SAR Test Configurations
&
Proposed TCB Review Procedures

for

802.11 Wireless LAN Transmitters

- May 2005 -

Overview

- background
- goal
  - 802.11 a/b/g configuration overview
  - recommended test configurations
- proposed TCB review considerations
- questions & discussions

Background

Typical 802.11 a/b/g Operations

- operating frequencies
  - 802.11a
    - §15.247: 5.725 – 5.850 GHz
    - § 15.407: 5.15 – 5.25, 5.25 – 5.35, 5.470 – 5.725, 5.725 – 5.825 GHz
  - 802.11 b/g: §15.247: 2400 – 2483.5 MHz
- operating modes
  - ad hoc
  - infrastructure
- other potential or similar operations
  - 4.9 GHz public safety
  - 5.9 GHz DSRCS

Transmitter Characteristics

- data rates
  - 802.11 a/g: 6-54 Mbps
  - 802.11 b: 1-11 Mbps
- modulation
  - 802.11 a/g: OFDM (BPSK, QPSK, 16 QAM, 64 QAM)
  - 802.11b: DBPSK, DQPSK (CCK, PBCC)
- proprietary turbo, half & quarter rate modes
- switched transmit diversity in some products
- communication protocols require dynamic operations
  - varying output power and transmit duty factor

Test Difficulties

- require complex test configurations in multiple frequency bands
- normal operating mode has unstable test conditions
- standardized device test configuration protocols currently unavailable
- device test configuration protocols is not considered in measurement standards
  - inconsistent test results likely
  - difficulties in review & approval

Identifying Issues

- Commission initiated exploratory measurements to identify test difficulties
  - conducted SAR measurements using legacy 802.11 a/b/g devices
    - using test mode software
    - in normal operating configurations
  - examined test configurations of new products
    - spatial multiplexing MIMO
    - simple 2-antenna beam-forming

Examining Difficulties

- normal operating mode unsuitable for SAR testing
- test mode results do not represent normal exposure
- common interface connectivity enables transmitter to operate in different hosts across platform
- SAR of switched antenna diversity cannot be measured
- other complex antenna configurations require additional consideration in SAR evaluation
- transmit duty factor during normal use may not be easily quantified
- burst duty factor & burst crest factor corrections need examination

Primary Goals

- establish device test configuration procedures
  - to reduce measurement variations
  - to minimize unnecessary testing
- develop acceptable SAR measurement protocols
  - to minimize SAR measurement variations
- provide necessary guidance
  - to facilitate TCB review & approval
- expand TCB scope on RF Safety
  - 3 – 6 GHz SAR review
  - SAR review of certain multiple-antenna systems
    - spatial multiplexing MIMO
    - simple 2-antenna beam-forming

Other Considerations

- address SAR measurement and device configuration procedures independently
  - according to SAR measurement requirements
    - at 0.3 – 3.0 GHz
    - at 3 – 6 GHz
  - according to 802.11 a/b/g communication protocols and operating configurations
  - according to exposure conditions in
    - fully defined host platforms
      - PCMCIA in laptop computer configurations
    - partially defined modular configurations (future)

Subsequent Goals

- address other test requirements independently
  - with additional test procedures
  - through subsequent TCB workshops
- address administrative and policy requirements independently of the test procedures
  - thresholds and exclusions
  - permissive change policies
  - grant condition policies
  - modular transmitter requirements
  - co-location & simultaneous transmission requirements

802.11 a/b/g Test Configuration Overview and Recommendations

(a different color font is used to identify certain recommended test configurations in the following slides)

Test Configuration Overview

- device test configurations
- default test configurations
- output power & signal modulation
- proprietary modes
- antenna diversity
- burst duty factor & burst crest factor correction
- PCMCIA transmitter in laptop computers & card extender

Normal use Conditions

- ad hoc or infrastructure mode
  - 2-way interactive communication link
    - client to client: wireless
    - client to AP to client: wireless + wired or wireless
  - network dynamics result in undesirable test conditions with highly varying results
    - data rate, modulation, output power, antenna diversity etc.
- normal mode is unsuitable for SAR testing and should not be used

