Challenges in standardization related to EMF compliance above 6 GHz

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Davide Colombi, Ericsson Research
Challenges in EMF compliance standardization for devices > 6 GHz
EMF compliance challenges for devices > 6 GHz

› Challenges related to the definition of the exposure metric

› Challenges related to the assessment of incident power density in close proximity of a device

› Challenges related to the efficiency of compliance assessment methods
Challenges related to the definition of the exposure metric

EMF exposure limits above 10 GHz (ICNIRP 1998) / 6 GHz (IEEE 2005) are defined in terms of incident power density

**IEC TR 63170 - Spatial-average power density**: energy per unit time and unit area crossing the surface of area $A$ characterized by the normal unit vector $\mathbf{n}$

$$
\frac{1}{2A} \int_A \text{Re}(\mathbf{E} \times \mathbf{H}^*) \cdot \mathbf{n} da
$$

Ongoing discussion IEC/IEEE:
- Is this free-space quantity appropriate in the near-field considering the possible antenna coupling to the human tissue?
- Is the amplitude of the Poynting vector ($\mathbf{S} = \mathbf{E} \times \mathbf{H}^*$) rather than the energy flux more appropriate to define exposure limits (e.g. due to coupling conditions)?
Incident power density, insights

- At mmW frequencies, the contribution from the reactive near-field to the energy deposition in the tissue is small and so is the perturbation of the body on the antenna characteristics ([1]-[3])

- The correlation with temperature increase is the highest when exposure is evaluated based on the definition given by TR 63170 [4]

- Numerical and experimental data (e.g. [5]-[9]) show that incident power density can be used to limit tissue temperature elevation from near-field RF sources

At mmW frequencies, the averaged incident power density is an appropriate metric for compliance assessment

[7] Xu et al.,”RF Compliance Study of Temperature Elevation in Human Head Model Around 28 GHz for 5G User Equipment Application: Simulation
Challenges related to the assessment of incident power density in close proximity of a device (IEC TR 63170)

Measurements of both E-field and H-field on the evaluation surface

- E-field and H-field are measured with subsequent scans.
- If the field amplitude only is measured, the phase need to be reconstructed

Challenges: (1) Probes should be designed to avoid perturbation of the DUT (2) Manufacturing and calibration of H-field mmW probe is difficult

Measurements of the E-field amplitude on the evaluation surface (phase reconstruction)

- E-field amplitude scan(s)
- E-field phase retrieval
- H-field determination
- Power density evaluation

Challenges: (1) Probe should be designed to avoid perturbation of the DUT (2) Phase is not measured and need to be reconstructed (uncertainty factor need to be characterized)

Measurement of the E-field (amplitude and phase) at a larger distance from the evaluation surface (field back-propagation)

- E-field measurements (amplitude and phase)
- E-field back-propagation (inverse source, PWS, etc.) to the evaluation plane
- H-field determination
- Power density evaluation

Challenges: (1) Measuring phase is a difficult task (2) The uncertainty of back-propagation need to be characterized
IEC TR 63170 use case

SONY mockup, notch antenna array, 28 GHz

Measurement of the $E$-field (amplitude and phase) at a larger distance from the evaluation surface (waveguide probe)

Measurements of the $E$-field amplitude on the evaluation surface (phase reconstruction)

PD distribution, simulation

PD distribution, measurements
Challenges related with the efficiency of compliance assessment methods

› Field measurements are extremely time consuming (hour(s) x per configuration)

› Devices will be characterized by multiple transmitters above and below 6 GHz
  - Antenna arrays require field combining to determine exposure for the possible excitations
  - The total exposure ratio (TER) including contributions from above and below 6 GHz need to be assessed

\[
\text{TER} = \frac{\text{SAR}}{\text{SAR}_{\text{lim}}} + \frac{\text{Sinc}}{\text{Sinc}_{\text{lim}}}
\]

› Compliance tests for 5G devices might involve a large number of configurations

IEC/IEEE JWG11 and JWG12 are working to improve the efficiency of EMF compliance testing
- mixed approach (measurements and numerical assessments)
- improve system efficiency
Challenges in EMF compliance standardization for base stations $>6$ GHz
EMF compliance challenges for base stations > 6 GHz

› Beamforming and massive MIMO (mMIMO)
  - Energy is focused in directions where it is needed
  - Large variability of transmitted signals in time and space

Conventional base station: transmits a radio signal to a wide area regardless how many users are connected
mMIMO/beamforming: transmits a radio signal only to connected users

Realistic EMF compliance assessment models applicable for mMIMO are to be included in IEC 62669 [1][2]

Example – massive MIMO @ 28 GHz (Macro)

**Perspective view**

Exclusion Zone
General Public
Occupational

Array antenna with $8 \times 8$ elements

- $f = 28$ GHz
- $60^\circ$ horizontal scan range
- $15^\circ$ vertical scan range
- $EIRP_{\text{max}} = 72$ dBm

**Without considering the effect of beamforming**

All transmitted power assumed directed in the same beam for several minutes
Process repeated for all beams

**Considering the effect of beamforming**

Distribute the power per beam to obtain statically conservative compliance boundaries

See also BioEM 2018 poster PB 26
Conclusions

— 5G NR is an evolution of LTE and will make use of frequency bands above 6 GHz
  — lower frequencies will still provide the backbone for mobile communications

— The current technical challenges in EMF compliance assessments are due to:
  — A constantly increasing complexity in the wireless equipment
  — A change in the exposure metric > 6 GHz

— EMF compliance assessment standards are evolving to ensure the availability of harmonized procedures
  — For base station, the priority is to standardize methods for mMIMO products
  — For devices, efforts should be made in specifying methods, procedures and in identifying equipment which allow for an increased efficiency of EMF compliance testing