Revisions to MIMO KDB Publication # 662911 D01

"Emissions Testing of Transmitters with Multiple Outputs in the Same Band"

TCB Workshop

October 9, 2012

Steve Martin

Summary of the Revisions

- Clarify that the KDB applies to:
  – A single transmitter with multiple outputs <u>or</u>
  – Multiple transmitters that are part of a composite system
- Revise Directional Gain Calculations for:
  – Cyclic Delay [Shift] Diversity (CDD/CSD)
  – Spatial multiplexing combined with CDD/CSD or beamforming
- Add new directional gain calculations for:
  – Out-of-Band and Spurious Emissions

Remainder of presentation after overview

Overview of MIMO KDB 662911 D01: Applicability

- Applies only to:
  - Antenna-port conducted measurements on…
  - Devices or composite systems with multiple-transmitter outputs in same or overlapping frequency range (e.g., MIMO)

Applies only to conducted measurements

Overview of MIMO KDB: Main Points

- **FCC limits apply to total emissions across all outputs**
- ***Directional gain =***
  individual antenna gain + array gain
  - For mutually uncorrelated signals (e.g., pure spatial multiplexing)
    - *Array gain = 0 dB*
  - For correlated signals (e.g., beamforming, cyclic delay diversity [CDD], or combination of correlated and uncorrelated):
    - *Array gain = 10 log(N_{ANT}) dB*,
      where N_{ANT} = number of transmit antennas.

Revision reduces calculated array gain for some cases of:
(1) Cyclic delay diversity (CDD)
(2) Combination of spatial multiplexing with beamforming or CDD.

Sidebar: When does directional gain matter for conducted measurements?

- When a conducted limit depends on directional gain
  - e.g., 15.247 (DTS), 15.407 (U-NII), or Part 90Y: Rules specify reduction in limits if directional gain exceeds X dBi.
- When conducted measurements are used for compliance with a radiated limit
  - e.g., in-band EIRP limit satisfied by measuring conducted power and adding directional gain
  - e.g., out-of-band field strength limit satisfied (in part) by measuring conducted emissions and adding directional gain *[New in this revision]*

Topics

Array gain calculations for:

- Spatial multiplexing when combined with beamforming or CDD
- Cyclic Delay Diversity (CDD/CSD)
- Out-of-Band and Spurious Emissions

Spatial Multiplexing

- Terms
  - N_{ANT} = *Number of transmit antennas*
  - N_{SS} = *Number of spatial streams* (i.e., # of independent data streams). Spatial multiplexing occurs when $N_{SS} > 1$
- Pure spatial multiplexing: Independent data is transmitted on each antenna
  - $N_{SS} = N_{ANT}$
  - No correlation between Tx outputs ➔ *Array gain = 0 dB*
- Spatial multiplexing combined with beamforming or CDD (correlated techniques) [$1 < N_{SS} < N_{ANT}$]
  - Previous guidance: *Array gain = 10 log(N_{ANT})*
  - **New guidance: *Array gain = 10 log(N_{ANT}/N_{SS})***
    - See variations for cyclic delay diversity in 802.11

Array gain is highest when $N_{SS} = 1$

Spatial Multiplexing (continued)

Caution!!!!

- Most devices that use spatial multiplexing also have some transmit modes with no spatial multiplexing (i.e., $N_{SS} = 1$)
- Highest gain occurs when $N_{SS} = 1$
  – More likely to exceed emission limits when $N_{SS} = 1$ unless transmit power increases with N_{SS}

➔ Be certain to ensure compliance with the lowest value of N_{SS} (usually $N_{SS} = 1$). The application filing must clearly include a proper justification for the lowest value used.

Spatial Multiplexing in 802.11

- **802.11a/b/g** → $N_{SS} = 1$
- **802.11n** modes– See table ➔
- **Pre 802.11ac** (Draft P802.11ac_D3.0)
  - Can operate with $N_{SS} = 1$ to 8
  - N_{SS} not defined by MCS index

802.11n Modes
(Tables 20-30 to 20-44
of IEEE Std 802.11-2012)

Modulation and Coding Scheme Index	Number of Spatial Streams (N_{SS})
MCS 0 – MCS 7	1
MCS 8 – MCS 15	2
MCS 16 – MCS 23	3
MCS 24 – MCS 31	4
MCS 32	1
MCS 33 – MCS 38	2
MCS 39 – MCS 52	3
MCS 53 – MCS 76	4

Cyclic Delay Diversity (CDD)
[also called Cyclic Shift Diversity (CSD)]

