SAR Measurement Procedures
for
802.11 a/b/g Transmitters

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Table of Contents

Summary

802.11 a/b/g devices are authorized under §§15.247 and 15.407 of Commission rules in the 2.45 GHz and 5 GHz bands. Similar transmitters may also be authorized in the 4.9 GHz band under Part 90, Subpart Y. These devices are required to comply with FCC RF exposure guidelines and some are also required to perform routine SAR evaluation to demonstrate compliance. This document describes the procedures required to establish specific device operating configurations for testing the SAR of 802.11 a/b/g transmitters. SAR should be measured according to Supplement C 01-01, IEEE Standard 1528 and the 3 – 6 GHz SAR measurement requirements provided by the FCC in 2006. While existing SAR measurement standards are mostly developed for testing wireless handsets, numerous laboratories have already adapted the measurement techniques to test other types of transmitters. As various LAN products continue to emerge, there is an increasing need to supplement existing SAR protocols for testing 802.11 devices.

The IEC TC106 committee has been working to develop body SAR measurement procedures for several years. A preliminary draft of the SAR measurement protocols was prepared in April 2005. However, device test configurations and operating requirements, such as signal modulation, data rates and other wireless communication parameters were not considered in these SAR protocols. Since 802.11 devices are designed to operate in highly dynamic network conditions, the lack of standardized test device operating configurations can lead to considerable variations in test results. Consequently, the Commission's Laboratory also initiated its own investigation to identify certain SAR measurement and device configuration difficulties. The results from this series of exploratory measurements indicate that normal network configurations are generally not suitable for testing 802.11 a/b/g transmitters. Furthermore, when switched diversity is used the SAR variations are unpredictable.[1] These LAN devices should be tested using chipset based test mode software to ensure test results are consistent and reliable. Descriptions of the test mode software, data rates, data modes and diversity antenna configurations are required in test reports to support compliance. Additional discussions on some of the measurement difficulties are included in the Appendix; however, the information is not intended to serve as tutorials for 802.11 a/b/g transmitters.

Besides configuring a device for testing there are other SAR measurement difficulties that remain to be addressed. A probe calibrated using CW signals may not correctly measure the SAR of 802.11 a/b/g signals that are noise-like with varying peak to average power ratios and voltage crest factors. This was demonstrated by the IEEE SCC-34/SC-2 committee in 2002 for a CDMA (IS-95) signal. It was reported that the measured SAR error would vary as a function of signal power level. The error was estimated to be within 10% at typical handset output power levels of 200-300 mW and expected to increase exponentially with power. Although the anticipated error for 802.11 signals has not been investigated, estimates of up to 20% at 1 W may not be unreasonable. Until comprehensive evaluations similar to those performed by the IEEE committee are

[1] Switched diversity used in 802.11 a/b/g devices typically allows transmission from one of two antennas in a random manner, according to the received signal quality of each antenna and the diversity algorithm implemented for the specific product.

available a sufficient level of conservativeness in the test protocols is necessary to ensure compliance.

The procedures in this document are derived from issues identified through testing legacy 802.11 a/b/g devices. Some of the procedures may also apply to certain products with MIMO and smart antenna configurations; however, it should be emphasized that these procedures can become insufficient for the more complex situations found in evolving products. As new technology continues to emerge and mature, the procedures will require revision to provide up-to-date guidance.

Configuring 802.11 a/b/g Transmitters for SAR Measurement

Normal network operating configurations are not suitable for measuring the SAR of 802.11 a/b/g transmitters. Unpredictable fluctuations in network traffic and antenna diversity conditions can introduce undesirable variations in SAR results. The SAR for these devices should be measured using chipset based test mode software to ensure the 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, the Commission's Laboratory should be consulted to determine if other test configurations may be possible.

General Device Setup

Chipset based test mode software is hardware dependent and generally varies among manufacturers. The device operating parameters established in test mode for SAR measurements must be identical to those programmed in production units, including output power levels, amplifier gain settings and other RF performance tuning parameters. The test frequencies should correspond to actual channel frequencies defined for domestic use. SAR for devices with switched diversity should be measured with only one antenna transmitting at a time during each SAR measurement, according to a fixed modulation and data rate. The same data pattern should be used for all measurements.

