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Laboratory Division Draft Publication Report

Title: SAR Measurement Guidance for IEEE 802.11 Transmitters

Short Title: SAR meas for IEEE 802.11

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

Publication: 248227

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

First Category: Radio Frequency Exposure - MPE; SAR

Second Category: Testing

Question:

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

Answer:

Yes, the attached document, 248227 D01 SAR meas for 802 11 a b g v02, SAR measurement procedures for 802.11 transmitters.

Note: This draft publication, 248227 D01 SAR meas for 802 11 a b g DR02-41929, can be used for demonstrating compliance prior to the final publication of this document.

Attachment List:

[248227 D01 SAR meas for 802 11 a b g v02](#)

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SAR GUIDANCE FOR IEEE 802.11 (Wi-Fi) TRANSMITTERS

1. INTRODUCTION

The SAR evaluation guidance provided in this document is intended for Wi-Fi[®] devices authorized under §§15.247 and 15.407 of Commission rules in the 2.4 GHz and 5 GHz bands that are implemented according to IEEE Std 802.11-2012 (802.11 a/b/g/n) and IEEE Std 802.11ac-2013.¹ Unless it is described in this document; for example, Wi-Fi Direct and TDLS in Appendix A, the guidance 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 in this document are applicable to Wi-Fi transmitters operating in consumer products that require SAR evaluation.³

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 802.11a/g/n and 802.11ac. Numerous combinations of signal modulations, data rates, channel bandwidths and multiple antenna transmission schemes are included in IEEE 802.11 protocols to provide substantial flexibility for improving coverage and data throughput. As new generation Wi-Fi products continue to emerge, coexistence with previously deployed devices is necessary to maintain migration continuity. Compatibility with older products may require the typical Wi-Fi devices to support both 2.4 GHz and some or all of the 5 GHz bands. Without streamlining the SAR test requirements, measurements for hundreds of Wi-Fi transmission configurations are required to demonstrate compliance.

For some devices, the maximum output power specifications, simultaneous transmission schemes or other operating parameters may vary across transmission modes and operating configurations in a frequency band; therefore, additional guidance is necessary to provide standardized procedures for SAR measurement. This KDB publication provides procedures for the most common implementations of Wi-Fi protocols; when ad hoc or proprietary configurations are used additional guidance from the FCC may be necessary. The fundamental SAR measurement procedures and reporting requirements are described, respectively, in KDB Publication 865664 D01 and D02. The SAR test requirements for product platform

¹ Wi-Fi[®] is a trademark of *Wi-Fi Alliance*.

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 or Part 15 subpart H; further consideration is required.

³ Evaluation includes addressing RF exposure compliance by analysis, SAR test exclusion, measurement or other acceptable methods.

and technology specific configurations are described in the KDB publications identified in KDB Publication 447498.⁴ These other requirements are necessary to apply the Wi-Fi SAR procedures. This document covers the most common types of SAR test configurations; a KDB inquiry is required to determine alternative SAR measurement procedures for additional configurations or special implementations. In the following sections, the general SAR measurement considerations and frequency band specific test requirements are first discussed and then followed by the power and SAR measurement procedures.

2. GENERAL SAR MEASUREMENT CONSIDERATIONS

A brief summary of the 802.11 PHY and typical peer-to-peer Wi-Fi configurations, such as TDLS, Mesh Services and Wi-Fi Direct, is included in Appendix A to identify applicable wireless configurations, modulations and data rates etc. that need consideration to apply the SAR measurement procedures. Transmit diversity, MIMO and TxBF configurations typically used in Wi-Fi transmitters are also summarized in Appendix A. The 5 GHz 802.11 channel configurations are illustrated in Appendix B. Provided the Wi-Fi transmission is not coordinated with other transmitters; for example, 3G/4G devices to support additional exposure conditions, SAR measurement is generally not necessary for standalone peer-to-peer operations. When simultaneous transmission is supported for Wi-Fi in multiple 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. For OFDM transmission modes, the SAR system validation procedures in KDB Publication 865664 are required to address high peak to average power ratio SAR probe calibration and measurement concerns.

2.1. SAR Measurement and Test Reduction Configurations

The SAR measurement and test reduction procedures are structured according to the transmission modes in each frequency band and aggregated band according to either DSSS or OFDM configurations. For devices that operate in exposure configurations with multiple test positions, additional SAR test reduction may be considered. When the maximum output power specified for production units are used to determine SAR test requirements, tune-up tolerance must be taken into consideration. The general test configurations are defined in the following:

- 1) An “initial test configuration” is first determined for 2.4 GHz and 5 GHz OFDM transmission configurations in each frequency band and aggregated band according to the maximum output power and tune-up tolerance specified for production units. When the same maximum power is specified for multiple transmission modes, channel bandwidth, modulation, data rate and other operating parameters are used to select a test configuration. SAR is measured using the initial test configuration procedures and applicable frequency band specific requirements (section 5.4).
 - a) Initial test configuration does not apply to DSSS. The 802.11b DSSS procedures (section 5.3.1) and 2.4 GHz band SAR test requirements (section 3.1) are used to establish the transmission configurations.
- 2) An “initial test position” is applied to further reduce the number of SAR tests for devices that operate in next to the ear, UMPC mini-tablet and hotspot mode exposure configurations requiring multiple test positions (section 5.2). SAR is measured using the exposure condition established by the initial

⁴ See Introduction section of KDB Publication 447498.

test position for 802.11b according to the 2.4 GHz DSSS procedure or the initial test configuration determined by the 2.4 GHz and 5 GHz OFDM configurations.

- a) Initial test position does not apply to devices with a fixed exposure test position. SAR is measured in a fixed exposure test position for 802.11b according to the 2.4 GHz DSSS procedure or the initial test configuration procedures for 2.4 GHz and 5 GHz OFDM configurations.
- 3) The “subsequent test configuration” procedures are applied to determine if additional SAR measurements are required for the OFDM transmission modes that have not been tested in the initial test configuration, according to reported SAR of the initial test configuration and power specifications or measured results for these remaining OFDM configurations.

2.2. Duty Factor Control

Wi-Fi transmitters are designed to operate seamlessly across networks where the traffic conditions are asynchronous and dynamic. Collision avoidance and retransmission of error packets are part of the network behavior, which can result in substantial variations in transmission patterns. The random transmission characteristics of Wi-Fi networks are 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 protocols. Various vendor specific external test software and chipset based internal test modes are typically used for SAR measurement. These chipset based test mode utilities are generally hardware and manufacturer dependent, and often include substantial flexibility to reconfigure or reprogram a device. It must be ensured that the unmodified settings in production units, including maximum output power, amplifier gain settings and other RF performance or tuning parameters, are used for SAR measurement.

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 tools for SAR measurement. A periodic duty factor is required for current generation SAR systems to measure SAR correctly. The test frequencies established using test mode must correspond to the actual channel frequencies required for operations in the U.S. When 802.11 frame gaps are accounted for in the transmission, a maximum transmission duty factor of 92 - 96% is typically achievable in most test mode configurations. A minimum transmission duty factor of 85% is required to avoid certain hardware and device implementation issues related to wide range SAR scaling. Unless it is permitted by specific KDB procedures or continuous transmission is specifically restricted by the device, the reported SAR must be scaled to 100% transmission duty factor to determine compliance at the maximum tune-up tolerance limit. When a device is not capable of sustaining continuous transmission or the output can become nonlinear, and it is by design hardware limited and unable to transmit at higher than 85% duty factor, a periodic duty factor within 15% of the maximum duty factor the device is capable of transmitting should be used. The reported SAR must be scaled to the transmission maximum duty factor to determine compliance. Descriptions of the procedures used to establish the specific duty factor used for SAR testing are required in the SAR report to support test results.

