bands in §15.247 and §15.407 (UNII), the calibration points should be valid for the entire transmission band that requires measurement. If a probe calibration point cannot cover the entire transmission band, multiple probe calibration points are required for measurements in the band. For wireless technologies that operate with substantially wide channel bandwidths, separate probe calibration points centered within the channels may be required. When a single calibration point is used to cover a frequency range larger than ±100 MHz for routine measurements, the test lab must verify the valid range of measurement frequencies supported by the probe calibration point, according to the tissue dielectric parameter requirements and signal modulation characteristics. This is normally performed during SAR system validation. These results must be included in a KDB inquiry to confirm that the frequency range for the probe calibration is acceptable before measurements are performed.

In routine SAR measurements, SAR error compensation algorithms may be applied to the measured tissue dielectric parameters, to enable the measured dielectric parameters to have a larger tolerance from the normally required target dielectric parameters. This type of SAR compensation may be applied for routine measurements only; it does not apply to probe calibrations. The measured ε_r and σ of the tissue-equivalent medium used during probe calibration must be within 5% of the target parameters specified in Supplement C 01-01. The expanded uncertainty for all probe calibrations must be ≤ 15%, for a confidence interval of k = 2. The applicable probe calibration data and calibration uncertainty must be included in the SAR documentation to support the test results.

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Probes are normally calibrated with sinusoidal CW signals for measuring the SAR of continuous or periodic pulse-modulated CW equivalent signals. The duty factor of periodic pulse-modulated CW equivalent signals can be easily compensated by existing SAR measurement systems when the amplitude variations within the pulses are insignificant; for example, the constant amplitude modulation used in GMSK for GSM. Although the duty factor is not directly related to the voltage crest factor of a signal, this type of compensation is often called "crest factor" by SAR system manufacturers. The duty factor compensation applied in SAR measurements to periodic signals is not applicable to non-periodic or high peak to average power ratio noise-like signals. The SAR measurement errors for noise-like non-periodic signals are generally expected to vary exponentially with increasing SAR levels. This issue was examined by the IEEE SCC-34 committee during the development of IEEE Std 1528-2003 for a CDMA signal (IS-95). These effects remain to be investigated for other digital modulations with different signal characteristics and different peak to average power ratios. Until more comprehensive results are available from standards organizations, the applicable SAR measurement procedures described in this document must be applied, in conjunction with the *published KDB procedures*, for specific wireless technologies to minimize measurement concerns.[1]

Tissue dielectric parameter requirements

The head and body tissue dielectric parameter targets specified in Supplement C 01-01 to OET Bulletin 65 must be linearly interpolated or extrapolated to the measurement channel frequencies, to determine the tissue- equivalent dielectric parameter targets valid for tissue-equivalent liquids SAR testing at specific device transmission frequencies. The dielectric constant (ε_r) and conductivity (σ) of typical tissue-equivalent media recipes are expected to be within 5% of the required target values for a range of approximately 50 MHz at frequencies below 300 MHz. At above 3 GHz, 5% tolerance can usually be maintained for ±100 MHz or more. For signals with a substantially wide channel bandwidth, the tissue-equivalent dielectric parameters must be within tolerance for the entire channel bandwidth frequency range. For SAR measurement systems that have implemented the SAR error compensation algorithms documented in draft standard IEEE P1528-2011, to automatically compensate the measured SAR results for deviations between the measured and required tissue dielectric parameters, the tolerance for ε_r and σ may be relaxed to ± 10%. Unless it is documented in the SAR report that the tissue dielectric parameters used for the measurements are within ± 10% of the required target values for the entire

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[1] See KDB 447498 for *published KDB procedures*.

transmission band, and the required SAR error compensation algorithm has been correctly applied; ±5% tolerances are required for ε_r and σ. Regardless of the frequency range and tissue dielectric tolerances supported by a tissue medium recipe, all measurements must be within the constraints of a probe calibration point. Information on temperature sensitivity and short term stability of the tissue media must also be reported to ensure the tissue dielectric parameters are within tolerance for all measurements.

It must be ensured that tissue-equivalent liquid mixtures (suspensions) containing non-polar liquids, such as mineral oil, glycerol, emulsifier or other agents, that are not fully soluble in water remain thoroughly mixed to maintain the required dielectric properties and within the required temperature range during each SAR measurement. It has been confirmed that sugar-based recipes are typically unable to achieve the required dielectric parameters above 1 – 2 GHz; therefore, such recipes must be limited to measurements below 1 GHz. Several mineral oil based proprietary broadband recipes have been available commercially, which typically require thorough mixing before use. It must be ensured that there are no air bubbles in the mixture before each measurement. Furthermore, some recipes may have a narrow temperature range for the dielectric parameters to be within tolerance; therefore, further documentation is required to use this type of tissue media.

