

A Preliminary Numerical Study of Radiofrequency Electromagnetic Field Exposure in Birds Using a Heterogeneous Sparrow Model

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Abstract. This study presents the first attempt to investigate electromagnetic field (EMF) exposure in birds, specifically the sparrow, using numerical dosimetry. The objective was to evaluate the specific absorption rate (SAR) in sparrow tissues from 0.9 to 60 GHz. Numerical simulations were performed using the Sim4Life software based on the finite-difference time-domain (FDTD) method. The sparrow was modeled as a six-tissue heterogeneous dielectric object, including feathers, beak, eyes, skin, inner tissue, and brain. Far-field EMF exposure was simulated using sinusoidal plane waves at a single frequency. The tissue-averaged, whole-body averaged (WBA), 1 g and 10 g SAR values were evaluated in bird tissues for all considered frequencies for all 10 incident plane wave polarizations. The results showed that EMF energy absorption in birds highly depends on frequency, polarization, and bird body dimensions and peculiarities. Significant EMF penetration inside the sparrow's body was observed within the 1.8-6 GHz range, with maximum volumetric absorption at 1.8 GHz. The peak SAR for the brain was observed at 3.7 GHz, whereas for the eyes, the maximum occurred at 25 GHz. © 2026 Bull. Georg. Natl. Acad. Sci.

Keywords: radiofrequency, electromagnetic field, bird, SAR, FDTD, Sim4Life

Introduction

Biological organisms, including birds, are increasingly exposed to radio-frequency electromagnetic fields (RF-EMFs), which are absorbed by their bodies and can induce dielectric heating (ICNIRP, 2020). The wavelengths used in current and future wireless communication networks are comparable to the body dimensions of some small biological organisms, such as birds, which can trigger whole-

body or partial-body resonance during exposure. Addressing this issue represents a significant and relevant research area today, as birds are the essential components of ecosystems and biodiversity. Existing studies have primarily focused on experimental investigations of the biological effects of EMF exposure on birds at frequencies below 6 GHz. In this context, a comprehensive review by Levitt et al. (2025) indicates that RF-EMF exposure may interfere with magnetoreception in birds, po-

tentially disrupting navigation and orientation, and may also affect behaviour, reproduction, and physiological processes; however, the evidence remains heterogeneous and context-dependent. An alternative and widely used approach for investigating the effects of EMF exposure on biological systems is numerical simulation using computational models or phantoms, in which EMF absorption is quantified in terms of the Specific Absorption Rate (SAR) [W/kg] (ICNIRP, 2020). Notably, numerical simulation-based studies of EMF exposure in birds have not yet been conducted. To partially address this gap, this study presents an initial step towards investigating RF-EMF exposure in birds using numerical dosimetry to evaluate the SAR values and to develop a realistic heterogeneous bird model. For this study, the house sparrow (*Passer domesticus*) was selected as a model organism, as it is among the most prevalent bird species in urban environments worldwide and, importantly, is a sedentary (non-migratory) species that leads to chronic, long-term exposure to RF-EMFs from multiple sources.

The assessment of SAR for the house sparrow (and other bird species) is important not only for understanding the direct impacts of RF-EMFs on this species, but also for evaluating broader environmental consequences and informing safety standards and environmental policies.

Materials and Methods

To study the influence of RF -EMF exposure on birds, quantified by the SAR, we used the EM-FDTD solver of the Sim4Life (ZMT, Zurich, Swit-

zerland) software, which is based on the Finite-Difference Time-Domain (FDTD) method. In Sim4Life, the EM solver is based on the numerical solution of the Maxwell Equations by the FDTD method and the Yee Algorithm (Taflove and Hagness, 2005). The FDTD method is the most suitable numerical technique for analyzing EMF absorption in complex-shaped and inhomogeneous biological structures (such as birds) and evaluating the SAR values in biological tissues. Sim4Life provides the capability for a precise evaluation of local, tissue-specific, and whole-body averaged SAR (WBA-SAR), as well as SAR averaging over different tissue masses.

Achieving these objectives required the following steps: (1) the development and discretization of a realistic 3D heterogeneous bird model; (2) the selection and assignment of dielectric properties to each specific tissue; and (3) the execution of EM simulations to evaluate the SAR inside the bird tissues.