2.3. SAR Probe Calibration Requirements

To adequately cover the 5 GHz bands, SAR probes used for testing Wi-Fi devices should be calibrated with at least ± 100 MHz coverage, according to the tissue dielectric parameter requirements in KDB Publication 865664, to minimize the number of probe calibration points required. 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 Publication 865664 requirements. The recommended probe calibration frequencies are indicated in Table 1, where the probe calibration point at 5.60 GHz is expected to be marginal for the bandedge channels in U-NII-2C (standalone) band. It is 200 MHz (5.5 –

5.7 GHz) wide between the channel center frequencies of the bandedge channels and 220 MHz (5.49 – 5.71 GHz) after accounting for channel bandwidth. Therefore, when a bandedge channel is tested, the tissue dielectric parameters must be within 5% of the required targets at the test frequency and the SAR error compensation provisions described in KDB Publication 865664 for allowing up to 10% tissue parameter tolerance should not be applied.

Table 1

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

* The portion above 5.65 GHz in U-NII-2C band is tested using the 5.75 GHz probe calibration point. Test labs may continue to use existing SAR probe calibrations with more than two calibration points or until the probe is due for recalibration.

3. FREQUENCY BAND AND TEST CHANNEL CONFIGURATIONS

SAR test requirements may vary according to Wi-Fi protocols and FCC rule requirements. The test configurations are organized according to transmission modes, as either DSSS or OFDM. The procedures are applied to each frequency band and aggregated band according to channel bandwidths and exposure conditions (i.e., operating configurations and exposure test positions). For purpose of SAR evaluation, simultaneously transmitting two non-contiguous channels or contiguous but independent and non-aggregated channels, regardless of using the same or different channel bandwidth, is not equivalent to transmitting a single contiguous channel. Two non-contiguous 80 MHz channels in 802.11ac VHT is not equivalent to a 160 MHz channel; these must be considered separately for SAR compliance. The procedures also support measurements across selected adjacent frequency bands that are within the frequency range covered by one or more SAR probe calibration points to streamline the SAR measurement. The frequency band specific SAR test configurations are described in this section.

3.1. 2.4 GHz Band (§15.247)

The maximum output power permitted for devices authorized under §15.247 is 1 W conducted and 36 dBm EIRP.⁵ 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 production units should be tested

⁵ As described in KDB Publication 447498, EIRP may not be relevant for evaluating the SAR of small portable transmitters designed to operate next to persons.

instead of channels 1, 6 or 11.⁶ When 40 MHz channels are supported, and provided higher maximum output power is not specified for other applicable 40 MHz channels, channel 6 should be used to measure SAR; otherwise, the channel with highest specified maximum output power should be tested instead. In addition, the SAR test reduction provisions in section 4.3.3 of KDB Publication 447498 should also be applied.

3.2. U-NII-1 and U-NII-2A Bands (§15.407)

The maximum output power permitted for devices authorized under §15.407 U-NII-1 band (5.15 – 5.25 GHz), with respect to interim provisions (for old rules) in ET Docket No. 13-49, (FCC 14-30), is 50 mW conducted and 23 dBm EIRP. The maximum output power permitted by the new rules in FCC 14-30 is 250 - 1000 mW conducted and 21 – 36 dBm EIRP, depending on transmitter configurations and antenna operating requirements.⁷ For U-NII-2A band (5.25 – 5.35 GHz), the maximum output power is 250 mW conducted and 30 dBm EIRP. When applicable, a lower maximum output power may be required to satisfy emission bandwidth restrictions for these bands. When both bands apply to a device, SAR test reduction may be considered according to procedures in section 5.4.1.

3.3. U-NII-2C, U-NII-3 Bands (§15.407) and 5.8 GHz Band (§15.247)

The maximum output power permitted for devices authorized under §15.407 U-NII-2C band (5.470 – 5.725) is 250 mW conducted and 30 dBm EIRP. For U-NII-3 band (5.725 – 5.825 GHz) and §15.247 5.8 GHz band (5.725 – 5.850 GHz) the maximum output power permitted is 1 W conducted and 36 dBm EIRP.⁸ When applicable, a lower maximum output power may be required due to emission bandwidth restrictions for these bands. 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 SAR measurements. The typical SAR probe calibration point in this frequency range should 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. In addition, when Terminal Doppler Weather Radar (TDWR) restriction applies, the channels at 5.60 – 5.65 GHz in U-NII-2C band must be disabled with acceptable mechanisms and documented in the equipment certification to avoid SAR requirements.⁹ TDWR restriction does not apply under the new rules; all channels at 5.60 – 5.65 GHz must be included to apply the SAR test reduction and measurement procedures.

When the same transmitter and antenna(s) are used for U-NII-2C band and U-NII-3 band or §15.247 5.8 GHz band, the bands may be aggregated to enable additional channels with 20, 40 or 80 MHz bandwidth

⁶ Channels 1, 6 and 11 should each be considered separately to determine the closest adjacent channel with higher output power.

⁷ Interim provisions for U-NII-1 band expire 12 months after the effective date of FCC 14-30. See KDB Publication 926956 for U-NII Transition Plan. For point-to-point operations, antenna gain up to 23 dBi at 1.0 W conducted maximum power is permitted; however, SAR and portable exposure conditions typically do not apply to point-to-point configurations. To satisfy SAR limit, it may be necessary for some devices to operate at maximum output power levels less than that permitted by the rules.

⁸ Interim provisions for approval of 5.8 GHz §15.247 expire 12 months after the effective date of FCC 14-30. For point-to-point operations, up to 23 dBi antenna gain at 1.0 W conducted maximum power is permitted for U-NII-3 band; however, SAR and portable exposure conditions typically do not apply to point-to-point configurations. For some devices, lower than permitted maximum output power may be necessary to meet SAR limit.

⁹ Interim provisions for excluding TDWR channels in U-NII-2C expire 12 months after the effective date of FCC 14-30. Compliance with the new rules is required upon expiration.

to span across the band gap, as illustrated in Appendix B. The maximum output power for the additional band gap channels is limited to the lower of those certified for the bands. Unless band gap channels are permanently disabled, SAR must be considered. To maintain SAR measurement accuracy and to facilitate test reduction, the channels in U-NII-2C band above 5.65 GHz are grouped with the 5.8 GHz channels in U-NII-3 band or §15.247 5.8 GHz band to enable two SAR probe calibration frequency points to cover the bands, including the band gap channels.¹⁰ When band gap channels are disabled, each band must be tested independently according to the normally required OFDM SAR measurement and probe calibration frequency points requirements.

A single 160 MHz channel may be supported by U-NII-2C band for client devices that are certified to operate at 5.60 – 5.65 GHz without TDWR restriction. Band aggregation for 160 MHz channel across U-NII-2C and U-NII-3 bands is not defined in IEEE Std 802.11ac-2013 for VHT; however, transmitters may operate with proprietary implementations to transmit across the bands. When applicable, these types of implementations and configurations must be taken into consideration to determine SAR compliance. A KDB inquiry is necessary to determine the test configurations.

