SAR Measurement Requirements
for
3 – 6 GHz

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Summary

Current SAR measurement procedures are based on the handset test protocols described in IEEE Standard 1528 and IEC 62209-1. The procedures in Supplement C 01-01 are derived mostly from the 2000 draft version of IEEE 1528. As new products are continuously introduced into the market, these procedures are often applied to test devices beyond the intended frequency range and scope of these documents. Certain measurement issues and validity of test results relating to smaller penetration depths at higher frequencies have often been ignored.

IEC TC106 initiated a project several years ago to address some of these measurement issues and prepared a preliminary 62209-2 working draft in 2005, which included certain 3 – 6 GHz SAR measurement considerations. The IEEE TC-34 committee also initiated a project in 2005 to address 3 – 6 GHz SAR measurement procedures for wireless handsets. While it may take several years for these standards to finalize, the Commission conducted a series of exploratory measurements to investigate certain measurement difficulties using typical 5 GHz LAN devices. The procedures described in this document are derived from the Commission's measurements and reviews of applicable proposals in the IEC preliminary working draft and certain IEEE TC-34 considerations.[1]

The 3 – 6 GHz SAR measurement procedures described in this document are intended to provide an acceptable level of measurement confidence until additional guidance is available from standards organizations. While other applicable procedures based on sound engineering practice may be used, additional information and validations are necessary to support the test data to demonstrate compliance. These non-standard procedures may be considered on a case-by-case basis when submitted to the FCC for approval.

[1] IEC 62209-2 and IEEE TC-34 drafts may change according to deliberations in these committees. The proposals in IEC 106/90/NP, 2005-02-09 were reviewed and considered in developing this document.

Recommended SAR Measurement Procedures

SAR measurement requirements and test procedures for 3 – 6 GHz are described in this section. Requirements for field probes, tissue dielectric properties, scan procedures, system accuracy and measurement uncertainties are specified to ensure measurement consistency. Additional discussions of measurement issues and other related information are included in the Appendix.

Field Probe

A probe tip diameter ≤ 4.0 mm and probe tip to sensor (geometric center) distance ≤ 2.0 mm are required for SAR measurements in the 3 – 4.5 GHz range. A probe tip diameter ≤ 3.0 mm and probe tip to sensor distance ≤ 1.5 mm are required for 4.5 – 6 GHz. Probes should be calibrated either by the manufacturer or an accredited calibration facility according to waveguide procedures described in matured versions of the IEC 62209-2 and IEEE P1528a drafts.[2] The calibrations must be valid within ±50 MHz of each calibration point. For measurements in the 5.725 – 5.85 and 5.47 – 5.725 GHz bands under §15.247 and §15.407 (UNII), greater than ±50 MHz coverage may be required. If the design of an individual probe or the calibration procedures do not support extended frequency measurements, multiple calibration points are necessary to cover such bands. An expanded calibration uncertainty (k=2) ≤ 15% is required. The applicable probe calibration data and probe calibration uncertainty must be included in test reports to support the test results.

The measured dielectric constant (ε_r) and conductivity (σ) of tissue-equivalent medium used for probe calibration must be within 10% and 5% respectively of the target parameters specified in Supplement C 01-01.[3] Deviations in ε_r and σ between probe calibration and routine measurements can reduce measurement accuracy; therefore, measurements exceeding ±100 MHz of a calibration point or using probes with expanded calibration uncertainty (k=2) >15% should only be considered when ε_r and σ for probe calibration and routine measurements are both within 5% and 2.5% respectively of the target values.[4] Equipment certifications with SAR measurements using probe calibrations extending beyond ±100 MHz must be submitted to the FCC for approval.[5] The probe calibration uncertainty of each SAR measurement must not exceed, under any circumstances, an expanded uncertainty (k=2) of 20%.

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[2] Until stable procedures are available, the waveguide procedures described in IEEE Standard 1528 should be adapted for used in the interim.

[3] Separate uncertainties apply to tissue dielectric parameter target values and measurement uncertainty.