Bird model and tissue parameters. As a bird model, we used the house sparrow model (Fig. 1a), which we developed based on an initial sparrow model obtained from the open-access repository 3Dmag (<http://3dmag.org>). The sparrow was modeled as a heterogeneous body using 6 different tissues: feathers, skin, inner tissue, brain, eyes and beak (Fig. 2). The sparrow brain model (Fig. 1b) was generated using Tripo AI (<https://www.tripo3d.ai>) based on the brain model from Olkiewicz et al. (2016) by converting 2D images into a 3D representation.

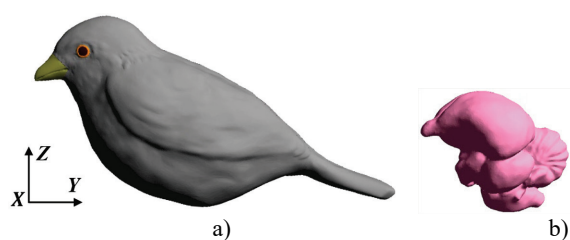


Fig. 1. Sparrow 3D models in STL format: a) sparrow model, b) brain model.

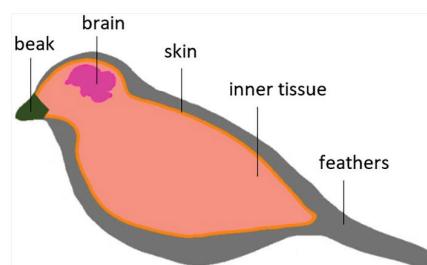


Fig. 2. Mid-sagittal cross-section of the 6-tissue discrete heterogeneous model of the sparrow.

For further processing of the sparrow model, we used the graphics software Blender (Stichting Blender Foundation, Amsterdam, Netherlands). The 3D surface (model) for skin tissue (Fig. 2) was created by removing limbs and other bulging areas from the sparrow model (Fig. 1a). This obtained 3D surface was then compressed within the primary model and smoothed. The 3D surface for the inner tissue was derived from the skin surface by compressing it to a depth of 0.5 mm inward. All parts of the sparrow model were exported in STL format. The physical dimensions of the sparrow model and body parts are presented in Table 1.

Table 1. Dimensions of the various body parts of the sparrow model

Bird Dimensions	Length (cm)	Width (cm)	Height (cm)	Volume (cm ³)	Mass (g)
Sparrow with feathers	10.47	3.46	4.28	43.81	27.77
Sparrow without feathers	7.48	2.91	3.55	24.53	26.55
Feathers	10.12	3.46	4.28	19.28	1.25
Skin	7.16	2.91	3.55	3.19	3.54
Inner tissue	7.01	2.76	3.41	20.86	22.4
Brain	1.17	0.94	0.82	0.35	0.37
Eye	0.27	0.16	0.27	0.02	0.02
Beak	0.85	0.64	0.69	0.12	0.22

The frequency-dependent EM parameters (permittivity and conductivity) of sparrow tissues and mass densities, excluding feathers, were selected from the IT'IS database of tissue properties (Has-

gall et al., 2022). While the properties for the skin and brain were directly obtained from the IT'IS database, the beak was modeled using cortical bone parameters. The tissue properties of the eyes were calculated by averaging the properties of their primary constituent structures, including the choroid, ciliary body, cornea, iris, lens, retina, sclera, and vitreous humor. Similarly, the properties of the inner tissue were derived by averaging the parameters of several key internal components, including the muscle, stomach, large and small intestines, cortical bone, blood, heart muscle, lung, and liver. The mass density of the feathers was calculated based on the difference between the body density of the bird with and without feathers, using the data provided by Hamershock et al. (1993). The permittivity and conductivity of the feathers were determined by analyzing various literature sources, as well as specifically considering the dielectric properties of keratin, the primary structural component of feathers. The obtained values of tissue parameters are given in Table 2.

The influence of variations in permittivity, conductivity, and mass density on SAR results was investigated in Jeladze et al. (2025), where the relative change in the results was found not to exceed 20%. Since the EM parameters of bird feathers are not characterized with high precision in the literature, the present study specifically examines several cases of permittivity and conductivity variations

