RF Exposure Procedures

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Overview

- LTE UL/DL Carrier Aggregation SAR
- WiGig/60 GHz RF Exposure Evaluation

LTE UL/DL

Carrier Aggregation

SAR

LTE Carrier Aggregation

- The number of LTE bands supporting carrier aggregation (CA) in recent products has increased substantially, especially for smartphones
- Requests for additional SAR test exclusion and test reduction have been received through KDB inquiries for individual products
  - to streamline the power measurement procedures for DL CA SAR test exclusion and
  - to consider generalized SAR test configurations for UL CA
- Related guidance has been provided to a few test labs through product specific KDB inquiries over the last few months
- An update to KDB 941225 D05A is necessary to incorporate these new considerations
- A summary of the proposed guidance is presented here for test labs to consider LTE CA SAR testing until KDB 941225 D05A can be updated
- To ensure the procedures can be applied without modification or adaptation, a KDB inquiry is recommended for complex combinations

DL CA Inter-Band Exclusion (1)

- SAR test exclusion for inter-band DL CA is determined by power measurements according to the number of frequency bands and component carriers (CCs) supported by the product implementation
- When the DL CA configurations are tabulated in separate columns
  - for example, CA_2A-5A (0), CA_2A-2A-5A (0), CA_2A-2A-5A-30A (0) and CA_2A-4A-5A-30A (0) would be listed in the columns corresponding to 2 bands/2CCs, 2 bands/3 CCs, 3 bands/4 CCs and 4 bands/4 CCs; and
  - the CA/CC combinations in each columns are sorted so that frequency bands listed in subsequent columns on each row are ascending subsets, as illustrated below; i.e., columns to the right correspond to increasing number of frequency bands and CCs

2 bands / 2 CC	2 bands / 3 CC	3 bands / 4 CC	4 bands / 4 CC
CA_2A-5A (0)	CA_2A-2A-5A (0)	CA_2A-2A-5A-30A (0)	CA_2A-4A-5A-30A (0)
	CA_2A-2A-12A (0)	CA_2A-2A-12A-30A (0)	CA_2A-4A-12A-30A (0)
CA_4A-12B(0)		XXXXXX	
	XXXXX		XXXXX
XXXXX			XXXXX
Fill in the XXXXX according to configurations supported by the product			

DL CA Inter-Band Exclusion (2)

2 bands / 2 CC	2 bands / 3 CC	3 bands / 4 CC	4 bands / 4 CC
CA_2A-5A (0)	CA_2A-2A-5A (0)	CA_2A-2A-5A-30A (0)	CA_2A-4A-5A-30A (0)
	CA_2A-2A-12A (0)	CA_2A-2A-12A-30A (0)	CA_2A-4A-12A-30A (0)
CA_4A-12B(0)		XXXXXX	
	XXXXX		XXXXX
XXXXX			XXXXX
Fill in the XXXXX according to configurations supported by the product			

- In applying the existing power measurement procedures of KDB 941225 D05A for DL CA SAR test exclusion
  - only the subset with the largest number of combinations of frequency bands and CCs in each row need consideration; i.e., the right most configuration
- When a power measurement configuration does not qualify for SAR test exclusion, power is measured for the previous lower order combination (next left column) for the remaining lower order subsets in the row to qualify for SAR test exclusion and to limit the number of SAR tests
- The configurations require power measurements should be highlighted in reports

DL CA Intra-Band Exclusion (1)

- For intra-band DL CA, contiguous and non-contiguous CA are considered separately by tabulating these in separate columns
  - all CA configurations for the same frequency band are grouped together in adjacent rows in each column; for example,
  - CA_41A-41A (0)(1) … CA_41A-41C (0) for non-contiguous CCs
  - CA_7B (0) … CA_7C(0)(1)(2) for contiguous CCs
- In applying the power measurement procedures of KDB 941225 D05A for DL CA SAR test exclusion
  - only the CA configuration with the largest aggregated DL CA bandwidth in each frequency band group need consideration
    - independently for contiguous and non-contiguous CA
  - when the same frequency band is used for both contiguous and non-contiguous CA, power may be measured using the configuration with the largest aggregated bandwidth "*and*" maximum output power among the contiguous and non-contiguous CA configurations
    - otherwise, these are considered separately