[4] The sensitivities of tissue dielectric parameters to frequency and temperature may vary with tissue recipes and affecting the frequency extend of a calibration point. The design of a probe, its frequency response, calibration methods and procedures can also affect the frequency extend of a calibration point.

[5] For channel bandwidths ≤ 20 MHz, the required range of a calibration point is determined according to the frequencies of the highest and lowest frequency channels measured by that calibration point. For larger channel bandwidths, the highest and lowest channel band-edge frequencies should be used to determine the required range of a probe calibration point.

Phantom

The head (SAM) phantom described in Supplement C 01-01 and IEEE Standard 1528 is used to test devices operating next to a person's ear. A liquid depth of at least 10 cm, measured from the Ear Reference Point, is required. A flat phantom is used for other exposure configurations. The dielectric constant, loss tangent and phantom shell thickness should conform to Supplement C and IEEE 1528 requirements.[6] SAR underestimations caused by deviations in phantom shell dielectric constant from the recommended nominal target in 62209-2 must be accounted for in determining compliance.[7] A flat phantom should provide a margin of at least 5 cm between its sidewalls and a transmitter or 3 penetration depths surrounding the measurement region.[8] A liquid depth of at least 10 cm is also required for flat phantom measurements.

Smaller flat phantoms may be used to measure the SAR of certain fully integrated standalone transmitters that are somewhat longer than the phantom in one dimension. This alternative procedure is only applicable when no more than two area scans with sufficient overlaps are used to identify all SAR peaks within the projections of a transmitter and it is demonstrated that SAR distributions are not affected by the split scans. The non-overlapping regions of the area scans must satisfy the necessary phantom margin requirements. Peaks identified in overlapped area scan regions would require additional area scans to ensure the required phantom margins are met in subsequent zoom scans. For transmitters contained within or attached to a host device that is known to have insignificant contributions to the SAR measurement, that portion of the host device may extend beyond the measurement boundary.

Tissue-Equivalent Media

The head and body tissue dielectric parameters specified in Supplement C 01-01 for 3.0 and 5.8 GHz should be linearly interpolated to the center frequency of a transmission band or measurement channels to determine the appropriate dielectric parameters required for SAR testing.[9] The dielectric constant (ε_r) and conductivity (σ) of the tissue-equivalent media used in SAR measurements should be within ±10 % and ±5 % respectively of the target parameters specified in Supplement C.[10] The tissue properties used in the SAR measurements must also be within the range of dielectric parameters specified for each probe calibration point.[11] Until standardized tissue recipes are identified and verified; for example, through the IEC 62209-2 projects or other reliable sources, information on temperature sensitivity and short term stability of the tissue

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[6] The more conservative parameters should be used.

[7] IEC 62209-2 has discussed in 2006 to use a nominal value of $\varepsilon_r = 3.7$ with an asymmetrical tolerance.

[8] The measurement region is typically 1 – 2 cm larger than the projected areas of a transmitter.

[9] The center frequency of measurement channels is the average frequency of the highest and lowest frequency channels within a transmission band of the test device covered by a probe calibration point.

[10] Target value uncertainty and measurement uncertainty for tissue dielectric parameters are separate uncertainty components.

[11] Tissue dielectric parameters should be within tolerance for the entire frequency range covered by a calibration point for both probe calibration and routine measurements.

media should be included in test reports to ensure the tissue dielectric parameters used in each measurement are within tolerance.[12]

SAR Scan Procedures

The area and zoom scan resolutions specified below should be used to avoid certain post-processing issues that may introduce additional SAR errors. Probe boundary effects error compensation is required when the probe tip is closer than half a probe tip diameter to the phantom surface or when probe boundary effects error is greater than 5%. The tolerances of post-processing algorithms should be verified for the scan resolutions used in the SAR measurements, according to the reference distribution functions specified in the latest matured versions of the IEC 62209-2 or IEEE P1528a drafts.[13]

Area Scan

The projected areas of a transmitter are measured in an area scan with a resolution ≤ 1.0 cm to ensure reliable and consistent zoom scan measurements. Area scan measurements are made at a constant distance from the phantom surface, ≤ 3.5 mm below 4.5 GHz and ≤ 2.5 mm at or above 4.5 GHz, with ≤ ± 0.5 mm variation.[14] When a measured peak is closer than 1.0 cm from the edge of the scan region, the measurement is repeated by expanding the scan region to ensure all peaks are at least 1.0 cm from the scan boundary.