Table 2. Tissue parameters used for the sparrow model

Tissue parameters	Skin		Inner tissue		Brain		Eye		Beak		Feathers	
	ϵ	σ [S/m]	ϵ	σ [S/m]	ϵ	σ [S/m]	ϵ	σ [S/m]	ϵ	σ [S/m]	ϵ	σ [S/m]
0.9 GHz	41.4	0.87	52.9	1.07	45.8	0.77	54.9	1.13	12.5	0.14	3.5	0.001
1.8 GHz	38.9	1.18	50.8	1.5	43.6	1.15	53.3	1.55	11.8	0.28	3.2	0.003
2.5 GHz	38.0	1.49	49.7	1.9	44.7	2.13	52.3	2.05	11.4	0.40	3.0	0.004
3.7 GHz	36.8	2.15	48.3	2.7	42.9	3.03	50.8	3.01	10.7	0.66	2.85	0.005
6 GHz	34.9	3.89	44.7	5.4	39.7	5.20	47.6	5.58	9.59	1.20	2.55	0.007
12 GHz	29.3	10.3	36.5	13.3	32.2	12.2	38.9	14.2	7.56	2.56	2.0	0.010
25 GHz	18.3	23.6	23.7	28.5	20.9	25.3	24.8	31.0	5.44	4.60	1.92	0.022
40 GHz	11.7	31.8	16.2	39.4	14.5	34.5	16.5	42.6	4.43	6.01	1.88	0.042
60 GHz	7.98	36.4	11.5	47.5	10.5	41.3	11.5	50.8	3.81	7.21	1.85	0.065
density ρ [kg/m ³]												
	1109		1073		1045.5		1055		1908		65	

using a sparrow-tissue-filled sphere model. This is crucial for understanding how the dielectric properties of feathers influence the absorption of EMFs within the bird's body. The considered 4-tissue sphere, with a 20 mm radius, is presented in Fig. 3. The outer layer (feathers) has a thickness of 2.5 mm, while the skin tissue thickness is 0.5 mm. The inner tissue is modeled using a sphere with a 17 mm radius, and the brain tissue is represented by a smaller sphere (radius = 5 mm) with a 10 mm offset from the main center. This model was exposed to an incident plane wave at 6 GHz (the configuration is shown in Fig. 3), and the corresponding findings are presented in the Results section.

EMF exposure modeling. To evaluate the influence of RF-EMF exposure on birds, we selected 9 representative frequencies: 0.9, 1.8, 2.5, 3.7, 6, 12, 25, 40 and 60 [GHz], which correspond to the frequency bands currently used in 2G-5G networks, as well as those planned for future implementation in next-generation (6G) systems. The EMF exposure was modeled using sinusoidal plane waves with an amplitude of 1 V/m at a harmonic frequency. We directed 10 incident plane waves onto the sparrow model for each frequency from 6 directions (top, bottom, front, back, and left) defined in the Cartesian coordinate system. Two orthogonal E-field polarizations were considered for each direction, as illustrated in Fig. 4.

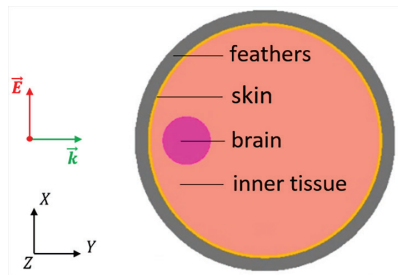


Fig. 3. Sphere with 4 main tissues of the considered bird (rad = 3 cm).

In the next step, we determined the grid resolution (cubic voxels) for the EM-FDTD simulations. According to the FDTD technique, the grid step (Δ) depends on the wavelength, the object's dimensions, and the required spatial accuracy. To obtain a stable and accurate solution, the grid step must satisfy the following criterion $\Delta < 0.1\lambda_0/\sqrt{|\epsilon_r^*|}$, where λ_0 is the free-space wavelength and ϵ_r^* - complex relative permittivity of the dielectric tissues within the simulation domain. Considering these requirements, the grid steps ranged from 250 μm (0.25 mm) to 120 μm (0.12 mm) across the frequency range of 0.9 to 60 GHz along all axes for all calculations.

After developing the bird model and defining the input parameters, the next step was conducting EM simulations using Sim4Life to estimate the SAR within the sparrow's body tissues. In accordance with the established SAR standards (ICNIRP, 2020) for human exposure, SAR is typically averaged over a specific tissue mass, such as 1 g or 10 g. We extrapolated it to birds to enable standardized dosimetrist evaluation and comparison, and calculate 1 g and 10 g SARs for the sparrow. Numerical dosimetry has not previously been applied to investigate RF-EMF exposure in birds; therefore, this study represents a pioneering effort in the fields of bioelectromagnetics and RF-EMF environmental impact assessment.