- A different cyclic delay is added to each Tx output
- Creates array gain unintentionally
- Direction(s) of maximum gain vary with frequency
  - At a single frequency (or over a narrow band), array gain can be ≈ 10 log(N_{ANT})
    [applies to power spectral density measurements]
  - Broadband array gain < narrowband array gain due to smearing for directional pattern with frequency
    [applies to power measurements]
- Gain varies with array geometry, cyclic delays, bandwidth, and center frequency

Analysis on next 10 slides is specific to CDD for 802.11

FCC Analysis of 802.11 CDD: Two Sets of Cyclic Delays

Short Cyclic Delays

(Table 22-10 of IEEE Draft P802.11ac_D3.0*)

Short cyclic delays change character for N>5: Multiples of 25 ns vs 50 ns and irregular order

	Delay (ns) for Specified Antenna							
N_{ANT}	1	2	3	4	5	6	7	8
2	0	200						
3	0	100	200					
4	0	50	100	150				
5	0	175	25	50	75			
6	0	200	25	150	175	125		
7	0	200	150	25	175	75	50	
8	0	175	150	125	25	100	50	200

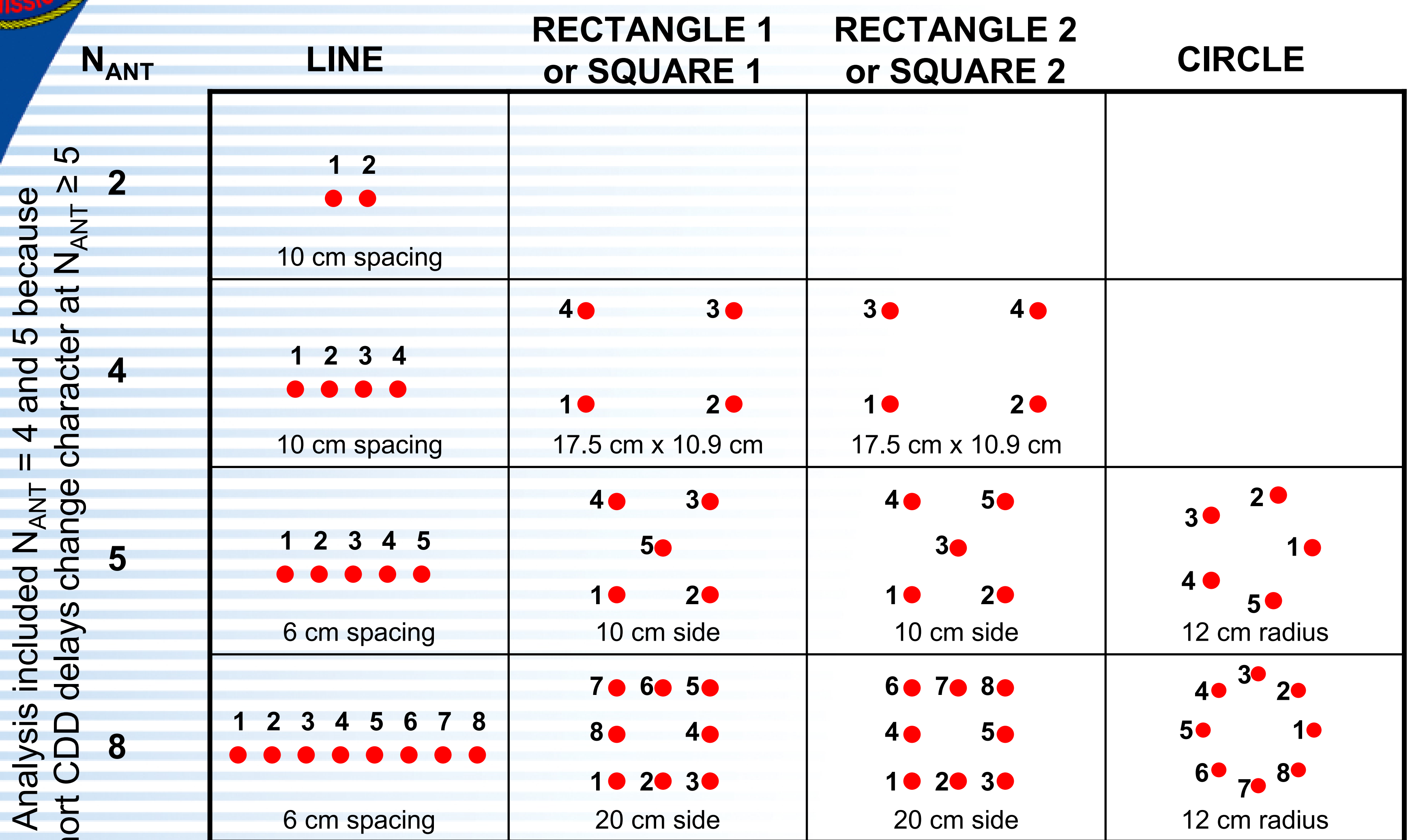
Long Cyclic Delays

(Table 22-11 of IEEE Draft P802.11ac_D3.0*)