The tissue dielectric parameters of tissue-equivalent media used for SAR measurements must be measured within a temperature range of 18°C – 25°C, using calibrated instruments and apparatuses. The temperature of the tissue-equivalent medium used during SAR measurement, must be within ± 2°C of the temperature when the tissue parameters are characterized. The dielectric parameters must be measured before a series of SAR measurements are performed using that tissue-equivalent medium. The parameters should be re-measured after each 3 – 4 days of use, or earlier if the dielectric parameters can become out of tolerance; for example, when the parameters are marginal at the beginning of the measurement series.

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Phantom requirements

The SAM phantom specified in IEEE Std 1528-2003 is required for SAR measurements next to the ear. When a flat phantom is required, it must be sufficiently large for the antennas and radiating structures of the transmitters and host device to couple correctly in the intended RF exposure conditions, for both standalone and simultaneous transmission SAR measurements. This generally requires the measurement region, corresponding to the antenna and radiating structures of the device, to be at least 3 – 5 cm from the flat phantom boundaries (side walls). When no unusual reflections from the phantom sidewalls are observed in the measured SAR distribution, a margin of at least 3 cm at 6 GHz and 5 cm at 100 MHz is typically acceptable; otherwise, a wider separation margin is required to minimize the reflection effects. When a test device is larger than the flat phantom, area scan measurements of multiple smaller regions that overlap with adjacent regions by at least 2 cm may be used to determine zoom scan requirements, provided that the same identical SAR distribution is measured in the overlapping regions and fully documented in the SAR report.

The test laboratory must confirm that the following phantom shell dielectric property and thickness tolerance requirements are satisfied.

- $2 \leq \varepsilon_r \leq 5$ at ≤ 3 GHz
- $3 \leq \varepsilon_r \leq 4$ at > 3 GHz
- loss tangent ≤ 0.05
- phantom shell thickness is 2.0 ± 0.2 mm in the measurement regions
- shell thickness at the ear reference point (ERP) location of the SAM phantom is 6.0 ± 0.2 mm
- The ear spacer shape and thickness for the SAM phantom are in accordance with specifications in the IEEE Std 1528-2003 CAD files

The depth of tissue-equivalent liquid in a phantom must be ≥ 15.0 ± 0.5 cm for SAR measurements ≤ 3 GHz and ≥ 10.0 ± 0.5 cm for measurements > 3 GHz. These depths should ensure the SAR probe is sufficiently immersed in the tissue medium while scanning along the curved surfaces of the SAM phantom at various probe angles, with an acceptable separation between the top of the zoom scan volume and the liquid-air boundary above. The required liquid depth must be determined at the ERP location of the SAM phantom and at the center of the measurement region for a flat phantom.

SAR measurement requirements

To minimize SAR measurement discrepancies due to probe calibration and tissue dielectric parameter concerns, measurements below 300 MHz must be within ±50 MHz of the probe calibration point frequency. At 300 MHz – 6 GHz, measurements must be within ±100 MHz of the probe calibration frequency point or the valid frequency range supported by the calibration, whichever is less. When the measured SAR is within 10% of the SAR limit, the following additional steps are required for measurements exceeding 50% of these intervals, i.e., ±25 MHz at < 300 MHz and ±50 MHz or ½ the frequency range supported by the probe calibration point at ≥ 300 MHz, to qualify for approval.

1) When the exact tissue dielectric parameters used in the probe calibration are recorded in the calibration data, the measured ε_r and σ of the liquid used in routine measurements must be
   a) within 5% of those recorded in the probe calibration data and also within 5% of the required target dielectric parameters, or
   b) within 10% of those recorded in the probe calibration data and also within 10% of the required target dielectric parameters, when the measured SAR is compensated for tissue dielectric deviations
2) When nominal tissue dielectric parameters are recorded in the probe calibration data; for example, reporting the target values and required tolerance, the tissue dielectric parameters of the liquid used in routine measurements must be:
   a) less than the target ε_r and higher than the target σ values and also within 5% of the required target dielectric parameters, or
   b) within +5% and -10% of the target ε_r and within -5% and +10% of the target σ values, when SAR compensation for dielectric deviation is applied
3) The applicable conditions must be clearly identified in the SAR report.

SAR scan procedures

The area and zoom scan resolutions specified in the table below must be applied to the SAR measurements and fully documented in SAR reports to qualify for TCB approval. Probe boundary effect error compensation is required for measurements with the probe tip closer than half a probe tip diameter to the phantom surface. Both the probe tip diameter and sensor offset distance must satisfy the measurement protocols, to ensure probe boundary effect errors are minimized and the higher fields closest to the phantom surface can be correctly measured and extrapolated to the phantom surface to compute the 1-g SAR. The tolerances of post-processing algorithms must be verified by the test laboratory for the scan resolutions used in the SAR measurements, according to the reference distribution functions specified in IEEE Std 1528-2003. The results should be documented as part of the system validation records and may be requested to support test results using marginal or unacceptable measurement resolutions.

