Federal Communications Commission
Office of Engineering and Technology
Laboratory Division

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Emissions Testing of Transmitters with Multiple Outputs in the Same Band

(*e.g.*, MIMO, Smart Antenna, etc)

A) SCOPE

This document provides guidance for measurement of conducted output emissions of devices or composite systems that employ a transmitter with multiple outputs in the same band or multiple transmitters operating in the same band, with the outputs occupying the same or overlapping frequency ranges. It applies to EMC compliance measurements on devices and systems (including hosts with multiple modular transmitters) that transmit on multiple antennas simultaneously in the same or overlapping frequency ranges through a coordinated process. Examples include, but are not limited to, devices and systems employing beamforming or multiple-input and multiple-output (MIMO.) This guidance applies to both licensed and unlicensed devices wherever the FCC rules call for conducted output measurements or where conducted output measurements are combined with directional antenna gain to demonstrate compliance with a radiated limit. Guidance is provided for in-band, out-of-band, and spurious emission measurements.

For devices having two outputs driving a cross-polarized pair of antennas, see Attachment 662911 D02 of this publication for additional guidance.

B) PURPOSE

This document addresses two issues associated with conducted testing of emissions from transmitters with multiple outputs in the same band:

1) <u>Summing emissions.</u>

The FCC's emission limits apply to the total of emissions from all outputs of the transmitter or of composite system transmitters. Thus, emission measurements from the transmitter outputs must be summed before comparing measured emissions to the emission limit. (An exception exists for devices having two outputs driving a cross-polarized pair of antennas and operating under a rule part that specifies radiated rather than conducted limits. See Attachment 662911 D02 of this publication for more information.)

2) <u>Accounting for array gain.</u>

Correlation between signals transmitted from different antennas can lead to array gain, which increases the directional gain of the device and leads to higher radiated levels in some directions. The contribution of array gain to the directional gain of the transmitter must be considered in rule parts where conducted in-band emission limits vary with directional gain, or in situations in which conducted measurements are combined with directional antenna gain to determine compliance with in-band radiated limits.

These issues are unique to conducted emissions measurements. In most cases, radiated measurements automatically combine the power emitted from multiple outputs and include the effects of directional gain if the measurements are performed in the direction of maximum response of the transmitter. However, for a device driving cross-polarized antennas, special considerations apply, as described in Attachment 662911 D02 of this publication.

C) LIMITATIONS

This document provides guidance only with respect to summing of emission measurements from multiple outputs and performing directional gain computations. It makes no change in other aspects of measurements and compliance, such as the type of power or power spectral density measurement to be made (e.g., peak or average) or the methods for making those measurements (e.g., spectrum analyzer setup parameters).

D) DEFINITION

Measure-and-sum technique. The conducted emission level (e.g., transmit power or power in specified bandwidth) is measured at each antenna port. The measured results at the various antenna ports are then summed mathematically to determine the total emission level from the device. Summing is performed in units that are directly proportional to power (e.g., mW or microvolts-squared—not dBm or microvolts).

E) GUIDANCE FOR SUMMING EMISSION MEASUREMENTS FROM MULTIPLE OUTPUTS OF A TRANSMITTER OR FROM MULTIPLE TRANSMITTERS

Acceptable methodologies for summing emission measurements from multiple transmitter outputs depend on the type of emission measurement being performed. Three types of emission measurements are considered: in-band power measurements; in-band power spectral density measurements; and out-of-band and spurious emissions measurements.

