Simulation of electromagnetic radiation passing through liquid-containing nanostructured materials

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ABSTRACT

A process of electromagnetic radiation traveling through liquid-containing nanostructured heterogeneous materials was simulated. Mobile phone antenna pattern is calculated and its change when applying protective shield made of said materials is studied. Transmission/reflection characteristics of antenna are calculated.

Keywords: electromagnetic radiation, transmission coefficient, reflectivity, antenna pattern, mobile phone.

1. INTRODUCTION

The question of mobile phone electromagnetic radiation (EMR) impact on human's health draws a lot of attention and is a subject of many investigations all over the world. Though the adverse effect of mobile phone EMR upon human's health is not categorically proved the majority of researchers incline to restrict its use, especially by children and teenagers. The mechanism of interaction between EMR and biological tissues and human organism is not ascertained, but the common approaches are based on thermal effect or low-level radiation influence.

The ways of studying of EMR influence on biological tissues can be arranged into several groups – experiments carried out on animals (rats, rabbits, cats, monkeys etc), usage of phantoms, possessing the same electromagnetic properties as biological tissues, which contain measuring equipment inside to register the changes caused by EMR exposure; and mathematical simulation of electromagnetic radiation interaction with different materials as a rule based on Maxwell's equations.

In classical approaches [1, 2] Finite Difference in Time Domain (FDTD) method is based on discrimination of Maxwell's equation formulated in space-time axes. Grids of electrical and magnetic fields are shifted with respect to each other in time and space. Finite-difference equations determine the electrical and magnetic fields at the moment using the known field levels at the previous moment basing on the preset initial conditions, properties of material and medium of propagation in the point of calculation etc.

Mathematical modeling ensures the possibility of altering the antenna models, properties and dimensions of materials, ambient conditions. It enables to solve the problems of characteristics calculation and prediction, materials and designs optimization.

2. EXPERIMENTAL

The electromagnetic wave interacting with a material is partially reflected off by its surface because of the difference between wave impedance of the free space and the material. Some part of the wave energy penetrating into the material is absorbed within its volume due to resistive, dielectric or magnetic losses and converted into heat energy. At the rear space-material boundary repeat reflection of the electromagnetic wave occurs and the rest part of electromagnetic energy propagates into the shielded area.

Various shielding materials and designs are offered to suppress electromagnetic radiation of radioelectronic equipment to prevent negative impact upon their users [3].

In [4, 5] we proposed to suppress the mobile phone electromagnetic radiation level by materials, having electromagnetic characteristics similar to properties of biological tissues of human body [6]. The shielding material of a certain size and structure is placed between the human body and the radiation source. As a result the radiated electromagnetic power is absorbed by said protective materials, and its effect upon human is decreased. The proposed materials (Fig. 1) are based on capillary-porous matrixes having developed structure, the interior space filled with liquid having dielectric losses. The non-uniform structure of matrix threads and the non-homogeneous structure of the liquid in the pores of the matrix owing to forming of thin near-surface liquid layers having different physical and electrical properties results in complex heterogeneous media formation containing micro- and nanosize elements appearing at three phases

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interface boundaries — air-liquid-solid and along the matrix surface causing the specific properties of the developed material [7].

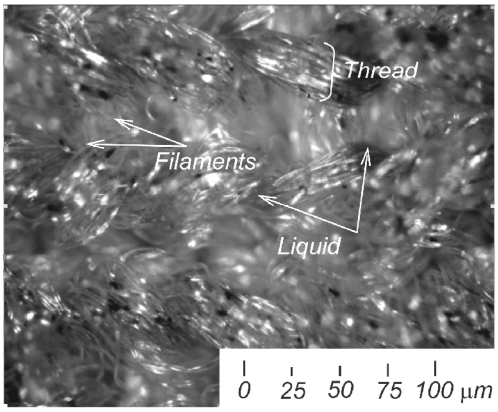


Fig. 1 — The microphotograph of liquid-containing material surface

The object of this investigation is the study of EMR traveling through liquid-containing nanostructured materials, used for mobile phone user protection and their influence on the mobile phone antenna pattern.

The process simulation was implemented by numerical technique using FDTD method, performed by appropriate software XFDTD [8].

The half-wave dipole was selected to perform the electromagnetic radiation source due to its nondirectional properties similar to mobile phone antenna [9]. The geometrical length of the radiating element is 80 mm at 1.8 GHz.