Frequency Channel Configurations

802.11 a/b/g and 4.9 GHz operating modes are tested independently according to the service requirements in each frequency band. 802.11 b/g modes are tested on channels 1, 6 and 11. 802.11a is tested for UNII operations on channels 36 and 48 in the 5.15-5.25 GHz band; channels 52 and 64 in the 5.25-5.35 GHz band; channels 104, 116, 124 and 136 in the 5.470-5.725 GHz band; and channels 149 and 161 in the 5.8 GHz band. When 5.8 GHz §15.247 is also available, channels 149, 157 and 165 should be tested instead of the UNII channels. 4.9 GHz is tested on channels 1, 10 and 5 or 6, whichever has the higher output, for 5 MHz channels; channels 11, 15 and 19 for 10 MHz channels; and channels 21 and 25 for 20 MHz channels.[2] These are referred to as the "default test channels" in this document.

SAR is not required for 802.11g channels when the maximum average output power is less than ¼ dB higher than that measured on the corresponding 802.11b channels. The average output power for 802.11a should be measured on all channels in each frequency band. When the maximum average output channel in each frequency band is not included in the "default test channels", the maximum channel should be tested instead of an adjacent "default test channel".[3] These are referred to as the "required test channels" and are illustrated in Table 1. The test channel requirements for 4.9 GHz Part 90 devices are illustrated in Table 2. When multiple channel BW configurations are applicable, the

[2] It is assumed that the procedures and configurations for 802.11a are also applicable to 4.9 GHz devices. Otherwise, contact the Commission's Laboratory for guidance.

[3] This is a direct substitution of channels, which does not increase the number of channels that need to be tested. If the maximum output channel is adjacent to two "default test channels", the lower output "default test channel" is replaced by the maximum output channel.

highest channel BW configuration with the highest output power limit (See Table 3) should be tested. Testing of lower BW configurations is not required when the maximum average output of the default test channels in each lower BW configuration is less than ¼ dB higher than the default test channels (See Table 2) in the highest BW configuration. These are the "required test channels" for 4.9 GHz devices.[4] Each channel should be tested at the lowest data rate in each a-b/g mode or 4.9 GHz channel BW configuration.

Table 1: "Default Test Channels"

Mode		GHz	Channel	Turbo Channel	"Default Test Channels"			
					§15.247		UNII	
					802.11b	802.11g		
802.11 b/g		2.412	1		√	∇		
		2.437	6	6	√	∇		
		2.462	11		√	∇		
802.11a	UNII	5.18	36				√	
		5.20	40	42 (5.21 GHz)				*
		5.22	44					*
		5.24	48	50 (5.25 GHz)			√	
		5.26	52				√	
		5.28	56	58 (5.29 GHz)				*
		5.30	60					*
		5.32	64				√	
		5.500	100	Unknown				*
		5.520	104				√	
		5.540	108					*
		5.560	112					*
		5.580	116				√	
		5.600	120					*
		5.620	124				√	
		5.640	128					*
		5.660	132					*
		5.680	136				√	
		5.700	140					*
	UNII or §15.247	5.745	149		√		√	
		5.765	153	152 (5.76 GHz)		*		*
		5.785	157		√			*
		5.805	161	160 (5.80 GHz)		*	√	
	§15.247	5.825	165		√			

- √ = "default test channels"
- * = possible 802.11a channels with maximum average output > the "default test channels"
- ∇ = possible 802.11g channels with maximum average output ¼ dB ≥ the "default test channels"

[4] These test configurations are only applicable to devices operating according to the channel plan and output power limits described in P802.11-REVma-D6.0 (Table J.2). See Table 3 in Appendix for band plan and output power limits. Contact the Commission's Laboratory for other configurations.