1) <u>In-Band Power Measurements</u>

   The measure-and-sum technique shall be used for measuring in-band transmit power of a device. Total power is the sum of the conducted power levels measured at the various output ports

2) <u>In-Band Power Spectral Density (PSD) Measurements</u>

   When performing measurements for compliance with PSD limits within the band of operation of a transmitter, any of the three techniques below may be used to combine the emission measurements from multiple outputs prior to comparing to the emission limit. The first is the most accurate method. The second and third techniques are offered as simpler alternatives, but they may lead to overestimates of the total PSD when emission levels differ between outputs; consequently, if measurements performed using methods b) or c) exceed the emission limit, the test lab may wish to retest using method a) before declaring that the device fails the emission test. With any of the methods, existing rules and guidance shall be applied in performing the measurements on the individual outputs and in determining the maximum permitted PSD for the device.

   a) *Measure and sum the spectra across the outputs*. With this technique, spectra are measured at each output of the device at the required resolution bandwidth. The individual spectra are then summed mathematically in linear power units. Unlike in-band *power* measurements, in which the sum involves a single measured value (output power) from each output, measurements for compliance with PSD limits involve summing entire spectra across corresponding frequency bins on the various outputs [*i.e.*, for a device with N_{ANT} transmitter outputs, if the spectrum measurements of the individual outputs are all performed with the same span and number of points, the spectrum value (in watts or milliwatts) in the first spectral bin of output 1 is summed with that in the first spectral bin of output 2 and that from the first spectral bin of output 3, and so on up to the $N_{ANT}{}^{th}$ output to obtain the value for the first frequency bin of the summed spectrum. The summed spectrum value for each of the other frequency bins is computed in the same way).] This will likely require transferring the measured spectra to a computer, where the bin-by-bin summing can be performed.

b) *Measure and sum spectral maxima across the outputs*. With this technique, spectra are measured at each output of the device at the required resolution bandwidth. The maximum value (peak) of each spectrum is determined. These maximum values are then summed mathematically in linear power units across the outputs. These operations shall be performed separately over frequency spans that have different out-of-band or spurious emission limits,

c) *Measure and add 10 log(N_{ANT}) dB*, where N_{ANT} is the number of outputs. With this technique, spectrum measurements are performed at each output of the device, but rather than summing the spectra or the spectral peaks across the outputs, the quantity *10 log(N_{ANT})* dB is added to each spectrum value before comparing to the emission limit. The addition of *10 log(N_{ANT})* dB serves to apportion the emission limit among the N_{ANT} outputs so that each output is permitted to contribute no more than $1/N_{ANT}{}^{\text{th}}$ of the PSD limit specified in the rules. (Note that the *10 log(N_{ANT})* term in this calculation is not related to that used in array gain calculations, to be discussed later in this document.)

3) <u>Out-of-Band and Spurious Emission Measurements</u>

a) Absolute Emission Limits

When performing measurements outside of the band of operation of a transmitter (*i.e.*, out-of-band and spurious emissions), any of the three techniques below may be used to combine the emission measurements from multiple outputs prior to comparing to the emission limit. The first is the most accurate method. The second and third techniques are offered as simpler alternatives, but they may lead to overestimates of the total emission level when emission levels differ between outputs; consequently, if measurements performed using methods (ii) or (iii) exceed the emission limit, the test lab may wish to retest using method (i) before declaring that the device fails the emission test. With any of the methods, existing rules and guidance shall be applied in performing the measurements on the individual outputs and in determining the maximum permitted emission level for the device.

(i) *Measure and sum the spectra across the outputs as described in sectionE)2)a).* Note that the summation must be performed in linear power units, or the equivalent. For example, if measurement units are microvolts or microvolts/meter, the values shall be squared before summing, and then a square root shall be applied to the sum in order to achieve the equivalent of summing in power units.

(ii) *Measure and sum spectral maxima across the outputs as described in sectionE)2)b).* Note that the summation must be performed in linear power units, or the equivalent. For example, if measurement units are microvolts or microvolts/meter, the values shall be squared before summing, and then a square root shall be applied to the sum in order to achieve the equivalent of summing in power units.

