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GUIDELINES FOR COMPLIANCE TESTING OF UNLICENSED NATIONAL INFORMATION INFRASTRUCTURE (U-NII) DEVICES PART 15, SUBPART E

I. INTRODUCTION

This document provides guidance for determining emissions compliance of U-NII devices under Part 15, Subpart E of the FCC rules. This publication and its previous versions supersede the guidance contained in the now obsolete Public Notice DA 02-2138 of August 30, 2002.

This document includes acceptable procedures for measuring emission bandwidth, maximum conducted output power, power spectral density, and unwanted emissions both in and out of the restricted bands. Procedures for evaluating Dynamic Frequency Selection (DFS) functionality are not covered in this document. For EUTs that can transmit on multiple outputs simultaneously (e.g., MIMO or beamforming devices) see KDB Publication 662911 for additional guidance.

All operating modes and data rates of the equipment under test (EUT) must satisfy all requirements. The operating mode and data rate that is the worst case for one test may not be the worst case for another test. Data rate settings may have a significant effect on test results.

Note that average emission measurements in the restricted bands are based on continuous transmission by the U-NII device during the measurement interval. Downward adjustment of test data based on actual operational duty cycle of the device is not permitted.

II. MEASUREMENT PROCEDURES

A. General Guidance

1. Antenna-port Conducted versus Radiated Testing

All in-band measurements (see II.B. through II.G.) are based on antenna-port conducted measurements. However, if antenna-port conducted tests cannot be performed on the EUT, radiated tests are acceptable to show compliance with the various conducted emission requirements. See KDB Publication 412172 for converting field strength measurements to EIRP. Subtract the antenna gain of the EUT (in dBi) from the EIRP associated with a given in-band measurement to compute transmit power in the measurement bandwidth.

2. Spectrum Analyzer Reference Level/Attenuation/Headroom

For all measurements performed with a spectrum analyzer, the analyzer input settings must be configured to prevent the signal from exceeding the maximum input mixer level for linear operation.

a) Set attenuation to auto. (If finer control of attenuation is required to achieve a sufficiently low noise floor for out-of-band measurements, manual setting of attenuation is permitted provided that the power level corresponding to the reference level setting specified in II.A.2.b) falls within the mixer level range recommended by the manufacturer of the spectrum analyzer.)

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

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

   (ii) For in-band measurements the reference level is based on in-band power or maximum in-band spectrum level. The same reference level is also used for out-of-band measurements unless a preselector attenuates the in-band signals sufficiently to justify a lower reference level.

3. Frequency Stability

Section 15.407(g) specifies that U-NII devices are required to ensure frequency stability. It is required that that the emissions are maintained within the band of operation under all conditions of normal operation as specified in the user’s manual. The grantee is responsible for ensuring that the EUT meets Section 15.407(g) requirements; however, the applications for equipment certification are not required to include test reports with explicit demonstration of compliance.

B. Duty Cycle (x), Transmission Duration (T), and Maximum Power Control Level

1. All measurements are to be performed with the EUT transmitting at 100% duty cycle at its maximum power control level; however, if 100% duty cycle cannot be achieved, measurements of duty cycle, x, and maximum-power transmission duration, *T*, are required for each tested mode of operation.

   a) *T* refers to the minimum transmission duration over which the transmitter is on and is transmitting at its maximum power control level for the tested mode of operation.

   b) Duty cycle (x), as used in this document, refers to the fraction of time over which the transmitter is on and is transmitting at its maximum power control level.

   c) The term “maximum power control level” is intended to distinguish between operating power levels of the EUT and differences in power levels of individual symbols that occur with some modulation types such as quadrature amplitude modulation (QAM). During testing, the EUT is not required to transmit continuously its highest possible *symbol* power level. Rather, it shall transmit all of the symbols and shall do so at the highest power control level (i.e., highest operating power level) of the EUT.

2. Measurements of duty cycle and transmission duration shall be performed using one of the following techniques:

   a) A diode detector and an oscilloscope that together have sufficiently short response time to permit accurate measurements of the on and off times of the transmitted signal.

b) The zero-span mode on a spectrum analyzer or EMI receiver, if the response time and spacing between bins on the sweep are sufficient to permit accurate measurements of the on and off times of the transmitted signal. Set the center frequency of the instrument to the center frequency of the transmission. Set RBW ≥ EBW if possible; otherwise, set RBW to the largest available value. Set VBW ≥ RBW. Set detector = peak or average. The zero-span measurement method shall not be used unless both RBW and VBW are > 50/*T*, where *T* is defined in II.B.1.a), and the number of sweep points across duration *T* exceeds 100. (For example, if VBW and/or RBW are limited to 3 MHz, then the zero-span method of measuring duty cycle shall not be used if *T* ≤ 16.7 microseconds.)

C. Bandwidth Measurement

1. Emission Bandwidth (EBW)

a) Set RBW = approximately 1% of the emission bandwidth.
b) Set the VBW > RBW.
c) Detector = Peak.
d) Trace mode = max hold.
e) Measure the maximum width of the emission that is 26 dB down from the maximum of the emission. Compare this with the RBW setting of the analyzer. Readjust RBW and repeat measurement as needed until the RBW/EBW ratio is approximately 1%.

2. Minimum Emission Bandwidth for the band 5.725−5.85 GHz

Section 15.407(e) specifies the minimum 6 dB emission bandwidth of at least 500 kHz for the band 5.725−5.85 GHz. The following procedure shall be used for measuring this bandwidth:

a) Set RBW = 100 kHz.
b) Set the video bandwidth (VBW) ≥ 3 × RBW.
c) Detector = Peak.
d) Trace mode = max hold.
e) Sweep = auto couple.
f) Allow the trace to stabilize.
g) Measure the maximum width of the emission that is constrained by the frequencies associated with the two outermost amplitude points (upper and lower frequencies) that are attenuated by 6 dB relative to the maximum level measured in the fundamental emission.

Note: The automatic bandwidth measurement capability of a spectrum analyzer or EMI receiver may be employed if it implements the functionality described in this section. For devices that use channel aggregation refer to III.A and III.C for determining emission bandwidth.

D. 99% Occupied Bandwidth

The 99% occupied bandwidth is the frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers are each equal to 0.5% of the total mean power of the given emission. Measurement of the 99% occupied bandwidth is *required* only as a condition for using the optional band-edge measurement techniques described in II.G.3.d). Measurements of 99% occupied bandwidth may also optionally be used in lieu of the EBW to define the minimum frequency range over which the spectrum is integrated when measuring maximum conducted output power as described in II.E. However, the EBW must be measured to determine bandwidth dependent limits on maximum conducted output power in accordance with Section 15.407(a).

