Estimation and Simulation of SAR Distribution in Biological Objects Excited by Various Types of Electromagnetic Signals

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***Abstract* – This article presents estimation and simulation results of the distribution of specific absorption rate (SAR) by biological objects, which are tissues of the human body (blood, muscles, fat). TEM-cell was used as a source of excitation. The simulation was carried out using various types of excitation (Gaussian pulse, bipolar Gaussian pulse and amplitude-modulated sinusoid). It is revealed that different signals cause differences in the distribution of SAR in the biological objects under consideration.**

Key words **– electromagnetic field, TEM-cell, SAR, biological objects.**

I. Introduction

The improvement of modern technologies causes an increase in the density of the electromagnetic field (EMF) impact on living organisms and plants. At present, a person uses a large number of different microwave devices in everyday life. For example, a mobile phone has become an indispensable device in everyday life. However, the concern over the impact of such devices and their microwave radiation on humans remains extremely high. Despite a considerable number of publications devoted to the study of the effects of EMF exposure on a biological object (BO), there is still no consensus on the mechanisms of the effect of electromagnetic radiation on BO. This makes it urgent to expand the field of research, including research on the influence of different types of radiation. Also, the interest of scientists to the pulsed fields of micro-, nano- and picosecond duration effects on the body increased. Due to exposure to similar radiation, various biological effects have been identified, for example, such as changing the membrane potential [1], electroporation of cell membranes [2], apoptosis, changes in proliferative activity of normal and tumor cells [3], pulsed fields of micro-, nano- and picosecond duration also use in oncotherapy [4, 5]. It is also interest to study the effect of radiation with a different pulse shape on the BO.

Specific absorption rate (SAR) of electromagnetic energy is one of the criteria evaluating the impact of EMF. The aim of this paper is to estimate and simulate the specific absorption rate under the influence of various types of electromagnetic radiation on biological objects.

II. Formulation of the Problem

Various scientists have already implemented many experiments to identify the effect of EMF on living tissue, in particular, fibroblasts [6, 7], so the field of our interests is represented by blood (because it spreads all over the body), muscle and fat tissues (because they located directly under the skin and therefore interact with electromagnetic radiation).

SAR represents the amount of electromagnetic energy absorbed by the living tissues. To analyze the SAR distribution it must first calculate its value for all BO according to the equation [8]:

$$SAR = \frac{\sigma \cdot E^2}{\rho}, \qquad (1)$$

where σ – conductivity, Sm/m; ρ – BO density, kg/m^3; E – electric field, V/m.

The influence on the SAR distribution in the BO of various forms of radio-technical signals used in various industries (such as a Gaussian pulse, a bipolar Gaussian pulse and an amplitude-modulated sinusoid) is considered (fig. 1).

One of the means of influencing EMF on an object is the Transverse Electromagnetic Mode (TEM) cell originally created to simulate the propagation of the T-wave in the open space in 1974 [9]. Currently, the TEM-cell is used to test for electromagnetic compatibility (EMC) of electronic devices, calibration of EMF sensors, studies of the effect of EMF on living tissues, etc. By now, a modification of such a TEM-cell has been created to study the effect of EPF on BO [10, 11]. The principle of operation of the TEM camera is as follows. The transverse electromagnetic wave propagates along the waveguide channel with a characteristic impedance of 50 Ω, in this case, a uniform EMF with a level of electric field strength from 10 μV/m to 500 V/m is established inside the waveguide channel. The voltage standing wave ratio (VSWR) ≤ 1,2. The nonuniformity of the propagation of the transverse EMF is 1-2 dB in the frequency range up to 900 MHz. This value of the uniformity of the achievement at 1/3 of the height of the object under test (OUT) from the total height between the casing and the central conductor. This ratio is satisfactory for the uniform propagation of the transverse electromagnetic wave in the TEM-cell with the OUT and, as a consequence, the minimum deviation of the VSWR.

