RF Exposure Procedures

TCB Workshop

April 2015

(corrected error on page 28)

Laboratory Division
Office of Engineering and Technology
Federal Communications Commission

Overview

- KDB Publication 248227
- Exposure Rules and Limits
- SAR Test Exclusion
- Product Platform Procedures
- Technology Specific Procedures
- RF Exposure Numerical Simulation
- SAR Measurement System and Methodology
- Miscellaneous Updates

KDB Publication 248227

- 802.11 Wi-Fi SAR Procedures -

KDB 248227 802.11 Wi-Fi SAR

- KDB Publication 248227 revised and released on March 16, 2015
  - no major changes from October 2014 draft
- Comments taken into consideration
  - aggregation of U-NII-2C and U-NII-3 (or §15.247 5 GHz) bands for SAR testing is optional
    - the channels above 5.65 GHz in U-NII-2C band may be tested using the 5.75 GHz probe calibration point; see section 3.3
    - test labs may continue to use multiple SAR probe calibration frequency points according to KDB 865664 requirements
  - expanded descriptions in some of the sections for clarity
  - 802.11modes, configurations and channel selection criteria are further simplified, added explanation and updated illustrative example
    - related information re-grouped and moved to adjacent sections for clarity
  - corrected error in step that identifies non-overlapping spatially separated SAR distributions
  - clarified Wi-Fi and WWAN simultaneous transmission configurations

Additional Wi-Fi Clarifications

- The channel selection condition for channels within ¼ dB of each other in footnote 5, 7 & 25; Section 5.3.2 and Table C.3 etc. has been removed
  - to avoid certain inherently confusing selection configurations
  - illustrative example in Appendix C had overlooked the ¼ dB consideration
- Example in Appendix C updated to match section 5.3.2
  - when the same maximum output power is measured for different channels in a Wi-Fi mode (bandwidth, modulation, data rate)
  - 802.11a/g/n/ac mode takes precedence over channel selection criteria
- Footnote 29 clarifies that *reported* SAR procedure is not available for single and multiple band simultaneous transmission SAR measurements due to
  - overlapping SAR distribution and peak SAR location concerns
  - maximum output power & tune-up tolerance differences in transmission chains
  - worst case *reported* SAR for simultaneous transmission may be determined by
    - the largest ratio of specified maximum output power including tolerance to measured maximum output power among the transmitters and antenna chains
    - when it is overly conservative, a KDB inquiry may be submitted to determine compliance

KDB 248227 Transition Provisions

- All SAR tested with old 802.11 procedures must be completed by May 16, 2015 for equipment certification by June 16, 2015
- New 802.11 Wi-Fi SAR procedures are required after May 16, 2015 for testing and equipment certification

Exposure Rules and Limits

- Clarification -

Exposure Limits

- RF exposure compliance applies to all frequencies operating under FCC authority
- For portable exposure conditions
  - SAR limits apply to 100 kHz – 6 GHz
  - power density limits apply above 6 GHz
- FCC rules have not specified exposure limits for
  - portable exposure conditions below 100 kHz
  - mobile exposure conditions below 300 kHz
- Devices operating below these frequencies are considered according to §1.1307(d)
  - applicants must consult with the FCC to determine applicable procedures for demonstrating RF exposure compliance

RF Exposure Above 6 GHz

- Power density limits apply to devices operating above 6 GHz for portable exposure conditions
- The limits are derived from whole-body SAR exposure and plane-wave equivalent free-space field conditions
  - free-space limits have inherent margins to account for variations in exposure conditions and device use configurations
    - in-tissue SAR evaluation is intended for specific (defined) exposure conditions and use configurations where certain margins may be irrelevant
- Power absorption is mostly confined to the superficial skin
  - due to small penetration depths, the mass/volume averaging criteria used for SAR is inappropriate at high frequencies
  - plane-wave equivalent power density criteria is applied to determine compliance for localized exposure

Exposure Limits Above 6 GHz

- Due to underlying differences between free-space and in-tissue exposure limits and associated compliance conditions
  - an apparent discontinuity at 6 GHz between SAR and power density limits is often perceived, but not unexpected
- Wireless manufacturers and RF exposure standards experts are beginning to review possible concerns relating to localized vs. whole-body exposure above 6 GHz
- Until additional information is available, exposure limits required by current rules must be applied to demonstrate compliance
  - any change in exposure limits will need to be addressed through rulemaking

