select the frequency at which highest amplitude was recorded. Rotate the turntable to first segment.

c) Place the measurement antenna away from each area of the EUT determined to be a source of emissions at the specified measurement distance or at a closer far-field distance, while keeping the measurement antenna aimed at the source of emissions at each frequency of significant emissions, with polarization oriented for maximum response. The measurement antenna may have to be higher or lower than the EUT, depending on the radiation pattern of the emission and staying aimed at the emission source for receiving the maximum signal. The final measurement antenna elevation shall maximize the emissions. The measurement antenna elevation for maximum emissions shall be restricted to a range of heights from 1 m to 4 m above the ground or reference ground plane.

d) For maximizing the emissions either the measurement antenna or the EUT may be tilted as described in ANSI C63.4. However, tilt measurements need not be performed for frequencies below 18 GHz.

e) In all cases the antenna boresighted distance shall be used for calculating the path loss.

f) Calculate the EIRP in the linear units (mW).

g) If significant emissions were recorded at the same frequency in the same measurement sector, make measurement using other polarization of the measurement antenna and calculate the EIRP in the linear unit.

h) Sum the EIRPs measured in vertical and horizontal polarizations. Record the amplitude at this frequency.

i) Make measurements for at least six frequencies with significant amplitudes for each measurement antenna.

j) Move on to next segment with next higher amplitude. Measure EIRP(s).

k) Arrange measured amplitudes in descending order for each emissions frequency. If the highest measured EIRP meets the limit, then the spurious emission limit is met on the frequency. Otherwise take average of highest amplitude and second highest amplitude. If the resulting equal sector cuts based TRP didn't meet the requirement, consider third highest amplitude and calculate the average. Repeat this process till measurements in all segments are completed.

l) At least six frequencies must be evaluated from the Initial exploratory scan measurements list unless lower number of significant frequencies are recorded in the Initial exploratory scan.

m) For channel edge, where frequency range is much smaller than spurious emissions, at least two frequencies must be evaluated unless lower number of significant frequencies are recorded in the Initial exploratory scan.

n) It may be required to use low pass, high pass, band pass, or band reject filters, when identifying and measuring low amplitude signals, to avoid overloading of the analyzer or measuring instrumentation.

APPENDIX D

GENERAL EQUATIONS

D.1 Equations to calculate and extrapolate field strength

Calculate the field strength from the radiated measurement in the far field as follows:

$$E = 126.8 - 20\log(\lambda) + P - G \qquad \text{(D.1)}$$

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 test antenna, in dBm
- G is the gain of the test antenna, in dBi

NOTE The measured power P includes all applicable instrument correction factors up to the connection to the test 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 as follows:

$$E_{\text{SpecLimit}} = E_{\text{Meas}} + 20\,log\left(\frac{D_{\text{Meas}}}{D_{\text{SpecLimit}}}\right) \qquad \text{(D.2)}$$

Where:

- $E_{\text{SpecLimit}}$ 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
- $D_{\text{SpecLimit}}$ is the distance specified by the limit, in m

Calculate the field strength in V/m from the field strength in dBuV/m as follows:

$$E_{\text{Linear}} = 10^{[(E_{\text{Log}}-120)/20]} \qquad \text{(D.3)}$$

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

D.2 Equations to calculate EIRP

Calculate the EIRP from the radiated measurement in the far field as follows

$$EIRP = 21.98 - 20\log(\lambda) + 20\log(d_{Meas}) + P - G \qquad \text{(D.4)}$$

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 test antenna, in dBm
G is the gain of the test antenna, in dBi

NOTE The measured power P includes all applicable instrument correction factors up to the connection to the test antenna

Calculate the EIRP from the conducted power as follows

$$EIRP = P_{Cond} + G_{EUT} \quad \text{(D.5)}$$

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 as follows

$$EIRP_{\text{Linear}} = 10^{[(EIRP_{\text{Log}} - 30)/10]} \quad \text{(D.6)}$$

Where:

$EIRP_{\text{Linear}}$ is the equivalent isotropic radiated power, in Watts
$EIRP_{\text{Log}}$ is the equivalent isotropic radiated power, in dBm

D.3 Equations to calculate power density/BW from Measured Field Intensity levels

Calculate the power density at the distance specified by the limit from the equivalent isotropic radiated power in Watts as follows:

$$PD = \frac{EIRP_{Linear}}{\left(4\pi d^2\right)} \quad \text{(D.7)}$$

Where:

