Draft For Review

Federal Communications Commission
Office of Engineering and Technology
Laboratory Division

February 1, 2019

<u>Draft Laboratory Division Publications Report</u>

Title: Basic Certification Requirements and Measurement Procedures for Upper Microwave Flexible Use Service Devices

Short Title: Upper Microwave Flexible Use Service

Reason: Add guidance on the evaluation of millimeter wave (mmW) devices that are subject to Part 30 of the FCC rules.

Publication: 842590 D01 Upper Microwave Flexible Use Service v01

Keyword/Subject: Millimeter wave device measurement procedures

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Question:

What measurement procedures should be used for demonstrating compliance of millimeter wave devices?

Answer:

See attachment 842590 D01 Upper Microwave Flexible Use Service v01 for guidance on the evaluation of millimeter wave (mmW) devices that are subject to Part 30 of the FCC rules.

Clause 9 of ANSI C63.10-2013 provides general measurement procedures for performing compliance measurements on millimeter wave devices operating under Sections 15.253, 15.255, 15.257, and 90.103. Note that Sections 15.255 and 15.257 require that the fundamental emission be measured using an RF detector.

Supporting information:

Attachment 60 GHz Clarification Letter 30Oct2013 clarifies that Section 15.255(b)(1) should be read such that for products other than fixed field disturbance sensors, operating in this band and located outdoors, may comply with either Section 15.255(b)(1)(i) or Section 15.255(b)(1)(ii).

Attachment TR 14-1001 MMW Measurements with Harmonic Mixers, is a technical report that discusses test instrumentation considerations when making millimeter wave measurements.

NOTE 1: ANSI C63.10-2013 in 9.5 at Equation (23) should read:

EIRP = P_cond + G_EUT
rather than:
EIRP = P_cond - G_EUT.

NOTE 2: The KDB Publications 200443 D02, RF Detector Method v01 and Millimeter Wave Test Procedures will be expired after the final publication of this document.

Attachment List:

842590 D01 Upper Microwave Flexible Use Service v01
60_GHz_Clarification_Letter_30Oct2013
TR 14-1001 MMW Measurements with Harmonic Mixers

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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 (mmW) devices that operate under Part 30 of the FCC rules. Part 30 equipment authorization is available for the following type of devices[1]:

- 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.)[2]

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.
   - 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 mmW measurements):

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[1] Adding 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 to TCB Council during April 2014 workshop:
(https://transition.fcc.gov/bureaus/oet/ea/presentations/files/apr14/41-Equipment-Authorization-Admin-MN-GT-update.pdf) .

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

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

ii) Clearly identify correction factors and how they were derived for mmW 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) Include calibration certificates for harmonic mixers, standard gain horn antennas, signal generators, and frequency extension modules as an appendix to the test report.

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).[3] 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). 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) 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
- Reference level and Offset
- Detector function shall be identified on the plot or in the Plot Title.
- Product under test

b) *Equipment operating under Section 30.201*

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 Section 2.a)2) and submit to the Commission upon request.

[3] Until KDB Publications 974614 D01 and 641163 are updated, Microwave and Millimeter Bands Radio Services Test Firm Scope and TCB Scope B4 are acceptable for granting of Part 30 devices.

3. GENERAL GUIDANCE FOR MMW DEVICE EVALUATION

A. General

Part 30 establishes specific requirements and sets 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) respectively. Section 3.B defines TRP for referencing throughout this document.

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*, as an acceptable measurement procedure.[4] 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.[5]

B. Definitions

Beam: Single peak intended emission pointing at a single user/station or single point in space.

Multiple beams: Multiple peaks where individual peak intended emissions could be pointing to multiple users/stations or points in space.

NOTE The preceding definitions do not consider beamforming, beam-steering, or beam scanning.

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, per 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:

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

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[4] 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.

[5] The guidance contained in this document is based on the test procedures developed by the ASC C63® C63.26 working group and are provided on an interim basis while the procedures are being finalized.

In the preceding expressions, f_n represents the frequency of each unwanted emission, (n = 1, 2, …, 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.

C. Basic Considerations

A radiated measurement method to demonstrate compliance has been selected in consideration of test equipment availability, and that many millimeter-wave 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 operating at or below the specified limits 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 signal and its image frequency, 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 but generally not applicable to fundamental downconverters.[6] 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. Most standard gain antennas, that operate at frequency ranges higher than the fundamental emissions act as high pass filters. Therefore, while measuring the harmonics, the fundamental emissions in the mmW range 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 compliance measurements shall not include averaging over periods when the transmitter is quiescent or when operating at reduced power levels (i.e., no duty cycle or duty factor reduction is permitted).

D. Equipment Required

a) Spectrum analyzer

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

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

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 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

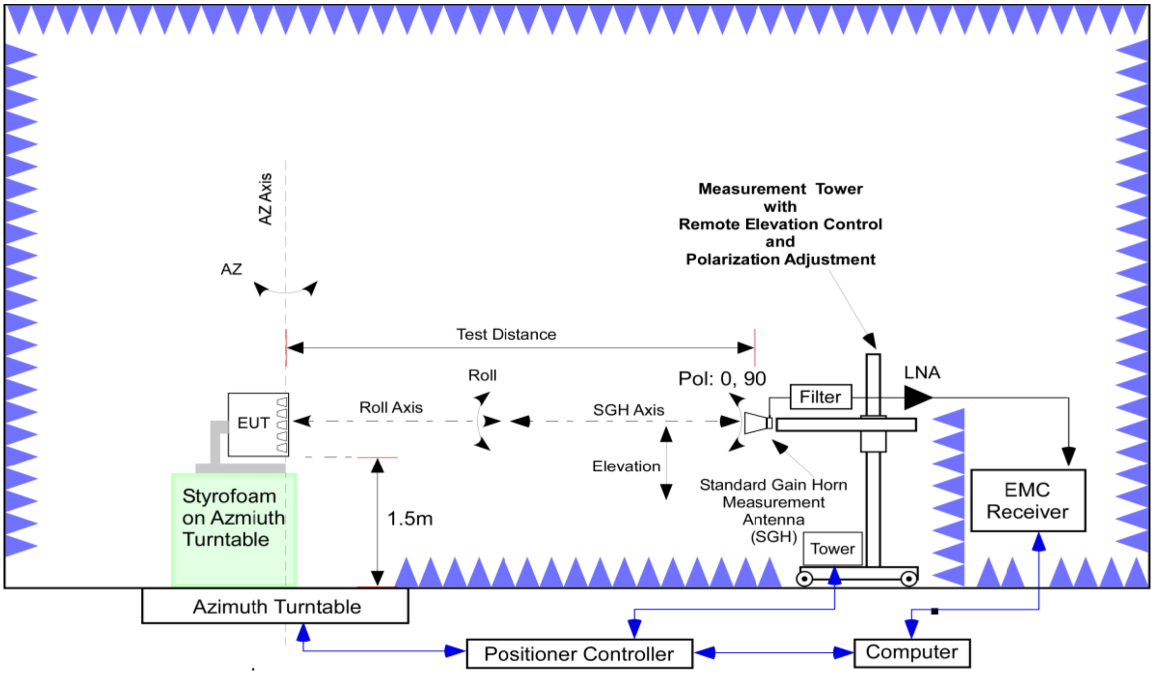
q) Millimeter-wave source

r) Variable waveguide attenuator if required

s) Millimeter-wave power sensor

E. 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 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 two or three orthogonal cuts shall be measured by manual rotations of the EUT and using the Azimuth turntable for the angular sweeps.

Figure 1 – Shielded anechoic chamber and positioner setup

F. Measurement Antenna Calibration

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.

G. 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[7]. 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 exercising the maximum number

[7] 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.

of antenna elements.

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 beam width, 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.

H. 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 mm-wave 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 or out-of-band emissions the largest distance of either the EUT antenna or measurement antenna shall be used. For spurious emissions the distance will be based on the measurement antenna.

I. 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.

4. SPECIFIC MMW DEVICE COMPLIANCE MEASUREMENT PROCEDURES

Compliance measurement procedures pertaining to Radiated RF output power, occupied bandwidth, unwanted radiated emissions, and frequency tolerance measurements are provided in 4.A through 4.D of this document.

A. 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 spectral density measurements of Part 30 devices. Fundamental emission must be maximized as described in Appendix G when a radiated method of measurement is selected. Note that a reference bandwidth of 100 MHz is chosen for all power spectral density measurements.

B. Occupied Bandwidth Measurements

Subclause 5.4 of ANSI C63.26-2015 is applicable to occupied bandwidth measurements of Part 30 devices. [8]

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[8] 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.

C. Unwanted Emission Measurements

1. General

Sections C.2 through C.3.3.4 describe unwanted emission measurement procedures. Sections C.2 and C.3 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 limit the early exit condition is met and the device is deemed compliant since it is assumed that maximum EIRP levels are higher than total conductive (or total radiated) power levels. If the device does not meet the emission limit at one or some frequencies, then TRP measurements shall be performed only at the failing frequencies.

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

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).

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

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 C.2.2 through C.2.4.