Source-Based Time-Averaging

- General time averaging requirement for SAR limits is identified in §2.1093(d)(2)
  - for compliance with general population limit, exposure may be averaged over a period not to exceed 30 minutes
- For general population limits, the time averaging requirements of §1.1310 do not apply to portable exposure conditions; as specified in §2.1093(d)(5), including above 6 GHz, where
  - "source-based" time-averaging according to an inherent property or duty-cycle of a device is applied instead
- The acceptable source-based averaging time (≤ 30 minutes) can depend on
  - device implementation, use and exposure conditions etc.
- Time- averaging alternatives are reviewed in ET Docket 13-84
  - relevant comments are addressed through this Docket

Occupational Exposure

- GMRS is typically bundled with FRS radios
  - general population exposure limit applies to FRS
  - GMRS operating authorities are described in §95.179
    - some use conditions may not satisfy occupational exposure requirements
- For all radio services, general population exposure limit applies
  - unless a radio transmitter is exclusively prohibited for use by the general public through acceptable mechanisms and also satisfies all occupational exposure and training requirements
- General population exposure limit is required for Part 15 U-NII and mm-wave devices
- Exposure limits are established and applied to a person's exposure condition
  - as defined in §2.1093(d)(1)(i) and §2.1093(d)(2)(i)

SAR Test Exclusion

KDB 447498 SAR Test Exclusion

- The SAR test exclusion thresholds in KDB 447498 apply to
  - antennas that radiate energy into free-space for communication purposes
- The SAR test exclusion provisions do not apply to devices with antennas or radiators, by design, couple energy into a person's body
  - for example, certain (external) magnetic field based operations targeting devices implanted in or attached to a person
  - SAR test exclusion for such operations may be considered through KDB inquiry
- Implanted medical devices must apply the 1 mW SAR test exclusion procedure in KDB 447498 for wireless communication
  - when RF energy is used for medical purposes, therapeutic exposure is generally addressed during FDA medical device approval
  - demonstration of FDA approval may be necessary for some situations

Reporting Compliance

- When SAR test exclusion is applied
  - it must be clearly identified in the SAR report
  - in conjunction with other measured SAR results

- When no SAR measurement is required
  - the test exclusion analysis must be documented according to the reporting requirements in KDB Publication 865664 D02 to support compliance
  - analysis reports are placed in the RF exposure exhibit of equipment certification filings

Simultaneous Transmission

- When simultaneous transmission SAR measurement is required
  - the highest sum of 1-g SAR configuration, according to the SAR test exclusion procedures in KDB 447498, may be considered
  - provided it is an applicable simultaneous transmission configuration used by the device
  - each exposure condition, test position and frequency band combination must be considered separately
- When it is unclear, a KDB inquiry is recommended to avoid unexpected issues

Product Platform Procedures

- Update -

Rigid Band Wrist Watch SAR

- The procedures in KDB 447498 are insufficient for wrist watches with rigid bands
  - that do not conform to a flat phantom or a limited neck section of the SAM phantom
  - that contain antennas or circuits in the wrist band and require the band to remain connected for proper operation or maintain performance
- When a flat phantom or the neck of SAM phantom is not suitable, the following should be considered
  - the wrist watch is first vacuum sealed, tightly, in thin plastic
  - all excess plastic edges are trimmed off, without overlaps to ensure the surface is smooth, especially around the measurement site

Wrist Watch SAR Procedures

- After the watch is vacuum sealed
  - all surfaces that are in contact with free-space during normal use should be covered with ~5 cm thick low-loss foam
  - including the edges of the wrist watch and band
  - use spray foam that bonds to the plastic after curing
- There are presently two SAR measurement alternatives
  - using either an up-right or L-shaped SAR probe supported by specific SAR measurement systems
  - both require the vacuum sealed and foam covered wrist watch to be submerged at the bottom of a liquid filled flat phantom
    - weighted down accordingly with non-perturbing material as necessary
  - test setup and measurement details must be coordinated with the FCC and SAR system manufacturer before, during and after the measurement
- The outer surfaces of the foam covering must be shaped according to the SAR measurement method used to support probe positioning