PD is the power density at the distance specified by the limit, in W/m^2

$EIRP_{\text{Linear}}$ 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 as follows:

$$PD = \frac{E_{SpecLimit}^2}{377} \quad \text{(D.8)}$$

Where:

377 is far-field free space impedance, in ohms

PD is the power density at the distance specified by the limit, in W/m^2

$E_{SpecLimit}$ is the field strength at the distance specified by the limit, in V/m

D.4 Equation to Calculate TRP Density from EIRP Density

Calculate the TRP (in watts) from the equivalent isotropic radiated power (in watts) as follows:

$$TRP = \frac{EIRP_{Linear}}{D_{EUT}} \quad \text{(D.9)}$$

Where:

TRP is the total radiated power, in W/BW

$EIRP_{Linear}$ is the equivalent isotropic radiated power, in W/BW

D_{EUT} is numeric realized gain of the EUT antenna

NOTE If G_{EUT} is used to calculate conducted power instead of using D_{EUT} to calculate TRP, then the estimate will be conservative as the conducted power will always be higher than the TRP.

APPENDIX E

PATTERN MULTIPLICATION METHOD

The pattern multiplication is performed in uv-coordinates and the data in the two cuts are denoted $u_H(\phi)$ at $\theta = \theta_H$ and a vertical cut with data $u_V(\theta)$ at $\phi = \phi_V$. The data is split in two parts corresponding to the forward and backward hemisphere, where the relation below defines forward and backward contributions.

$$\sin\boldsymbol{\theta}\cos\boldsymbol{\phi} \geq \mathbf{0}$$

holds for the forward hemisphere data. The remaining data correspond to the backward hemisphere. The uv-coordinates are defined as

$$\begin{cases} \boldsymbol{u} = \sin\boldsymbol{\theta_H}\sin\boldsymbol{\phi} \\ \boldsymbol{v} = \cos\boldsymbol{\theta} \end{cases}$$

for each hemisphere. The data is extrapolated to the uv-plane using the formula

$$\mathrm{EIRP}(\boldsymbol{u},\boldsymbol{v}) = \frac{\mathrm{EIRP_V}(\boldsymbol{u})\mathrm{EIRP_H}(\boldsymbol{v})}{\mathrm{EIRP_{peak}}}$$

The TRP is calculated as

$$\mathrm{TRP} = \frac{\mathbf{1}}{\mathbf{4\pi}}\left[\iint_{\boldsymbol{u^2+v^2}\leq\mathbf{1}}^{\mathrm{fwd}} \mathrm{EIRP}(\boldsymbol{u},\boldsymbol{v})\mathrm{d}\boldsymbol{\Omega} + \iint_{\boldsymbol{u^2+v^2}\leq\mathbf{1}}^{\mathrm{bwd}} \mathrm{EIRP}(\boldsymbol{u},\boldsymbol{v})\mathrm{d}\boldsymbol{\Omega}\right]$$

Here $\mathbf{d\Omega}$ is the infinitesimal solid angle at the point $(\boldsymbol{u},\boldsymbol{v})$.

Note that only points on the unit disc $\boldsymbol{u^2} + \boldsymbol{v^2} \leq \mathbf{1}$ will contribute.

APPENDIX F

EXPLORATORY SCAN PROCEDURE

At a high level the following procedure shall be used for initial exploratory scan:

a) Connect the test antenna to the instrumentation system.

b) Place the EUT in its worst case continuous transmission mode as per 3.7.

c) Set the instruments to the proper values (RBW= 1MHz, VBW> RBW, average (rms) detector, and appropriate span settings.

d) Perform an exploratory search for emissions, and determine the approximate direction at which each observed emission emitting from the EUT, as follows:

   1) It is recommended 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 test antenna is directed toward the main beam(s) of the EUT antenna.

   2) Begin hand-held or measurement system measurements with the test antenna in a horizontally polarized position.

   3) Scan the test antenna around all surfaces of the EUT, keeping the test antenna at a separation distance equal to the selected measurement distance, except increase the distance as needed to prevent measurement system overload when the test antenna is directed at the main beam(s) of the EUT antenna.

   4) As the surfaces of the EUT are scanned, keep the test antenna pointed toward the EUT.