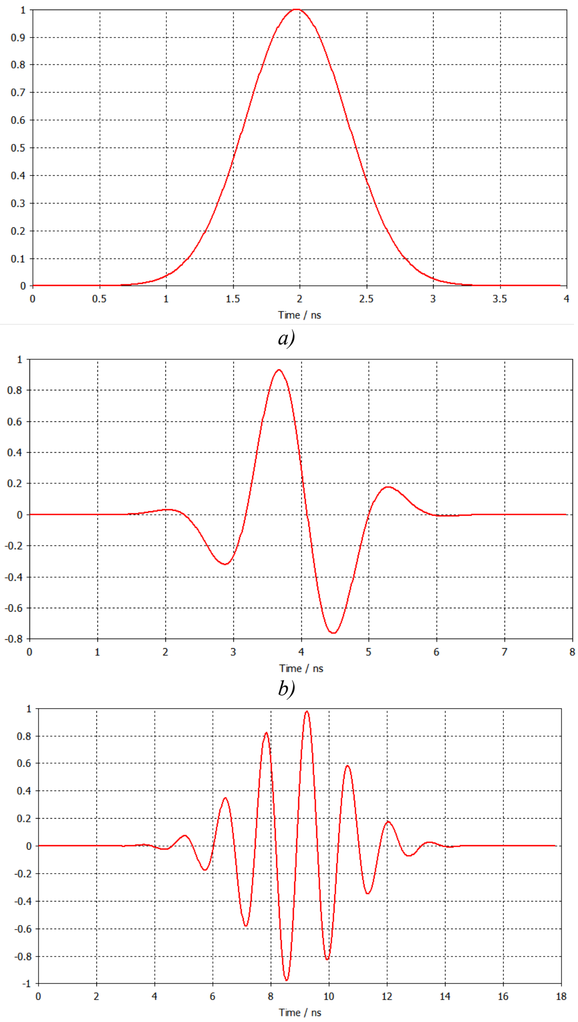


Fig. 1. Used signals: Gaussian pulse *(a)*, bipolar Gaussian pulse *(b)* and amplitude-modulated sinusoid *(c)*.

III. Estimation and Simulation of SAR

This section presents the results of SAR estimation and simulation using the CST MWS software.

Since a transverse electromagnetic wave is excited in the TEM-cell, the estimation of SAR is based on radiation from a dipole in the far zone. Thus, the distance between the dipole and the BO is chosen equal to 0.5 m, which corresponds to the far zone condition $r > \lambda / (2\pi)$, where r – the distance between the irradiated object and the antenna, m. Length of dipole (153.2 mm) was chosen to comply with condition $\lambda/2$ taking into account shortening coefficient. Transmitted power P_t was selected to be 1 W. The power density of the antenna radiation S, electric field over the BO E were calculated according to the equations [12]:

$$S = \frac{P_t \cdot G_t}{4 \cdot \pi \cdot r^2}, \quad (2)$$

where P_t – transmitted power, W; $G_t = 1$; r – distance from BO to antenna, m.

$$E = (S \cdot \eta)^{1/2}, \quad (3)$$

where η – living tissue impedance, Ohm.

The parameters of the selected BO (for the frequency of 900 MHz) and calculated SAR values can be seen in Tab. 1.

TABLE I

Charachteristics of Biological Objects and Calculated Values of SAR

BO	ρ, kg/m^3	ε_r	σ, Sm/m	η, Ohm	E, V/m	SAR, mW/kg
Blood	1000	61.36	1.538	48.13	3.92	23.63
Fat	1100	5.46	0.051	161.34	7.18	2.39
Muscle	1040	56.88	0.995	49.99	4	15.3

ρ – density, ε_r – dielectric constant, σ – conductivity, η – tissue impedance, E – electric field.

The TEM-cell was used as a source of influence to simulate the effect of EMF on the BO, the model of TEM-cell was previously created in CST MWS (fig. 2). The model of TEM-cell consists of the central conductor and three volumetric parts of rectangular cross-section, two of which have linear expansion of the cross sections in the shape of a pyramidal horn, and the third part is shaped as a cube with a regular cross section along the cell, in which the object of the study is placed. The exposure frequency, which was simulated in the TEM cell, is equal to 900 MHz. Simulation of the EMF effect was carried out for the case of placing BO in a plastic Petri dish, because this biomedical vessel introduces the smallest distortions [13], in this case, the BO represents a cylinder 33 mm in diameter and 3 mm in height.

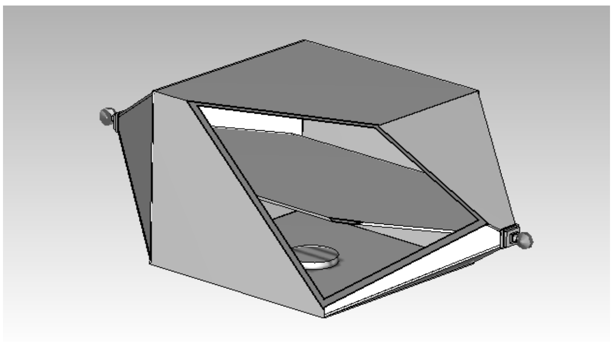


Fig. 2. Model of TEM-cell with BO created in CST MWS.