4. POWER MEASUREMENT REQUIREMENTS

The maximum output power of typical 802.11 transmitters may vary with transmission modes, frequency bands, antenna implementation and operating conditions. The peak to average output power ratio of signals in different transmission modes is typically a function of the channel bandwidth and transmission scheme. While different modulations may be applied to the raw data bits in DSSS and OFDM, for example, BPSK, CCK, PBCC, ERP, QPSK, 16- to 256-QAM, etc., these are generally not expected to have significant influence to the DSSS or OFDM output characteristics and SAR. The choice of modulation and data rate used in SAR measurements is mostly for maintaining test configuration consistency.

Maximum output power must be measured according to the default power measurement procedures in this section. When SAR measurement is required, power measurement is also required to confirm output power settings and to determine *reported* SAR according to procedures in KDB Publication 447498. Additional power measurements may be necessary to apply SAR test reduction for the test channels in a transmission mode. When different maximum output power is specified across the channels in a Wi-Fi transmission mode, a KDB inquiry is required to determine the test requirements. If the required power measurement is not included in the default configurations, it is typically measured immediately before and/or after the SAR measurement. Otherwise, when power measurement is not required for a transmission mode, the maximum output power and tune-up tolerance specified by production units can generally be used to determine SAR test exclusion and reduction.

The default power measurement procedures are described in the following:

- 1) Power must be measured at each transmit antenna port according to the DSSS and OFDM transmission configurations in each standalone and aggregated frequency band.

¹⁰ Test labs may continue to use existing SAR probe calibrations with more than two calibration points or until the probe is due for recalibration.

- 2) Power measurement is required for the transmission mode configuration with the highest maximum output power specified for production units.¹¹
- 3) For transmission modes with the same maximum output power specification, the largest channel bandwidth, lowest order modulation and lowest data rate is measured.
- 4) For configurations with identical maximum specified output power, channel bandwidth, modulation and data rate requirements, power measurement is required for all identical configurations.
- 5) For each transmission mode configuration, power must be measured for the highest and lowest channels; and at the mid-band channel(s) when there are at least 3 channels.¹² For configurations with multiple mid-band channels, due to an even number of channels, both channels should be measured.

5. SAR TEST PROCEDURES

SAR test reduction is determined according to 802.11 transmission mode configurations and certain exposure conditions with multiple test positions. In the 2.4 GHz band, separate SAR procedures are applied to DSSS and OFDM configurations to simplify DSSS test requirements. For OFDM, in both 2.4 and 5 GHz bands, an initial test configuration must be determined for each frequency band and aggregated band, according to the transmission mode configuration with the highest maximum output power specified for production units to perform SAR measurements. When applicable, an initial test position may be applied to reduce the number of SAR measurements required in next to the ear, UMPC mini-tablet and hotspot mode configurations with multiple test positions. For 2.4 GHz 802.11b DSSS, either the initial test position procedure for multiple exposure test positions or the DSSS procedure for fixed exposure position is applied; these are mutually exclusive. For 2.4 GHz and 5 GHz OFDM configurations, the initial test configuration is applied to measure SAR with either the initial test position procedure for multiple exposure test position configurations or the initial test configuration procedures for fixed exposure test conditions. Based on the reported SAR of the measured configurations and maximum output power of the transmission mode configurations that are not included in the initial test configuration, the subsequent test configuration and initial test position procedures are applied to determine if SAR measurements are required for the remaining OFDM transmission configurations. In general, the maximum output power measured for test sample(s) are used to minimize the number of test channels require SAR measurements. For OFDM configurations with the same maximum output power, channel bandwidths, modulations and data rates, additional procedures are applied to determine which test configuration to use for SAR measurement.

5.1. OFDM transmission mode and SAR Test Channel Selection Requirements

For the 2.4 GHz and 5 GHz bands, when the same maximum output power is specified for multiple OFDM transmission mode configurations in a frequency band or aggregated band, SAR is measured using the configuration with the largest channel bandwidth, lowest order modulation and lowest data rate. When there are multiple mid-band channels due to an even number of channels, SAR is measured using the higher number channel. When the maximum output power of a channel is the same for equivalent

¹¹ The Wi-Fi transmission modes include all channel bandwidths, modulations and data rates for the 802.11a/g/n/ac OFDM configurations in a frequency band or aggregated band. For 2.4 GHz, 802.11b DSSS and 802.11g/n OFDM configurations are considered separately.

¹² When only one channel is supported by the 802.11 mode; for example, in 160 MHz channel configurations, high and low channels do not apply.

OFDM configurations; for example, 802.11a, 802.11n and 802.11ac or 802.11g and 802.11n with the same channel bandwidth, modulation and data rate etc., the lower order 802.11 mode i.e., 802.11a, then 802.11n and 802.11ac or 802.11g then 802.11n, is used for SAR measurement. When the maximum output power is the same for multiple test channels, either according to the default or additional power measurement requirements, SAR is measured using the channel closest to the middle of the frequency band or aggregated band.¹³ An example showing how SAR test reduction is determined for channels and transmission mode configurations with the same maximum output power is given in Appendix C; a power measurement template is also included.

5.2. Multiple Exposure Test Position SAR Test Reduction

The following procedures are applied to select an initial test position for handsets operating next to the ear, devices with hotspot mode or UMPC mini-tablets to minimize the number of SAR measurements normally required for exposure configurations with multiple test positions.¹⁴ SAR is measured on the highest measured maximum output power channel using the initial test position. The *reported* SAR and power measurement results are used to determine if SAR measurements are required for some of the other exposure positions and test channels.

SAR conservativeness is established by area scan measurements, in the multiple exposure test positions, to determine the initial test position. The area scans must be measured using the same SAR measurement configurations, including test channel, maximum output power, probe tip to phantom distance, scan resolution etc. for the results to be comparable. The SAR is extrapolated to the phantom surface at each peak SAR location. The test position with the highest extrapolated SAR is used as the initial test position. Instead of extrapolated SAR, the 1-g estimated SAR procedures (fast SAR) in KDB Publication 447498 may be used. The interpolated or 1-g estimated SAR must be scaled according to *reported* SAR requirements to compare the area scan results.

As an alternative, when antenna location and implementation details, such as antenna orientation and polarization, are available from device manufacturers the test separation distance between the phantom and outer surface of a device, at the geometric center of a Wi-Fi antenna, and antenna to phantom RF coupling conditions may be used to establish the initial test position.¹⁵ A test lab may consider using such information to assess test separation distance and antenna to phantom RF coupling conditions to determine the initial test position. However, if the required information is unavailable, insufficient or the test separation distance and antenna to phantom RF coupling conditions of multiple test positions are indistinguishable, area scans must be measured to determine the initial test position. Explanations on how the initial test position is established must be clearly described in the SAR report for the results to be acceptable.

¹³ Channels with measured maximum output power within ¼ dB of each other are considered to have the same maximum output.

¹⁴ 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 consumer products and host configurations. The SAR margins identified for Wi-Fi are not applicable to WWAN or other transmitters operating at higher output power levels or different conditions.