	≤ 3 GHz	> 3 GHz
Maximum distance from closest measurement	5 ± 1 mm	½·δ·ln(2) ± 0.5 mm

point (geometric center of probe sensors) to phantom surface				
Maximum probe angle from probe axis to phantom surface normal at the measurement location			30° ± 1°	20° ± 1°
Maximum area scan spatial resolution: Δx_{Area}, Δy_{Area}			≤ 2 GHz: ≤ 15 mm 2 – 3 GHz: ≤ 12 mm	3 – 4 GHz: ≤ 12 mm 4 – 6 GHz: ≤ 10 mm
			When either the x or y dimension of the test device in the measurement plane is smaller than the above, the measurement resolution must be ≤ the corresponding x and y dimensions of the test device with at least one measurement point on the test device.	
Maximum zoom scan spatial resolution: Δx_{Zoom}, Δy_{Zoom}			≤ 2 GHz: ≤ 8 mm 2 – 3 GHz: ≤ 5 mm	3 – 4 GHz: ≤ 5 mm 4 – 6 GHz: ≤ 4 mm
Maximum zoom scan spatial resolution, normal to phantom surface	uniform grid: $\Delta z_{Zoom}(n)$		≤ 5 mm	3 – 4 GHz: ≤ 4 mm 4 – 5 GHz: ≤ 3 mm 5 – 6 GHz: ≤ 2 mm
	graded grid	$\Delta z_{Zoom}(1)$: between 1st two points closest to phantom surface	≤ 4 mm	3 – 4 GHz: ≤ 3 mm 4 – 5 GHz: ≤ 2.5 mm 5 – 6 GHz: ≤ 2 mm
		$\Delta z_{Zoom}(n>1)$: between subsequent points	≤ 1.5·$\Delta z_{Zoom}(n-1)$	
Minimum zoom scan volume	x, y, z		≥ 30 mm	3 – 4 GHz: ≥ 28 mm 4 – 5 GHz: ≥ 25 mm 5 – 6 GHz: ≥ 22 mm
Note: δ is the penetration depth of a plane-wave at normal incidence to the tissue medium.				

Stephen Liu
Comment [1]: Are there similar requirements for zoom scan resolution when testing a device with a small form factor?

Area scan

The projected areas of a transmitter are measured in an area scan, with the required spatial resolution to ensure the 1-g SAR can be reliably and consistently measured at the peak SAR location(s) in the zoom scan measurements. Area scans are made at a constant distance from the phantom surface, according to requirements at the measurement frequency. When a measured peak is closer than ½ of the zoom scan volume dimension (x, y) from the edge of the area scan region, the measurement must be repeated by shifting and expanding the area scan region, to ensure all peaks are away from the area scan boundary.

When the test device orientation has a small projected area on the phantom; for example, the side edges of a handset or USB dongles, the area scan measurement resolutions must be less than or equal to the corresponding dimensions of the device surface being measured. At least one measurement point must be on the device.

Zoom scan

A zoom scan measurement is required to determine the 1-g SAR at the highest peak SAR location determined in the area scan. When the 1-g SAR for the highest peak is within 2 dB of the SAR limit, additional zoom scans are also required for the other peaks within 2 dB of the highest peak that have not been already included in any zoom scan, to ensure there is no increase in 1-g SAR. The required minimum zoom scan volume must be applied. There must be at least two measurement points within the first 5 mm from the phantom surface, and three measurement points are recommended above 5 GHz.[2] When graded grids are used, which only applies in the phantom surface normal direction, the initial grid separation closest to the phantom surface and subsequent graded grid increment ratios must satisfy the required protocols in this document. The 1-g SAR averaging volume must be fully contained within the zoom scan measurement volume boundaries; otherwise, the scan must be repeated by shifting or expanding the zoom scan volume.

Post-processing

The interpolation and extrapolation procedures used by the SAR measurement system must be verified against the reference SAR distribution functions described in IEEE Std 1528-2003 to ensure the measurement resolutions used in area and zoom scans are acceptable. SAR values are generated by these functions for the required measurement resolutions, and processed by the interpolation and extrapolation procedures in the SAR system using different grid offsets. The results from the SAR system are compared to values calculated using the reference functions, to determine whether the measurement, interpolation and extrapolation resolutions used by the SAR system for routine measurement setups are acceptable. Most SAR systems have built-in provisions to perform these procedures. The test laboratory is required to perform these verifications using the area and zoom scan measurement resolutions required in routine measurements, and the interpolation and extrapolation resolutions used in the post-processing procedures, as a part of the SAR measurement system validation. Validations are required after hardware upgrades and after software updates have been applied to SAR systems, and/or when new measurement resolutions are used in routine measurements. The results should be kept by the test lab as part of the system validation record.

