# Modeling of Wave Propagation from a 5GHz Wi-Fi Router in the Experiment of an Electromagnetic Field on Biological Objects Effect Study

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***Abstract*—The study of the impact of electromagnetic pollution on the environment and living organisms is relevant in the context of the increasing role of 5GHz technologies. The aim of this work is to study the characteristics of the Wi-Fi router electromagnetic field placed in a Faraday cage. The Faraday cage in this experiment is used as a construction that isolates biological objects from an external electromagnetic field. The electromagnetic field was modeled using the ANSYS and COMSOL Multiphysics software packages. The mathematical basis for constructing the electromagnetic field was the finite element method. The simulation results were verified experimentally on a stand to determine the electromagnetic field in a Faraday cage. This experimental stand was later used in a biological study of the influence of man-made effects from the electromagnetic field created by microwave devices on biological objects at the Pavlov Institute of Physiology, Russian Academy of Sciences. The results of the numerical and experimental study became the basis for determining the location of biological objects in the Faraday cage.**

## I. INTRODUCTION

The electromagnetic background has existed since the very beginning of life on the planet. The intensity of this background is growing at high speed with the development of humanity. In this regard, natural and anthropogenic electromagnetic fields are distinguished.

Sources of the natural electromagnetic field include radiation emanating from the Earth's magnetic field, electrical processes in the atmosphere and nuclear fusion in the depths of the Sun. Such electromagnetic fields remain virtually unchanged throughout their entire existence and constitute an environmentally friendly electromagnetic environment for the environment.

Electromagnetic fields of anthropogenic origin can be divided into low-frequency from 0 to 3 kHz and high-frequency from 3 kHz to 300 GHz.

Any device that uses electrical energy is a source of electromagnetic fields and radiation. Today, there is an active growth in the number of electrical appliances and various radio-electronic devices, that people use in everyday life.

High-frequency radiation sources include cell towers, mobile phones, Wi-Fi routers, microwave equipment, as well as any wireless equipment. Low-frequency radiation sources include all wired equipment that operates from the network (computers, washing machines, refrigerators, etc.).

Most of the alleged types of equipment such as mobile phones, computer equipment, telecommunication technologies are sources of electromagnetic waves of different frequencies emitted into the surrounding space, thereby "polluting" the human environment. In such cases, one speaks of electromagnetic pollution, electromagnetic damage. The total strength of such an electromagnetic field is approximately 1000 times higher than the natural background.

This fact today serves as the primary reason for the start of various active studies aimed at studying the effect of this kind of “noise” on biological objects and on humans.

Technogenic electromagnetic fields are primarily characterized by increased power and higher radiation frequencies. The peculiarity of their impact is to reduce the depth of penetration and increase the energy factor of the impact. The dangerous effect of electromagnetic radiation is the phenomenon of “thermal effect,” which manifests itself in the form of a force that heats the fluid in the cells and leads to their damage.

Technogenic electromagnetic fields can play an etiologically important role in the epidemiology of mental, oncological, ophthalmological, cardiovascular and other diseases, negatively affecting the immune, endocrine system, and genetic structures of the human body. And most importantly, the influence of electromagnetic radiation is cumulative in nature, so it is very difficult to identify a clear connection between the disease that has arisen and the influence of electromagnetic radiation.

One of the dangerous ranges of radiation is non-ionizing, for example, from Wi-Fi routers. This type of electromagnetic radiation can affect a biological system, both due to thermal and non-thermal effects. Non-ionizing radiation, on the other hand, can act as ionizing radiation and cause long-term health problems.

The ways and mechanisms of the influence of electromagnetic radiation on the genetic apparatus of cells and the organism as a whole still remain poorly understood. The individual characteristics of the body's reaction to the effects of electromagnetic fields, as well as the role of the functional state of its nervous system in regulating sensitivity and resistance to their effects, are practically unknown.

The study of the influence of a wireless communication device was carried out in an experimental stand consisting of a faraday cage and a router in its center. The results obtained in the course of these studies make it possible to judge the effect of electromagnetic waves on living objects, provide grounds for assessing such an effect on the human body and highlight the way for setting up subsequent similar experiments, one of which will be the study of the effect of router radiation at a frequency of 5 GHz.