The signal source with internal resistance 50 Ohm generates Gaussian beam with 1 V amplitude. The chosen signal type allows transmission (S21)/reflection (S11) coefficients calculation in a wide frequency range. The antenna pattern was determined for sine input signal of 1.8 GHz.

Shielding effectiveness of the described liquid-containing nanostructured materials and absorbent structures based on them was assessed using network analyzers and rectangular waveguide measurement path with horn antennas. The frequency characteristics of attenuation and reflection of electromagnetic radiation by the EMR absorbers were measured in the frequency band 0.76…2 GHz.

Attenuation of electromagnetic radiation is determined by the ratio between the power of incident electromagnetic wave and the power of the wave transmitted through the sample under study. The reflection level indicates the portion of electromagnetic energy retransmitted by the sample back to the direction of the radiation. The measurements were carried after a standard calibration procedure under the normal incidence of electromagnetic waves on the sample.

3. RESULTS AND DISCUSSION

The obtained frequency characteristics of S11 and S21 parameters and antenna pattern of the chosen antenna are similar to those of half-wave vibrator in the free space confirming simulation correctness [10].

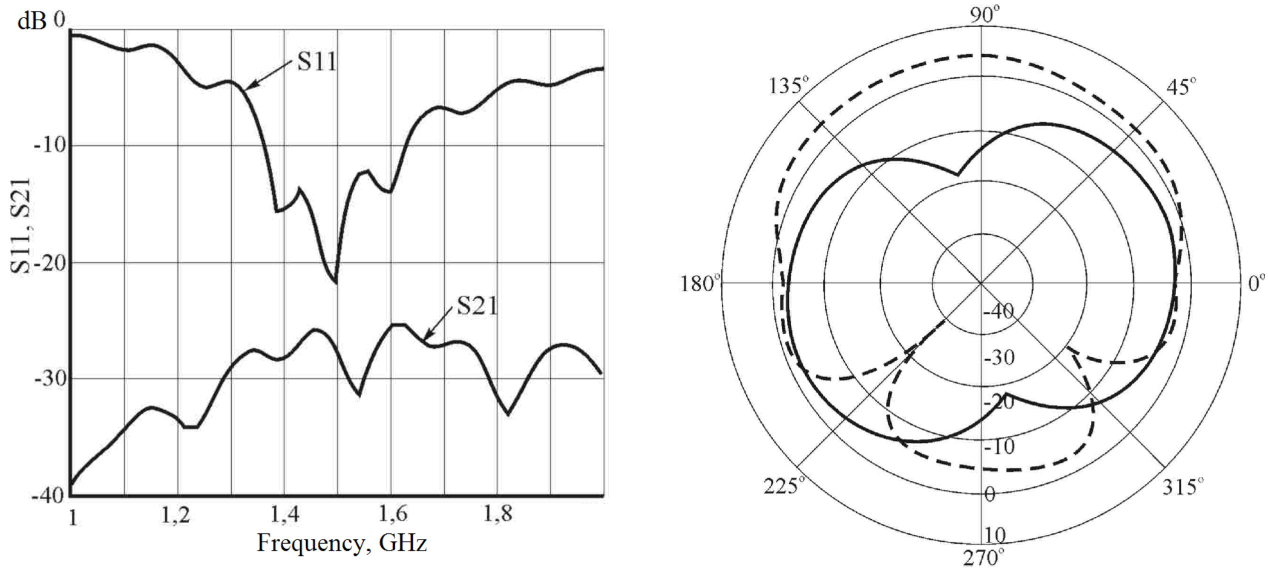
The influence of human body on the antenna pattern was studied using the 3D-model of a human body with the following characteristics: permittivity of skin — 35, bones — 21, density of skin — 1080 kg/m3, bones — 1850 kg/m^3. The human head was positioned in the center of the antenna pattern with azimuth angle 270º. The results are presented in Fig. 2.

As the results of the modeling show the electromagnetic energy is gradually attenuated while traveling into the model of the biological tissues because of their dielectric properties. Human body placement 3 cm away from the radiating element resulted in antenna pattern decrease at elevation angles 225º and 310º to –40 dB and –20 dB appropriately. According to that the transmission coefficient is decreased by 17 dB below the normal conditions owing to absorption of some part of electromagnetic radiation by the human body.