Zoom Scan

In the lateral directions (x & y), zoom scan resolutions ≤ 5.0 mm are required below 4.5 GHz and ≤ 4.0 mm at or above 4.5 GHz. In the normal direction (z or depth), spatial resolutions ≤ 3.0 mm below 4.5 GHz and ≤ 2.5 mm at or above 4.5 GHz are required for fixed grid measurements. The closest measurement points from the phantom surface in a zoom scan should be ≤ 3.5 mm below 4.5 GHz and ≤ 2.5 mm at or above 4.5 GHz. At least two measurement points are required within the first 5 mm of the phantom surface; three points are recommended above 4.5 GHz. When graded grids are used (z), the first measurement point should be within 3 mm of the phantom surface for measurements below 4.5 GHz and within 2.0 mm at or above 4.5 GHz. The initial grid separation, closest to the phantom, should be ≤ 2.0 mm. A subsequent graded grid ratio of 1.5 is recommended and less than 2.0 is required. A zoom scan volume of 30 x 30 x 24 mm^3 or larger should be used below 4.5 GHz and 24 x 24 x 20 mm^3 or larger is required at or above 4.5 GHz.[15] The 1-g average SAR volume should be at least 0.5 cm from the zoom scan boundary; otherwise, the scan should be repeated by shifting to the peak location measured in the preceding scan.

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[12] When standardized tissue recipes become available from standards organizations tighter target tissue dielectric parameter uncertainty may apply.

[13] Until the latest reference distributions are implemented in SAR systems those specified in IEEE 1528 may be used; however, additional considerations in uncertainty margins may be required.

[14] Above or below 4.5 GHz is determined according to the center frequency of a transmission band or the measurement channels covered by a probe calibration point.

[15] The outermost layer of measurement points should be on or outside the minimum zoom scan volume boundary for both fixed and graded grids.

Post-Processing Procedures

The post-processing procedures should extrapolate and interpolate the measured results to at least the equivalent of measurements made with 5.0 mm area scan resolution and 1.0 mm zoom scan resolution. These are verified using the reference SAR distribution functions described in the latest matured versions of IEC 62209-2 and IEEE P1528a drafts. The peak SAR location, peak, 1-g and 10-g SAR values are compared to those specified in these draft standards to determine measurement uncertainty. Since the verification is only applicable to area and zoom scan resolutions used in the specific tests, independent verifications are required for different measurement and interpolation resolutions.

In addition to reporting 1-g or 10-g averaged SAR, the maximum extrapolated and interpolated peak SAR value should also be verified. The measured, extrapolated and interpolated SAR values through the peak SAR location in the X, Y and Z directions can be plotted (see Figure 1 in Appendix) for the highest SAR configurations in each transmission mode and frequency band to identify potential post-processing errors.

SAR System Validation and Verification

The reference dipoles described in IEC 62209-2 and IEEE P1528a are used to verify the measurement accuracy of SAR systems at 3 – 6 GHz. The 1-g or 10-g SAR values measured using the required tissue dielectric parameters should be within 10% of the manufacturer calibrated dipole SAR values. The extrapolated peak SAR value at the phantom surface above the dipole feed-point should be within 15% of the calibrated target value. When other radiating sources instead of the reference dipoles are used for system verification, vigorous validations are required to determine target SAR values. SAR measurements based on non-standard system verification methods should be submitted to the FCC for equipment approval.

