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**Title:** SAR Measurement Guidance for IEEE 802.11 Transmitters

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**Reason:** Updated measurement procedures in attachment 248227 D01 SAR meas IEEE 802.11.

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**Keyword/Subject:** RF Exposure, SAR, Wi-Fi, IEEE 802.11

**First Category:** Radio Frequency Exposure - MPE; SAR

**Second Category:** Testing

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**Question:**
Are there any SAR measurement procedures for IEEE 802.11 wireless transmitters?

**Answer:** Yes, the attached document, 248227 D01 SAR meas for IEEE 802 11 transmitters v02, SAR measurement procedures for 802.11 transmitters.

**Attachment List**:
248227 D01 SAR meas for IEEE 802 11 transmitters v02

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# SAR MEASUREMENT GUIDANCE FOR IEEE 802.11 TRANSMITTERS

## I. Introduction

The SAR guidance provided in this document is intended for Wi-Fi devices authorized under §§15.247 and 15.407 of Commission rules in the 2.45 GHz and 5 GHz bands that are implemented according to IEEE Std 802.11-2012 (802.11a/b/g/n) and IEEE 802.11ac-2013.[1] Unless it is described; for example, Wi-Fi Direct, the procedures may not fully apply to devices that are subject to other FCC rule parts or using variants of the IEEE 802.11 protocols.[2] The test procedures are established for Wi-Fi transmitters operating in consumer products that require SAR evaluation.[3] The typical Wi-Fi devices may operate in multiple frequency bands with numerous 802.11 wireless configurations. IEEE 802.11 protocols have included requirements to maintain compatibility with earlier implementations. These inherent flexibilities have introduced additional complexity to SAR evaluation.

Wi-Fi technology has evolved from the simple frequency hopping and DSSS configurations at 2.4 GHz to today's highly complex OFDM implementations for 802.11n and 802.11ac. The recent IEEE Std 802.11-2012 and Std 802.11ac-2013 have included numerous combinations of signal modulations, data rates, channel bandwidths and multiple antenna transmission schemes to provide substantial flexibility for improving coverage and throughput. As the new generation of Wi-Fi products continue to emerge, coexistence with earlier generation devices that are already deployed is also necessary for migration continuity. To maintain compatibility with older products, the typical Wi-Fi device may support both 2.4 GHz and some or all of the 5 GHz bands with hundreds of transmission configurations. Without further consideration, the amount of tests required to demonstrate SAR compliance could be significant. While various SAR test reduction schemes may be considered to reduce the number of SAR measurements, Wi-Fi devices often incorporate ad hoc implementations to improve performance or overcome specific issues. For some devices, the maximum output power specifications, simultaneous transmission schemes and other requirements may vary across the transmission modes and operating configurations in each frequency band. In some cases, the maximum output power may vary across the channels or among transmission chains of a transmission mode or frequency band. These types of variations, when coupled with the large number of transmission modes and configurations that require support for backward

[1] Draft is based on IEEE P802.11ac/D7.0, will need update according to IEEE Std 802.11ac-2013.

[2] This KDB does not fully apply to Wi-Fi devices operating in the 4.94 – 4.99 GHz band, with respect to §§90.1213 and 90.1215, or other 802.11 related frequency bands such as §90.377 in the 5.85 – 5.925 GHz band for OBU/RSU; further consideration is required.

[3] Evaluation includes addressing RF exposure concerns by analysis, SAR test exclusion or measurement.

compatibility have introduced various difficulties for establishing uniform procedures to consistently test Wi-Fi devices. The similar concerns are also reflected in the TCB review and approval process.

The fundamental SAR measurement procedures are described in KDB 865664. The SAR test requirements for product platform and technology specific configurations are described in other related KDB publications. The procedures in this document are used to configure Wi-Fi devices for SAR measurements. Due to the large number of Wi-Fi transmission configurations that need consideration, the procedures are also streamlined to facilitate SAR test reduction. IEEE Std 802.11 does not define loop back test modes, such as those used by 3G/4G transmitters, for testing Wi-Fi devices. Chipset based test mode and vendor specific test software are commonly used instead of Wi-Fi networks, which are highly dynamic and generally do not provide the stable conditions required for SAR testing. Furthermore, when transmit diversity, MIMO or transmit beamforming is used, the SAR measurement conditions may depend on the diversity and simultaneous transmission schemes, antenna spatial arrangements, maximum output power and signal condition variations in the transmission chains and other implementation specifics.

The guidance in this document is established according to typically used Wi-Fi configurations. By keeping the procedures simple while accommodating the flexibility and complexity supported by Wi-Fi protocols, certain less common or non-standard implementations may require a KDB inquiry to apply alternative procedures for SAR measurement.

## II. 802.11 PHY Configurations

A brief summary of the 802.11 PHY is included in the following to identify the applicable wireless configurations, modulations and data rates etc. that need consideration when applying the SAR measurement procedures.[4] In general, a test lab should consult with the Wi-Fi device manufacturer for further clarification of device capabilities in individual implementations before applying the procedures in this document.

<u>Frequency Hopping PHY</u> (802.11) - The is considered obsolete in IEEE Std 802.11-2012 and may be removed in future revisions. Frequency hopping should be tested on the highest, middle and lowest channels in the 2.4 GHz band according to normally required SAR measurement procedures. The device must be locked to the required test frequency channel with frequency hopping disabled. The SAR procedures in this KDB do not apply to 2.4 GHz frequency hopping operations.

<u>DSSS RF LAN</u> (802.11) systems provide WLAN operations in the 2.4 GHz band with 1 and 2 Mb/s data rates using DBPSK and DQPSK baseband modulations, respectively. This mode is supported by 802.11b for backward compatibility.

<u>High Rate PHY</u> (802.11b) extension increases DSSS RF LAN data rates to 5.5 and 11 Mb/s using 8-chip CCK modulation at a chipping rate of 11 MHz, with the same occupied channel bandwidth as DSSS system. CCK may be optionally replaced with HR/DSSS/PBCC. However, PBCC is considered obsolete in IEEE Std 802.11-2012 and may be removed in future revisions. HR/DSSS/short and HR/DSSS/PBCC/short are optional modes that allow increased data throughput at 2, 5.5, and 11 Mb/s using a shorter PLCP preamble.