L-Shaped Probe Watch SAR

- L-shape probe is supported by specific IndexSAR systems
- The watch is embedded in foam with the circular or elliptical band positioned horizontally near the bottom of the flat phantom
- Tissue-equivalent liquid fills the cylindrical region at the center of the foam covered watch structure
- SAR is measured by scanning the L-shaped probe tip along the inside surface of the wrist watch and band
  - the probe remains vertical
  - the horizontal probe tip is positioned against the inside surface of the watch through mechanical detection
  - this may not work for some small diameter wrist band configurations

Straight Probe Watch SAR

- SPEAG has been providing ad hoc support for DASY systems to measure the SAR of submerged watch devices using up-right probes
- The vacuum sealed and foam covered watch is placed on a test bed/platform that
  - provides device support and also serves as the phantom structure
  - enables sufficiently accurate probe positioning
  - allows SAR measurement at a fixed distance to the inside watch surface
  - enables SAR extrapolation and 1-g SAR computation
- The foam covered watch must be tilted and oriented using multiple degrees of freedom to position the antenna and measurement region
  - approximately parallel to the bottom of the flat phantom for SAR probe access (< 20°)

Head Mounted Device SAR

- Transmitters mounted on the head, such as those incorporated in
  - eyeglasses, head bands or certain helmets
  - may require special phantom setup and device positioning considerations to enable SAR measurement
- The SAM phantom is mainly designed for next to the ear handset SAR testing
  - it is not intended for testing other exposure configurations
- Flat phantoms generally do not support contoured device designs
- Certain antenna configurations and device use conditions may require SAR measurement at multiple device surfaces and edges
- A KDB inquiry is recommended to avoid invalid test configurations and unacceptable results

Proximity Movement Detection

- A few tablet manufacturers have indicated that wireless carriers are requiring human movement detection to
  - minimize false triggering associated with power reduction by proximity sensors
  - provide enhanced user experience
- The proposed implementations are host device dependent, typically using combinations of
  - distributed sensing techniques
  - statistical analyses
  - timeout conditions
  - sometimes in conjunction with G-sensor or other mechanisms
  - existing proximity sensor procedures in KDB Publication 616217 are insufficient
- Most proposed configurations seem to have some difficulties satisfying both wireless carrier and RF exposure compliance requirements
  - typically the algorithms can only determine movements indirectly

KDB 447498 Exposure Platforms

- Three exposure platforms are defined in KDB Publication 447498 for approval of transmitter modules
  - mobile exposure host platform
  - portable exposure host platform
  - mixed mobile and portable exposure host platform
  - must identify support for standalone or standalone and simultaneous transmission
  - subsequent changes, Class I or II, are limited to the original approved platform
- Approved host platform and exposure conditions, including restrictions
  - must be fully described in equipment approval and OEM integration instructions
  - grantee is responsible for ensuring installers and integrators have clear understanding of compliance requirements and to provide support
  - different disclosures required for the entire supply chain to ensure compliance must be fully documented in equipment approval
- Modules cannot be approved for some configurations
  - small devices with multiple transmitters with RF energy coupling concerns

Technology Specific Procedures

- Update -

Part 15 mm-Wave Devices

- Power density limit applies to Part 15 mm-wave devices operating in portable exposure conditions
- Compliance may be established by measurement, numerical simulation or combination of these techniques
- Measurements in the reactive near-field is generally difficult
  - due to antenna loading and field perturbation issues
  - especially at higher frequencies; for example, 60 GHz WiGig
- Plane-wave spectrum techniques may be explored to estimate near-field exposure according to measured far-field results
  - the implementation has been reported in the literature
    - "Application of the Planar-Scanning Technique to the Near Field Dosimetry of Millimeter-Wave Radiators"; Bioelectromagnetics, Volume 36, Issue 2, pages 108–117, February 2015

mm-Wave Exposure Evaluation

- Numerical simulation requires
  - KDB 447498 requires code validation according to draft IEC 62704-1 (or equivalent) procedures
    - for FDTD and other acceptable simulation techniques
  - models can be validated against measured results (fields, power density, EIRP etc.) at the far-field boundary
  - simplified canonical benchmark relevant to the compliance simulation is typically required
    - to demonstrate sufficiently accurate near-field results can be achieve for the configurations simulated for compliance
- Certain EMC mapping system has support far-field to near-field transformation
  - μ-Lab System by Microwave Vision Group
- A KDB inquiry is highly recommended to avoid invalid test configurations and unacceptable results

