Challenges in standardization related to EMF compliance above 6 GHz

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Challenges in EMF compliance standardization for devices > 6 GHz

EMF compliance challenges for devices > 6 GHz

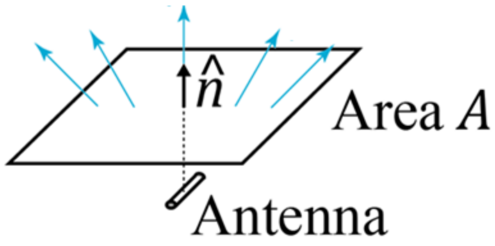
- Challenges related to the definition of the exposure metric
- Challenges related to the assessment of incident power density in close proximity of a device
- Challenges related to the efficiency of compliance assessment methods

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 $\hat{\boldsymbol{n}}$

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



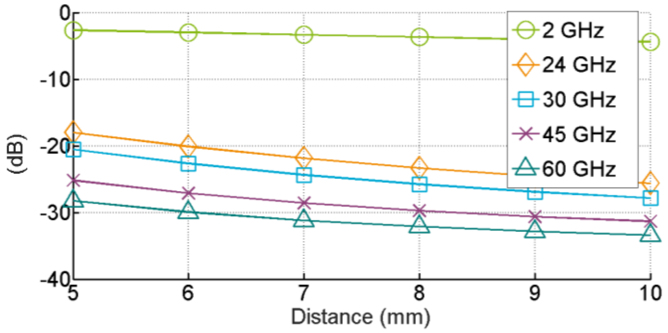
Ongoing discussion IEC/IEEE:

- 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 ($\boldsymbol{S} = \boldsymbol{E} \times \boldsymbol{H}^*$) rather than the energy flux more appropriate to define exposure limits (e.g. due to coupling conditions)?

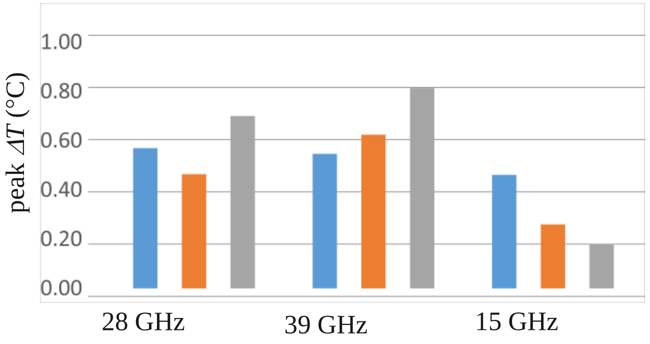
Incident power density, insights

- 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

2 x 2 array, contribution of the reactive field to the total absorbed energy [1]



Measured temperature elevation on the forearm at Pmax to comply with IEEE/ICES draft ERLs (horn antennas)

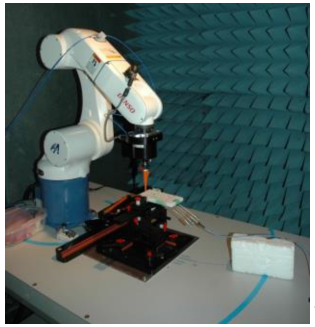


[1] Colombi et al., "RF Energy Absorption by Biological Tissues in Close Proximity to Millimeter-Wave 5G Wireless Equipment", IEEE Access, 2018
[2] Christ et al., "Thermal Modeling of the Near-Field Exposure from Wireless 5G Devices", EuCap 2018
Analysis", IEEE Access, 2018
[3] Carrasco et al., "Exposure Assessment of Portable Wireless Devices above 6 GHz", under review
[4] Christ, "Thermal Modeling of the Near-Field Exposure from Wireless 5G Devices, preliminary report MWF '6GHz+" research project, 2018,
[5] Hashimoto et al., "On the averaging area for incident power density for human exposure limits at frequencies over 6 GHz", Phys Med Biol, 2017
[6] Foster et al, "Thermal Modeling for the Next Generation of Radiofrequency Exposure Limits: Commentary", 2017
[7] Xu et al.,"RF Compliance Study of Temperature Elevation in Human Head Model Around 28 GHz for 5G User Equipment Application: Simulation
[8] Sasaki et al., "Monte Carlo simulations of skin exposure to electromagnetic field from 10 GHz to 1 THz", Phys Med Biol, 2017
[9] Colombi et al., "Comparison Between Numerically and Experimentally Assessed Skin Temperature Elevations for Localized RF Exposure at Frequencies Above 6 GHz", BioEM 2018 PB36