[4] Refer to IEEE Std 802.11-2012 and Std 802.11ac-2013 for definition of specific terms and abbreviations.

ERP (802.11g) provides further rate extension for DSSS and HR/DSSS in the 2.4 GHz band. The additional data rates include 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s. Date rates at 1, 2, 5.5, 6, 11, 12, and 24 Mb/s are mandatory. ERP-PBCC modulation is optional for supporting 22 and 33 Mb/s data rates. DSSS-OFDM is also optional for supporting 6, 9, 12, 18, 24, 36, 48, and 54 Mb/s data rates. ERP has the capability to decode all DSSS and HR/DSSS PLCPs and all ERP-OFDM PLCPs. It is mandatory for all ERP-compliant equipment to send and receive short preamble that is optional for HR/DSSS.

OFDM PHY (802.11a) supports 6, 12, 24, 36, 48 and 54 Mb/s data rates. Data rates higher than 24 Mb/s are optional. There are 52 subcarriers modulated with BPSK, QPSK, 16-QAM or 64-QAM using forward error correction convolutional coding rates of 1/2, 2/3 or 3/4. "Half-clocked" operation with 10 MHz channel spacing at 3, 4.5, 6, 9, 12, 18, 24, and 27 Mb/s and "quarter-clocked" operation with 5 MHz channel spacing at 1.5, 2.25, 3, 4.5, 6, 9, 12, and 13.5 Mb/s data rates may be used.

OFDM HT PHY (802.11n) expands the OFDM PHY to support up to four 20 or 40 MHz bandwidth spatial streams and provide optional features such as 400 ns short guard interval (GI), transmit beamforming, HT-greenfield format, and STBC. Modulation, coding, and number of spatial streams are identified by MCS indices 0 - 76. MCSs 0 -7 and 32 use a single spatial stream. MCS 8 to 31 use multiple spatial streams with equal modulation (EQM) for all streams. MCS 33 - 76 use multiple spatial streams with unequal modulation (UEQM) for the spatial streams. MCS 0 to 7 are mandatory for all stations using 20 MHz with 800 ns GI. MCS 0 to 15 are mandatory for APs using 20 MHz bandwidth and 800 ns GI. All other MCSs and modes are optional, including support for 400 ns GI, 40 MHz bandwidth and support of MCS 16 to 76. All EQM rates are supported by non-AP HT stations using MCS 0 – 7 with 20 MHz bandwidth using one spatial stream. All EQM rates are supported by HT APs using MCS 0 – 15 with 20 MHz bandwidth and one or two spatial streams. A 40 MHz channel is specified by two fields: the primary channel number and whether the secondary channel is above or below the primary channel.

OFDM VHT PHY (802.11ac) supports frequency bands below 6 GHz, excluding the 2.4 GHz band. OFDM HT stations supporting VHT also support DSSS. Support for 20, 40 and 80 MHz bandwidths is mandatory. Support for 160 MHz and 80 + 80 MHz bandwidth, NDP (null data packet) transmit beamforming sounding, STBC, LDPC and downlink multi-user (MU) transmissions are optional for VHT. The maximum number of space-time streams supported by VHT is eight. VHT can support four users and up to four space-time streams per user with a total of up to eight space-time streams for downlink MU transmission. The subcarriers are modulated using BPSK, QPSK, 16-QAM, 64-QAM and 256-QAM using forward error correction (FEC) convolutional or LDPC coding with 1/2, 2/3, 3/4 and 5/6 coding rates. Support for single spatial stream for all channel bandwidths using VHT MCS 0 – 7 is mandatory. Support of two or more spatial streams, 400 ns short GI and VHT MCS 8 and 9 are optional. Cyclic shifts are applied to the modulated preamble and data fields to prevent unintended beamforming when correlated signals are transmitted in multiple space-time streams. MCS 0 – 9 are defined in 802.11 VHT to identify modulations and code rates; however, different channel bandwidth and the number of streams allowed are not specified by the MCS. This is different than the MCS configurations used in 802.11n. There are also exceptions for certain MCS configurations; for example, MCS 6 does not support 3 and 7 streams for 80 MHz channels, MCS 9 does not support 1, 2, 4, 5, 7 and 8 streams for 20 MHz channels, 6 streams for 80 MHz channels or 3 streams for 160 MHz channels. During transmission, the channel bandwidth for 802.11 VHT can change frame by frame.

## III. Peer-to-Peer Wi-Fi Configurations

The typical peer-to-peer Wi-Fi configurations supported by IEEE Std 802.11-2012 or the *Wi-Fi Alliance* may include Tunneled direct-link setup (TDLS), mesh services, Wi-Fi Direct and other similar *ad hoc* network (IBSS) connections. The exposure characteristics for these Wi-Fi operating modes are usually covered by the normally required SAR test conditions for infrastructure mode operations. Provided the Wi-Fi transmission is not coordinated with other transmitters; for example, 3G/4G devices to support hotspot mode, additional SAR is generally not necessary for standalone peer-to-peer operations. When simultaneous transmission is supported by multiple Wi-Fi frequency bands or in conjunction with other wireless technologies, SAR compliance must be determined according to the applicable exposure conditions and SAR test positions for each simultaneous transmission configuration.

TDLS transmits encapsulated signaling frames within the regular data frames, transparently through an AP to establish TDLS service according to IEEE 802.11z protocol, to enable devices to connect directly with each another using improved connection speed and overall bandwidth efficiency without adhering to the functionalities and requirements of an AP. The more efficient 802.11 modes supported by TDLS devices that are not available from an AP may also be used over a direct link between TDLS devices, including different channel bandwidths and frequency bands. The AP is unaware of the TDLS setup and not required to support the link. TDLS can be used with all existing and new APs because it is transparent.

Mesh Services enable the creation and operation of a mesh basic service set (MBSS) to support mutual exchange of messages between autonomous neighboring stations and to transfer messages between stations that are not in direct communication using the multi-hop capability. The services enable data delivery between stations within a mesh BSS that are not within range of each other. A mesh station is not a member of an *ad hoc* network (IBSS) or an infrastructure BSS. Mesh stations do not communicate with non-mesh stations.