Simultaneous transmission SAR measurement

When simultaneous transmission SAR measurement is required, the following procedures must be considered for test results to qualify for TCB approval. The normal area and zoom scan procedures are required to measure the SAR of any multiple transmitters transmitting simultaneously at the same frequency using the same or different antennas, within the same frequency range of a SAR probe calibration point and tissue- equivalent medium. When transmitters and antennas operate in multiple frequency bands are transmitting simultaneously, and multiple SAR probe calibration points and separate tissue-equivalent media are required for SAR measurements, the transmitters and antennas must be tested separately, according to the different SAR probe calibration points and tissue-equivalent media requirements.

1) For transmissions in the same frequency band covered by a single probe calibration point:

a) The area scan must cover the entire projection of the test device and all antennas.

b) When the simultaneously transmitted signals are coherent, a KDB inquiry must be submitted to determine SAR measurement requirements, with respect to the transmission configurations and

Stephen Liu
Comment [2]: It is only possible to calculate this if the transmitters are operating at the exact same frequency, not just within the same frequency band due to system constraints. If multiple frequencies within the same band are meant to be tested, how should the test lab determine which frequency to have the system evaluate the SAR at?

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[2] A measurement point is determined by the geometric center of the probe sensors, which is identified by the probe sensor offset and probe tip to phantom surface distances.

SAR system capabilities.[3]

2) Transmissions in different frequency bands covered by multiple probe calibration points:

a) When some of the transmitters and antennas in a device are operating in the same frequency and covered by the same probe calibration point and tissue-equivalent medium, these must be tested together in an enlarged zoom scan measurement. All other transmitters and antennas in the device that operate at different frequencies, requiring different probe calibration points and tissue-equivalent media, must be tested in separate enlarged zoom scans. All these enlarged zoom scans are superimposed together using the volume scan post-processing procedures, to determine the highest 1-g SAR for the aggregate SAR distribution.

i) Other than a larger measurement volume to enclosed all the antennas and radiating structures of the test device, the measurement requirements of an enlarged zoom should be the same as those required for normal zoom scan; for example, the measurement resolution. An area scan is not required to identify the peak SAR locations; however, if it is necessary or useful, area scans at the different test frequencies may be used to determine the extent of SAR distributions for the different transmitters and antennas. The information can be analyzed to determine the minimum extend of enlarged zoom scans required to ensure all peak SAR locations are included in the enlarged zoom scan measurements and volume scan post-processing procedures.

ii) The volume scan post-processing procedures implemented in different SAR systems or particular versions of a system may vary, which may impose different measurement requirements or restrictions for the enlarged zoom scans; for example, measurement and post-processing spatial resolutions, requirements of identical or overlapping measurement regions etc.

(1) When identical enlarged zoom scan measurement regions are required, the measurement region must include the entire projection of the test device or a justified enlarged zoom scan region that covers all the simultaneous transmitting antennas and radiating structures.

(2) When the volume scan post-processing procedures require the same spatial resolution to be used in the enlarged zoom scan measurements, the most stringent and conservative spatial resolution required for measurement, interpolation and extrapolation, must be applied to all the enlarged zoom scans. This generally requires the parameters for the highest frequency measurements to be applied to all enlarged zoom scans.

(3) When overlapping enlarged zoom scan regions, and different measurement, interpolation and extrapolation spatial resolutions are supported by the volume scan post-processing procedures of the SAR system, all conditions and restrictions required by the measurement system must be applied and fully explained in the SAR report, to support the test setup and results.

b) SAR contour plots for each enlarged zoom scan, and the aggregate distribution determined by the volume scan post-processing procedures must be included in the SAR report. All plots should be shown using the interpolated results corresponding to the measured points closest to the phantom surface, before extrapolation. The distance between the measured points and the phantom surface must satisfy the general SAR measurement requirements. The measurement setup parameters should be clearly identified in both the reported results and SAR plots.

[3] IEC Technical Report 62630 may be considered when the required SAR measurement and post-processing results are accessible to the end user to perform the required additional analysis.

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c) Volume scan post-processing procedures generally assume the RF performance and SAR characteristics of transmitters and antennas remain unchanged for standalone and simultaneously transmitting operations; therefore, it enables the SAR to be tested separately with enlarged zoom scans and analyzed through post-processing procedures, by superposition, to determine the aggregate SAR distribution and 1-g SAR. However, this assumption may not always be true for all transmitters due to various device design requirements. When it is unclear if the volume scan post-processing procedures may be applied, the transmitter manufacturer must be consulted and a KDB inquiry is required to determine applicable test alternatives.

3) When the measured SAR of a simultaneously transmitting transmitter/antenna in the enlarged zoom scan must be scaled, specific implementations and other considerations are required for volume scan post-processing. The entire SAR distribution in the enlarged zoom scan must be scaled before applying the volume scan post-processing procedures to determine the aggregate SAR distribution and 1-g SAR. The scaling must be applied to the measured points in the enlarged zoom scan before interpolation and extrapolation. The details of the implementation and procedures applied must be clearly described in the SAR report to support the test setup and results.

a) This type of implementation may not be available in all SAR systems.

b) This also applies to simultaneous transmissions in the same frequency band when the SAR of at least one of the transmitters/antennas needs scaling.

c) A KDB inquiry is required to confirm the measurement and scaling procedures are acceptable if scaling methods not described in published KDB procedures are used.