DL CA Intra-Band Exclusion (2)

- The existing procedures in KDB 941225 D05A are applied
  - for contiguous CA to position additional CCs adjacent to the PCC
    - alternatively on either side of the PCC and already added CCs, within the frequency band and
    - within the transmission band for channels at the ends of a frequency band
  - for non-contiguous CA to use the largest allowed channel separation to distribute the CCs evenly across the frequency band
- DL PCC channel is determined by the UL channel and UL/DL pairing requirements for FDD
- DL SCC and subsequent CCs should be configured using the channel bandwidth and RB configurations closest to that used for the DL PCC
- When a power measurement configuration does not qualify for SAR test exclusion, power is measured for the next largest aggregated bandwidth to qualify for SAR test exclusion and to limit the number of SAR tests
- The configurations that require power measurements should be highlighted in test reports

Uplink CA SAR Test Guidance (1)

- All applicable UL CA configurations intended for U.S. operations should be identified according to KDB 941225 D05A requirements
  - maximum output power and tune-up tolerances for both standalone and UL CA operations, including any operating restrictions, power reduction or variations among LTE modes and configurations (channel BW, RB allocations, MPR, modulation, 3GPP release variations etc.)
  - all details are required in the SAR report to support the test configurations
- This guidance applies to intra-band contiguous UL CA only
  - other configurations require separate consideration through KDB inquiry
- Maximum output power is measured for each UL CA configuration for the *required test channels* described in KDB 941225 D05 (Rel. 8)
  - UL PCC configuration is determined by the *required test channel*
  - SCC and subsequent CCs are added
    - alternatively to either side of the PCC or
    - within the transmission band for channels at the ends of a frequency band

Uplink CA SAR Test Guidance (2)

- SAR for UL CA is required in each exposure condition (highest standalone head test position, body etc.) and frequency band combination
- When the maximum output for UL CA is ≤ standalone LTE mode (without CA)
  - PCC is configured according to the highest standalone SAR configuration tested
  - SCC and subsequent CCs are configured according to procedures used for power measurement and parameters (BW, RB etc.) similar to that used for the PCC
- When the *reported* SAR for UL CA configuration, described above, is > 1.2 W/kg, UL CA SAR is also required for all *required test channels* (PCC based)
- UL CA SAR is also required for standalone SAR configurations > 1.2 W/kg when they are scaled to the UL CA power level
- The maximum measured output power, RB allocation, CC offsets, CC channel BWs, MPR, modulation and other relevant information for all UL CA SAR configurations are required in SAR reports to support the test setup and results, including explanations, call box configurations and certain testing restriction etc.
- A KDB inquiry is required to determine SAR measurement requirements
  - when maximum output power for UL CA is greater than that used in standalone mode
  - due to power reduction considerations or other implementation concerns

WiGig/60 GHz

RF Exposure Evaluation

WiGig RF Exposure

- Initial approvals of WiGig and other 60 GHz (WirelessHD etc.) have been mostly for low power devices in mobile exposure conditions
  - MPE compliance is determined at 20 cm or more
  - exposures are generally low due to free-space attenuation
- Devices that operate in portable exposure conditions have been gradually available over the last 2 years
  - tablets, 2-in-1 and convertible laptops, camera accessories etc.
  - the maximum output power for these have been mostly less than 5 dBm; a few around 5 – 10 dBm are under consideration
  - virtual reality head-worn devices are also under consideration
  - power increases are expected for future product implementations
    - for improved antenna designs or
    - incorporation of certain built-in mitigations to reduce exposure concerns

mm-Wave Standards Development

- IEC TC106 AHG10 is in the process of completing a Technical Report (TR) on mm-wave power density assessment
  - test approaches applicable to free-space power density measurements at 6 GHz – 100 GHz are identified and described
  - draft submission to IEC is expected by the end of 2017
- The work by AHG10 will continue after TR completion
  - to draft an International Standard (IS)
  - to develop detailed and specific measurement guidelines
  - to address specific issues that need further investigation and validation
- A separate IEEE/IEC dual logo project, IEEE P1528.6, is also underway to establish numerical simulation protocols above 6 GHz
- While the TR is expected to be available in 2018, it can take 2 years or more for the IS and P1528.6 to finalize

