SAR Measurement
Considerations at 3-6 GHz

Proposed TCB Review Procedures
- May 2005 -
Overview

- current status
- goal

SAR measurement difficulties

recommended procedures

proposed TCB review considerations

questions & discussions
Current Status
SAR Measurement Standards

0.3 – 3.0 GHz

– SAR procedures for handsets only
  • Supplement C-0101 (2001)
  • IEC 62209-1 (2005)

30 MHz – 6 GHz

– SAR procedures for body-worn and generic configurations
  • IEC 62209-2 preliminary working draft (2005)
Typical 3 – 6 GHz Frequencies

5 GHz: 802.11a
- §15.247: 5.725 – 5.850 GHz (125 MHz)
- §15.407 UNII
  - 5.15 – 5.25 GHz (100 MHz)
  - 5.25 – 5.35 GHz (100 MHz)
  - 5.725 – 5.825 GHz (100 MHz)
  - 5.470 – 5.725 GHz (255 MHz)

2.4 GHz: 802.11 b/g with 802.11a built-in
- §15.247: 2400 – 2483.5 MHz (83.5 MHz)
Other 3 – 6 GHz Frequencies

- 4.9 GHz public safety
  - Part 90, subpart Y
    - 4940 – 4990 MHz

- 5.9 GHz DSRCS (5.850 – 5.925 GHz)
  - OBUs - Part 95, subpart L (1.0 mW portable)
  - RSUs – Part 90, subpart M (hand carry option)

- 802.16 Wi-Max
  - licensed (3650 – 3700 MHz)
  - unlicensed (most likely 5 GHz)
SAR above 3 GHz

- no standard measurement procedures
  - 62209-2 preliminary working draft
- measurement requirements
  - 6 GHz field probe: available
  - tissue dielectric parameters: achievable
  - field scanning and analyses procedures: under investigation
  - system validation procedures: being confirmed by IEC TC106
  - test device configuration requirements: FCC initiated exploratory measurements
Goal

establish acceptable test procedures to
– minimize measurement variations
  • for SAR measurements above 3 GHz
  • in 802.11a/b/g device test configurations
– provide necessary guidance for
  • manufacturers & test laboratories
  • TCB review & approval
– to expand TCB scope on RF Safety
  • 3 – 6 GHz SAR review
  • certain multiple-antenna system SAR review
SAR Measurement Difficulties and Recommendations
3 – 6 GHz SAR Measurement

- field probes
- signal conversion
- system validation & verification
- Phantom & tissue dielectric properties
- SAR Scan procedures
- post-processing analysis
Penetration Depth

Penetration depth reduced at 3 – 6 GHz

- about 6 mm at 6 GHz
  - 55% attenuation at 0.375 penetration depth
- need measurements at 2-3 mm from phantom surface
Field Probe Requirements

- need measurements at 2-3 mm from phantom surface
- need to reduce probe tip diameter
  - to minimize probe boundary effect errors
    - from 6-7 mm for typical probes
    - to \( \leq 3-4 \) mm for 6 GHz probes
- need smaller sensor to probe tip offset
  - to reduce measurement point to phantom distance
    - from 2-3 mm sensor offset in typical probes
    - to 1-2 mm in 6 GHz probes
- available probes
  - 2.5 mm tip diameter
  - 1.0 mm sensor offset
# Field Probe Proposals

<table>
<thead>
<tr>
<th></th>
<th>62209-2</th>
<th>FCC/TCB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>&gt; 2 GHz</td>
<td>3-6 GHz</td>
</tr>
<tr>
<td><strong>Probe Tip</strong></td>
<td>≤ (16/f(\text{GHz})) mm</td>
<td>≤ 3 mm</td>
</tr>
<tr>
<td></td>
<td>(2.67 mm @ 6 GHz)</td>
<td></td>
</tr>
<tr>
<td><strong>Sensor Offset</strong></td>
<td>≤ (8/f(\text{GHz})) mm</td>
<td>≤ 1.5 mm</td>
</tr>
<tr>
<td></td>
<td>(1.35 mm @ 6 GHz)</td>
<td></td>
</tr>
<tr>
<td><strong>Calibration</strong></td>
<td>waveguide</td>
<td></td>
</tr>
</tbody>
</table>
| **Closest Measurement** | ≤ 8.0 ±1.0 mm | < 5 GHz: ≤ 3.5 ± 0.5 mm
|                      |        | ≥ 5 GHz: ≤ 2.5 ± 0.5 mm |
Field Probe Calibration