¹⁵ Instead of the geometric center of a Wi-Fi antenna, locations within the antenna structure that are demonstrated to be equivalent or more conservative may be used.

- 1) Head Exposure Configuration: The left, right, touch and tilt test positions for next to 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 according to area scans or 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 RF coupling conditions.
- 2) Hotspot mode and UMPC mini-tablets: The surfaces and edges that require SAR measurement in hotspot mode or UMPC mini-tablet configuration may be considered collectively as one exposure configuration to facilitate SAR test reduction. The initial test position is determined according to area scans or 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 RF coupling conditions.

5.2.1. Initial Test Position SAR Test Reduction Procedure

DSSS and OFDM configurations are considered separately according to the required SAR procedures. SAR is measured in the initial test position using the 802.11 transmission mode configuration required by the DSSS procedure or initial test configuration and subsequent test configuration(s) according to the OFDM procedures.¹⁶ The initial test position procedure is described in the following:

- 1) When the reported SAR of the initial test position is ≤ 0.4 W/kg, further SAR measurement is not required for the other (remaining) test positions in that exposure configuration and 802.11 transmission mode combination within the frequency band or aggregated band. SAR is also not required for that exposure configuration in the subsequent test configuration(s).
- 2) When the reported SAR of the initial test position is > 0.4 W/kg, SAR is repeated for the 802.11 transmission mode configuration tested in the initial test position to measure the subsequent highest extrapolated or estimated 1-g SAR condition, according to the area scans or next closest/smallest test separation distance and maximum RF 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.¹⁷
- 3) For all positions/configurations tested using the initial test position and subsequent test positions, when the reported SAR is > 0.8 W/kg, SAR is measured for these test positions/configurations on the subsequent next highest measured output power channel(s) until the reported SAR is ≤ 1.2 W/kg or all required channels are tested.
 - a) Additional power measurements may be required for this step, which should be limited to those necessary for identifying the subsequent highest output power channels.

¹⁶ For OFDM, the initial test position applies to both the initial test configuration and subsequent test configuration(s).

¹⁷ The subsequent next highest SAR configuration determined by the initial test position area scans or according to manufacturer details is used. For example, if four area scans are performed to determine the initial test position with 0.8, 0.75, 0.72 and 0.7 W/kg, respectively, as the extrapolated (or 1-g estimated) SAR results; the 0.8 W/kg configuration would correspond to the initial test position and, when SAR measurement is required, the other configurations (in descending SAR) would correspond to the subsequent test positions. The test lab should be able to minimize the number of area scans based on the reported SAR obtained from the first few area scans.

5.3. 2.4 GHz SAR Procedures

Separate SAR procedures are applied to DSSS and OFDM configurations in the 2.4 GHz band to simplify DSSS test requirements. For 802.11b DSSS SAR measurements, DSSS SAR procedure is used for fixed exposure test position and initial test position procedure is used for multiple exposure test positions. When SAR measurement is required for an OFDM configuration, the initial test configuration, subsequent test configuration and initial test position procedures are applied. The SAR test exclusion requirements for 802.11g/n OFDM configurations are described in section 5.3.2.

5.3.1. 802.11b DSSS SAR Test Requirements

SAR is measured for 2.4 GHz 802.11b DSSS using either a fixed test position or, when applicable, the initial test position procedure. SAR test reduction is determined according to the following:

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

5.3.2. 2.4 GHz 802.11g/n OFDM SAR Test Exclusion Requirements

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

- 1) When KDB Publication 447498 SAR test exclusion applies to the OFDM configuration.
- 2) When the highest reported SAR for DSSS is adjusted by the ratio of OFDM to DSSS specified maximum output power and the adjusted SAR is ≤ 1.2 W/kg.
 - a) When SAR test exclusion applies to DSSS, a reported SAR of 0.4 W/kg is used to determine the adjusted SAR.

5.4. SAR Test Requirements for 2.4 and 5 GHz OFDM Configurations

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. When the same transmitter and antenna(s) are used U-NII-1 and U-NII-2A bands, additional SAR test reduction applies. When the band gap channels are used between U-NII-2C band and U-NII-3 band or §15.247 5.8 GHz band, the maximum output power may vary across the channels; the highest maximum output power transmission mode configuration and maximum output power channel across the bands must be used to determine SAR test reduction, according to the initial test configuration and subsequent test configuration requirements.¹⁸ In applying the initial test configuration and subsequent test configuration procedures, the 802.11 transmission configuration with the highest specified maximum output power and the channel within a

¹⁸ Band gap channels must satisfy the maximum output power and equipment certification requirements for both adjacent bands.

test configuration with the highest measured maximum output power should be clearly distinguished to apply the procedures.

5.4.1. U-NII-1 and U-NII-2A Bands

For devices that operate in only one of the bands, the normally required SAR procedures for OFDM configurations are applied. For devices that operate in both U-NII bands using the same transmitter and antenna(s), SAR test reduction is determined according to the following, with respect to the highest *reported* SAR and maximum output power specified for production units.

- 1) When the same maximum output power is specified for both bands, begin SAR measurement in U-NII-2A by applying the OFDM SAR requirements.¹⁹ If the highest *reported* SAR is ≤ 1.2 W/kg, SAR is not required for U-NII-1 band; otherwise, both bands should be tested independently for SAR.
- 2) When different maximum output power is specified for the bands, begin SAR measurement in the band with higher specified maximum output power. The highest *reported* SAR is adjusted by the ratio of lower to higher specified maximum output power for the two bands. When the adjusted SAR is ≤ 1.2 W/kg, SAR is not required for the band with lower maximum output power; otherwise, both bands should be tested independently for SAR.²⁰
- 3) The two U-NII bands may be aggregated to support a 160 MHz channel on channel number 50. The maximum output power for this is limited to the lower of the maximum output power certified for the two bands. When SAR measurement is required for at least one of the bands and the highest *reported* SAR is > 1.2 W/kg, SAR is required for the 160 MHz channel. This procedure does not apply to an aggregated band with maximum output higher than the standalone band(s) where the aggregated band must be tested independently for SAR. SAR is not required when the 160 MHz channel is operating at a reduced maximum power and also qualifies for SAR test exclusion.

5.4.2. Initial Test Configuration Procedures

An initial test configuration is determined according to the channel bandwidth, modulation and data rate combination(s) with the highest maximum output power specified for production units in each frequency band and aggregated band for SAR measurement using the highest measured maximum output power channel. SAR test reduction for OFDM configurations is partly based on *reported* SAR of the initial test configuration. For next to the ear, hotspot mode and UMC mini-tablet exposure configurations where multiple test positions are required, the initial test position procedure is applied to minimize the number of test positions required for SAR measurement using the initial test configuration transmission mode.²¹ For other exposure conditions that do not require multiple SAR test positions, SAR is measured in the transmission mode determined by the initial test configuration. When the *reported* SAR of the initial test configuration is > 0.8 W/kg, SAR measurement is required for the subsequent next highest measured

¹⁹ The applicable procedures for OFDM configurations include the initial test configuration, initial test position and subsequent test configuration procedures.

²⁰ For example, if the highest *reported* SAR for U-NII-1 band is 1.4 W/kg and the specified maximum output power for U-NII-1 and U-NII-2A bands are 250 mW and 200 mW respectively, the adjusted SAR is $1.4 \times 200/250 = 1.12$ W/kg. The adjusted SAR is ≤ 1.2 W/kg; therefore, SAR is not required for U-NII-2A band.