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

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

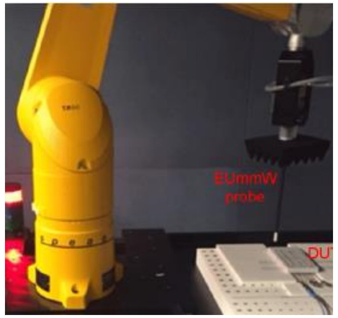


Source: IEC TR 63170

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)



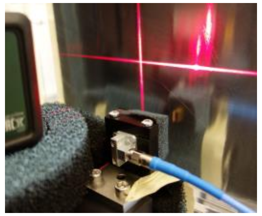
Source: IEC TR 63170

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)

Source: MVG presentation for IEC TC106 JWG12



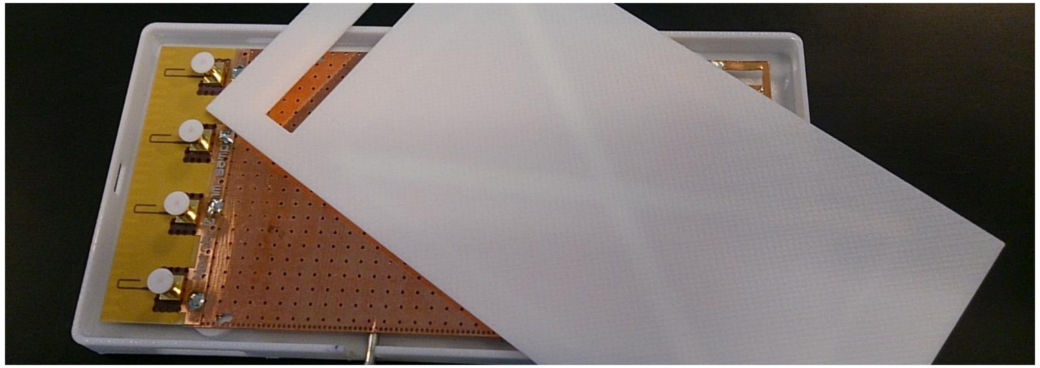
Source: IEC TR 63170

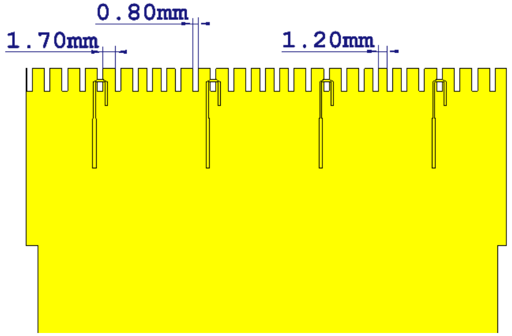
E-field measurements (amplitude and phase)
E-field back-propagation (inverse source, PWS, etc.) to the evaluation plane
H-field determination
Power density evaluation

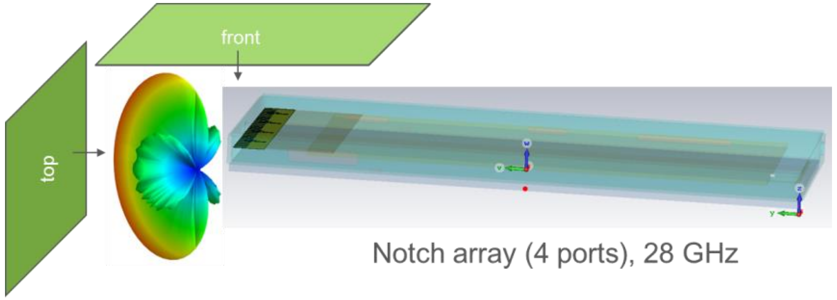
Challenges: (1) Measuring phase is a difficult task (2) The uncertainty of back-propagation need to be characterized

