Proposed Updated Guidance for Conducted Emissions Testing of Transmitters with Multiple Outputs in the Same Band (e.g., MIMO, Smart Antenna, etc)

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Applicability

This proposed guidance is intended to apply to:
- Conducted emissions testing (In-Band, Out-of-Band, Spurious) to demonstrate compliance with FCC rules
- Licensed and Unlicensed Devices
- Single transmitter with multiple outputs in the same band (Device transmits on multiple antennas simultaneously through a coordinated process); for example:
  - 802.11n modem with multiple transmit antennas
  - WiMAX device with multiple transmit antennas

This guidance does **not** apply to:
- Radiated emissions testing
- Composite-system devices
  - Multiple transmitters (e.g., an 802.11 modem and a GSM phone in one enclosure)—each driving its own antenna
Issues for Conducted Testing of Emissions from Transmitters with Multiple Outputs

**Combined emissions**
- Emission limits apply to the total of emissions from all outputs
- Emissions from transmitter outputs must be combined or summed

**Array gain → directional gain**
- **Correlation** between transmitted signals can lead to array gain
  - Increases the directional gain of the device
  - Leads to higher radiated levels in some directions
- **Array gain** must be considered whenever directional gain matters; i.e.,
  - For conducted in-band emission limits that vary with directional gain
  - Or, when conducted measurements + antenna gain are used for compliance with in-band radiated limits

These factors are automatically included in radiated emissions measurements (if measurements are performed in direction of maximum response);

Topics of this presentation:
(1) How to combine emissions from multiple outputs
(2) How to include array gain in directional gain computations
Common Techniques for Combining Emissions from Multiple Outputs

Measure and sum
- Measure conducted emissions (e.g., transmit power or power in specified bandwidth) of at each antenna port
- Add the emissions in linear power units (e.g., mW—not dBm)

Use a combiner
- Measure using a 0-degree combiner and adjust for insertion loss of the combiner.
- Result will correctly indicate power in the measurement band only if transmitted signals are uncorrelated at zero time-delay.
  - Otherwise, result may be too high (positive correlation) or too low (negative correlation)
Proposed Guidance for Combining Emissions from Multiple Outputs

**In-band power**
- Use the **measure-and-sum** technique. Do NOT use a combiner.
  [Matches existing FCC guidance since 2005.]

**In-band power spectral density (PSD)** [New guidance]
Use one of the following methods:
- **Measure and sum spectra**
  - Measure each output individually and sum the spectra in linear power units
  - Probably requires external calculations—e.g., in a spreadsheet

- **Measure and add 10 log(N) dB**, where N is the number of outputs
  - Measure each output individually.
  - Add 10 log(N) before comparing to the emission limit. This serves to apportion the emission limit among the N outputs so that each output is permitted to contribute only $1/N^\text{TH}$ of the total power permitted in the specified measurement bandwidth by the rules. [This 10 log(N) term is not related to array gain calculations.]
Proposed Guidance for Combining Emissions from Multiple Outputs (continued)

**Out-of-band and spurious emissions** [New guidance]

Use one of the following methods:

- **Measure and sum spectra** (as described on preceding slide)
- **Measure and add 10 log(N) dB** (as described on preceding slide)
- **Use a 0-degree combiner** (Be sure to adjust for insertion loss)
  - Must test out-of-band and spurious emissions for multiple beam steering positions

Measurements should be performed in a representative sampling of beam positions. For example, for a device with a single steerable beam, it is recommended that tests be performed with a three beam positions—one at each extreme steering angle and one near the middle of the steering range. In any case, ensure that the angle forming the maximum beam is tested.

Relative out-of-band and spurious emission limits may be tested individually on each output without summing or adding 10 log(N) if measurements are made relative to the in-band emissions on the individual outputs.

