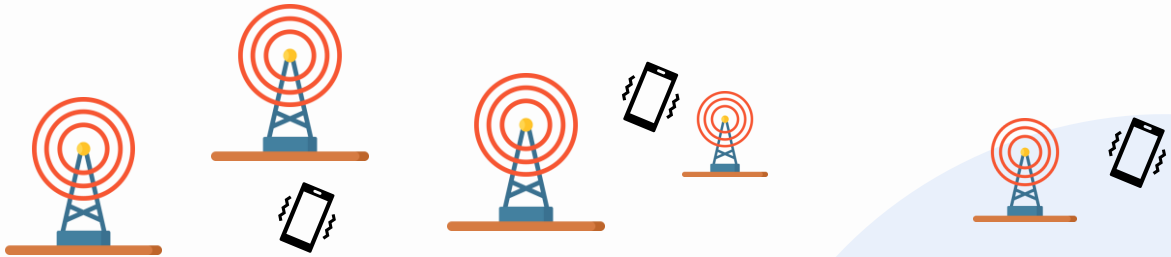
Computational Study of 5G Technology Dosimetry on SAM Human Head Model



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5TH GENERATION (5G) TECHNOLOGY

- Why is it introduced?
  - **Increased capacity demands**
- Applications:
  - **Mobile networks**
  - Patient monitoring in healthcare (wearables)
  - Virtual reality
- Frequency range – **3.4-3.8 GHz**
- Accompanying technology - **MIMO antennas; Beamforming**
- Electromagnetic dosimetry – **increased exposure** (more dense coverage and beam intersection)
- **State-of-the-art findings:**
  - Exposure depends on the e.g. **beamforming patterns**
  - **Deeper brain tissue is less affected** than in previous networks (higher fr.)
  - No study shows results surpassing the current guidelines
  - **Epidemiological study on mice – gene expression changes!**

EMF EXPOSURE CLASSIFICATION

- **What factors influence electromagnetic field (EMF) exposure? –** frequency, field intensity, exposure interval, field polarization and dielectric properties of the absorbing material (e.g. tissues' dielectric properties) [1]
- **2 main effect groups - thermal effects** (principally) and **non-thermal effects** (more subtle biochemical and bioelectrical consequences)
- **Thermal effects** :
  - Considered hazardous in case tissue's temp. rises by >1°C (conservative measure)
  - Used to classify the exposure as they are direct, measurable, well-documented and predictable
  - Expressed by specific absorption rate (SAR)
- **Non-thermal effects:**
  - Research results vary – often inconsistent and contradictory
  - Usually after long-term exposure – development of atypical symptoms (e.g. headaches, weakness, skin tingling etc.)

STUDY'S OBJECTIVE

Computational study

of the **5G radiation** into the IEEE Specific Anthropomorphic Mannequin **(SAM) head model**

Why?

- Modeling of EMF doses reproduceable in epidemiological studies
- Establishment of safer guidelines
- Reference for future experimental studies with the physical head phantom

NUMERICAL MODELING

- FEKO 2024 (Altair Engineering Inc., Troy, Michigan) software for high-frequency electromagnetic simulations
- **Software capabilities:**
  - Variety of numerical techniques and hybridizations for different electromagnetic problems
  - Finite element method **(FEM),**
  - Method of moments **(MoM),**
  - MLFMM,
  - Finite Difference Time Domain (FDTD), etc.

- **FEM** - solves partial differential equations:
  - problem domain volume is discretized – tetrahedrons
  - Each element is assigned with a simpler eq. Approximating the original eq.
  - All eq. are assembled into a larger system to describe the full field behavior of the problem
- **MoM** –solves integral equations:
  - Problem domain is discretized – segments /patches (usually used for antennas)
  - Unknown quantity (e.g.. Current density) is approximated by a basis function for each element
  - All eq. are assembled in a larger system to describe the problem's behavior

COMPUTATIONAL MODEL COMPOSITION

HEAD MODEL

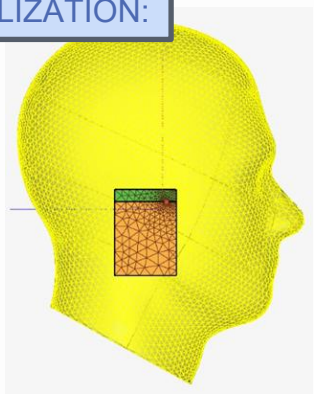
- SAM head model [1]
- Designed according to the 90th -percentile anthropometric data corresponding to the adult male head (US Army)
- Homogenous model with the following properties at 2.45 GHz: $\varepsilon_r = 37.9$, $\sigma = 2.91\ S/m$,$\rho = 1000\ kg/m^3$ (IEEE Std 1528-2013)