	Delay (ns) for Specified Antenna							
N_{ANT}	1	2	3	4	5	6	7	8
2	0	400						
3	0	400	200					
4	0	400	200	600				
5	0	400	200	600	350			
6	0	400	200	600	350	650		
7	0	400	200	600	350	650	100	
8	0	400	200	600	350	650	100	750

* Delays for $N_{ANT} \leq 4$ match 802.11-2012

FCC Analysis of 802.11 CDD: Array Configurations



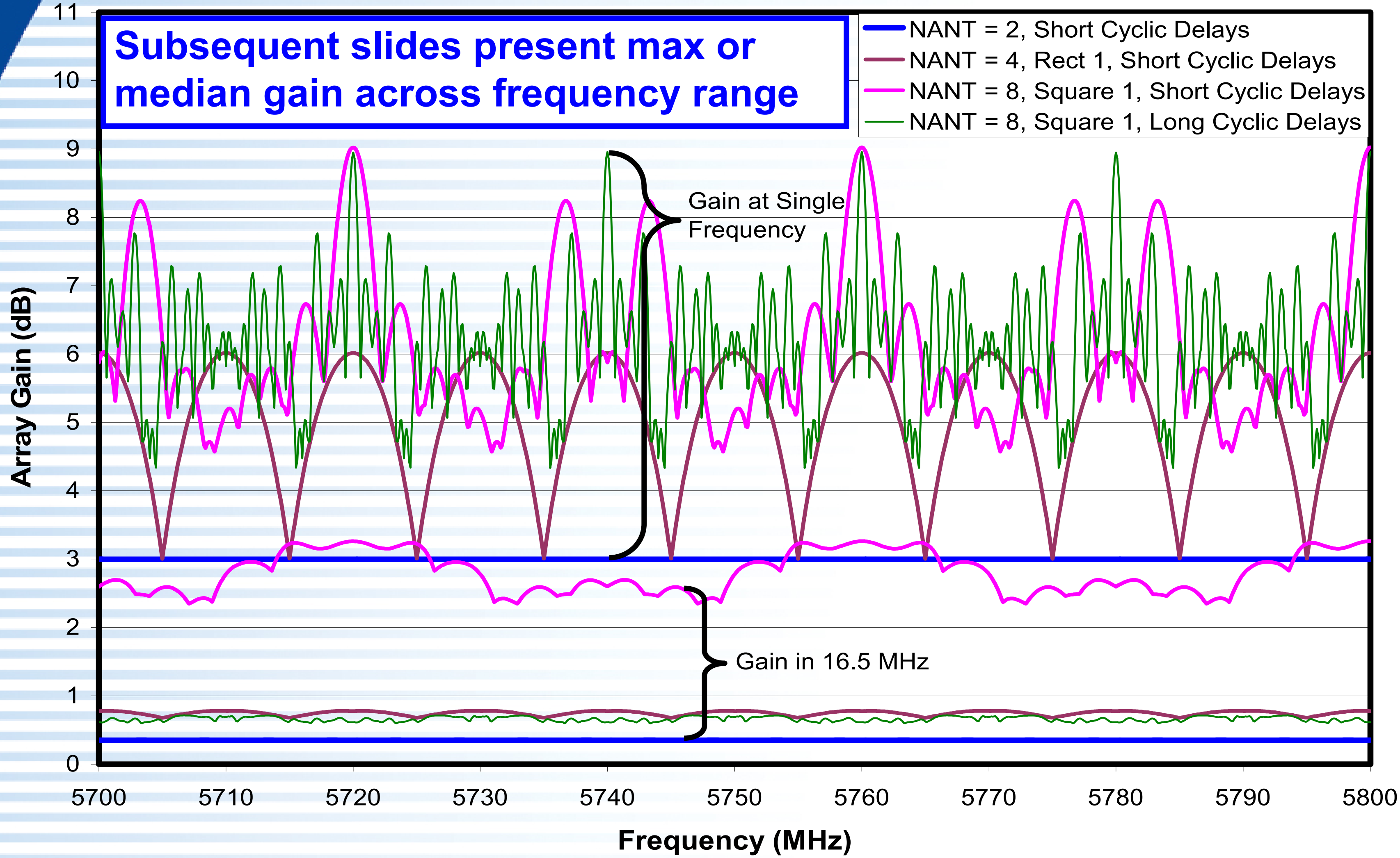
All arrays are in horizontal plane with omnidirectional antennas