SAR measurement repeatability and uncertainty

SAR measurement repeatibility

When the highest scaled 1-g SAR within a frequency band is < 1.5 W/kg, the extensive SAR measurement uncertainty analysis described in IEEE Std 1528-2003 is not required in SAR reports submitted for equipment approval. To qualify for TCB approval, results from the following procedures are required for each device to verify SAR measurement repeatability.

1) SAR measurement repeatability must be assessed for each frequency band, which is determined by the SAR probe calibration point and tissue-equivalent medium used for the device measurements.

a) When both head and body tissue-equivalent media are required for measurements in a frequency band, the procedures should be applied to the tissue medium with the highest measured SAR.

2) SAR measurement repeatability is evaluated for the highest scaled SAR among all configurations tested in a frequency band according to the following:

a) < 0.4 W/kg, additional measurement is not required.

b) ≥ 0.4 W/kg and < 1.2 W/kg, repeat once.

c) ≥ 1.2 W/kg and < 1.5 W/kg, repeat twice.

d) ≥ 1.5 W/kg; repeat at least three times.

3) These additional measurements must be repeated after the completion of all other device measurements in a frequency band. The test device should be returned to ambient conditions (normal room temperature) with the battery fully charged before it is re-mounted on the device holder for each measurement. The measurements should be within the standard uncertainty (k=1) indicated in the SAR test report.

4) The results must be clearly identified and included in the SAR report.

Comment [3]: To harmonize with scaling requirements for standalone transmitters per KDB 447498, all volume scan measurements should be scaled to the upper range of the tune-up to ensure compliance.

Comment [4]: We believe test reduction and exclusions should be consistently based on measured or scaled results. See KDB 447498 comments

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Comment [5]: Could a metric be provided for test labs and TCBs to determine if the results are considered sufficiently repeatable?

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Comment [6]: See previous comment about measured/scaled SAR consistency

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Comment [7]: This is a suggested criteria only….. but it seems like the intent of this section is to assess device + system + operator + environmental uncertainty.

5) The same procedures should be adapted for measurements according to extremity and occupational exposure limits by applying a factor of 2.5 for extremity exposure and a factor of 5 for occupational exposure.

SAR measurement uncertainty

SAR measurement uncertainty analysis is required in SAR reports only when the highest scaled SAR in a frequency band is ≥ 1.5 W/kg. The procedures described in IEEE Std 1528-2003 should be applied. The uncertainty analysis must be consistent with the measurement parameters used for the frequency band, including penetration depth, tissue-equivalent medium, probe calibration uncertainty etc. The expanded SAR measurement uncertainty must be ≤ 30%, for a confidence interval of k = 2.

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Comment [8]: See previous comments about measured/scaled consistency
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SAR System Validation and Verification

Before a system is deployed and whenever hardware or software changes are made; for example, through system upgrade, software update or when probes and components are recalibrated, all performance specifications of the SAR system must be validated with respect to the probes and components used by the system. After a system is validated, routine verification of system measurement accuracy within the measurement frequency range of each probe calibration point is required before testing each individual device.

Reference dipoles

Reference dipoles are used for SAR system validation and verification. These are available from SAR system manufacturers for users to confirm measurement accuracy. The dipoles are normally tuned to the frequency and tissue-equivalent media required for transmitter testing; therefore, different dipoles are required for different SAR probe calibration point frequencies. A dipole is normally tuned to and calibrated at the same frequency as the probe calibration frequency. The calibrated SAR target of a dipole is dependent on the measurement setup; for example, dipole to phantom distance and phantom shell dielectric properties and thickness; therefore, the same test setup used to calibrate the dipole must also be used for SAR system validation and verification.

Dipoles are only defined for selected discrete frequencies in IEEE Std 1528-2003. As additional spectrums are introduced these existing dipoles have become insufficient for covering new frequencies. In some cases, it may be possible for a dipole to cover an adjacent frequency band without substantial deviation from its tuned performance due to differences in frequency and tissue dielectric parameter requirements; therefore, re-evaluation of the SAR target at the new offset frequency may be acceptable. However, when this is not feasible and dipoles are unavailable, there could be difficulties to verify SAR measurement accuracy.

When dipoles or other equivalent RF sources are developed by SAR equipment manufacturers for new frequencies, the SAR targets must be validated according to the same vigorous numerical simulation and experimental validation protocols used in developing the target values published in IEEE Std 1528-2003. Detailed documentation, similar to those described in IEEE Std 1528-2003, should be available for each dipole. If unclear, test laboratories using newly developed dipoles or other equivalent sources should submit a KDB inquiry to confirm the validity and acceptance of such reference sources before initial use, and especially before testing devices.