Wi-Fi Direct is a *Wi-Fi Alliance* feature that enables Wi-Fi devices to establish direct connection groups to support printing, sync or share contents conveniently when an AP or router is unavailable. A Wi-Fi Direct network can be one-to-one or one-to-many, under the control of a group leader. Simultaneous transmission at 2.4 GHz and 5 GHz in Wi-Fi Direct and AP modes or 3G/4G hotspot mode might be possible for the group leader. The hotspot mode SAR procedure is for connections between Wi-Fi and 3G/4G transmitters; it does not apply to cross connections established using Wi-Fi only devices with AP equivalent features, where the simultaneous transmission is related to multiple Wi-Fi devices. It may also be possible to establish TDLS services in Wi-Fi Direct by tunneling through the group leader that acts as the equivalent of an AP.

## A. Configuring 802.11 Wi-Fi Transmitters for SAR Measurement

Normal network operating configurations are not suitable for measuring the SAR of 802.11 Wi-Fi transmitters. Unpredictable fluctuations in network traffic and simultaneous transmission or transmit antenna diversity conditions can introduce undesirable variations in SAR results. The SAR measurement conditions for these devices are typically established using chipset based or equivalent test mode software to ensure results are consistent and reliable. When test mode is not available and there is no other means to test a product in test mode equivalent conditions, a KDB inquiry is required to determine possible alternatives.

A Wi-Fi device must be configured to transmit continuously at the required data rate, channel bandwidth and signal modulation using the highest transmission duty factor supported by the test mode software for SAR measurement. A periodic duty factor is required to measure SAR correctly using current generation SAR systems. The test frequencies established with test mode software must correspond to the actual channel frequencies required for normal operations in the U.S. With 802.11 frame gaps included in the transmission, a maximum transmission duty factor of 96-98% is typically supported by most test mode configurations. A duty factor of at least 85% is required for SAR testing. Unless it is permitted by specific KDB procedures, all measured results must be scaled to 100% transmission duty factor and apply the *reported* SAR procedures in KDB 447498 to determine compliance. The implementation of chipset based test mode software is typically hardware and manufacturer dependent. When the test software is an integral part of the production tools, it may include substantial flexibility to reconfigure or reprogram a device. The device operating parameters established for SAR measurement must be identical to those programmed within production units, including maximum output power, amplifier gain settings and other RF performance or tuning parameters. It must be ensured that the unmodified production settings are used for SAR measurements.

## IV. Frequency Band and Test Channel Considerations

To facilitate SAR test reduction, the test configurations for each frequency band and aggregated band are identified as either DSSS or OFDM and grouped according to channel bandwidth and exposure conditions (i.e., operating configurations and exposure test positions) to streamline the SAR test procedures. The channel configurations for 5 GHz 802.11 operations are illustrated in Appendix A. When multiple test positions are required for an exposure condition, an initial test position is used for certain specific exposure conditions to determine SAR test reduction. The number of wireless mode configurations that require testing in each frequency band can also be reduced according to the *reported* SAR of an initial test configuration determined for the transmission modes.

The SAR procedures can support channel aggregation using 20, 40, 80 or 160 MHz channels, across contiguous channels within a band or across adjacent bands (without mixing different channel bandwidths); however, simultaneously transmitting two non-contiguous channels of the same bandwidth or contiguous channels of different channel bandwidths is not equivalent to transmitting using a single contiguous channel. In general, only adjacent frequency bands may be considered collectively, according to the frequency range covered by each SAR probe calibration point, to streamline the SAR measurements. For 802.11ac VHT, use of two non-contiguous 80 MHz channels is not equivalent to a 160 MHz channel. These must be considered separately for SAR compliance.

### A. 2.4 – 2.4835 GHz Band

The maximum output power permitted for devices authorized under §15.247 is 1 W/36 dBm EIRP. Within the frequency range of 2400 – 2483.5 MHz, a total of 13 channels may be used in the U.S. However, non-overlapping frequency channels are necessary to minimize interference degradation; therefore, channels 1, 6 and 11 are used most often. Channels 12 and 13, in general, require reduced output power to satisfy bandedge radiated field strength requirements at 2483.5 MHz. Provided higher maximum output power is not specified for the other channels, channel 1, 6 and 11 should be used to configure 22 MHz DSSS and 20 MHz OFDM channels for SAR measurements; otherwise, the closest adjacent channel with the highest maximum output power specified for the product should be tested instead of channels 1, 6 or 11. When 40 MHz channels are used and provided higher maximum output power is not specified for other applicable 40 MHz channels, channel 6 should be used for SAR measurement; otherwise, the channel with the highest specified maximum output power should be tested instead. The maximum output power of a channel must also include any tolerances specified for production units in each wireless configuration.

### B. 5.15 – 5.25 and 5.25 – 5.35 GHz Bands

The maximum output power permitted for devices authorized under §15.407 UNII band 1 (5.15 – 5.25 GHz) and UNII band 2A (5.25 – 5.35 GHz) are 50 mW/23 dBm EIRP and 250 mW/30 dBm EIRP respectively.[5] When applicable, a lower maximum output power may be required due to emission bandwidth restrictions. For devices that operate in only one of the bands, the normally required SAR procedures are required. For devices that operate in both UNII bands using the same transmitter and antenna(s), SAR test reduction may be considered according to frequency, power and SAR.[6] When SAR measurement is required for both bands, SAR test reduction is determined according to the highest *reported* SAR and maximum output power specified for production units, including tolerance, described in the following.

1) When the specified maximum output power is the same for both bands, begin SAR measurement in UNII band 2A; and if the highest *reported* SAR for UNII band 2A is
   a) ≤ 1.2 W/kg, SAR is not required for UNII band 1.
   b) > 1.2 W/kg, both bands should be tested independently for SAR.
2) When the specified maximum output power is different for the bands, begin SAR measurement in the band with higher specified maximum output power; and if the highest *reported* SAR for the band with higher maximum output power is
   a) ≤ 1.2 W/kg, SAR is not required for the band with lower maximum output power.
   b) > 1.2 W/kg and the difference in specified maximum output power between the bands is ≤ 1 dB; both bands should be tested independently for SAR; otherwise, apply the initial test position and initial test configuration procedures.
3) The two UNII bands may be aggregated to support 160 MHz bandwidth on channel number 50. The maximum output power of 160 MHz channel is limited to the lower of the maximum output power certified for the two bands.
   a) When the highest *reported* SAR for both bands are ≤ 1.2 W/kg and the specified maximum output power of the aggregated band is at least 1 dB lower than the individual bands, SAR measurement is not required for the aggregated band; otherwise, SAR is required for the 160 MHz channel to demonstrate compliance. If only one of the bands qualifies for SAR test exclusion, the SAR for that band is assumed to be ≤ 1.2 W/kg.
   b) When SAR test exclusion applies to both bands, SAR measurement for 160 MHz channel is not required.