(iii) *Measure and add 10 log(N_{ANT}) dB*, where N_{ANT} is the number of outputs, as described in section E)2)c).

b) Relative Limits

When testing out-of-band and spurious emissions against relative emission limits, tests may be performed on each output individually without summing or adding *10 log(N_{ANT})* if the measurements are made relative to the in-band emissions on the individual outputs. For example, if a rule states that out-of-band emissions in a 100 kHz bandwidth must be at least 20dB below the 100 kHz bandwidth in-band that contains the highest power, compliance may be established by confirming that the maximum *total* out-of-band emission is at least 20 dB below the maximum *total* in-band PSD, as determined by the "measure and sum the spectra" technique in both instances; alternatively, compliance may be demonstrated by confirming that the maximum out-of-band emission *on each individual output* is at least 20 dB below the maximum in-band PSD (in 100 kHz bandwidth) *on that output*. Similarly, if a rule states that out-of-band emissions in a 1MHz bandwidth must be at least *X dB* below the transmit power (where *X* does not vary with transmit power), compliance may be established by confirming that the maximum *total* out-of-band emission, as determined by the "measure and sum the spectra" technique, is at least *X dB* below the *total* transmit power; alternatively, compliance may be demonstrated by confirming that the maximum out-of-band emission *on each individual output* is at least *X dB* below the maximum transmit power *on that output*.

Emission limits specified as *X + 10 log(P) dB* below the transmit power (where *P* is the transmit power) are absolute limits and are not considered "relative limits" for purposes of this guidance. Out-of-band and spurious emissions must be tested against absolute limits using techniques described in section a) above.

F) GUIDANCE ON DIRECTIONAL GAIN CALCULATIONS

Some rule parts define a limit on output power or power spectral density that is a function of the directional gain of the antenna system. There may also be cases in which *conducted* measurements are combined with directional antenna gain to determine compliance with *radiated* limits. In such cases, the effect of array gain must be included in the calculation of overall directional antenna gain for devices that transmit on multiple outputs simultaneously in the same band, in the same or in overlapping frequency ranges.

Array gain results when the signals transmitted on different antennas are positively correlated when viewed from a specific direction. In most cases, *beamforming* systems attempt to achieve 100 percent correlation between the transmitted signals when viewed from the intended beam direction, though actual correlation may be slightly lower. A transmitter that transmits correlated signals from its multiple antennas has the potential to create array gain even when that is not the intent.

For simplicity, the guidance presented here categorizes transmissions as *correlated* (*i.e.,* correlation exists between the signals on at least two antennas) or *completely uncorrelated*. Unless the transmitted signals are categorized as completely uncorrelated based on the guidance provided below, the signals must be considered correlated for the purposes of computing directional gain. In the case of correlated signals, array gain will be computed based on 100 percent correlation even if the actual correlation is lower except in certain cases involving cyclic delay diversity or multiple spatial streams.

1) Categorization as Correlated or Completely Uncorrelated

For the purposes of this guidance, transmitter output signals are considered *correlated* if any of the following are true:

- The same digital data are transmitted from two or more antennas in a given symbol period, even with different coding or phase shifts; or,
- Correlation between two transmitted signals exists at any frequency and time delay; or,
- Multiple transmitter outputs serve to focus energy in a given direction or to a given receiver; or,
- The operating mode combines correlated techniques with uncorrelated techniques.

Otherwise, the output signals are considered *completely uncorrelated*.

Correlated signals include, but are not limited to, signals transmitted in any of the following modes:

- *Any transmit beamforming mode*, whether fixed or adaptive (*e.g.*, phased array modes, closed loop MIMO modes, Transmitter Adaptive Antenna modes, Maximum Ratio Transmission (MRT) modes, and Statistical Eigen Beamforming (EBF) modes).
- *Cyclic Delay Diversity (CDD) modes, also known as Cyclic Shift Diversity (CSD)* (including modes for 802.11n and later devices to communicate with legacy 802.11 devices). In CDD modes, the same digital data is carried by each transmit antenna, but with different cyclic delays. The signals are highly correlated at any one frequency, though not necessarily at zero time delay. In particular, correlations tend to be high over the bandwidths specified for in-band PSD measurements in FCC rule parts that require reductions in PSD when directional gain exceeds a threshold.