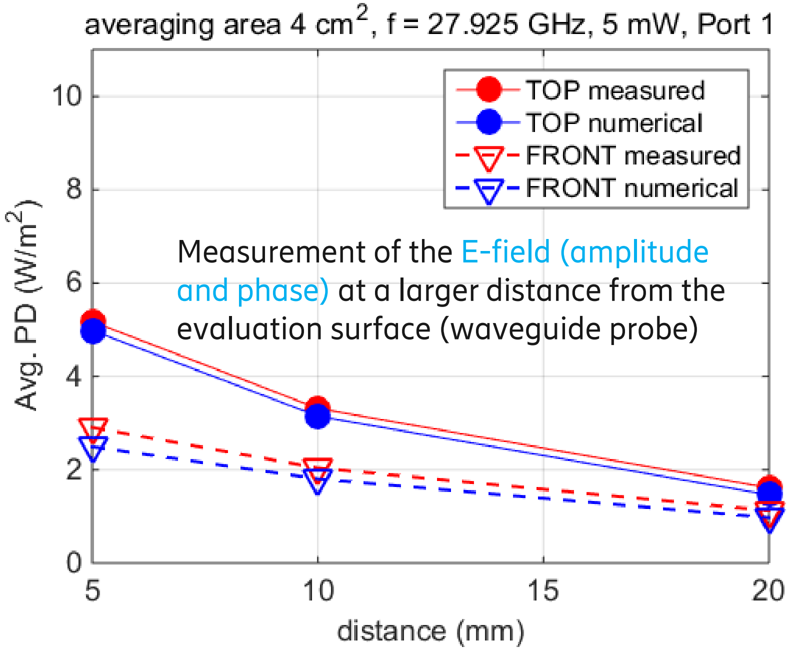
IEC TR 63170 use case

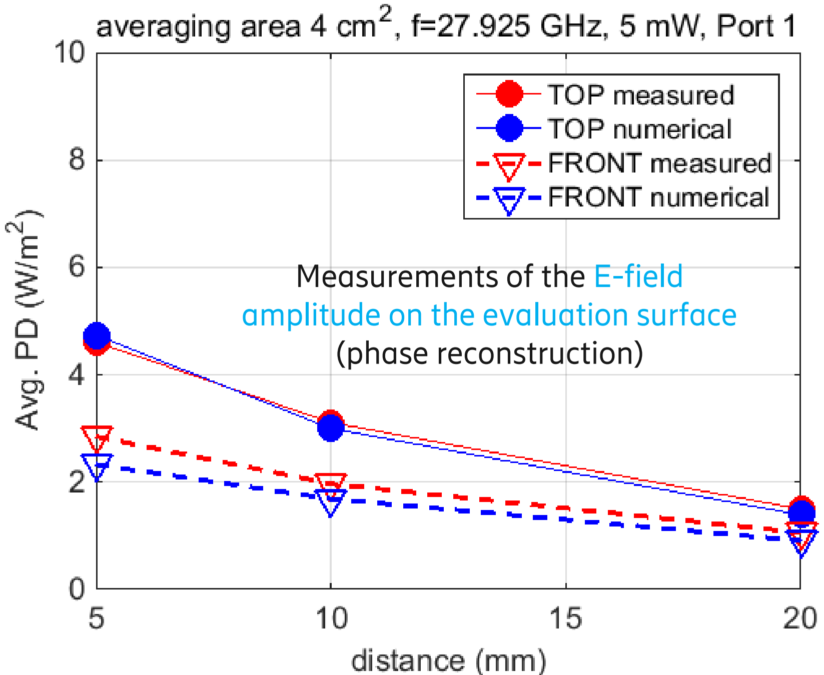
SONY mockup, notch antenna array, 28 GHz



