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
  - 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

### Default Test Configurations

#### Default “a-b/g” Mode Test Channels

<table>
<thead>
<tr>
<th>Mode</th>
<th>GHz</th>
<th>Channel</th>
<th>Turbo Channel</th>
<th>Default “a-b/g” Mode Test Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.11 b/g</td>
<td>2.412</td>
<td>1</td>
<td>6</td>
<td>§15.247</td>
</tr>
<tr>
<td></td>
<td>2.437</td>
<td>6</td>
<td>6</td>
<td>§15.407</td>
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<tr>
<td></td>
<td>2.462</td>
<td>11</td>
<td></td>
<td>§15.407</td>
</tr>
<tr>
<td>802.11 a</td>
<td>5.18</td>
<td>36</td>
<td>42 (5.21 GHz)</td>
<td>§15.247</td>
</tr>
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<td></td>
<td>5.20</td>
<td>40</td>
<td></td>
<td>§15.407 802.11b §15.407 802.11g</td>
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<tr>
<td></td>
<td>5.22</td>
<td>44</td>
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<td>48</td>
<td>50 (5.25 GHz)</td>
<td>§15.407 802.11b §15.407 802.11g</td>
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<td>5.26</td>
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<td>5.28</td>
<td>56</td>
<td>58 (5.29 GHz)</td>
<td>§15.407 802.11b §15.407 802.11g</td>
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<td>60</td>
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<td>152 (5.76 GHz)</td>
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<td>§15.407 802.11b §15.407 802.11g</td>
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<td>160 (5.80 GHz)</td>
<td>§15.407 802.11b §15.407 802.11g</td>
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<td>5.825</td>
<td>165</td>
<td></td>
<td>§15.407 802.11b §15.407 802.11g</td>
</tr>
</tbody>
</table>

Note: √ - Standard, ▽ - Not Standard
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.
signal modulation and amplifier requirements typically require the average output of 802.11g to be $\leq$ 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
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-carryers 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 \( \leq 0.8 \) W/kg with \( \leq 25\% \) 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
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)