Test Mode Configurations

- proprietary test software required
  - 1-way passive transmission
    - independent of network dynamics
    - apply fixed transmission parameters to enable stable test conditions
      - data rate, modulation, output power, antenna conditions etc.
  - measured SAR is uncorrelated with exposure in normal operating conditions

Default Test Configurations

Mode	GHz	Channel	Turbo Channel	Default "a-b/g" Mode Test Channels			
				§15.247		§15.407	
				802.11b	802.11g		
802.11 b/g	2.412	1		√	∇		
	2.437	6	6	√	∇		
	2.462	11		√	∇		
802.11 a	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				√	
	5.745	149		√		√	
	5.765	153	152 (5.76 GHz)		*		*
	5.785	157		√			*
	5.805	161	160 (5.80 GHz)		*	√	
§15.247	5.825	165		√			

Default Channel Selection

- select √ channels in each frequency band
- for 5 GHz bands: when highest output * channel is 0.25 dB > nearest √ channels, select * instead of √ channel with lowest output
- for 2.4 GHz band: when each ∇ channel is 0.25 dB > √ channel, select both * & ∇ channels
- test the highest output channel in each frequency band
- test other selected channels only when the peak SAR > 1.6 W/kg or 1-g SAR > 0.8 W/kg on highest output channel
- test all required channels at the lowest data rate

Output Power

- 802.11a -

- 5 GHz devices are typically designed to cover approximately 1 GHz for domestic & international channels, output may be optimized for each band
- high, middle & low channels may not cover maximum output in each frequency band
- the channel with maximum average output power should be tested in place of adjacent default channel with lowest output to minimize unnecessary testing

Output Power

- 802.11 b/g -

- signal modulation and amplifier requirements typically require the average output of 802.11g to be ≤ 802.11b configurations
- 802.11g channels should be tested only when the average output is 0.25 dB > the corresponding 802.11b channel

Signal Modulation

- conditions -

- higher data rates use higher order modulations requiring higher peak to average output ratios
- higher data rates usually have lower average output
- higher data rates may have higher average output power when the output power at lower data rates are held back from the maximum average output of the amplifier

Signal Modulation

- procedures & requirements -

- testing SAR for higher order modulations is typically unnecessary
- higher data rates should be tested only when the average output is 0.25 dB > that at the lowest data rate for the default "a-b/g mode" test channels

Proprietary Data Mode

- conditions -

- turbo mode operates at higher data rates requiring higher order modulations & lower average power
- bandwidth may be widened but the total average output is typically lower to satisfy amplifier performance
- half & quarter rates may apply slower but more reliable error correction coding to improve error recovery, but average output is not expected to be higher than lowest data rate

Proprietary Mode

- procedures & requirements -

- proprietary modes are vendor, product and chipset dependent and ad hoc considerations may be necessary to ensure proper evaluation according to product implementation
- turbo, half & quarter rate channels should be tested at the lowest data rate used in each proprietary mode when the average output is greater than that on the closest default “a-b/g mode” channels

Legacy Switched Diversity

- conditions -

- legacy 802.11 a/b/g transmitters typically operate with 2 antennas for receive diversity
- some also have switched transmit diversity
- the energy is multiplexed in both space & time between the two antennas in random fashions according to received signals quality & bit error rate requirements
- test software can only activate one antenna at a time because legacy devices do not support simultaneous transmission

Legacy Switched Diversity

- procedures & requirements -

- a conservative correction factor may be considered
  - to estimate normal use exposure
  - to compensate the SAR measured in test mode
- for legacy 802.11 a/b/g devices with switched transmit diversity
  - the SAR of each antenna should be measured independently on the highest output channel in each “a-b/g mode”
  - other channels should be tested only when the SAR vary by > 25% for the two antennas on highest output channel or > 1.2 W/kg
  - SAR for each antenna should be adjusted by a 75% correction factor

Other Antenna Configurations

- conditions -

- 802.11 a/b/g configurations that transmit simultaneously through multiple transmitters with antennas at close proximity to each other
- when the SAR distributions of antennas overlap, the measured, interpolated and extrapolated SAR of these antennas should be summed grid-by-grid in identical test configurations, including device test position, area & zoom scan resolutions etc. to compute 1-g SAR