Dipole calibration

It is necessary to re-calibrate reference dipoles at regular intervals to confirm the electrical specifications and SAR targets. A dipole must be calibrated using a fully validated SAR system according to the tissue dielectric parameters and SAR probe calibration frequency required for device testing. It is generally unacceptable to calibrate a dipole using the SAR system that has been validated by the same dipole;

therefore, dipoles should be returned to the SAR system manufacturer or its designated calibration facilities for re-calibration. However, instead of the typical annual calibration recommended by measurement standards, longer calibration intervals of up to 3 years may be considered when it is demonstrated that the SAR target, impedance and return loss of a dipole have remain stable according to the following requirements.

1) The test laboratory must ensure that the required supporting information and documentation are included in the SAR report to qualify for the 3-year extended calibration interval; otherwise, the IEEE Std 1528-2003 recommended annual calibration applies.

2) Immediate re-calibration is required for the following conditions.

   a) After a dipole is damaged and properly repaired to meet required specifications.

   b) When the measured SAR deviates from the calibrated SAR value by more than 10% due to changes in physical, mechanical, electrical or other relevant dipole conditions; i.e., the error is not introduced by incorrect measurement procedures or other issues relating to the SAR measurement system.

   c) When the most recent return-loss results, measured at least annually, deviates by more than 20% from the previous measurement (i.e. value in dB x 0.2) or not meeting the required -20 dB return-loss specification.

   d) When the most recent measurement of the real or imaginary parts of the impedance, measured at least annually, deviates by more than 5 Ω from the previous measurement.

Dipoles are often optimized individually by manufacturers to provide the best impedance match (50Ω) and return loss (≤ -20 dB), according to the tissue and phantom shell dielectric property requirements. This may introduce some small variations between the SAR targets specified in IEEE Std 1528-2003 and the dipole calibration results. Therefore, SAR system validation and verification results must be compared to the SAR calibrated for the individual dipole. The 1-g and 10-g SAR measured with a reference dipole, using the required tissue-equivalent medium at the test frequency, must be within 10% of the manufacturer calibrated dipole SAR target. The extrapolated peak SAR at the phantom surface above the dipole feed-point should be within 15% of that reported in the calibration data or specified in IEEE Std 1528-2003. It must also be ensured that the measured SAR distribution is identical to that in the dipole calibration record for the results to be valid.

SAR system validation

The SAR system must be validated against its performance specifications before it is deployed. When SAR probes, system components or software are changed, upgraded or recalibrated, these must be validated with the SAR system(s) that operates with such components. Reference dipoles are used with the required tissue-equivalent media for system validation according to the following.

Stephen Liu
Comment [9]: Are these procedures to be performed for every frequency band tested? For every type of tissue equivalent liquid? Probe calibration point?

1) SAR is measured within the sensitivity range of the SAR probe and measurement system, with a CW signal fed to a reference dipole at different power levels, for each probe calibration point. The measured 1-g and 10-g SAR levels should correspond to approximately 0.1, 0.8, 1.6 and 2.0 W/kg. The measured SAR when normalized to 1.0 W net power must be within 10% of the calibrated dipole SAR targets. When extremity SAR applies, 10-g SAR at 4.0 W/kg is required. When occupational exposure limits apply, measurements with input power settings to achieve 1-g SAR at 4.0 and 8.0 W/kg, and 10-g SAR at 4.0, 8.0, 16.0 and 20.0 W/kg are also required.

2) SAR probe linearity is verified by applying the results measured in 1), for each probe, to determine the maximum deviation in 1-g and 10-g SAR from a linear straight line, drawn through the calibrated SAR target of the dipole and the origin (0), with respect to net power applied to the dipole. The

maximum deviation should satisfy the SAR probe and system specifications, and must be within 10% of the linear straight line.

3) Probe isotropy is verified by positioning the geometric center of the probe sensors at the peak SAR location of the reference dipole, with the probe tip located at ½ the tip diameter from the phantom surface. The probe is rotated along its axis, at the measurement point, and SAR is measured at 15° intervals, at a SAR level of approximately 1.6 W/kg. When extremity and occupational exposure limits apply, measurements at approximately 4.0, 8.0 and 20.0 W/kg are required. The maximum deviation from the average of all measured values at each SAR level is determined and compared to isotropy specifications of the probe.

Stephen Liu
Comment [10]: When the probe is calibrated, probe isotropy is determined by using a waveguide and not using a reference dipole. Per the manufacturer, this leads to a more accurate overall assessment, but makes it difficult for a test lab to match those same levels using a reference dipole set up. Could a fixed value be provided?

When the SAR system and associated probes are used to measure modulated signals, such as those used by recent generation wireless transmitters, additional system validation with respect to the operating characteristics of the test signals is necessary.

