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Simulation-Based Assessment of Radiofrequency Electromagnetic Fields Exposure of Insects in Terms of Specific Absorption Rate

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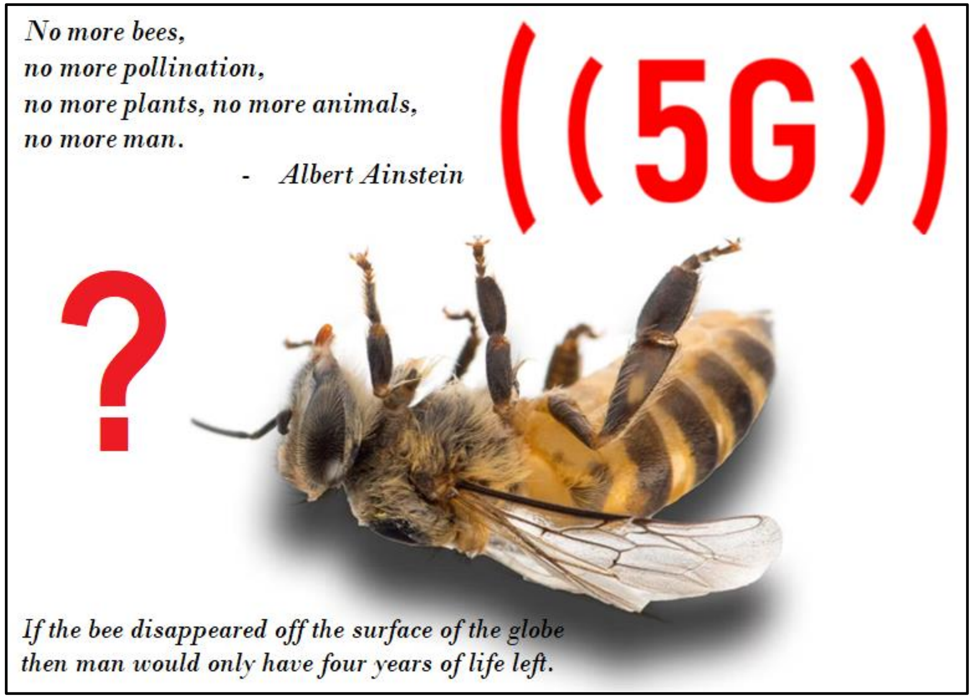
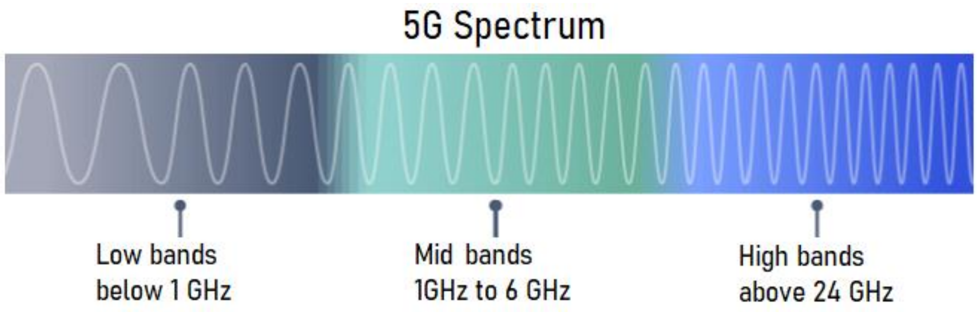
Introduction





The development of the 5th generation (5G) and next-generation of wireless communication networks could alter the nature of radio-frequency electromagnetic field (RF-EMF) exposure in the environment. Biological organisms, including insects, are exposed to these fields. A fraction of these RF-EMFs is absorbed by their bodies and can cause dielectric heating (ICNIRP 2020).

The future planned telecommunication systems will use millimeter wavelengths (30-300 GHz), which have wavelengths comparable to the body (part) dimensions of some small-size biological objects, such as insects. This could cause whole-body or partial-body resonance during exposure. For some insects, the resonant frequencies also could be found in the currently used and future planned frequencies between 2-30 GHz. The study of these issues is a significant and relevant topic today as insects, especially bees, pollinate 80% of all plants and are an essential part of the ecosystem and biodiversity.

State of art of the field before

The existing studies are mostly focused on determining the mechanisms of bio-effects of the EMFs using experimental measurements for the frequencies less than 6 GHz. These frequencies are usually not resonant for insects and do not properly pose a risk of their extinction. Although, some adverse effects have been described.

An alternative approach to studying EMF exposure influence on bio-objects is numerical simulations to determine the RF-EMFs absorption in body tissues using numerical models and phantoms. The absorption of RF-EMFs energy in biological organisms quantified by the SAR (Specific Absorption Rate [W/Kg])

Existing studies related to insect EMF exposure for the frequencies above 6 GHz were conducted at Ghent University (Belgium). These studies have shown a maximal absorption of RF-EMFs in insects at frequencies above 6 GHz.

- A. Thielens, D. Bell, D. B. Mortimore, et al. “Exposure of Insects to Radio-Frequency Electromagnetic Fields from 2 to 120 GHz,” Sci Rep. vol. 8, p. 3924, 2018.
- A. Thielens, M.K. Greco, L. Verloock et al., “Radio-Frequency Electromagnetic Field Exposure of Western Honey Bees,” Sci Rep 10, p. 461, 2020.
- De Borre E, Joseph W, Aminzadeh R, et al. Radio-frequency exposure of the yellow fever mosquito (A. aegypti) from 2 to 240 GHz. PLoS Comput Biol. 2021 Oct 28; 17(10):e1009460. doi: 10.1371/journal.pcbi.1009460. PMID: 34710086; PMCID: PMC8577778.
- Toribio D, Joseph W, Thielens A, “Near Field Radio-Frequency Electromagnetic Field Exposure of a Western Honey Bee”, IEEE TAP, 2021.
- Herssens, H., Toribio, D., De Borre, E, Thielens, A. “Whole-Body Averaged Absorbed Power in Insects Exposed to Far-Field Radio-Frequency Electromagnetic Fields”, IEEE Trans. vol. 70, no. 11, pp. 11070-11078, Nov. 2022, doi: 10.1109/TAP.2022.3209201.

In these studies, the insects are modeled as homogeneous dielectric objects (includes one tissue). Also, the SAR values have not been calculated.

Goals and Objectives

The goal of this proposed research is to investigate the possible harmful effect of radio-frequency electromagnetic fields (RF-EMFs) emitted from telecommunication networks, including 5G networks on the most important insect, a honey bee from 2.5 to 100 GHz frequencies using computer simulations.

To achieve this goal, it was necessary to implement the following tasks:

(1) Creation of honey bee 3D realistic heterogeneous model.
(2) Selecting and assigning dielectric properties to tissues.
(3) Conducting EM simulations to determine the SAR values inside the insect tissues, at selected frequencies 2.5 GHz, 3.7 GHz, 6 GHz, 12 GHz, 25 GHz, 40 GHz, 60 GHz, 85 GHz, and 100 GHz (9 frequencies).

Methods and Materials

Creation of the Insect models

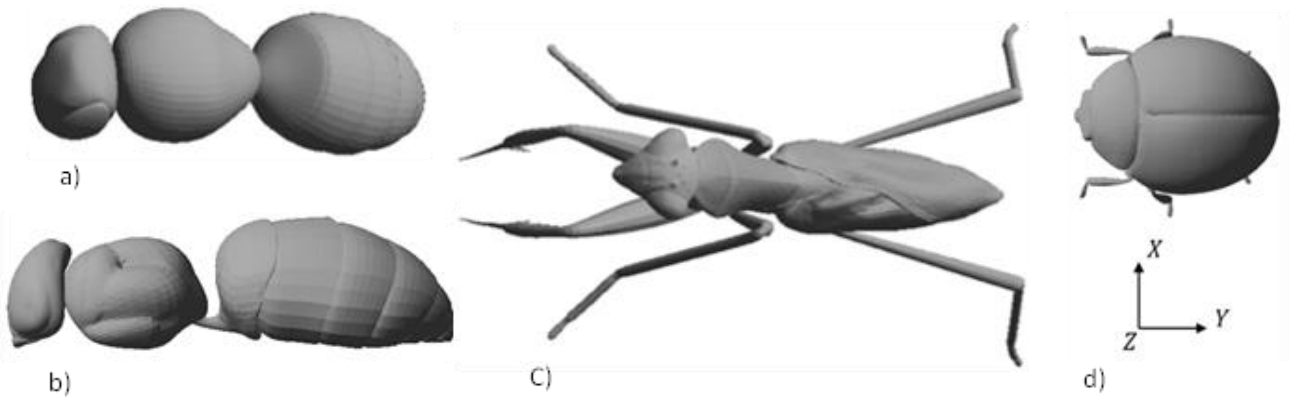


Fig 1. Insects’ 3D models in STL format: (a) the honeybee, (b) the wasp, (c) the mantis, and (d) the ladybug.

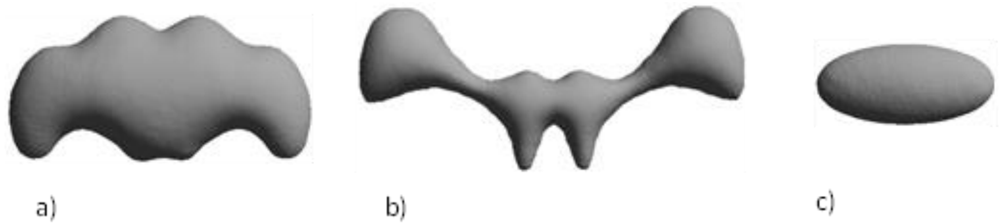


Fig 2. Brain models for (a) the honeybee and the wasp, (b) the mantis, and (c) the ladybug.

