Draft KDB 248227

802.11 Wi-Fi SAR Procedures

TCB Workshop

April 2014

Laboratory Division
Office of Engineering and Technology
Federal Communications Commission

Overview

- Proposal to update KDB 248227
  - presented in Oct 2013 TCB workshop and posted for review on Dec 5
  - Review period closed on Jan 10, 2014 and received two comments
- Draft KDB 248227 for release around April TCB workshop time frame, includes
  - general info on 802.11 Wi-Fi protocols
  - expanded details of the test procedures
  - changes and adjustments to the original proposal

General Considerations

- The procedures are intended for §§15.247 and 15.407 Wi-Fi devices operating in the 2.4 and 5 GHz bands according to IEEE Std 802.11-2012 and Std 802.11ac-2013
  - P802.11ac/D7.0 used, need update according to 802.11ac-2013
- Unless it is specifically described, the test guidance may not fully apply to devices approved under other FCC rules or 802.11 Wi-Fi variants and proprietary implementations
- Typical SAR testing difficulties for Wi-Fi include
  - compatibility with earlier 802.11 protocols resulting in numerous wireless transmission mode configurations
  - simple generic procedures may not accommodate various types of Wi-Fi variant or proprietary implementations
- Test difficulties also introduce TCB review & approval issues

Wi-Fi Evolution

- The earlier IEEE 802.11 standards and amendments have been consolidated by the latest IEEE Std 802.11-2012
  - from the early-on 2.4 GHz 802.11 frequency hopping and DSSS
  - to latest 802.11n/ac MIMO and transmit beamforming (TxBF)
- Wi-Fi devices are continuously evolving
  - from simple cordless phones and plug-in cards to today's cellphones, laptops, tablets and other complex host devices
  - from standalone operations to recent peer-to-peer connections, simultaneous transmission and hotspot mode etc.
- Ad hoc, proprietary or non-standard designs are often used
  - to enhance data throughput and wireless coverage
  - to accommodate draft standard (pre-release) implementations

SAR Testing Concerns

- Fundamental SAR measurement guidance is in KDB 865664
- Host platform specific procedures are in other KDB publications
- KDB 248227 provides specific SAR guidance for 802.11 Wi-Fi
  - SAR test reduction and exclusion considerations
  - transmission mode configurations required for SAR measurement
- Chipset & vendor specific test modes are used for SAR testing
  - loopback test modes are not defined in 802.11 standards
  - Wi-Fi networks are unstable and not suitable for SAR measurement
- Additional SAR considerations may be required to address
  - transmit diversity, MIMO, TxBF and other simultaneous transmission schemes
  - maximum output power variations, certain antenna spatial arrangements

802.11 PHY

- The SAR test configurations are closely associated with 802.11 PHY characteristics
- 2.4 GHz 802.11 frequency hopping
  - device must be locked to the specific test channel for SAR measurement
  - the normally required (general) SAR test procedures apply
  - frequency hopping is not covered by KDB 248227
- 2.4 GHz 802.11 DSSS LAN and HR 802.11b
  - DBPSK, DQPSK, CCK, PBCC etc. can support 1 – 11 Mb/s
- 2.4 GHz & 5 GHz 802.11a/g OFDM
  - 802.11g ERP extends data rate up to 54 Mb/s; 22 & 33 Mb/s optional
  - 802.11a BPSK, QPSK, 16-QAM & 64-QAM can support up to 54 Mb/s
  - half-clocked and quarter-clocked configurations are optional

802.11 PHY

- 2.4 GHz & 5 GHz OFDM HT 802.11n extends OFDM PHY to HT
  - 20 and 40 MHz channel bandwidths
  - 400 ns short GI, STBC, TxBF etc.
  - modulation coding, spatial streams etc. identified by MCS 0 - 76
  - can use equal and unequal modulation (EQM/UEQM) in spatial streams
- 5 GHz OFDM VHT802.11ac
  - IEEE Std 802.11ac-2013; excludes 2.4 GHz band
  - 20, 40, 80, 80+80 and 160 MHz channel bandwidths
  - modulations and code rates identified by MCS 0 - 9
  - supports downlink MU-MIMO, up to 8 spatial streams, NDP sounding for TxBF etc.

