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)
    - IEEE Standard 1528 (2003)
    - 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

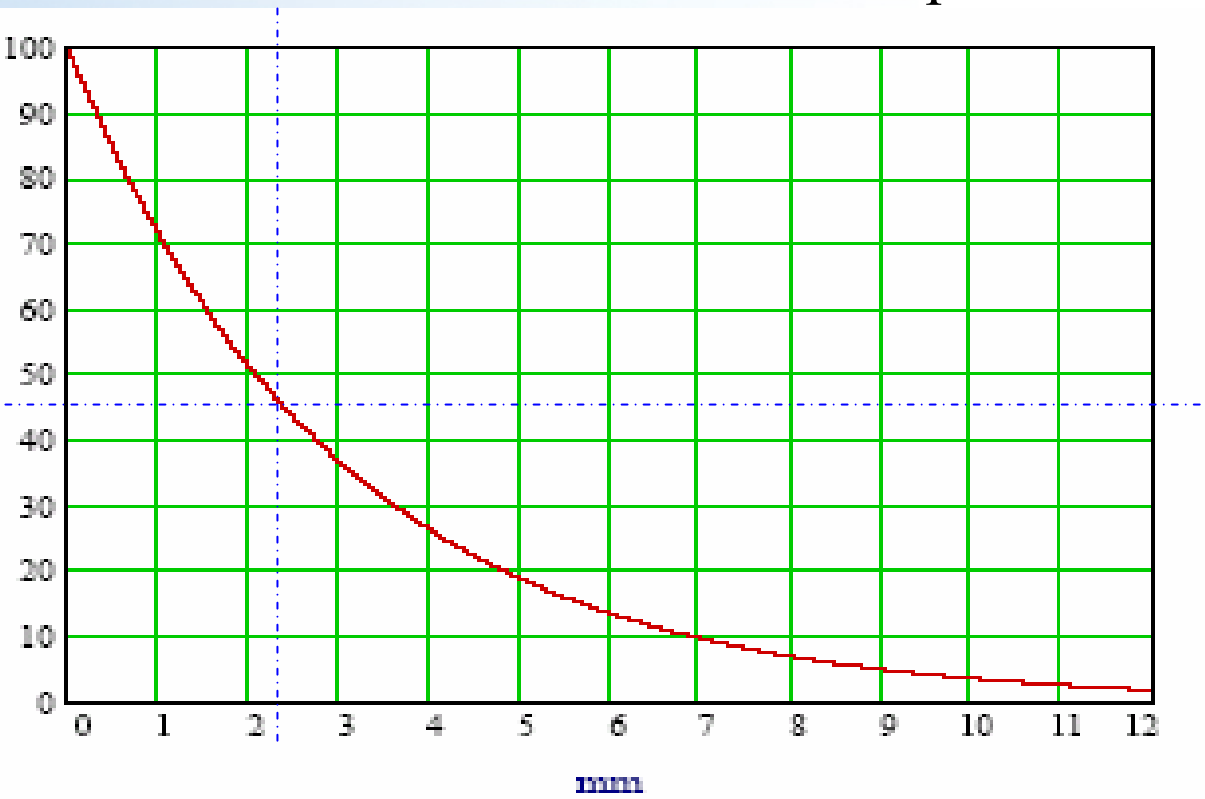
SAR Measurement Difficulties and Recommendations

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 ≤ 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