Table 2: Default 4.9 GHz Test Channels

Mode	GHz	Channel No.	Channel BW (MHz)	Default/Required Test Channels
Part 90 Subpart Y	4.9425	1	5	√
	4.9475	2		
	4.9525	3		
	4.9575	4		
	4.9625	5		√√
	4.9675	6		
	4.9725	7		
	4.9775	8		
	4.9825	9		
	4.9875	10		√
	4.945	11	10	√
	4.955	13		
	4.965	15		√
	4.975	17		
	4.985	19		√
	4.955	21	20	√
	4.975	25		√

- √ = default channels
- √√ = for channels 5 and 6, the higher output channel should be tested

For each frequency band, testing at higher data rates and higher order modulations is not required when the maximum average output power for each of these configurations is less than ¼ dB higher than those measured at the lowest data rate. Testing of proprietary modes such as turbo, half and quarter rates available in certain 802.11 a/b/g products are not required when the maximum average output power in each mode is less than ¼ dB higher than those measured on the "required test channels". All proprietary channels should be tested at the lowest data rate; for example, 12 Mbps for turbo, 3 Mbps for half and 1.5 Mbps for quarter rates using QPSK.[5]

Duty Factor and Peak to Average Power Ratio

Unless a device is not capable of sustaining continuous transmission or the output becomes nonlinear, it should be tested with continuous periodic data frames to simulate close to 100% duty factor.[6] For duty factor scaling, SAR may be verified with the SAR probe at a fixed location in the high SAR region by measuring the SAR at approximately 25%, 50% and 100% duty factor to determine SAR linearity.[7] If the device is by design

[5] Proprietary channels should be tested using the actual operating channel frequency. See Table 4 in Appendix.
[6] These conditions are established using test mode software.
[7] The SAR of periodic pulse trains (802.11 frames) must be compensated by the SAR measurement system using the correct duty factor before applying duty factor scaling. SAR systems may have certain limitations on duty factor compensation.

unable to operate at 100% duty factor, SAR linearity should be verified at 25%, 50% and 100% of the intended maximum duty factor. Once SAR linearity is confirmed, SAR should be measured at the maximum duty factor that allows linear scaling. The measured SAR is scaled to 100% duty factor for devices that are capable of continuous transmission and to the maximum duty factor for devices that are hardware limited. The procedures for establishing the specific duty factor for SAR testing should be documented in SAR reports to support the test results.

In addition to duty factor compensation and SAR scaling, certain higher output devices may also need to address SAR measurement issues due to high peak to average power ratios of noise-like signals. Unless the signals measured by the diode sensors in the SAR probe are substantially below the diode compression voltages, the procedures outlined in the Appendix should be considered to minimize SAR measurement errors.

Switched Diversity

The transmitting antenna must be clearly identified when multiple antennas are only used for receive diversity. When transmit diversity is applicable, the output characteristics of each antenna must be confirmed to ensure all antennas are substantially equivalent.[8] Each transmitting antenna should be tested independently, one at a time, on the maximum average output power channel in each frequency band and BW configuration.[9] When the 1-g SAR values for all the antennas are less than 1.2 W/kg (75% of limit), the remaining "required test channels" should be tested in each frequency band or BW configuration using the antenna with the highest SAR measured on the maximum output channel.[10] Otherwise, if the 1-g SAR values are not below 1.2 W/kg and also not within 25% of each other, all antennas should be tested for the "required test channels" in the corresponding frequency band and BW configuration.[11]

The measured SAR for each diversity antenna should be scaled to a duty factor of 75% to demonstrate compliance. When switched diversity is not applicable a duty factor of 100% should be applied. Both measured and scaled SAR values should be included in the test report to support the test results.