### C. 5.470 – 5.725, 5.725 – 5.825 GHz and 5.725 – 5.850 GHz Bands

The maximum output power permitted for devices authorized under §15.407 UNII band 2C (5.470 – 5.725) is 250 mW/30 dBm EIRP; however, for UNII band 3 and 5.8 GHz §15.247 the maximum allowed output power is 1 W/36 dBm EIRP. When applicable, a lower maximum output power may be required due to emission bandwidth restrictions. The frequency range covered by these bands is 380 MHz (5.47 – 5.85 GHz), which requires a minimum of at least two SAR probe calibration frequency points to support the SAR measurements. The typical SAR probe calibration point in this frequency range should normally cover at least ± 100 MHz. The difference in tissue-equivalent media conductivity among the bands is about 8%, which is larger than the 5% tissue dielectric tolerance required for SAR probe calibration and typical SAR measurements. In addition, Terminal Doppler Weather Radar (TDWR) restriction may apply to 5.60 – 5.65 GHz operations in UNII band 2C due to interference concerns. For devices that are specifically disabled to operate in this frequency range through acceptable mechanisms, SAR is not required. When TDWR restriction does not apply to a device or when the restriction is removed,

[5] ET Docket 13-49 may introduce changes to maximum output power or other requirements.

[6] The energy absorption characteristics of tissue-equivalent dielectric parameters for UNII band 2A are somewhat more conservative than UNII band 1. The difference in tissue media conductivity for the two bands is about 4.5% and is expected to have insignificant difference in antenna loading.

channels in the 5.60 – 5.65 GHz range must be included to apply the SAR test reduction and measurement procedures.

When the same transmitter and antenna(s) are used for UNII band 2C and UNII band 3 or 5.8 GHz §15.247, the bands may be aggregated to enable additional channels with 20, 40 or 80 MHz bandwidth span across the band gap as illustrated in Appendix A. The maximum output power for the additional channels is limited to the lower of those certified for the bands. Unless the additional channels in the band gap are permanently disabled, SAR must be considered for these channels. To maintain SAR measurement accuracy and to facilitate test reduction, the channels in UNII band 2C that are above 5.65 GHz should be grouped with the 5.8 GHz channels in UNII band 3 or §15.247 to enable two SAR probe calibration frequency points to cover the bands, including the band gap channels. However, when the band gap channels are disabled, each band should be tested independently according to the normally required SAR measurement and probe calibration frequency points requirements.[7]

A single 160 MHz channel may be supported within UNII band 2C for client devices that are certified to operate within 5.60 – 5.65 GHz or when the TDWR restriction is removed. Band aggregation for 160 MHz channel across UNII band 2C and UNII band 3 is not defined in IEEE Std 802.11ac-2013 for VHT; however, transmitters may operate using ad hoc implementations to transmit across the bands. When applicable, these types of implementations and configurations must be taken into consideration to determine SAR compliance.

## V. SAR Measurement Considerations

802.11 Wi-Fi transmitters are designed to operate seamlessly through wired and wireless networks where the traffic is asynchronous and dynamic. Collision avoidance and retransmission of error packets are part of the network behavior that can result in substantial variations in transmission patterns. However, when used in somewhat isolated configurations, continuous video streaming and sustained file transfer at a rather high transmission duty factor is achievable. Unless continuous transmission is specifically restricted by the device, a duty factor of 100 % should be applied for Wi-Fi devices to determine SAR compliance. Besides configuring a device for testing, the SAR measurement requirements of KDB 865664 must be applied for the test results to be acceptable. The SAR procedures required for specific product platforms or operating configurations, such as handsets, laptop and tablet computers, UMPC-mini tablets, USB dongles or hotspot mode must also be applied.

### A. Duty Factor Considerations

The randomness of Wi-Fi networks is not suitable for configuring devices to support SAR measurements. Loopback test modes similar to those used by 3G/4G WWAN transmitters are not defined in 802.11 Wi-Fi protocols. Various chipset based internal test mode and vendor specific external test software are typically used to establish an acceptable and consistent duty factor for SAR measurement. Unless a device is not capable of sustaining continuous transmission or the output can become nonlinear, continuous periodic data frames with higher than 85% duty factor are required for the SAR measurement. The measured SAR is scaled from the test mode transmission duty factor to 100% and followed by applying the *reported* SAR procedures to determine compliance. A minimum duty factor of 85% is required to avoid certain hardware and device implementation concerns relating to wide range SAR scaling. For devices that are by design hardware limited and unable to transmit at duty factors higher than 85%, a periodic duty factor within 15% of the maximum duty factor the device is capable of transmitting

[7] See also SAR Probe Calibration Requirements section.

should be used. The measured SAR is scaled to the maximum duty factor and the *reported* SAR procedure is applied to determine compliance. Descriptions of the procedures used to establish the specific duty factor for SAR testing is required in the SAR report to support the test results. In addition to duty factor compensation and SAR scaling, when OFDM is used for Wi-Fi the SAR system validation procedures in KDB 865664 are required to address high peak to average power ratio probe calibration and measurement concerns.