²¹ When a test lab chooses not to apply the initial test position procedure, the initial test configuration procedures must be applied separately to each exposure test position.

output power channel(s) in the initial test configuration until the reported SAR is ≤ 1.2 W/kg or all required channels are tested.²²

5.4.3. Subsequent Test Configuration Procedures

SAR measurement requirements for the remaining 802.11 transmission mode configurations that have not been tested in the initial test configuration are determined separately for each frequency band and aggregated band, in each exposure condition, according to the maximum output power specified for production units. The initial test position procedure is applied to next to the ear, UMPC mini-tablet and hotspot mode configurations. When the same maximum output power is specified for multiple transmission modes, the procedures in section 5.1 are applied to determine the test configuration. Additional power measurements may be required to determine if SAR measurements are required for subsequent test channels in a subsequent test configuration. The subsequent test configuration and SAR measurement procedures are described in the following.

- 1) When the SAR test exclusion provisions of KDB Publication 447498 are applicable and SAR measurement is not required for the initial test configuration, SAR is also not required for the next highest maximum output power transmission mode subsequent test configuration(s) in that frequency band or aggregated band and exposure configuration.
- 2) When the highest reported SAR for the initial test configuration, according to the initial test position or fixed exposure position requirements, is adjusted by the ratio of the subsequent test configuration to initial test configuration specified maximum output power and the adjusted SAR is ≤ 1.2 W/kg, SAR is not required for that subsequent test configuration.
- 3) The number of channels in the initial test configuration and subsequent test configuration can be different due to differences in channel bandwidth. When SAR measurement is required for a subsequent test configuration and the channel bandwidth is smaller than that in the initial test configuration, all channels in the subsequent test configuration that overlap with the larger bandwidth channel tested in the initial test configuration should be used to determine the highest maximum output power channel. This step requires additional power measurement to identify the highest maximum output power channel in the subsequent test configuration to determine SAR test reduction.
 - a) SAR should first be measured for the channel with highest measured output power in the subsequent test configuration.
 - b) SAR for 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(s) in the subsequent test configuration is > 1.2 W/kg or until all required channels are tested.
 - i) For channels with the same measured maximum output power, SAR should be measured using the channel closest to the center frequency of the larger channel bandwidth channel in the initial test configuration.²³
- 4) SAR measurements for the remaining highest specified maximum output power OFDM transmission mode configurations that have not been tested in the initial test configuration (highest maximum output) or subsequent test configuration(s) (subsequent next highest maximum output power) is

²² Required channels are those identified in Appendix B and according to procedures described in this document; for example, 2.4 GHz band in section 3.1. Also see section 5.1 for channels with the same measured maximum output power, multiple mid-band channels or equivalent 802.11 transmission modes etc.

²³ Channels with measured maximum output power within ¼ dB are considered to have the same maximum output.

determined by applying the subsequent test configuration procedures in this section to the remaining configurations according to the following:

- a) replace “subsequent test configuration” with “next subsequent test configuration” (i.e., subsequent next highest specified maximum output power configuration)
- b) replace “initial test configuration” with “all tested higher output power configurations”

6. SIMULTANEOUS TRANSMISSION SAR CONSIDERATIONS

For MIMO, TxBF and 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 more complex implementations found in proprietary designs, evolving products or future generation devices. Under such circumstances, a KDB inquiry is required to determine simultaneous transmission SAR test exclusion and measurement requirements.

6.1. Antenna Spatial Configurations

When 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. In general, when the aggregate SAR from multiple antennas at any location in the SAR distribution is ≤ 1.2 W/kg and also ≤ 0.1 W/kg higher than the standalone SAR of each individual antenna at the same location, either determined by inspection or quantitative comparison, the antennas may be considered as spatially separated. Each transmitting antenna is tested independently, one at a time, according to procedures in this document. Otherwise, when SAR distributions overlap, the simultaneous transmission SAR test exclusion provisions in KDB Publication 447498 or SAR measurement requirements in KDB Publication 865664 are applied to determine compliance.

6.2. 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 reported SAR for the antennas are averaged to determine compliance. Both measured and reported SAR for all diversity antennas are required in the SAR report to support compliance.

6.3. Simultaneous Transmission SAR Test Exclusion

The simultaneous transmission conditions for MIMO, TxBF and other similar configurations must be considered separately for each frequency band and aggregated band according to the 802.11 transmission mode configurations 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. The most conservative SAR test separation distance among the antennas must be used to apply the standalone SAR test exclusion provisions in KDB Publication 447498.²⁴ When the power-based standalone SAR test exclusion does not apply, the sum of 1-g SAR provision in KDB Publication 447498 should be used to determine simultaneous transmission SAR test exclusion. When estimated SAR is required for configurations that do not require standalone SAR measurement, simultaneous transmission SAR test

²⁴ This only applies to simultaneous transmission in a single frequency band.

exclusion is determined by the smaller of the estimated SAR or highest *reported* SAR for the 802.11 transmission modes in that frequency band. The SAR peak to location ratio provision in KDB Publication 447498 is intended for peak SAR locations measured in the same (2D) plane within the phantom. When a peak SAR location is estimated because standalone SAR measurement is not required and the antenna is located at > 5 cm from the phantom, there could be substantial overestimation when applying peak SAR to location ratio test exclusion. Under such circumstances, a standalone SAR measurement may be considered to facilitate the SAR test exclusion.

For MIMO configurations, when lower order subsets of the maximum MIMO chains are used; for example, different 2×2 subsets of a 3×3 MIMO configuration, 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 among the MIMO chains or when antenna interaction is expected in an integrated MIMO antenna structure.

The simultaneous transmission SAR test exclusion provisions in KDB Publication 447498 can be applied to avoid simultaneous transmission SAR measurement or to reduce the number of tests. For the typical circumstances, the number of simultaneous transmission SAR measurements can usually be kept to less than two to three. 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, 802.11 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 for the group. The decision to consolidate standalone SAR results into meaningful groups according to 802.11 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 in each frequency band, among all transmission modes 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 test exclusion because the SAR peak to location ratio procedure is specific to the simultaneous transmitting antennas and test configuration considered.²⁵

To apply the simultaneous transmission SAR test exclusion procedures in KDB Publication 447498, it must be ensured that the maximum output power of each antenna during simultaneous transmission is not greater than that used in standalone transmission. When power reduction is applied to simultaneous transmission, instead of the higher maximum power for standalone transmission, additional standalone SAR measurements at the (reduced) maximum output power may be considered to apply simultaneous transmission SAR test exclusion. The number of additional standalone measurements at the reduced maximum power may be minimized by demonstrating that SAR scaling is applicable; however, a KDB inquiry may be required to address the details for 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 SAR distributions do not overlap, when antennas transmit simultaneously in the same frequency band, within the frequency range covered by a single SAR probe

²⁵ See simultaneous transmission SAR test exclusion section of KDB Publication 447498 for additional explanation.

calibration point, SAR is generally measured with all applicable antennas transmitting simultaneously at maximum output power in a single SAR measurement.²⁶

CHANGE NOTICE

10/17/2014: 248227 D01 802.11 SAR v02 replaces the previous document 248227 D01 SAR meas for 802.11 a b g v01r02. This is a major revision of the document to provide guidance for Wi-Fi devices authorized under §§15.247 and 15.407 of Commission rules in the 2.4 GHz and 5 GHz bands that are implemented according to IEEE Std 802.11-2012 (802.11 a/b/g/n) and IEEE Std 802.11ac-2013.