FCC Analysis of 802.11 CDD: Methodology

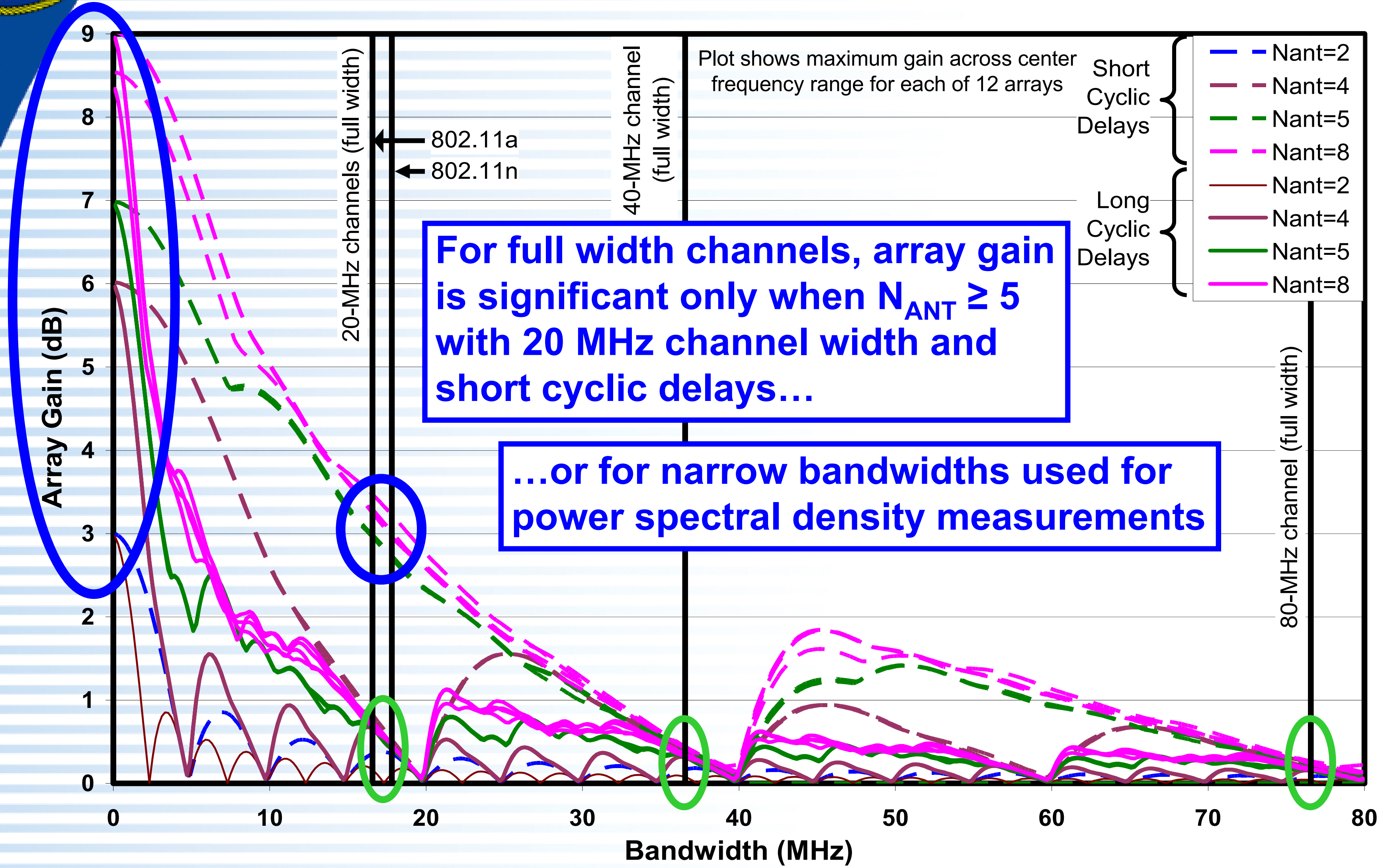
- Wrote MATLAB code to compute directional response
  - 0-360° azimuth and 0-45° elevation
  - "Smeared" patterns over bandwidths of 0 – 80 MHz
  - Center frequencies from 5700-5800 MHz
  - For each bandwidth and center frequency, found peak response (array gain)
  - Found max and median array gain across center frequency range