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. The measurement difficulties could be reduced by testing under non-steering (stationary) conditions.

a) Align the cardinal planes with the xy-plane and the xz-plane of the antenna measurement coordinate system. Make sure that the cross-over point of the cardinal cuts is pointing 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).

d) For the highest frequency (smallest wave length) 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.

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.

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 C.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.

2.4 Spherical Grid Method

a) Measure the antenna dimensions, i.e., depth (d), width (w), and height (h), see Figure A.1 of 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 wave length) 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 Annex 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 Annex B.

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

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 available in given polarity as a function of frequency over the out- of- band emissions/ measurement range that covers both band/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 measurement shall be made in the far-field.

Calculate antenna port conducted power level using following equations:

- Conduct Power level (dBm) at any frequency/BW = Measured EIRP level (dBm) – EUT antenna Gain (dBi)

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

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

a) EUT Radiating a Single Beam on 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) If EUT employs multiple cross-polarized transmissions, then sum the power spectral densities across polarizations to calculate total PSD.

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

b) EUT radiating multiple beams on 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, evaluation on only one beam is sufficient. Total power on each of the OOB frequency can be calculated using 10 log(number of beams)

   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 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 TRP limit.

3. Measurement Procedures for Emissions in Spurious Domain

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 this section.

3.2 Initial Exploratory Scan Procedure

Set the EUT in a test configuration mode as per 3.G 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 and analysis of the EIRP and/or TRP shall be performed using the measurement procedures specified in C.3.3 and C.3.4, respectively.

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

3.3 TRP Based Measurement Procedure

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).

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

c) If the maximum EIRP is less than TRP limit then the 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 C.3.3.2 through C.3.3.4

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 For harmonics and spurious emission frequencies which are beamforming 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.

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

d) For the highest frequency (smallest wave length) 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 The 2 dB correction factor for two cut and 1.5 dB correction factor for three cuts is derived from [4].

3.3.3 Equal Sector Method

If the calculated EIRP level on the highest peak of the radiation pattern meets the TRP limits, the EUT deemed met the TRP requirements on that frequency. 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. The number of measurement segment needed for making measurements around the EUT is based on the size of the EUT measurement antenna beamwidth and measurement distance. Based on the ANSI C63.5 approved measurement antennas for measurements up to 40 GHz and the commercially available standard gain antennas, 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). If TRP measurement method is not possible to use, equal sector cuts based TRP method should be used considering additional measurement segments. Alternatively, longer test distances may be used for large size EUTs provided analyzer has sufficient signal to noise ratio.

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

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 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 60cm, then EIRP measurements shall be made in each half quadrant 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 measure for each quadrant 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) Power levels measured each of the segment may be considered for meeting the TRP limits. If strongest measured beam did not meet the TRP limit, measured other segment power levels in descending order may be used. Noise levels and signals 10 dB below the strongest EIRP measured shall not be used in averaging. 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.

3.3.4 Spherical Grid Method

The procedure to determine the step size for constant step spherical grid type is described in detail in C.2.4.

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

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

c) For the highest frequency (smallest wave length) 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 Annex A.

d) Set the grid spatial sampling step $\Delta\theta$ref$\leq\Delta\theta\leq$15 degrees for the vertical angle and $\Delta\phi$ref$\leq\Delta\phi\leq$15 degrees 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 the spherical grid.

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

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.

D. Frequency Tolerance Measurements

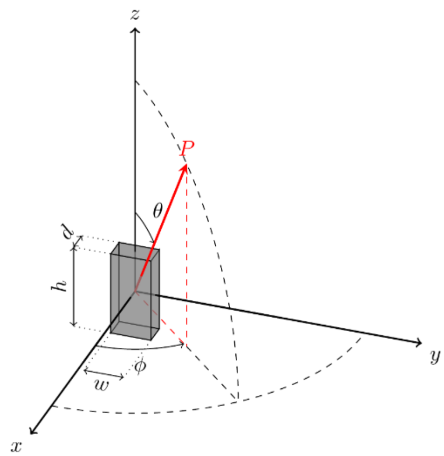
Subclause 5.6 of ANSI C63.26-2015 is applicable.

APPENDIX A

COORDINATES AND SAMPLING GRID

This section 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

$$\boldsymbol{D} = \sqrt{\boldsymbol{d}^2 + \boldsymbol{w}^2 + \boldsymbol{h}^2} \tag{A.1}$$

$$\boldsymbol{D}_{\mathrm{cyl}} = \sqrt{\boldsymbol{d}^2 + \boldsymbol{w}^2} \tag{A.2}$$

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

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

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

$\Delta\theta_{\mathrm{ref}}$ and $\Delta\phi_{\mathrm{ref}}$ 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

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

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.

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**
$D = 15.7$	$D_{\mathrm{cyl}} = 7.1$	$D = 15.7$	$D_{\mathrm{cyl}} = 7.1$
$D/\lambda = 9.2$	$D_{\mathrm{cyl}}/\lambda = 4.1$	$D/\lambda = 47$	$D_{\mathrm{cyl}}/\lambda = 21.5$
$\Delta\theta_{\mathrm{ref}} = 6.3^{\circ}$	$\Delta\phi_{\mathrm{ref}} = 13.8^{\circ}$	$\Delta\theta_{\mathrm{ref}} = 1.2^{\circ}$	$\Delta\phi_{\mathrm{ref}} = 2.6^{\circ}$
$\Delta\theta = 6^{\circ}$	$\Delta\phi = 12^{\circ}$	$\Delta\theta = 6^{\circ}$	$\Delta\phi = 12^{\circ}$
$\Delta\theta\ max = 15^{\circ}$	$\Delta\phi\ max = 15^{\circ}$	$\Delta\theta\ max = 15^{\circ}$	$\Delta\phi\ max = 15^{\circ}$
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	
$\Delta\mathrm{TRP} = \frac{\mathrm{SF}-1}{\mathrm{SFmax}-1} = 0\mathrm{dB}$		$\Delta\mathrm{TRP} = \frac{\mathrm{SF}-1}{\mathrm{SFmax}-1} = 0.36\mathrm{dB}$	
Note: Choosing max sampling grid step size ($\Delta\theta = \Delta\theta\_\mathrm{max} = 15\ deg$ & $\Delta\phi = \Delta\phi\_\mathrm{max} = 15\ deg$), means SF = SFmax, which results in TRP correction of 1dB (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

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

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.

In cases when an OEM chooses the full sphere sampling grid step to be a value larger than the reference steps, then an OEM needs to provide thorough technical theoretical analysis or empirical data to support their choice and 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.

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:

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

Where $\mathrm{EIRP}^{(\boldsymbol{n})} = \mathrm{EIRP}_{\mathbf{0}}^{(\boldsymbol{n})} + \mathrm{EIRP}_{\mathbf{90}}^{(\boldsymbol{n})}$ 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

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

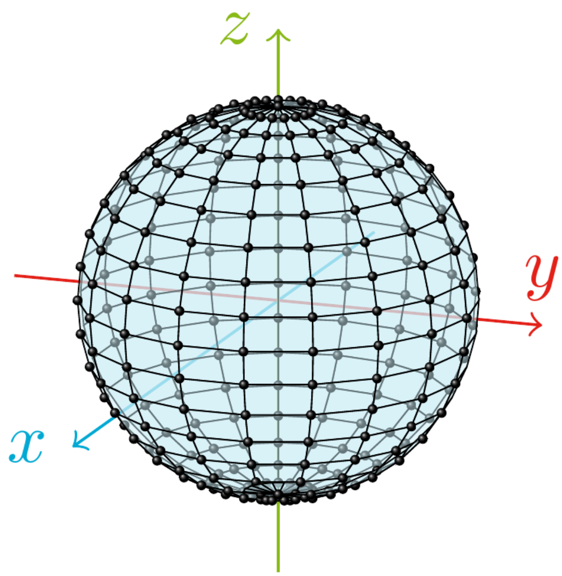
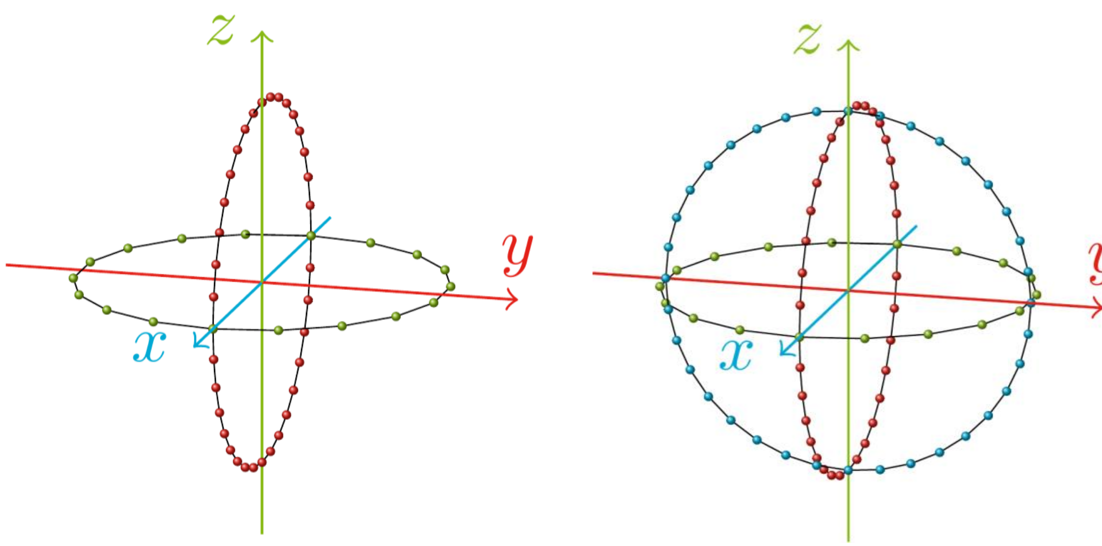