²⁶ Until procedures are available to determine *reported* SAR for simultaneous transmission SAR measurements, a KDB inquiry should be submitted for interim requirements.

APPENDIX A – BRIEF SUMMARY OF 802.11 CONFIGURATIONS AND PARAMETERS

A.1. 802.11 PHY Configurations

The 802.11 PHY configurations described in this section provide a brief summary of the applicable wireless transmission modes, modulations and data rates etc. that need consideration when applying the SAR measurement procedures.²⁷ In general, before applying the procedures in this document, a test lab should confirm the operating capabilities of individual device implementations with the Wi-Fi device manufacturers to ensure all wireless modes and exposure conditions are considered.

- 1) Frequency Hopping PHY (802.11) is considered obsolete in IEEE Std 802.11-2012 and may be removed in future revisions. Frequency hopping should be tested on the high, middle and low channels in the 2.4 GHz band according to normally required SAR measurement procedures. The transmitter must be locked to each required test frequency channel with frequency hopping disabled for the SAR measurement. The SAR procedures described in this KDB publication do not apply to 2.4 GHz frequency hopping operations.
- 2) DSSS RF LAN (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.
- 3) High Rate PHY (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 systems, and 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) ERP (802.11g) provides further data 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. Data 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 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, which is optional for HR/DSSS.
- 5) 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 using BPSK, QPSK, 16-QAM or 64-QAM with 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.²⁸
- 6) 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

²⁷ Refer to IEEE Std 802.11-2012 and IEEE Std 802.11ac-2013 for definitions of specific terms, abbreviations and protocol details.

²⁸ Unless the maximum output power for half-clocked or quarter-clocked mode is higher than that in the normal mode, SAR is generally not required.

spatial streams with unequal modulation (UEQM) for the spatial streams. MCS 0 - 7 are mandatory for all stations using 20 MHz bandwidth with 800 ns GI. MCS 0 - 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 - 76. All EQM rates are supported by non-AP HT stations using MCS 0 - 7 for 20 MHz bandwidth with one spatial stream. All EQM rates are supported by HT APs using MCS 0 - 15 for 20 MHz bandwidth with 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.

- 7) **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 channel bandwidth is mandatory for VHT. Support for 160 MHz and 80 + 80 MHz bandwidths, NDP (null data packet) transmit beamforming sounding, STBC, LDPC and downlink multi-user (MU) transmissions are optional. 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 or 256-QAM with forward error correction (FEC) convolutional or LDPC coding rates of 1/2, 2/3, 3/4 and 5/6. Support of 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, the number of streams and channel bandwidths allowed are not specified by MCS, which is different from 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.

A.2. 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 of these Wi-Fi operating modes are usually covered by the normally required SAR test conditions for infrastructure mode operations.

- 1) **TDLS** service is established by applying IEEE 802.11z protocol to transmit encapsulated signaling frames transparently within the regular 802.11 data frames through an AP. It enables devices to connect directly with each other using improved connection speed and overall bandwidth efficiency without adhering to the functionalities and requirements of an AP. The AP is unaware of the TDLS setup and not required to provide any support for the link. The more efficient 802.11 modes supported by TDLS devices, including different channel bandwidths and frequency bands, that are not available from an AP can be used over a direct link between TDLS devices. TDLS may be used with all existing and new APs because it is transparent.
- 2) **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 multi-hop capability. It enables data transfer between stations in 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.

- 3) 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 a one-to-one or one-to-many connection 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 may be supported by certain device implementations. The hotspot mode SAR procedure is for connections between Wi-Fi and 3G/4G transmitters in specific host platform configurations; it does not apply to cross connections using AP equivalent features where the simultaneous transmission is for multiple Wi-Fi transmitters within the device. TDLS services may also be supported in Wi-Fi Direct mode by tunneling through the group leader, which serves as the equivalent of an AP.

A.3. 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 enhancement features typically vary with the flexibility and complexity of individual implementations. When multiple antennas are transmitting simultaneously, transmission characteristics and antenna spatial arrangements can influence the test configurations required for SAR measurement. The simultaneous transmission schemes and antenna characteristics must be clearly identified to determine SAR test requirements. When there are noticeable differences in maximum output power or antenna performance among the simultaneous transmitting antennas or transmission chains, the normally required SAR test procedures may not fully apply. In addition, 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.²⁹

1) Typical MIMO Configurations

- a) *Spatial Multiplexing* (SM): The data is subdivided into multiple streams for transmission through different antennas by spatial multiplexing. The spatial streams from the antennas are expected to 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.
 - b) *Space-Time Block Coding* (STBC): STBC transmits redundant data in blocks that are coded differently for transmission through separate 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.
- 2) Transmit Beamforming (TxBF) applies channel knowledge acquired either implicitly or explicitly to steer the signal to a desired direction. Improved receive signal strength and data rates can be achieved by exploiting reflection and multipath phenomena. TxBF has not been widely used in OFDM HT (802.11n) because of highly flexible protocols that include a substantially large number of

²⁹ Correlated and coherent signal concerns for SAR are mainly in the near-field of the transmitter or antenna, where the exposed person is located. These conditions are generally unrelated to the far-field conditions associated with EMC testing requirements and procedures described in KDB Publication 662911.

configurations with increased implementation complexity. In OFDM VHT (802.11ac), however, more restrictive configurations with better defined implementation requirements are specified to limit the number of configurations, which are expected to encourage 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.

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

When correlated signals are transmitted in multiple space-time streams, 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 to these implementations. However, Wi-Fi devices that use other proprietary implementations or antenna array configurations and coherent transmission schemes to enhance throughput and coverage must address coherent transmission SAR issues for test results to be acceptable (see KDB Publication 865664).

A.4. Signal Coherence

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. For SAR measurement purposes, the HT and VHT TxBF applied to individual OFDM sub-carriers are not expected to result in significant or noticeable signal coherence at the OFDM channel output of 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 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 and 4 coherent transmission streams. The extent of focusing is expected to be highly dependent on antenna proximity, antenna to phantom separation and use configurations; therefore, a KDB inquiry is required to address the SAR measurement issues. The SAR probes used in SAR measurements are designed to measure scalar fields, which are insufficient for measuring coherent signals. However, the measured scalar results may be used to estimate coherent signal SAR based on IEC/TR 62630 recommendations, on a case-by-case basis according to individual product design and implementation. Except when antennas are sufficiently far apart with no noticeable overlapping SAR distributions, the simultaneous transmission SAR test exclusion provisions in KDB Publication 447498 generally do not apply to coherent signal configurations.