The following procedure shall be used for measuring (99%) power bandwidth:

1. Set center frequency to the nominal EUT channel center frequency.
2. Set span = 1.5 times to 5.0 times the OBW.
3. Set RBW = 1% to 5% of the OBW
4. Set VBW $\geq 3 \times$ RBW
5. Video averaging is not permitted. Where practical, a sample detection and single sweep mode shall be used. Otherwise, peak detection and max hold mode (until the trace stabilizes) shall be used.
6. Use the 99% power bandwidth function of the instrument (if available).
7. If the instrument does not have a 99% power bandwidth function, the trace data points are recovered and directly summed in power units. The recovered amplitude data points, beginning at the lowest frequency, are placed in a running sum until 0.5% of the total is reached; that frequency is recorded as the lower frequency. The process is repeated until 99.5% of the total is reached; that frequency is recorded as the upper frequency. The 99% occupied bandwidth is the difference between these two frequencies.

Note: For devices that use channel aggregation refer to III.A and III.C for determining 99% bandwidth.

E. Maximum Conducted Output Power

Maximum conducted output power may be measured using a spectrum analyzer/EMI receiver or an RF power meter. Refer to III.A and III.C for additional guidance for devices that use channel aggregation.

1. Device Configuration

If possible, configure or modify the operation of the EUT so that it transmits continuously at its maximum power control level (see II.B.).

a) The intent is to test at 100% duty cycle; however a small reduction in duty cycle (to no lower than 98%) is permitted if required by the EUT for amplitude control purposes. Manufacturers are expected to provide software to the test lab to permit such continuous operation.
b) If continuous transmission (or at least 98% duty cycle) cannot be achieved due to hardware limitations (e.g., overheating), the EUT shall be operated at its maximum power control level with the transmit duration as long as possible and the duty cycle as high as possible.

2. Measurement using a Spectrum Analyzer or EMI Receiver (SA)

Measurement of maximum conducted output power using a spectrum analyzer requires integrating the spectrum across a frequency span that encompasses, at a minimum, either the EBW or the 99% occupied bandwidth of the signal.[1] However, the EBW must be used to determine bandwidth dependent limits on maximum conducted output power in accordance with Section 15.407(a).

[1] The option of using 99% occupied bandwidth to determine the frequency span for integration provides flexibility to the test lab.

a) The test method shall be selected as follows:

   (i) Method SA-1 or SA-1 Alternative (averaging with the EUT transmitting at full power throughout each sweep) shall be applied if either of the following conditions can be satisfied:

   - The EUT transmits continuously (or with a duty cycle ≥ 98%).
   - Sweep triggering or gating can be implemented in a way that the device transmits at the maximum power control level throughout the duration of each of the instrument sweeps to be averaged. This condition can generally be achieved by triggering the instrument's sweep if the duration of the sweep (with the analyzer configured as in Method SA-1, i.e., II.E.2.b)) is equal to or shorter than the duration *T* of each transmission from the EUT and if those transmissions exhibit full power throughout their durations.

   (ii) Method SA-2 or SA-2 Alternative (averaging across on and off times of the EUT transmissions, followed by duty cycle correction) shall be applied if the conditions of (i) cannot be achieved and the transmissions exhibit a constant duty cycle during the measurement duration. Duty cycle will be considered to be constant if variations are less than ± 2%.

   (iii) Method SA-3 (power averaging (rms) detection with max hold) or SA-3 Alternative (reduced VBW with max hold) shall be applied if the conditions of (i) and (ii) cannot be achieved.

b) **Method SA-1** (trace averaging with the EUT transmitting at full power throughout each sweep):

   (i) Set span to encompass the entire emission bandwidth (EBW) (or, alternatively, the entire 99% occupied bandwidth) of the signal.

   (ii) Set RBW = 1 MHz.

   (iii) Set VBW ≥ 3 MHz.

   (iv) Number of points in sweep ≥ 2 × span / RBW. (This ensures that bin-to-bin spacing is ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

   (v) Sweep time = auto.

   (vi) Detector = power averaging (rms), if available. Otherwise, use sample detector mode.

   (vii) If transmit duty cycle < 98%, use a video trigger with the trigger level set to enable triggering only on full power pulses. Transmitter must operate at maximum power control level for the entire duration of every sweep. If the EUT transmits continuously (i.e., with no off intervals) or at duty cycle ≥ 98%, and if each transmission is entirely at the maximum power control level, then the trigger shall be set to "free run."

   (viii) Trace average at least 100 traces in power averaging (rms) mode.

   (ix) Compute power by integrating the spectrum across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal using the instrument's band power measurement function with band limits set equal to the EBW (or occupied bandwidth) band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the spectrum.

c) **Method SA-1 Alternative** (power averaging (rms) detection with slow sweep and EUT transmitting continuously at full power):

(i) Set span to encompass the entire EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal.

(ii) Set RBW = 1 MHz.

(iii) Set VBW ≥ 3 MHz.

(iv) Number of points in sweep ≥ 2 × span / RBW. (This ensures that bin-to-bin spacing is ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

(v) Manually set sweep time ≥ 10 × (number of points in sweep) × (symbol period of the transmitted signal), but not less than the automatic default sweep time.

(vi) Set detector = power averaging (rms).

(vii) The EUT shall be operated at 100% duty cycle.

(viii) Perform a single sweep.

(ix) Compute power by integrating the spectrum across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal using the instrument's band power measurement function with band limits set equal to the EBW (or occupied bandwidth) band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the spectrum.

d) **Method SA-2** (trace averaging across on and off times of the EUT transmissions, followed by duty cycle correction).

(i) Measure the duty cycle, x, of the transmitter output signal as described in II.B.

(ii) Set span to encompass the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal.

(iii) Set RBW = 1 MHz.

(iv) Set VBW ≥ 3 MHz.

(v) Number of points in sweep ≥ 2 × span / RBW. (This ensures that bin-to-bin spacing is ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

(vi) Sweep time = auto.

(vii) Detector = power averaging (rms), if available. Otherwise, use sample detector mode.

(viii) Do not use sweep triggering. Allow the sweep to "free run."

(ix) Trace average at least 100 traces in power averaging (rms) mode; however, the number of traces to be averaged shall be increased above 100 as needed to ensure that the average accurately represents the true average over the on and off periods of the transmitter.

(x) Compute power by integrating the spectrum across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal using the instrument's band power measurement function with band limits set equal to the EBW (or occupied bandwidth) band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal.

(xi) Add 10 log (1/x), where x is the duty cycle, to the measured power in order to compute the average power during the actual transmission times (because the measurement represents an average over both the on and off times of the transmission). For example, add 10 log (1/0.25) = 6 dB if the duty cycle is 25%.

e) **Method SA-2 Alternative** (power averaging (rms) detection with slow sweep with each spectrum bin averaging across on and off times of the EUT transmissions, followed by duty cycle correction).