The purpose of the presented study is to simulate the electromagnetic field from a Wi-Fi router at a frequency of 5 GHz, which is planned for use in experiments on biological objects, as well as to verify the simulation results in practice. The object of research work was the electromagnetic field created by the Xiaomi Mi Wi-Fi Router Pro router at a frequency of 5 GHz. The results obtained in the course of the work are planned to be used as additional input data for the biological research in this area.

In general, the following technical characteristics are accepted as limitations and assumptions of this work:

Parameters of the router under study: antenna length L=15 mm; radius R = 0.9 mm; the material is an ideal conductor; discrete port (excitation source) – Lumped Port, with dimensions 1.8x2 mm. The operating frequencies of the router are 2.4 GHz and 5 GHz.

Parameters of a Faraday cage - a container made of several layers of metal mesh. Cage dimensions: length – 50 cm, width – 40 cm, height 42 cm.

One of the relatively recent experiments revealed the negative effect of electromagnetic radiation on the feeding behavior of bees. For two years, insects were exposed to a standard Wi-Fi router, which ultimately contributed to a decrease in food motivation by 1.2 times, while the results of the analysis of long-term memory gave the opposite effect - the memory of bees placed in a Faraday cage improved by 1.6 times [1]. And this is not all research aimed at resolving the issues of exposure to high-frequency EMR. Much of the work remains to be done.

However, most of the experiments conducted looked at standard 2.4 GHz routers, which are designed based on the 802.11n standard.

The maximum speed of such wireless communications reaches about 450 Mbit/s, which is often difficult to achieve in real conditions due to space congestion with various types of other devices that also operate at the 2.4 GHz frequency: gadgets using Bluetooth technology, cell phones, microwave emitters.

Today, there is a rapid development of routers, which leads to the emergence of devices operating on two frequency bands - 2.4 GHz and 5 GHz. This operating mechanism is provided by Dual-Band technology. Unlike previous models, routers with a frequency of 5 GHz have a number of advantages, among which the main ones can be highlighted. Firstly, at this frequency there are a large number of free channels, which ensures a low level of interference. Secondly, devices in this frequency range are designed based on the new 802.11ac standard, thanks to which the maximum information transfer rate is about 1300 Mbit/s.

Thus, the standard of five-gigahertz devices is increasingly appearing in human everyday life, which raises the question of the need to study the influence of this frequency range on living organisms.

Carrying out this kind of experiments requires preliminary data on the electromagnetic field of this frequency. A detailed analysis of the impact of EMR is possible if information is available on the nature of the field, its distribution in space and the Faraday chamber in particular, its properties and other details that give the broadest idea of electromagnetic radiation in this frequency range.

The presented study is in addition to the work of the Pavlov Institute of Physiology, Russian Academy of Sciences in the field of studying the influence of UHF radiation from a standard Wi-Fi router on biological objects. The results of the study were transferred to this organization as recommendations for further research.

## II. FORMULATION OF THE PROBLEM FOR MODELING THE ELECTROMAGNETIC FIELD FROM A WI-FI ROUTER

A Wi-Fi router with 4 external non-removable antennas with a transmission power of 19 dBm was considered as a source of 5 GHz EMR. The type of antenna used is a monopole. The external dimensions of the device are 146×195×66 mm. The router is placed on an additional shelf in the upper central area of the box placed in the faraday cage. Global variables that store all the main parameters of the analyzed structure: antenna radius - 0.9 mm, router antenna length - 15 mm, lumped port dimensions - 1.8 × 2 mm. A monopole antenna is half a dipole one, taking into account the fact that the second half of the dipole is replaced by a plane of considerable length comparable to the size of the emitted wave.

The choice of monopole antenna length is dictated by the wavelength of the electromagnetic radiation and is typically $1/4\ \lambda$, where $\lambda$ is the wavelength. This ratio allows you to most effectively radiate and receive electromagnetic waves with the lowest level of interference. Sometimes, for some wireless communication devices, a small signal coverage area is characteristic due to the specific properties of electromagnetic radiation in such a range, then in order to increase the maximum radiated power in the horizontal direction, the length of the antenna is chosen equal to $5/8\ \lambda$. In the experiment under consideration, a router with a wavelength of $1/4\ \lambda$ is used. A monopole antenna is a straight rod conductor mounted perpendicular to some type of conductive surface, which is the ground plane.