Interim WiGig Considerations

- Potential KDB guidance or draft considerations
  - to identify interim power density measurement procedures
  - for evaluating devices operating in portable exposure conditions
  - according to latest available test equipment and measurement approaches, taking into consideration AHG10 draft TR approaches
  - account for the operating characteristics and exposure conditions of both recently approved and certain highly expected product implementations
- WiGig products and mm-wave power density measurement methodology are both expected to evolve over the next few years
  - as measurement techniques continue to improve, devices with new exposure concerns may arise and require additional considerations
  - for example, certain new antenna designs or simultaneous transmission involving both SAR and mm-wave power density will need further consideration

Power Density Assessment

- Routine evaluation is required for most consumer devices operating in portable exposure conditions
- Certain test exclusions may be considered through KDB guidance
  - when the maximum output power is less than 1 mW and coherent signal transmission is not supported or of no exposure concern
  - when a built-in inherent separation distance is incorporated in products that can ensure low user exposure
- For devices that operate at close proximity to users at higher power
  - especially with beam-forming and beam-steering
  - power density evaluation by measurement or numerical simulation is necessary to demonstrate compliance
  - typically by determining a subset of the worst case exposure conditions for the expected use conditions to reduce the evaluation time

Test Exclusion Considerations

- For certain products with simple antenna configurations that transmit uncorrelated signals and low exposure is justified
  - due to low power or certain inherent operating conditions
  - the power density at close proximity to users may be estimated according to the maximum power available at the antenna aperture and applicable beam width
- Depending on the antenna design and antenna element arrangements
  - for example, whether elements are active at the same time or combinations of elements may transmit in varying amplitude and phase conditions
  - simple configurations may consider test exclusion or power density estimation
- If exposure mitigation is by design an integral part of the implementation
  - test exclusion or test reduction may apply to certain reduced exposure conditions
- In general, the exposure conditions used to determine test exclusion should be sufficiently conservative according to worst case exposure conditions
  - otherwise, test reduction should be considered to demonstrate compliance

Test Reduction Considerations (1)

- Antenna design complexity, transmission characteristics and use conditions can introduce large combinations of configurations that require power density evaluation
- The number of tests varies with antenna element configurations; for example
  - all elements may reside on a single plane or surface
  - certain elements may be distributed (in 3D) over the antenna or product housing
  - different subsets of antenna elements could be used to optimize transmissions
- Test configurations also vary with transmission characteristics; for example
  - range of amplitude & phase conditions used in beam-forming and beam-steering
  - certain built-in mitigations used to maintain or optimize transmission links
- Although individual product designs may vary, the number of test configurations that need consideration is often in the hundreds
- Test reduction schemes are applied to identify the subset(s) of worst case exposure conditions that need evaluation to determine compliance

Test Reduction Considerations (2)

- Status of mm-wave test methodology for portable exposure conditions
  - measurement and numerical simulation standards are under consideration
  - measurement techniques are evolving and improving
  - numerical simulations can have varying difficulties – material dielectric properties, device model validation, computing resources, impact of RF components and thermal considerations etc.
  - when applicable, in some situations simulation and measurement results may be used to supplement each other to demonstrate compliance
- A subset of the worst case exposure conditions may be identified by numerical simulations according to transmission and exposure conditions
  - for example, at the device surface where measurements may not be suitable
- Measurements can be performed at distances supported by the methodology
  - for the subset of transmission conditions determined using numerical simulation
  - the numerical and measured results are correlated at applicable measurement distances to verify the simulations
  - for numerical results to show compliance at locations measurement is not suitable

Power Density Evaluation

- Power density is generally assessed by field measurements
- The measurement region is typically a plane and depending on the test methodology, which may not necessarily coincide with the exposure plane or locations
  - instead of a plane, a conformal surface has also been proposed in the IEC AHG 10 draft TR
  - when the test methodology requires fields to be measured at distances further away from the exposure plane, power density can be derived using field reconstruction techniques
- Either E or H fields may be measured to derive both fields to determine power density at the exposure plane according to test methodology requirements
- When phase is not measured, it can be derived from the measured fields; for example
  - using plane wave expansion or similar techniques
  - methods that use a redundant measurement procedure through an iterative process to determine field polarization and other information necessary for the field reconstruction algorithms to derive power density at the exposure locations
- Alternatively, if both E and H field amplitude & phase can be measured at the exposure plane, power density can be determined directly from the measured fields without field reconstruction

