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WP4.8: 6G.Bioelectromagnetics Interactions

Bioelectromagnetic studies to assess the exposure of European honey bees at 6G frequencies

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The present study deals with a preliminary analysis of the penetration of high-frequency radiation into the European honey bee (Apis mellifera) by utilizing an optimized 2D representation of the insect's primary cross-sectional area, namely the abdomen. We have quantified and characterized the dielectric properties of crucial bee components – such as the cuticula, wings, and inner parts. Following this, the potential protective capability of the cuticula layer, especially in the bee's abdomen, is assessed numerically based on the mentioned measurements.

1. Motivation and objective

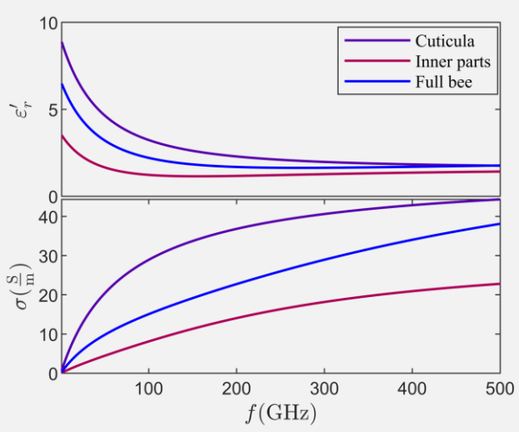
■ Investigating how high-frequency radiation, specifically ranging from 1 GHz to few THz, affects European honey bees (Apis mellifera) has recently piqued the interest of the scientific community. This newfound interest stems from concerns that the swift expansion of radiofrequency communication, from technologies such as 5G and 6G to THz frequencies, might increase the electromagnetic (EM) exposure of arthropods. This is especially relevant given the notable decline in honey bee populations observed around the start of the millennium. Given the crucial role honey bees play in our ecosystem as primary pollinators, our study centers on understanding the dynamics of (sub-) THz radiation interaction, particularly in the 1-500 GHz spectrum, with these bees.

2. A heterogenous bee model

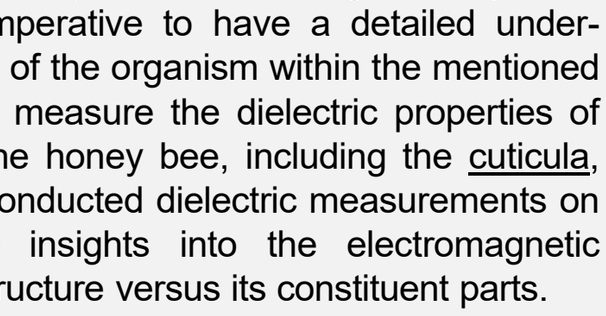
■ In conducting a comprehensive analysis of electromagnetic exposure effects on *Apis mellifera*, it is imperative to have a detailed understanding of the material properties of the organism within the mentioned frequency spectrum. We therefor measure the dielectric properties of discrete anatomical sections of the honey bee, including the cuticula, inner parts, and wings. We also conducted dielectric measurements on full bees to draw comparative insights into the electromagnetic characteristics of the composite structure versus its constituent parts.

3. Measurements

■ Freshly dead, worker European honey bees were acquired from local bee keepers and dissected into their major parts. Each part was subsequently measured in a waveguide-based, transmission/reflection measurement setup for two frequency ranges, namely in the K_a band (25-40 GHz), as well as in the D band (110-170 GHz) using the corresponding commercially available material characterization kits (MCKs) from SWISSto12.



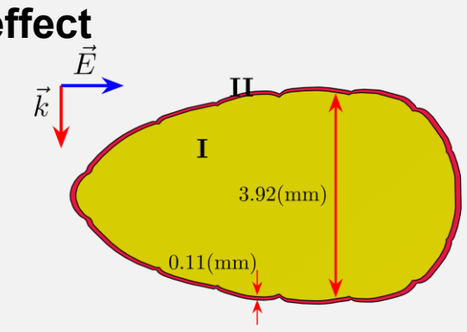
$$F = \left(\sum_{n=1}^{N_{\text{num}}} \frac{1}{N_{\text{num}}} \left(\frac{|\varepsilon'_{\text{mes}} - \varepsilon'_{\text{deb}}|^2}{\varepsilon'^2_{\text{mes}}} + \frac{|\varepsilon''_{\text{mes}} - \varepsilon''_{\text{deb}}|^2}{\varepsilon''^2_{\text{mes}}}\right)\right)^{-1}$$



Coefficient	ε_∞	$\Delta\varepsilon_1$	$\Delta\varepsilon_2$	$\Delta\varepsilon_3$	$\Delta\varepsilon_4$	$\Delta\varepsilon_5$	$\tau_1(ps)$	$\tau_2(ps)$	$\tau_3(ps)$	$\tau_4(ns)$	$\tau_5(\mu s)$	$\sigma_s(S/m)$
Wing	9.65	956	976	828.5	94.5	790.5	625	999.5	241.5	66.5	340.5	15.6
Inner parts	1.61	452	737.5	899	694.5	983.5	3.5	63	266.5	299.5	761	15.6
Cuticula	1.59	373.5	10	70.5	288.5	773	416	232	894.5	79.5	698.5	15.6
Full bee	2.19	265.5	9.5	608	975.5	918.5	42	16.5	531.5	555.5	187	13.6