(i) Measure the duty cycle, x, of the transmitter output signal as described in II.B.

(ii) Set span to encompass the entire EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal.

(iii) Set RBW = 1 MHz.

(iv) Set VBW ≥ 3 MHz.

(v) Number of points in sweep ≥ 2 × span / RBW. (This ensures that bin-to-bin spacing is ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

(vi) Manually set sweep time ≥ 10 × (number of points in sweep) × (total on/off period of the transmitted signal).

(vii) Set detector = power averaging (rms).

(viii) Perform a single sweep.

(ix) Compute power by integrating the spectrum across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal using the instrument's band power measurement function with band limits set equal to the EBW (or occupied bandwidth) band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the spectrum.

(x) Add 10 log (1/x), where x is the duty cycle, to the measured power in order to compute the average power during the actual transmission times (because the measurement represents an average over both the on and off times of the transmission). For example, add 10 log (1/0.25) = 6 dB if the duty cycle is 25%.

f) **Method SA-3** (power averaging (rms) detection with max hold):

(i) Set span to encompass the entire EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal.

(ii) Set sweep trigger to "free run."

(iii) Set RBW = 1 MHz.

(iv) Set VBW ≥ 3 MHz

(v) Number of points in sweep ≥ 2 × span / RBW. (This ensures that bin-to-bin spacing is ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

(vi) Sweep time ≤ (number of points in sweep) × *T*, where *T* is defined in II.B.1.a).

Note: If this results in a sweep time less than the auto sweep time of the analyzer, Method SA-3 Alternative shall not be used. (The purpose of this step is to ensure that averaging time in each bin is less than or equal to the minimum time of a transmission.)

(vii) Detector = power averaging (rms).

(viii) Trace mode = max hold.

(ix) Allow max hold to run for at least 60 seconds, or longer as needed to allow the trace to stabilize.

(x) Compute power by integrating the spectrum across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal using the instrument's band power measurement function with band limits set equal to the EBW (or occupied bandwidth) band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the spectrum.

g) **Method SA-3 Alternative** (Reduced VBW with max hold):

(i) Set span to encompass the entire emission bandwidth (EBW) of the signal.

(ii) Set sweep trigger to "free run."

(iii) Set RBW = 1 MHz.

(iv) Set VBW ≥ 1/*T*, where *T* is defined in II.B.1.a).

(v) Number of points in sweep ≥ 2 × span / RBW. (This ensures that bin-to-bin spacing is ≤ RBW/2, so that narrowband signals are not lost between frequency bins.)

(vi) Sweep time = auto.

(vii) Detector = peak.

(viii) Video filtering shall be applied to a voltage-squared or power signal (rms), if possible. Otherwise, it shall be set to operate on a linear voltage signal (which may require use of linear display mode). Log mode must not be used.

- The preferred voltage-squared (i.e., power or rms) mode is selected on some analyzers by setting the "Average-VBW Type" to power or rms.
- If power averaging (rms) mode is not available, linear voltage mode is selected on some analyzers by setting the display mode to linear. Other analyzers have a setting for "Average-VBW Type" that can be set to "Voltage" regardless of the display mode.

(ix) Trace mode = max hold.

(x) Allow max hold to run for at least 60 seconds, or longer as needed to allow the trace to stabilize.

(xi) Compute power by integrating the spectrum across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the signal using the instrument's band power measurement function with band limits set equal to the EBW (or occupied bandwidth) band edges. If the instrument does not have a band power function, sum the spectrum levels (in power units) at 1 MHz intervals extending across the EBW (or, alternatively, the entire 99% occupied bandwidth) of the spectrum.

(xii) If linear mode was used in II.E.2.g)(viii), add 1 dB to the final result to compensate for the difference between linear averaging and power averaging.

3. Measurement using a Power Meter (PM)

a) **Method PM** (Measurement using an RF average power meter):

(i) Measurements may be performed using a wideband RF power meter with a thermocouple detector or equivalent if all of the following conditions are satisfied:

- The EUT is configured to transmit continuously or to transmit with a constant duty cycle.
- At all times when the EUT is transmitting, it must be transmitting at its maximum power control level.
- The integration period of the power meter exceeds the repetition period of the transmitted signal by at least a factor of five.

(ii) If the transmitter does not transmit continuously, measure the duty cycle, x, of the transmitter output signal as described in II.B.

(iii) Measure the average power of the transmitter. This measurement is an average over both the on and off periods of the transmitter.

(iv) Adjust the measurement in dBm by adding 10 log (1/x) where x is the duty cycle (e.g., 10 log (1/0.25) if the duty cycle is 25%).

b) Method PM-G (Measurement using a gated RF average power meter):

Measurements may be performed using a wideband gated RF power meter provided that the gate parameters are adjusted such that the power is measured only when the EUT is transmitting at its maximum power control level. Since the measurement is made only during the ON time of the transmitter, no duty cycle correction factor is required.

F. Maximum Power Spectral Density (PSD)

The rules requires "maximum power spectral density" measurements where the intent is to measure the maximum value of the time average of the power spectral density measured during a period of continuous transmission. Refer to III.A for additional guidance for devices that use channel aggregation.

1. Create an average power spectrum for the EUT operating mode being tested by following the instructions in II.E.2. for measuring maximum conducted output power using a spectrum analyzer or EMI receiver: select the appropriate test method (SA-1, SA-2, SA-3, or alternatives to each) and apply it up to, but not including, the step labeled, "Compute power…." (This procedure is required even if the maximum conducted output power measurement was performed using a power meter, method PM.)
2. Use the peak search function on the instrument to find the peak of the spectrum and record its value.
3. Make the following adjustments to the peak value of the spectrum, if applicable:
   a) If Method SA-2 or SA-2 Alternative was used, add 10 log (1/x), where x is the duty cycle, to the peak of the spectrum.
   b) If Method SA-3 Alternative was used and the linear mode was used in II.E.2.g)(viii), add 1 dB to the final result to compensate for the difference between linear averaging and power averaging.
4. The result is the Maximum PSD over 1 MHz reference bandwidth.
5. For devices operating in the bands 5.15−5.25 GHz, 5.25−5.35 GHz, and 5.47−5.725 GHz, the preceding procedures make use of 1 MHz RBW to satisfy directly the 1 MHz reference bandwidth specified in Section 15.407(a)(5). For devices operating in the band 5.725−5.85 GHz, the rules specify a measurement bandwidth of 500 kHz. Many spectrum analyzers do not have 500 kHz RBW, thus a narrower RBW may need to be used. The rules permit the use of RBWs less than 1 MHz, or 500 kHz, "provided that the measured power is integrated over the full reference bandwidth" to show the total power over the specified measurement bandwidth (i.e., 1 MHz, or 500 kHz). If

measurements are performed using a reduced resolution bandwidth (< 1 MHz, or < 500 kHz) and integrated over 1 MHz, or 500 kHz bandwidth, the following adjustments to the procedures apply:

a) Set RBW ≥ 1/*T*, where *T* is defined in II.B.l.a).

b) Set VBW ≥ 3 RBW.

c) If measurement bandwidth of Maximum PSD is specified in 500 kHz, add 10 log (500 kHz/RBW) to the measured result, whereas RBW (<500 kHz) is the reduced resolution bandwidth of the spectrum analyzer set during measurement.

d) If measurement bandwidth of Maximum PSD is specified in 1 MHz, add 10 log (1MHz/RBW) to the measured result, whereas RBW (< 1 MHz) is the reduced resolution bandwidth of spectrum analyzer set during measurement.

e) Care must be taken to ensure that the measurements are performed during a period of continuous transmission or are corrected upward for duty cycle.