1) For signals with a periodic duty factor and constant pulse amplitude, such as GMSK in GSM, SAR should be measured for the range of duty factors required for routine device testing. The dipole should be fed with a pulse modulated CW signal at a power level to achieve approximately 1.6 W/kg for 1-g SAR, and 4.0 W/kg for 10-g SAR, if extremity limit applies. When occupational exposure limits apply, measurements with power levels to achieve approximately 8.0 and 20.0 W/kg for 1-g and 10-g SAR are required. The measured SAR should be duty factor compensated and normalized to 1.0 W net power and must be within 10% of the calibrated dipole SAR target.

2) For signals with high peak to average power ratios (> 5 dB),[4] such as those used in OFDM or similar systems, system validation compares the measured 1-g SAR of the modulated signal to a CW signal with equivalent average power. The dipole must be fed with a signal having the equivalent modulation characteristics as those required for routine device testing. The procedures in 1) and 2) should be adapted to include more SAR levels to generate a smooth curve sufficient to quantify the probe conversion linearity.

   a) The resulted required by 2) should be presented in a plot to identify the linearity error as a function of the CW-equivalent power fed to the dipole.

   b) At higher SAR (and power) levels, the SAR error can become quite large and unacceptable; therefore, test devices must be measured at a reduced power and results should be scaled to the corresponding higher power levels to minimize linearity error. This system validation establishes the acceptable error threshold for using the probe with the specific signal modulation type nd characteristics.

      i) It must be ensured that the SAR error introduced by probe conversion linearity does not underestimate SAR, which could lead to compliance concerns.

      ii) When the probe conversion linearity error is > 10%, SAR should be tested at a reduced power level for the probe conversion linearity error to be less than 10%.

         (1) Substantial reduction in output power is not recommended because such conditions may not be representative of the normal operating characteristics of a device near maximum output conditions.

         (2) A reduced power level with probe conversion linearity error at 5 – 10 % should be considered.

[4] For SAR measurement purposes, when unclear, CCDF measurements should be used to determine the peak to average power ratio, with less than 1% of the highest peaks in the waveform unaccounted for.

c) When signal specific probe calibrations are considered, the same validation procedures should be applied to determine probe conversion linearity. The maximum deviation should satisfy the SAR probe and system specifications and must be within 10% of the linear straight line.

d) A copy of the relevant system validation results for the SAR probe and signal modulation used in the system validation must be included in the SAR report to demonstrate probe conversion linearity for high peak to average power ratio or signal specific probe calibration.

3) When both periodic duty factor and high peak to average power ratio are applicable to a signal, the procedures for modulated signals in 1) and 2) must be assessed during system validation for the probes used with the SAR system.

4) For signals with non-periodic duty factors, such as in TDD systems, SAR must be measured using the highest periodic duty factor representative of conservative normal use conditions; therefore, the procedures for modulated signals in 1) and 2) must be applied during system validation for the probes used with the SAR system.

5) For signals with very wide channel bandwidths or devices requiring very wide transmission bands, the validity of a probe calibration point must be confirmed through system validation. However, the measurement procedures required by these types of new technologies have not been established and must be determined as products become available. A KDB inquiry is required to determine the applicable SAR measurement procedures for such devices.

System validation results must be maintained by each test laboratory, which are normally not required to be included with SAR reports for equipment approval. However, when questions arise or details are required due to probe conversion linearity concerns, relevant parts of the system validation results should be included in SAR reports to support the measurement results for equipment approval.

SAR system verification

The purpose of SAR system verification is to confirm measurement accuracy according to the tissue dielectric media, probe calibration points and other system operating parameters used to measure the SAR of a test device. SAR system verification must be performed at a frequency within the valid range of a probe calibration point required for device testing. The same SAR probe and tissue-equivalent medium as used with the specific SAR system for system verification must also be used for device testing. When multiple probe calibration points are required to cover the transmission band of a test device, independent system verifications are required.

System verification options

When products are introduced in new frequency bands, reference dipoles may not be available within the probe calibration or test device frequency range. Sometimes the reference dipole, test device and probe calibration frequencies could be substantially misaligned, hence, measurement accuracy may not be easily confirmed.

At above 1.5 – 2 GHz, the reference dipoles can normally maintain return losses of -15 dB or better for approximately 150 – 200 MHz; therefore, additional calibrations at offset frequencies may provide the necessary SAR target values for system verification at nearby frequencies using an existing dipole.

At lower frequencies, depending on the frequency range, return losses of -15 dB or better are typically limited to 15 – 100 MHz for a reference dipole; therefore, it may not be feasible or practical to use the dipole outside its resonance frequency range. However, the impact can be much less if the dipole is used at its resonance frequency with the tissue media intended for the nearby offset frequencies. The changes in tissue dielectric parameters within a frequency range of ±100 – 250 MHz are usually within ±10%. Therefore, it would be more practical to establish a new SAR target by operating the dipole at its tuned

3) All results and analyses must be included in the test report to justify the use of these system verification alternatives, including dipole return loss plots, probe conversion factors, tissue dielectric parameter measurements, coefficient of variation calculations etc. The same SAR probe and tissue dielectric media used with the dipole for system verification must be used for device testing.