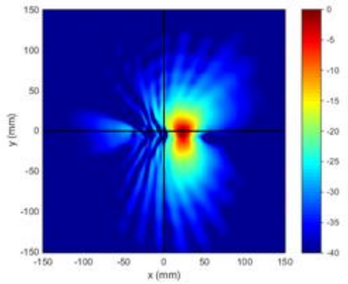




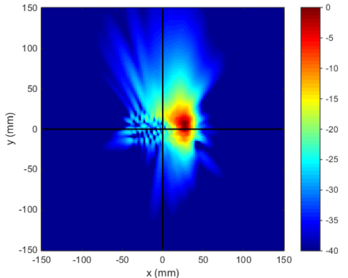




PD distribution, simulation



PD distribution, measurements

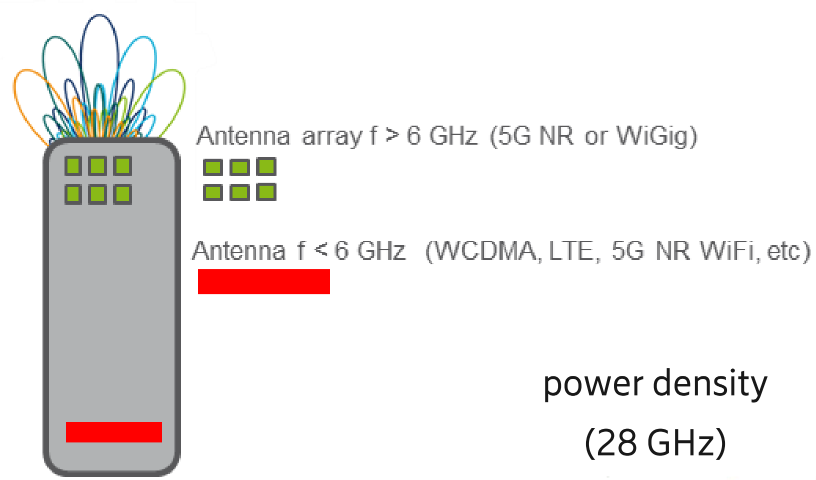


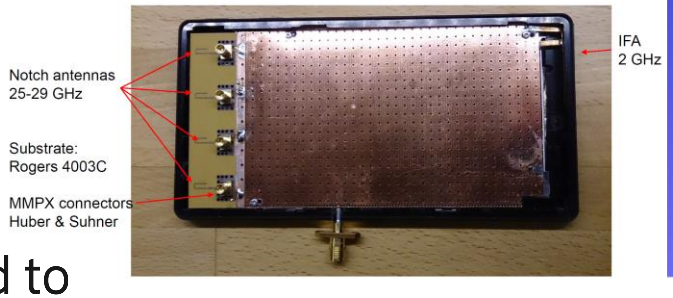
Challenges related with the efficiency of compliance assessment methods

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

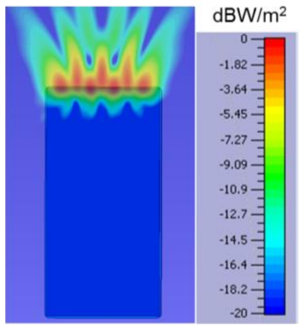
› Devices will be characterized by multiple transmitters above and below 6 GHz
  – Antenna arrays require field combining to determine exposure for the possible excitations
  – The total exposure ratio (TER) including contributions from above and below 6 GHz need to be assessed) $TER = SAR/SAR_{lim} + Sinc/Sinc_{lim}$

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

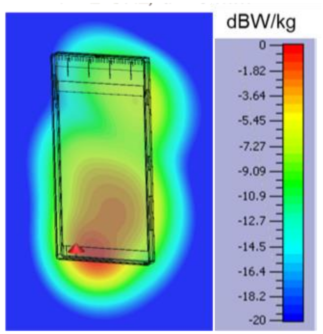




power density (28 GHz)



SAR (2 GHz)



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

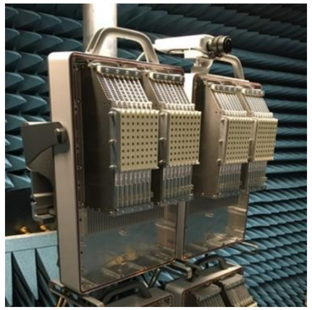
- Beamforming and massive MIMO (mMIMO)
  - Energy is focused in directions where it is needed
  - Large variability of transmitted signals in time and space

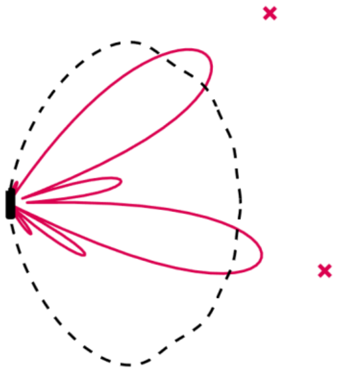
Source: GSMA

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

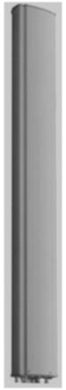
mMIMO/beamforming: transmits a radio signal only to connected users