As most of protective means for mobile phones are based on metals and their alloys metallic shields with different dimensions and 1 mm in thickness [11, 12] was used in the process of simulation. In the case when the shield dimensions were 180×80 mm calculations revealed the transmission coefficient decrease by 40 dB comparing to single dipole antenna characteristics. The antenna pattern increased by 5 dB at elevation angle 90º, and at elevation angles from 225º to 315º it decreased by 20 dB in average. This shield ensures electromagnetic radiation level lowering on the human side due to EMR reflection in the direction of a radiating element.

When the dimensions of the metal shield were reduced to 100x80 mm the antenna pattern level increased up to -25 dB at the azimuth angle of 250º, and the transmission coefficient increased by 5 dB. Using the 80×80 mm metal shield the level of the power reaching the load enhanced because of smaller wave diffraction on the shield edges and the transmission coefficient increased by 15 dB.

The metal shield more than 100 mm in dimensions that corresponds to half-wavelength of the mobile phone radiation, suppresses the level of electromagnetic radiation traveling in human head direction by partial reflection of EMR in the reverse direction. But at the same time the level of the mobile phone antenna pattern lowers to -40 dB, forming "shadow areas" in which the mobile phone automatically increases the radiated power level to enhance the communication quality.

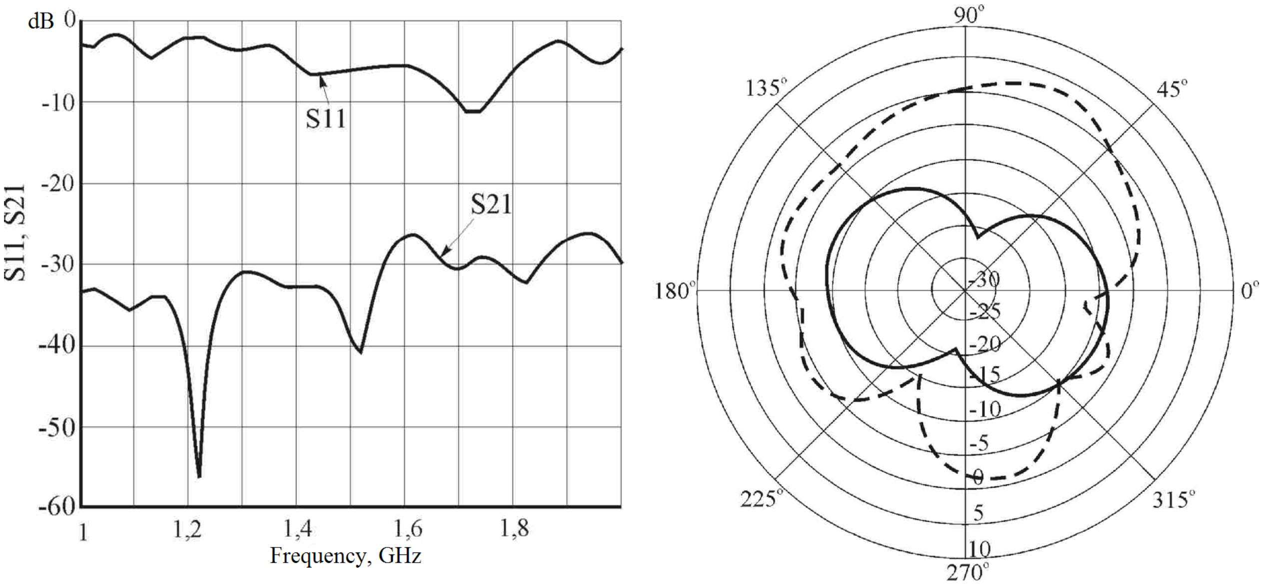


а)   б)

Fig. 2. — The frequency characteristics of transmission/reflection coefficients (a) and the antenna pattern (b) for half-wave vibrator placed near the human body

The transmission/reflection coefficients of a radioabsorber based on liquid-containing nanostructured materials placed between the radiating antenna and the human body model and its influence on dipole antenna pattern were studied. The simulation results are given in Fig. 3. The studied shield placement results in antenna pattern decrease to the level of –15 dB at elevation angle 270º, and to –30 dB at elevation angles 250º and 290º, the transmission coefficient value changes to –32 dB. It is caused by absorptive losses in the liquid-containing material and human body.