MIMO and other Multiple Antenna Configurations

SAR for MIMO and similar multiple antenna configurations is measured with all antennas transmitting simultaneously. The antennas should be transmitting at close to 100% duty factor during the SAR measurements. If the test mode software does not support simultaneous transmission, each antenna is tested independently, one at a time; and the SAR measured for all antennas must be summed spatially, grid by grid, to

[8] Output characteristics can usually be confirmed according to the design, field strength, radiated output or SAR distributions.
[9] The maximum average output power channel among the "required test channels".
[10] 1.2 W/kg at 75% duty factor as described in the next paragraph.
[11] Otherwise means when the 1-g SAR values of all antennas at 75% duty factor are not below 1.2 W/kg.

compute the 1-g SAR.[12] When the sum of individual 1-g SAR for all antennas are less than the SAR limit, grid by grid summing is optional. The 1-g SAR should be scaled to 100% duty factor to determine compliance.

[12] SAR measurement systems have specific modes that would allow multiple sets of SAR distributions measured using identical grids to be summed spatially, interpolated and extrapolated, to compute the 1-g averaged SAR.

Appendix

Background

IEEE 802.11b was introduced in 1999 to increase the data rate of 802.11 (2.4 GHz DSSS). 802.11a was developed concurrently with 802.11b to provide more channels with even higher data rates in 5 GHz bands. This subsequently led to the development of 802.11g at 2.4 GHz, which mirrored 802.11a specifications while maintaining compatibility with 802.11b. These standards have introduced a number of data rates, modulation and transmission schemes in the different 802.11 modes and frequency bands. The use of diversity antenna designs in most 802.11 devices has further complicated test requirements. The release of 802.11e in 2005 includes additional operating flexibility (QoS etc.) and optimization of inter-frame spacing requirements, which are available in recent products. There is an increasing need to establish standardized device test configurations and protocols to maintain consistency in test results and to minimize unnecessary testing.

The Commission's Laboratory conducted exploratory measurements to examine the difficulties related to configuring 802.11 a/b/g transmitters for SAR evaluations. The investigation included external plug-in devices with integral antennas and mini-PCI adapters with antennas built-in on laptop computer displays. SAR was measured using both test mode software and normal network operating configurations. The measurements identified device configuration difficulties and measurement reliability issues.

Transmitter Test Configurations

The highly dynamic operating conditions of 802.11 a/b/g networks are not suitable for making SAR measurements. More stable operating conditions are necessary and can be achieved by using chipset based test mode software. Although test mode provides consistent test results, the test configurations may overestimate the expected normal use exposure conditions for certain antenna configurations. Substantial research and investigation of various networking issues are needed in order to establish procedures for adjusting the test results conservatively while minimizing unnecessary overestimation.

Normal Network Operating Mode

802.11 a/b/g devices can operate in either ad hoc (peer-to-peer) or infrastructure (access point) modes. Peer-to-peer mode provides wireless only connections between individual clients. Infrastructure mode requires an access point to forward transmissions from a wireless client to a wired or another wireless client on the network. During normal operation data packets are transmitted at different data rates to optimize transmission speed and signal quality. As error rate increases due to interference or weak signal conditions, data rate is reduced to optimize throughput. When higher order modulations are used at higher data rates, a larger output dynamic range is necessary to achieve acceptable packet error rates. These fluctuating conditions in the wireless and wired segments of the underlying network infrastructure can have substantial influences on RF exposure evaluation. In addition, some products may include propriety features that operate with twice the normal channel bandwidth (about 33 MHz) in turbo mode or use half and quarter rates to further optimize throughput, performance and coverage. All these are configured dynamically according to network conditions.

When SAR is measured in normal network operating conditions, significant variations in transmission duty factor are expected. When transmit diversity (legacy switched diversity) is available, it could become substantially difficult to determine the corresponding transmission time for each antenna during the SAR measurement. The output power is dispersed both temporally and spatially among the transmitting antennas in a random and unknown manner. The measured SAR is also expected to vary under such operating conditions and the variations could become intolerable. Hence, normal network operating mode is not suitable for SAR evaluation.