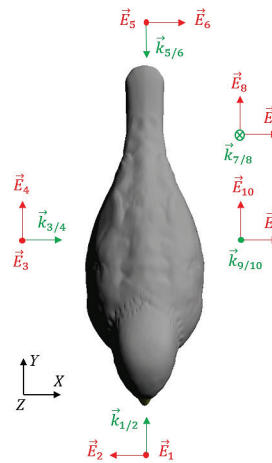


Fig. 4. Considered E-field polarizations and incidence directions.

Discussion and Results

We have conducted 90 EM simulations (9 frequencies $\times$ 10 incident E-field polarizations) for the sparrow using Sim4Life Software. With these simulations, the peak values of local SAR, 1 g SAR, and 10 g SAR in the whole body of the sparrow, tissue-averaged SARs, and whole-body averaged SAR (WBA SAR) were determined at frequencies from 0.9 to 100 GHz. The results are presented in Fig. 5-7. The reference level of the incident power density for 30 min exposure is 10 W/m^2 (1 mW/cm^2) (IEEE, 1999; ICNIRP, 2020). Therefore, all the SAR values are normalized to an incident power density of 1 mW/cm^2 in this paper.

Figure 5 shows the peak local SAR values over the whole body of the sparrow for each E-field polarization at all considered frequencies. It seems that peak SAR values vary depending on incident E-field polarization, highlighting the sensitivity of SAR to exposure orientation. The results also show strong frequency dependence, with significantly higher peak SAR values observed at millimeter-wave frequencies 25, 40 and 60 GHz. In these

cases, most of the absorbed power is localized in the superficial tissues of the sparrow (Fig. 6).

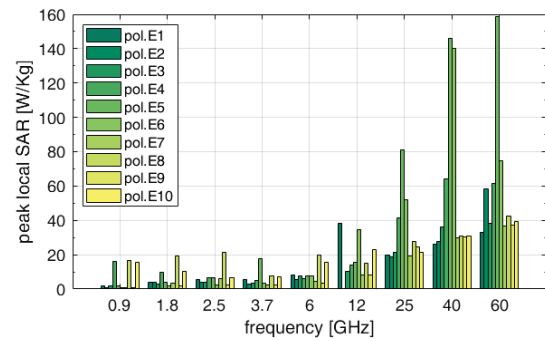


Fig. 5. Peak local SAR values in the sparrow's whole body for an incident power density of 1 mW/cm^2 .

Figure 6 illustrates the local SAR distributions for the sparrow model in the ZY plane when a plane wave is incident from above with the E-field polarized horizontally along the sparrow's length (pol. E8), and when the plane wave is incident from the front to the sparrow with the vertical E-field polarization (pol. E1). It seems that EMFs penetrate deeper into the sparrow tissues at frequencies from 0.9 to 12 GHz. Therefore, the peak local SAR values are localized deeply inside the sparrow's