$N_{SS} = 1$ for all analysis

FCC Analysis of 802.11 CDD: Array Gain Vs Frequency Examples

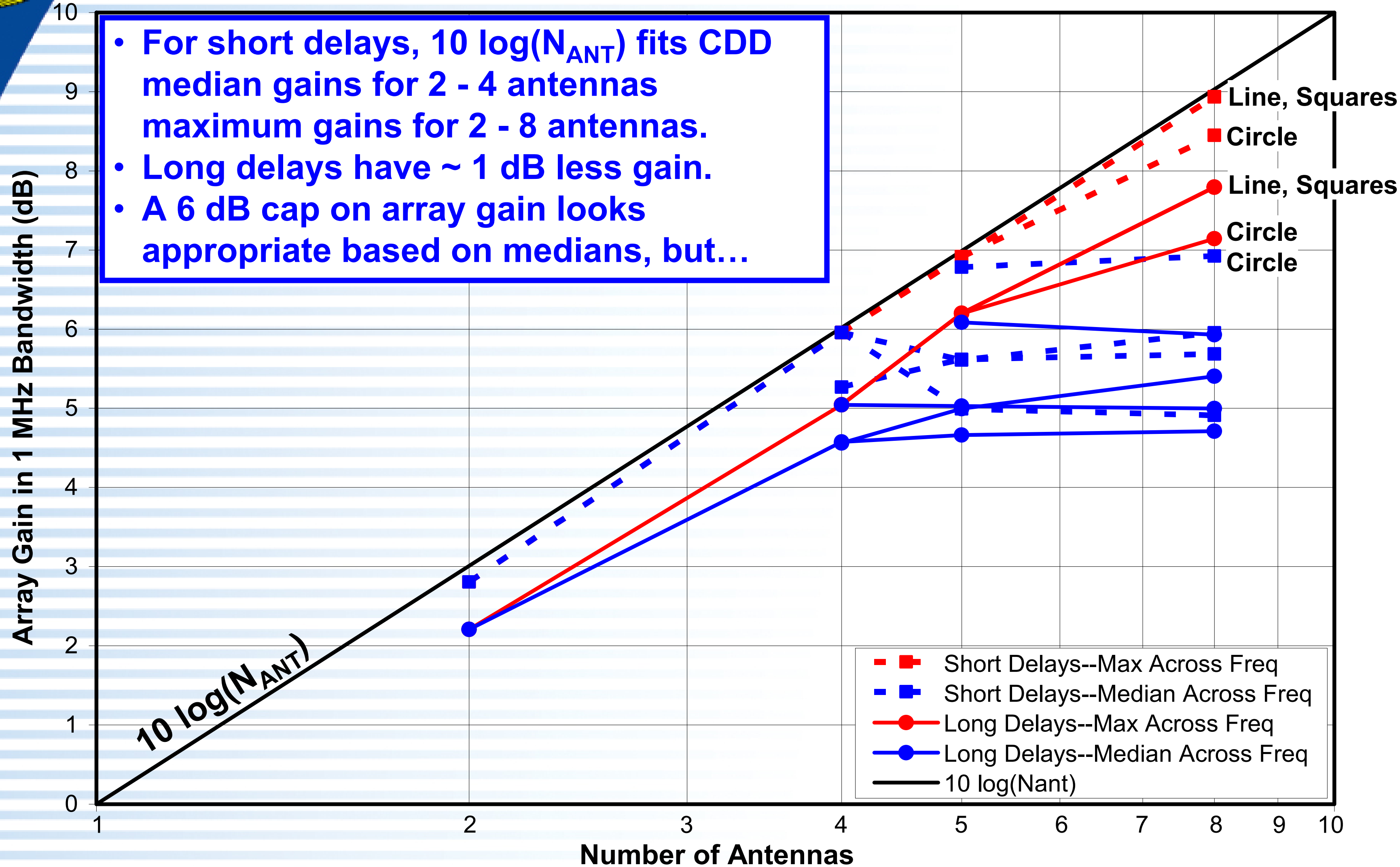


FCC Analysis of 802.11 CDD: Maximum Array Gain Vs Bandwidth

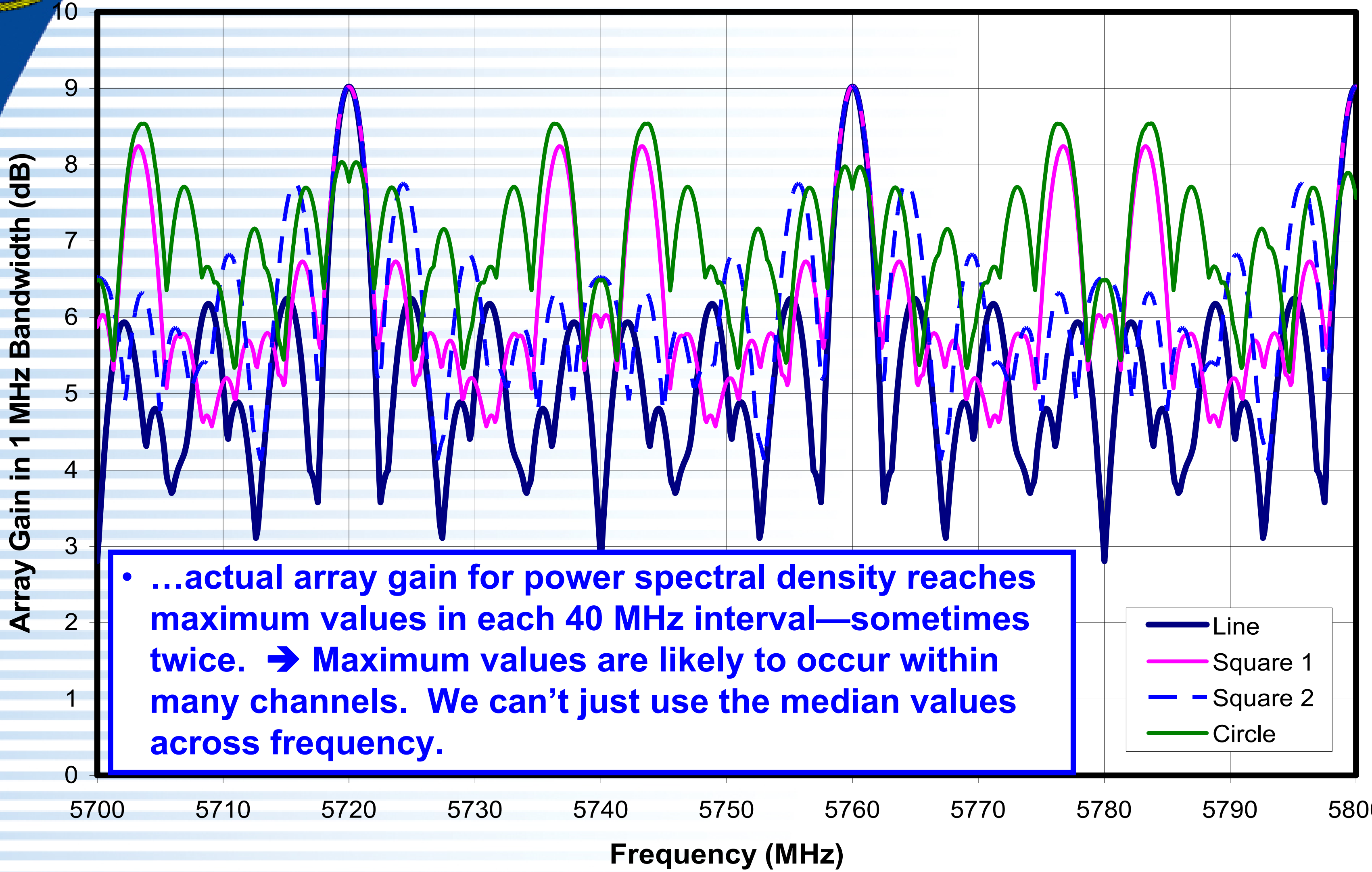


FCC Analysis of 802.11 CDD: Array Gain for 1 MHz Bandwidth

- For short delays, $10 \log(N_{ANT})$ fits CDD median gains for 2 - 4 antennas maximum gains for 2 - 8 antennas.
- Long delays have ~ 1 dB less gain.
- A 6 dB cap on array gain looks appropriate based on medians, but…