Completely uncorrelated signals include those transmitted in the following modes, if they are not combined with any correlated modes, such as beamforming:

- Space Time Block Codes (STBC) or Space Time Codes (STC) for which different digital data is carried by each transmit antenna during any symbol period (*e.g.,* WiMAX Matrix A [Alamouti coding]).
- Spatial Multiplexing MIMO (SM-MIMO), for which independent data streams are sent to each transmit antenna (*e.g.*, WiMAX Matrix B). WiMAX Matrix C, which adds diversity, also produces uncorrelated transmit signals.

The FCC Laboratory may consider adjustments to this guidance as new modes of operation are brought to its attention.

2) Directional Gain Calculations for In-Band Measurements

a) Basic methodology with N_{ANT} transmit antennas, each with the same directional gain G_{ANT} dBi, being driven by N_{ANT} transmitter outputs of equal power. Directional gain is to be computed as follows:

(i) If *any* transmit signals are *correlated* with each other,
Directional gain = G_{ANT} + 10 log(N_{ANT}) dBi

(ii) If *all* transmit signals are *completely uncorrelated* with each other,
Directional gain = G_{ANT}

Special cases and exceptions to the basic methodology follow in sections b) through f) below.

b) *Sectorized antenna systems*. In sectorized antenna systems in which each antenna is used to transmit different data in a different direction from the other antennas, directional gain is equal to the gain of an individual sector antenna.

c) *Cross-polarized antennas*. For a system in which the antennas have fixed orientations relative to one another that ensure that the antennas are cross-polarized regardless of any user actions, the directional gain is computed as follows.

(i) *Cross-polarized antennas with* $N_{ANT} = 2$. In the case of a transmitter with only two outputs driving a pair of antennas that are cross-polarized (*e.g.*, vertical and horizontal or left-circular and right-circular), directional gain is the gain of an individual antenna. If the two antennas have different gains, the larger gain applies.

(ii) *Multiple antennas, each of which has one of two (or three) polarizations that are orthogonal to one another (i.e., cross polarized)*. (If three polarizations are used, all three polarizations must be mutually orthogonal.) The total gain—including array gain—is computed separately for each of the two (or three) polarizations using the procedures presented in this document. The highest of the total gains shall apply.

d) *Unequal antenna gains, with equal transmit powers.* For antenna gains given by G_1, G_2, …, G_N dBi

(i) If transmit signals are *correlated*, then
Directional gain = $10 \log[(10^{G1/20} + 10^{G2/20} + \ldots + 10^{GN/20})^2 / N_{ANT}]$ dBi [Note the “20”s in the denominator of each exponent and the square of the sum of terms; the object is to combine the signal levels coherently.]

(ii) If all transmit signals are *completely uncorrelated*, then
Directional gain = $10 \log[(10^{G1/10} + 10^{G2/10} + \ldots + 10^{GN/10})/N_{ANT}]$ dBi

e) *Spatial Multiplexing.* In some cases spatial multiplexing is combined with techniques that produce correlated signals, such as beamforming or cyclic delay diversity. This is common when the number transmit antennas exceeds the number of independent data streams (i.e., the number of “spatial streams”) to be transmitted. For cyclic delay diversity, see section f) below. In all other cases directional gain is calculated as follows.

CAUTION: Most devices can operate with one spatial stream ($N_{SS} = 1$, where N_{SS} is the number of spatial streams) even if they also are capable of more spatial streams. The worst case directional gain will occur when $N_{SS} = 1$; therefore, it is especially important to ensure that the device complies with all emission limits for the case of $N_{SS} = 1$ (or with the lowest possible value of N_{SS}, if the device always uses spatial multiplexing). **The application filing must clearly include a proper justification for the lowest value N_{SS} used.**

(i) If all antennas have the same gain, G_{ANT}:

Directional gain = $G_{ANT} + 10 \log(N_{ANT}/N_{SS})$ *dBi*, where N_{SS} = the number of independent spatial streams of data and G_{ANT} is the antenna gain in dBi. (This formula can also be applied when antennas have different gains if the highest antenna gain is substituted for G_{ANT}.)