System verification is performed either at a frequency within the transmission band of the test device or within ± 100 MHz of the mid-band frequency, according to valid probe calibrations. Measurements should only be performed at frequencies with calibrated reference dipole SAR values. When a reference dipole is not defined within ± 100 MHz the system verification may be conducted within ± 200 MHz of the center frequency of a test device or measurement channels. However, it must be ensured that the SAR probe calibration is valid and the same tissue-equivalent medium is used for both system verification and routine measurements. The same probe calibration point, area and zoom scan resolution, interpolation and extrapolation procedures must be used for the dipole and routine measurements. Alternatively, multiple probe calibration points with independent system verifications may be used to cover an extended frequency range.

Measurement Uncertainty

The measurement uncertainty procedures described in Supplement C 01-01, IEEE Standard 1528, IEEE P1528a and IEC 62209-2 should be followed, whichever are more conservative. The uncertainty analyses must apply the appropriate parameters for 3 – 6

GHz. Uncertainties due to measurement resolutions and post-processing procedures are evaluated according to reference SAR distribution functions defined in 62209-2 and P1528a. Uncertainty for distance related components should be estimated according to the penetration depth at 6 GHz for head or body tissues. Probe calibration uncertainty and applicable tissue dielectric target uncertainty (10% ε_r and 5% σ) should be applied to the analyses. SAR measurement discrepancies introduced by phantom shell dielectric property differences should be addressed according to the most recent information available from IEC 62209-2 and procedures described in the Appendix; especially when the shell dielectric constant is lower than the recommended nominal target value, which typically results in underestimated SAR.

Appendix

Existing SAR measurement standards such as the IEEE 1528 and IEC 62209-1 are intended for handsets operating next to a person's ear. The procedures are often applied to test devices outside the scope of these documents and used to test wireless products such as Wi-Fi and other LAN devices. In some cases the procedures are applied beyond the frequency range intended for these standards, leading to measurement difficulties where the validity of results is often overlooked. However, theory and experience indicate that without additional measurement considerations the procedures intended for 0.3 – 3.0 GHz are usually inadequate at higher frequencies. The measurement issues are mainly related to the smaller penetration depths of tissue-equivalent media at higher frequencies; about 6 mm at 6 GHz as compared to 14 mm at 3 GHz.

This prompted the IEC TC106 committee to initiate a project, 62209-2, to address these measurement problems, which subsequently expanded to a much larger and slower project that covers various body exposure configurations for 30 MHz – 6 GHz. A preliminary working draft was prepared by 62209-2 in 2005 that included certain considerations and discussions on field probes, simulated tissue and field scanning requirements relating to measurement difficulties introduced by smaller penetration depths at 3 – 6 GHz. The Commission's Laboratory also conducted exploratory measurements using LAN devices to investigate SAR measurement requirements at 5 GHz. The experience acquired from this study and applicable proposals in the 62209-2 preliminary working draft were considered in developing the procedures in this document.

Field Probe

The tip diameters of traditional SAR probes intended for measurements below 3 GHz are about 6 – 7 mm. These larger probe tips can cause undesirable probe boundary effects error when used at closer than 3 – 4 mm from the phantom surface. Field probes with smaller probe tip diameters and sensor offsets are required at higher frequencies to correctly measure the higher SAR closet to the phantom surface. Probe tips are typically maintained at half a probe tip diameter or more from the phantom surface to minimize probe boundary effects error; otherwise, error compensation is required. Furthermore, at higher frequencies with reduced penetration depths and steeper field gradients, the typical sensor to probe tip offset distance of 2.5 – 3.0 mm in the larger probes would prevent the higher SAR closest to the phantom surface to be measured.

Sensor offsets of 1 – 1.5 mm are necessary at 6 GHz to measure the higher fields at 2 – 3 mm from the phantom surface. A probe tip diameter of 2 – 3 mm would provide the necessary distance of 1 – 1.5 mm between the probe tip and the phantom surface to minimize probe boundary effects error. It also enables the closest measurement points to capture 38 – 50% of the highest SAR at the phantom surface. Larger probe tips or sensor offsets would require the closest measurement points to be further away from the high SAR region where the lower SAR values are likely to be dominated by noise. This would reduce the reliability of the extrapolation procedures used to estimate the higher SAR values closest to the phantom surface for computing the 1-g SAR.