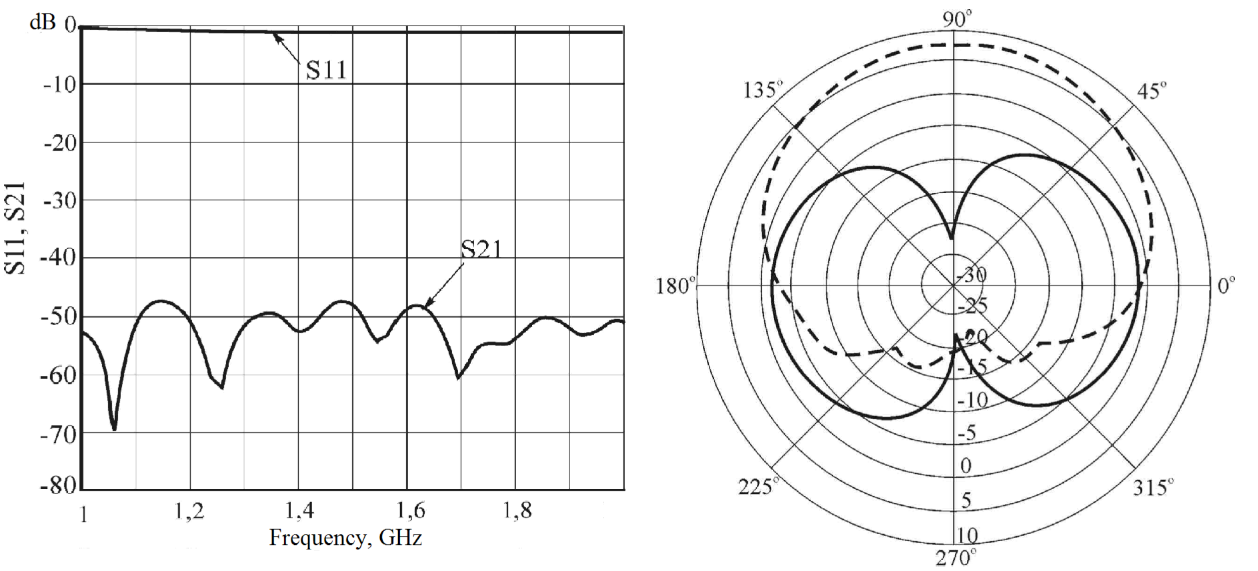
Two-layered EMR absorber construction containing the first layer of liquid-containing nanostructured material of 5,5 mm thickness and the second metallic layer of 1 mm thickness was studied (Fig. 4). Absorber thickening results in antenna pattern side lobe lowering to the level of –20 dB while the reflection coefficient does not change. In addition the antenna pattern is decreased at elevation angle 250º to –15 dB.



a) б)

Fig. 3. — The frequency characteristics of transmission/reflection coefficients (a) and the antenna pattern (b) of half-wave vibrator when EMR absorptive material is placed between the antenna and the human body

If the absorber dimensions are reduced to 80×80 mm the transmission coefficient increases by 5 dB in average comparing to absorbers with dimensions greater than half-wavelength of the radiation. If the dimensions of the absorbing material are further reduced to 60×80 mm the antenna pattern is changed to -50 dB at the azimuth angle of 250º, and to -30 dB at the azimuth angle 300º.



a) б)

Fig. 4. — The frequency characteristics of transmission/reflection coefficients (a) and the antenna pattern (b) of half-wave vibrator when the two-layered absorber construction is placed between the antenna and the human body

Analyzing the modeling results it is shown that the human body in proximity of the half-wave vibrator results in “shadow areas” forming, caused by the antenna pattern decrease from -30 to -40 dB level at the azimuth angles 225º and 310º, that deteriorates the communication quality in poor reception areas.

The metallic shields more than 100×80 mm in dimensions placed by the antenna form the directivity of the antenna pattern by dominating reradiating of EMR from the shield back to antenna.