Dimensions of the insect models and their brain models.

Insects	Length (mm)	Width (mm)	Height (mm)	Volume (mm^3)	Mass (mg)
Ladybug	7.2	5.4	3.6	33.71	36.20
Honey bee	13.4	5.0	5.2	122.19	131.24
Wasp	17.4	5.4	6.0	146.28	156.82
Mantis	68.3	13.7	24.6	2097.44	2252.65
Ladybug brain	1	0.4	0.4	0.105	0.11
Honeybee brain	1.8	0.8	1.3	0.931	0.97
Wasp brain	2	1	1.5	1.035	1.08
Mantis brain	3.7	1.1	1.6	1.371	1.43

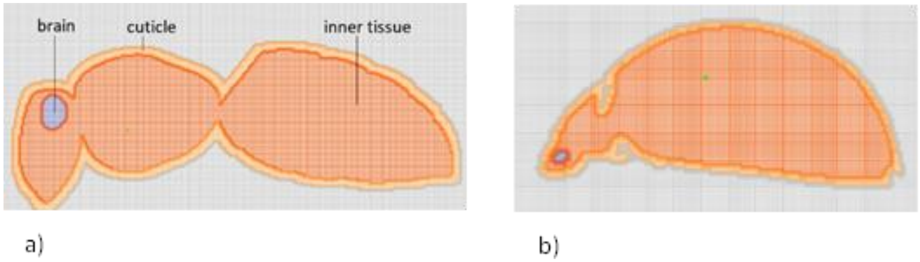


Fig 3. Mid-Sagittal cross-sections of two 3-tissue discrete heterogeneous models of: (a) the honeybee and (b) the ladybug.

- Initial insect models -> is taken from open repositories of 3D models (Open3DModel - https://open3dmodel.com/, CadNav - https://cadnav.com/
- We have created 3D surfaces for the brain and inner tissues of the insects.
- Used Graphics Software for processing insect 3D models and brains: **Blender** and **Autodesk Netfabb premium.**
- Brain models -> The honeybee and wasp brain models were created using Blender based on the brain model of Heinze et al. (2021). The mantis brain model was based on the brain model from Rosner et al. (2017)
- Tissue EM parameters are selected from the IT’IS Database (IT’IS Foundation, Zurich, Swithzerland).

Methods and Materials

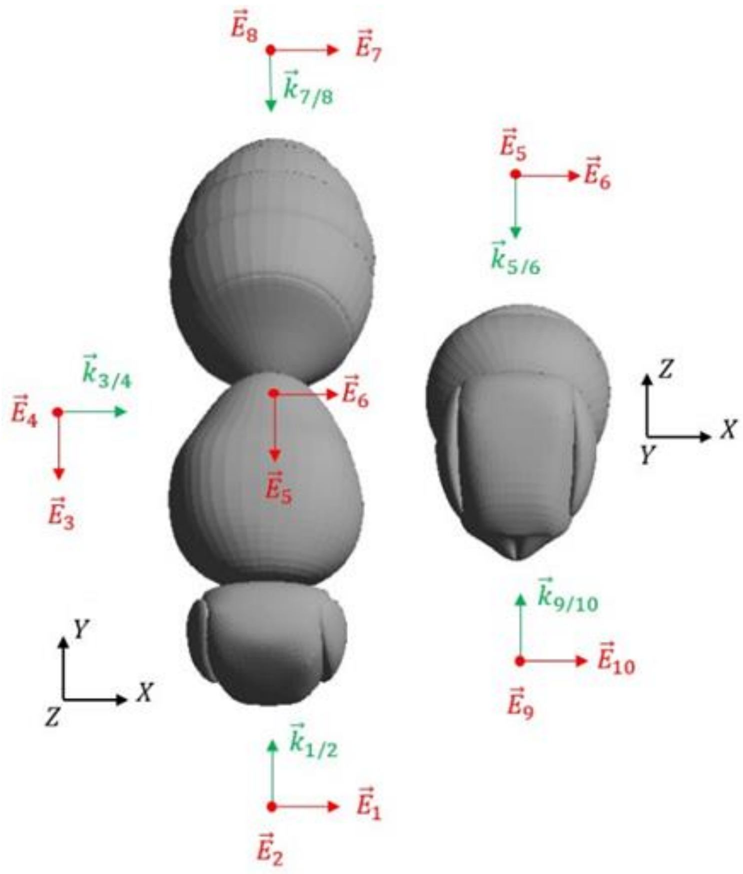


Fig 4. The directions of incident plane waves and considered E-field polarizations.

Tissue parameters used in this study.

Tissue Parameters	cuticle		inner tissue		brain	
	ε	σ [S/m]	ε	σ [S/m]	ε	σ [S/m]
2.5 GHz	38.7	1.79	51.5	2.0	42.5	1.54
3.7 GHz	36.2	2.83	49.8	3.0	40.9	2.38
6 GHz	31.8	5.09	47.2	5.5	38.1	4.44
12 GHz	23.2	10.8	38.2	13.9	31.0	11.1
25 GHz	14.3	18.8	25.3	30.1	20.2	23.7
40 GHz	10.3	23.7	17.2	41.8	14.1	32.5
60 GHz	8.04	27.5	12.2	50.7	10.2	39.05
85 GHz	6.75	30.4	9.3	56.9	8.2	43.7
100 GHz	6.30	31.7	8.28	59.49	7.24	45.6
	density ρ [kg/m³]					
	1100		1061		1043	

- **EMF Source:** sinusoidal waveform of a plane wave at a single (harmonic) frequency.
- **The selected frequencies: 2.5, 3.7, 6, 12, 25, 40, 60, 85, and 100 [GHz]** (9 frequencies)
- **Incident plane wave directions: front, back, top, bottom, left** (5 directions) with two orthogonal E-field polarizations (10 E-field polarizations).
- **EM Simulation software: FDTDLab, EM-FDTD Solver (TSU, Tbilisi, GEorgia).** [90 EM simulations (10 polarizations × 9 frequencies) for each insect.

The Finite-Difference Time-Domain (FDTD) technique was used for EM simulations to evaluate the SAR values inside the insect body tissues.

The obtained results

RF-EMF Absorption in the Ladybug

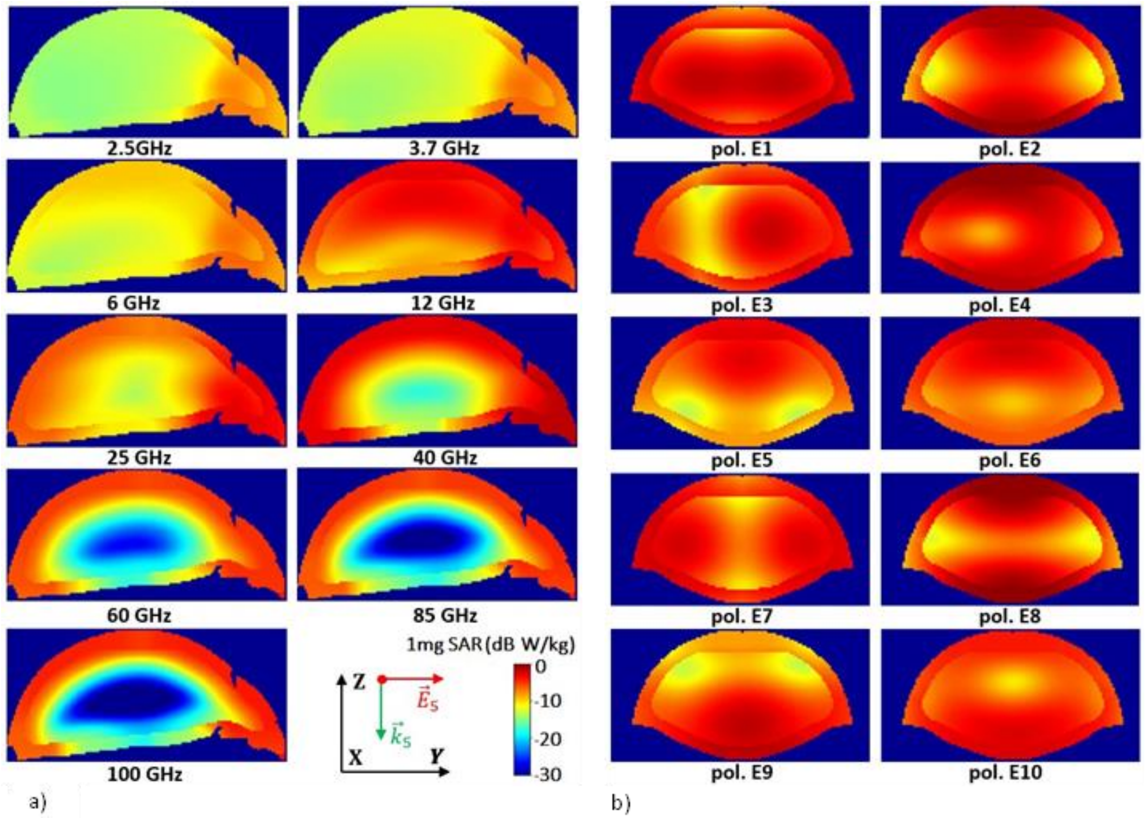


Fig 5. 1 mg SAR distribution inside the ladybug model for (a) the mid-sagittal section of the insect, when the E-vector is directed along the Y-Axis (Pol. E5),

and (b) for all 10 plane waves at 12 GHz frequency in a section of the ladybug parallel to the ZX plane. 1 mg SAR values on the ruler are given in W/kg using a logarithmic (dB) scale. This ruler also belongs to Figure 9(b).