Test Modes

802.11 a/b/g transmitters are typically designed with two antennas for receive diversity. The antennas are often also used to provide transmit diversity or legacy switched diversity. Since a communication link is not required in test mode, access point and network support are not needed. However, the test mode software can only activate one antenna at a time and it is not feasible to switch transmissions from one antenna to another without reconfiguring the device. The test device is configured to transmit at a fixed data rate, which automatically determines the required signal modulation. When continuous data frames are selected, a maximum transmission duty factor of 96-98% is usually achieved for SAR measurement.[13] The test software may also have provisions to simulate lower transmission duty factors by skipping data frames. The random duty factor introduced by data frame separators in normal network operating conditions, such as DIFS, SIFS, acknowledgement and back-off durations, are usually not emulated by the test mode software.

Typically, test mode software is also used by manufacturers to calibrate and configure devices during production. These production tools usually include substantial flexibility to reconfigure or reprogram a device; therefore, it is important to ensure that the unmodified production settings are activated for compliance testing. The operating parameters of a transmitter, including output power calibrations, can usually be downloaded from the firmware (flash memory, EEPROM etc.) and verified accordingly. Proprietary features such as turbo mode, half and quarter rates, used to optimize transmission speed and operating range are generally vendor dependent. Although supported by the chipset and test mode software, sometimes these features may not be fully implemented in a vendor's product. Therefore, non-standard and proprietary features must be enabled according to manufacturer specifications to avoid unpredictable test results.

[13] Small gaps are inserted between individual data frames by the test mode software to conform to 802.11 transmission protocols.

Channel and Frequency Assignments

802.11 a/b/g transmitters are typically designed to operate in multiple regulatory jurisdictions. Frequency channels that are not applicable for domestic operations should not be used for compliance testing. The channel and frequency assignments are defined in the 802.11 a/b/g standards. Besides these defined channels, manufacturers have also introduced proprietary configurations that may overlay existing channels to optimize data rate and operating range; for example, additional channel bandwidth is used to support turbo mode.

The channel spacing for 802.11 b/g is 5 MHz; there are 11 assigned channels and only 3 are non-overlapping (channels 1, 6 and 11). 802.11a uses 20 MHz channels and there are 24 non-overlapping channels in the 5 GHz bands. The channel assignment for 4.9 GHz has recently been included in a draft version of IEEE P802.11-REVma-D6.0 (Table J.2), which allows 5, 10 and 20 MHz channels. Half-clocked and quarter-clocked operations are used for 5 and 10 MHz channels. The channel assignments are indicated in Table 3. Table 4 identifies certain commonly used turbo mode channels that are non-standard to 802.11. Together with the available data rates and modulations, a large number of test configurations are possible for each operating mode and each frequency band.

Table 3: Regulatory classes for 4.9 GHz and 5 GHz bands in the USA (P802.11-REVma-D6.0 Table J.2)

Regulatory class	Channel starting frequency (GHz)	Channel spacing (MHz)	Channel set	Transmit power limit (mW)	Emissions limits set	Behavior limits set
1	5	20	36, 40, 44, 48	40	1	1, 2
2	5	20	52, 56, 60, 64	200	1	1
3	5	20	149, 153, 157, 161	800	1	1
4	5	20	100, 104, 108, 112, 116, 120, 124, 128, 132, 136, 140	200	1	1
5	5	20	165	1000	4	1
6	4.9375	5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	25	5	9
7	4.9375	5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	500	5	9
8	4.89	10	11, 13, 15, 17, 19	50	5	9
9	4.89	10	11, 13, 15, 17, 19	1000	5	9
10	4.85	20	21, 25	100	5	9
11	4.85	20	21, 25	2000	5	9
612–255	Reserved	Reserved	Reserved	Reserved	Reserved	Reserved

Table 4: Typical 802.11 a/b/g Turbo Mode Channels

802.11a		802.11b/g	
Channel No.	**Frequency (GHz)**	**Channel No.**	**Frequency (GHz)**
42	5.21	6	2.437
50	5.25		
58	5.29		
152	5.76		
160	5.80		

Antenna diversity

802.11 a/b/g transmitters are typically designed with two antennas. Receive antenna diversity has no significance for RF exposure. Legacy switched diversity (transmit diversity) is implemented in 802.11 products by allowing transmission on one antenna at a time according to the received signal quality on these antennas. Output power is time and spatially multiplexed dynamically between the antennas.