Figure B.1 – Full sphere grid using fixed steps in θ and ϕ and a weighting factor $|sin\theta|$ in the TRP calculation to compensate for denser sampling near the z-axis



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.G (a), (b) and (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 half quadrant (22.5°). For each half quadrant, the antenna shall be height scanned from 1 m to 4 m. List at least six strongest radiating frequencies for each test antenna polarities. The list shall also include half quadrant number and height at which maximum amplitude was measured.

n) Emission levels 20 dB below the limit need not be included in this list and analyzer noise levels shall not be considered.

o) mmW standard gain antennas approximately have 20 dBi to 24 dBi gain and the 3 dB beam width will cover approximately 60 cm (24") wide EUT located at 3 m distance. While measuring mmW frequencies the 3 dB beam width 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 lower than half quadrant turn-table rotation.

p) For frequencies below 18 GHz, it is sufficient to measure at each quadrant of the turn table.

q) 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 turn table 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 bore-sighted 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:

$$E = 126.8 - 20\log(\lambda) + P - G \quad (1)$$

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:

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

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:

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

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

$$EIRP = 21.98 - 20\log(\lambda) + 20\log(d_{Meas}) + P - G \quad (4)$$

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

$$EIRP = P_{Cond} + G_{EUT} \tag{5}$$

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

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

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:

$$PD = \frac{EIRP_{Linear}}{\left(4\pi d^2\right)} \tag{7}$$

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:

$$PD = \frac{E^2_{SpecLimit}}{377} \tag{8}$$

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:

$$TRP = \frac{EIRP_{Linear}}{D_{EUT}} \tag{9}$$

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.

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

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

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

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

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

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

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

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.G.

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.

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[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.

Federal Communications Commission
Washington, D.C. 20554

October 30, 2013

Mr. Michael J. Hart
Alpental Technologies, Inc.
10203 NE 156th Pl.,
Bothell, WA 98011

Dear Mr. Hart:

This is in response to your letter of September 10, 2013 in which you request a clarification of the rule in Section 15.255 that was adopted by the Commission in ET Docket No. 07-113 on August 9, 2013 for unlicensed devices operating in the 57-64 GHz (60 GHz) frequency band. You specifically request that we clarify that Section 15.255(b)(1) should be read such that products other than fixed field disturbance sensors, operating in this band and located outdoors, may choose to comply with either Section 15.255(b)(1)(i) or Section 15.255(b)(1)(ii).

Section 15.255(b), adopted on August 9, 2013 in the above proceeding, states in relevant part:

> (b) Within the 57-64 GHz band, emission levels shall not exceed the following equivalent isotropically radiated power (EIRP):
>
> "(1) Products other than fixed field disturbance sensors shall comply with one of the following emission limits, as measured during the transmit interval:
>
> (i) Except as indicated in paragraph (ii) below, the average power of any emission shall not exceed 40 dBm and the peak power of any emission shall not exceed 43 dBm.
>
> (ii) For transmitters located outdoors, the average power of any emission shall not exceed 82 dBm minus 2 dB for every dB that the antenna gain is less than 51 dBi. The peak power of any emission shall not exceed 85 dBm minus 2 dB for every dB that the antenna gain is less than 51 dBi..."

Your letter states that this rule language could be misinterpreted in a particular scenario when a device that can operate both indoors and outdoors uses a low-gain antenna (*e.g.* 20 dBi) and that this incorrect interpretation would result in a significant EIRP penalty when a device is located outdoors relative to that allowed under the original rules for Part 15.255(b).

We first note that your interpretation of the text of the rules is consistent with the plain language of the rule, as it states in the introductory text of subsection (b)(1), as reproduced above, "products other than...shall comply with <u>one</u> of the following..." options, *i.e.*, either subparagraph(i) or (ii). Therefore, an outdoor 60-GHz device with a low-gain antenna could choose to meet the emission limit in either subparagraph, whichever is higher, as long as other conditions are met. In this example, the device would be acceptable if it meets the 40 dBm EIRP (average)/43 dBm EIRP (peak) limit in subparagraph (i). There is nothing in the rule to suggest that subparagraph (ii) should be read out of the full context of its relationship to the rest of subsection (b).

Moreover, the Commission's intention in adopting the rule is clear. The Commission adopted the *Notice of Proposed Rulemaking* (*NPRM*) in this proceeding in response to a petition from the Wireless Communications Association (WCA). To encourage broader deployment of point-to-point digital systems in the 60 GHz band without increasing the potential for harmful interference, the Commission proposed, *inter alia*, to increase the emission limit from the existing 40 dBm EIRP to 82 dBm EIRP for 60-GHz devices using an antenna with gain greater than 51 dBi. The *Report and Order* (*Order*) in this proceeding adopted this proposal and specifically stated in paragraph 8 "for 60-GHz devices located outdoors, we *increase* the average equivalent isotropically radiated power (EIRP) limit *from* 40 dBm to 82 dBm minus 2 dB for every dB that the antenna gain is below 51 dBi, and peak EIRP emission limit *from* 43 dBm to 85 dBm minus 2 dB for every dB that the antenna gain is below 51 dBi [emphasis added]." Elsewhere in paragraph 24, the *Order* also confirms that "consistent with our proposals in the *NPRM*, we are modifying the rules to adopt an average EIRP limit of 82 dBm and a peak EIRP limit of 85 dBm, in each case minus 2 dB for every dB that the antenna gain is below 51 dBi, for 60-GHz devices using very high gain antennas that are located outdoors," and emphasizes that "this *increase* in emission limits for antennas located outdoors will facilitate the use of longer range 60-GHz devices in wireless applications [emphasis added]."

Throughout this proceeding, and supported by the record, the Commission's intent has been to allow higher average and peak power of 60-GHz devices operating outdoors in order to encourage broader deployment of point-to-point digital systems in the 60 GHz band, not to lower the existing emission limit applicable to both indoor and outdoor 60-GHz devices (*i.e.*, 40 dBm EIRP (average)/43 dBm EIRP (peak)) that it adopted in 1995. Further, the Commission spoke at length on the necessity of higher power for 60-GHz outdoor devices due to the oxygen and water vapor absorption and scattering phenomena that occur at 60 GHz. *Order* at paragraphs 25 and 40. It is therefore clear that the rules in Section 15.255(b)(1) provide 2 options for outdoor 60-GHz devices to comply with the EIRP power limits stated therein. The first option, provided in subparagraph (i), specifies an emission limit of 40 dBm EIRP (average)/43 dBm EIRP (peak); it can be used for both outdoor and indoor 60-GHz devices. The second option, provided in subparagraph (ii), applies specifically to outdoor devices with very high-gain antennas that would exceed the emission limit in subparagraph (i); these devices may comply with the higher limit provided in subparagraph (ii), but must reduce their power from the maximum 82 dBm EIRP (average)/85 dBm EIRP (peak) by 2 dB for each dB that the antenna gain exceeds 51 dBi.

I trust that the above is responsive to your inquiry. Please let me know if I can be of further assistance.

Sincerely,

Julius P. Knapp

Julius P. Knapp
Chief,
Office of Engineering and Technology

Alpental Technologies
10203 NE 156th Pl, Bothell, WA, 98011

September 10, 2013

VIA: ECFS
Electronic Mail

Mr. Julius P. Knapp
Chief
Office of Engineering & Technology
Federal Communications Commission
445 12th Street SW
Washington, DC 20554

RE: Revision of Part 15 of the Commission's Rules Regarding Operation in the 57-64GHz Band, ET Docket No. 07-113

Dear Mr. Knapp,

Alpental Technologies has been following the Petition and NPRM related to the above referenced proceeding that led to the recent Report and Order. We are developing next generation, low-cost, multi-gigabit per second 60GHz communications solutions that we believe will enable service providers, enterprises and consumers to fully benefit from the very positive regulatory environment that the FCC has put in place for this band. We were very pleased to see the FCC was proposing to further evolve the rules in the NPRM to foster on-going investment in technologies related to this band.

We believe that the slight changes to the rule language introduced in the Report & Order relative to that in the NPRM for Part 15.255(b)(1) regarding allowed EIRP, could make it possible for the new rule to be misinterpreted. The particular scenario under which this could occur is for a device that can operate both indoors and outdoors, using a lower gain antenna (e.g. 20dBi).