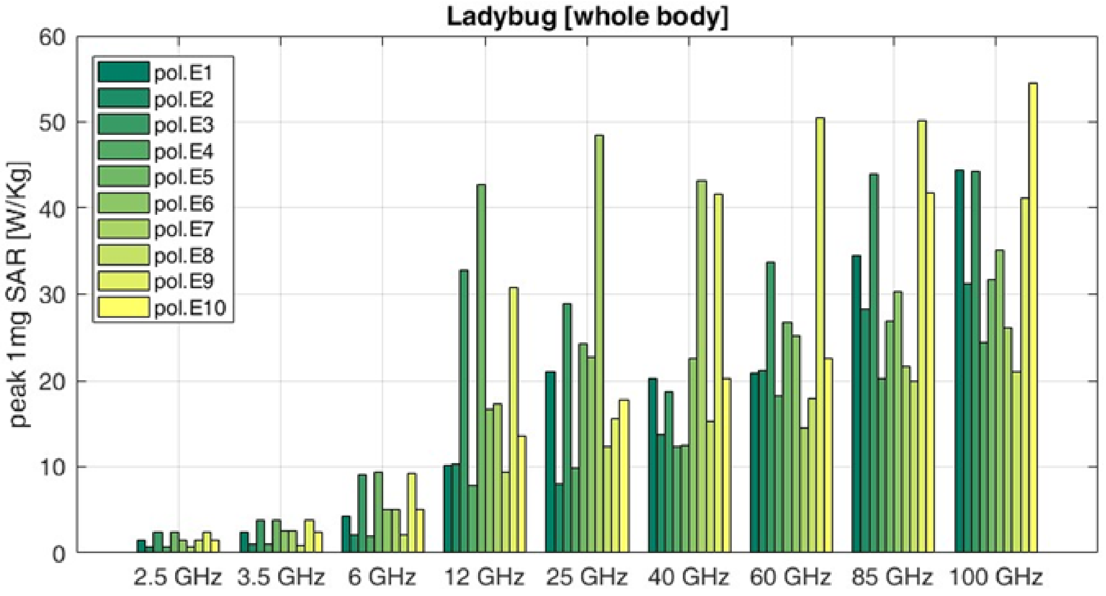


Fig 6. Peak 1mg SAR values in the ladybugs's whole body for an incident power density of 1 mW/cm².

The most efficient absorption of RF-EMFs in the inner tissue is found at 12 GHz. Such an absorption happened for all polarization at 12 GHz, as illustrated in Figure 5(b). The half wavelengths in the ladybug tissues at 12 GHz are $\lambda_c(12\,\mathrm{GHz})/2 = 1.90\,\mathrm{mm}$, $\lambda_i(12\,\mathrm{GHz})/2 = 2.35\,\mathrm{mm}$, $\lambda_b(12\,\mathrm{GHz})/2 = 2.11\,\mathrm{mm}$. The dimensions $(L \times W \times H)$ of the ladybug's inner tissue without the head are $5.66 \times 4.74 \times 2.75\,[\mathrm{mm}]$. The height of the inner tissue 2.75 mm is close to the half wavelength $\lambda_i/2 = 2.35\,\mathrm{mm}$ at 12 GHz, while the width of the inner tissue 4.74 mm is quite close to the wavelength in the inner tissue $\lambda_i = 4.70\,\mathrm{mm}$ at 12 GHz. Therefore, the resonant absorption of EMFs inside the ladybug body at 12 GHz (Figure 5(b)), can be explained. The hemispherical shape of the ladybug's body also plays a significant role in the efficient absorption of EMFs.

The obtained results

RF-EMF Absorption in the Honeybee and Wasp

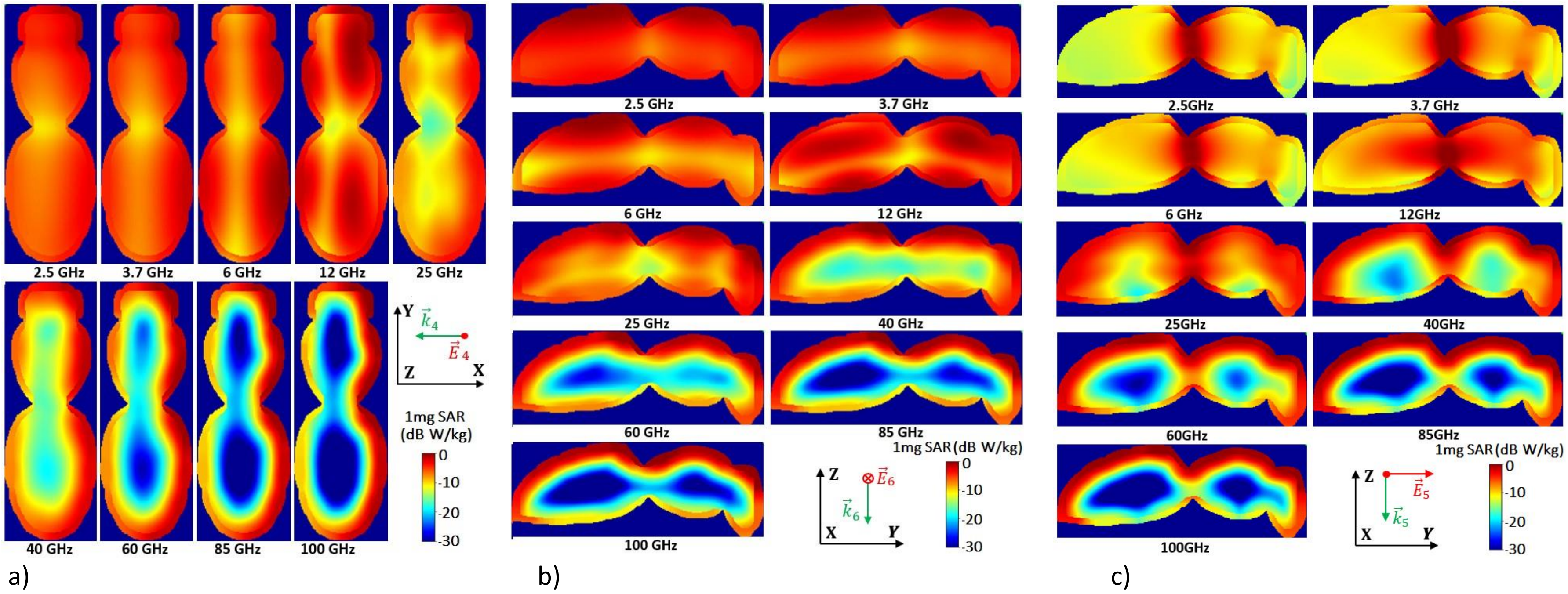


Fig. 7. 1 mg SAR distribution inside the honeybee model

(a) at the parallel section of the XY plane. The E-vector is directed along the Z-Axis (Pol. E4),

(b) at the parallel section of the ZY plane. The E-vector is directed along the X-Axis (Pol. E6),

and (c) at the parallel section of the ZY plane. The E-vector is directed along the Y-Axis (Pol. E5).

1mg SAR values on the ruler are given in W/kg using a logarithmic (dB) scale.

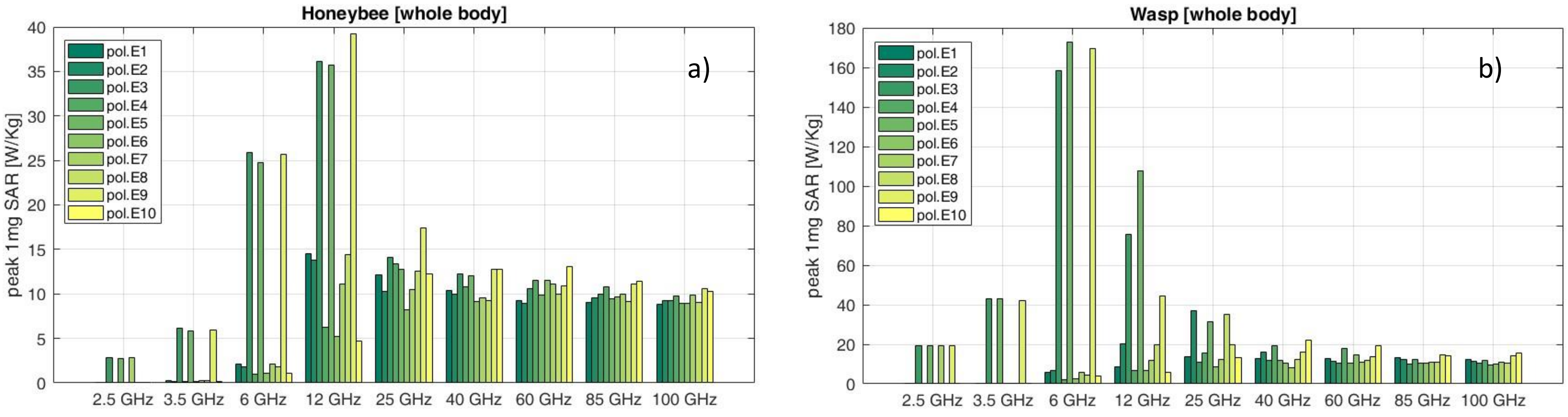


Fig 8. Peak 1 mg SAR values in the (a) honeybee's and (b) wasp's whole body for an incident power density of 1 mW/cm². 0