Probes with 2.5 mm tip diameter and 1.0 mm sensor offset are currently available. It is generally accepted that a probe tip to phantom distance less than half a probe tip diameter is necessary to minimize probe boundary effect errors. These enable measurements at closer than 2.25 mm from the phantom surface to capture 45% or more of the highest SAR closest to the phantom surface at 6 GHz. A probe tip diameter $\leq 16/f_{(GHz)}$ mm and a tip to sensor offset distance $\leq 8/f_{(GHz)}$ mm were proposed in the IEC 62209-2 working draft for SAR measurements above 2 GHz. These require a probe tip diameter ≤ 2.67 mm and sensor offset ≤ 1.35 mm for measurements at 6 GHz. In general, the smaller sensors required in smaller probe tips are expected to reduce measurement sensitivity and increase measurement uncertainty.

Transfer calibrations based on temperature measurements are not suitable for frequencies above 1 GHz. Waveguide procedures are required to calibrate probes according to theoretically calculated fields. Calibrations must be valid within ±50 MHz of each calibration point to enable coverage of most frequency bands. For coverage of wider bands, such as 5.725 – 5.85 GHz in §15.247 and 5.47 – 5.725 GHz in §15.407 (UNII), calibration points covering > ±50 MHz may be necessary. This would require the overall probe calibration uncertainty to be further controlled with respect to probe design, calibration techniques, tissue dielectric parameters and other measurement considerations, to reduce the uncertainty of both probe calibration and routine SAR measurements.

Probes are typically calibrated according to single frequency sinusoidal CW waveforms for measuring the SAR of periodic signals within a range of pulse duration and pulse repetition rate, such as GSM or TDMA. The peak to average power ratios for this type of periodic pulse trains are easily compensated by existing SAR systems. Although not related to the voltage crest factors of a signal, this type of compensation is sometimes termed "crest factor", which cannot be applied to non-periodic noise-like signals. In general, the SAR measurement error of noise-like non-periodic signals is expected to vary exponentially with power. This was examined by the IEEE SCC-34 committee during the development of Standard 1528 for a CDMA signal (IS-95). The effects of similar errors for other digital modulations have not been evaluated. Until more comprehensive investigations are available from standards organizations, the applicable SAR measurement procedures described in applicable FCC guidance documents for specific wireless technologies should be followed to address this issue.

Phantom and Tissue Dielectric Parameters

The head and flat phantoms specified in IEEE Standard 1528 and Supplement C 01-01 may be used for SAR measurements above 3 GHz. Instead of using a phantom shell dielectric constant of $\varepsilon_r \leq 5$ specified by IEEE 1528 and IEC 62209-1, IEC 62209-2 proposed using $\varepsilon_r = 4 \pm 1$.[16] Most plastics used in existing phantom shells generally have dielectric constants of 2 – 5 and such variations can introduce noticeable influences on the measured SAR above 3 GHz. Existing phantom shells with dielectric constants

[16] Latest IEC 62209-2 discussions in 2006 proposed a nominal value of $\varepsilon_r = 3.7$ with an asymmetrical tolerance to assess SAR influences due to phantom shell dielectric property variations above 3 GHz.

higher or lower than the recommended nominal target value in 62209-2 are expected to introduce over or under estimations in the measured SAR. This type of SAR error should be typically accounted for as a measurement bias according to information available from applicable investigations. The measured SAR should be adjusted by the bias and the tolerance of the bias should be included in the SAR measurement uncertainty analyses.