The SAR measured in test mode with continuous transmission through a single antenna is quite different from that expected in normal network operating conditions when transmissions are temporally multiplexed to spatially separated antennas. The SAR is dependent on the spatial separation between the diversity antennas and the way power is multiplexed between the antennas. For the same total power, diversity antennas are expected to produce lower SAR than a dedicated antenna (no diversity) in normal network conditions because of time and spatial averaging. Therefore, the test results for diversity and dedicated antenna configurations must be analyzed differently.

Among the transmitters used in the Commission's investigation, only half of them had switched diversity.[14] About one-third are limited to receive diversity only. It was observed that the test software might activate an antenna regardless of whether it was capable of transmitting; however, the SAR measured under such conditions would be invalid and typically less than 0.1 W/kg. There were also two transmitters where the antenna configurations could not be identified from the SAR distributions because of low power (11 dBm) and lack of information.

Duty Factor

802.11 a/b/g transmitters are designed to transmit data seamlessly through wireless and wired networks. The transmissions are asynchronous and often vary substantially according to the dynamics of network infrastructure. Collision avoidance and retransmission of error packets are part of the anticipated network behavior that often result in substantial variations in transmission duty factor. The goal of an evaluation is to

[14] The test samples were requested in late 2003 and tests were conducted in early 2004. These 802.11 devices may not represent the newer products currently available in the market.

determine a conservative best estimate of the exposures expected by users in normal operating conditions. It is generally accepted that when users can operate transmitters continuously, usage or traffic based duty factors should be disregarded. Protocol based duty factors that are source-based, such as GSM or TDMA are periodic, which can be compensated easily without difficulty by existing SAR measurement systems. The transmission duty factors for non-periodic systems, such as 802.11, are mostly unpredictable because of antenna configurations and network traffic conditions. Substantial research and investigations are necessary to determine appropriate duty factors that are conservative for the various 802.11 network operating conditions. Until such information is available, the highest duty factor a device is capable of transmitting, which is usually 100% for typical 802.11 a/b/g devices, should be used.

Modulation, Data Rate and Output Power

SAR is highly dependent on the output power of a transmitter. The output of 802.11 devices typically varies with operating mode, transmitting frequency and data rates. The modulations and data rates defined for 802.11 a/b/g transmitters are identified in Table 5. 802.11 a/g modes use OFDM, which contains 52 sub-carries, each 312.5 kHz wide, with a total occupied bandwidth of approximately 16.6 MHz. Different modulations are used at different data rates for the sub-carriers, including BPSK, QPSK, 16 and 64 QAM. Direct sequence spread spectrum (DSSS) with CCK, PBCC or QPSK is used in 802.11b. Additional ERP (extended rate PHYs) modes are available in 802.11g, which include ERP-DSSS, ERP-CCK, ERP-PBCC, ERP-OFDM and DSSS-OFDM.

Table 5: 802.11 Data Rate and Modulation

802.11 a/g OFDM, 802.11g DSSS-OFDM, 4.9 GHz half/quarter-clocked				**802.11 b/g**	
Data Rate (Mbps)			**Modulation**	**Data Rate (Mbps)**	**Modulation**
full	**half**	**quarter**			
6	3	1.5	BPSK	1	DBPSK
9	4.5	2.25	BPSK	2	DQPSK
12	6	3	QPSK	5.5	CCK / PBCC
18	9	4.5	QPSK	11	CCK / PBCC
24	12	6	16-QAM	22	ERP-PBCC
36	18	9	16-QAM	33	ERP-PBCC
48	24	12	64-QAM		
54	27	13.5	64-QAM		

802.11 a/g data rates range from 6 to 54 Mbps. 802.11b data rates range from 1 to 11 Mbps. Data rates for half-clocked and quarter-clocked operations in the 4.9 GHz band are at ½ and ¼ of those in 802.11a.[15] The available maximum average output power is usually limited by high crest factors in the higher order modulations. Hence, some dual band and/or dual mode 802.11 a/b/g transmitters may operate with somewhat higher

[15] See IEEE P802.11-REVma-D6.0 section 17 for details.

average maximum output in 802.11b to increase operating range. In most cases, when the average outputs of higher order modulations are less than those used in lower order modulations, the required test configurations may be simplified.