   5) As the surfaces of the EUT are scanned, vary the test antenna polarization by rotating through at least 0° to 180° to cover all possible polarizations of the emission.

   6) For each observed emission frequency note the approximate test antenna position and emission power level at which the maximum level occurs.

   7) Where applicable, using two active traces on a spectrum analyzer (one set to clear-write, the second to max-hold) can aid the process.

APPENDIX G

MAXIMIZING EMISSION PROCEDURES

Maximize emissions as follows:

a) Connect the test antenna to the instrumentation system.

b) Place the EUT in a worst case continuous transmission mode as per 3.7.

c) Set the instruments to the proper values (RBW= 1MHz, VBW> RBW, average (rms) detector, and appropriate span settings.

d) For each emission observed in the exploratory scan, perform a final measurement as follows:

   1) Begin with the EUT and test antenna at the approximate orientation where the maximum level occurred during the exploratory scan.

   2) Place the test antenna at a measurement distance that meets the minimum and maximum distances specified above.

   3) Slowly scan the test antenna around this position, slowly vary the test antenna polarization by rotating through at least 0° to 180°, and slowly vary the orientation of the test antenna (so that it is not always pointing directly at the EUT) to find the final position, polarization and orientation at which the maximum level of the emission is observed.

e) Record the measure reading with the test antenna fixed at this maximized position, polarization, and orientation. Record the measurement distance.

References

[1] "IEEE Standard Test Procedures for Antennas" ANSI/IEEE Std 149-1979.

[2] "IEEE Standard for Definition of Terms for Antennas" IEEE Std 145-2013.

[3] Hald, J., Hansen, J.E., Jensen, F., and Holm Larsen, F. "Spherical Near-Field Antenna Measurements" Peter Pergrinus Ltd. 1988.

[4] Fridén, J., Razavi, A., and Stjernman, A. "Angular sampling, Test Signal, and Near Field Aspects for Over-the-Air Total Radiated Power Assessment in Anechoic Chambers". [Online]. Available: https://arxiv.org/abs/1803.10993.

[5] CTIA Test Plan for Wireless Device Over-the-Air Performance Ver. 3.7.1.

[6] ANSI C63.26-2015, American National Standard for Compliance Testing of Transmitters Used in Licensed Radio Services, American National Standards Institute (ANSI).

[7] FCC 16-89 – Page 8119, R&O NPRM, July 14, 2016.

[8] FCC Technical Report, TR 14-1001, TR 14-1001 MMW Measurements with Harmonic Mixers.

Change Notice

3/11/2020: 842590 D01 Upper Microwave Flexible Use Service v01 changed to 842590 D01 Upper Microwave Flexible Use Service v01r01 to reflect the following changes:

1- Corrected typographical and grammatical errors in the document
2- Added Downconverter in 2 a) 2) i
3- Removed digital storage oscilloscope (DSO) and 10 MHz low pass filter from list of required equipment in 3.4
4- Added the following note to 4.4.2.1 a) and 4.4.3.3.1 a): EIRP measurements are performed using linearly polarized antenna. Both horizontal and vertical polarizations are measured separately and not summed. The highest amplitude signal measured from horizontal or vertical polarization is used to demonstrate compliance to the unwanted emission limit.

4/20/2021: 842590 D01 Upper Microwave Flexible Use Service v01r01 changed to 842590 D01 Upper Microwave Flexible Use Service v01r02 to reflect the following changes:

1- Changed mmW (acronym for millimeter wave) to mm wave throughout the document
2- Clarified statement in 2 a) 2) iii) regarding accredited calibration of equipment operating at frequencies of investigation
3- Added clarifying statement in 4.2 to allow channel power integration method to be used when maximum resolution bandwidth of measurement equipment is less than the reference bandwidth.
4- Created three distinct scenarios in 4.2 that may be encountered while testing and measuring power spectral density of equipment under test (EUT)
5- Added rolling integration method to 4.2 c)

6- Added a note to 4.4.2.1 a) and 4.4.3.3.1 a) clarifying that EIRP measurements are performed using linearly polarized antenna. Both horizontal and vertical polarizations are measured separately and not summed. The highest amplitude signal measured from horizontal or vertical polarization is used for determining compliance to the unwanted emission limit
7- Added clarifying statements to step m in C.1 of Appendix C, Equal Sector Method
8- Corrected typographical errors throughout the document