Peer-to-Peer Configurations

- Ad Hoc peer-to-peer connections are supported by IEEE 802.11 and the Wi-Fi Alliance
  - using AP-equivalent group owner or client modes
- The exposure conditions are typically covered by normal Wi-Fi operating configurations
  - proprietary implementations & variants may need additional SAR consideration
- Cross connection using Wi-Fi alone through AP-equivalent group owner configurations is not hotspot mode
  - when multiple Wi-Fi transmitters operate simultaneously; e.g., 2.4 and 5 GHz, simultaneous transmission SAR needs consideration, but not hotspot mode
- Hotspot mode (KDB 941225) supports
  - cross connection between 3G/4G WWAN and WLAN
  - simultaneous transmission of higher output licensed and lower output unlicensed connections for purposes of wireless routing

Peer-to-Peer Configurations

- TDLS – (tunnel direct-link setup) establishes connections by sending encapsulated frames through AP according to 802.11z
  - the setup and connection are transparent to the AP
  - TDLS may use channel bandwidth and frequency bands not supported by the AP
- Mesh services – creation of MBSS for neighboring stations and multi-hop to hidden stations according to IEEE Std 802.11-2012
  - mesh connection cannot coexist with IBSS (*ad hoc*) or BSS (AP) modes
- Wi-Fi Direct is a Wi-Fi Alliance feature
  - supports one-to-one and one-to-many connections under the control of a group leader
  - simultaneous transmission at 2.4 & 5 GHz is possible for group leader
  - use of TDLS to tunnel through group leader (AP) is not prohibited

802.11 Wi-Fi SAR Testing Approaches for Frequency Bands

General Approach

- Original KDB 248227 started with 802.11a/b
  - followed by subsequent ad hoc considerations to accommodate 802.11g/n and 802.11ac configurations through TCB workshop updates
  - 802.11a/b framework has made it quite difficult and inflexible to streamline test procedures and consider test reduction for more complex 802.11 Wi-Fi modes
- Draft KDB 248227 gives priority to more recent Wi-Fi modes to
  - streamline SAR procedures and facilitate SAR test reduction
  - concentrate on the more typical product and exposure configurations
  - exclude proprietary and non-standard designs and ad hoc implementations
- SAR procedures are grouped according to DSSS and OFDM configurations
- Test reduction is considered according to
  - exposure conditions with multiple test positions using an initial test position
    - for next-to-ear, hotspot mode & UMPC mini-tablet configurations
  - channel bandwidths, modulations and data rates available in the wireless modes
    - for each frequency band & aggregated band using an initial test configuration