A4WP Wireless Charging

- Transmitter and receiver are identified as PTU and PRU in A4WP
  - operating at 6.78 MHz
  - single or multiple devices can be charged simultaneously
  - different PTU Classes and PRU Categories can support 2 W to 70 W
  - Bluetooth is used for communication and control
- Implementations have been based on A4WP approved coil designs
  - H-field based conformance criteria may be under consideration
- Depending on the design, exposure and use conditions
  - compliance is according to §2.1091, §2.1091(d)(4) or §2.1093
  - MPE limits at 6.78 MHz are 122 V/m & ~~6.2~~ 0.323 A/m
- When SAR evaluation is required
  - measurement procedures are not established below 100 MHz
  - numerical simulation requires model validation by measured field results
  - SAR test exclusion criteria are under investigation

A4WP SAR Simulation

- SAR may be simulated using homogeneous muscle-equivalent slab
  - slab phantom of ~ 70 cm x 50 cm x 20 cm is generally acceptable for modeling torso exposure ; with $\varepsilon_r = 211$ and $\sigma = 0.63$ S/m
  - large correction factors are proposed in recent literature to ensure compliance
- A KDB inquiry is required to determine acceptable heterogeneous human models and modeling parameters
- Resonance condition may require substantially long iteration time to reach convergence and steady state conditions; hybrid methods could be useful
- The procedures in section 4.4 of KDB Publication 447498 are required
- Results are reported according to KDB Publication 865664 D02
  - measured and simulated results are correlated at strategic points to validate the simulated model (coil and other structures)
  - demonstration of modeled resonance conditions against actual operating configurations must be addressed
  - using unloaded simulation conditions to demonstrate compliance for loaded conditions, with client devices on charger, requires further validation

Other A4WP Considerations

- The test separation distance must be sufficiently conservative for supporting the actual use conditions expected by typical users during normal operation
  - but not overly conservative~~ly~~ to introduce undue compliance issues
  - tested conditions must be in agreement with the operating and installation instructions provided to users
- Bluetooth typically transmits intermittently at rather low power
  - when KDB Publication 447498 standalone SAR test exclusion applies, including low duty factor exclusion, simultaneous transmission SAR exclusion analysis for Bluetooth and charging is typically not necessary provided it is clearly explained in the test reports
- For equipment certification, PBA is required for SAR simulation
- For Part 18 DoC, RF exposure test reports are kept in KDB system
  - the equivalent of PBA process is applied to the KDB inquiry
- For designs that use multiple protocols; for example, combinations of A4WP, PMA or Qi
  - each protocol is tested independently

LTE Carrier Aggregation

- The power measurement procedures in section 3) b) ii) of KDB 941225 D05A, Rel. 10 LTE, need further considerations to address recently identified issues relating to
  - which DL channel bandwidth configurations should be considered for the power measurement
  - UL test channels defined in Rel. 8 procedures may not operate in certain combinations of UL-DL paired channels for some carrier aggregation configurations
    - for example, an UL channel close to the transmission band edge may result in an invalid DL aggregated-channel configuration extending outside the DL transmission band
    - the issues may vary with UL and DL inter-band or intra-band carrier aggregation configurations

Rel. 10 LTE SAR Exclusion

- A KDB inquiry is required, until further notice, to identify the applicable power measurement configurations for Rel. 10 LTE DL carrier aggregation to determine SAR test exclusion
  - measurement proposals regarding UL-DL channel plans and carrier aggregation configurations are required
  - the specific details are also required in SAR reports
- When the necessary information is acquired through KDB inquiries or alternative sources
  - KDB 941225 D05A will be updated accordingly
  - to alleviate KDB inquiry requirements