The experimental stand includes a box with the following dimensions: height 42 cm, width 40 cm and length 50 cm. The wooden base of the box was upholstered with a fine-mesh metal mesh connected to ground, which made it possible to use it as a Faraday cage. The principle of operation of the Faraday cage is as follows. The electric field hitting the boundary of the conductor causes a redistribution of free charge carriers in it, which leads to the formation of a new field directed opposite to the incident one. Thus, there is a compensation of the external electromagnetic field inside the cell. Similarly, this design allows you to protect the surrounding space from the field propagating inside the cell.

The figure of the process under study is shown in Fig. 1.

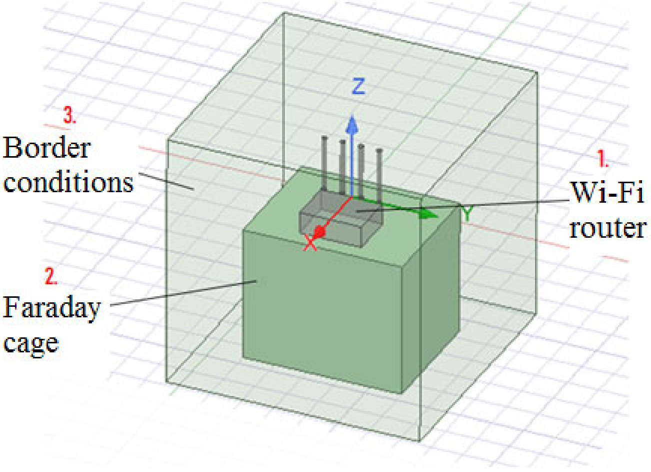

Fig. 1. Model under study

In the verification experiment, measurements of the attenuation distribution of the radiation of the router over the volume of the box were carried out at two levels from the placed router: 0 cm and 13 cm. The choice of heights was due to the planned placement of living objects for further research.

The boundary conditions are:

- The ground plane on which monopole antennas are located is a conductive surface.
- The Faraday cage is presented as an ideal electrical wall.
- Grounding is done when ports are assigned. • Antennas are presented as an ideal electrical conductor.
- The bounding area of the model is air.

## III. CHOICE OF METHOD AND PROGRAM FOR NUMERICAL SIMULATION OF THE ELECTROMAGNETIC FIELD

The search for an approximate solution of the Maxwell equations that meet the given boundary and initial conditions is a key task in modeling electromagnetic fields. Different methods of solving Maxwell's equations are used, they are divided into direct and indirect modeling of electromagnetic fields, planar and volumetric modeling [2]. The direct approach is implemented by the Finite Element Method (FEM) [3-6]. In this method, discretization of the volume of the simulation area and further step-by-step integration in time are performed, the movement of electromagnetic waves is represented in an explicit form. The FEM is applicable to the calculation of structures with complex geometry and consideration of radiation issues, for example, the parasitic effect of the package of a RF / microwave integrated circuit. Indirect methods allow solving Maxwell's equations through matrices. Indirect methods include the Finite Difference Time Domain Method (FDTDM) and the Method of Moments (MoM). The FDTDM optimizes the calculation of the electromagnetic field in complex conducting and dielectric media [7-12]. This is a three-dimensional method that can be applied to the analysis of objects of electromagnetic study of arbitrary shape. The MoM is used for "planar" multilayer structures [13-16]. Such structures include most RF / microwave devices, printed circuit boards.

The finite difference method uses a time-step integration algorithm that updates the field values in a grid cell step by step, explicitly tracking the progress of the EMR through the modeled structure. There is a displacement of the points of application of various EMF parameters in relation to the dimensional grid cell - voxel.

Finite-difference equations make it possible to determine the EMF at a given time based on known field values at the previous time, and under given initial conditions, the computational procedure unfolds the solution in time from the origin with a given step.

The universality of the finite difference method determines its use in almost all problems of electrodynamics that require numerical solutions. Problems successfully solved by finite-difference methods include the analysis of waveguide and resonant structures of complex shapes with inhomogeneities, waveguide and microstrip, as well as modeling of radiating structures, antennas, and analysis of active microwave devices, and much more. The use of the finite difference method is especially effective in those problems where it is important to analyze non-stationary processes. After conducting a separate model experiment using the finite difference method for each EMR source in the room, it is possible to analyze the resulting field parameter from all EMR sources.