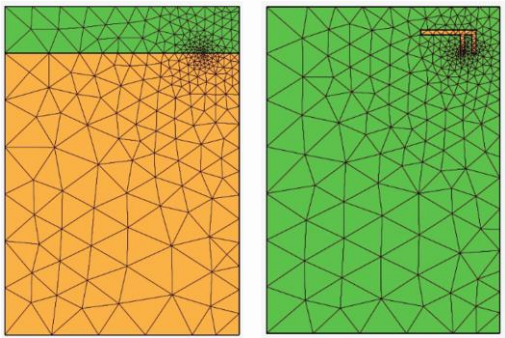
5G ANTENNA

- Planar inverted F antenna (**PIFA**) [2] – **3.5 GHz**
- Dim. of 5x7x0.16 cm
- Substrate properties (FR4 material): $\varepsilon_r = 4.8$; $tan\delta = 0.017$
- Tot. radiated power - 0.2 W (FCC guidelines for 5G networks) [3]
- 10 & 15 mm distances from the model [2]

IDEA:

REALIZATION:





[1] IEEE, 2013, IEEE Std 1528-2013
[2] Kundu et al., 2021, J. Phys.: Conf. Se
[3] FCC, 2024, FCC Ruling

EXPOSURE GUIDLINES

Expressed in...

a form of specific absorption rate (SAR) averaged over 1 or 10 g of tissue (depending on the reference)

Guideline differentiation:

- General public and occupational exposure; both are conservative
- Head, limbs and whole body exposure

Our scope – general public

Standard bodies and regulators:

- IEEE (ICES/TC9RF/EMF exposure 5)
- International Commission on Non-Ionizing Radiation Protection (ICNIRP)
- Federal Communications Commission (FCC)

Head exposure guidelines:

$SAR_{10g} = 2\ W/kg$

$SAR_{1g} = 1.6\ W/kg$

SAR COMPUTATION (1)

Pointwise SAR [1,2]

$$SAR = \frac{\sigma}{2\rho}|\vec{E}|$$

- σ – tissue conductivity
- ρ – tissue density
- $|\vec{E}|$- electric field magnitude at a specific coordinate in the model

SAR averaged over 1 /10 g

General expression:

$$SAR_{av} = \frac{1}{V}\int_V SAR\ dV$$

- V - tissue volume encompassing either 1 or 10 g of tissue
- SAR – point-wise SAR value calculated in the points encompassed by the volume; or function that describes the SAR's distribution in the volume

Illustrative implementation:

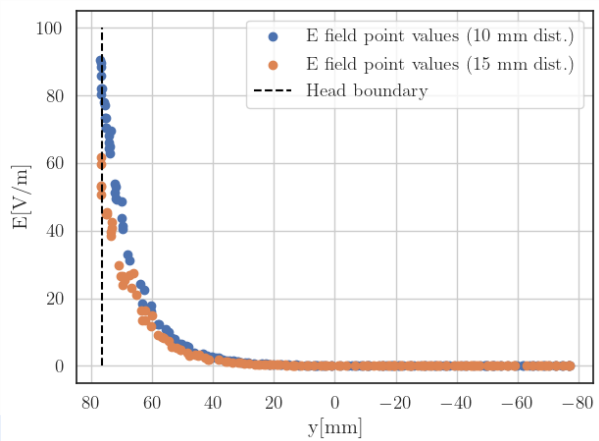
$$SAR_{av} = \frac{\sum_i^N SAR_i V_i}{\sum_i^N V_i}$$

- Used in FEM-based software
- SAR_i – average SAR of a specific finite element (Vi to scale it)
- V_i – volume of each finite element
- Summation – SAR contributions from all relevant elements
- Total volume – encompasses 1/10 g of tissue

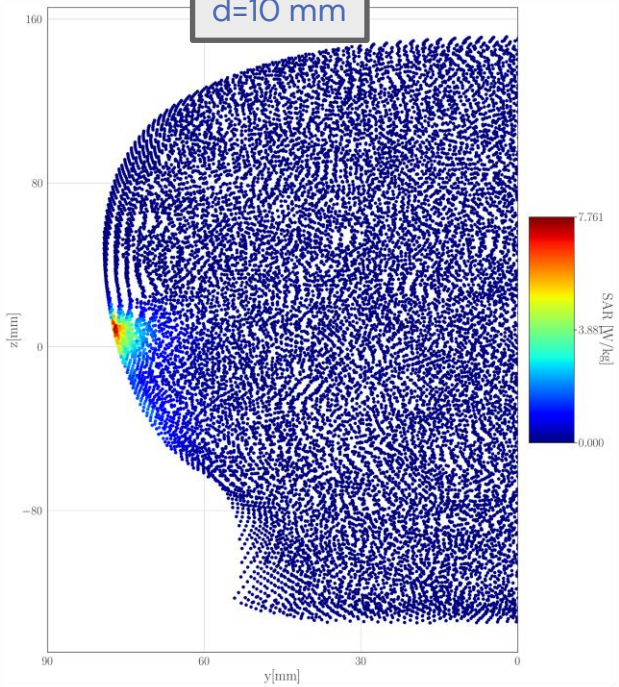
RESULTS (1)