Turbo mode (x2), half and quarter rate modes are typically available in many 802.11 a/b/g products to optimize data throughput and operating range. As data rate changes due to signal quality, the signal modulation is adjusted during the transmission. Higher peak to average power ratios are needed to maintain output dynamic range and bit error rate requirements for the more complex, higher order modulations. This typically requires a reduction in the average output power to maintain amplifier performance. When bandwidth is increased; for example, in turbo mode, the output is usually reduced.

Tests have shown that higher data rates tend to produce somewhat lower SAR because of lower average output imposed by higher order modulations. When the maximum SAR for the lowest data rate conditions are sufficiently below the SAR limit and the maximum average output power for the other data rates and modulations are lower, extensive SAR measurements at higher data rates are typically unnecessary. Although higher data rates typically imply better signal quality and network performance, which could influence transmission duty factor and antenna diversity operations in normal network operating conditions; however, these network fluctuations are already addressed by testing a device at its maximum possible duty factor to ensure test results are conservative.

The operating parameters of 802.11a transmitters indicate that these devices are generally designed to operate across the entire 4.9-5.9 GHz bands. The output power and gain settings in different frequency blocks are typically coded in the EEPROM or flash memory to optimize amplifier performance across this 1 GHz operating range. It has been observed that this type of optimization can be more extensive for some transmitters than others where maximum output may not be captured by the typical high, middle and low frequency test channels.

One of the integral antenna transmitters measured in the Commission’s investigation had noticeably higher SAR in half and quarter rate modes. The SAR for normal, half and quarter rate modes were quite similar for the other transmitters. Although the same chipset and test mode software were used during the tests, it appeared that these proprietary modes might have been implemented differently among vendors. These non-standard features generally require ad hoc considerations during each evaluation.

Peak to Average Power Ratios

Besides configuring a device for testing there also exist certain SAR measurement difficulties that remain to be addressed. A probe calibrated with single frequency sinusoidal CW waveforms may not measure correctly the SAR of digital modulated noise-like 802.11 signals with varying peak to average power ratios or voltage crest factors. The duty factor correction implemented in current SAR measurement systems is intended for periodic pulse trains, such as those used in GSM. This duty factor correction has also been termed “crest factor” correction; however, it is not related to the crest factors of non-periodic signals in 802.11 modulations.

It was demonstrated in 2002 by the IEEE SCC-34/SC-2 committee during its development of IEEE Standard 1528 with an IS-95 CDMA signal that the measured SAR error would vary as a function of signal power levels. The estimated error is within 10% at typical CDMA handset output levels of 200-300 mW and increasing exponentially with power. This type of error is believed to be caused by the random crest factor of noise-like signals and has not been investigated for the various 802.11 modulations. Based on the CDMA data, the estimated error could be as high as 20% for 802.11 devices operating at 1 W. Until comprehensive evaluations similar to those performed by the IEEE committee are available, a sufficient level of conservativeness is necessary to ensure compliance.

Most 802.11 a/b/g client transmitters that require SAR evaluation generally do not transmit at high power levels because of typical amplifier design requirements. Among the transmitters used in the Commission's investigation, the typical output power was about 15 dBm, with a couple at 17 dBm (50 mW). Over 99% of the measured signal levels in the SAR measurements were below 50% of the diode compression point (about 100 mV) of the SAR probe.[16] Crest factor correction is mostly unnecessary when the measured values are well within the square-law region of the probe sensors. However, the error may also vary with probe design and is expected to increase exponentially at higher signal levels. As the measured SAR approaches compliance limits and crest factor errors become significant at high output power levels, it would be desirable to perform SAR evaluation at lower power levels and scale the results to the maximum average output power to minimize such errors. The appropriate device output power and SAR linearity must be verified experimentally for the scaled SAR results to be valid.[17] The SAR probe should be at a fixed location within the highest SAR region of the same setup used for testing the device. The output power is varied so that the measured SAR would correspond to 1, 5, 10, 50 and 100% of the sensor compression point of the SAR probe. The output power and SAR levels are plotted to identify the linear SAR region. SAR should be subsequently evaluated at a device output power level where the highest measured SAR is within the upper 10% of the linear SAR region of the specific SAR probe used in the measurements. The measured 1-g SAR is scaled to the maximum average output power of the device.