Today, FEM is considered key in most design fields, allowing the modeling of complex geometric structures with a variety of materials. The finite element method, which is one of the direct solution methods, as opposed to the method of moments, can be used when considering various volumetric structures. The essence of the approach under consideration is as follows. As noted earlier, the unknown parameter here is the field value, which is approximated over the entire volume. Accordingly, it follows that it is logical and necessary to limit the space around the model to a certain area within which the modeling will be performed.

The construction of a discrete model of a continuous value can be reduced to the following algorithm:

1) the domain of definition of a continuous quantity is divided into a finite number of subdomains called elements. These elements have common nodal points and together approximate the shape of the area;

2) a finite number of node points is fixed in the region under consideration;

3) the value of a continuous quantity at each nodal point is initially considered known, but these values in reality still

have to be determined by imposing additional restrictions on them depending on the physical nature of the problem;

4) using the value of the studied continuous value at the nodal points and the approximating function, determine the value of the studied value within the region.

The tasks of modeling EMF using FEM require the use of high-speed computers. Today, on the software market you can find a large number of calculation systems using FEM.

Being relatively simple to implement, the finite difference method in the time domain is most often used when considering problems of photonics and plasmonics.

The basis of this mathematical approach is the finite-difference scheme of discretization of Maxwell's equations. In the case of a linear homogeneous medium, this scheme converges with second order accuracy on rectangular uniform and non-uniform grids when the Courant condition is satisfied.

Separately, it is worth noting an important nuance in the case of layered media, when one of the material parameters (dielectric constant $\varepsilon$ or magnetic susceptibility $\mu$) or both are piecewise continuous. If the discontinuity point falls inside the pattern of the difference scheme, then it is not possible to achieve normal convergence. There is only convergence in the norm with a fractional exponent depending on the a priori order of accuracy.

The unknown parameter in the method of moments is the current distribution on metal surfaces, in contrast to the other mentioned methods, where such quantities are the electric and magnetic fields present throughout the entire volume of the model. This principle makes it possible to significantly reduce the cost of computer memory and significantly increase the efficiency of modeling, since only the metal parts of the structure under study are subject to sampling, which leads to a reduced number of cells at the meshing stage.

After determining the analyzed model, all conductors are divided into segments, the size of which is dictated by the wavelength and should be very small relative to the latter. This stems from the assumption that the current does not change its value when passing through such a region.

Next, a system of linear equations is constructed, the solution of which makes it possible to determine the currents for each segment and, as a result, calculate the EM field at any point in the space of the analyzed model.

The construction of the field in the method under consideration is based on an analytical solution to the problem of excitation of a structure by an elementary current source. The solution to this problem is called the Green's function. However, the process of finding this function can be quite simple only for a limited number of situations, namely for plane-layered structures and free space, which makes it impossible to use this method for studying three-dimensional models.

Taking into account the above-mentioned features of this approach, it is more expedient to use the method of moments when considering RF/microwave devices that have an overwhelmingly planar structure.

From a mathematical point of view, solving the modeling problem using the method of moments comes down to the following steps:

1) obtaining integral equations of structure from Maxwell's equations;

2) discretization of the structure: partitioning the structure into N subregions, in each of which the desired function is approximated by basis functions;

3) calculation of matrix elements of systems of linear algebraic equations of size N*N;

4) calculation of elements of the impact vector of size N;

5) solving systems of linear algebraic equations;

6) calculation of the required characteristics from the solution vector of systems of linear algebraic equations.

The vast majority of modern software packages for the analysis of the electromagnetic field are based on the FEM, since this method is used for three-dimensional bodies; unlike the FDTDM, this method works well in the frequency domain and with complex circuits containing a large number of ports.

Among the existing variety of software products designed to solve field FEM problems, three universal packages can be distinguished. Firstly, this is ANSYS - one of the first finite element analysis packages, secondly, Femlab - the latest package for solving field problems, and thirdly, Elcut - practically the only domestic package suitable for EMF modeling. All three packages are universal (designed to solve various types of field problems), allow solving linear and nonlinear problems, and have approximately the same accuracy and capabilities.