Note: As a practical matter, it is recommended to use reduced RBW of 100 kHz for the II.F.5.c) and II.F.5.d), since RBW=100 kHz is available on nearly all spectrum analyzers.

G. Unwanted Emission Measurement

Note: II.G.1. and II.G.2 cover measurements in the restricted and non-restricted bands, respectively. However, those sections are not self-contained. Rather, they reference the general unwanted emissions measurement requirements in II.G.3. and the specific measurement procedures in II.G.4., II.G.5., and II.G.6.. Refer to III.B. for additional guidance for devices that use channel aggregation.

1. Unwanted Emissions in the Restricted Bands

a) For all measurements, follow the requirements in II.G.3. *"General Requirements for Unwanted Emissions Measurements."*

b) At frequencies below 1000 MHz, use the procedure described in II.G.4. *"Procedure for Unwanted Emissions Measurements Below 1000 MHz."*

c) At frequencies above 1000 MHz, measurements performed using the peak and average measurement procedures described in II.G.5. and II.G.6., respectively, must satisfy the respective peak and average limits. If all peak measurements satisfy the average limit, then average measurements are not required.

d) For *conducted* measurements above 1000 MHz, EIRP shall be computed as specified in II.G.3.b) and then field strength shall be computed as follows (see KDB Publication 412172):

   (i) E[dBμV/m] = EIRP[dBm] - 20 log (d[m]) + 104.77, where E = field strength and d = distance at which field strength limit is specified in the rules;

   (ii) E[dBμV/m] = EIRP[dBm] + 95.2, for d = 3 m.

e) For *conducted* measurements below 1000 MHz, the field strength shall be computed as specified in II.G.1.d) and an additional 4.7 dB shall be added as an upper bound on the field strength that would be observed on a test site with a ground plane for frequencies between 30 MHz and 1000 MHz, or an additional 6 dB shall be added for frequencies below 30 MHz.[2]

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[2] At frequencies above 30 MHz, Section 15.209 specifies the limit on emissions at a distance of 3 m. Below 30 MHz, the emission limit is specified at 30 m or 300 m. At the 30 m and 300 m distances, the contribution of the

2. Unwanted Emissions that fall Outside of the Restricted Bands

a) For all measurements, follow the requirements in II.G.3. *"General Requirements for Unwanted Emissions Measurements."*

b) At frequencies below 1000 MHz, use the procedure described in II.G.4. *"Procedure for Unwanted Emissions Measurements Below 1000 MHz."*

c) At frequencies above 1000 MHz, use the procedure for maximum emissions described in II.G.5., *"Procedure for Unwanted Emissions Measurements Above 1000 MHz."*

(i) Sections 15.407(b)(1-3) specifies the unwanted emissions limit for the U-NII-1 and U-NII-2 bands. As specified, emissions above 1000 MHz that are outside of the restricted bands are subject to a peak emission limit of −27 dBm/MHz.[3]

(ii) Section 15.407(b)(4) specifies the unwanted emissions limit for the U-NII-3 band. A band emissions mask is specified in Section 15.407(b)(4)(i). The emission limits are based on the use of a peak detector.

d) If *radiated* measurements are performed, field strength is then converted to EIRP as follows:

(i) EIRP = ((E×d)^2) / 30

where:

- E is the field strength in V/m;
- d is the measurement distance in m;
- EIRP is the equivalent isotropically radiated power in W.

(ii) Working in dB units, the preceding equation is equivalent to:

EIRP[dBm] = E[dBμV/m] + 20 log (d[m]) − 104.77

(iii) Or, if d is 3 m:

EIRP[dBm] = E[dBμV/m] − 95.2

3. General Requirements for Unwanted Emissions Measurements

The following requirements apply to all unwanted emissions measurements, both in and outside of the restricted bands:

a) EUT Duty Cycle

(i) The EUT shall be configured or modified to transmit continuously except as stated in II.G.3.a)(ii). The intent is to test at 100% duty cycle; however a small reduction in duty

ground reflection can approach 6 dB, whereas at 3 meters it is limited to 4.8 dB [for example, Report and Order FCC 82-359, August 1982, Appendix B (Bulletin OST-55, "Characteristics of Open Field Test Sites"), paragraph 7.4.2]. A value of 4.7 dB has commonly been used as representative of the ground-reflection addition for 3-meter measurements (for example, FCC Bulletin OCE 44, "Calibration of a Radiation Measurement Site—Site Attenuation," Figure 2; and, First Report and Order FCC 02-48, released April 22, 2002, paragraph 245).

[3] Previous KDB guidance permitted compliance with the average and peak limits of Section 15.209 as satisfactory demonstration of compliance for limits as specified in Sections 15.407(b)(1-3). After January 01, 2019 all emissions are required to meet the limits as specified in the rules and it will not be sufficient to show compliance to the limits specified in Section 15.209.

cycle (to no lower than 98%) is permitted if required by the EUT for amplitude control purposes. Manufacturers are expected to provide software to the test lab to permit such continuous operation.

(ii) If continuous transmission (or at least 98% duty cycle) cannot be achieved due to hardware limitations of the EUT (e.g., overheating), the following additions to the measurement and reporting procedures are required:

- The EUT shall be configured to operate at the maximum achievable duty cycle.
- Measure the duty cycle, x, of the transmitter output signal as described in II.B.
- Adjustments to measurement procedures (e.g., increasing test time and number of traces averaged) shall be performed where described in the II.G. procedures.
- The test report shall include the following additional information:
  - The reason for the duty cycle limitation.
  - The duty cycle achieved for testing and the associated transmit duration and interval between transmissions.
  - The sweep time and the amount of time used for trace stabilization during max-hold measurements for maximum emission measurements.

(iii) **Reduction of the measured emission amplitude levels to account for operational duty cycle is not permitted. Compliance is based on emission levels occurring during transmission – <u>not</u> on an average across on and off times of the transmitter.**

b) Radiated versus Conducted Measurements.