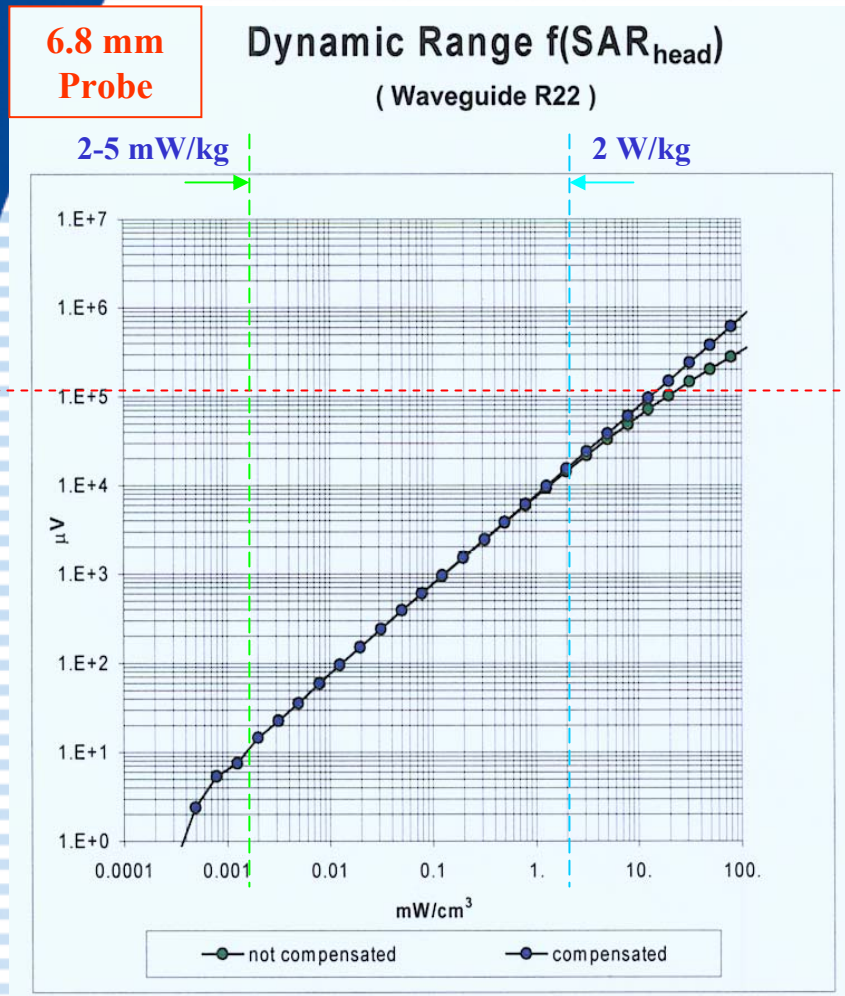
	62209-2	FCC/TCB
frequency	> 2 GHz	3-6 GHz
probe tip	$\leq 16/f_{(GHz)}$ mm (2.67 mm @ 6 GHz)	≤ 3 mm
sensor offset	$\leq 8/f_{(GHz)}$ mm (1.35 mm @ 6 GHz)	≤ 1.5 mm
calibration	waveguide	
closest measurement	≤ 8.0 ±1.0 mm	**< 5 GHz: ≤ 3.5 ± 0.5 mm** **≥ 5 GHz: ≤ 2.5 ± 0.5 mm**