Our understanding, given the spirit of the Petition and NPRM, and all the documents on the record, is that Part 15.255(b)(1) should be read such that products other than fixed field disturbance sensors, operating in this band and located outdoors may chose to comply with either Part 15.255(b)(1)(i) or Part 15.255(b)(1)(ii). It is our understanding that this is what is intended by the highlighted language in the following excerpt of the new rule for Part 15.255(b)(1):

"(1) Products other than fixed field disturbance sensors shall comply **with one of the following** emission limits,..."

On the contrary, it should not be interpreted that Part 15.255(b)(1)(ii) shall always apply for a device when it is located outdoors, as could be wrongly interpreted due to the "Except as indicated in paragraph (ii), …" language at the start of Part 15.255(b)(1)(i). This incorrect interpretation would result in a significant EIRP penalty for a device with a lower gain antenna (e.g. 20dBi) when the device was located outdoors relative to that allowed under the original rules for Part 15.255(b).

We have discussed this issue with others in the industry and have found other companies have similarly reached the conclusion that the possibility for misinterpretation exists, particularly if the rules are not read in the context of the proceeding. Given this, we would be very grateful if you could confirm our interpretation of the rules is correct – specifically please clarify that a device when located outdoors can chose to comply with either Part 15.255(b)(1)(i) or Part 15.255(b)(1)(ii).

If you have any questions regarding this request, please do not hesitate to contact me.

Sincerely,

/s/ Michael J. Hart

Michael J. Hart
CTO
Alpental Technologies, Inc

cc (via electronic mail): Mark Settle
Tom Peters

Report: TR 14-1001

MILLIMETER WAVE MEASUREMENTS WITH EXTERNAL HARMONIC MIXERS

April 4, 2014

Prepared by:

Thomas W. Phillips

Technical Research Branch
Laboratory Division
Office of Engineering and Technology
Federal Communications Commission

MILLIMETER WAVE MEASUREMENTS
WITH EXTERNAL HARMONIC MIXERS

I. INTRODUCTION

In order to observe the spectrum of a signal at frequencies above the maximum frequency capability of a spectrum analyzer, an external harmonic mixer may be used with a spectrum analyzer configured to display the spectrum of the signal with a compatible mixer. Usually this is accomplished in the external mixer by using a harmonic of the L.O. output from the spectrum analyzer to produce an output signal at the IF frequency of the spectrum analyzer which processes the IF signal and displays the spectrum of the mixer input signal at the actual frequencies and amplitudes of the input signal.

There are two major drawbacks to the use of an external harmonic mixer: high conversion loss and the production of image and other unwanted signals. The mixer input signal is displayed by the spectrum analyzer at the actual amplitude by correcting for the conversion loss. But using a correction factor does not change the signal to noise ratio. Also many unwanted signals, including image signals, appear on the display. This can make it difficult to recognize and make measurements of the desired signal spectrum. The conversion loss of a typical external mixer can be of the order of 30 to 40 dB in the V and W millimeter wave bands and increases at higher frequencies. This requires that the amplitude of the mixer input signal be high enough to overcome the conversion loss and produce a spectral display on the analyzer which permits making the desired measurements. There are several ways of dealing with unwanted signals in the display. Typically an analyzer configured to work with an external harmonic mixer has two built-in functions: image shift and image suppression. The image shift function permits the identification of the desired signal in the presence of the image signal. When selected, image shift causes the desired signal and the image signal to alternately appear on the display with the image signal shifting in horizontal position while the desired signal remains fixed. Image suppression eliminates the image and displays only the desired signal. However, when implementing either of these functions, some other functions of the analyzer may be disabled and measurements may not be accurate. Another way to deal with unwanted signals is the use of a preselected external harmonic mixer at the cost of higher conversion loss.

II. PULSED SIGNALS

Figure 1 shows the spectrum of a pulsed signal produced by a 100 nsec pulse at a PRF of 1 MHz using an external harmonic mixer. The image appears at twice the analyzer's IF frequency of 321.4 MHz. By using an image suppression function, the desired signal can also be viewed as shown in Figure 2. Since the bandwidth of the desired signal is significantly less than the IF bandwidth, it is not difficult to identify and perform measurements on the desired signal.

However, when the signal bandwidth approaches twice the IF frequency, the desired signal and image spectrums begin to overlap as shown in Figure 3 for a 10 nsec pulse, which has a wider bandwidth. Figure 4 shows the spectrum of the same signal with the image suppressed. Figure 5 shows the desired signal spectrum superimposed on the spectrum with no image suppression. Figure 6 shows a computer simulated harmonic mixer spectrum of a 1 nsec pulse. Since the bandwidth of the main lobe of the sinx/x spectrum of a 1 nsec wide pulse is 2 GHz, which is more than twice the IF frequency, there is significant overlap of the image and the desired signal spectrum. The figure shows the desired and the image spectrum and the sum of the two. Only the sum actually appears on the spectrum analyzer display so measurements of the desired signal cannot be made without the use of image suppression.

III. WIDEBAND SIGNALS

Figure 7 shows the spectrum produced by a harmonic mixer with an approximately 1.7 GHz wide signal. Since this is nearly three times twice the IF frequency, there is significant overlap of the desired and the image spectrum which makes it difficult to make accurate measurements. Figure 8 shows the spectrum obtained of the desired signal by use of the image suppression function and Figure 9 shows this spectrum superimposed on the signal with the image unsuppressed.

One way of eliminating the problem of images is the use of a preselected harmonic mixer. Figure 10 shows the spectrums produced by a preselected and an unpreselected mixer with the same CW signal input. The preselected spectrum has been shifted slightly to permit better display of the two plots. Although the amplitude of the desired signal at 60 GHz is nominally the same, the noise level with the preselected mixer is greater than with the unpreselected mixer because of the higher conversion loss. Figure 11 shows the results of measuring the same signal at a lower amplitude with the two different types of mixers. The signal is detectable with the unpreselected mixer but is below the noise level with the preselected mixer. Figure 12 shows the difference when using a preselected and an unpreselected mixer with image suppression with a wideband signal. The spectrum of the desired signal between 59.5 and 61.5 GHz is essentially the same but there are unwanted out-of-band emissions appearing in the unpreselected spectrum which do not appear when using the preselected mixer. However, as previously shown, the signal to noise ratio for the preselected mixer is less. The problems of high conversion loss and images and other unwanted signals can be reduced by the use of a downconverter instead of a harmonic mixer. A downconverter translates the signal to a lower frequency which can be applied to the RF input of the spectrum analyzer within its frequency range capability. Figure 13 is a block diagram of a downconverter assembled from components to downconvert a signal with up to a 4 GHz bandwidth in the 75 to 85 GHz band to 10 GHz for measurement with a spectrum analyzer.