The unwanted emission limits in both the restricted and non-restricted bands are based on radiated measurements; however, as an alternative, antenna-port conducted measurements in conjunction with cabinet emissions tests will be permitted to demonstrate compliance provided that the following steps are performed:

(i) Cabinet emissions measurements. A radiated test shall be performed to ensure that cabinet emissions are below the emission limits. For the cabinet-emission measurements the antenna may be replaced by a termination matching the nominal impedance of the antenna.

(ii) Impedance matching. Conducted tests shall be performed using equipment that matches the nominal impedance of the antenna assembly used with the EUT.

(iii) EIRP calculation. A value representative of an upper bound on out-of-band antenna gain (in dBi) shall be added to the measured antenna-port conducted emission power to compute EIRP within the specified measurement bandwidth. (For emissions in the restricted bands, additional calculations are required to convert EIRP to field strength at the specified distance.) The upper bound on antenna gain for a device with a single RF output shall be selected as the maximum in-band gain of the antenna across all operating bands or 2 dBi, whichever is greater.[4] However, for devices that operate in multiple bands using the same transmit antenna, the highest gain of the antenna within the operating band nearest to the out-of-band frequency being measured may be used in lieu of the overall highest gain when

[4] If an EUT uses an "electrically short antenna" (i.e., an antenna shorter than its resonant length of 1/4 wavelength or 1/2 wavelength), the in-band antenna gain may be low - perhaps even less than 0 dBi, but the gain may be higher at an out-of-band frequency where the antenna is resonant. In such a case, the gain is not expected to exceed that of a resonant 1/2 wavelength dipole, which is 2.15 dBi - rounded, here, to 2 dBi.

measuring emissions at frequencies within 20% of the absolute frequency at the nearest edge of that band, but in no case shall a value less than 2 dBi be selected.

(iv) EIRP adjustments for multiple outputs. For devices with multiple outputs occupying the same or overlapping frequency ranges in the same band (e.g., MIMO or beamforming devices), compute the total EIRP as follows:

- Compute EIRP for each output, as described in II.G.3.b)(iii).
- Follow the procedures specified in KDB Publication 662911 for summing emissions across the outputs or adjusting emission levels measured on individual outputs by $10 \log (N_{ANT})$, where N_{ANT} is the number of outputs.
- Add the array gain term specified in KDB Publication 662911 for out-of-band and spurious signals.[5]

c) Direction of maximum emission.

For all radiated emissions tests, measurements shall correspond to the direction of maximum emission level for each measured emission (see ANSI C63.10 for guidance).

d) Band edge measurements.

Unwanted band-edge emissions may be measured using either of the special band-edge measurement techniques (the marker-delta or integration methods) described in the following paragraphs. Note that the marker-delta method is primarily a radiated measurement technique that requires the 99% occupied bandwidth edge to be within 2 MHz of the authorized band edge, whereas the integration method can be used in either a radiated or conducted measurement without any special requirement with regards to the displacement of the unwanted emission(s) relative to the authorized bandwidth.

(i) Marker-Delta Method.

The marker-delta method, as described in ANSI C63.10, can be used to perform measurements of the radiated unwanted emissions level of emissions provided that the 99% occupied bandwidth of the fundamental is within 2 MHz of the authorized band-edge.

(ii) Integration Method

- For maximum emissions measurements, follow the procedures described in II.G.5., "*Procedures for Unwanted Maximum Emissions Measurements above 1000 MHz,"* except for the following changes:
  - Set RBW = 100 kHz
  - Set VBW ≥ 3 × RBW
  - Perform a band-power integration across the 1 MHz bandwidth in which the band-edge emission level is to be measured. CAUTION: You must ensure that the spectrum analyzer or EMI receiver is set for peak-detection and max-hold for this measurement.

[5] Though out-of-band signals are not intentionally correlated between outputs and are not intended to exhibit array gain, we note the following: (1) if the in-band signals on two outputs are correlated, out-of-band intermodulation products and harmonics are also expected to be correlated; (2) narrowband signals originating from the same source are also expected to exhibit correlation between channels.

- For average emissions measurements, follow the procedures described in II.G.6., "*Procedures for Average Unwanted Emissions Measurements above 1000 MHz*," except for the following changes:
  - Set RBW = 100 kHz
  - Set VBW ≥ 3 × RBW
  - Perform a band-power integration across the 1 MHz bandwidth in which the band-edge emission level is to be measured.

4. Procedure for Unwanted Emissions Measurements below 1000 MHz

a) Follow the requirements in II.G.3. *"General Requirements for Unwanted Emissions Measurements."*

b) Compliance shall be demonstrated using CISPR quasi-peak detection; however, peak detection is permitted as an alternative to quasi-peak detection.

5. Procedure for Unwanted Maximum Emissions Measurements above 1000 MHz

a) Follow the requirements in II.G.3, *"General Requirements for Unwanted Emissions Measurements."*

b) Maximum emission levels are measured by setting the analyzer as follows:

(i) RBW = 1 MHz.

(ii) VBW ≥ 3 MHz.

(iii) Detector = Peak.

(iv) Sweep time = auto.

(v) Trace mode = max hold.

(vi) Allow sweeps to continue until the trace stabilizes. Note that if the transmission is not continuous, the time required for the trace to stabilize will increase by a factor of approximately 1/x, where x is the duty cycle. For example, at 50% duty cycle, the measurement time will increase by a factor of two relative to measurement time for continuous transmission.

6. Procedures for Average Unwanted Emissions Measurements above 1000 MHz

a) Follow the requirements in II.G.3. *"General Requirements for Unwanted Emissions Measurements."*

b) Average emission levels shall be measured using one of the following two methods.

c) **Method AD** (Average Detection): Primary method

(i) RBW = 1 MHz.

(ii) VBW ≥ 3 MHz.

(iii) Detector = power averaging (rms), if span/(# of points in sweep) ≤ RBW/2. Satisfying this condition may require increasing the number of points in the sweep or reducing the span. If the condition is not satisfied, the detector mode shall be set to peak.

(iv) Averaging type = power averaging (rms)

As an alternative, the detector and averaging type may be set for linear voltage averaging. Some instruments require linear display mode in order to use linear voltage averaging. Log or dB averaging shall not be used.

(v) Sweep time = auto.

(vi) Perform a trace average of at least 100 traces if the transmission is continuous. If the transmission is not continuous, the number of traces shall be increased by a factor of 1/x, where x is the duty cycle. For example, with 50% duty cycle, at least 200 traces shall be averaged. (If a specific emission is demonstrated to be continuous—i.e., 100% duty cycle—rather than turning on and off with the transmit cycle, at least 100 traces shall be averaged.)