The analysis of software products showed that each of them has its own specifics of work. In particular, for the most common crimes in practice, one can summarize:

- ANSYS HFSS is based on the finite element method, allows you to solve the problems of obtaining the necessary characteristics of antennas, to consider the problems of electromagnetic field radiation. A distinctive feature of the software environment is the use of a hybrid calculation method that allows you to combine the finite element methods and the method of moments, thereby reducing the load on the computing system [17, 18].
- COMSOL Multiphysics has similar functionality to ANSYS HFSS. A distinctive feature of the software package is a wide range of possibilities for building a model: from various types of surfaces to all kinds of Boolean operations [19], [20].
- The ELCUT program is the only Russian tool for engineering analysis and 2D finite element modeling. ELCUT developers, in order to save the user's software implementation resource, use adequate simplifying assumptions instead of solving the full system of Maxwell equations [21].

Thus, depending on the complexity of the problem being solved and the requirements for the accuracy of representation of a real object in the model, you can select the desired program for carrying out calculations.

Solving physical problems using numerical methods usually involves a number of mathematical approximations. Sometimes translating mathematical formulas into computational algorithms turns out to be very difficult. This leads to the need to use calculation control methods in order to have confidence in the correctness and accuracy of the solutions found. To do this, it is recommended to use the following methods: the principle of reciprocity, the law of conservation of energy, verification of convergence, comparison with the results of other methods, fulfillment of boundary conditions and experimental confirmation.

It should be noted that very often computational programs are compiled for a wide range of initial parameters. This is one of the main advantages of using computers. Control methods are applicable only in a limited range of initial parameters. Therefore, no control method can provide complete confidence in the correctness of the decision. Thus, only the use of several verification methods makes it possible to verify the truth of the results.

As part of the work, the ANSYS HFSS software package was used, which is most often used in structural studies and CFD simulations.

## IV. EXPERIMENTAL STAND FOR DETERMINING THE ELECTROMAGNETIC FIELD IN A FARADAY CAGE

The purpose of the experiment is to measure the distribution of the electromagnetic field from the router located on the experimental stand. The experimental stand is a Faraday cage. In the future, this experimental stand will be used to study electromagnetic fields on biological objects. In the experiment, a Wi-Fi receiver such as a TP-Link AC600 Nano Wi-Fi USB adapter was used as a sensor measuring the attenuation of radiation (Fig. 2). In fact, it was used as a radiation sensor for the router.

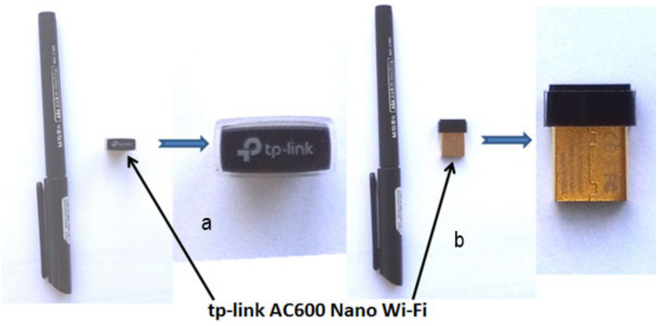

Fig. 2. Radiation sensor: a – top view; b – side view

Fig. 3 shows the sensor placement points on the plane. The connection point for the grounding bus ("Grounding" in Fig. 3) is located 10 cm from the floor and 18 cm from the left edge of the box.

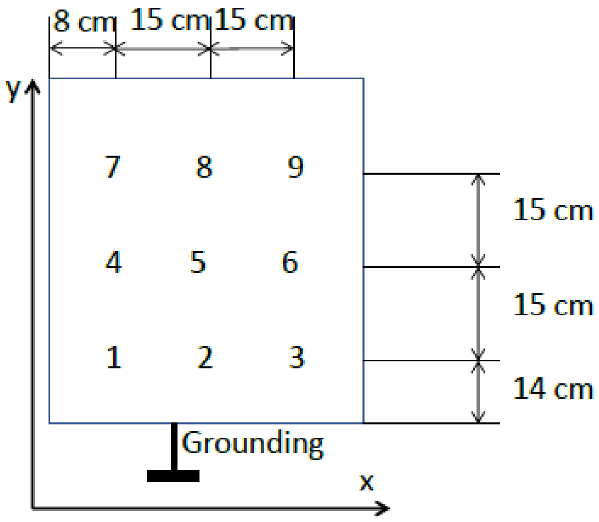

Fig. 3. Sensor placement points

## V. NUMERICAL SIMULATION RESULTS

Fig. 4 shows the radiation pattern of a system of four monopole antennas of the analyzed model, which is a prototype of a Wi-Fi router. As you can see from the presented diagram, the gain reaches its maximum value along the plane that the antennas form.