B. SAR Probe Calibration Requirements

The SAR probes used for testing Wi-Fi devices should be calibrated at the following frequencies, with at least ± 100 MHz coverage, according to the tissue dielectric parameter requirements of KDB 865664 to adequately cover the 5 GHz bands. The SAR system validation dipoles must be calibrated within the frequency range covered by the probe calibration points required for device testing, according to KDB 865664 requirements. In the following, the probe calibration point at 5.60 GHz is expected to be marginal for the bandedge channels in UNII band 2C (standalone). It is 200 MHz (5.5 – 5.7 GHz) wide between the channel center frequencies of the bandedge channels; however, if accounting for channel bandwidth this becomes 220 MHz (5.49 – 5.71 GHz). When a bandedge channel is tested, the tissue dielectric parameters must be within 5% of the required targets at the test frequency, the SAR error compensation provisions described in KDB 865664 for allowing up to 10% tissue parameter tolerance should not be applied.[8]

| 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 |
| | UNII-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. | | | |

C. Power Measurement Requirements

The maximum output power of typical 802.11 Wi-Fi devices may vary with transmission modes, frequency bands, antenna implementation, or use conditions. The peak to average output power ratio of signals used in different transmission modes is a function of the signal modulation characteristics required by the DSSS and OFDM configurations, for example, BPSK, CCK, PBCC, different combinations of ERP, QPSK, 16 -256 QAM etc. Some Wi-Fi implementations may also support half-clocked and quarter-clocked data rate operations. The measured SAR is highly dependent on the maximum output power and peak to average power ratios required to support these transmission configurations. In addition, it is not unusual for Wi-Fi devices to incorporate proprietary transmission modes to provide enhancements, which often require case-by-case considerations through KDB inquiries to determine if the existing procedures are suitable.

SAR test reduction can be considered according to the maximum output power specified for production units and measured selectively for test samples in different Wi-Fi modes and transmission conditions.

[8] Conservativeness of existing tissue-equivalent dielectric parameters at 2.4 and 5 GHz for certain test separation distances and exposure conditions is currently under review by SAR measurement standards committees.

Power must be measured in each frequency band and aggregated band for the highest maximum output power wireless mode specified for production units, including tolerance, to support the initial test configuration SAR test reduction procedures. The highest maximum output power channel(s) identified for the maximum output power Wi-Fi transmission mode configurations is used to streamline SAR measurements, according to the DSSS and OFDM SAR procedures. When the same maximum output power and tolerance are specified for production units across multiple Wi-Fi transmission modes/configurations in the frequency band, channel bandwidth, modulation and data rate are considered to reduce the number of power measurements according to the following procedures for power measurement test reduction. A KDB inquiry is required when different maximum output power is specified across the channels in a Wi-Fi transmission mode.

1) Measure the maximum output power in each standalone and aggregated frequency band for the Wi-Fi transmission mode configuration with the highest maximum output power specified for production units, including tolerance. For modes with the same maximum output power specification, the largest channel bandwidth, lowest order modulation and lowest data rate should be measured. The power measurement results are used to determine SAR test reduction.
2) Power must be measured at the highest and lowest channels in each frequency and aggregated band; and at the mid-band channel when there are at least 3 channels.
3) Power measurement is also required for all configurations that require SAR measurement to determine *reported* SAR and to confirm the output power used in SAR measurements to satisfy the conditions required by KDB 447498. These are typically measured before and after each SAR measurement.
4) When power measurement is not required, according to power measurement test reduction or other KDB requirements, the maximum output power specified and supported by production units, including tolerance, is used to determine SAR test exclusion and reduction.

## VI. SAR Test Reduction for Specific Exposure Configurations

SAR measurement for handsets used next to the ear, UMPC mini-tablets and hotspot mode requires multiple exposure test positions. SAR test reduction may be considered for some of the test positions that are expected to have lower SAR. An initial test position is determined to measure SAR using the highest maximum output power channel for SAR test reduction. In addition, an initial test configuration is applied according to the DSSS or OFDM SAR test procedures to facilitate further SAR test reduction. The following is applied to select the initial test position for handsets operating next to the ear, hotspot mode or UMPC mini-tablets to minimize the number of SAR measurements normally required for exposure configurations that require multiple test positions.[9]

The test separation distance between the phantom and outer surface of a device, at the geometric center of the Wi-Fi antenna facing the phantom, and antenna to phantom coupling conditions are used to determine the initial test position. Depending on the design and implementation of the individual device, antenna location and certain other implementation details are necessary to determine the test separation distance and antenna to phantom coupling conditions. A test lab will be unable to apply initial test position test reduction if the required information is unavailable from a device manufacturer. When the differences in test separation distance are indistinguishable for multiple test positions, the position with maximum antenna to phantom (SAM or flat) coupling, according to antenna orientation and polarization etc., should

[9] The initial test position test reduction considerations are based on the range of output power, exposure and use configurations for Wi-Fi transmitters used in typical host configurations. The SAR margins considered for Wi-Fi are not applicable to other transmitters that require higher output power.

be applied to determine the initial test position. When antenna coupling is known to dominate the exposure, it should be considered first and then followed by test separation distance to determine the initial test position. When it is unclear or a single initial test position cannot be easily established, all equivalent smallest separation and maximum coupling conditions must be considered for initial test position testing. A clear explanation of how the initial test position is determined must be included in the SAR report for the results to be acceptable.[10]

Head Exposure: The left, right, touch and tilt test positions for next to the ear exposure testing using the SAM phantom may be considered collectively as one head exposure configuration to facilitate initial test position SAR test reduction. The initial test position is determined by the side (left or right) of the SAM phantom and test position (touch or tilt) with the smallest test separation distance from the device outer surface, at the Wi-Fi antenna location, to the SAM phantom and maximum antenna to phantom coupling conditions.

Hotspot mode and UMPC mini-tablets: The surfaces and edges that require SAR measurement in hotspot mode or UMPC mini-tablet configurations may be considered collectively as one exposure configuration to facilitate SAR test reduction. The initial test position is determined by the test position with the smallest test separation distance from the device outer surface, at the Wi-Fi antenna location, to the flat phantom and maximum antenna to phantom coupling conditions.

A. Initial Test Position SAR Test Reduction

The multiple test positions require SAR measurements in head, hotspot mode or UMPC mini-tablet configurations may be reduced according to the highest *reported* SAR determined using the initial test position(s) by applying the DSSS or OFDM SAR measurement procedures in the required wireless mode test configuration(s). The initial test position(s) is measured using the highest measured maximum output power channel in the required wireless mode test configuration(s). When the *reported* SAR for the initial test position is:

1) ≤ 0.4 W/kg, further SAR measurement is not required for the other test positions in that exposure configuration and wireless mode combination within the frequency band or aggregated band. DSSS and OFDM configurations are considered separately according to the required SAR procedures.
2) > 0.4 W/kg,
   a) SAR is repeated using the same wireless mode test configuration tested in the initial test position to measure the subsequent next closest/smallest test separation distance and maximum coupling test position, on the highest maximum output power channel, until the *reported* SAR is ≤ 0.8 W/kg or all required test positions (left, right, touch, tilt or subsequent surfaces and edges) are tested.
      i) For subsequent test positions with equivalent test separation distance or when exposure is dominated by coupling conditions, the position for maximum coupling condition should be tested.
      ii) When it is unclear, all equivalent conditions must be tested; i.e., a single subsequent test position cannot be easily established.
3) For all positions/configurations tested using the initial test position and subsequent test positions, when the *reported* SAR is > 0.8 W/kg, measure the SAR for these test positions/configurations on the

[10] More specific criteria may be considered in subsequent updates according to information provided by test labs in SAR reports that apply initial test position test reduction.

subsequent next highest measured output power channel(s) until the *reported* SAR is ≤ 1.2 W/kg or all required test channels are considered.

a) The additional power measurements required for this step should be limited to those necessary for identifying subsequent highest output power channels to apply the test reduction.