(vii) If tests are performed with the EUT transmitting at a duty cycle less than 98%, a correction factor shall be added to the measurement results prior to comparing to the emission limit in order to compute the emission level that would have been measured had the test been performed at 100% duty cycle. The correction factor is computed as follows:

- If power averaging (rms) mode was used in II.G.6.c)(iv), the correction factor is 10 log (1/x), where x is the duty cycle. For example, if the transmit duty cycle was 50%, then 3 dB must be added to the measured emission levels.
- If linear voltage averaging mode was used in II.G.6.c)(iv), the correction factor is 20 log (1/x), where x is the duty cycle. For example, if the transmit duty cycle was 50%, then 6 dB must be added to the measured emission levels.
- If a specific emission is demonstrated to be continuous (100% duty cycle) rather than turning on and off with the transmit cycle, no duty cycle correction is required for that emission.

d) **Method VB** (Averaging using reduced video bandwidth): Alternative method.

(i) RBW = 1 MHz.

(ii) Video bandwidth.

- If the EUT is configured to transmit with duty cycle ≥ 98%, set VBW ≤ RBW/100 (i.e., 10 kHz) but not less than 10 Hz.
- If the EUT duty cycle is < 98%, set VBW ≥ 1/*T*, where *T* is defined in II.B.1.a).

(iii) Video bandwidth mode or display mode

- The instrument shall be set to ensure that video filtering is applied in the power domain. Typically, this requires setting the detector mode to rms and setting the Average-VBW Type to power averaging (rms).
- As an alternative, the analyzer may be set to linear detector mode. Ensure that video filtering is applied in linear voltage domain (rather than in a log or dB domain). Some analyzers require linear display mode in order to accomplish this. Others have a setting for Average-VBW Type, which can be set to "Voltage" regardless of the display mode.

(iv) Detector = Peak.

(v) Sweep time = auto.

(vi) Trace mode = max hold.

(vii) Allow max hold to run for at least 50 traces if the transmitted signal is continuous or has at least 98% duty cycle. For lower duty cycles, increase the minimum number of traces by a factor of 1/x, where x is the duty cycle. For example, use at least 200 traces if the duty cycle is 25%. (If a specific emission is demonstrated to be continuous—i.e., 100% duty cycle—rather than turning on and off with the transmit cycle, at least 50 traces shall be averaged.)

H. Measurement of emission at elevation angle higher than 30° from horizon

In addition to the emission limits specified in Section 15.407(a)(1)(i), if the access point is an outdoor Point-to-Multipoint device operating in the band 5.15−5.25 GHz, the rules require that the maximum EIRP at any elevation angle above 30° not exceed 125 mW (21 dBm) as measured from the horizon. This restriction leads to a general requirement for the antenna pattern: if the EIRP within 3 dB elevation beamwidth of any radiation lobe is higher than 125 mW, this lobe must be controlled, either mechanically or electrically, so that the 3 dB elevation beamwidth of this lobe is below 30° elevation angle relative to horizon.

For the purposes of compliance, information for all the antenna types must be included in the filing. In order for antennas to be considered of similar type, the antenna patterns must also be similar as well as other characteristics of the antenna.

Note: For the sake of clarity, we define the elevation angle where 0° is horizontal and 90° is straight-up.

1. For fixed infrastructure, not electrically or mechanically steerable beam antenna

a) If elevation plane radiation pattern is available:

i) Determine the device intended mounting elevation angle and define 0° reference angle on the elevation plane radiation pattern.

ii) Indicate any radiation pattern between 30° and 90° which has highest gain.

iii) Calculate the EIRP based on this highest gain and conducted output power.

iv) Compare to the limit of 125 mW to find compliance.

v) Include the elevation pattern data in the application filing with the test report to show how the calculations are made.

Note: For MIMO devices, take the maximum gain of each antenna and apply the guidance in KDB Publication 662911 for calculating the overall gain including directional gain for maximum EIRP calculation.

b) If elevation plane radiation pattern is not available, but the antenna type (such as dipole omnidirectional, Yagi, parabolic, or sector antenna) has symmetrical elevation plane pattern referenced at main beam and all lobes on the main beam elevation plane have highest gains, then the following measurement method is acceptable to determine compliance:

(i) Determine the device's intended mounting elevation angle referenced to the horizon.

(ii) Rotate EUT antenna by 90° around the main beam axis in horizontal position to transform measurement in elevation angle into azimuth angle and define 0° reference angle based on device's intended mounting elevation angle.

(iii) Move test antenna along the horizontal arc, or rotate the turn table with EUT antenna placed at the center, between 30° and 90° relative to the 0° reference angle, and then continuing down from 90° to 30° on the other side of the pattern, while maintaining the test antenna pointing with constant distance to the EUT antenna and search for the spot which has the highest measured emission. Both horizontal and vertical polarization shall be investigated to find out the maximum radiated emission level.

Note: Moving of test antenna along the horizontal arc, or rotating the turn table, shall be performed in angular step size as small as possible, but not larger than 3°.

(iv) Calculate the EIRP based on the highest measured emission and compare to the limit of 125 mW to determine compliance.

(v) The antenna pattern measurements should be included in the filing.

2. For All Other Types of Antenna

For all other types of antenna (such as patch antenna, array antenna, antennas with irregular shape of radiators, etc.) which have any combination of following characteristics:

- Asymmetrical, complex radiation patterns
- 2-D or 3-D steerable beam
- Portable/mobile, not fixed infrastructure device

Provide following information in the report:

a) Describe what type of antenna is used.

b) Determine by calculation, measurement or simulation, all radiation lobes/beams, which have EIRP higher than 125 mW within 3 dB elevation beamwidth.

c) Provide an explanation of how those antenna beams are controlled to be kept below 30° elevation angle. The explanation should include installation instruction of the device, mechanical control, electro-mechanical control or software algorithm, if the beams are electrically controlled by software.

III. CHANNEL AGGREGATION

Some IEEE Std 802.11 channels operate under two U-NII sub-bands. For example, IEEE Std 802.11 Channels 42+138 (80+80 MHz) is distributed over the U-NII-1 and U-NII-2C bands. Some of these channels that operate in more than one U-NII band are deemed "straddle" channels. The following channels are considered to be straddle channels:

- Channel 50 (160 MHz channel)
- Channel 138 (80 MHz channel)
- Channel 142 (40 MHz channel)
- Chanel 144 (20 MHz channel)

A. In-band emission limits

The following interpretations apply to in-band measurements when transmitted signals consist of two or more non-contiguous spectrum segments (e.g., 80+80 MHz mode) or when a single spectrum segment of a transmission crosses the boundary between two adjacent U-NII bands, i.e., straddle channels.