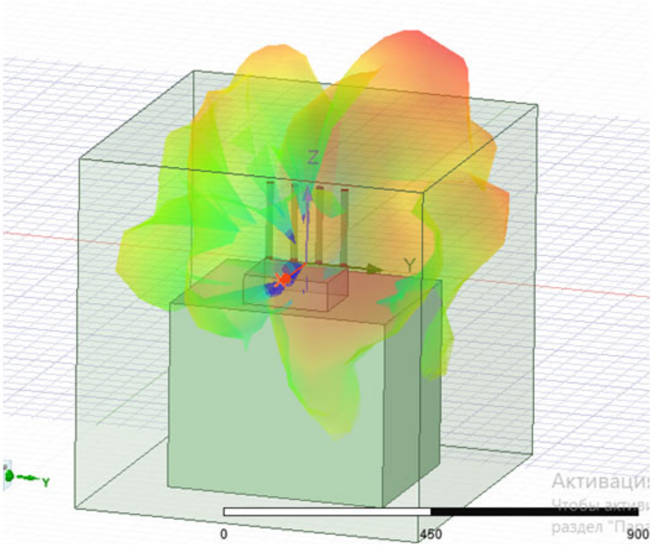

Fig. 4. Volumetric radiation pattern of a system of four monopole antennas in a model of an experimental stand

The influence of electromagnetic radiation on living organisms is usually assessed by the following parameters: indicators of field intensity and the energy load they create. According to safety standards, GOST 12.1.006-84 [16], the frequency range 300 MHz - 300 GHz is characterized by the surface energy flux density, reflecting the level of radiation intensity, and the energy load created by the field, which is defined as the product of the energy flux density and the time of exposure to the field.

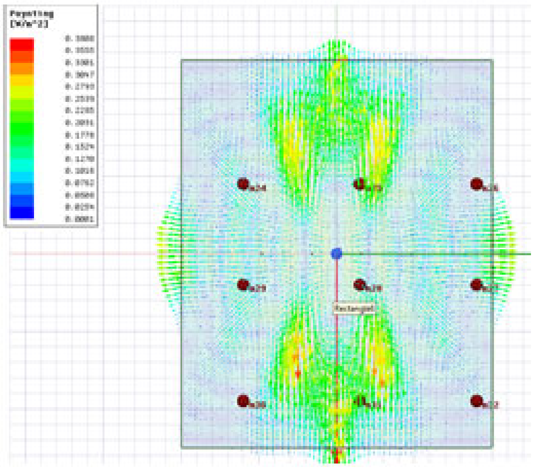

Fig. 5. Distribution of the electromagnetic field from the router in the XY plane

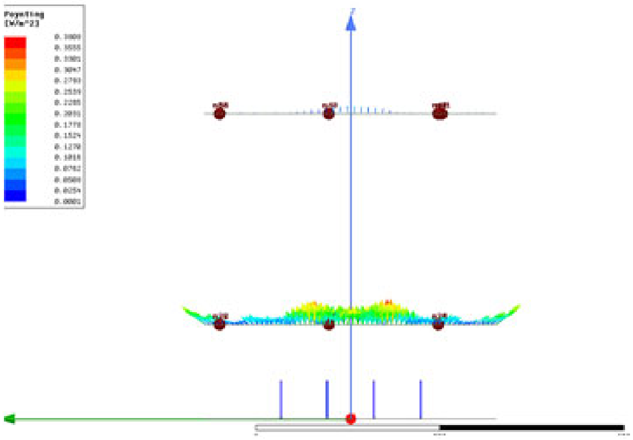

Fig. 6 Distribution of the electromagnetic field from the router in the YZ plane

Fig. 5-6 shows the results of field simulation in the stand at a distance of 13 cm from the surface of the wireless communication device and at the level of the top cover of the Faraday cage. The electric and magnetic field strength values are shown in Fig. 7-8.

Energy transfer by an electromagnetic field is determined by the radiation intensity S, W/m$^2$, which is characterized by the Umov-Pointing vector (1).

where $\bar{E}$ is the electric field strength vector, $\bar{H}$ is the magnetic field strength vector.

$$S = \left[\bar{E} \times \bar{H}\right] \tag{1}$$

Fig. 5-8 shows the Umov-Poynting vector in selected planes.