Field Probe Calibration

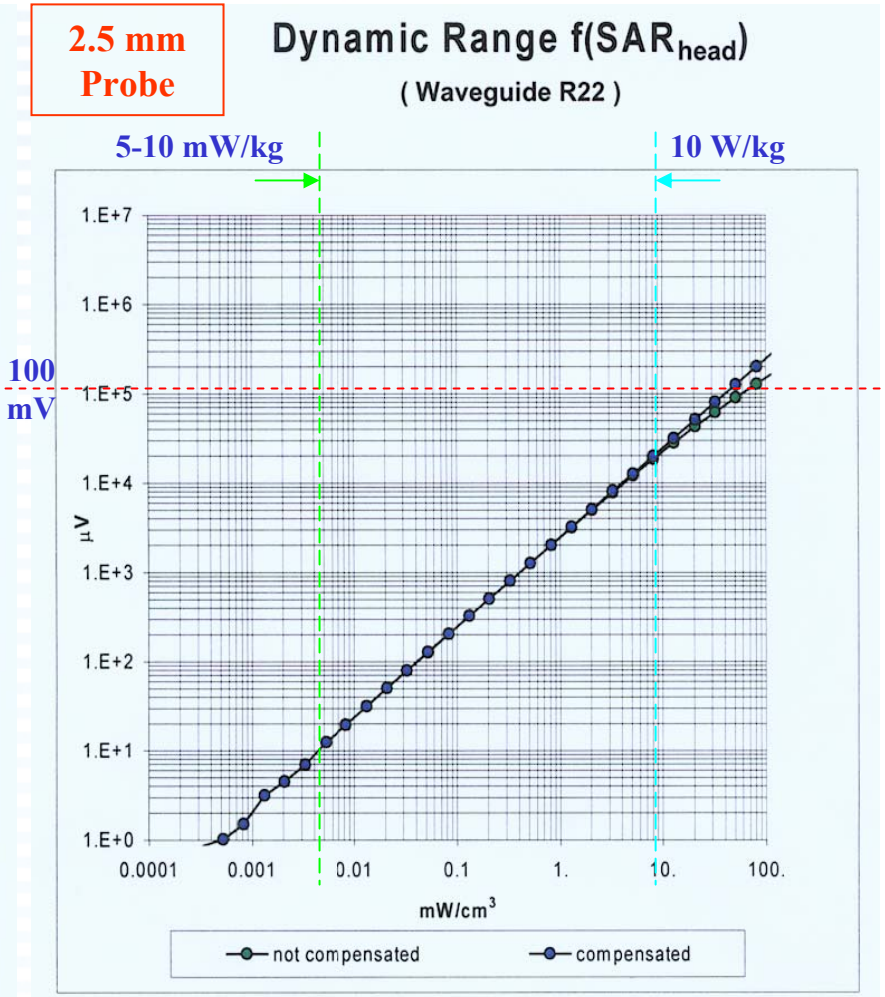
- specifications somewhat unclear in 62209-2
- proposed interim guidance for 3 – 6 GHz
  - validity of each calibration point
    - Supplement C-0101 dielectric parameters
    - $\geq \pm 50$ MHz, Uc (k=2) $\leq 15\%$
      - $\varepsilon_r < 10\%$ and $\sigma < 5\%$ for calibration & measurements
    - $\geq \pm 100$ MHz, Uc (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