1. Emission bandwidth (EBW) in U-NII bands

a) Transmissions with non-contiguous spectra. For intentional emissions that are not contiguous in frequency, total EBW is defined as follows:

i) the difference between the outer −26 dB points if the 26 dB bandwidths overlap (Figure 1);

ii) the sum of the individual 26 dB bandwidths if the 26 dB bandwidths do not overlap (Figure 2). The EBW of each non-contiguous segment is measured at points that are 26 dB below the maximum for that segment.

b) Band-crossing emissions. For an emission that crosses the boundary between two adjacent U-NII bands, the boundary frequency between the bands serves as one edge for defining the portion of the EBW that falls within a particular U-NII band; however, the −26 dB points are measured relative to the highest point on the contiguous segment—regardless of which band contains that highest point (Figure 3).

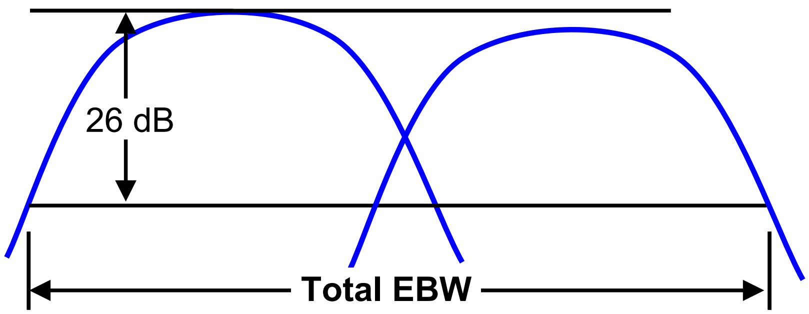


Figure 1. Total Emission Bandwidth (EBW) of Signals with Overlapping EBWs

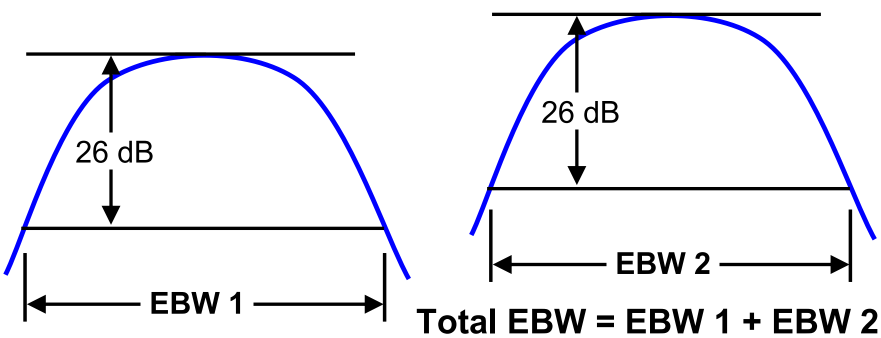


Figure 2. Total Emission Bandwidth (EBW) of Signals with Non-Overlapping EBWs

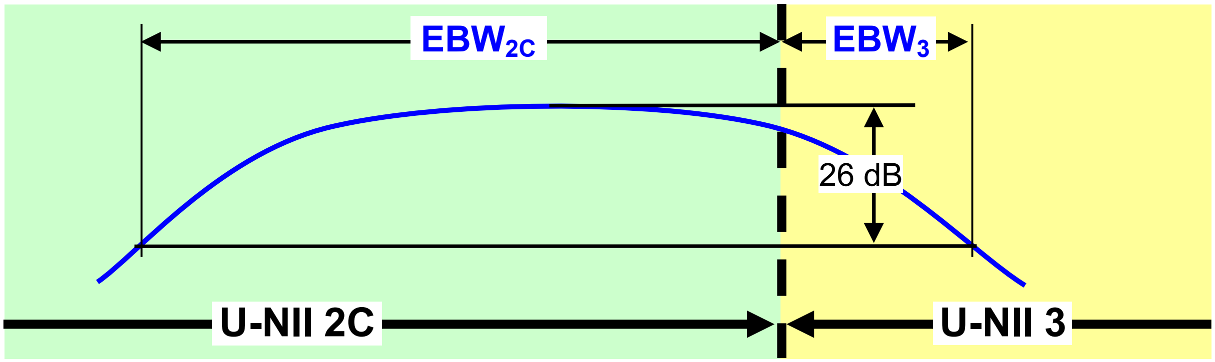


Figure 3. Emission Bandwidth (EBW) within a Band for Band-Crossing Signals

2. Power spectral density (PSD)

Emissions in each band shall comply with the PSD limits applicable to that band under the appropriate rule section.

3. Maximum conducted output power

a) The maximum conducted output power within each band of operation shall comply with the limits for that band.

b) The limit on maximum conducted output power in each U-NII band is computed based on the portion of the emission bandwidth contained within that band (e.g., Figure 3).

B. Unwanted emissions (out-of-band and spurious)

1. Bands of operation. A given transmission may include multiple spectral segments in different bands and/or individual spectral segments that overlap boundaries between bands.
2. For any given transmission, the out-of-band spurious emissions limits apply outside of the frequency bands of operation for that transmission except as noted in III.B.2.a). This means, for example, that the U-NII out-of-band emission limit applies within any U-NII band in which the device is not currently transmitting.

   a) U-NII-1 and U-NII-2A bands (5.15−5.25 and 5.25−5.35 GHz). Sections 15.407(b)(1) and (b)(2) include exceptions to the requirement that the out-of-band emission limit applies outside the current band of transmission.

      (i) For devices operating in the 5.15−5.25 GHz band, the −27 dBm/MHz peak EIRP limit applies outside of the lower pair of U-NII bands, i.e., 5.15−5.35 GHz. However, any transmission that does not intentionally extend into the 5.25−5.35 GHz band must be down 26 dB above 5.25 GHz per Section 15.215(c). As a practical matter, the 99% bandwidth may be used in lieu of the 26 dB bandwidth. If the emission does intentionally extend into the 5.25−5.35 GHz band, DFS and TPC must be implemented per Section 15.407(h).

      (ii) For devices that operate in the 5.25−5.35 GHz band, the −27 dBm/MHz peak EIRP limit applies outside of the lower pair of U-NII bands, i.e., 5.15−5.35 GHz.

      (iii) Straddle channel 50 is considered to be operating in both U-NII-1 and U-NII-2A. An out-of-band emission limit of −27 dBm/MHz peak EIRP is required to be met outside of the 5.15−5.35 GHz band.

b) U-NII-2C and U-NII-3 bands (5.47−5.725 GHz and 5.725−5.85 GHz).

(i) Channels that operate in U-NII-2C have an out-of-band emission limit of −27dBm/MHz peak EIRP outside of the 5.47−5.725 GHz band.

(ii) Channels that operate in the U-NII-3 have an out-of-band emission limit defined by Section 15.407(b)(i). Limits are in terms of a Peak measurement.