Examples of relative limits:

- OOB emissions in 100 kHz bandwidth must be 20 dB below the highest power in 100 kHz in-band
- Emissions in a 1-MHz bandwidth must be reduced at least X dB below the transmit power (where X does not vary with transmit power)

Emission limits specified as X + 10 log(P) dB below the transmit power are not considered “relative limits” for purposes of this guidance.
Existing FCC Guidance on Directional Gain

Directional Gain Computation (from “Smart Antenna Systems” presentation by Joe Dichoso to TCBs in 2005)

- **Phased array systems**
  - Directional gain = gain of antenna element + 10 log(# of TX antenna elements)

- **Sectorized systems**
  - Directional gain = gain of each antenna

- **Spatial Multiplexing MIMO system**
  - For any spatial multiplexing “MIMO” mode in which the elements are always driven incoherently at each frequency…
    - Directional gain = gain of each antenna
  - For all other modes that drive multiple antenna elements, including legacy modes for communicating with non-MIMO devices…
    - Directional gain = gain of antenna element + 10 log(# of TX antenna elements)

Bottom line: Must add 10 log(N) to individual antenna gains except for sectorized systems and spatial multiplexing MIMO modes
Outline of Proposed Changes in Guidance on Directional Gain

Define directional gain based on output correlation
- “Correlated”: Gain = antenna gain + 10 log(N)
- “Completely uncorrelated”: Gain = antenna gain

Categorize as correlated or completely uncorrelated
- General guidance
- Specific cases

Exceptions
- Sectorized systems \(\rightarrow\) Gain = sector antenna gain
- Cross-polarized antennas \(N=2\) \(\rightarrow\) Gain = antenna gain
- Unequal antenna gains \(\rightarrow\) new formula
Proposed Guidance for Determining Directional Gain

N antennas of directional gain $G_{\text{ANT}}$ dBi driven w/equal power
- If any transmit signals are correlated with each other
  - Directional gain = $G_{\text{ANT}} + 10 \log(N)$ dBi
- If all transmit signals are completely uncorrelated with each other
  - Directional gain = $G_{\text{ANT}}$ dBi

Special Cases
- Sectorized antenna systems
  Each antenna is used separately to communicate in a different direction
  - Directional gain = gain of individual sector antenna
- Cross-polarized antennas with $N = 2$ [New guidance]
  (e.g., vertical and horizontal or left-circular and right-circular )
  - Directional gain = $G_{\text{ANT}}$
- Unequal antenna gain, equal transmit powers [New guidance]
  For antenna gains = $G_1, G_2, \ldots, G_N$ dBi
  - If transmit signals are correlated, then
    - Directional gain = $10 \log\left(\frac{10^{G_1/20} + 10^{G_2/20} + \ldots + 10^{G_N/20}}{N}\right)$ dBi
  - If all transmit signals are completely uncorrelated, then
    - Directional gain = $10 \log\left(\frac{10^{G_1/10} + 10^{G_2/10} + \ldots + 10^{G_N/10}}{N}\right)$ dBi

Note “20” in exponents!
Output signals are considered **correlated** if: [New guidance]
- 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 any 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 signals are considered **completely uncorrelated**.

The FCC Laboratory may consider adjustments to this guidance as new modes of operation are brought to its attention.
Specific Cases of Signal Correlation Among Multiple Outputs

**Correlated signals**
- Any transmit beamforming mode, whether fixed or adaptive
  - Examples: Phased arrays, Closed Loop MIMO, Transmitter Adaptive Antenna, Maximum Ratio Transmission (MRT), or Statistical Eigen Beamforming (EBF)
- Cyclic Delay Diversity (CDD) modes
  - Example: Legacy modes in 802.11n
  - Same digital data carried by each Tx antenna, but with different cyclic delays
  - Signals are highly correlated at any one frequency

  [Consistent with FCC guidance since 2005, CDD modes are considered correlated when computing directional gain due to high correlations over the bandwidths specified for in-band power spectral density (PSD) in FCC rule parts that require reductions in PSD when directional gain exceeds a threshold.]

**Completely uncorrelated signals** (if not combined with a correlated mode)
- Space Time Block Codes (STBC) or Space Time Codes (STC) for which different digital data is carried by each Tx antenna during any symbol period
  - Example: WiMAX Matrix A (Alamouti coding)
- Spatial Multiplexing MIMO (SM-MIMO)
  - Example: WiMAX Matrix B; Matrix C, which adds diversity, is also uncorrelated
  - Independent data streams sent to each Tx antenna

  [Under previous guidelines, only SM-MIMO signals could be considered uncorrelated for purposes of directional gain computation.]
We Want Your Feedback

These proposed guidelines represent an attempt to balance the following—often conflicting—objectives:

- Simplicity and ease of interpretation
- Unambiguous interpretation
- Flexibility in adapting to future communication modes
- Precision in implementing the rules
- Tests can be conducted with equipment beyond commonly available at test labs

We want your suggestions

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The End