For device to phantom separation distances less than 5 cm, 62209-2 proposed to use a flat phantom with a minimum dimension of 240 x 160 mm and at least 20% larger than the test device. This provides a 10% perimeter surrounding the test device, which may not be sufficient for some combinations of device and phantom dimensions. For example, a device that fits the minimum phantom requirement would have a perimeter of 21.8 x 14.5 mm between the test device and phantom boundary. A separation of 14.5 mm is approximately 1 penetration depth (13.95 mm) at 3 GHz, which may not be sufficient to reduce reflections from the phantom sidewalls to a desirable level.

Smaller phantoms are generally desired for measuring the SAR of small transmitters. This is usually acceptable when test devices are appropriately coupled to the phantom with a distance of 2.5 – 3.0 penetration depths between the measurement region and phantom sidewalls. Measurement regions are typically 1 – 2 cm larger than the projected area of a transmitter. This would require 25 – 52 mm between the transmitter and the phantom sidewalls for measurements at 3 – 6 GHz. When smaller flat phantoms are used to test certain fully integrated standalone transmitters that are somewhat longer than the phantom in one dimension, separate area scans with sufficient overlaps may be used to cover the projections of the transmitter to identify all the peak SAR locations. This alternative procedure may be used when it is demonstrated that SAR distributions are not affected by the overlapping split scans. The zoom scans may need to be centered over the flat phantom to satisfy phantom margin requirements, especially when peaks are identified in the overlapped scan regions, which would require additional area scans to properly configure the required zoom scans. To further minimize the size of unnecessarily large flat phantoms for testing larger host devices such as laptop computers where the SAR is confined to the immediate location of a transmitter, it would be acceptable to extend portions of the host that do not contributions to the measured SAR beyond the required phantom boundary.

The tissue-simulating liquid should be at least 10 cm deep to ensure the SAR probe is sufficiently immersed in the liquid while scanning along the curved surfaces of the SAM phantom at various probe angles. This also ensures a sufficient distance from the top of the zoom scan volume to the liquid-air boundary above. IEC 62209-2 proposed a liquid depth that results in ≤ 1% influence to the measured SAR, which could introduce interpretations and would require additional measurement verifications.

The range of target dielectric parameters at 3 – 6 GHz generally requires a mixture of water and non-polar liquid(s), such as mineral oil, glycerol, emulsifier or other agents. The dielectric constants (ε_r) and conductivities (σ) for these tissue-equivalent media are typically within 10% and 5% respectively of the target parameters. However, it should be ensured that mixtures (suspension) containing non-polar liquids that are not fully soluble in water remain thoroughly mixed to maintain the target dielectric properties within the required temperature range during each SAR measurement. It has been confirmed that sugar-based recipes used earlier in some SAR measurements are unable to achieve the required dielectric parameters above 3 GHz; therefore, such recipes are unacceptable and must not be used. Several mineral oil based proprietary broadband recipes have also been developed and tested by a few test organizations, which may also be used at above 3 GHz.

SAR Scans

Smaller penetration depths and steeper field gradients at 3 – 6 GHz generally result in locally concentrated SAR distributions. Existing SAR and field scanning procedures intended for 0.3 – 3.0 GHz can be insufficient for measurements at higher frequencies. Smaller spatial resolutions are usually required in both area and zoom scans to ensure post-processing algorithms can correctly interpolate and extrapolate the measured fields to compute peak and 1-g averaged SAR values.

Area Scan

Area scan requirements for 0.3 – 3 GHz require the peak SAR location to be identified within half of the linear dimension of the averaging cube, 5 mm for 1-g averaging, with a spatial resolution of 20 mm of less.[17] According to the Commission's exploratory measurements at 5 GHz, an area scan resolution of 15 mm had introduced inconsistent zoom scans that were shifted in repeated measurements and sometimes with the 1-g cube too close to the scan boundary. The interpolated peak SAR location resulted from a coarse area scan resolution comparable to the zoom scan volume dimensions was insufficient for the zoom scan to precisely locate the actual peak. It would require a relatively larger zoom scan volume to compensate for the inaccuracy resulted from overly coarse area scans. The steeper field gradients and smaller SAR distribution seemed to have contributed to this. The difficulty disappeared when an area scan resolution of 10 mm was used. Although a larger zoom scan volume could be used, the increase in measurement time would be substantial.