The obtained results

RF-EMF Absorption in the Mantis

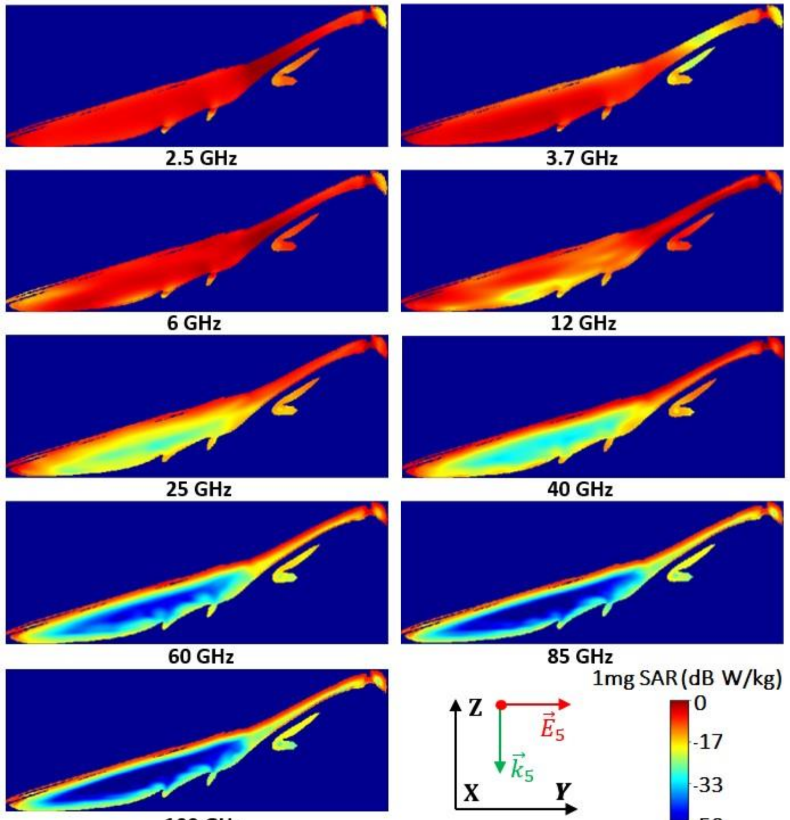


Fig 9. 1 mg SAR distribution inside the mantis model at the parallel section of the ZY plane. The E-vector is directed along the Y-axis (Pol. E5). 1 mg SAR values on the ruler are given in W/kg using a logarithmic (dB) scale.

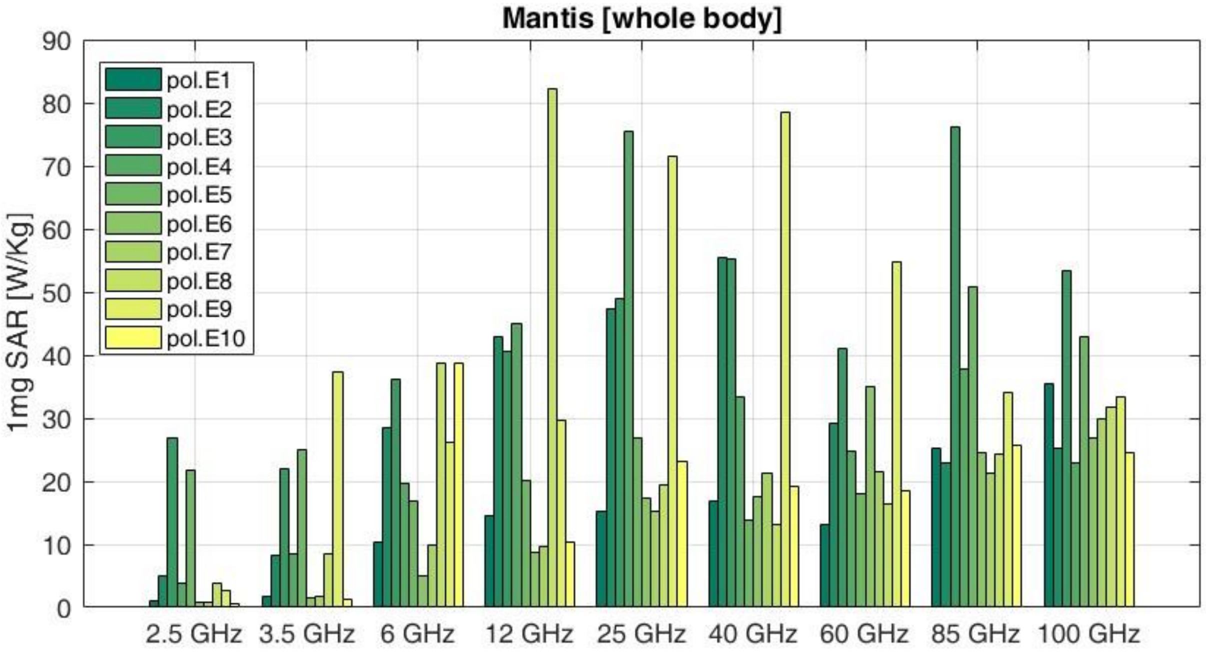
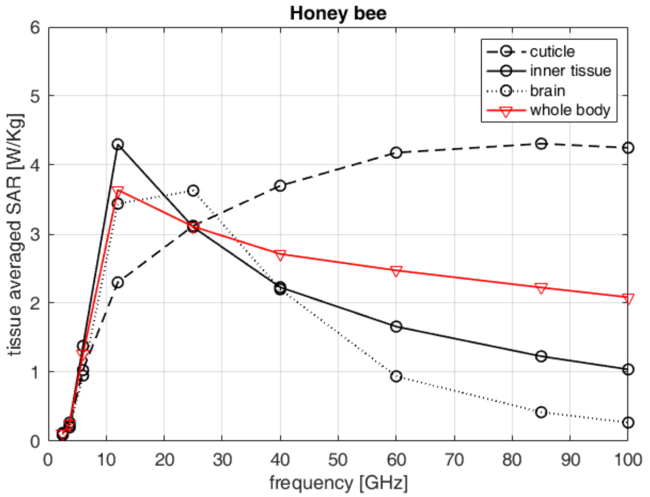


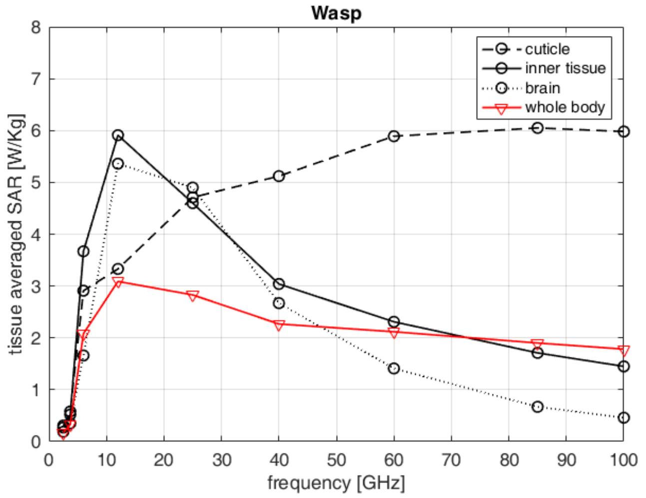
Fig 10. Peak 1 mg SAR values in the mantis for an incident power density of 1 mW/cm².

The obtained results

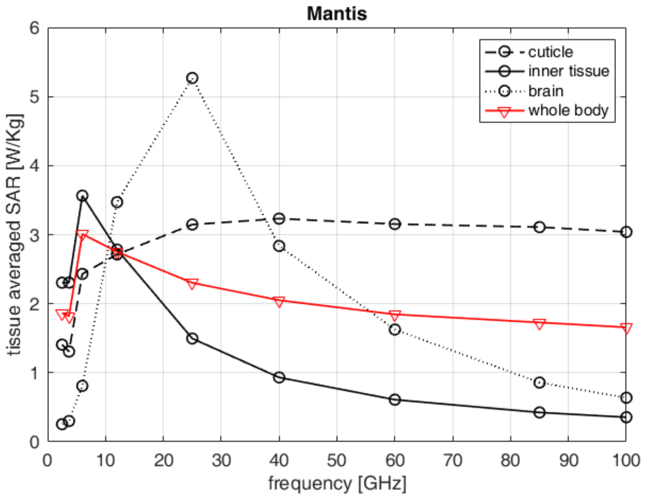
Tissue-specific SAR Values and Comparison of Insects



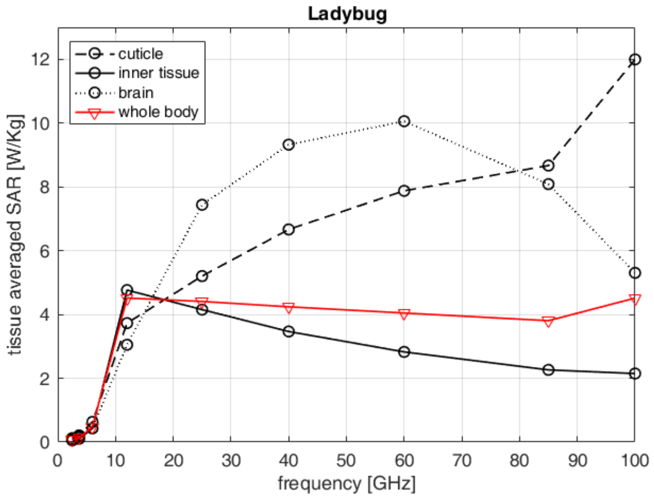
a)



b)



c)



d)

Fig 11. Tissue-averaged SAR values for all tissues and WBA SAR of insects (a) honeybee, (b) wasp, (c) mantis, and (d) ladybug. SAR values averaged for all 10 polarizations of incident E-field for an incident power density of 1 mW/cm².