- specifications somewhat unclear in 62209-2
- proposed interim guidance for 3 – 6 GHz
  - validity of each calibration point
    - Supplement C-0101 dielectric parameters
    - $\geq \pm 50$ MHz, $U_c (k=2) \leq 15\%$
      - $\varepsilon_r < 10\%$ and $\sigma < 5\%$ for calibration & measurements
    - $\geq \pm 100$ MHz, $U_c (k=2) < 20\%$
      - $\varepsilon_r < 5\%$ and $\sigma < 2.5\%$ for calibration
      - $\varepsilon_r < 5\%$ and $\sigma < 2.5\%$ between calibration & measurement
      - equipment certification by FCC only
Signal Compression

Dynamic Range $f(SAR_{\text{head}})$

( Waveguide R22 )

- **6.8 mm Probe**
  - 2-5 mW/kg
  - 2 W/kg

- **2.5 mm Probe**
  - 5-10 mW/kg
  - 10 W/kg

Dynamic Range $f(SAR_{\text{head}})$

( Waveguide R22 )

- 100 mV

Graphs show dynamic range with compensated and not compensated signals.
Signal Conversion

SAR field-probe signal conversion equation in typical systems:

\[ V_i = U_i + U_i^2 \frac{cf}{dcpi} \]

- \( U_i \) is the measured voltage
- \( V_i \propto \text{power} \)
- \( cf \) is \( \propto \text{power} \)
- \( dcpi \) is the diode compression voltage

\[ E_i = \sqrt{\frac{V_i}{Norm_i \ast \text{ConvF}}} \]

- \( E_i \propto \text{E-field} \)
Duty Factor Compensation

- Duty factor correction in existing systems are mostly intended for periodic signals, such as GSM or IS-136.
- Duty factor correction may be limited to certain:
  - Pulse repetition rate
  - Pulse duration
- Duty factor correction could be dependent on:
  - Probe design
  - Probe calibration requirements
  - Signal characteristics
  - Crest factor variations within bursts
- Duty factor correction for non-periodic signals may require additional considerations; for example, multiple carrier signals with different sub-carrier modulation & bandwidth.
Duty Factor & Crest Factor

GSM 1 slot
GSM 2 slots
System Validation & Verification

- proposed procedures at 3 – 6 GHz
- using 62209-2 dipole configuration
  - within transmission band or ± 100 MHz of mid-band
  - $\varepsilon_r < 10\%$ and $\sigma < 5\%$ for calibration & measurements
  - within 10% of 1-g SAR targets
  - within 15% of extrapolated peak SAR at phantom surface above dipole feed-point
Optional Verification Procedures

SAR system verification procedures for wideband requirements at 3 – 6 GHz

- apply same tolerances as dipole target values
- within ± 200 MHz of mid-band, $\varepsilon_r < 5\%$ and $\sigma < 2.5\%$
  - both verification and routine measurement should be based on
    - same probe calibration point – single points
    - same tissue simulating liquid
    - same area and zoom scan resolutions
    - same interpolation and extrapolation resolutions

- equipment certification by FCC only
  - measurements with extended probe calibration range > ± 100 MHz
    based on a single probe calibration point
  - use of other RF sources for system verification
**Phantom Requirements**

IEEE Standard 1528 & IEC 62209-1
- SAM & flat phantom

**tissue dielectric parameters**
- \( \varepsilon_r < 10\% \) & \( \sigma < 5\% \) of Supplement C-0101 head & body targets
- water and non-polar liquid mixture/suspension

<table>
<thead>
<tr>
<th>flat phantom</th>
<th>62209-2</th>
<th>FCC/TCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>shell ((\varepsilon_r))</td>
<td>(4 \pm 1)</td>
<td>(\leq 5) (IEEE 1528)</td>
</tr>
</tbody>
</table>
| size              | \(20\% > \text{DUT}\)  \\
|                   | \(\geq 24 \times 16 \text{ cm}^2\) | 5 cm around \\
|                   |                  | measurement region       |
| liquid depth      | measured SAR     |                          |
|                   | variation < 1\%  | 10 cm                    |
## Area Scan Requirements