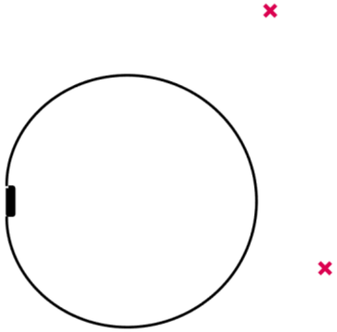
mMIMO product





'Conventional' base station



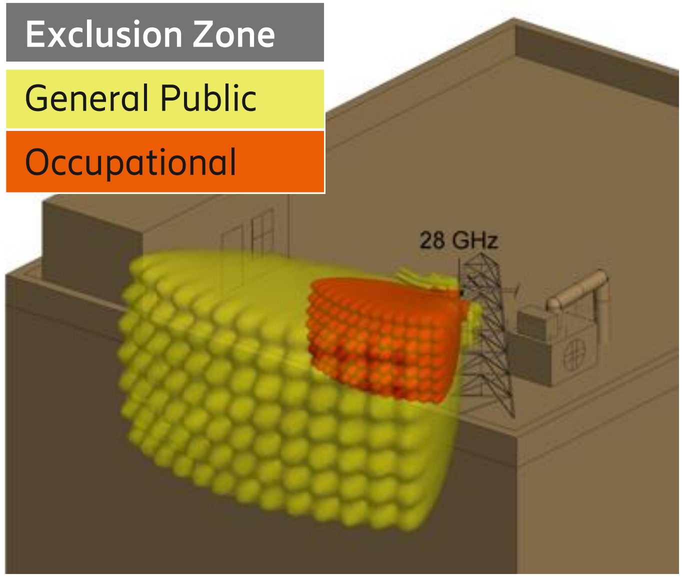


Realistic EMF compliance assessment models applicable for mMIMO are to be included in IEC 62669 [1][2]

[1]Thors et al., "Realistic Maximum RF EMF Exposure for 5G BS using Array Antennas and Massive MIMO", IEEE Access, 2017
[2]P. Baracca, A. Weber, T. Wild and C. Grangeat, "A Statistical Approach for RF Exposure Compliance Boundary Assessment in Massive MIMO Systems", WSA 2018

Example – massive MIMO @ 28 GHz (Macro)

Perspective view



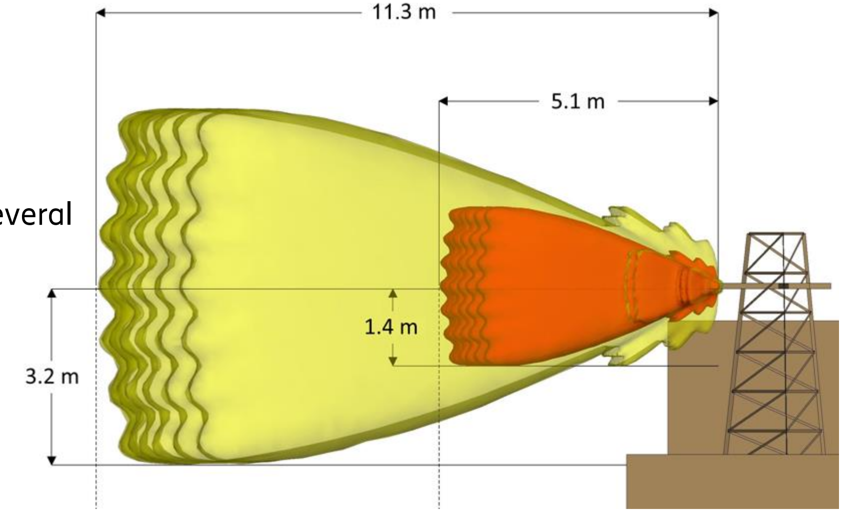
Array antenna with 8 × 8 elements

$f = 28$ GHz
60° horizontal scan range
15° vertical scan range
$EIRP_{\max} = 72$ dBm

Without considering the effect of beamforming

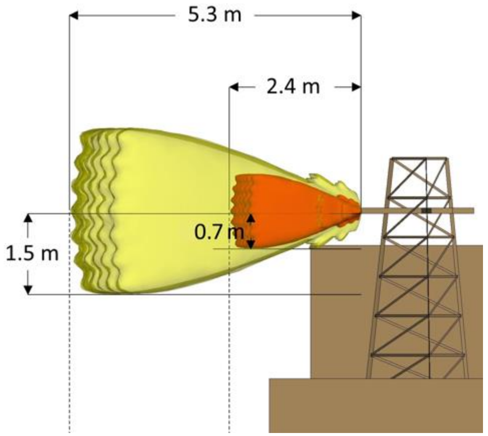
All transmitted power assumed directed in the same beam for several minutes

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

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