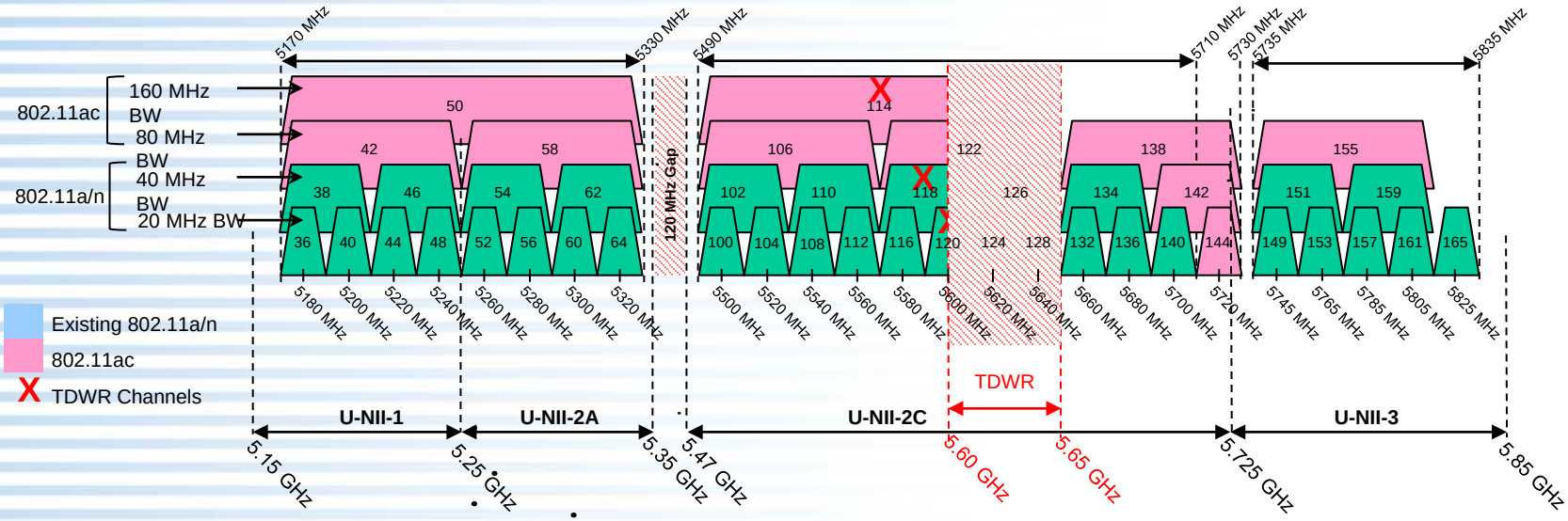
Frequency Band Considerations

- Maximum output power (**ET Docket 13-49 introduces new rules**)
  - 2.4 GHz §15.247: 1 W/36 dBm EIRP
  - UNII-1: 50 mW/23 dBm EIRP **(250 mW/1.0 W etc.)**
  - UNII-2A & 2C: 250 mW/30 dBm EIRP
  - **UNII-3** & 5.8 GHz §15.247: 1 W/36 dBm EIRP
  - Emission bandwidth restrictions may require a reduced maximum output power
- Channel bandwidths
  - 2.4 GHz: 20/22 or 40 MHz (802.11 b/g/n)
  - 5 GHz: 20, 40, 80 or 80+80 MHz (802.11 a/n/ac)
  - UNII-1 & 2A: 160 MHz (802.11ac)
  - UNII-2C: 160 MHz without TDWR restriction
- Modulation and data rate are for maintaining test setup consistency
  - data rates are mostly associated with modulation
  - modulation used by OFDM sub-carriers are not expected to have significant SAR influence at the OFDM output of data streams

2.4 GHz Band Configurations

- There are 13 total available channels in 2.4 GHz band for §15.247
  - only 3 non-overlapping channels: 1, 6 and 11
  - channels 12 and13 generally require reduced output power to satisfy bandedge radiated field strength requirements at 2483.4 MHz
- SAR is measured using channels 1, 6 and 11; provided
  - higher maximum output power is not specified for other channels
  - otherwise, use closest adjacent channel with highest power
- For 40 MHz channels in 802.11n, test on channel 6; provided
  - higher maximum output power is not specified for other 40 MHz channels
  - otherwise, use channel with highest maximum output power
- Maximum output power is that specified for production units
  - taking into account tune-up or specification tolerances

§15.407 U-NII BANDS



5.15 – 5.35 GHz Bands

- Note: ET Docket 13-49 introduces new rules for certain U-NII requirements
- When a device is approved for either UNII-1 or UNII-2A, but not both
  - apply the normally required SAR procedures
  - frequency band specific test reduction does not apply
- When a device is approved for both bands, with same transmitter and antenna(s), where the maximum output power, including tolerance, is
  - the same, begin SAR measurement in UNII-2A; and if highest ***reported*** SAR is
    - ≤ 1.2 W/kg, SAR is not required for UNII-1
    - > 1.2 W/kg, test each band independently
  - different, measure SAR in the band with higher specified maximum output power; and if highest ***reported*** SAR is
    - ≤ 1.2 W/kg, SAR is not required for band with lower maximum power
    - > 1.2 W/kg and difference in output power is < 1 dB, test each band independently; otherwise, apply initial test position and initial test configuration procedures

UNII-1 & UNII-2A Band Aggregation

- Aggregation of UNII-1 and UNII-2A can support one 160 MHz channel using channel number 50
  - for SAR purposes, a single 160 MHz channel and two 80 MHz channels are not equivalent
- Maximum output of aggregated band is limited to the lower maximum output power certified for the two bands
- SAR is not required for 160 MHz channel when
  - highest *reported* SAR for both bands is ≤ 1.2 W/kg and maximum output of aggregated band is ≥ 1 dB lower than the individual bands
    - when SAR test exclusion applies to only one of the bands, SAR is assumed to be ≤ 1.2 W/kg for that band to determine aggregated band test reduction
  - SAR test exclusion applies to both bands
    - note: the 1 dB condition (above) does not apply