(ii) If antenna gains are not equal and each transmit antenna is driven by only one spatial stream, directional gain may be calculated by either of the following two formulas.

- *Directional gain* = $G_{ANT\,MAX} + 10 \log(N_{ANT}/N_{SS})$ *dBi*, where N_{SS} = the number of independent spatial streams of data and $G_{ANT\,MAX}$ is.the gain of the antenna having the highest gain (in dBi).

Or,

- $$DirectionalGain = 10 \cdot \log \left[\frac{\sum_{j=1}^{N_{SS}} \left\{ \sum_{k=1}^{N_{ANT}} g_{j,k} \right\}^2}{N_{ANT}} \right]$$

  where

  Each antenna is driven by no more than one spatial stream;
  N_{SS} = the number of independent spatial streams of data;
  N_{ANT} = the total number of antennas
  $g_{j,k} = 10^{G_k/20}$ if the *k*th antenna is being fed by spatial stream *j*, or zero if it is not;
  G_k is the gain in dBi of the kth antenna.

(iii) If antenna gains are not equal and each transmit antenna can be driven by more than one spatial stream, directional gain may be calculated by either of the following two formulas.

- *Directional gain* = $G_{ANT\,MAX} + 10 \log(N_{ANT}/N_{SS})$ *dBi*, where N_{SS} = the number of independent spatial streams of data and $G_{ANT\,MAX}$ is.the gain of the antenna having the highest gain (in dBi).

Or,

$$DirectionalGain = 10 \cdot \log\left[\frac{\sum_{j=1}^{N_{SS}}\left\{\sum_{k=1}^{N_{ANT}} g_{j,k}\sqrt{P_{j,k}}\right\}^2}{N_{ANT}}\right]$$

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where

N_{SS} = the number of independent spatial streams of data;

N_{ANT} = the total number of antennas;

$g_{j,k}$ = $10^{G_k/20}$ if the *k*th antenna is being fed by spatial stream *j*, or zero if it is not;

G_k is the gain in dBi of the *k*th antenna;

$P_{j,k}$ is the relative normalized power (in linear terms, not decibels) of spatial stream *j* feeding the *k*th antenna, normalized such that

$$\sum_{j=1}^{N_{SS}}\left\{\sum_{k=1}^{N_{ANT}} P_{j,k}\right\} = N_{ANT}$$

Note: $P_{j,k} = 0$ if spatial stream *j* does not feed the *k*th antenna.

f) *Cyclic Delay Diversity (CDD) [also known as cyclic shift diversity (CSD)]*. CDD signals are correlated and create unintended array gain that varies with signal bandwidth, antenna geometry, and cyclic delay values. Consequently, depending on system parameters, it may be appropriate to use different values of array gain for compliance with power limits versus compliance with power spectral density limits.
CAUTION: The term CDD, as used here, does not apply to any transmission mode in which the cyclic delay values are chosen to optimize performance at a given receiver; such a system shall be classified as an intentional beamforming system. CDD refers only to cases in which the cyclic delay values are selected apriori with out regard to the specific communication device pair.

For CDD transmissions, directional gain is calculated as follows. In all formulas,
N_{ANT} = number of transmit antennas and
N_{SS} = number of spatial streams. (Assume $N_{SS} = 1$ unless you have specific information to the contrary.)
CAUTION: Most devices can operate with one spatial stream ($N_{SS} = 1$) even if they also are capable of more spatial streams. The worst case directional gain will occur when $N_{SS} = 1$; therefore, it is especially important to ensure that the device complies with all emission limits for the case of $N_{SS} = 1$ (or with the lowest possible value of N_{SS}, if the device always uses spatial multiplexing). **The application filing must clearly include a proper justification for the lowest value N_{SS} used.**

(i) If all antennas have the same gain, G_{ANT}, Directional gain = G_{ANT} + Array Gain, where Array Gain is as follows.