Mitigation Considerations

- Certain WiGig implementations may include built-in mechanisms to minimize poor link quality
  - by redirecting transmissions away from partially blocked conditions as a part of the beam-forming and beam-steering process or
  - allowing time-out conditions to initiate a low duty factor search mode to reestablish a connection
  - these typically would not fully eliminate the exposure potential; however, limiting the exposure duration may alleviate certain concerns
- Mitigation test results may be considered
  - to demonstrate a device can consistently and correctly apply systematic procedures to reduce exposure
  - when applicable; for example, mitigation considerations may help reduce the compliance margins necessary to support simulation and measurement results that show marginal correlation
- A KDB inquiry is required to consider mitigation tests and results

Measurement Methodologies

- A few power density measurement approaches have been described in the IEC AHG10 draft TR for evaluating mm-wave devices
  - when exposure is in the far-field, either E or H field magnitude may be measured to determine plane-wave equivalent power density
  - depending on the measurement methodology, additional considerations are necessary to assess power density at closer distances
- A mm-wave E-field probe and miniature waveguides have been considered for power density assessment in the near-field
  - to overcome field perturbation and other concerns, power density at the exposure plane may be derived from fields measured at further distances
  - field reconstruction techniques are used to transform or project the measured fields to derive power density at the exposure plane
  - it has been discussed in AHG10 that in some situations it could be problematic to back-propagate measured fields to reactive field regions

mm-Wave Field Probe

- This probe is designed for use with an existing SAR measurement system
- The probe (sensors) may be positioned as close as 2 mm from the RF source
  - amplitude and phase of E and H fields are derived through an iterative process from E-fields measured at multiple planes and sensor orientations (polarization)
  - power density is computed from the E and H fields derived through reconstruction algorithms
- AHG10 draft TR has included proposals to use certain waveguides for system validation and routine system check
  - the availability of these reference sources, calibration protocols or detailed protocol and procedures may need additional coordination
- A sufficiently large measurement region and proper measurement spatial resolution are required to maintain field reconstruction accuracy
  - fields at the measurement region boundary should be ~20-30 dB below the peaks
  - system configured measurement resolution is used to satisfy algorithm accuracy
  - a typical measurement is expected to take 2 – 4 hours or more
- Through increasing use of the system for product testing, further improvements to the implementation can be identified

Miniature Waveguide Probe

- Miniature waveguide probes have been described in the literature and used in many near-field measurement conditions
- For power density assessment at 60 GHz, the following need consideration
  - maintain sufficient distance (a few λ) from the source to avoid field perturbation
  - back-propagating the measured fields into reactive field regions could be problematic for certain situations and may need further consideration
- We have been unaware of commercial RF exposure measurement systems supporting miniature waveguide probes (for the time being)
  - for test labs to implement this methodology, system validation, including algorithm implementation and other conversion requirements will need full consideration before use
  - probe calibration, measurement accuracy and uncertainty will also need to be addressed

System Validation & System Check

- System validation is required before a system is deployed for measurement
- System check is also required before each series of continuous measurement and, as applicable, repeated at least weekly
- The system validation waveguides and target reference values described in the IEC AHG10 draft TR should be considered
  - the mm-wave probe or miniature waveguide must be calibrated within the frequency range required for WiGig testing
  - the system validation/check waveguide(s) must also be calibrated according to system manufacturer requirements within the WiGig frequency range
- Peak and spatially averaged power density at the peak location(s) must be compared to calibrated results according to the defined test conditions
  - the same spatial resolution and measurement region used in the waveguide calibration should be applied to system validation and system check
  - 1 cm^2 and 4 cm^2 spatial averaging have been recommended in the AHG10 draft TR with reference targets available for specific waveguide
  - power density distribution should also be verified, both spatially (shape) and numerically (level) through visual inspection for noticeable differences
  - the measured results should be within 10% of the calibrated targets