5.47 – 5.85 GHz Bands

- UNII-2C, UNII-3 and 5.8 GHz §15.247 cover 380 MHz
  - require at least two SAR probe calibration points, each with ≥ ± 100 MHz coverage, to apply the OFDM SAR procedures
- 5.60 – 5.65 GHz has TDWR channels relating to interim guidance and new rules
  - SAR is required when TDWR restriction does not apply
- When the same transmitter and antenna(s) are certified for both UNII-2C and UNII-3 or 5.8 GHz §15.247, where the aggregated band supports
  - additional 20, 40 or 80 MHz channels across the band gap
  - the lower of maximum output power certified for the bands apply to band gap channels
  - to facilitate SAR test reduction, channels above 5.65 GHz in UNII-2C are grouped with UNII-3 or 5.8 GHz §15.247 channels for SAR measurement
- When band gap channels are disabled, each band is tested independently
- 160 MHz channel
  - may be supported in UNII-2C when TDWR restriction does not apply
  - band aggregation across UNII-2C and UNII-3 or 5.8 GHz §15.247 is not defined in IEEE Std 802.11ac
  - other proprietary or ad hoc 160 MHz channel implementations require separate consideration

SAR and Power Measurement Considerations

Test Parameter Concerns

- SAR measurement requires continuous transmission
  - current generation SAR systems require transmission duty factor to be periodic
- Chipset and vendor specific test modes are normally used
  - to support test configurations with at least 85% duty factor
  - measured SAR is scaled to 100%
  - *reported* SAR procedure is then applied
- When the hardware does not support at least 85% duty factor
  - SAR is measured within 15% of the maximum supported duty factor
  - SAR is scaled to the maximum supported duty factor
  - *reported* SAR procedure is then applied
- The test modes must establish transmission parameters according to those programmed in production units for the SAR measurements, including
  - maximum output power, amplifier gain, channel bandwidth and frequencies etc.
- High peak to average power ratio SAR system validation is required according to KDB 865664 for OFDM

SAR Probe Calibration

- SAR probes should be calibrated with at least ± 100 MHz coverage

Probe Calibration Frequency (GHz)	Wi-Fi Bands	Frequency Range	
		Channels	Probe Calibration
		GHz	MHz
5.25	UNII-1, UNII-2A	5.17 – 5.33	± 80
5.60	UNII-2C (standalone)	5.49 – 5.71	± 110
	UNII-2C (< 5.65 GHz)*	5.49 – 5.65	-110/+50
5.75	UNII-3, §15.247 (standalone)	5.735 – 5.835	-15/+85
	UNI- 2C (> 5.65 GHz) + UNII-3 or §15.247 across band gap	5.65 – 5.835	-100/+80

*** The portion above 5.65 GHz for UNII-2C is tested using the 5.75 GHz probe calibration point.**

- SAR system validation dipoles must be calibrated
  - within frequency range covered by probe calibration points required for device testing

Power Measurements

- The maximum output power specified for production units or measured for test samples are applied to determine SAR test exclusion and reduction
- Power measurement is required to determine SAR test reduction
  - for each frequency band and aggregated band
  - for highest maximum output power mode specified for production units, including tolerance
  - for modes with the same maximum output according to the configuration with largest channel bandwidth, lowest modulation and lowest data rate
  - for highest and lowest channels in the frequency band or aggregated band
  - at the mid-band channel when there are at least 3 channels
- Power measurement is also required for all configurations that require SAR measurement to determine *reported* SAR
  - typically performed before and after each SAR measurement
- A KDB inquiry is required when different maximum power is specified across the channels in a Wi-Fi transmission mode or configuration
- When power measurement is not required, the maximum power and tolerance specified for production units are used to determine SAR test exclusion and reduction

SAR Test Reduction Considerations

Initial Test Position

- Next-to-ear, UMPC mini-tablet and hotspot mode exposure conditions require multiple SAR test positions
- An initial test position is determined for SAR test reduction based on
  - distance from phantom to device outer surface at Wi-Fi antenna location
  - antenna to phantom coupling conditions; orientation & polarization etc.
  - coupling is considered first for positions with same separation distance or when coupling dominates
- When unclear or a single initial test position cannot be established, all equivalent positions must be considered for testing
- Test reduction cannot be applied when test lab does not have required information from device manufacturer
- Initial test position is determined according to test positions for
  - SAM phantom: left, right, touch and tilt configurations used by handsets
  - flat phantom: test device surfaces and edges require SAR testing