The penetration depth of the target tissue dielectric properties at 6 GHz is about 6 mm. A small probe sensor to phantom surface distance is required to measure the higher fields closest to the phantom surface. A small probe tip diameter is also required to minimize probe boundary effects error. The post-processing algorithms used to extrapolate the highest SAR values are highly dependent on how close to the phantom surface where accurate measurements can be made by a probe. Despite an earlier suggestion of 4 ± 0.5 mm or less between the probe sensors (measurement location) and phantom surface, 8.0 ± 1.0 mm was proposed in the IEC 62209-2 working draft.[18]

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[17] This has been proposed in the IEC 62209-2 draft, possibly due to oversight.

[18] This also appears to be an oversight in the 2005 working draft because 8.0 ± 1.0 mm is the requirement for 0.3 – 3.0 GHz. Other proposals have been discussed by IEC 62209-2 in 2006.

Zoom Scan

IEC 62209-2 proposed zoom scan resolutions of ≤ 24/ $f_{(GHz)}$ mm in the lateral direction (x & y) and 12/ $f_{(GHz)}$ mm in the normal direction (depth or z).[19] A zoom scan volume at least 1.3 times the linear dimension of a 1 or 10 gram averaging cube and a minimum zoom scan volume of 30 x 30 x 30 mm^3 were also proposed.[20] These proposals require zoom scan resolutions of 4 – 5 mm in the lateral direction and 2 – 2.5 mm in the normal direction for measurements at 5 – 6 GHz. This represents a substantial increase in the number of measurement points, which could increase the typical measurement time by 2 – 3 times.[21]

There were other proposals in earlier versions of 62209-2. A phantom to closest measurement point distance ≤ 4.0 ± 0.5 mm was recommended in version 0.8. The closest two measurement points in a zoom scan should be ≤ 5 mm from the phantom surface, preferably at 2 and 4 mm, was proposed. A post-processing resolution of ≤ 2 mm to achieve reliable interpolation and extrapolation results was suggested. However, all these were not included in the 2005 preliminary working draft.

Graded grid procedures were discussed early on but not included in the 62209-2 preliminary working draft. The procedures would enable a zoom scan volume to include more measurement points in the high field regions closest to the phantom surface and proportionally reduce the measurement resolution at depth to keep the measurement time reasonable.[22]

An SAR probe with 2.5 mm tip diameter and 1.0 mm tip to sensor offset was used in the Commission's exploratory measurements. The measurements of a 5 GHz dipole in 9 scan configurations using different volume and spatial resolutions are summarized in Table 1. There are some discrepancies in the extrapolated peak SAR, which appear to be masked by the 1 and 10 gram averaging process. The reduced penetration depth at 5 – 6 GHz has resulted in more than half of the averaging volume dominated by very low SAR values. Since the contributing SAR in the 1 or 10 gram volume are mostly extrapolated based on a very limited number of measured values closest to the phantom surface, the computed 1-g or 10-g SAR values can become highly dependent on the location of such measured points and how they are used in the post-processing procedures.

Post-processing Analyses

The post-processing procedures should be verified using reference functions described in the latest matured versions of IEC 62209-2 or IEEE P1528a drafts.[23] These reference functions are used to generate simulated measurement points according to the area and

[19] Besides 12/$f_{(GHz)}$ mm proposed in the 2005 62209-2 draft, other proposals have been discussed in 2006.
[20] These requirements appear to be in conflict. It is unclear if these conditions might have been intended for different frequencies. Other proposals have been discussed by IEC 62209-2 in 2006.
[21] When compared to the typical SAR measurement time required below 3 GHz.
[22] Graded grid proposals have reappeared in IEC 62209-2 during 2006.
[23] These functions may change as IEC 62209-2 and IEEE P1528a continue to evaluate post-processing requirements.

zoom scan resolutions of a measurement. The simulated data is imported into the SAR system and post-processed by the system software. The interpolated and extrapolated data produced by the post-processing procedures are compared to those calculated at finer grid resolutions using the same reference functions. The 1-g, 10-g and peak SAR errors introduced by the interpolation and extrapolation procedures can be estimated according to these SAR distributions[24].