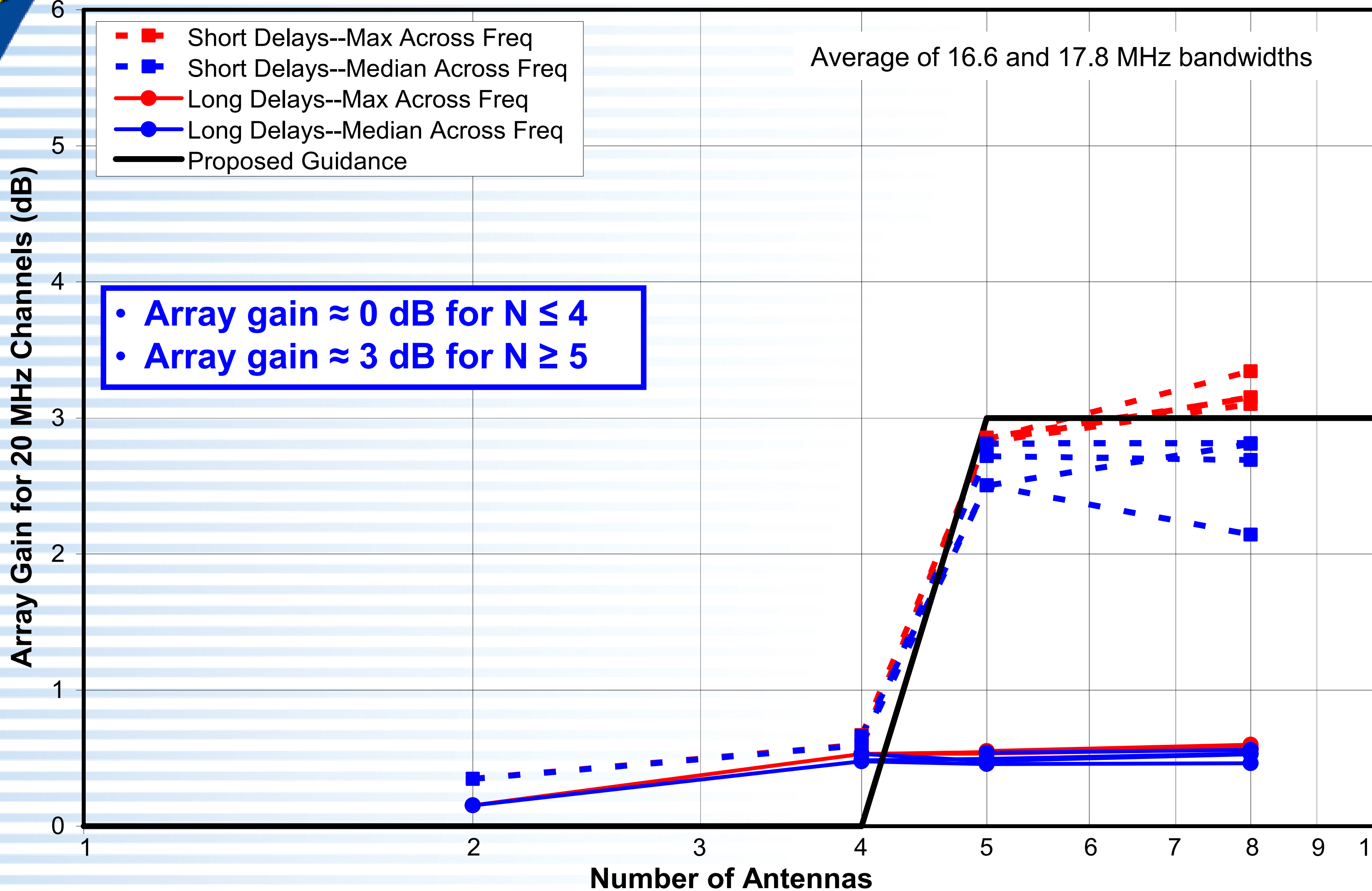


FCC Analysis of 802.11 CDD: Array Gain for 1 MHz Bandwidth



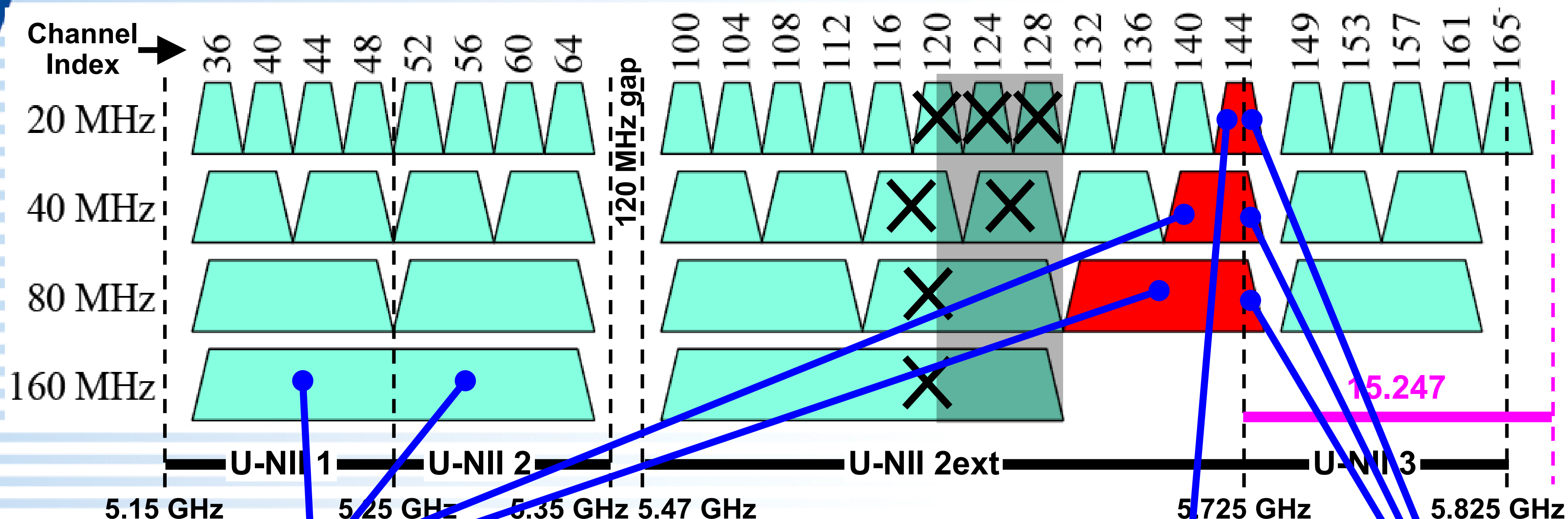
- …actual array gain for power spectral density reaches maximum values in each 40 MHz interval—sometimes twice. ➔ Maximum values are likely to occur within many channels. We can't just use the median values across frequency.