## VII. SAR Test Reduction for Wi-Fi Configurations

SAR test reduction for 802.11 Wi-Fi transmission mode configurations are considered separately for DSSS and OFDM. An initial test position is determined to reduce the number of tests required for certain exposure configurations with multiple test positions. An initial test configuration is determined for each frequency band and aggregated band according to maximum output power, channel bandwidth, wireless mode configurations and other operating parameters to streamline the measurement requirements. For 2.4 GHz DSSS, either the initial test position or DSSS procedure is applied to reduce the number of SAR tests; these are mutually exclusive. For OFDM, an initial test position is only applicable to next to the ear, UMPC mini-tablet and hotspot mode configurations, which is tested using the initial test configuration to facilitate test reduction. For other exposure conditions with a fixed test position, SAR test reduction is determined using only the initial test configuration.

### A. 2.4 GHz 802.11b DSSS

When SAR measurement is required for 2.4 GHz 802.11b DSSS, if applicable, an initial test position is used to minimize the number of tests required for multiple test positions in next to the ear, hotspot mode or UMPC mini-tablet exposure configurations according to the highest maximum output power channel.

For other exposure conditions with a fixed test position, where the initial test position does not apply, SAR test reduction is apply according to the following DSSS procedure.

1) When the *reported* SAR of the highest maximum output channel for the exposure configuration is ≤ 0.8 W/kg, no further testing is required for that exposure configuration for 802.11b DSSS.
2) When the *reported* SAR is > 0.8 W/kg, SAR is required for the next highest measured output channel in that exposure configuration. When any *reported* SAR is > 1.2 W/kg, SAR is required for the 3rd channel; i.e., all channels require testing.

### B. 2.4 GHz 802.11g/n OFDM SAR Test Exclusion

When SAR is required, the measurement and test reduction procedures for OFDM are applied. For 2.4 GHz 802.11g/n OFDM, SAR is not required for the following conditions.

1) When the maximum output power specified for production units, including tolerance, is
   a) ≥ 1 dB lower than that specified for 802.11b DSSS and the highest *reported* SAR for DSSS is ≤ 1.2 W/kg
   b) ≤ ¼ dB higher and < 1 dB lower than that specified for DSSS and the highest *reported* SAR for DSSS is ≤ 0.8 W/kg
2) When KDB 447498 SAR test exclusion applies.

### C. OFDM SAR Measurement and Test Reduction Considerations

When SAR measurement is required for 802.11 a/g/n/ac OFDM configurations, each frequency band and aggregated band is considered separately for SAR test reduction. If the band gap channels between UNII band 2C and UNII band 3 or 5.8 GHz §15.247 are used, the portion of UNII band 2C above 5.65 GHz and 5.8 GHz band are considered as an aggregated band for SAR measurements. While the maximum output power can be different for these bands, the highest maximum output power transmission mode configuration and maximum output power channel across the bands are used to determine SAR test reduction according to the initial test configuration and subsequent test configuration requirements described in the following.[11]

An initial test configuration is determined for SAR measurement according to the channel bandwidth, modulation and data rate combination(s) with the highest maximum output power specified for production units, including tolerances, for each frequency band and aggregated band using the channel with the highest measured maximum output power. When the same maximum output power is specified for multiple channel bandwidths, modulation and data rate combinations, the largest channel bandwidth, lowest order modulation and lowest data rate configuration should be tested. When the maximum output power measured according to the power measurement test reduction requirements is the same for multiple or all channels, the channel closest to the middle of the frequency or aggregated band should be used. For SAR measurement purposes, the signal modulation associated with OFDM sub-carriers is generally not expected to have significant influence to the aggregated output at the OFDM channel. The selection of specific modulation and associated data rates for SAR measurement is to maintain consistency in the test configurations.

The Initial test configuration: SAR measurement in the initial test configuration is required for all OFDM configurations. For next to the ear, hotspot mode or UMC mini-tablet exposure configurations where multiple test positions are required, the initial test position procedure is also applied to minimize the number of test positions required for SAR measurement in the initial test configuration. For other exposure conditions that do not require multiple SAR test positions, when the *reported* SAR of the initial test configuration is > 0.8 W/kg, SAR measurement is required for the subsequent next highest measured output channel(s) in the initial test configuration until the *reported* SAR is ≤ 1.2 W/kg or all required channels are tested.[12]

Subsequent test configurations: SAR measurements and test reduction for the remaining Wi-Fi transmission mode configurations that have not been tested in the initial test configuration are determined separately for each frequency band and aggregated band, for each exposure condition, according to the maximum output power specified for production units, including tolerance, for these configurations. When the same maximum output power applies to multiple configurations, the largest channel bandwidth, lowest order modulation and lowest data rate is used. Within each subsequent test configuration, SAR test reduction may be applied to the subsequent highest maximum output power channels. For purpose of applying the initial test configuration or subsequent test configurations, the Wi-Fi transmission mode configuration with the highest maximum output power and the channel within a test configuration with highest maximum output power should be clearly distinguished to apply the procedures.

1) When the next highest maximum output power transmission mode configuration is
   a) ≤ ½ dB lower than the maximum output power in the initial test configuration and the highest *reported* SAR for the initial test configuration(s), according to the initial test position or fixed exposure condition, is[13]

[11] The band gap channels must satisfy compliance requirements for both bands.

[12] Required channels are those identified in Appendix A and according to procedures described in this document; for example, the 2.4 GHz band.