- For power spectral density (PSD) measurements on all devices,
  Array Gain = 10 log(N_{ANT}/N_{SS}) dB.

- For power measurements on IEEE 802.11 devices, [1,2]

  Array Gain = 0 dB (i.e., no array gain) for $N_{ANT} \leq 4$;
  Array Gain = 0 dB (i.e., no array gain) for channel widths ≥ 40 MHz for any N_{ANT};
  Array Gain = 5 log(N_{ANT}/N_{SS}) dB or 3 dB, whichever is less, for 20-MHz channel widths with $N_{ANT} \geq 5$.

- For power measurements on all other devices:

  Array Gain = 10 log(N_{ANT}/N_{SS}) dB. The FCC may permit a lower array gain value based on analysis involving the specific cyclic delays, signal bandwidths, channelization, and antenna configurations used by the device. Contact the FCC through the Knowledge DataBase (www.fcc.gov/labhelp) for more information.

(ii) If antenna gains are not equal, the user may use either of the following methods to calculate directional gain, provided that each transmit antenna is driven by only one spatial stream:

- Directional gain may be calculated by using the formulas applicable to equal gain antennas with G_{ANT} set equal to the gain of the antenna having the highest gain; or,

- $$DirectionalGain = 10 \cdot \log \left[\frac{\sum_{j=1}^{N_{SS}} \left\{ \sum_{k=1}^{N_{ANT}} g_{j,k} \right\}^2}{N_{ANT}} \right]$$

[1] This guidance is based on modeling by the FCC of array gain as documented in a subsequent FCC technical report (Stephen Martin, "Directional Gain of IEEE 802.11 MIMO Devices Employing Cyclic Delay Diversity", FCC/OET 13TR1003, April 5, 2013). The technical report analysis is for the case where no spatial multiplexing is performed (*i.e.*, $N_{SS} = 1$). N_{ANT} in formulas in the technical report is replaced here by N_{ANT}/N_{SS} because spatial multiplexing effectively reduces the number of correlated streams that are transmitted. The model in the technical report sets broadband array gain = 3 dB for the case of 20-MHz channel widths with $N_{ANT} \geq 5$. Here we replace this with the formula 5 log(N_{ANT}/N_{SS}) or 3dB, whichever is less, to accommodate multiple spatial streams. The revised formula was selected to yield a broadband array gain of 3 dB (matching the value in the technical report) when $N_{SS} = 1$, but to permit the value to drop to fixed fraction of the narrowband array gain value of 10 log(N_{ANT}/N_{SS}) with spatial processing, based on the shapes of the upper three curves in Figure 18 of the technical report. We wanted broadband array gain to be no less than 3 dB with $N_{SS} = 1$, which a required that the multiplier of the log(N_{ANT}/N_{SS}) be reduced from 10 by a factor of at least 3 dB / 7 dB or 4.3 to accommodate the case of $N_{ANT} = 5$, so we selected the next higher integer value of 5.)

[2] For channels that cross the 5725 MHz boundary between the upper two U-NII bands, the array gain for the portion of the signal within a single U-NII band can exceed the values shown here. However, in those cases the power levels within the given band will have sufficient margin to make the higher array gain acceptable provided that the relative power levels of the subcarriers above 5725 MHz are not increased to take advantage of the higher power limit in the upper band (See Stephen Martin, "Directional Gain of IEEE 802.11 MIMO Devices Employing Cyclic Delay Diversity", FCC/OET 13TR1003, April 5, 2013). Consequently, a requirement to use the higher gains associated with partial-channels is not included in this guidance. This guidance may be revised in the future if the FCC discovers that subcarrier levels are being adjusted upward for band-straddling channels.

where

Each antenna is driven by no more than one spatial stream;
N_{SS} = the number of independent spatial streams of data;
N_{ANT} = the total number of antennas
$g_{j,k}$ = $10^{G_k/20}$ if the *k*th antenna is being fed by spatial stream *j*, or zero if it is not;
G_k is the gain in dBi of the kth antenna.