Test Position SAR Reduction

- Initial test position measurement uses the DSSS or OFDM SAR procedures and highest measured maximum output power channel
- When highest *reported* SAR for the initial test position (s) is
  - ≤ 0.4 W/kg, further SAR measurement is not required for other test positions in that exposure configuration and Wi-Fi transmission mode configuration for that frequency band
  - > 0.4 W/kg, repeat SAR using Wi-Fi mode tested in initial test position for subsequent next smallest antenna to phantom separation and maximum antenna coupling test positions until
    - *reported* SAR is ≤ 0.8 W/kg or all test positions are considered
- Initial & subsequent positions with *reported* SAR > 0.8 W/kg
  - test these on subsequent next highest measured output channels until *reported* SAR is ≤ 1.2 W/kg or all channels are considered
  - need additional power measurement to determine subsequent channels

2.4 GHz DSSS SAR Reduction

- 2.4 GHz DSSS (802.11b) and OFDM (802.11g/n) are considered separately for SAR
- An initial test position is applied to next-to-ear, UMPC mini-tablet and hotspot mode exposure conditions for SAR test reduction
- When initial test position does not apply
  - DSSS SAR is measured on required test channel with highest specified output power and if highest *reported* SAR is
    - ≤ 0.8 W/kg, no further SAR is required for 802.11b DSSS
    - > 0.8 W/kg, SAR is measured on next highest measured output channel for the exposure configuration
    - when any *reported* SAR is > 1.2 W/kg, SAR is required for all required test channels

2.4 GHz OFDM SAR Exclusion

- SAR is not required for 802.11g/n OFDM when
  - maximum output power specified for production units, including tolerance, is
    - ≥ 1 dB lower than 802.11b DSSS and
    - highest *reported* SAR for DSSS is ≤ 1.2 W/kg

    or
    - ≤ ¼ dB higher and < 1 dB lower than DSSS and
    - highest *reported* SAR for DSSS is ≤ 0.8 W/kg
  - KDB 447498 SAR test exclusion applies to 802.11g/n
- When SAR measurement is required, the OFDM SAR procedures are applied

OFDM SAR Considerations

- SAR measurement and test reduction for 802.11 a/g/n/ac modes are considered separately for each frequency band and aggregated band
  - using the initial test configuration and, if applicable, initial test position procedures
  - additional test reduction may apply to aggregated band according to the SAR results of the individual bands
- When band gap channels between UNII-2C and UNII-3 or 5.8 GHz §15.247 are used by the same transmitter and antenna(s)
  - the portion of UNII-2C above 5.65 GHz is grouped with 5.8 GHz band for SAR measurement
  - maximum output power can be different above and below the band gap; the highest power Wi-Fi transmission mode and highest maximum output power channel across the bands should be used to apply the initial test position and initial test configuration procedures

Initial Test Configuration

- Initial test configuration is determined by the channel bandwidth, modulation and data rate combination with highest maximum output power specified for productions units, including tolerance, for each frequency band and aggregated band
  - modulation and data rate are for measurement setup consistency; not expected to have significant SAR influence at OFDM output
- For combinations with the same maximum output power, select configuration with the highest channel bandwidth, lowest order modulation and lowest data rate
- The channel with highest measured maximum output power is used in the Initial test configuration for SAR measurement
  - for channels with the same measured maximum measured output power, select channel closest to middle of frequency band or aggregated band

OFDM SAR Measurement

- The OFDM SAR procedures apply to 2.4 GHz and all 5 GHz bands
- When SAR is required for OFDM, further test reduction is determined by the initial test configuration procedures
- When applicable, an initial test position is used to reduce the test positions for next-to-ear, hotspot mode and UMPC mini-tablet exposure conditions using the initial test configuration
- When initial test position does not apply and if highest *reported* SAR for initial test configuration is
  - > 0.8 W/kg: SAR is required for subsequent next highest measured output power channel in initial test configuration until *reported* SAR is ≤ 1.2 W/kg or all channels are tested

OFDM SAR Test Reduction

- Subsequent test configurations are the remaining Wi-Fi configurations that are not tested in the initial test configuration
  - these are considered separately for each frequency band, aggregated band and exposure condition according to the maximum output power specified for production units, including tolerance
  - for configurations with the same maximum output power, select highest channel bandwidth, lowest order modulation and lowest data rate
- Within each subsequent test configuration, SAR test reduction is considered according to subsequent next highest maximum output power channels
- Maximum output power of a subsequent test configurations and maximum output power of a channel within a subsequent test configuration should be clearly distinguished to apply the procedures