Conclusion

- The paper presented a study of RF-EMF dosimetry of honeybee worker, wasp, mantis, and ladybug from 2.5 to 100 GHz, including frequencies that will be utilized in future 5G technologies.
- Discrete, 3-tissue heterogenous insect 3D models were created and used for FDTD modeling.
- The whole-body averaged SAR values and tissue-averaged SAR values were estimated in insects' tissues for 9 considered frequencies and 10 polarizations of incident plane wave. For the first time, 1 mg SAR values were determined in insect tissues.
- The obtained results showed SAR values in honeybee, wasp, ladybug, and mantis body tissues, which depend on the direction of the incident plane wave and polarization, frequency, and the insects' body sizes and peculiarities.
- The highest values of the peak 1mg SAR for the honeybee and wasp - 39.2 W/kg and 169.2 W/kg for an incident field strength of 1 mW/cm², were observed when E-field polarization was directed along the insect's length (pol. E3, E5, E9).
- The obtained results showed maximal tissue-specific SAR values in the brain at 25 GHz for the honeybee (3.6 W/kg), 12 GHz for the wasp (5.4 W/kg), 25 GHz for the mantis (5.2 W/kg), and 60 GHz for the ladybug (10 W/kg), all for an incident power density of 1 mW/cm². Maximal EMF absorption in the inner tissue was observed at 12 GHz, 4.3 W/kg, 5.9 W/kg, 4.8 W/kg for the honey bee, waps, and ladybud, respectively, and for the mantis 3.3 W/kg at 6 GHz for an incident power density of 1 mW/cm². The absorption in insects' cuticles increased proportionally with frequency. For example, for the ladybug, the tissue-specific SAR in the cuticle was 0.1 W/kg at 2.5 Ghz and 11.9 W/kg at 100 GHz for the same incident power density of 1 mW/cm².

- Future studies will consider introducing insect models that will be obtained using micro-CT scanning, examining the effects of high-frequency electromagnetic fields on other insects of different forms and sizes, conducting thermal simulations along with EM simulations, and evaluating temperature rise in insect tissues.
- Based on the present results, we expect this research to have an impact on (environmental) policymaking and standardization and regulation regarding RF-EMF emissions. We expect to contribute to the harmonization of 5G EMF safety and compliance doses and to the development of future recommendations about safe frequencies and doses of 5G-EMF on the organisms studied in the present research.

RF-EMF Fields Exposure of Insects using CT Scan-based Models

Methods and Materials

Creation of the Insect models

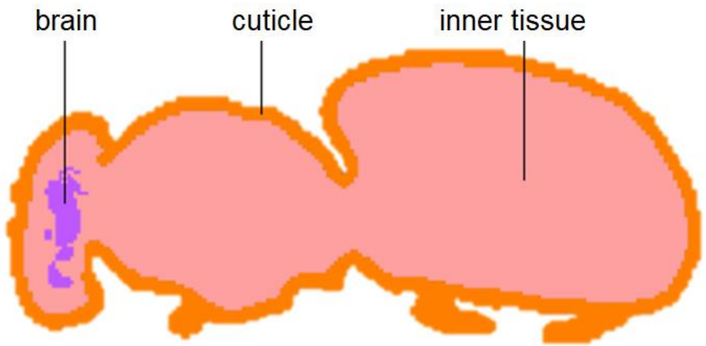
Western honeybee model

Mud Dauber wasp model

Mantis Model

3D surface for creating inner tissue

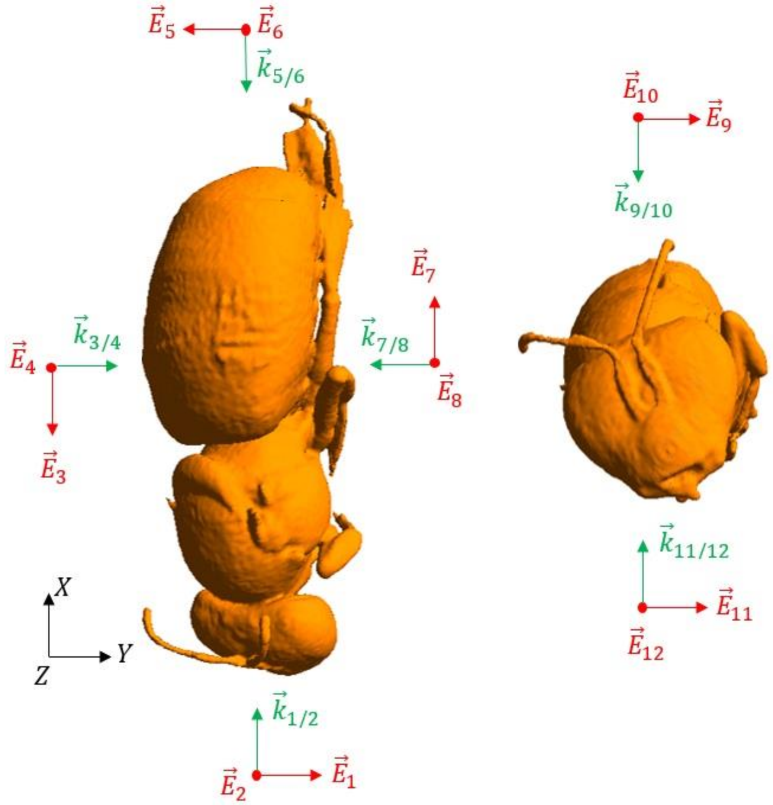
brain model



3-tissue heterogeneous discrete model of the honey bee

- Western honey bee model -> is created using micro CT imaging at Western Sydney University.
- We created Mud Dauber Wasp and Mantis models from the scans obtained micro CT imaging at Ghent University using CT reconstruction module of the software VGStudio MAX.
- Used Graphics Software for processing 3D models: **Blender** and **Autodesk Netfabb premium.**
- Brain models -> Insect Brain Database, https://www.insectbraindb.org/
- Tissue EM parameters are selected from the IT'IS Database (IT'IS Foundation, Zurich, Swithzerland)

Methods and Materials

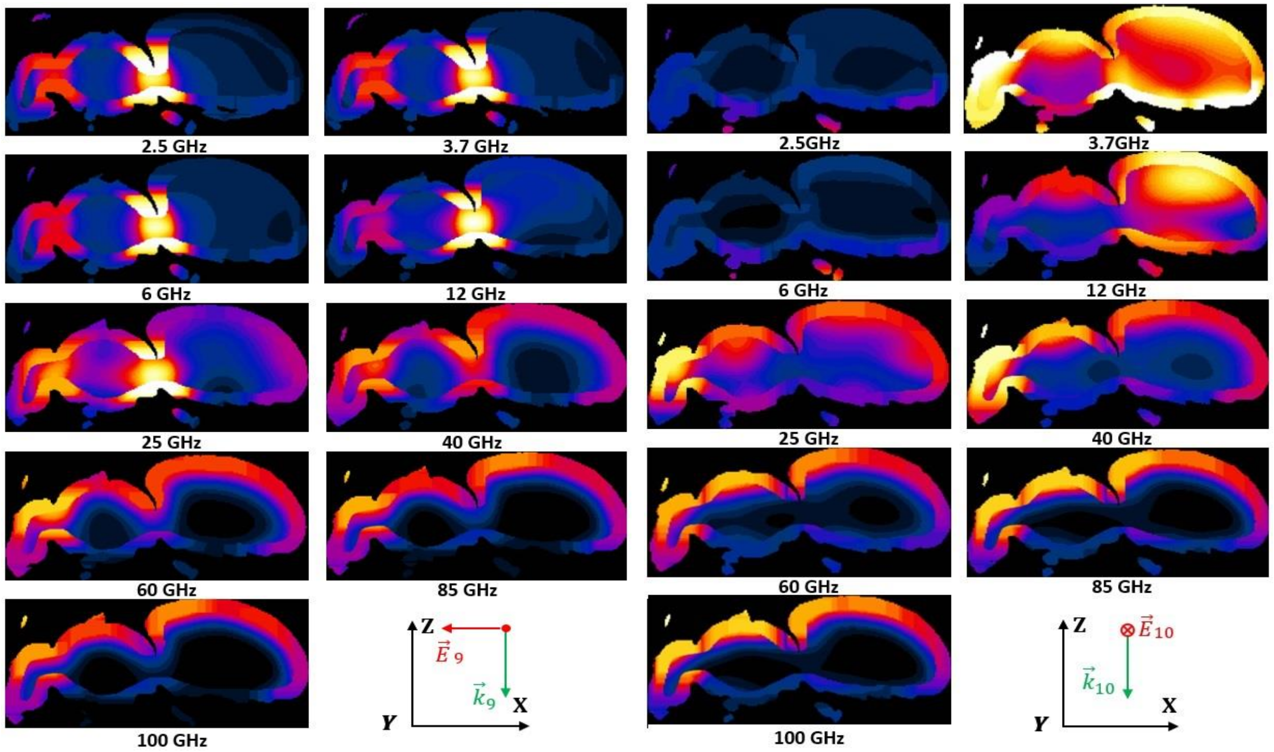


The directions of incident plane waves and considered E-field polarizations.