(iii) If antenna gains are not equal and each transmit antenna can be driven by more than one spatial stream:

- Directional gain may be calculated by using the formulas applicable to equal gain antennas with G_{ANT} set equal to the gain of the antenna having the highest gain; or,
- $$DirectionalGain = 10 \cdot \log \left[\frac{\sum_{j=1}^{N_{SS}} \left\{ \sum_{k=1}^{N_{ANT}} g_{j,k} \sqrt{P_{j,k}} \right\}^2}{N_{ANT}} \right]$$

where

N_{SS} = the number of independent spatial streams of data;
N_{ANT} = the total number of antennas;
$g_{j,k}$ = $10^{G_k/20}$ if the *k*th antenna is being fed by spatial stream *j*, or zero if it is not;
G_k is the gain in dBi of the *k*th antenna;
$P_{j,k}$ is the relative normalized power (in linear terms, not decibels) of spatial stream *j* feeding the *k*th antenna, normalized such that

$$\sum_{j=1}^{N_{SS}} \left\{ \sum_{k=1}^{N_{ANT}} P_{j,k} \right\} = N_{ANT}$$

Note: $P_{j,k}$ = 0 if spatial stream *j* does not feed the *k*th antenna.

3) Directional Gain Calculations for Conducted Out-of-Band and Spurious Measurements

a) Directional gain calculations for out-of-band and spurious measurements are not required in the following circumstances:

(i) When out-of-band and spurious emissions compliance is demonstrated exclusively by radiated measurements (unless radiated measurements are performed with a subset of the antennas transmitting and then combined with measurements performed with other antennas transmitting); or

(ii) When out-of-band and spurious emission limits are specified as absolute conducted power levels at the antenna ports (rather than EIRP) in a given bandwidth with no required reduction based on directional gain;[3] or

(iii) When conducted measurements are used (if permitted) to demonstrate compliance with a relative out-of-band limit (e.g., a requirement that out-of-band emissions be attenuated by X dB relative to in-band emissions, where X does not depend on power). In such cases, adjustment for directional gain is generally not necessary because the directionality applies to both the in-band and the out-of-band emissions.

b) In cases where a combination of conducted measurements and cabinet radiated measurements are permitted to demonstrate compliance with absolute radiated out-of-band and spurious limits (e.g., KDB Publications 558074 for DTS and 789033 for U-NII), the conducted measurements must be combined with directional gain to compute the radiated levels of the out-of-band and spurious emissions as described in this section.

c) Directional gain for out-of-band and spurious emissions shall be computed in the same way as for in-band signals except as follows:

(i) Gain of each antenna shall be based on the guidance in the relevant KDB publication (e.g., the guidance may not permit use of gain values less than 2 dBi in the formulas).

(ii) For narrowband lines such as might originate from a clock or local-oscillator (including harmonics thereof), the formulas for correlated transmit signals shall be used. For all other out-of-band emissions, the correlation assumptions applicable to the in-band signals shall apply.[4]

d) Radiated testing alternative. The guidance in section c) above is likely to overestimate the out-of-band gains of the individual antennas as well as the array gain—leading to computed emission levels that may significantly exceed the actual radiated emission levels. Consequently, if conducted tests

[3] Many licensed rule parts express out-of-band emission limits as an attenuation below the in-band power level of X + 10 log P dB, where P is the transmit power. Such limits correspond to absolute out-of-band limits. For example, if the out-of-band emissions must be attenuated by at least 43 + 10 log P dB below the transmit power, the limit corresponds to an absolute limit of -43 dBW or -13 dBm. When the attenuation levels are expressed relative to transmit power (rather than relative to EIRP or ERP), the absolute emission limit corresponds to an absolute conducted power level. In such a case, there is no need to add the effect of directional gain. If the limit specifies a minimum attenuation below the in-band EIRP or ERP, then the out-of-band limit corresponds to an absolute EIRP or ERP and directional gain must be added to the conducted measurements.