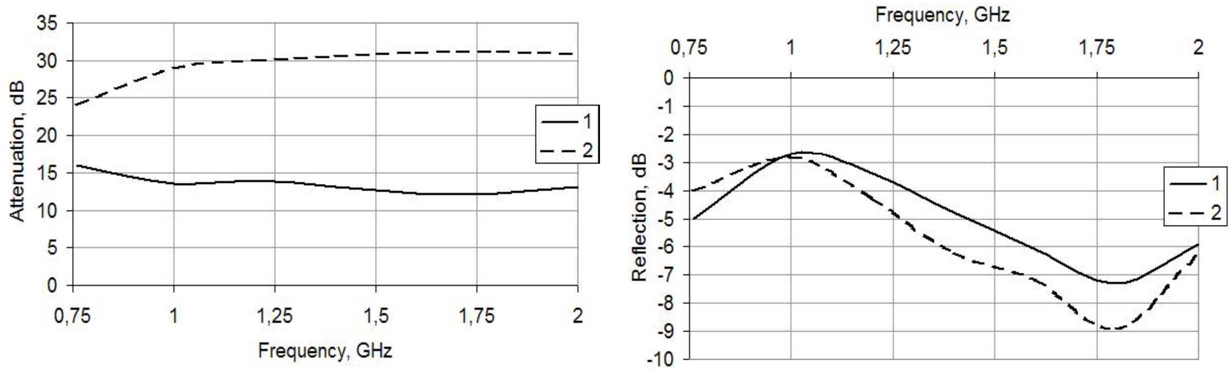
Shielding structures based on composite liquid-containing materials as well as metallic shields form the directivity of the antenna pattern, but the back lobe level increases by 20 dB at the azimuth angles 225º and 310º. The transmission coefficient, meaning the power of radiation traveling in the direction of the human, is decreased to -50 dB. It is caused by the heat losses of the shielding material containing polar dielectric liquid and the dispersed structure of this liquid within the porous matrix having nano- and microsized elements.

If the shielding material dimensions are changed around half-wavelength margins the antenna pattern is deteriorated and the diffraction occurs reducing the effectiveness of such materials.

Wave diffraction is reduced by enlarging the absorber dimensions and as a result the major part of the electromagnetic radiation is attenuated. The further extension of the dimensions do not result in sufficient increase of its efficiency so the dimensions of the EMR absorber equal to half of wavelength of 1.8 GHz operating mobile phone radiation is optimal.

EMR absorber used to attenuate the electromagnetic radiation of the mobile phone with the proved dimensions decreases the impact of the radiated energy on the human head and do not deteriorate significantly the phone antenna pattern.

The electromagnetic radiation attenuation and reflection by the liquid-containing nanostructured material and two-layered absorber construction comprising the composite material and metallic shield were assessed experimentally (Fig. 5).



a b

Fig. 5. — Experimental frequency characteristics of EMR attenuation (a) and reflection (b) by absorber materials: 1 — single-layered liquid-containing nanostructured material;
2 — two-layered absorber construction

Liquid-containing nanostructures material provides 12…15 dB attenuation of electromagnetic radiation in the frequency band 0.76…2 GHz. The EMR energy is reflected off the front surface of the sample at -3…-7 dB level and is absorbed by the polar liquid, containing in the porous space of the matrix. In the case of double-layered absorber structure the EMR attenuation is up to 30 dB due to metal placed behind the composite layer but the reflectivity of the material do not change significantly as the waves reflected off the rear surface of the sample and off the metal are absorbed and dissipated by the elements of liquid-containing material.

Liquid-containing materials placed in front of metallic shield decrease the high reflectivity of metal as it was previously shown enhance the mobile phone antenna operating and attenuate the mobile phone radiation which is directed to the human head to prevent possible health hazards.

CONCLUSION

The simulation results show that human body placed in proximity of mobile phone antenna causes antenna pattern decrease to –20 and –40 dB at elevation angles 225º and 310º, leading to the necessity of mobile phone radiating power increase for the communication process implementation in said shadow areas. Metallic electromagnetic radiation shield placed between antenna and human body model ensures the dipole transmission coefficient lowering for 40 dB comparing to single antenna simulation results. Antenna pattern is decreased by 20 dB in average at elevation angles from 225º to 315º, providing lowering of EMR level affecting the human's body due to its reflection off the metal.

It is revealed that application of multilayered radioabsorbing constructions based on liquid-containing materials between the electromagnetic radiation source and human body results in lowering of the EMR influence on the human body because of dielectric losses of the material, reflection of electromagnetic waves inside of its heterogeneous structure. The liquid-containing layer thickness increase from 2 to 5.5 mm results in antenna pattern back lobe decrease to –20 dB.

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