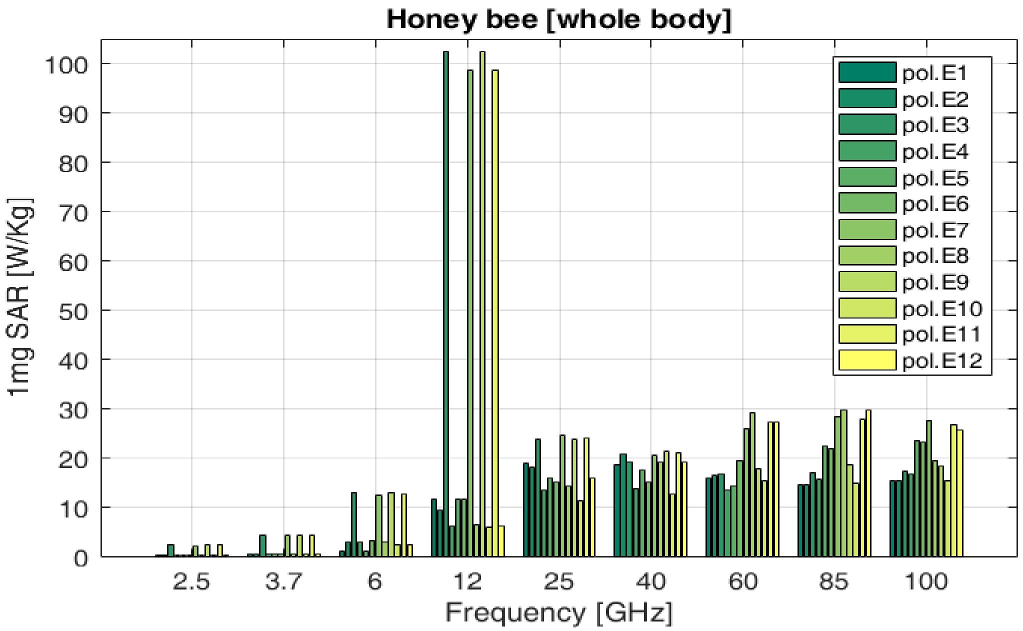
- **EMF Source:** sinusoidal waveform of plane wave at single (harmonic) frequency.
- **The selected frequencies: 2.5, 3.7, 6, 12, 25, 40, 60, 85, and 100 [GHz]** (9 frequencies)
- **Incident plane wave directions: front, back, top, bottom, left, and right** (6 directions) with two orthogonal E-field polarizations (12 E-field polarizations).
- **EM Simulation software: Sim4Life, EM-FDTD Solver (ZMT, Zurich, Switzerland).** [108 EM simulations (12 polarizations × 9 frequencies) for each insect]

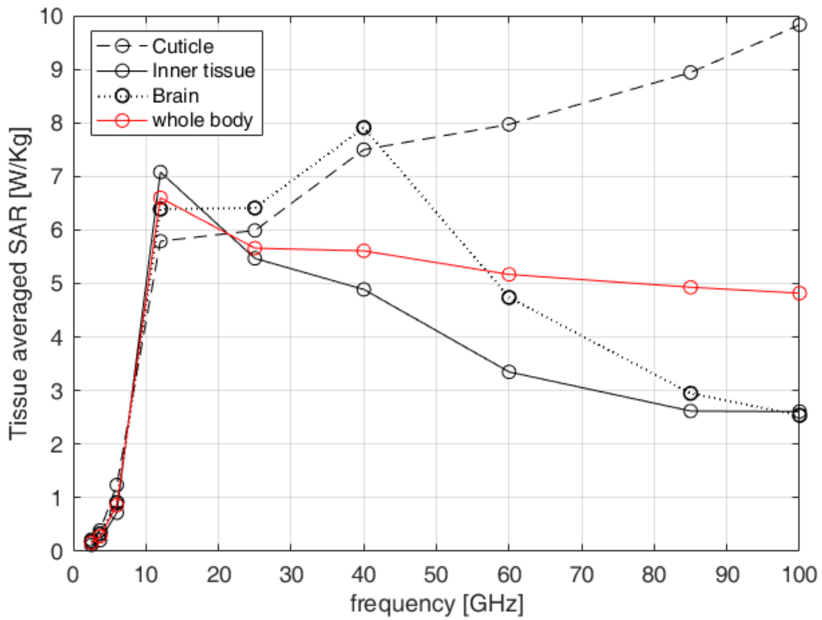
The obtained results

RF-EMF Absorption in the Western Honeybee



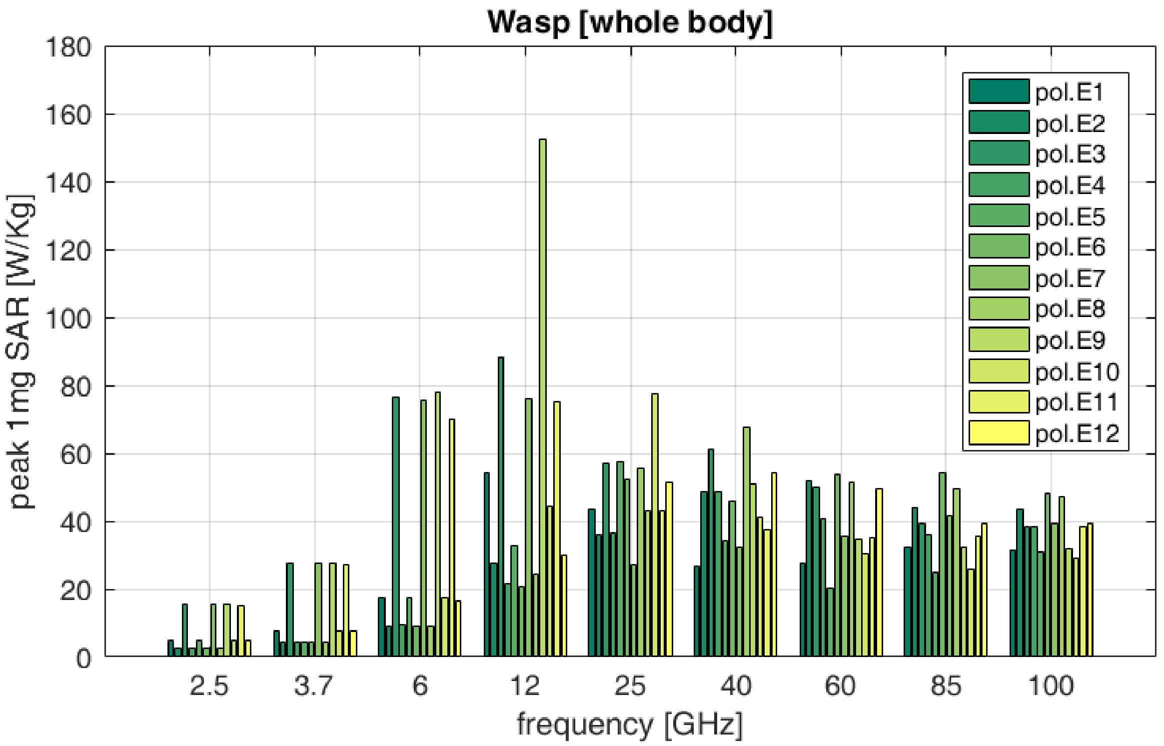
1mg SAR distributions inside the honeybee body at different sections for some E-field polarization



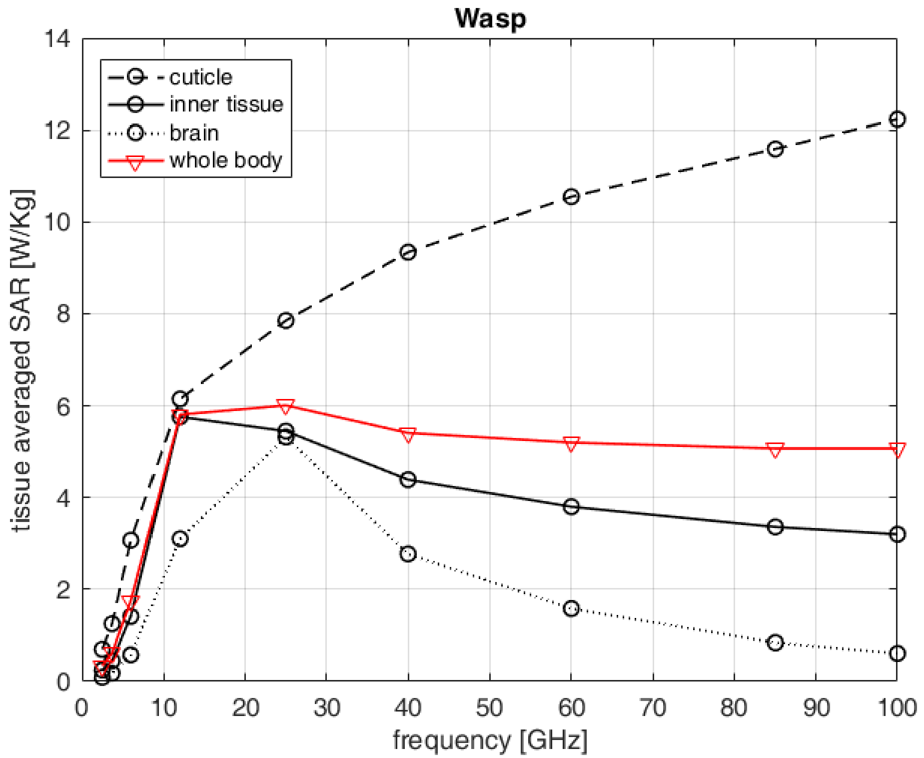


The obtained results

RF-EMF Absorption in the Mud Dauber Wasp



Peak 1 mg SAR values in the waspwhole body.