[13] Maximum output is the maximum output power specified for production units, including tolerance, for the applicable 802.11 wireless configuration.

i) ≤ 0.8 W/kg: further SAR measurement is not required for that exposure condition and frequency band or aggregated band combination.

ii) > 0.8 and ≤ 1.2 W/kg:

(1) SAR is required for all conditions measured in the initial test configuration(s) with *reported* SAR > 0.8 W/kg according to the subsequent test configuration (with next highest specified maximum output power) procedure for channels that overlap in the initial test configuration and subsequent test position due to differences in channel bandwidth or apply the procedures required for > 1.2 W/kg in step 2) below.

(2) SAR should be first measured for the channel with highest measured output power in the subsequent test configuration.[14] SAR for the subsequent highest measured maximum output power channels in the subsequent test configuration is required only when the *reported* SAR of the higher maximum output power channel is > 1.2 W/kg. When the measured maximum output power is the same for the channels, SAR should be measured using the channel closest to the center frequency of the larger channel bandwidth channel. Additional power measurement is necessary to apply this step for SAR test reduction.

b) > ½ dB lower than the maximum output power in the initial test configuration and the highest *reported* SAR for the initial test configuration(s), according to the initial test position or fixed exposure condition, is ≤ 1.2 W/kg; further SAR measurement is not required for that exposure condition and frequency band or aggregated band combination.

2) When the highest *reported* SAR for the initial test configuration(s), according to the initial test position or fixed exposure condition, is > 1.2 W/kg, the initial test configuration SAR measurement procedure is applied to the subsequent test configuration with the next highest maximum output power. The number of channels in the initial test configuration and subsequent test configuration can be different due to differences in channel bandwidth. The channels supported by the channel bandwidth in the subsequent test configuration should be used to determine the highest maximum output power channel. This step requires power measurement to identify the highest maximum output power channel in the subsequent test configuration to apply the initial test configuration procedures for SAR measurement and to determine *reported* SAR.

3) SAR measurement for the remaining highest specified maximum output power transmission mode configurations, other than the initial test configuration (highest maximum output) and subsequent test configuration (next highest maximum output power), is determined by applying the subsequent test configuration procedures in step 1) to the remaining configurations according to the following:

a) replace "subsequent test configuration" with "next subsequent test configuration" (subsequent next highest specified maximum output power configuration

b) replace "initial test configuration" with "all tested higher output power configurations"

4) When a 160 MHz channel is used, regardless of whether it is in the initial test configuration or a subsequent test configuration, SAR measurement is required for all channels in a smaller channel bandwidth configuration that overlaps with the 160 MHz channel with *reported* SAR > 1.2 W/kg.

## VIII. Antenna Diversity, MIMO and Transmit Beamforming Considerations

Transmit diversity, MIMO, beamforming etc. are features found in 802.11 Wi-Fi transmitters for improving coverage and data throughput. The SAR measurement concerns associated with these enhancements vary with the flexibility and complexity of individual implementations. When multiple antennas are transmitting simultaneously, signal characteristics and antenna spatial arrangements can influence the test configurations required for SAR measurement. The transmitting antennas and antenna

[14] Initial test configuration with larger channel bandwidth would result to multiple channels for subsequent test configuration with a lower channel bandwidth.

characteristics must be clearly identified. The normally required SAR test procedures may not apply when there are noticeable differences in maximum output power or antenna performance among the simultaneous transmitting antennas or transmission chains. Frequency, signal correlation, antenna proximity, antenna interactions and transmission conditions are some of the factors that may require SAR to be measured either independently for each antenna or with all antennas transmitting simultaneously, according to the measurement and post-processing procedures supported by individual SAR measurement systems.

### A. Switched Transmit Diversity

Switched transmit diversity is a feature commonly used in early generation Wi-Fi devices. The output power is time and spatially multiplexed dynamically among the antennas. Since the energy is dispersed both temporally and spatially, with only one antenna transmitting at a time, the SAR measured for each antenna may be scaled with a duty factor of 75% to demonstrate compliance according to *reported* SAR procedures in KDB 447498. The measured, scaled and *reported* SAR results are required in the SAR report to support compliance.

### B. Typical MIMO Configurations

*Spatial Multiplexing* (SM): The data is subdivided into multiple streams for transmission through different antennas by spatial multiplexing. The spatial streams from the antennas propagate along different transmission paths and arrive at the destination with different signal strengths and delays. When two spatial streams are multiplexed onto a single RF channel, the maximum data rate is effectively doubled. All APs operating in OFDM HT mode (802.11n) are required to support at least two spatial streams and up to a maximum of four. Non-AP devices can support one or more spatial streams. When multiple spatial streams are transmitted, SAR compliance for simultaneous transmission is required.

*Space-Time Block Coding* (STBC): STBC transmits redundant data in blocks that are coded differently for transmission through different antennas. While multiple receive antennas can improve performance, it is not required for STBC. When the number of transmit antennas are more than the number of receive antennas, STBC may be applied in conjunction with spatial multiplexing.

### C. Transmit Beamforming

Transmit Beamforming (TxBF) applies the channel knowledge obtained either implicitly or explicitly to steer the signal to a desired direction to achieve improved receive signal strength and data rates by exploiting reflection and multipath phenomena. TxBF is not widely used in OFDM HT (802.11n) because of the highly flexible protocol that resulted in implementation complexity and a substantially large number of configurations. In OFDM VHT (802.11ac), however, more restrictive configurations and defined requirements are used to limit the number of configurations, which are expected to encourage the use of TxBF in Wi-Fi devices. VHT TxBF (802.11ac) requires the streams to have equal modulation (EQM). Null data packets (NDP) are required for sounding. For HT TxBF (802.11n), streams with unequal modulations (UEQM) are allowed.

*Implicit feedback* TxBF assumes the channel is reciprocal, where the propagation condition is identical in both directions. The beamformer can request and use the training symbols (sounding PPDU) received from the beamformee to estimate channel condition and compute the transmit steering matrix. Implicit feedback can be unidirectional or bidirectional where a Wi-Fi device can be both the beamformer and beamformee.

*Explicit feedback* TxBF allows the beamformee to estimate the channel conditions from training symbols sent by the beamformer to prepare CSI (Channel State Information) or the steering feedback matrix (V). Transmit steering vector matrix (Q) is determined by the beamformer according to the beamformee feedback.