Pointwise SAR – values are the greatest around the head's surface and directly below the antenna, as expected

- **Point-wise SAR** across the coronal head section (cut directly below the antenna position above the head's surface)

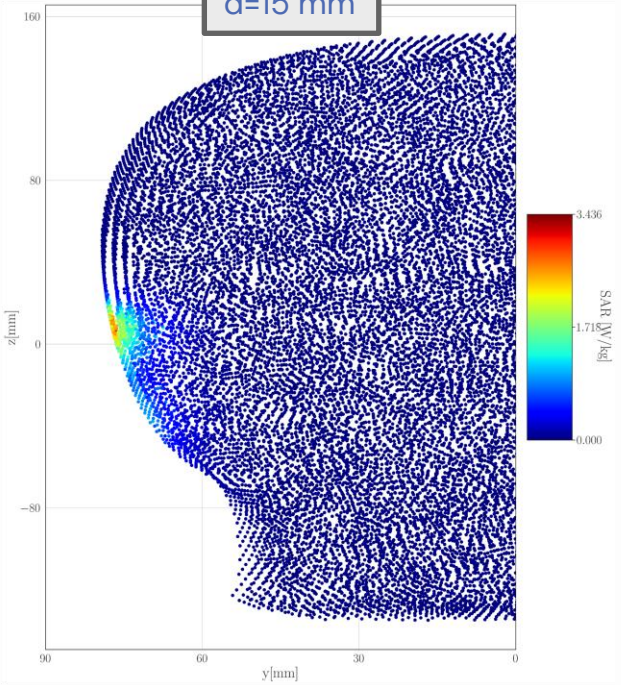


d=10 mm



(a)

d=15 mm



(b)

[1] Razek A. Appl Sci. 2023;13(3):1265.

RESULTS (2)

- SAR_{1g}/SAR_{10g} – calculated using a build-in feature in FEKO
- **Target points:**
  - **1st point – 5 mm below the maximum E – field value** (it was on the surface and hence averaging would be performed over air)
  - **Subsequent points –** 3 points along the direction of the positive y axis (inside the head; 5 mm apart)

Ant. Dist.	Points (x,y,z)	SAR 1g [W/kg]	SAR 1g [W/kg]	SAR 10g [W/kg]	SAR 10g [W/kg]
10 mm	-3.936, 72.106, 9.184	4.05	3.88	/	/
	-3.936, 67.106, 9.184	1.48	1.35	1.51	1.51
	-3.936, 62.106, 9.184	0.547	0.480	0.732	0.661
	-3.936, 57.106, 9.184	0.206	0.173	0.287	0.258
15 mm	-3.640, 71.810, 6.603	1.72	1.62	/	/
	-3.640, 66.810, 6.603	0.676	0.648	0.727	0.597
	-3.640, 61.810, 6.603	0.274	0.259	0.364	0.406
	-3.640, 56.810, 6.603	0.109	0.098	0.148	0.168

Guidlines	SAR 1g [W/kg]	SAR 10g [W/kg]
ICNIRP & IEEE	/	2
FCC	1.6	/

SAR_{1g} value in case of the 10 mm antenna distance is above the FCC guideline, but at present it is not alarming as the guidelines are conservative, and homogenous models tend to overestimate exposure [1]

SAR COMPUTATION (2)

Commercial software (e.g. FEKO)

- Exact numerical algorithm is not specified
- Generally accepted practice for electromagnetic FEM – edge basis functions are used (ensure tangential E-field component travels continuously)
- SAR calculation – when computing the SAR over each tetrahedron, **edge basis functions** were used

In-house computation

- Python code
- E-field values at all nodes of the model were exported from FEKO and an in-house tetrahedron mesh was created
- SAR calculation – when computing the SAR over each tetrahedron, **vertex/node basis functions** were used

DISCUSSION AND CONCLUSION

- A SAM head model was placed in the near field of a 3.5 GHz PIFA antenna placed at 2x different distances and the electromagnetic dosimetry was evaluated trough SAR
- The achieved SAR values **never exceeded ICNIRP/IEEE guidelines, but they exceeded FCC ones** (superficial part of the head)
- Usage of **homogenous head model could potentially overstate the exposure**, but it is used to obtain more conservative results
- **Successive steps:**
  - Computational studies on **more complex head models** (additional tissues and accurate ear model) and **realistic antenna**
  - **New head-antenna distances** – new FCC computational study guidelines

Thanks!

Do you have any questions?

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