Tissue-averaged SARs for all wasp tissues and WBA SAR. SAR values averaged for all 12 polarizations of incident E-field for an incident power density of 1 mW/cm².

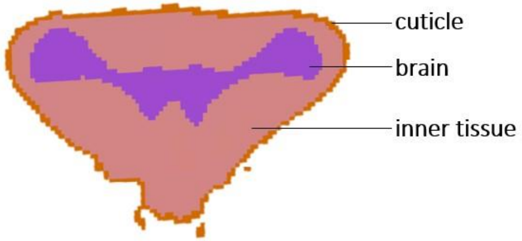
Main results for the honeybee and the wasp:

The results showed high absorbtion of EMFs in considered insects' tissues, especially inside the brain tissues at 12 GHz, 25 GHz, and 40 GHz frequencies.

The obtained SAR values highly depend on the direction of the incident plane wave, polarization, frequency, and also the insect's body peculiarities.

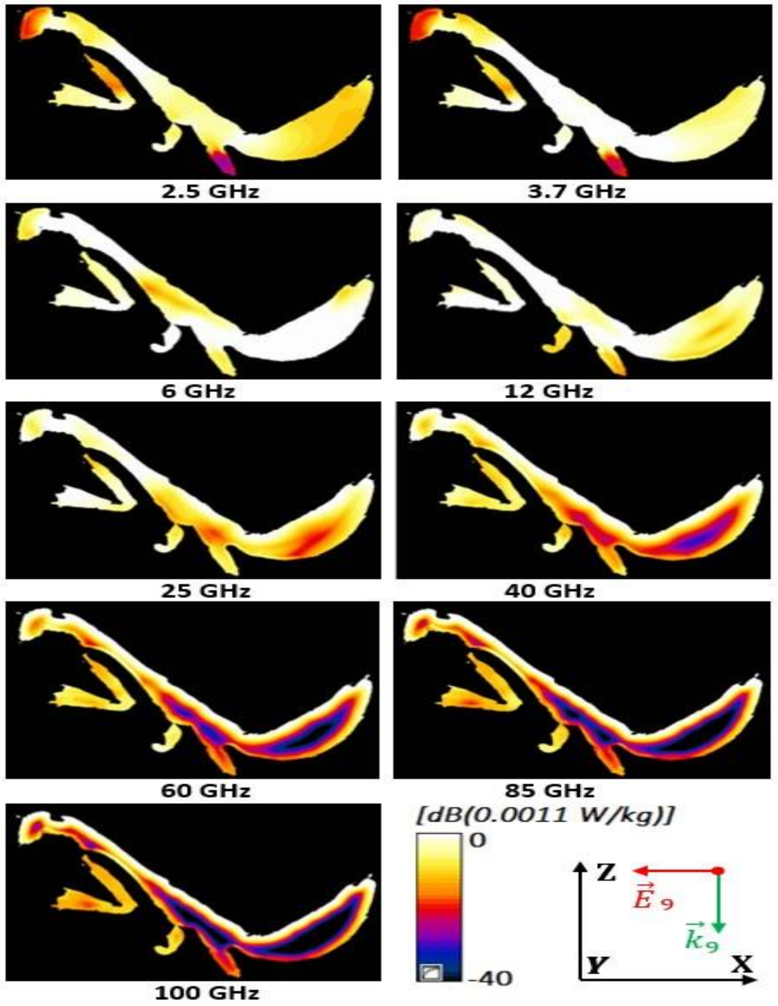
The obtained results

RF-EMF Absorption in the Mantis (*Mantis religiosa*)

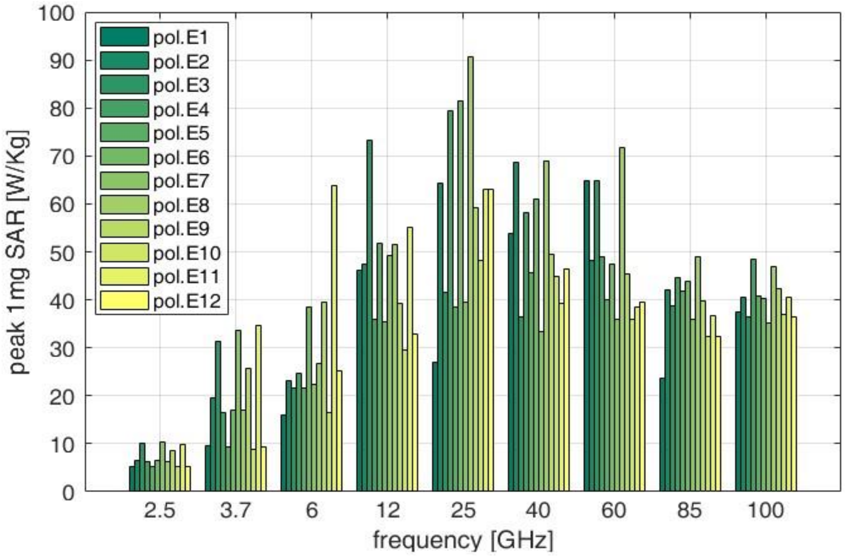


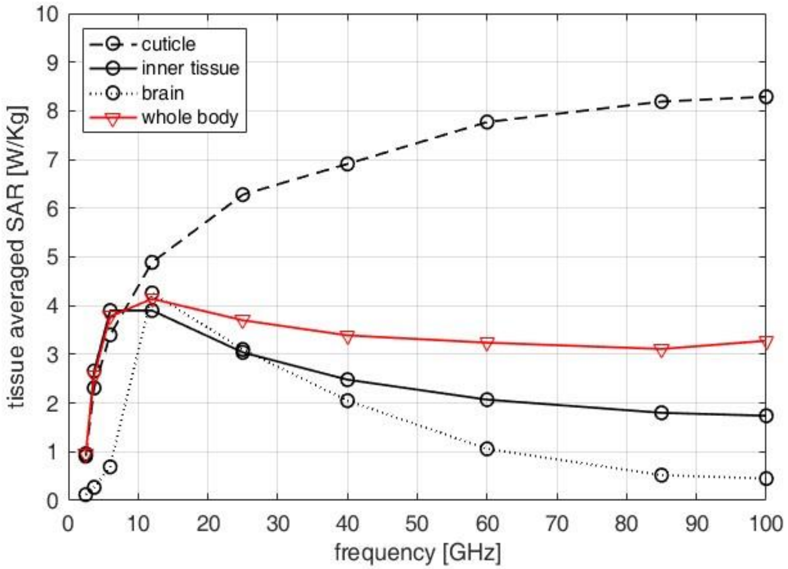
A discrete 3-tissue heterogeneous model of the mantis.

Insect	Length (mm)	Width (mm)	Height (mm)	Volume (mm^3)	Mass (mg)
Mantis	44.1	28.5	28.9	789.6	845
Mantis brain	5.9	1.4	2.6	4.7	4.9



1 mg SAR distribution inside the mantis model at the ZX plane. The E-field vector is directed along the X-axis.

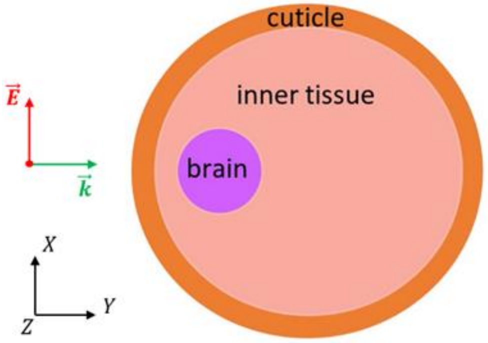




SAR values averaged for all 12 polarizations of incident E-field for an incident power density of 1 mW/cm².

SAR values are maximal (4.9 – 8.3 W/Kg) in the cuticle tissue for frequencies from 12 to 100 GHz. At 6, 12, and 25 [GHz] frequencies, the mantis has the highest inner tissue and brain SARs in the 3.0 - 4.3 W/kg range. WBA SARs range from 2.6 to 4.2 W/kg from 3.7 to 100 GHz. Since the mass of the studied mantis is close to 1g, the WBA SAR can be considered as 1g SAR and it exceeds the SAR limit (1.6 W/kg averaged over 1 g tissue) at 3.7 and 6 GHz frequencies according to IEEE Std C95.1-1999 up to 6 GHz. Based on the analysis of all the obtained visual and numerical results, the most susceptible part of the mantis is the upper part of its body, especially the neck and the head with the brain.

Validation of the Results



Sphere with 3 tissues (rad = 5mm).