MIMO and other SISO Configurations

The discussions in this document are based on single-input single-output (SISO) 802.11 a/b/g transmitters that do not transmit simultaneously with multiple antennas. However, multiple-input multiple-output (MIMO) devices have been introduced and these early generation MIMO transmitters are already available in some 802.11 wireless LAN

[16] Dynamic range and square-law region of individual SAR probes are typically design dependent.

[17] SAR linearity may be verified at various device output power levels using single point SAR measurements provided the same device operating characteristics and signal conditions are used at maximum output power and lower power levels; for example, power control, data rate, modulation and other essential operating conditions etc. Otherwise, contact FCC to determine if other measurement alternatives are possible.

products. The rationale in setting up a MIMO device for exposure evaluation should be similar to SISO. When a group of antennas are transmitting simultaneously in a spatial multiplexing MIMO configuration, the SAR distribution and peak SAR locations are expected to spread over an area corresponding to the locations of the radiating antennas. If the antennas are in close proximity to each other; for example, within 3-5 cm, it would be necessary to consider the exposure from all antennas to determine the 1-g averaged SAR within the region. Depending on the test software, if the antennas are tested independently, one at a time, the exposure from all antennas must be summed spatially, grid by grid, to compute the 1-g SAR. If the test software allows all antennas to transmit simultaneously and continuously, the resulting SAR distribution may be used to compute the 1-g SAR directly. For many low-power devices, when the peak SAR locations are more than 5 cm apart, the 1-g SAR can usually be treated independently with little or no noticeable impact; therefore, spatial summing could be optional.

Chipsets used for spatial multiplexing MIMO configurations may also have a legacy mode that applies cyclic delay diversity to the OFDM data to optimize transmission range. The technique takes advantage of the multiple antenna configurations by sending a shifted version of the same OFDM signal in one of the MIMO channels to make the output signals uncorrelated (at zero delay) over the signal bandwidth. This mode may be used either independently or as a fall back for the MIMO spatial multiplexing configurations to optimize transmission range. The SAR test configurations for spatial multiplexing MIMO may be applied to test cyclic delay legacy configurations.

Chipsets that allow simple beam-forming using 2 antennas are also available. In such systems, independent transmitters transmitting simultaneously at the same frequency are used to optimize signal gain in the direction of interest. The same data is transmitted through each transmitter, but with different magnitude and phase to steer the energy according to training sequences received in the data frames. The applicable test configurations for other beam-forming configurations can be highly dependent on the availability of smart test software. However, for simple 2-antenna beam-forming configurations, SAR may be performed using the spatial multiplexing MIMO procedures. In addition, the SAR for optimal gain configuration(s), at maximum EIRP, should also be considered for both antennas. The antennas may be activated either independently or simultaneously in a non-coherent manner to evaluate the 1-g SAR according to the grid-summed procedures. Since body tissues may affect beam-forming characteristics, which could subsequently modify the SAR distribution, more investigations are necessary to improve the measurement procedures. Until further details are available, the procedures described above should be used along with other applicable considerations to test simple beam-forming configurations.

The procedures for testing other transmission techniques used by MIMO, such as time-space code diversity, require further investigation. SAR measurement integration time and crest factor issues for MIMO systems also require additional examination. When overlapping and delayed transmission techniques are used to enhance error recovery and antenna diversity, specific synchronization is necessary to capture the correct exposure at the correct spatial location and time during the SAR scan. The test procedures can be highly dependent on test software capabilities. Special SAR test procedures are also necessary for device with other beam-forming capabilities.