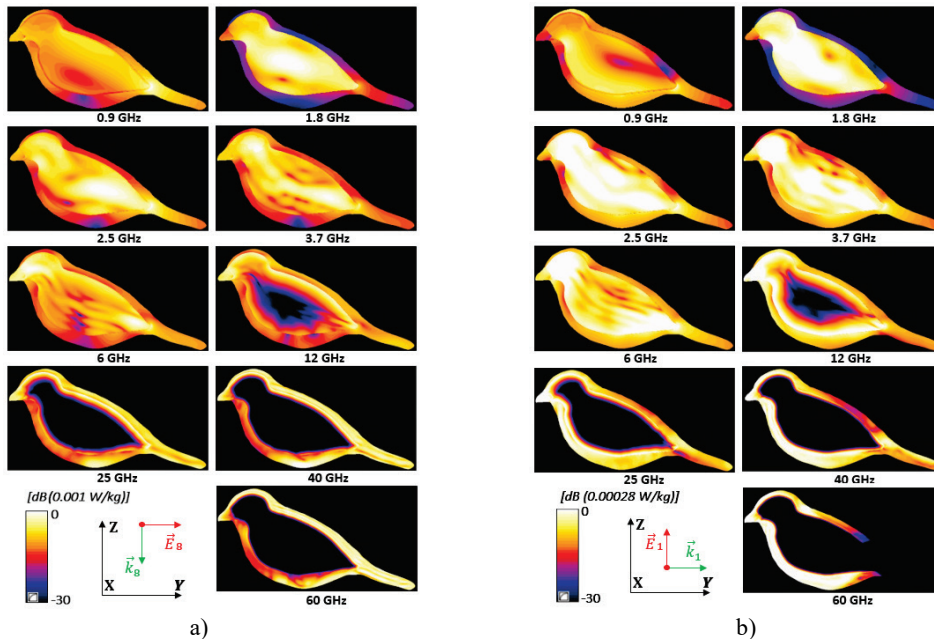


Fig. 6. Local SAR distribution inside the sparrow model as a function of frequency for a) the mid-sagittal section of the bird, when the E-vector is directed along the Y-axis (Pol. E8), and b) when the E-vector is directed along the Z-axis. Local SAR values on the ruler are given in W/kg using a logarithmic (dB) scale.

body (in the brain and main body parts), while at other frequencies from 25 to 60 GHz, the EMF absorption is mainly distributed in the superficial tissues of the bird, and therefore, the peak SAR values are located in the same areas.

Figure 7 shows the tissue-averaged SARs, 1 g and 10 g SARs, and WBA SAR values all averaged over ten polarization states at each frequency, for an incident power density of 1 mW/cm². It should be noted that the feathers were excluded from the averaging process for WBA, 1 g, and 10 g SAR calculations because feathers are non-living tissues and do not significantly absorb EMF energy, whereas SAR in biological tissues is critical for assessing thermal and bio-effects.

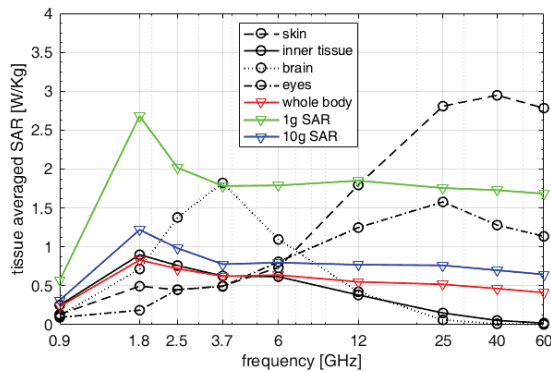


Fig. 7. Tissue-averaged SARs for sparrow tissues, 1 g SAR, 10 g SAR, and WBA SAR. The SAR values averaged for all 10 polarizations of incident E-field for an incident power density of 1 mW/cm².

It can be seen from Fig. 7 that SAR values for the skin and eyes exhibit a consistent upward trend, particularly within the 12-60 GHz frequency range, contrasting with the behavior of internal organs. However, their peak absorption points differ, while the SAR in the eyes reaches a maximum of 1.6 W/kg at 25 GHz, the skin continues to show increasing absorption, peaking at 3.0 W/kg at 40 GHz. The sparrow has the highest brain SARs in the 1.1-1.9 W/kg range from 2.5 to 6 GHz. The peak value of brain SAR of 1.85 W/kg was observed at 3.7 GHz; The frequency range where the eye tissue exhibits its highest SAR levels is between 12 GHz and 60 GHz, with an absolute maximum observed

at 25 GHz (approx. 1.6 W/kg). The SAR value in the inner tissue reaches its maximum of 0.9 W/kg at a frequency of 1.8 GHz (1800 MHz). The inner tissue SAR, WBA SAR, 1 g SAR, and 10 g SARs show a consistent trend across the studied frequency spectrum. All four metrics reach their maximum peak at 1.8 GHz, followed by a gradual reduction as the frequency increases. The peak 1 g, 10 g, and WBA SAR values are 2.7 W/kg, 1.2 W/kg, and 0.8 W/kg, respectively. A comparison of the calculated SAR values with IEEE C95.1 and ICNIRP safety standards reveals significant findings. For an incident power density of 1 mW/cm², the WBA SARs for all frequencies exceed the general public limit of 0.08 W/kg. Furthermore, the localized 1 g SAR values exceed the 1.6 W/kg public exposure limit, except at 0.9 GHz (900 MHz). However, the 10 g SAR remains below the 2 W/kg safety limit. At high frequencies, EMF absorption is strictly localized, and spatial averaging over 1 g or 10 g volumes effectively masks localized hotspots. Due to the bird's small body mass, these volumes are disproportionately large, resulting in a true peak local SAR that is significantly higher than averaged values (see Fig. 5).