FCC Analysis of 802.11 CDD: Array Gain for 20 MHz Channels



FCC Analysis of 802.11 CDD: Effects of Band Straddling

What if array gain is high for the portion of a channel that falls within one FCC band?



No problem here: 33-78 MHz in band ➔ Gain < 1 dB

But here: 13.3 – 13.9 MHz in U-NII 3 ➔ up to 4 dB gain

And here: 3.3 – 3.9 MHz in U-NII 2ext ➔ up to 8 dB gain

FCC Analysis of 802.11 CDD: Effects of Band Straddling

- Decision: No requirement for separate calculation of array gain of band-straddling channels
  – Increased gain is offset by reduced power in band and by higher limits in U-NII 3 band
- May revisit if we find that power of U-NII 3 subcarriers of split channels are increased

Revised Cyclic Delay Diversity Guidance

- *Total Directional Gain = Individual antenna gain + Array gain*
- **To Compute Limits on Power Spectral Density (PSD):**
  - ***Array gain = 10 log(N_{ANT}/N_{SS})***, where N_{ANT} = # of transmit antennas and N_{SS} = # of spatial streams
- **To Compute Limits on Power**
  - **For 802.11 devices**:
    - ***Array gain = 0 dB*** for $N_{ANT} \leq 4$
    - ***Array gain = 0 dB*** for channel widths ≥ 40 MHz for any N_{ANT}
    - ***Array gain = 5 log(N_{ANT}/N_{SS}) or 3 dB***, whichever is less, for 20-MHz channel widths with $N_{ANT} \geq 5$
  - **For all other devices**:
    - ***Array gain = 10 log(N_{ANT}/N_{SS})***, or…
    - Consult with the FCC, providing details of specific cyclic delays, channelization, signal bandwidths, and antenna configurations.

Be certain to ensure compliance with $N_{SS} = 1$

Need for Array Gain Calculation for Out-of-Band (OOB) and Spurious Emissions

- Applies only when conducted measurements contribute to proving compliance with radiated limits
- Motivation: KDB Pubs. 558074 (DTS) and 789033 (U-NII) now permit OOB & spurious compliance to be demonstrated by combination of:
  - Cabinet radiated measurements and
  - Antenna-port conducted measurements
    - *Radiated emission = measured conducted emission + directional gain + conversion to field strength*

New Guidance on Array Gain for Out-of-Band (OOB) and Spurious Emissions

- *Directional gain = individual antenna gain + array gain*
- *Array gain =*
  – *10 log(N_{ANT})* for narrowband lines such as might originate from a clock or local-oscillator, including harmonics;
  – The value applicable for in-band PSD measurements, at all other frequencies.

These array gain values are conservative. Use radiated measurements at/near frequencies where conducted tests do not show compliance.

Summary of Revisions to MIMO KDB Publication 662911 D01

- Clarification that the KDB applies to:
  - A single transmitter with multiple outputs or
  - Multiple transmitters that are part of a composite system
- Revised Directional Gain Calculations for:
  - Cyclic Delay Diversity (CDD) for 802.11 devices
  - Spatial multiplexing when combined with CDD or beamforming
- New directional gain calculations for:
  - Out-of-Band and Spurious Emissions

Applies only to conducted measurements

Questions and Answers

Thanks!