(iii) Straddle channels 138, 142 and 144 are considered to be operating in both U-NII-2C and U-NII-3. The worst case out-of-band emission limit, i.e., −27 dBm/MHz peak EIRP, applies at the band edges. The band edges are considered to be 5.47 GHz and 5.85 GHz.

C. Measurement Procedures

1. The following measurement procedures apply:
   - FCC KDB Publication 662911 for MIMO under any rule part;
   - FCC KDB Publication 905462 for DFS.
2. The following adjustments to those procedures apply when measuring U-NII transmissions that are not contiguous in frequency or that extend across the boundary between adjacent U-NII bands.

a) Emission bandwidth

(i) For transmissions that are not contiguous in frequency, see III.A.1.a).

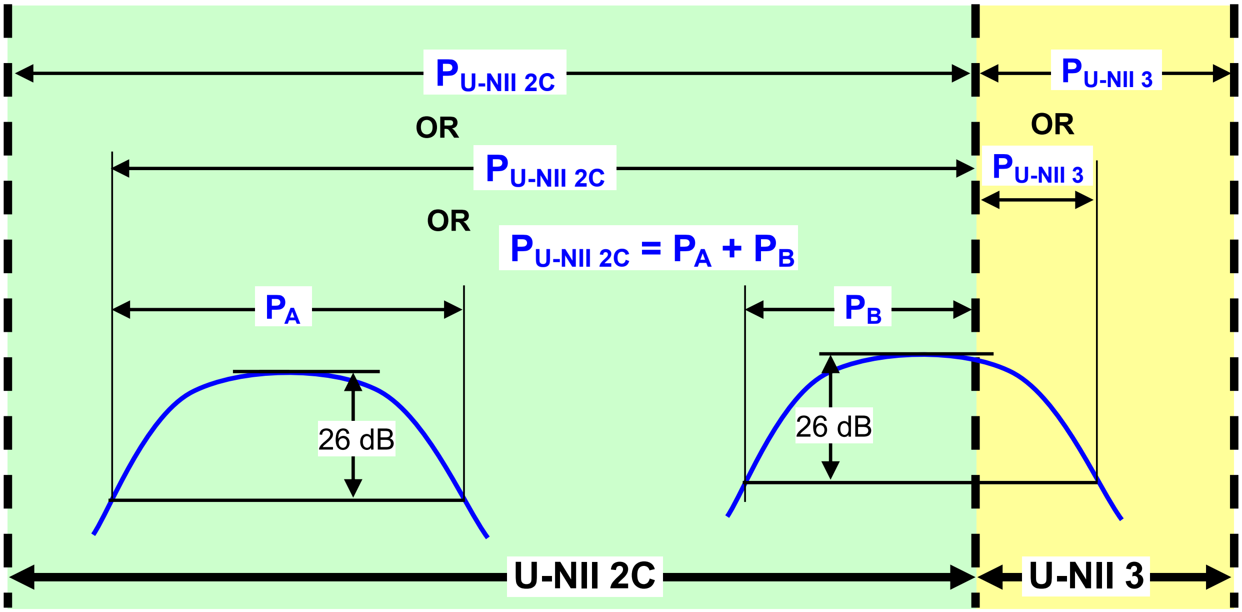
(ii) For an emission that crosses the boundary between adjacent U-NII bands, see III.A.1.b).

b) Maximum conducted output power (see examples in Figure 4).

(i) Transmissions with non-contiguous spectra. For transmission segments that are not contiguous in frequency, the total power of the spectrum segments can be determined by either of the following methods:

- Measure the power of each spectrum segment by integrating across the EBW of that segment following the procedures outlined in this KDB. Sum the power measurements.
- Or, measure the total power of the segments simultaneously by integrating across a frequency range that encompasses the EBWs of all segments, following the procedures of this KDB. (The power-meter based procedure, Method PM, may be used as an alternative.)

(ii) When measuring the portion of the maximum conducted output power within a single U-NII band, the power shall be integrated across only the portion of the EBW that falls within that band. That is, if an EBW extends across the boundary between two adjacent bands, the boundary frequency between the bands serves as one edge of the frequency range to be integrated. Integration across an entire U-NII band without regard to 26 dB points is also acceptable for determining conducted output power within that band.



Conducted output power within a U-NII band: Integrate over the band or integrate over a span including the 26 dB EBWs of transmission segments within the band or integrate over 26 dB EBW of each transmission segment in the band and sum.

Figure 4. Conducted Output Power Measurement Examples

IV. CHANNEL PUNCTURING

Some standards such as IEEE Std 802.11.ax allow for channel puncturing, aka Zero Wait DFS, whereby 80 MHz or 160 MHz channels are notched in some 20 MHz portions when radar is detected. If an 80 MHz or a 160 MHz channel meets all the technical requirements, i.e., power, psd, spurious emissions, etc., then notching a 20 MHz portion is not expected to degrade those technical parameters of the remaining portion of the channel. However, the test lab should verify that no anomalies arise as a consequence of the channel puncturing. In addition, the following items will need to be measured and reported:

1. When a 20 MHz portion is punctured the remaining emissions do not bleed into the notched channel, i.e., 26 dB or 99% bandwidth is contained outside of the notched band.
2. For purposes of DFS testing verify channel closing and move times are met when one and two 20 MHz channels are punctured.

Change Notice

01/08/2016: 789033 D02 General UNII Test Procedures New Rules v01 has been replaced by 789033 D02 General U-NII Test Procedures New Rules v01r01. Added procedure for channels that straddle the U-NII-2C and U-NII-3 bands in Section III (from December 2014 TCB notes).

04/08/2016: 789033 D02 General UNII Test Procedures New Rules v01r01 has been replaced by 789033 D02 General U-NII Test Procedures New Rules v01r02. Sections II. G. 2. c) and III. updated to address rule changes in Section 15.407.

08/22/2016: 789033 D02 General UNII Test Procedures New Rules v01r02 has been replaced by 789033 D02 General U-NII Test Procedures New Rules v01r03. Section III. has been updated to allow for use of a simplified test procedure.

05/02/2017: 789033 D02 General UNII Test Procedures New Rules v01r03 has been replaced by 789033 D02 General U-NII Test Procedures New Rules v01r04. Clarify OOBE requirements above 1 GHz [II) G) 2) c)] and straddle channel requirements [III).

12/08/2017: 789033 D02 General UNII Test Procedures New Rules v01r04 has been replaced by 789033 D02 General U-NII Test Procedures New Rules v02. Merged KDB Publication 789033 with 644545.

12/14/2017: 789033 D02 General UNII Test Procedures New Rules v02 has been replaced by 789033 D02 General U-NII Test Procedures New Rules v02r01. Corrected typographical error on band edge.