<table>
<thead>
<tr>
<th></th>
<th>62209-2</th>
<th>FCC/TCB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>peak location accuracy</strong></td>
<td>± 5 mm</td>
<td>± 5 mm</td>
</tr>
<tr>
<td><strong>scan resolution</strong></td>
<td>≤ 20 mm</td>
<td>≤ 10 mm</td>
</tr>
<tr>
<td><strong>distance to phantom surface</strong></td>
<td>proposed: 4 ± 0.5 mm</td>
<td>&lt; 5 GHz: ≤ 3.5 ± 0.5 mm</td>
</tr>
<tr>
<td></td>
<td>considered: 8 ± 1.0 mm</td>
<td>≥ 5 GHz: ≤ 2.5 ± 0.5 mm</td>
</tr>
<tr>
<td><strong>peak to scan boundary dist.</strong></td>
<td>½ zoom scan dimension</td>
<td>≤ 10 mm</td>
</tr>
<tr>
<td></td>
<td>(IEEE 1528 / IEC 62290-1)</td>
<td></td>
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</tbody>
</table>
# Zoom Scan Requirements

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>scan volume</strong></td>
<td>$\geq 30 \times 30 \times 30 \text{ mm}^3$</td>
<td>$\geq 25 \times 25 \times 25 \text{ mm}^3$</td>
</tr>
<tr>
<td></td>
<td>$\geq 1.3 \text{ times gram-cube linear dimension}$</td>
<td>recommend $30 \times 30 \times 25 \text{ mm}^3$</td>
</tr>
<tr>
<td><strong>scan resolution</strong></td>
<td>$x/y: \frac{24}{f_{(\text{GHz})}} \text{ mm}$</td>
<td>$x/y: &lt; 4.5 \text{ mm}$, recommend $\leq 3.0 \text{ mm} \geq 5 \text{ GHz}$</td>
</tr>
<tr>
<td></td>
<td>$z: \frac{12}{f_{(\text{GHz})}} \text{ mm}$</td>
<td>$z: &lt; 2.5 \text{ mm}$, recommend $\leq 2.0 \text{ mm} \geq 5 \text{ GHz}$</td>
</tr>
<tr>
<td></td>
<td>(4 / 2 mm @ 6 GHz)</td>
<td></td>
</tr>
<tr>
<td><strong>distance to phantom surface</strong></td>
<td>proposed: $\leq 4 \pm 0.5 \text{ mm}$ non considered</td>
<td>$&lt; 5 \text{ GHz}: \leq 3.5 \pm 0.5 \text{ mm}$ $\geq 5 \text{ GHz}: \leq 2.5 \pm 0.5 \text{ mm}$</td>
</tr>
<tr>
<td></td>
<td>none considered</td>
<td></td>
</tr>
<tr>
<td><strong>closest 2 two measurement points</strong></td>
<td>proposed: $&lt; 5 \text{ mm}$ none considered</td>
<td>$&lt; 5 \text{ mm}$</td>
</tr>
<tr>
<td></td>
<td>none considered</td>
<td></td>
</tr>
<tr>
<td><strong>graded grids</strong></td>
<td>proposed earlier none considered</td>
<td>$1^{st} \text{ point} \leq 2.0 – 2.5 \text{ mm}$ initial grid $\leq 2.0 \text{ mm}$ grid ratio $&lt; 2.0$, recommend 1.5</td>
</tr>
</tbody>
</table>
large peak to 1-g averaged SAR ratio

- 6 mm penetration depth (δ) at 6 GHz
- 55% of energy attenuated at 0.375δ
- extent of 1-g cube is about 2δ
- only points closest to phantom are useful
- very low values in rest of scan volume
- 1-g SAR very insensitive to measurement & extrapolation errors
- extrapolated SAR at phantom surface highly dependent on measured values

  • highest SAR and noise in the low SAR values
  • attenuation characteristics assumed by extrapolation algorithms of measurement system
Post-Processing Requirements

- extrapolated/interpolated data should be at least equivalent to those typically measured with
  - 5 mm area scan resolution
  - 1 mm zoom scan resolution
- verify post-processing algorithms
  - according to 62209-2 reference functions
  - with the post-processing procedures in the SAR system according to the same area and zoom scan resolutions used during measurement
- verify potential extrapolation errors in zoom scan with 2-D profile plots through peak SAR location in x, y & z direction
Extrapolation Errors

typically expected

acceptable

unacceptable
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 operating configuration requirements

FCC review required if device
- not tested as specified in various recommended procedures
- signal characteristics
  - < 10% pulse duty factor
  - periodic repetition rate < 10 Hz
  - non-periodic signals