6.8 mm Probe



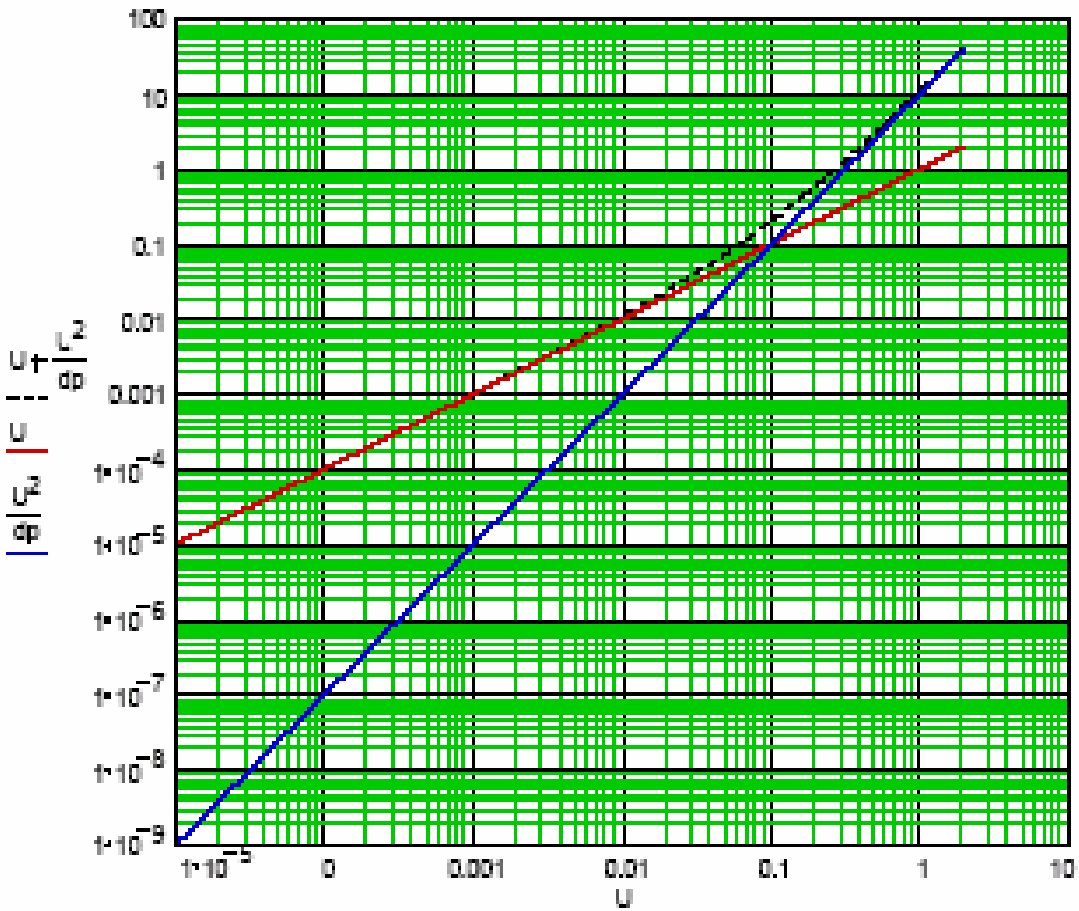
2.5 mm Probe



Signal Conversion

- **SAR field-probe signal conversion equation in typical systems :**

$$V_i = U_i + U_i^2 \frac{cf}{dcp_i}$$



- U_i is the measured voltage
- $V_i \propto$ power
- cf is $\propto$ power
- dcp_i is the diode compression voltage