Changing feather properties. Table 3 compares the tissue-averaged SAR and WBA SAR values in W/kg for the 4-tissue sphere (Fig. 3) when the feather's permittivity and conductivity vary at 6 GHz. $\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b$ and $\sigma_f, \sigma_s, \sigma_i, \sigma_b$ denote permittivities and conductivities of the feather, skin, inner tissue, and brain from Table 2 (used in our simulations) at 6 GHz. The results demonstrate how variations in the EM parameters of feathers influence EMF absorption in the sub-feather tissues. If ϵ_f changed by 1 and σ_f increase tenfold or set to 0, either separately or simultaneously, the SAR values in feathers vary sharply due to the known relationship: $SAR = \sigma E^2 / (2\rho)$. However, the relative changes in tissue-specific SARs and WBA SARs (feathers excluded from this averaging) in the sub-feather tissues range from 0.1% to 19%.

Table 3. Comparison of the tissue-specific and WBA SARs for the 4-tissue sphere for the different EM parameters of feathers at 6 GHz. The SARs are normalized to the incident power density of 1 mW/cm²

		Feather SAR (W/kg)	Skin SAR (W/kg)	Inner tissue SAR (W/kg)	Brain SAR (W/kg)	WBA SAR (W/kg)
1	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.141	0.653	0.519	0.521	0.531
	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f = 0, \sigma_s, \sigma_i, \sigma_b$	0.000	0.657	0.522	0.522	0.534
	Relative change %	-100.00	0.55	0.55	0.17	0.51
2	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.141	0.653	0.519	0.521	0.531
	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; 10\sigma_f, \sigma_s, \sigma_i, \sigma_b$	1.350	0.623	0.495	0.513	0.507
	Relative change %	856.71	-4.65	-4.69	-1.61	-4.61
3	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.14	0.65	0.52	0.52	1.4
	$\epsilon_f - 1, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.23	0.53	0.42	0.50	1.28
	Relative change %	65.15	-18.39	-18.36	-4.70	9.37
4	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.14	0.65	0.52	0.52	0.53
	$\epsilon_f + 1, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.11	0.76	0.61	0.58	0.62
	Relative change %	-21.65	16.65	16.52	10.38	16.38
5	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.14	0.65	0.52	0.52	0.53
	$\epsilon_f + 1, \epsilon_s, \epsilon_i, \epsilon_b; 10\sigma_f, \sigma_s, \sigma_i, \sigma_b$	1.07	0.73	0.58	0.57	0.59
	Relative change %	656.81	11.72	11.63	8.39	11.54
6	$\epsilon_f, \epsilon_s, \epsilon_i, \epsilon_b; \sigma_f, \sigma_s, \sigma_i, \sigma_b$	0.14	0.65	0.52	0.52	0.53
	$\epsilon_f + 2, \epsilon_s, \epsilon_i, \epsilon_b; 100\sigma_f, \sigma_s, \sigma_i, \sigma_b$	6.99	0.58	0.46	0.50	0.47
	Relative change %	4852.97	-10.81	-11.02	-3.66	-10.81

Conclusion

This paper investigated the impact of RF-EMF exposure on birds by estimating SAR values within sparrow tissues across the 0.9–60 GHz frequency range using FDTD-based numerical dosimetry. For FDTD simulations, a discrete, heterogeneous sparrow model consisting of six tissues (feathers, skin, inner tissue, brain, eyes, and beak) was developed and assigned specific dielectric properties. The tissue-averaged, WBA SAR, 1g, and 10g SAR values were evaluated in bird tissues for all considered frequencies and 10 plane wave polarizations. The obtained SAR values depend on the plane-wave polarization, frequency, and the bird's body size and shape. Significant EMF penetration inside the sparrow's body was observed in the 1.8 - 6 GHz range, with maximum volumetric absorption at 1.8 GHz for inner tissue. The WBA SAR, 1g SAR, and 10g SAR values also show

peaks at 1.8 GHz. The peak SAR for the brain was observed at 3.7 GHz, whereas for the eyes, the maximum occurred at 25 GHz. The impact of varying feather parameters on EMF absorption in the underlying tissues was evaluated using a spherical model filled with bird tissues. The variation of the results (relative change) did not exceed 19% at 6 GHz. However, it is desirable to study this issue more thoroughly. Future studies will investigate the impact of RF-EMFs on birds of different sizes and shapes.