The dipole measurements in Table 1 have revealed several obvious extrapolation errors. The extrapolated peak SAR for the 9 x 9 x 5 scan at 2.0 mm resolution is about 100% higher than those at 1.5 and 3.0 mm resolutions. The extrapolated peak SAR for the 5 x 5 x 7 scan at 3.0 mm resolution is about 30 % higher than those at 1.5 and 2.0 mm resolutions. Examples of correct, acceptable and incorrect extrapolations in post-processing are shown in the 2-D profile plots in Figure 1. The incorrect extrapolation has overestimated the extrapolated peak SAR by a factor of 2.[25] An odd or even number of measurement points in the lateral direction (x or y) may affect the interpolated and extrapolated SAR values near the center of the zoom scan volume. The extrapolation seems to provide better-fitted curves when the measurement points are aligned at or near the center of the zoom scan volume and coincided with the peak SAR location. These conditions are usually dependent on the precision of peak SAR locations identified according to the measurement resolution and extrapolation procedures used in the area scan.

Measurement Uncertainty

The SAR measurement uncertainty analyses described in Supplement C 01-01 and IEEE Standard 1528 for handsets at 0.3 – 3.0 GHz require some adaptation for use above 3 GHz. Uncertainty components that are distance related should be estimated according to the penetration depth at 6 GHz for head or body tissues. The probe calibration uncertainty and measurement requirements should be applied according to 3 – 6 GHz requirements. The target tissue dielectric parameters for both probe calibration and routine measurements should be within 10% for ε_r and 5% for σ.[26] Issues on measurement discrepancies introduced by phantom shell dielectric property differences should be addressed according to the latest information available from IEC 62209-2. The spreadsheet below is an example template for calculating the SAR measurement uncertainty of handsets at 0.3 – 3 GHz. It may be adapted for 3 – 6 GHz according to the measurement uncertainty procedures being developed by 62209-2 and IEEE P1528a.

Figure 1 SAR-Uc.xls

[24] These reference functions are intended to represent a range of typical SAR distributions.

[25] As discussions continue in IEC 62209-2 and IEEE P1528a, SAR measurement systems are expected to incorporate improved measurement and extrapolation procedures through software updates.

[26] Tissue dielectric properties target value uncertainty are different than tissue dielectric property measurement uncertainty, which is 5% for both ε_r and σ.

Table 1 - Zoom Scan Measurement Configurations of 5 GHz Dipole with 2.5 mm probe[27]

Volume (mm^3)	Measured Points	X, Y Resolution (mm)	Z Resolution (mm)	Minimum Phantom to Sensor Distance (mm)	Graded Grids Ratio	Measured Peak SAR (W/kg)	Extrapolated Peak SAR (W/kg)	1-g SAR (W/kg)	10-g SAR (W/kg)
21 x 21 x 24	9 x 9 x 5 (405)	3.0	1.5	1.5	1.8	38.5	63.5	15.8	4.4
			2.0	2.0		33.4	119.9	16.1	4.5
			3.0	3.0		24.5	58.9	15.8	4.5
30.1 x 30.1 x 21	8 x 8 x 8 (512)	4.3	1.5	3.0	1.0 (none)	34.9	58.7	15.4	4.4
			2.0			29.5	59.3	15.6	4.5
			3.0			22.5	55.3	15.5	4.4
32 x 32 x 30	5 x 5 x 7 (175)	8.0	1.5	5.0		39.1	65.1	15.3	4.3
			2.0			33.6	68.9	15.6	4.4
			3.0			25.4	87.2	16.0	4.6

[27] Highlights: yellow – configurations expected to produce identical results, green – large extrapolation error detected