Overlapping LTE Bands

- October 2014 TCB workshop RF exposure slides included SAR guidance for overlapping bands that support roaming using multiple frequency band indicator (MFBI); for example
  - band 12 (699 – 716 MHz) SAR can support band 17 (704 – 716 MHz)
  - band 41 TDD (2.495 – 2.690 GHz) SAR can cover band 38 TDD (2570 – 2620 MHz)
  - however, band 41 TDD (2.495 – 2.690 GHz) or band 38 TDD (2570 – 2620 MHz) SAR cannot support band 7 FDD (2.5 – 2.57 GHz)
  - depending on channel BW configurations, submit KDB inquiry to confirm the channels required for SAR measurement
- Additional clarification has been requested by test labs
  - the maximum output power, including tolerance, for the smaller band must be ≤ the larger band to qualify for the SAR test exclusion
  - the channel bandwidth and other operating parameters for the smaller band must be fully supported by the larger band

RF Exposure

- Numerical Simulation -

RF Exposure Simulation

- The general requirements for applying numerical simulation techniques to demonstrate RF exposure compliance are described in section 4.4 of KDB Publication 447498 D01
- The reporting requirements for SAR simulation are included in KDB Publication 865664 D02
  - similar requirements should be applied to exposure simulations for field strengths or power density
- Depending on the numerical techniques and voxel or mesh structure used in the modeling
  - varying 1-g SAR averaging algorithms may be applied by different numerical tools
  - simulated results may differ from measured values due to differences in spatial resolution and sampling or interpolation techniques used
  - these are addressed by the code validation and benchmark procedures in IEC draft 62704-1 for FDTD
    - the equivalent procedures are required for other numerical methods

Code Validation & Benchmark

- Numerical code validation is normally performed by software package vendors to demonstrate numerical accuracy of the core algorithms and conformance with standardized protocols
- Canonical benchmarks may be performed by either the software vendor or end user to demonstrate general applicability of the simulation tools for the intended exposure evaluation
- Additional benchmark results with close relevance to the specific conditions and configurations simulated for an individual device are used to confirm
  - modeling resolution, RF source-feed configurations, lump-circuit elements, specific simplifications and special techniques used, return-loss and resonance conditions etc.
  - the results are compared against known analytical, published or equivalent reference results to demonstrate user competence in applying the numerical tools to simulate the problem at hand

TCB Review & Approval

- A TCB must have the proficiency to perform review and approval of equipment certification applications involving numerical techniques to demonstrate RF exposure compliance
- Sufficient expertise is necessary to determine if the numerical method used in the simulation has been applied correctly according to
  - the fundamental requirements specific to the numerical techniques
  - code validation and benchmark procedures described in IEC draft 62704-1
  - the general requirements in section 4.4 of KDB Publication 447498
- Guidance for specific issues can be addressed through KDB inquiries; however, the initial acceptance review should be coordinated through TCB to prepare for PBA
- A PBA with incomplete information or TCB review can be rejected
  - when requirements for KDB Publication 447498, IEC draft 62704-1, specific modeling issues, demonstration of acceptable accuracy and margins or KDB Publication 865664 D02 are not fulfilled or satisfactorily documented

Vehicle-Mounted Antennas

- When SAR simulation is used to determine compliance for vehicle-mounted antennas, the requirements of IEC draft 62704-2 are applied
  - the IEC procedures require specific vehicle, passenger and bystander models for SAR simulation
  - separate code & modeling validations are specified in IEC draft 62704-2 to address computation and modeling uncertainty
  - the specific correction factors defined in IEC 62704-2 must be applied to determine compliance
- The general requirements established in KDB publication 447498 and IEC draft 62704-1 for using numerical simulation must also be satisfied

Vehicle-Mounted Antennas

- IEC 62704-2 procedures are limited to roof top and trunk mounted antenna configurations
  - for other antenna mounting configurations, a KDB inquiry is required to address the simulation configurations
- Benchmark results and comparison studies within the IEC 62704-2 working group have shown rather high uncertainty budgets
  - up to 90% for k=2, which can bring compliance concerns for certain high SAR conditions
  - case-by-case consideration through KDB inquiry is necessary to address compliance concerns for such circumstances