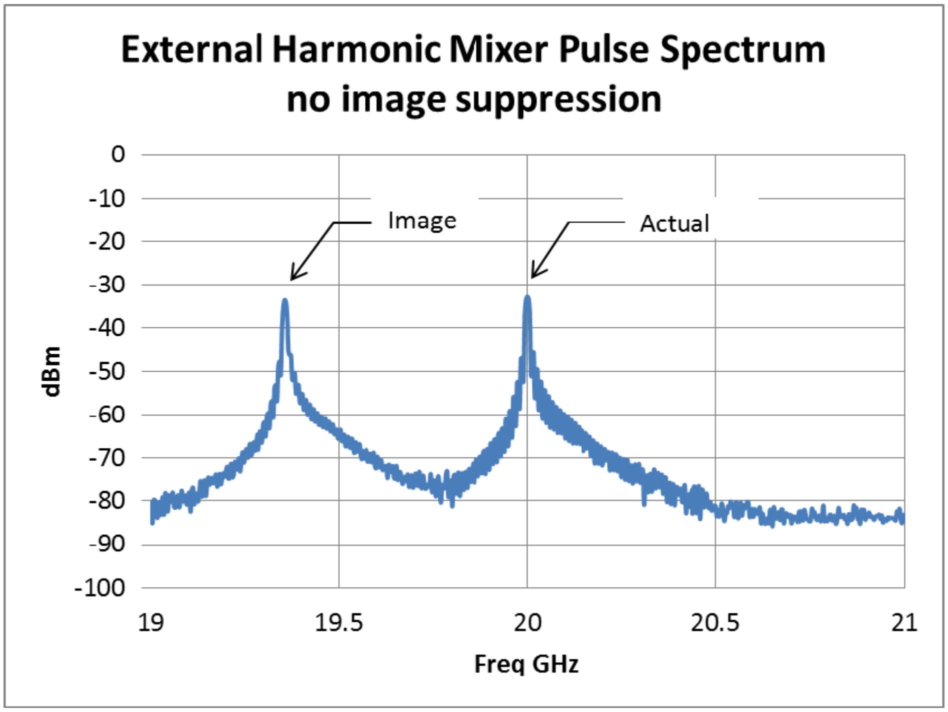

Figure 1

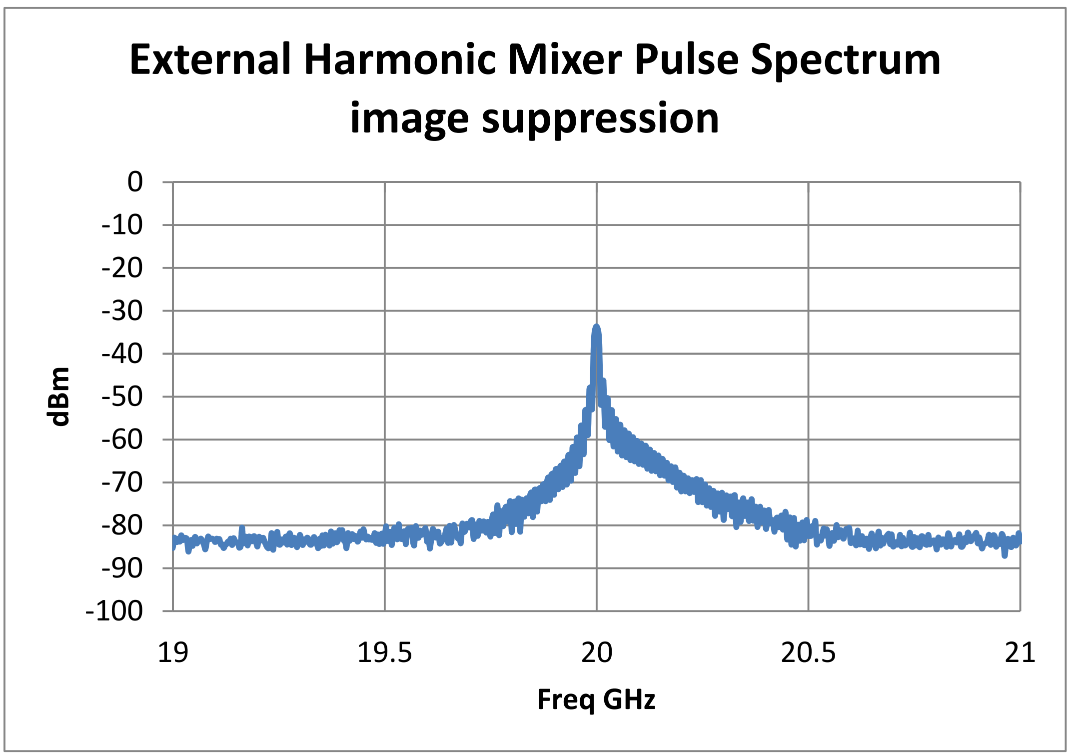

Figure 2

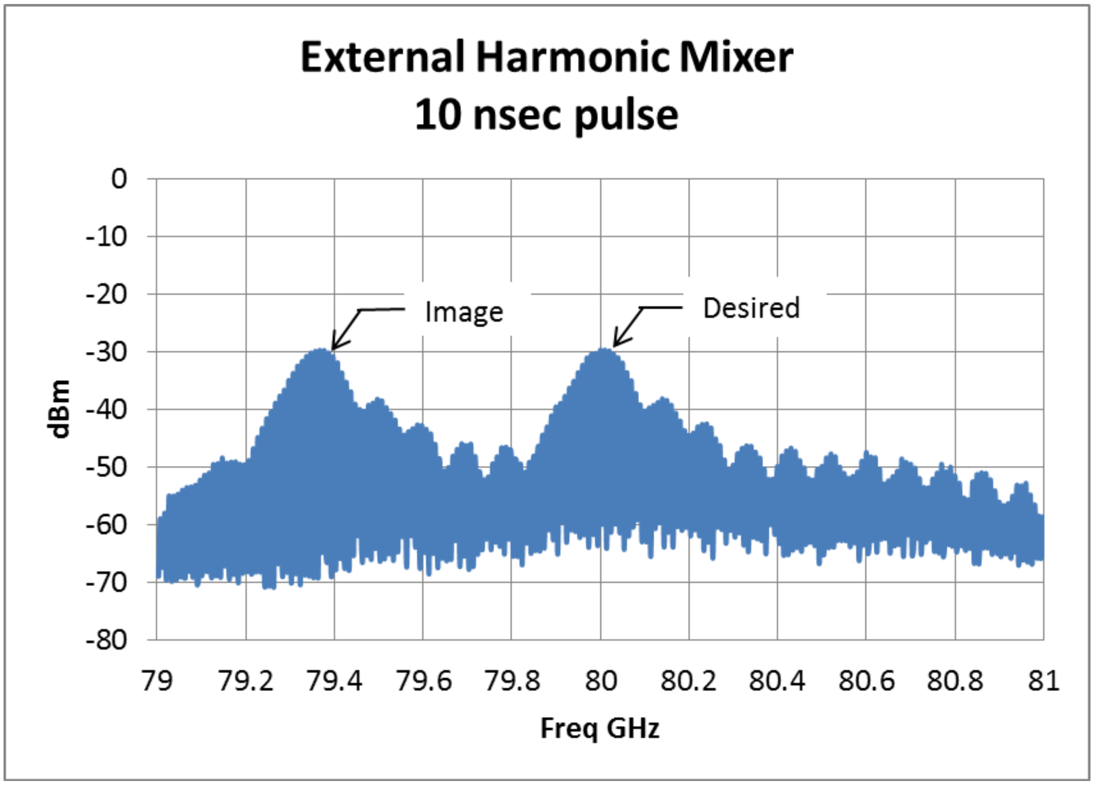

Figure 3

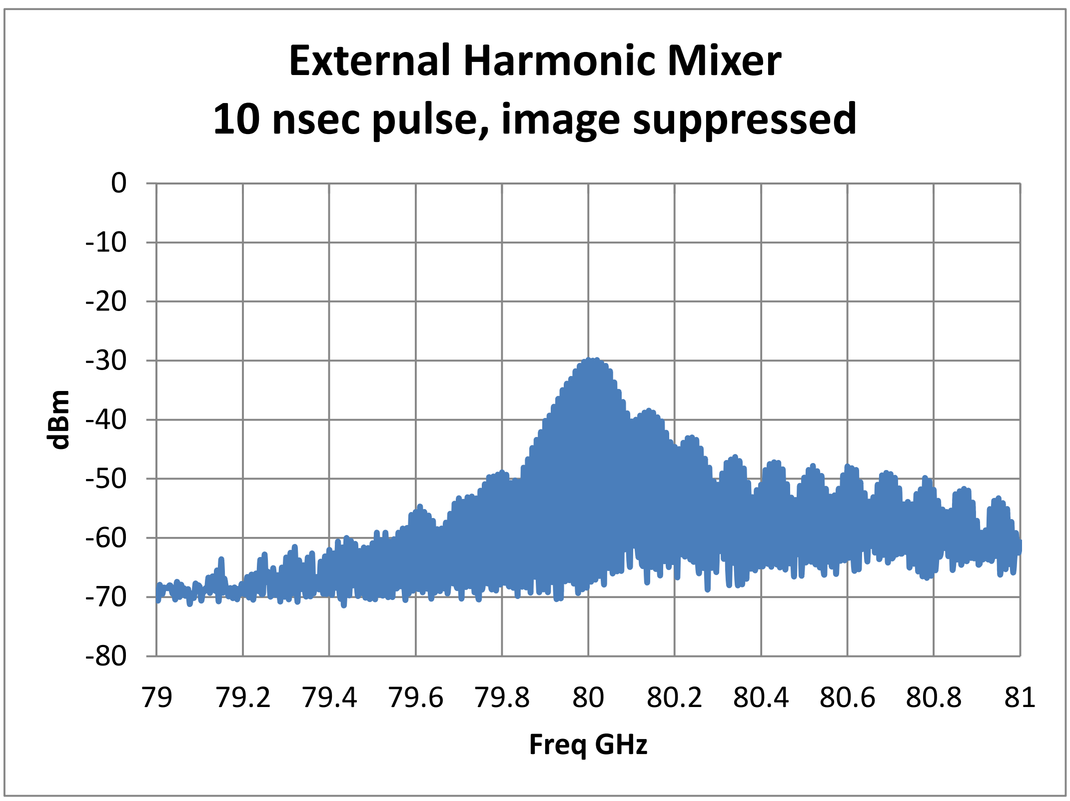

Figure 4

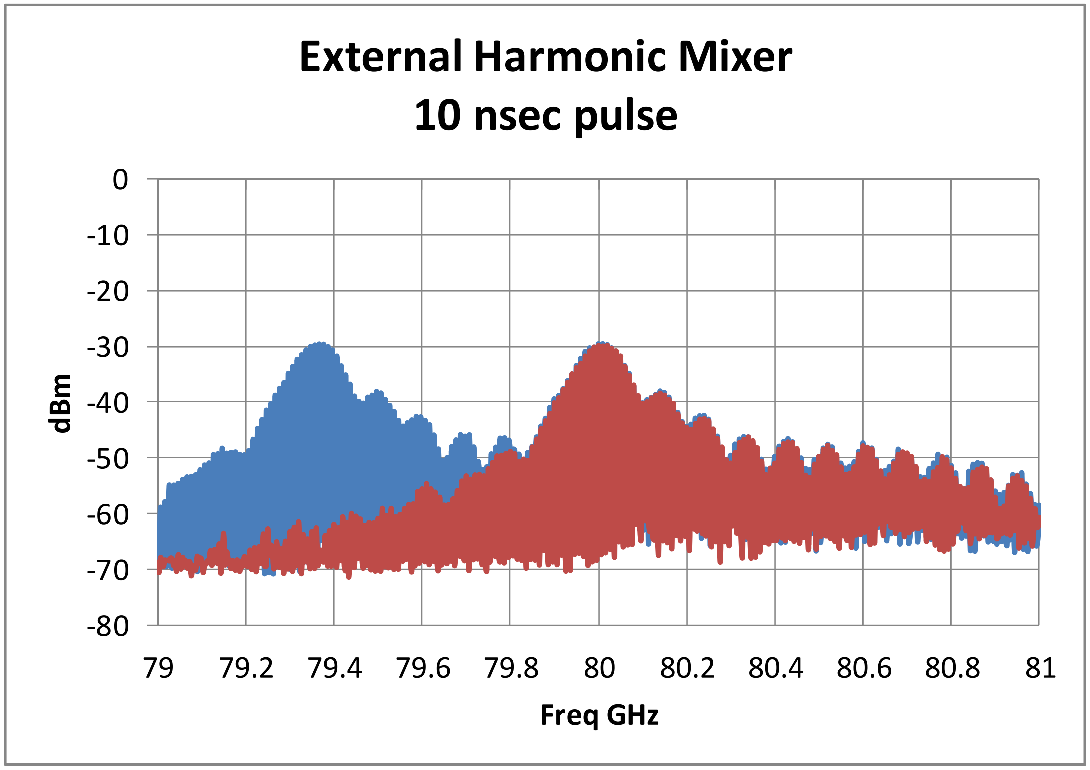

Figure 5

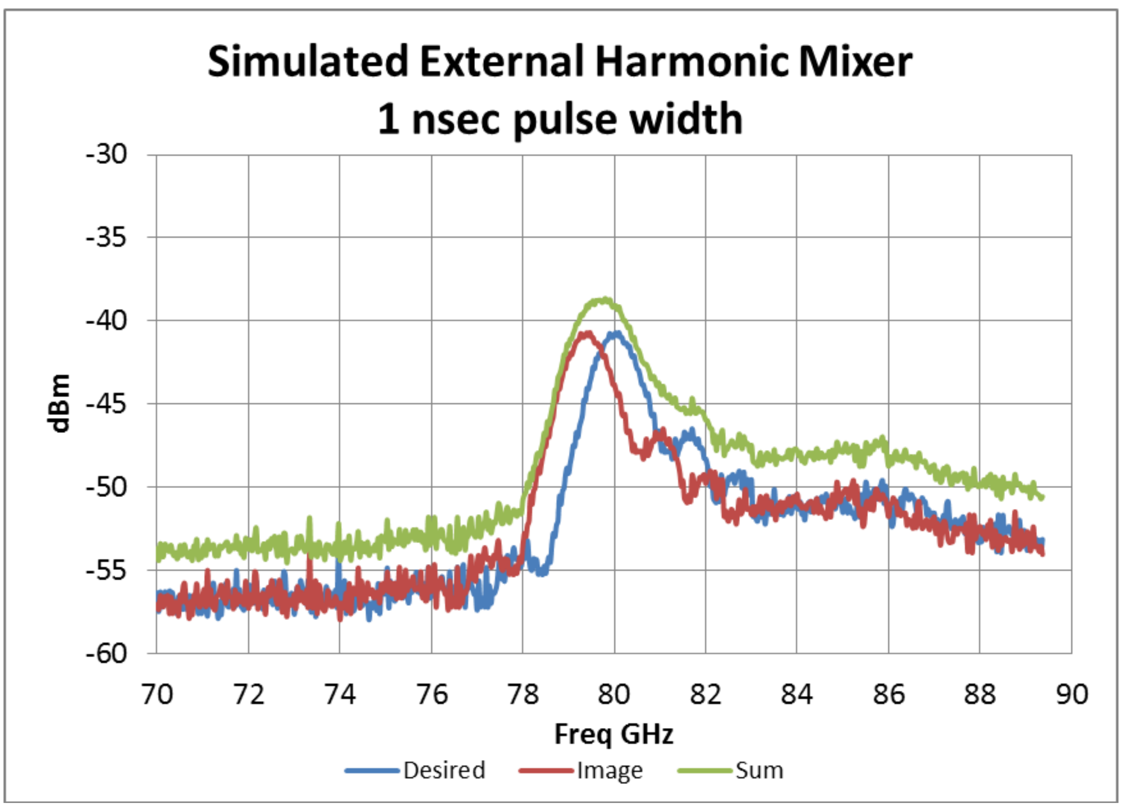

Figure 6

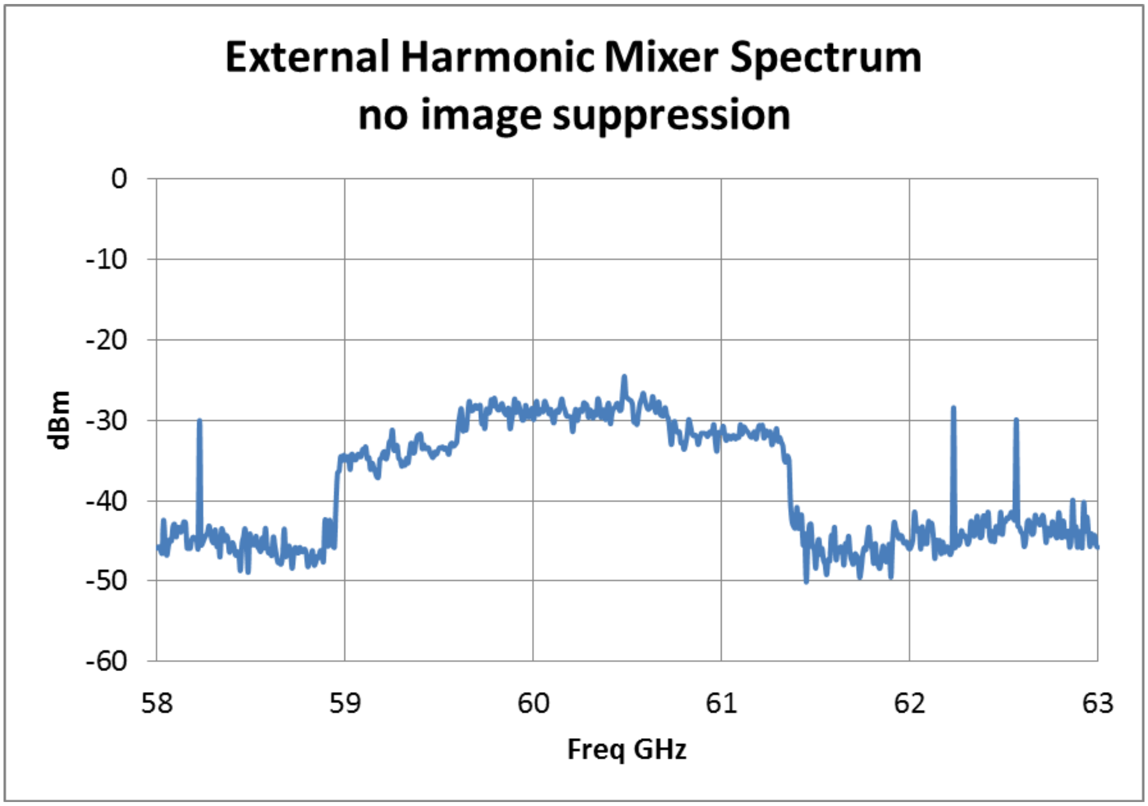

Figure 7

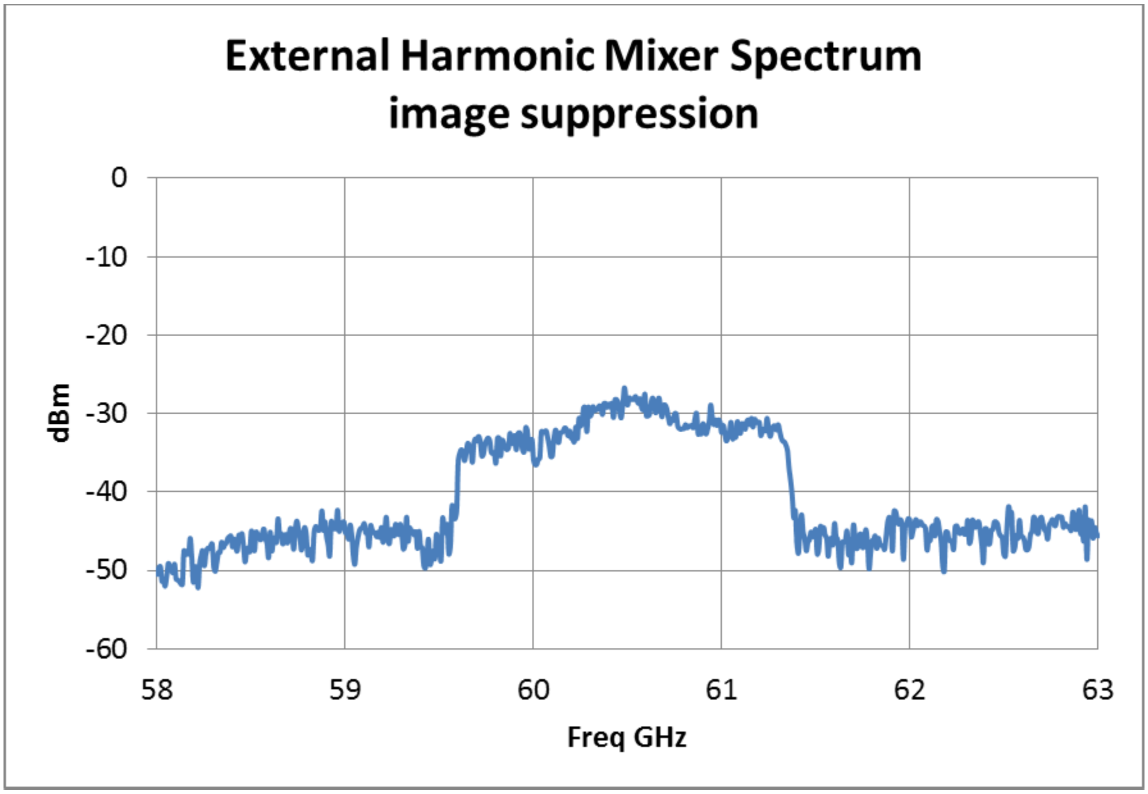

Figure 8

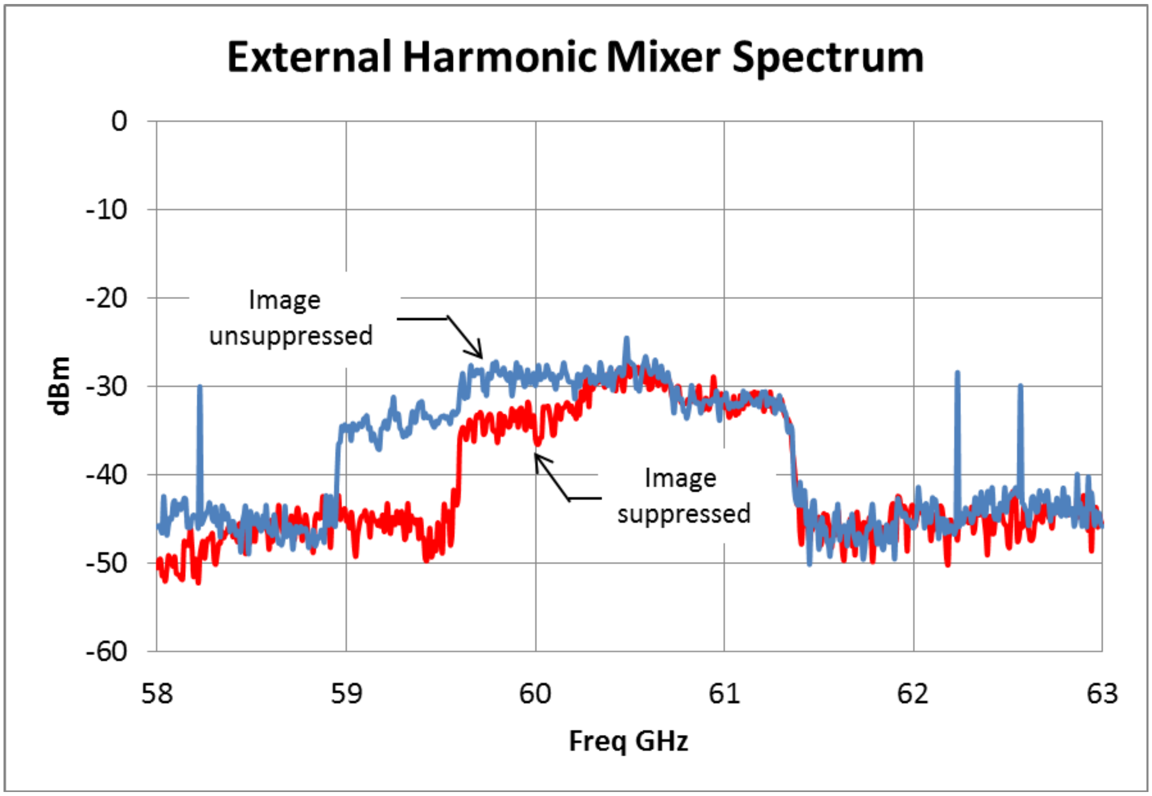

Figure 9

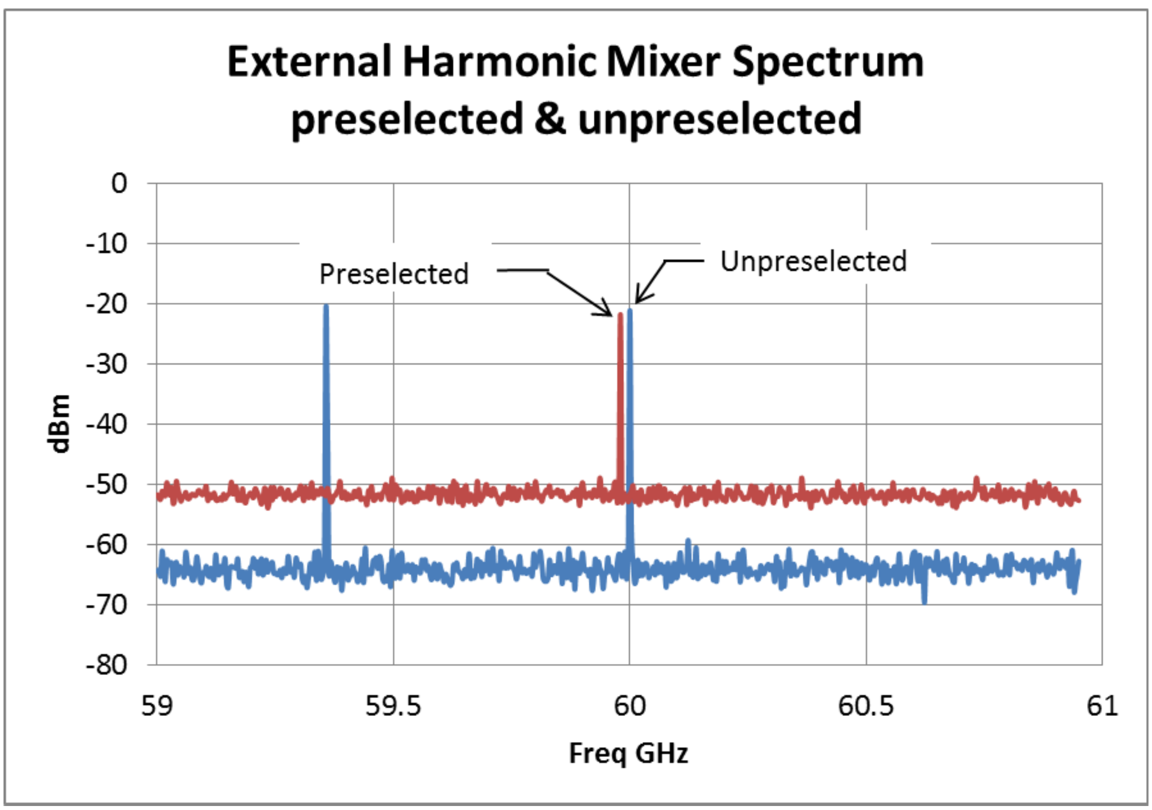

