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 $1/N^{TH}$ 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.

  <u>Relative</u> 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 <u>individual</u> 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 absolute limits are <u>not</u> 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 → Gain = sector antenna gain
  - Cross-polarized antennas (N=2) → Gain = antenna gain
  - Unequal antenna gains → new formula

Proposed Guidance for Determining Directional Gain

- N antennas of directional gain G_{ANT} dBi driven w/equal power
  - If <u>any</u> transmit signals are <u>correlated</u> with each other
    - Directional gain = G_{ANT} + 10 log(N) dBi
  - If <u>all</u> transmit signals are <u>completely uncorrelated</u> with each other
    - Directional gain = G_{ANT} dBi
- Special Cases
  - <u>Sectorized antenna systems</u>

    Each antenna is used separately to communicate in a different direction
    - Directional gain = gain of individual sector antenna
  - <u>Cross-polarized antennas</u> with N = 2 [New guidance]

    (e.g., vertical and horizontal or left-circular and right-circular)
    - Directional gain = G_{ANT}
  - <u>Unequal antenna gain</u>, equal transmit powers [New guidance]

    For antenna gains = G_1, G_2, …, G_N dBi

    Note "20" in exponents!
    - If transmit signals are <u>correlated</u>, then
      - Directional gain = $10 \log[(10^{G_1/20} + 10^{G_2/20} + \ldots + 10^{G_N/20})^2 / N]$ dBi
    - If all transmit signals are <u>completely uncorrelated</u>, then
      - Directional gain = $10 \log[(10^{G_1/10} + 10^{G_2/10} + \ldots + 10^{G_N/10})/N]$ dBi

General Guidance for Determining Signal Correlation Among Multiple Outputs

- 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