SAR Measurement

System and Methodology

KDB 447498 – Fast SAR

- The estimated 1-g SAR procedure in KDB Publication 447498 only applies to the polynomial version of the Motorola fast SAR algorithm
- Proprietary fast/quick SAR measurement procedures may be available in different SAR systems
  - the algorithms used can be adaptive or have certain restrictions
  - the use of these requires prior FCC coordination and approval
- The demographics information generated automatically by SAR systems for SAR measurement is required for all SAR plots to clearly identify the SAR test setup configurations are compliant with
  - full SAR procedures & reporting requirements of KDB 865664, or
  - estimated 1-g SAR provisions in KDB Publication 447498
- TCBs must review and ensure the SAR measurement results are valid and acceptable before issuing equipment approval

Sensor Array SAR Systems

- Two sensor array systems started delivery in mid-summer of 2014
- FCC has provided case-by-case guidance to use these systems for SAR screening through individual KDB inquiries
  - to reduce the number of full SAR measurements required for smart phones with certain dynamic antenna tuner configurations
- No screening results have been received despite the given guidance
  - a noticeable reduction in the number of dynamic antenna tuner inquiries, compared to 2014, has been observed for early 2015
- The IEC 62209-3 project team is in its early stage of drafting SAR measurement requirements for sensor array and vector probe systems
  - system validation and routine system check/verification protocols are essential for establishing interim measurement guidance
  - the protocols must accommodate varying system implementations
  - the range of expected measurement uncertainty for individual implementations must be established to consider results for compliance

SAR Probe Calibration

- DASY systems are in the process of implementing sensor model based SAR probe calibration procedures
- The DASY system models or firmware revisions that may apply this are presently unclear
- The calibration requirements are not described in on-going SAR measurement standards
- Until specific details are available to provide measurement guidance for test labs, TCBs must ensure SAR measurements using probes with such calibrations have prior coordination and acceptance by the FCC through KDB inquiries

Miscellaneous Updates

Hotspot Mode

- For devices that support Wi-Fi and WWAN simultaneous transmission, hotspot mode SAR is also required, except
  - when an applicant can substantiate with convincing evidence that hotspot mode cannot be enabled through third party apps
- There is no distinction between embedded and downloaded apps for hotspot mode support and SAR compliance

Third-Party Accessories

- When SAR measurement is required for third-party accessories
  - it is necessary to verify the host device test sample SAR against results in the original filing before any 3rd party accessory testing
- When the *reported* SAR of a host test sample has certain noticeable variations or differences from results in the original filing
  - provided the SAR distribution and peak SAR location are (practically) identical where discrepancies can be attributed to low noise floor issues associated with low SAR conditions or certain undetermined fixed bias
  - *reported* SAR of the host test sample with accessory attached should be adjusted according to the following
    - no adjustment is required when *reported* SAR of the host test sample without accessory attached is ≥ highest *reported* SAR in the original and all applicable permissive change filings
    - otherwise; *reported* SAR of the host test sample with accessory attached is adjusted by the ratio of *reported* SAR in the original filing to the host test sample, both without accessory attached

Coherent Signals for 802.11

- As described in KDB Publication 248227, coherent signal conditions generally do not apply to 802.11 MIMO and TxBF SAR measurements
  - signal correlation for 802.11 TxBF is applied to the subcarriers
  - 802.11 protocol also requires cyclic shifts to be added to avoid signal correlation due to TxBF
  - for RF exposure purposes, signal coherence should be insignificant, after the iFFT, at the OFDM outputs and antenna chains
- Data blocks are coded differently for spatial multiplexing and STBC in 802.11 MIMO, where varying propagation paths are expected for data transmitted through different antenna chains
  - for purpose of RF exposure (SAR or MPE) and with the added cyclic shifts, signal coherence is generally not expected

Coherent Signal Considerations

- For proprietary implementations that support signal correlation, such as phased arrays
  - a KDB inquiry is required to determine RF exposure evaluation requirements
  - IEC TR 62630 equivalent procedures should be considered
  - additional info is also available in on-going IEC draft 62209-1 for correlated signal conditions in typical MIMO and phased array type configurations

- The simultaneous transmission SAR test exclusion provisions in KDB Publication 447498 do not apply to coherent signals