Figure 10

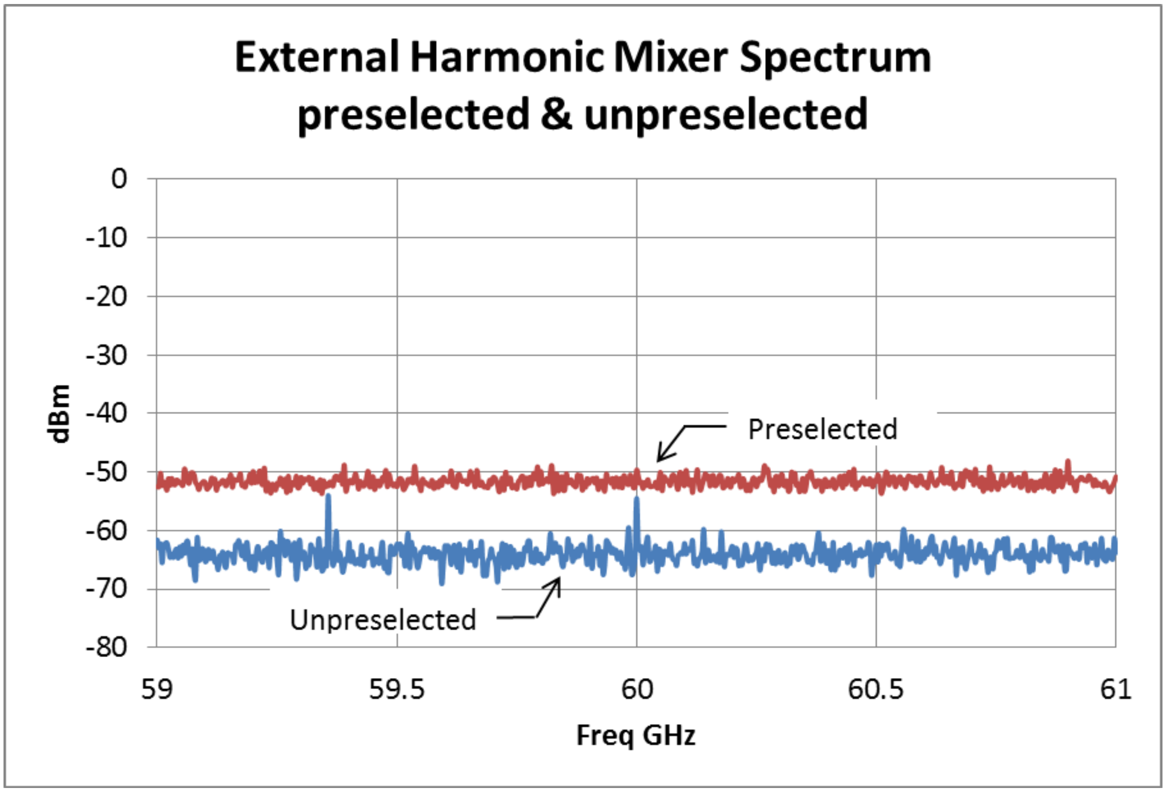

Figure 11

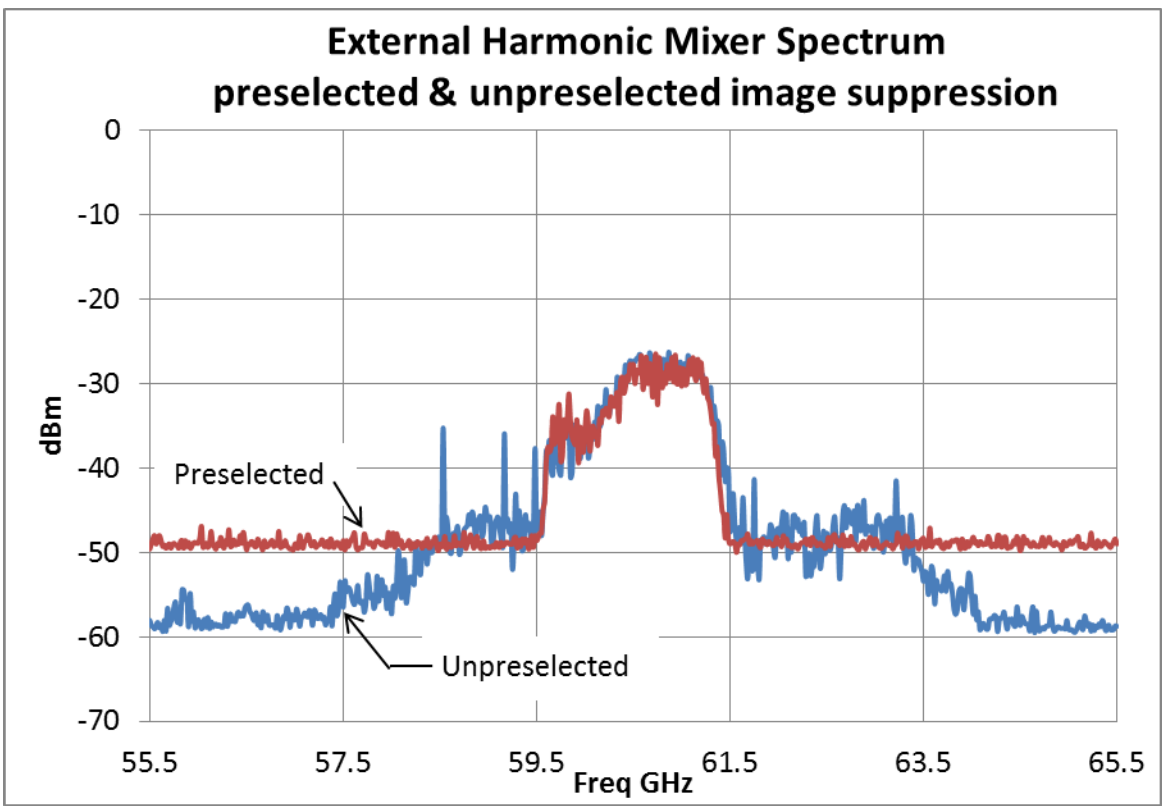

Figure 12

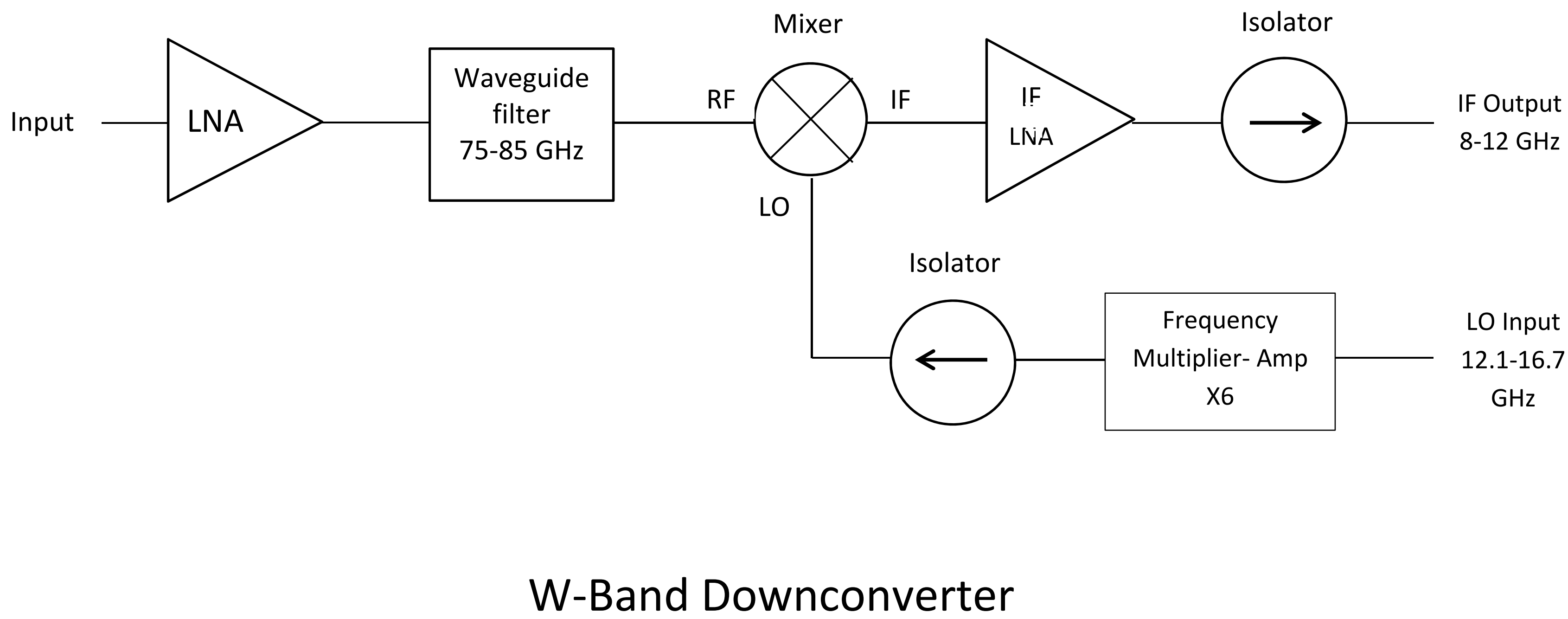
Input
LNA
Waveguide
filter
75-85 GHz
RF
Mixer
IF
LO
IF
LNA
Isolator
IF Output
8-12 GHz
Isolator
Frequency
Multiplier- Amp
X6
LO Input
12.1-16.7
GHz
W-Band Downconverter

Figure 13

IV. CONCLUSIONS

The use of an external harmonic mixer to make measurements of millimeter wave signals with a spectrum analyzer requires careful attention to the capabilities and limitations of this method. The signal strength with respect to the conversion loss must be sufficient to provide enough signal to noise to permit the desired measurements and the effect of images and other unwanted signals must not interfere with the ability to identify the desired signal. Images are especially a problem in the case of wideband signals where the bandwidth is equal to or greater than twice the IF frequency of the spectrum analyzer. This problem can be significantly diminished if an image suppression function is available or a preselected mixer is used and the higher conversion loss is acceptable. Better results can be obtained with a downconverter but commercial test equipment for compliance testing of equipment such as LPRs in the 75 to 85 GHz band is generally not available. However, the components to design and assemble a downconverter which will provide superior performance to an external harmonic mixer are readily available.