Other Antenna Configurations

- procedures & requirements -

- SAR should be measured with the antennas transmitting simultaneously
- when the antennas are activated independently, the grid-summed SAR must be used to compute 1-g averaged SAR
- a duty factor of 100% should be applied to the 1-g SAR
- the procedure applies to spatial multiplexing MIMO, including legacy cyclic delay diversity, and simple 2-antenna beam-forming configurations
- contact FCC for other complex antenna configurations

Burst Duty Factor

- conditions -

- duty factor compensation for periodic signals should account for
  - pulse width & pulse repetition rate
  - SAR probe design & calibration procedures
  - probe sensor compression
  - SAR system sampling & integration times
- compensation for non-periodic signals could be highly dependent on
  - signal characteristics
  - SAR probe design & calibration methodology
  - SAR measurement procedures

Burst Duty Factor

- procedures & requirements -

- duty factor compensation for SAR generally applies to periodic signals and prior knowledge of signal characteristics is required
- duty factor compensation may be verified by comparing the SAR of the same signal at power levels above and below the probe sensor compression point
- if the SAR cannot be scaled linearly, the correction factor could be incorrect
- duty factor correction must be verified for non-periodic signals

Burst Crest Factor

- conditions -

- peak to average power ratio of higher order modulations may have large variations within burst and also among bursts
- SAR probe output relates to average power that varies with
  - burst duty factor
  - average burst envelope power
  - the average envelope to overall average power
- compensation for large and varying crest factors within bursts could be highly dependent on signal modulation, probe design & calibration
- complex multi-carrier signals can have large number of sub-carriers each using different modulations with varying burst crest factors

Burst Crest Factor

- procedures & requirements -

- probe performance and calibration data should be examined to determine if burst crest factor correction is applicable according to the characteristics of the test signal
- periodic burst duty factor & repeatable burst waveform should be used in test mode to minimize measurement issues
- crest factor correction may be verified by comparing the SAR of the same signal at power levels above and below the probe sensor compression point, with and without the correction
- if the SAR cannot be scaled linearly, the correction factor could be incorrect
  - SAR should be measured at a lower power, below sensor compression, and scaled to the applicable higher average power

PCMCIA in Laptop Computers

- conditions -

- common interface connectivity
  - operating systems on laptops generally enable unrestricted PCMCIA transmitter operations
  - transmitter driver software is user installable
- operating considerations
  - influence between laptop computers and PCMCIA transmitters with integral antennas extending outside of laptops is expected to be small
  - may consider an acceptable margin to ensure compliance for variations among typical laptops

PCMCIA in Laptop Computers

- procedures & requirements -

- measure SAR at a fixed separation distance of 1.5 cm to minimize SAR variations due to setup differences
- test with and without PCMCIA extender on highest average output “a-b/g mode” channels
  - test other channels with extender only when SAR with & without extender are ≤ 0.8 W/kg with ≤ 25% variation on highest output channel
  - otherwise, test other channels with & without extender (ignore 0.8 W/kg low SAR exclusion)
  - when any measured SAR > 1.2 W/kg, submit to FCC for approval
    - provide data to demonstrate SAR limit is not likely to be exceeded due to variations among typical laptop computers
    - lower output power in applicable channels and modes

Documentation

- test software and test mode configurations
- device test configurations
  - test channel, output power, proprietary modes etc.
- other justifications
  - antenna diversity
  - signal duty factor
  - burst crest factor
- applicable data and plots
- tabulated summary of all measurements

TCB Review considerations

- TCB review proposal (time frame TBD)
  - requires previous SAR training qualifications
  - device tested according to
    - applicable 3-6 GHz procedures
    - applicable LAN device configurations or other DUT configuration requirements
- FCC review required if device
  - not tested as specified in various recommended procedures
- applicability of PCMCIA & extender procedures: TBD
- procedures apply to 3- 6 GHz SAR measurements
- new procedures required for 2.4 GHz SAR measurements after a transition period (TBD)