APPENDIX B – 5 GHz 802.11 CHANNEL CONFIGURATIONS

(For Illustration Only)

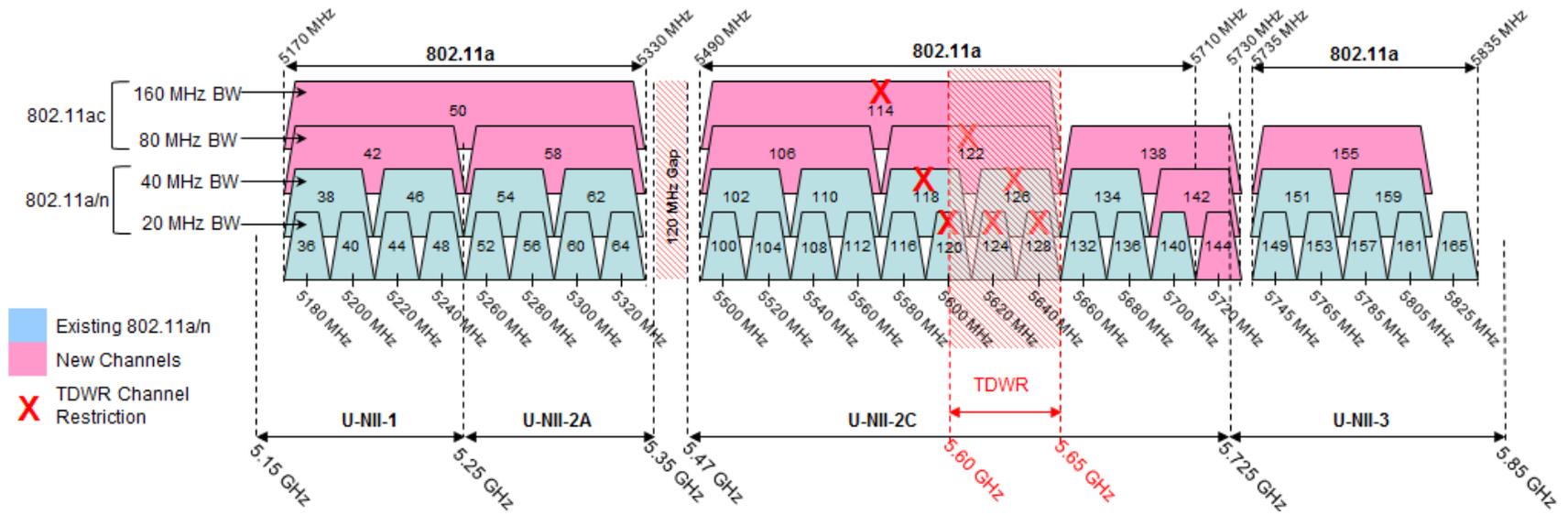


Figure B. 1 - 5 GHz 802.11 Channel Configurations

APPENDIX C – SAR TEST REDUCTION ILLUSTRATIVE EXAMPLE

C.1. Typical steps to consider for SAR test reduction of OFDM configurations

- 1) Identify the maximum output power specified at each antenna port of production units for the applicable OFDM configurations; as illustrated in Table C.1.
 - a) An initial test configuration is selected for each antenna port based on the highest maximum output power specified for production units and according to channel bandwidth, modulation and data rate combinations in each frequency band or aggregated band.
 - i) For most products, the same maximum output power is typically used for the modulations and data rates in each channel bandwidth.
 - ii) When different maximum output power levels are specified for different modulations and data rates, the combination with the highest maximum output power should be entered in the table; and identify any variations using footnotes or modify the table accordingly.
 - iii) The maximum output power specified for production units are used to determine which OFDM configuration is tested first in each frequency band in order to reduce the number of subsequent SAR tests required for lower power OFDM modes.

Table C.1 – Specified maximum output power at an antenna port									
802.11 Modes	a	g		n (HT) [@]		ac (VHT) [@]			
Channel Bandwidth (MHz)	20	20	40	20	40	20	40	80	160
§15.247 (2.4 GHz)		X	X	X	X				
U-NII-1	X			X	X	X	X	X	
U-NII-2A	X			X	X	X	X	X	
U-NII-1 + U-NII-2A									X
U-NII-2C	X			X	X	X*	X*	X*	X [#]
U-NII-3	X			X	X	X*	X*	X*	
§15.247 (5.8 GHz)	X			X	X	X*	X*	X*	

- X: numerical value (mW) of maximum (conducted) output power specified for production units at each antenna port
- [@]: modify table as necessary for multiple antenna ports or repeat the applicable columns for additional antenna ports used for MIMO or TxBF and split into multiple tables as necessary
- [#]: this configuration applies only to the new rules in FCC 14-30, without TDWR restriction
- *: when applicable, include the band gap channels

- 2) Apply the default power measurement procedures to measure maximum output power for each standalone and aggregated frequency band.
 - a) When band gap channels between U-NII-2C band and U-NII-3 band or §15.247 5.8 GHz band are used, apply the following to determine high, middle and low channels for power measurement and SAR test reduction.
 - i) channels in U-NII-2C band below 5.65 GHz are considered as one band
 - ii) channels above 5.65 GHz, together with channels in U-NII-3 band or §15.247 5.8 GHz band, are considered as a separate band
 - b) The maximum output power of band gap channels is limited to the lowest maximum output power certified for the adjacent bands.
 - c) The measured maximum output power results are used to reduce the number of channels that need testing.
- 3) Apply initial test configuration procedures to each frequency band or aggregated band.
 - a) For next to the ear, UMPC mini-tablet or hotspot mode exposure configurations with multiple test positions, the initial test position procedure is applied using the initial test configuration to reduce the number of test positions.
 - b) For fixed exposure positions, apply the initial test configuration procedures.
- 4) Subsequent test configuration procedures are applied to determine if the remaining OFDM transmission mode configurations may need testing.
 - a) All channels in a smaller channel bandwidth configuration that overlap with a larger channel bandwidth in the initial test configuration need consideration.
 - b) Additional test reduction may be applied according to the highest *reported* SAR of the initial test configuration or previous subsequent test configuration(s).
- 5) Apply simultaneous transmission SAR test exclusion and, when required, perform SAR measurement.
 - a) Apply KDB Publication 447498 estimated SAR procedures or use highest *reported* SAR for the 802.11 mode in that frequency band, whichever has a smaller value, to configurations that do not require standalone SAR.

C.2. SAR Test Reduction Illustrative Example

Table C.2 – Maximum output power specified at the antenna port of production units for the applicable OFDM configurations of the test sample.										
802.11 Modes		a	g		n (HT) [@]		ac (VHT) [@]			
Channel Bandwidth (MHz)		20	20	40	20	40	20	40	80	160
§15.247 (2.4 GHz)	mW		50	45	50	45				
U-NII-1		50			50	45	50	45	30	
U-NII-2A		50			50	45	50	45	30	
U-NII-1 + U-NII-2A										25
U-NII-2C		45			45	40	45 [*]	40 [*]	30 [*]	25 [#]
U-NII-3		45			45	40	45 [*]	40 [*]	30 [*]	
§15.247 (5.8 GHz)		50			50	45	50 [*]	45 [*]	30 [*]	

- See Table C.1 for definition of symbols #, @, * etc.
- The maximum output power specified for production units is assumed to be the same for all channels, modulations and data rates for each 802.11 mode and channel bandwidth configurations in this example.
- The **blue highlighted** cells represent highest output configurations used in subsequent tables to determine the initial test configuration.
- For SAR test reduction in 2.4 GHz band, the maximum output specified for production units for 802.11b is assumed to be 50 mW and highest reported SAR for DSSS is assumed to be 0.75 W/kg for this example.