$$E_i = \sqrt{\frac{V_i}{Norm_i * ConvF}}$$

- $E_i \propto$ E-field

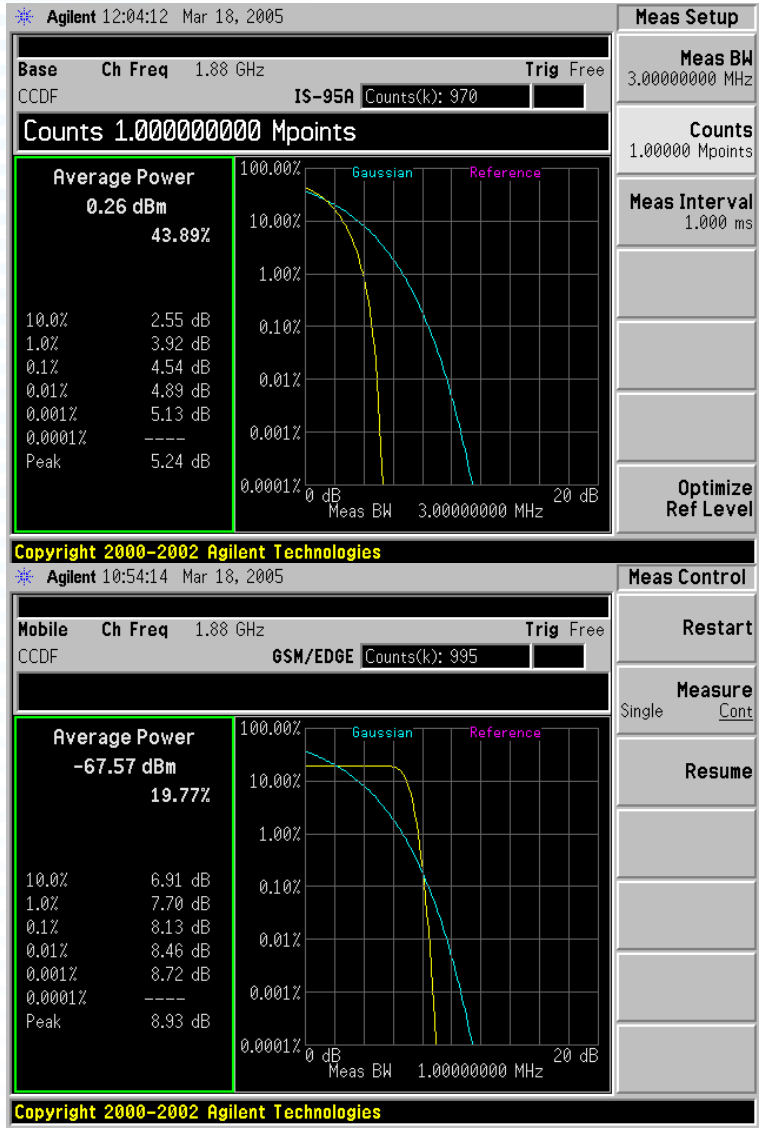
Duty Factor Compensation

- 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

CW

IS-95



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
  - ε_r < 10% and σ < 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, ε_r < 5% and σ < 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
  - ε_r < 10% & σ < 5% of Supplement C-0101 head & body targets
  - water and non-polar liquid mixture/suspension

flat phantom	62209-2	FCC/TCB
shell (ε_r)	4 ± 1	≤ 5 (IEEE 1528)
size	20% > DUT $\geq 24 \times 16$ cm^2	5 cm around measurement region
liquid depth	measured SAR variation < 1%	10 cm

Area Scan Requirements

	62209-2	FCC/TCB
peak location accuracy	± 5 mm	± 5 mm
scan resolution	≤ 20 mm	≤ 10 mm
distance to phantom surface	proposed: 4 ± 0.5 mm considered: 8 ± 1.0 mm	< 5 GHz: ≤ 3.5 ± 0.5 mm ≥ 5 GHz: ≤ 2.5 ± 0.5 mm
peak to scan boundary dist.	½ zoom scan dimension (IEEE 1528 / IEC 62290-1)	≤ 10 mm

Zoom Scan Requirements

	62209-2	FCC/TCB
scan volume	≥ 30 x 30 x 30 mm^3 ≥ 1.3 times gram-cube linear dimension	≥ 25 x 25 x 25 mm^3 recommend 30 x 30 x 25 mm^3
scan resolution	x/y: $24/f_{(GHz)}$ mm z: $12/f_{(GHz)}$ mm (4 / 2 mm @ 6 GHz)	x/y: < 4.5 mm, recommend ≤ 3.0 mm ≥ 5 GHz z: < 2.5 mm, recommend ≤ 2.0 mm ≥ 5 GHz
distance to phantom surface	proposed: ≤ 4 ± 0.5 mm non considered	< 5 GHz: ≤ 3.5 ± 0.5 mm ≥ 5 GHz: ≤ 2.5 ± 0.5 mm
closest 2 two measurement points	proposed: < 5 mm none considered	< 5 mm
graded grids	proposed earlier none considered	1st point ≤ 2.0 – 2.5 mm initial grid ≤ 2.0 mm grid ratio < 2.0, recommend 1.5

Post-Processing Analyses

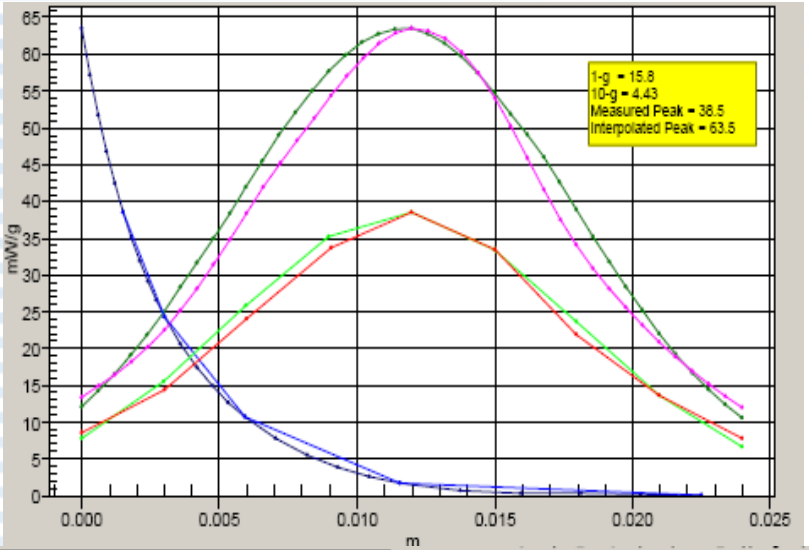
- large peak to 1-g averaged SAR ratio
  - 6 mm penetration depth (δ) at 6 GHz
  - 55% of energy attenuated at 0.375δ
  - extent of 1-g cube is about 2δ
  - only points closest to phantom are useful
  - very low values in rest of scan volume
  - 1-g SAR very insensitive to measurement & extrapolation 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