SAR system validation and verification below 300 MHz

When technical requirements are not established, such as applicable limits and evaluation requirements, the provisions of §1.1307(c) and (d) are considered. Both tissue-equivalent dielectric parameters and SAR measurement requirements are unavailable below 100 MHz; therefore, special considerations are required. When SAR evaluation is required to show compliance below 100 MHz, a KDB inquiry must be submitted to determine the acceptable test procedures. When appropriate, SAR simulations may be applied to demonstrate compliance due to SAR measurement difficulties. A combination of numerical simulation, analytical or measured field strength results may also be considered, as determined through KDB inquiries.

When SAR measurements are required in the 100 – 300 MHz range, the following must be considered.

1) The tissue dielectric parameters in Supplement C 01-01 must be interpolated and/or extrapolated to prepare tissue-equivalent media for measurements.

2) This frequency range must be supported by the SAR measurement system. The SAR probe must be calibrated for the device test frequency range and also at 300 MHz.

3) When dipoles or equivalent RF sources are available from SAR system manufacturers for system validation and verification, the applicable sources must be used.[5] When unavailable, the 300 MHz dipole defined in IEEE Std 1528-2003 must be used in conjunction with these procedures to perform SAR system validation and verification.

   a) The SAR probe must be calibrated at both 300 MHz and 150 MHz or 300 MHz and the applicable device measurement frequency.

   b) A normal SAR system verification is required at 300 MHz.

4) The test laboratory must establish a new SAR target value for the 300 MHz dipole using the 150 MHz SAR probe calibration point and 150 MHz tissue dielectric parameters with the dipole transmitting at 300 MHz, according to the procedures required for establishing a new SAR target at the tuned dipole frequency according to the probe calibration and tissue dielectric parameters at an offset frequency.

      i) If any of these conditions cannot be satisfied, a KDB inquiry is required to determine acceptable solutions, especially before testing devices.

[5] RF ~~sources for 30, 64, 128, 150 and 220~~ MHz are being developed by SAR standards committees and expected to be available soon.

Attachment 865664 D02 SAR Reporting v01

Comment [SL1]: We suggest to make a new KDB # for Reporting and Documentation Requirements, and not embedded in the 6 GHz SAR KDB.

RF Exposure Compliance

Reporting and Documentation

Considerations

DRAFT

April 20, 2012

Laboratory Division

Office of Engineering and Technology

Federal Communications Commission

a) Information on test date, wireless mode, exposure configuration and test position, test channel & frequency, SAR probe serial numbers, probe conversion factors, duty factor applied, tissue dielectric parameters, area and zoom scan measurement resolutions and dimensions, measurement drift, 1-g SAR and highest extrapolated SAR must be included on each SAR plot.

b) A SAR plot is required for the highest measured SAR in each exposure configuration, wireless mode and frequency band combination; for example, WCDMA at 1900 MHz head.

i) Additional plots should be included when required by the *published KDB procedures*; for example, to support SAR to peak location separation ratio test exclusion and/or volume scan post-processing procedures.

ii) Plots are required for all SAR measurement results > 1.5 W/kg, or > 7.0 W/kg for occupational exposure limit.

iii) Other plots are optional and should be included, as necessary, to illustrate certain specific concerns, as determined by the test laboratory and measurement results. Explanations for including these specific plots must be included in the SAR report.

c) The SAR contour should be zoomed-in to the peak SAR location(s) to show the SAR distribution. The relevant boundaries of the test device should also be identified or illustrated on the plots. Plots that do not clearly show the contour levels, peak location(s) and device boundaries are unacceptable.

d) A z-axis plot representing each tissue type used is to be provided to confirm the tissue depth is sufficient so as to avoid reflections within the tissue medium in the SAR phantom. This plot may be from the test measurement on the device or from the system check.

8) The SAR numbers to be reported on the grant(s) of equipment authorization must be identified on a summary page at the front of the SAR report, for each equipment class, according to KDB 690783. These reported numbers should be highlighted in the SAR summary results for easy identification.

a) The reported SAR number for simultaneous transmission is generally the same for all equipment classes (PCE, DTS, NII etc.) involved in the simultaneous transmission; however, the standalone SAR numbers in each equipment class for "other use conditions" as used to determine simultaneous transmission SAR test exclusion are typically different.

9) General specifications of the SAR system, SAR probe and dipole calibration certificates and results, tissue-equivalent media recipes, SAR system verification (dipole) plots, generic test setup photos and certain SAR system validation information etc. should be all included in a separate attachment or appendix to the SAR report.

a) All scanned black and white copies of calibration certificates and related results must be legible.

b) Only one SAR system verification plot is required for each dipole, SAR probe calibration point and SAR system combination. Showing the plot with the largest deviation from the dipole SAR target is generally acceptable.

c) Certain SAR system validation information may be required by the *published KDB procedures* or requested during equipment approval; for example, due to SAR probe linearity concerns.