OFDM SAR Test Reduction

- When the specified maximum output power of a subsequent test configuration is
  - ≤ ½ dB lower than that specified for the initial test configuration or already tested subsequent test configurations and the highest *reported* SAR for such configurations is
    - ≤ 0.8 W/kg, further SAR is not required for that exposure condition and frequency band or aggregated band
    - > 0.8 and ≤ 1.2 W/kg
      - SAR is measured for the next highest output combination (next subsequent test configuration) on channels that overlap with the earlier initial or subsequent test configuration, begin with the highest measured output channel and continue with subsequent highest output channels until *reported* SAR is ≤ 1.2 W/kg or
      - apply the > 1.2 W/kg procedures (next slide)
  - > ½ dB lower than that specified for the initial test configuration or already tested subsequent test configurations and the highest *reported* SAR is ≤ 1.2 W/kg, further SAR is not required for that exposure condition and frequency band or aggregated band combination

OFDM SAR Test Reduction

- When the highest *reported* SAR of the initial test configuration or already tested subsequent test configurations is
  - > 1.2 W/kg, apply the initial test configuration procedures to the next subsequent test configuration(s)
    - power measurement is necessary to determine *reported* SAR and identify subsequent highest output channels
- SAR is required for all channels that overlap with a 160 MHz channel with *reported* SAR > 1.2 W/kg

Antenna Diversity MIMO and TxBF Considerations

Simultaneous Transmission

- Different simultaneous transmission schemes and antenna spatial arrangements can influence SAR test configurations
- When maximum output power or antenna performance is different among antenna or transmission chains, the usual SAR test exclusion or measurement procedures may not fully apply
- Frequency, signal correlation, antenna proximity and other transmission requirements may require SAR to be measured with
  - all transmitters and antennas transmitting simultaneously or
  - each antenna transmitting one at a time and apply SAR post-processing
- Subsets of MIMO chains also need consideration
  - especially when maximum power is different
  - there is antenna interaction in integrated MIMO antenna structure
- SAR measurement system capability also need consideration

Test Reduction Consideration

- When simultaneous transmitting antennas are spatially separated to the extent the SAR distributions do not overlap
  - SAR can be considered independently for each antenna
- KDB 447498 standalone SAR test exclusion provision may be applied according to the aggregate maximum output power of all simultaneous transmitting antennas
- When test exclusion according to aggregate power does not apply
  - sum of 1-g SAR test exclusion in KDB 447498 may be applied
  - peak SAR to location ratio is only applicable when all antennas are in the same plane from the phantom

Transmission Configurations

- Switched transmit diversity is a common feature used in early generation Wi-Fi devices
  - only one antenna transmits at a time
  - power is time & spatially multiplexed dynamically among antennas
  - a duty factor of 75% may be applied, followed by *reported* SAR procedures to determine compliance
- Typical 802.11 MIMO configurations
  - spatial multiplexing: data is divided into multiple streams and transmitted through different antennas
  - space-time block coding (STBC): redundant data is transmit in blocks with different coding through different antennas.
    - multiple receive antennas not required.
  - STBC may be applied in conjunction with spatial multiplexing when there is more transmit than receive antennas

Transmission Configurations

- Transmit beamforming (TxBF) is used in HT (802.11n) and VHT (802.11ac) according to implicit or explicit feedback
- VHT has specific implementation requirements to encourage TxBF and to reduce implementation complexities associated with HT
  - null data packets (NDP) are used for sounding
  - allows only equal modulations (EQM) data streams
  - HT allows both EQM and UEQM
- IEEE 802.11 requires cyclic shifts for HT and VHT data streams from different antennas to prevent unintended beamforming
- Correlation of data streams for sub-carriers in OFDM along with cyclic shift required by HT and VHT is not expected to introduce coherent signal issues for SAR measurement

Coherent Signals

- Implementations using phased array and other beamforming operations may need to address coherent signal conditions for SAR
- Maximum worst-case SAR possible for coherent signals is a function of N^2, where N is the number of coherent signals
  - i.e., 4, 9 and 16 times for 2, 3 & 4 coherent signals
- When signal coherence applies
  - sum of SAR and SAR to peak location ratio test exclusion do not apply
  - except when antennas are sufficiently far apart with no noticeable overlapping SAR distributions
    - where the SAR of each antenna does not contribute to the other antennas
- Applying results of scalar field probes to estimate SAR according to IEC TR 62230 for coherent signals need case-by-case consideration
  - according to individual product design and implementation