Spatial Averaging Requirements

- A spatial averaging area of 1 cm^2 is required to determine power density compliance in any 1 cm^2 area until further notice
- Either a circular or square averaging area is acceptable
- While larger averaging areas have been described in different exposure standards, these have been mainly established for whole-body exposure
  - unlike SAR and MPE limits used at frequencies below 6 GHz where whole-body and (highly) localized exposures can be addressed independently
  - the applicability of certain notably larger averaging areas to highly localized partial body exposure can be unclear and require further review
  - for example, antenna arrays used in WiGig devices are typically on the order of 1 – 2 cm in linear dimensions, sometimes incorporating up to 15 – 20 transmitting elements that are < 1 mm each
  - depending on the antenna and transmission characteristics, highly localized peaks are possible through beam-forming and beam-steering implementations
- Changes in averaging area; e.g., 4 cm^2, could be considered in the future
- A 1 cm^2 averaging area provides consistency with the 1 cm^3 averaging volume used at lower frequencies for SAR to maintain conservativeness

Poynting Vector Considerations

- Certain results requested through equipment certification have shown noticeable differences in power density results determined using three orthogonal components of the Poynting vector vs. only the component normal to the exposure plane
  - close to 3 dB differences have been observed for some configurations
- In the near-field at close proximity to the antenna
  - especially for complex antenna array structures involving beam-forming and beam-steering or in reactive field regions
  - field characteristics can be highly unpredictable
  - it is also inappropriate to assume actual user exposure occurs at a fixed distance, position or orientation to the test device or antenna structure, where only normal component of the Poynting vector applies
  - to maintain conservativeness and account for user and device positioning variability, three orthogonal components of the Poynting vector are required to determine compliance against power density limit; i.e., all components of the measured and derived E and/or H fields are used

Simultaneous Transmission

- Most antennas used for WiGig products are highly directional, especially with beam-forming and beam-steering
- The likelihood of overlapping exposure concerns due to simultaneous transmission from multiple WiGig antennas in the same product can generally be mitigated within the design
  - as product design and antenna implementation continue to evolve to support use conditions that may allow overlapping exposures, additional considerations will be necessary
- The procedures required to sum volume-based SAR results and surface-based mm-wave power density according to exposure conditions and measurement locations will need further investigation and consideration when such products become available

Coherent Transmissions

- Exposure enhancements due to coherent transmissions should be addressed according to antenna design and transmission characteristics
- Numerical simulations and other techniques may be applied
  - according to certain upper bound conditions or code book transmission configurations to identify the subset(s) of worst case exposure conditions for power density assessment
- When applicable, information in the IEC 62630 TR on coherent signals may be considered
- Addressing signal coherence issues for RF exposure can be complex and time consuming
  - a detailed test plan should be submitted through KDB inquiry to ensure the test proposals are valid and acceptable for evaluating a device

Test and Operating Parameters

- WiGig and WirelessHD devices can transmit with substantially wide channel bandwidths
  - maximum output power and RF component performance can have noticeable variations among the 3 channels allowed for U.S. operations
  - unless it can be demonstrated that the maximum power across all 3 channels, along with other performance factors that can influence RF exposure, remain the same across the channels, all 3 channels must be considered for testing
- When highly integrated antenna arrays are used, there is often no provision for conducted power measurement
  - the power available to the array or individual antenna elements are often estimated or derived from far-field radiated measurements or design parameters
  - this can directly impact power density scaling
  - in some cases, additional compliance margins may need consideration to ensure compliance for all production units
- Justification for source-based time-averaging is necessary to support test results according to transmission protocol, hardware or firmware restrictions
- Depending on device implementation, exposure and use conditions, multiple exposure planes may need evaluation

Reporting Considerations

- Depending on the power density assessment methodologies used
  - test reports for measurements, simulations, certain pre-screening tests or exposure mitigation verification results are necessary to support compliance
- The general reporting requirements in KDB 865664 D02 are applied to the individual reports
  - rationale and justifications must be clearly identified to support the purpose of each assessment and associated test setup, including operating parameters
  - system validation is required and system check results must be included in the test report, including reference source calibration results and distribution plots
- When numerical simulation is used for test reduction and pre-screening
  - validity of the simulation, antenna and device models used must be fully justified
- When numerical simulation is used as the primary tool to show compliance
  - KDB 865664 D02 and KDB 447498 requirements for numerical simulation apply
  - validation of the numerical tools and models, modeling details, accuracy of results and appropriate uncertainty considerations are necessary
- Pre-screening, simulation, measurement and comparison (compliance) results should be included in separate reports