D. Cyclic Shift Requirements

When correlated signals are transmitted in multiple space-time streams, the MIMO and TxBF requirements specified in IEEE Std 802.11 require cyclic shifts to be applied to data streams transmitted from different antennas to prevent unintended beamforming. The SAR measurement issues relating to correlated signals and coherent transmissions generally do not apply for these implementations. However, Wi-Fi devices using other proprietary implementations or antenna array configurations and coherent transmissions to enhance throughput and coverage must address coherent transmission SAR issues for the test results to be acceptable (see KDB 865664).

## IX. Simultaneous Transmission SAR Considerations

For MIMO, TxBF or other simultaneous transmission configurations, a transmission duty factor of 100% is required to determine SAR compliance. The following discussions are based on common SAR testing issues found in recent generation Wi-Fi devices. It should be emphasized that the procedures can be insufficient for the more complex implementations found in proprietary designs, evolving products or future generation devices. Under such circumstances, a KDB inquiry is required to determine the simultaneous transmission SAR test exclusion and measurement requirements.

A. Antenna Spatial Configurations

When the antennas are spatially separated to the extent that SAR distributions do not overlap and can be treated independently, SAR compliance for simultaneous transmission is determined separately for each individual antenna. Each transmitting antenna is tested independently, one at a time, according to procedures in this document. Otherwise, the simultaneous transmission SAR test exclusion provisions in KDB 447498 or SAR measurement requirements in KDB 865664 are applied to determine compliance.

B. Signal Coherence

For SAR measurement purposes, when correlated signals are transmitted in multiple space-time streams, cyclic shifts are applied to IEEE Std 802.11 compliant MIMO and TxBF configurations to prevent unintended beamforming. The HT and VHT TxBF applied to individual sub-carriers in OFDM are not expected to result in significant or noticeable signal coherence at the OFDM channel output of the antenna chains. However, for other implementations that allow or promote energy focusing in the near-field, SAR issues relating to coherent signals must be addressed according to the individual implementation. When signal coherence applies, the maximum worst-case SAR 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 transmission streams. The extent of focusing is expected to be highly depending on antenna proximity and antenna to phantom or use configurations; therefore, a KDB inquiry is required to address the SAR measurement issues. Current generation SAR probes are designed to measure scalar fields, which are insufficient for coherent signals. However, the measured scalar results may be used to estimate coherent signal SAR according to IEC TR 62230 recommendations, on a case-by-case basis according to individual product design and implementation. Except when the antennas are sufficiently far apart with no noticeable overlapping SAR distributions, the simultaneous transmission SAR test exclusion provisions in KDB 447498 generally do not apply to coherent signal configurations.

C. Simultaneous Transmission SAR Test Exclusion

The simultaneous transmission conditions for MIMO, TxBF and other similar configurations must be considered separately for each channel bandwidth and frequency band or aggregated band combination and exposure conditions to determine SAR compliance. The aggregate maximum output power of all simultaneous transmitting antennas in all transmission chains may be used to determine SAR test exclusion for each frequency band and transmission mode configuration according to the standalone SAR test exclusion provisions in KDB 447498. When standalone SAR test exclusion does not apply, the sum of 1-g SAR provision in KDB 447498 should be applied to determine simultaneous transmission SAR test exclusion. The SAR peak to location ratio provision in KDB 447498 is only applicable when all simultaneous transmitting antennas are in the same (2D) spatial plane from the phantom; therefore, it cannot be applied to antennas located at different separation distances to the phantom. For MIMO configurations, when lower order subsets of the maximum MIMO chains are used; for example, 2x2 as subsets of 3x3, all MIMO combinations must be accounted for to determine compliance, either by SAR test exclusion or measurement; especially when there is a difference in maximum output power or antenna interactions for integrated MIMO antenna structures.

The simultaneous transmission SAR test exclusion provisions in KDB 447498 can be applied to avoid simultaneous transmission SAR measurement or reduce the number of tests. For the typical circumstances, the number of simultaneous transmission SAR measurements can be kept to less than 2 – 3. To correctly apply simultaneous transmission SAR test exclusion, the *reported* standalone SAR results must be examined according to all combinations of channel bandwidths, maximum output power, Wi-Fi transmission modes, frequency bands, exposure configurations and test positions to determine if certain combinations may be considered collectively to apply the SAR test exclusion procedures according to the highest *reported* SAR in the group. The decision to aggregate standalone SAR results into meaningful groups according to Wi-Fi transmission mode configurations, exposure conditions and test positions etc. must be consistent with the actual transmission and use conditions. When the sum of 1-g SAR is used to determine SAR test exclusion for all simultaneous transmission configurations in a group, the highest *reported* standalone SAR among all Wi-Fi and exposure configurations for each antenna must be used to determine if simultaneous transmission SAR measurement is unnecessary. However, if SAR peak to location ratio is also applied to some of the configurations for further SAR test reduction, it is generally inappropriate to consider these transmission and exposure configurations collectively with respect to the highest SAR used for sum of 1-g exclusion because the SAR peak to location ratio procedure is specific to the simultaneous transmitting antennas and test configuration considered.[15]

To apply the simultaneous transmission SAR test exclusion procedures in KDB 447498, it must be ensured that the maximum output power for each antenna during simultaneous transmission is not greater than that used in standalone transmission. Otherwise, additional standalone SAR measurements at the (reduced) maximum output power used for simultaneous transmission should be considered to apply the simultaneous transmission SAR test exclusion. The number of additional standalone measurements at the reduced maximum power may be minimized when it can be demonstrated that SAR scaling can be applied; however, a KDB inquiry may be required to address the details for the individual circumstances.

When simultaneous transmission SAR test exclusion is not satisfied for a transmission mode and exposure configuration, simultaneous transmission SAR measurement is required for the specific configuration. Unless the antennas are spatially separated and the SAR distributions do not overlap, when antennas transmit simultaneously in the same frequency band, within the frequency range covered by a

[15] See simultaneous transmission SAR test exclusion section of KDB 447498 for additional explanation.

single SAR probe calibration point, SAR is generally measured with all antennas transmitting simultaneously at maximum output power in a single SAR measurement.

**Appendix A**

<u>5 GHz 802.11 channel configurations</u>

(For illustration only)