Table C.3 – Maximum output power measured at the antenna port of a test sample, for the applicable OFDM configurations, according to the default power measurement procedures

802.11 Modes		a	g		n (HT) [®]		ac (VHT) [®]			
Channel Bandwidth (MHz)		20	20	40	20	40	20	40	80	160
§15.247 (2.4 GHz)	Ch. # mW		1/6/11	6	1/6/11	6				
			48/46/47	lower power	47/48/46	lower power				
U-NII-1		36/40/44/48			36/40/44/48	38/46	36/40/44/48	38/46	42	
		45/46/46/48			46/45/48/47	lower power	46/48/47/46	lower power	lower power	
U-NII-2A		52/56/60/64			52/56/60/64	54/62	52/56/60/64	54/62	58	
		46/45/48/47			45/46/46/48	lower power	48/46/49/47	lower power	lower power	
U-NII-1 + U-NII-2A										50 lower power
U-NII-2C		100/112/116/128			100/112/116/128	102/110/118/126	100/112/116/128	102/110/118/126	106/112	114
		42/44/43/44			43/44/42/43	lower power	42/43/44/43*	lower power*	lower power*	lower power [#]
U-NII-3		132/149/165			132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155	
	lower power			lower power	lower power	lower power*	lower power*	lower power*		
§15.247 (5.8 GHz)	132/149/165			132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155		
	48/46/49			49/48/46	lower power	43/47/49*	lower power*	lower power*		

- The example assumes the same modulations and data rates are used for all 802.11 modes.
- When applicable, initial test configuration is chosen according to maximum measured output channel closest to mid-band frequency among all identical configurations. For multiple mid-band channels with the same measured maximum output power, the higher channel number is selected. When the same transmission mode configurations have the same maximum output power on the same channel for the 802.11 a/g/n/ac modes, the channel in the lower order/sequence 802.11 mode (i.e. a, g, n then ac) is selected.
- An entry of “lower power” means power measurement is not required.
- Specified maximum output power is higher for 5.8 GHz §15.247; therefore, power measurement is not required for U-NII-3.
- Channels selected for initial test configuration(s) are **highlighted in yellow**.
- This example assumes new rules in FCC 14-30 are applied, without TDWR restriction.
- U-NII-2C and U-NII-3 or 5.8 GHz §15.247 band gap channels are enabled. Aggregated band procedures for SAR probe calibration apply.

Table C.4 – Reported SAR of initial test configuration with frequency band test reduction taken into consideration

802.11 Modes		a	g		n (HT) [®]		ac (VHT) [®]			
Channel Bandwidth (MHz)		20	20	40	20	40	20	40	80	160
§15.247 (2.4 GHz)	Ch. # W/kg		1/6/11	6	1/6/11	6				
		SAR not required; 802.11b adjusted SAR ≤ 1.2 W/kg								
U-NII-1		36/40/44/48			36/40/44/48	38/46	36/40/44/48	38/46	42	
					not required					
U-NII-2A		52/56/60/64			52/56/60/64	54/62	52/56/60/64	54/62	58	
							0.85			
U-NII-1 + U-NII-2A										50
U-NII-2C		100/112/116/128			100/112/116/128	102/110/118/126	100/112/116/128	102/110/118/126	106/112	114
							0.95			
U-NII-3		132/149/165			132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155	
§15.247 (5.8 GHz)	132/149/165			132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155		
	1.08									

- This example assumes the device has a fixed exposure test position; therefore, initial test position SAR test reduction does not apply.
- It is also assumed that the test separation distance and measured power (illustrated in Table C.3) do not qualify for standalone SAR test exclusion in KDB Publication 447498.
- SAR probe(s) are assumed to have valid calibrations at 5.25, 5.60 and 5.75 GHz.
- SAR values illustrated in the table have been scaled to 100% transmission duty factor with reported SAR procedure applied.
- U-NII-1 and U-NII-2A bands have same specified maximum output and tolerance; SAR is measured for U-NII-2A band first. Adjusted SAR of U-NII-2A band is ≤ 1.2 W/kg, SAR is not required for U-NII-1 band.

Table C.5 – Reported SAR of Initial test configuration for next highest measured output channel

802.11 Modes		a		g		n (HT) [®]		ac (VHT) [®]			
Channel Bandwidth (MHz)		20		20	40	20	40	20	40	80	160
§15.247 (2.4 GHz)				1/6/11	6	1/6/11	6				
		SAR not required; 802.11b adjusted SAR ≤ 1.2 W/kg									
U-NII-1		36/40/44/48				36/40/44/48	38/46	36/40/44/48	38/46	42	
						not required					
U-NII-2A	Ch. #	52/56/60/64				52/56/60/64	54/62	52/56/60/64	54/62	58	
		channel 60 already tested				0.92		0.85			
U-NII-1 + U-NII-2A	W/kg										50
U-NII-2C		100/112/116/128				100/112/116/128	102/110/118/126	100/112/116/128	102/110/118/126	106/112	114
		0.98						0.95			
U-NII-3		132/149/165				132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155	
§15.247 (5.8 GHz)		132/149/165				132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155	
		1.08				0.97		channel 165 already tested			

- The **yellow highlighted** channels are next highest measured output channel that require SAR testing.
- Initial test configuration SAR for U-NII-2A band is > 0.8 W/kg, SAR is required for next highest output channel. Lowest order 802.11 mode applied to next highest output channel selection. Next highest output channel SAR is ≤ 1.2 W/kg, SAR is not required for subsequent next highest output channel. Similar circumstances apply to 5.8 GHz band in §15.247.
- When a next highest output channel has already been tested in an earlier configuration, apply the procedures to next subsequent highest output channel; see entries for U-NII-2A and §15.247 5.8 GHz in above table.
- Note: If reported SAR of next highest output channel for 5.8 GHz band in §15.247 is > 1.2 W/kg (does not apply to this example), subsequent next highest output power channels would also need testing until reported SAR is ≤ 1.2 W/kg or all channels are tested.

Table C.6 – Reported SAR of subsequent test configuration

802.11 Modes		a		g		n (HT) [®]		ac (VHT) [®]					
Channel Bandwidth (MHz)		20		40		20		40		80		160	
§15.247 (2.4 GHz)	Ch. # W/kg			1/6/11	6	1/6/11	6						
				not required; 802.11b scaled OFDM (est.) SAR ≤ 1.2 W/kg									
U-NII-1		36/40/44/48			36/40/44/48	38/46	36/40/44/48	38/46	42				
					not required								
U-NII-2A		52/56/60/64			52/56/60/64	54/62	52/56/60/64	54/62	58				
					0.92		0.85						
U-NII-1 + U-NII-2A										50			
U-NII-2C		100/112/116/128			100/112/116/128	102/110/118/126	100/112/116/128	102/110/118/126	106/112	114			
U-NII-3		132/149/165			132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155				
§15.247 (5.8 GHz)	132/149/165			132/149/165	134/142/151/159	132/149/165	134/142/151/159	138/155					

- The reported SAR of all initial test configurations are ≤ 1.2 W/kg. Adjusted SAR according to the ratio of the specified maximum output power of subsequent test configuration to initial test configuration will result in lower SAR; therefore, subsequent test configuration SAR is not required for this example.