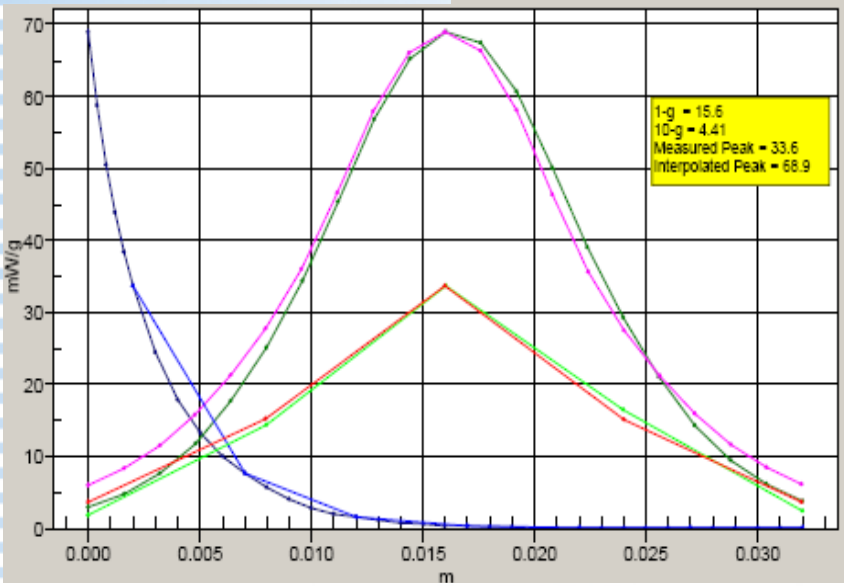
- extrapolated/interpolated data should be at least equivalent to those typically measured with
  - 5 mm area scan resolution
  - 1 mm zoom scan resolution
- verify post-processing algorithms
  - according to 62209-2 reference functions
  - with the post-processing procedures in the SAR system according 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

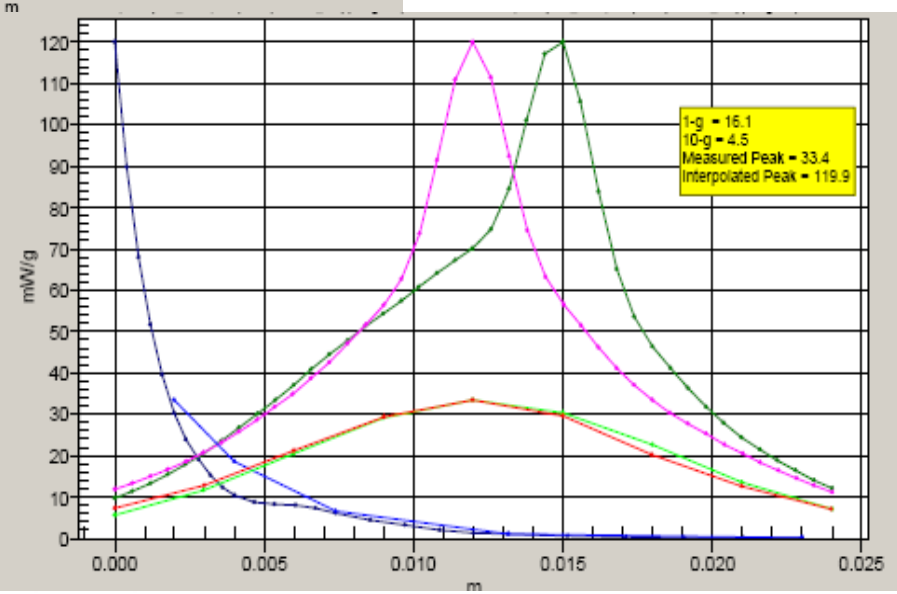
typically expected



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