4. Potential cuticula's shielding effect

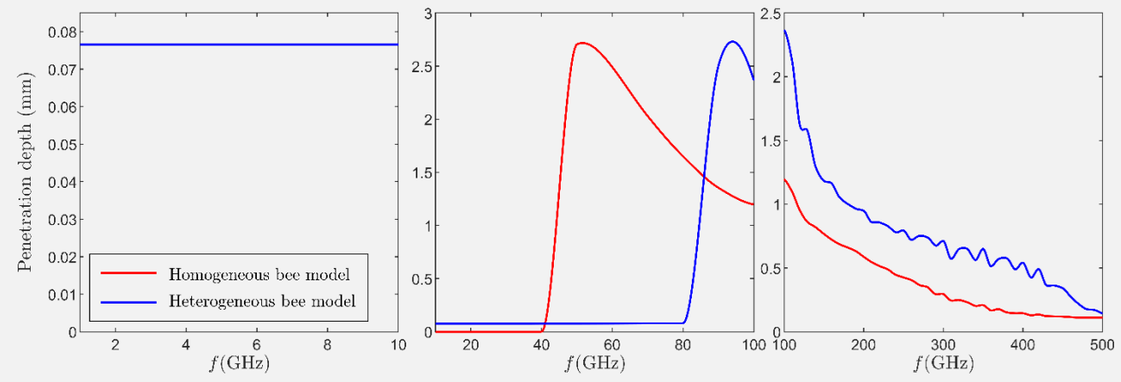
■ To delve deeper into the potential electromagnetic (EM) shielding properties of the honey bee's cuticle, we have introduced a thin layer into a 2D cross-sectional model of the bee's abdomen, characterized by the dielectric function of the actual cuticle. The precise thickness of the cuticle, determined to be 0.11 mm, was ascertained from micro-CT scans of the honey bees.



	Homogeneous	Heterogeneous
I	Full bee	Inner parts
II	Full bee	Cuticula

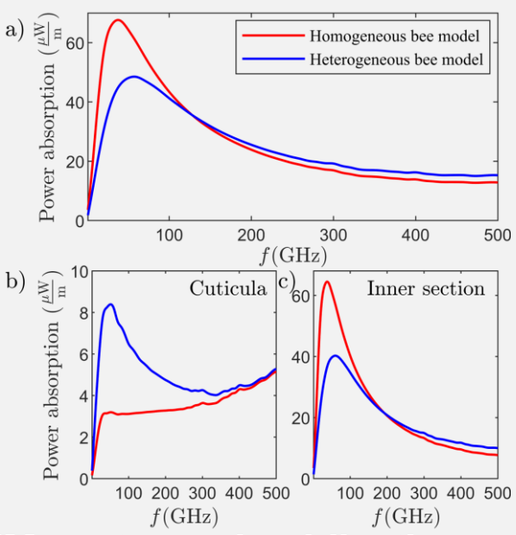
5. Penetration depths

■ The penetration depth, defined as the distance within the bee abdomen where the electric field strength decays to e^{-1} times the initial value at the abdomen's border, is calculated for both simulation scenarios, namely the homogenous bee model and the heterogenous one.



6. Integrated absorbed power

■ The simulated spectral response of absorbed power integrated over the whole abdomen's cross-section in both of the simulation scenarios, namely the homogenous bee model (red solid line), and the heterogeneous bee model (blue solid line) for a) the whole bee abdomen, b) the cuticula layer, and c) the inner section.



7. Project exploitation: ATE BioEM center and publications

■ ATE BioEM center is established (https://www.uni-due.de/ate-bioemcenter), hosts 5 active research projects and state-of-the-art THz BioEM measurement equipment.

■ There are three publications in addition to two patent applications.

(1) F. Sheikh, A. Proksch, A. Batra, D. Lessy, B. Salah, B. Sievert, M. Degen, A. Rennings, M. Jalali, Jan. T. Svejda, P. Alibeigloo, C. Preuss, E. Mutlu, R. Kress, S. Clochiatti, K. Kolpatzeck, T. Kubiczek, I. Ullmann, K. Root, F. Brix, U. Krämer, M. Vossiek, J. C. Balzer, N. G. Weimann, T. Kaiser, and D. Erni, "Towards continuous real-time plant and insect monitoring by miniaturized THz systems," *IEEE J. Microw.*, Vol. 3, no. 3, pp. 913-937, 2023.

(2) M. Jalali, A. Proksch, Y. Yan, T. Kubiczek, T. Kaiser, J. C. Balzer, and D. Erni, "Non-invasive, easy to implement glucose sensing via the fingernail bed using THz radiation," *CDBME*, Vol. 9, no. 1, pp. 507-510, 2023.

(3) M. Jalali, J. T. Svejda, B. Sievert, D. Erni, "Investigating a possible shielding behavior of the European honey bee's cuticle at THz frequencies," presented at the 2024 German Microwave Conference (GeMiC 2024), Duisburg, Germany, March, 2024 (submitted).

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Dieses Projekt wird durch das Bundesministerium für Bildung und Forschung (BMBF) im Rahmen der Förderbekanntmachung „6G-Forschungs-Hubs; Plattform für zukünftige Kommunikationstechnologien und 6G" unter dem Förderkennzeichen 16KISK038 gefördert.

Supported by

Federal Ministry of Education and Research