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ფიზიკა

ფრინველებზე რადიოსიხშირული ელექტრომაგნიტური ველის ზემოქმედების წინასწარი რიცხვითი კვლევა ბელურას ჰეტეროგენული მოდელის გამოყენებით

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კვლევა ფრინველებზე, კერძოდ, ბელურაზე, წარმოადგენს ელექტრომაგნიტური ველის (EM) ზემოქმედების შესწავლის პირველ მცდელობას რიცხვითი დოზიმეტრიის გამოყენებით. კვლევის მიზანი იყო ფრინველის ქსოვილებში შთანთქმის კუთრი კოეფიციენტის (SAR) შეფასება 0,9-60 გჰც სიხშირულ დიაპაზონში. რიცხვითი სიმულაციები ჩატარდა Sim4Life პროგრამული უზრუნველყოფის EM ამომხსნელის გამოყენებით, რომელიც დაფუძნებულია დროის არეში სასრული სხვაობის (FDTD) მეთოდზე. ფრინველი (ბელურა) დამოდელოდა, როგორც 6-ქსოვილოვანი ჰეტეროგენული დიელექტრული ობიექტი, მათ შორის ბუმბული, ნისკარტი, თვალეზი, კანი, შიდა ქსოვილი და ტვინი. შორი EM ველის ზემოქმედება დამოდელოდა სინუსოიდური ბრტყელი ტალღების გამოყენებით ცალკეულ სიხშირეზე. ფრინველის ქსოვილებში განისაზღვრა ცალკეულ ქსოვილსა და, ასევე, მთელ სხეულზე გასაშუალოებული (WBA) SAR და 1 გ და 10 გ მასაზე გასაშუალოებული SAR მნიშვნელობები ყველა განხილული სიხშირისთვის 10 სხვადასხვა დაცემული ბრტყელი ტალღის პოლარიზაციისთვის. შედეგებმა აჩვენა, რომ ფრინველებში ელექტრომაგნიტური ველის ენერგიის შთანთქმა მნიშვნელოვნადაა დამოკიდებული სიხშირეზე, პოლარიზაციასა და ფრინველის სხეულის ზომებსა და ფორმაზე. ბელურას სხეულში EM ველის მნიშვნელოვანი შეღწევა დაფიქსირდა 1,8-6 გჰც სიხშირულ დიაპაზონში, მაქსიმალური მოცულობითი შთანთქმით 1,8 გჰც-ზე. ტვინისთვის SAR-ის პიკური მნიშვნელობა დაფიქსირდა 3,7 გჰც-ზე, ხოლო თვალეზისთვის 25 გჰც სიხშირეზე.

REFERENCES

- Hamershock, D. M., Seamans, T. W., & Bernhardt, G. E. (1993). Determination of body density for twelve bird species. *Ibis*, 137, 424-428.
- Hasgall, P. A., Di Gennaro, F., Baumgartner, C., Neufeld, E., Lloyd, B., Gosselin, M. C., Payne, D., Klingeböck, A., & Kuster, N. (2022). IT'IS database for thermal and electromagnetic parameters of biological tissues (version 4.1). <https://doi.org/10.13099/VIP21000-04-1>
- IEEE. (1999). *IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 100 GHz* (IEEE Std C95.1-1999). DOI:10.1109/IEEESTD.1999.89423
- International Commission on Non-Ionizing Radiation Protection. (2020). Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). *Health Physics*, 118(5), 483-524.
- Jeladze, V., Nozadze, T., Partsvania, B., Thielens, A., Shoshiashvili, L., & Gogoladze, T. (2025). Numerical dosimetry of specific absorption rate of insects exposed to far-field radiofrequency electromagnetic fields. *International Journal of Radiation Biology*, 101(3), 327-340.
- Levitt, B. B., Lai, H. C., Manville II, A. M., & Scarato, T. (2025). Flora and fauna: how nonhuman species interact with natural and man-made EMF at ecosystem levels and public policy recommendations. *Frontiers in Public Health*, 13, 1693873.
- Olkowicz, S., Kocourek, M., Lučan, R. K., Portěš, M., Fitch, W. T., Herculano-Houzel, S., & Němec, P. (2016). Birds have primate-like numbers of neurons in the forebrain. *Proceedings of the National Academy of Sciences*, 113(26), 7255-7260. <https://doi.org/10.1073/pnas.1517131113>
- Taflove, A., & Hagness, S. C. (2005). *Computational electrodynamics: The finite-difference time-domain method* (3rd ed.). Artech House.

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