IV. Results

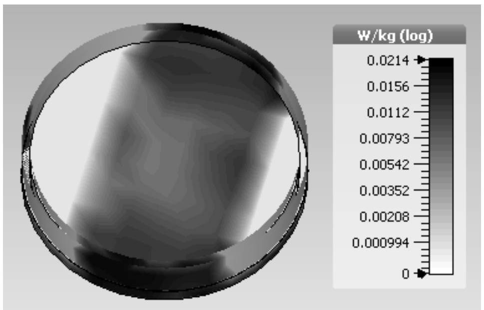
The results of estimation and simulation of SAR values are presented in Tab. 2. From this table it can be seen that for different BO different pulses give different values. So, the highest SAR value for blood and fat tissue is observed with an amplitude-modulated sinusoid, 17.93 mW/kg and 17.40 mW/kg respectively. For muscle tissue, the greatest value of SAR was obtained by modeling the effect of a bipolar Gaussian pulse (16.58 mW/kg), However, with its amplitude-modulation, the SAR value decreases insignificantly (16.54 mW/kg). The lowest SAR values for blood and muscle tissue are observed with a Gaussian pulse (17.23 mW/kg and 16.05 mW/kg respectively), for fat tissue in case when exposed to bipolar Gaussian pulse (15.88 mW/kg).

TABLE II

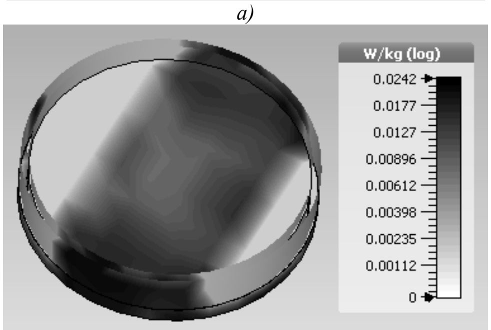
ESTIMATED AND SIMULATED SAR VALUES (mW/kg) AT THE IMPACT OF VARIOUS PULSES

BO	Pulse	Estimated SAR	Simulated SAR			
			Total		Maximum	
			num.	Δ	num.	Δ
Blood	Gaussian pulse	23.63	17.23	-6.4	23.8	6.57
	bipolar Gaussian pulse		17.82	-5.81	25.8	7.98
	amplitude-modulated sinusoid		17.93	-5.7	26.2	8.27
Fat	Gaussian pulse	2.39	16.5	14.11	22.1	5.6
	bipolar Gaussian pulse		15.88	13.49	21.1	5.22
	amplitude-modulated sinusoid		17.40	15.01	22.7	5.3
Muscle	Gaussian pulse	15.3	16.05	0.75	21.4	5.35
	bipolar Gaussian pulse		16.58	1.28	24.2	7.62
	amplitude-modulated sinusoid		16.54	1.24	24.2	7.66

* Δ for total SAR is indicated relative to the calculated values, Δ for maximum SAR is indicated relative to the total SAR.



a)



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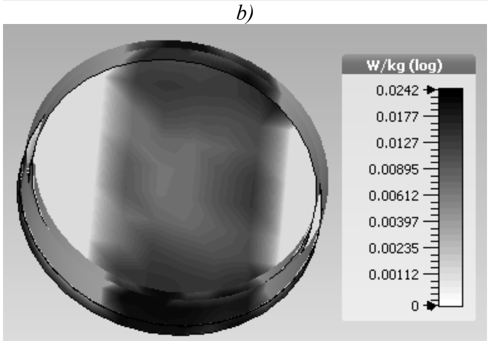

c)

Fig. 3. SAR distribution in muscle tissue at the impact of various pulses: Gaussian pulse *(a)*, bipolar Gaussian pulse *(b)* and amplitude-modulated sinusoid *(c)*.

It can also be noted that the estimated and simulated SAR values are closest to muscle tissue.

However, in all cases, so-called "hot spots" are observed - areas of peak SAR. In order to minimize such heterogeneity, it is possible to reduce the diameter of the Petri dish. Thus, it is possible to exclude areas of peak and minimum values located near the walls of the bowls, as a result, will increase the homogeneity of the SAR distribution and give a better quality of the study.

Then, as an example, the visualization of the SAR distribution is simulated in the simulation of the effect of all these pulses on muscle tissue (fig. 3).

Also, from Tab. 2 it can be seen that when the muscle tissue is affected by a Gaussian impulse, the SAR value closest to the estimated value is observed ($\Delta SAR = 0.75$ mW/kg) and one of the most minimal increases in peak values ($\Delta SAR = 5.35$ mW/kg). From this we can conclude, that this combination of the chosen BO, the type and conditions of the impacts is the most successful and can be realized in a full-scale experiment.

V. CONCLUSION

This paper presents the results of estimations of the distribution of the specific absorption coefficient in human tissues. Modeling of the SAR distribution under the influence of three pulse forms (Gaussian pulse, bipolar Gaussian pulse and amplitude-modulated sinusoid) in different BO (blood, muscle and fat tissues). It was revealed that for different BO, the most effective are pulses of different types. This makes it possible to take into account the characteristics of the objects under study and the types of impact in the planning of full-scale experiments, thus determining the most effective combinations.

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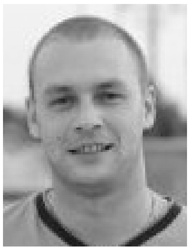

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