[4] 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.

based on this guidance indicate failures to satisfy the out-of-band limits, it is recommended that radiated tests be performed around the frequencies at which the apparent failures occurred.

CHANGE NOTICE

10/28/2011: 662911 D01 Multiple Transmitter Output v01 change to 662911 D01 Multiple Transmitter Output v01r01 to add references to new attachment 662911 D02 in the second paragraph of the document and in the INTRODUCTION section. The referenced attachment identifies an exception to the requirement for summing emissions across outputs in certain cases involving devices that drive cross-polarized antennas and identifies the need to sum radiated emissions across polarizations in certain other cases.

09/26/2012: 662911 D01 Multiple Transmitter Output v01r01 change to 662911 D01 Multiple Transmitter Output v01r02 as follows:

(1) Changed language in the first three paragraphs (before INTRODUCTION) to clarify that the guidance also applies composite systems that employ multiple transmitters with outputs occupying the same or overlapping frequency ranges.

(2) Add special provisions for broadband array gain of transmissions employing cyclic delay diversity and for transmissions that combine spatial diversity with beamforming or with cyclic delay diversity. Reason for change: to improve the accuracy of directional gain calculations, thus minimizing required power reductions.

(3) Add section, "Directional Gain Calculations for Conducted Out-of-Band and Spurious Measurements", to specify that array gain must be included when using conducted measurements to demonstrate compliance with radiated out-of-band and spurious emission limits and to specify how that array gain is to be computed. Reason for change: to provide guidance for conducted out-of-band emission measurements, where permitted (*e.g.*, KDB Publications 558074 for DTS and 789033 for U-NII)

5/24/2013: 662911 D01 Multiple Transmitter Output v01r02 change to 662911 D01 Multiple Transmitter Output v02 as follows:

(1) Added paragraph and heading numbers and table of contents. Reason for change: to make it easier to reference sections of the publication

(2) Restructured and clarified wording, including clarification in section A) that the document applies to hosts with multiple modular transmitters.

(3) Added measurement alternatives for in-band power spectral density and for out-of-band and spurious emissions to permit summation of spectral maxima across the outputs (sections E)2)b) and E)3)a)(ii)). Reason for change: may offer simplified testing in some cases.

(4) Clarified that the requirement to sum outputs in power units is satisfied by summing in voltage-squared units (sections D) and E)3)a)). Reason for change: this may be more convenient than mW when emission limits are specified in field-strength units.

(5) Added formulas for directional gain of communication modes involving spatial multiplexing and/or cyclic delay diversity for cases where antenna gains are not equal (sections F)2)e) and F)2)f)). Reason for change: add flexibility.

(6) Rewrote section F)3), "Directional Gain Calculations for Conducted Out-of-Band and Spurious Measurements", to reference all formulas used for the corresponding in-band calculations. Reason for change: to incorporate special cases such as sectorized antennas, cross-polarized antennas, unequal antenna gains, etc.

(7) Referenced Technical Report FCC/OET 13TR1003, "Directional Gain of IEEE 802.11 MIMO Devices Employing Cyclic Delay Diversity"). Reason for change: provide the technical basis for formulas for array gain of IEEE 802.11 devices transmitting with Cyclic Delay Diversity (CDD).

(8) Added paragraph F)3)a)(ii) specifying that directional gain calculations for out-of-band and spurious measurements are

not required when out-of-band and spurious emission limits are specified as absolute conducted power levels in a given bandwidth with no required reduction based on directional gain.

10/31/2013: 662911 D01 Multiple Transmitter Output v02 change to 662911 D01 Multiple Transmitter Output v02r01 as follows. Revised section F)2)c) to include gain calculation methodology for devices with multiple antennas having two or three mutually orthogonal polarizations.