	Cuticle SAR (W/kg)			Inner tissue SAR (W/kg)			Brain SAR (W/kg)			WBA SAR (W/kg)		
	homog	3 tissue	Diff (%)	homog	3 tissue	Diff (%)	homog	3 tissue	Diff (%)	homog	3 tissue	Diff (%)
2 GHz	0.07	0.07	0.00	0.05	0.05	0.00	0.067	0.068	1.15	0.09	0.09	0.00
3 GHz	0.28	0.32	-12.50	0.26	0.30	-13.33	0.278	0.329	15.50	0.44	0.51	-13.73
6 GHz	1.04	0.99	5.05	1.68	1.64	2.44	1.036	0.993	4.33	1.20	1.05	14.29
12 GHz	2.12	1.83	15.85	1.57	1.51	3.97	2.103	1.854	13.43	2.06	1.84	11.96
25 GHz	3.81	3.32	14.76	1.18	1.17	0.85	3.661	3.139	16.63	1.27	1.15	10.43
60 GHz	6.34	5.7	11.23	0.64	0.75	-14.67	6.349	5.698	11.43	0.49	0.48	2.08

Tissue-averaged SAR and WBA SAR values for the 3-tissue Sphere with the different tissue properties and with the same tissue properties.

	Sim4Life Muscle SAR (W/kg)	**FDTDLab** Muscle SAR (W/kg)	**Difference (%)**
2.5 GHz	0.12	0.12	0.00
3.7 GHz	1.48	1.57	-5.73
6 GHz	1.55	1.50	3.33
12 GHz	1.46	1.45	0.69
25 GHz	1.28	1.18	8.47
40 GHz	1.20	1.10	9.09
60 GHz	1.17	1.06	10.38
85 GHz	1.13	1.01	11.88
100 GHz	1.10	0.96	14.58

Comparison of the tissue-averaged SAR values for a muscled sphere (r = 5 mm) calculated by Sim4Life and FDTDLab, and the relative difference (%) between them for the frequencies from 2.5 to 100 GHz.

Validation of the Results

#		Cuticle SAR (W/kg)	Inner Tissue SAR (W/kg)	Brain SAR (W/kg)	1 mg SAR (W/kg)	WBA SAR (W/kg)
1	ε_c, ε_i, ε_b, σ_c, σ_i, σ_b	1.14	1.16	3.14	4.91	1.4
	ε_c+4, ε_i+4, ε_b+4, σ_c +4 s/m, σ_i+4 s/m, σ_b+4 s/m	1.01	1.07	3.25	4.79	1.33
	Difference %	12.87	8.41	-3.38	2.51	5.26
2	ε_c, ε_i, ε_b, σ_c, σ_i, σ_b	1.14	1.16	3.14	4.91	1.4
	ε_c +4, ε_i+4, ε_b+4, σ_c -4 s/m, σ_i-4 s/m, σ_b-4 s/m	1.42	1.26	2.61	4.63	1.41
	Difference %	-19.72	-7.94	20.31	6.05	-0.71
3	ε_c, ε_i, ε_b, σ_c, σ_i, σ_b	1.14	1.16	3.14	4.91	1.4
	ε_c+8, ε_i+8, ε_b+8, σ_c+8 s/m, σ_i+8 s/m, σ_b+8 s/m	0.95	1.04	3.33	4.68	1.28
	Difference %	20.00	11.54	-5.71	4.91	9.37
4	ε_c, ε_i, ε_b, σ_c, σ_i, σ_b	1.14	1.16	3.14	4.91	1.4
	ε_c -8, ε_i-8, ε_b-8, σ_c -8 s/m, σ_i-8 s/m, σ_b-8 s/m	1.421	1.375	2.864	5.089	1.552
	Difference %	-19.77	-15.64	9.64	-3.52	-9.79
5	ε_c, ε_i, ε_b, σ_c, σ_i, σ_b	1.14	1.16	3.14	4.91	1.4
	ε_c, ε_i+8, ε_b+8, σ_c, σ_i+8 s/m, σ_b+8 s/m	0.99	1.104	2.8	4.78	1.31
	Difference %	15.15	5.07	12.14	2.72	6.87
6	ε_c, ε_i, ε_b, σ_c, σ_i, σ_b	1.14	1.16	3.14	4.91	1.4
	ε_c, ε_i-8, ε_b-8, σ_c, σ_i-8 s/m, σ_b-8 s/m	1.28	1.23	3.68	5.12	1.52
	Difference %	-10.94	-5.69	-14.67	-4.1	-7.89

Comparison of the Tissue-averaged SAR, 1 mg SAR and WBA SAR values for the 3-tissue Sphere with different permittivities and conductivities at 25 GHz.

#		Cuticle SAR (W/kg)	Inner Tissue SAR (W/kg)	Brain SAR (W/kg)	1 mg SAR (W/kg)	WBA SAR (W/kg)
1	ρ_c, ρ_i, ρ_b	5.70	0.79	0.27	6.90	1.37
	ρ_c+50 kg/m³, ρ_i+50 kg/m³, ρ_b+50 kg/m³	5.45	0.75	0.25	6.67	1.31
	Difference %	4.54	4.70	4.80	3.48	4.68
2	ρ_c, ρ_i, ρ_b	5.70	0.79	0.27	6.90	1.37
	ρ_c+100 kg/m³, ρ_i+100 kg/m³, ρ_b+100 kg/m³	5.22	0.72	0.24	6.47	1.25
	Difference %	9.09	9.41	9.61	6.62	9.42
3	ρ_c, ρ_i, ρ_b	5.70	0.79	0.27	6.90	1.37
	ρ_c+150 kg/m³, ρ_i+150 kg/m³, ρ_b+150 kg/m³	5.01	0.69	0.23	6.30	1.20
	Difference %	13.64	14.12	14.39	9.55	14.11
4	ρ_c, ρ_i, ρ_b	5.70	0.79	0.27	6.90	1.37
	ρ_c+200 kg/m³, ρ_i+200 kg/m³, ρ_b+200 kg/m³	4.82	0.66	0.22	6.14	1.15
	Difference %	18.17	18.83	19.17	12.29	18.74
5	ρ_c, ρ_i, ρ_b	5.70	0.79	0.27	6.90	1.37
	ρ_c+100 kg/m³, ρ_i, ρ_b	5.22	0.79	0.27	6.78	1.35
	Difference %	9.20	0.00	0.00	1.77	1.48
6	ρ_c, ρ_i, ρ_b	5.70	0.79	0.27	6.90	1.37
	ρ_c+200 kg/m³, ρ_i, ρ_b	4.82	0.79	0.27	6.69	1.34
	Difference %	18.26	0.00	0.00	3.14	2.24

Comparison of the Tissue-averaged SAR, 1 mg SAR and WBA SAR values for the 3-tissue Sphere with different densities at 60 GHz.

The SAR values are given in W/kg and normalized to the incident power density of 1 mW/cm2.

Validation of the Results

	Cuticle SAR (W/kg)			Inner Tissue SAR (W/kg)			Brain SAR (W/kg)			WBA SAR (W/kg)		
	25 µm	50 µm	Diff %	25 µm	50 µm	Diff %	25 µm	50 µm	Diff %	25 µm	50 µm	Diff %
pol. E1	7.76	7.23	7.33	1.61	1.43	12.59	12.58	11.18	12.52	3.09	2.83	9.19
pol. E2	8.55	8.23	3.89	2.08	1.88	10.64	12.03	11.48	4.79	3.64	3.41	6.74
pol. E3	8.26	7.92	4.29	1.94	1.75	10.86	7.50	6.75	11.11	3.46	3.24	6.79
pol. E4	9.46	9.16	3.28	2.50	2.27	10.13	9.78	9.01	8.55	4.17	3.93	6.11
pol. E5	9.46	9.13	3.61	2.74	2.48	10.48	5.56	5.11	8.81	4.35	4.08	6.62
pol. E6	9.33	8.95	4.25	2.76	2.52	9.52	2.95	2.64	11.83	4.34	4.07	6.65
pol. E7	12.92	12.19	5.99	1.77	1.69	4.73	0.98	0.94	4.26	4.45	4.21	5.70
pol. E8	13.21	12.27	7.66	1.82	1.75	4.00	1.10	0.97	13.40	4.55	4.27	6.56
pol. E9	22.28	20.96	6.30	2.68	2.60	3.08	2.54	2.24	13.39	7.37	7.01	5.14
pol. E10	24.58	23.90	2.85	3.28	3.10	5.81	2.91	2.73	6.59	8.39	8.09	3.71

Comparison of the Tissue-averaged SAR and WBA SAR values for the ladybug using different grid steps at 100 GHz.

	Sim4Life Muscle SAR (W/kg)	FDTDLab Muscle SAR (W/kg)	Difference (%)
2.5 GHz	0.12	0.12	0.00
3.7 GHz	1.48	1.57	-5.73
6 GHz	1.55	1.50	3.33
12 GHz	1.46	1.45	0.69
25 GHz	1.28	1.18	8.47
40 GHz	1.20	1.10	9.09
60 GHz	1.17	1.06	10.38
85 GHz	1.13	1.01	11.88
100 GHz	1.10	0.96	14.58

Comparison of the tissue-averaged SAR values for a muscled sphere (r = 5 mm) calculated by Sim4Life and FDTDLab, and the relative difference (%) between them for the frequencies from 2.5 to 100 GHz.

The SAR values are given in W/kg and normalized to the incident power density of 1 mW/cm2.

Dicemination of the Results

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