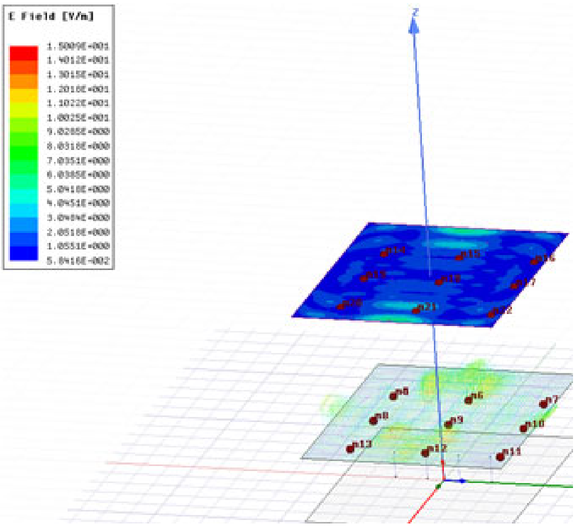

Fig. 7. Visualization of electric field propagation

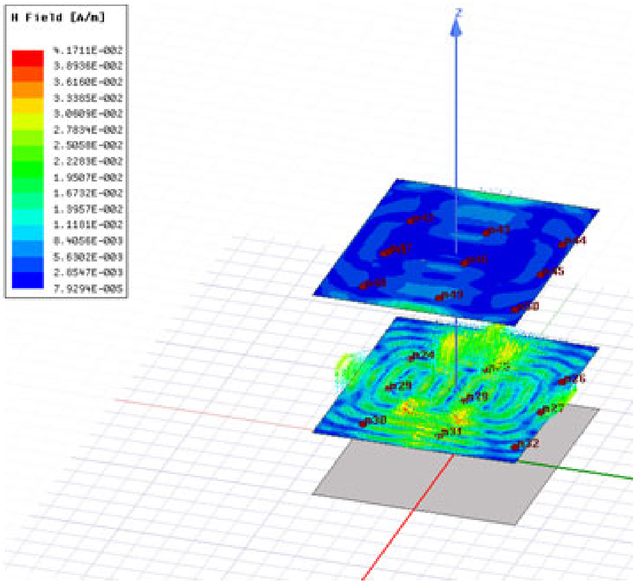

Fig. 8. Visualization of magnetic field propagation

The data obtained clearly show that at the top cover of the stand, changes in field values occur more linearly and evenly than at a distance of 13 cm from the router. As can be seen from the figures shown above, the Umov-Pointing vector reaches its maximum values on a plane located at a distance of 13 cm from the router. Consequently, it is in this area that it seems logical and optimal to place living objects in order to study the influence of high-frequency EMF - it is on this plane that this value changes extremely unevenly, while the strength of the magnetic and electric fields is also maximum.

The results of measurements of the distribution of attenuation of the radiation power of the router over the above sites in dB are shown in the form of matrices $A_1$ (h=13 cm) and $B_1$(h=0).

$$A_1 = \begin{bmatrix} 6.4 & 2.0 & 5.7 \\ 2.2 & 5.7 & 3.3 \\ 4.2 & 3.6 & 0.6 \end{bmatrix} \qquad (2)$$

$$B_1 = \begin{bmatrix} 7.2 & 8.0 & 7.4 \\ 6.0 & 8.7 & 7.1 \\ 7.5 & 8.2 & 6.7 \end{bmatrix} \qquad (3)$$

## VI. EXPERIMENTAL MODELING RESULTS

The results of measurements of the distribution of attenuation of the radiation power of the router over the above sites in dB are shown in the form of matrices $A_2$ (h=13 cm) and $B_2$ (h=0), and, for clarity, are presented in the form of surfaces obtained using spline interpolation of the results measurements (Fig. 9). It can be seen that opposite the connection point of the grounding wire, the attenuation is maximum.

$$A_2 = \begin{bmatrix} 5.0 & 2.0 & 0 \\ 1.0 & 2.0 & 1.0 \\ 4.5 & 1.0 & 2.0 \end{bmatrix} \qquad (4)$$

$$B_2 = \begin{bmatrix} 6.0 & 6.0 & 2.5 \\ 1.0 & 4.0 & 5.0 \\ 1.5 & 4.0 & 3.0 \end{bmatrix} \qquad (5)$$

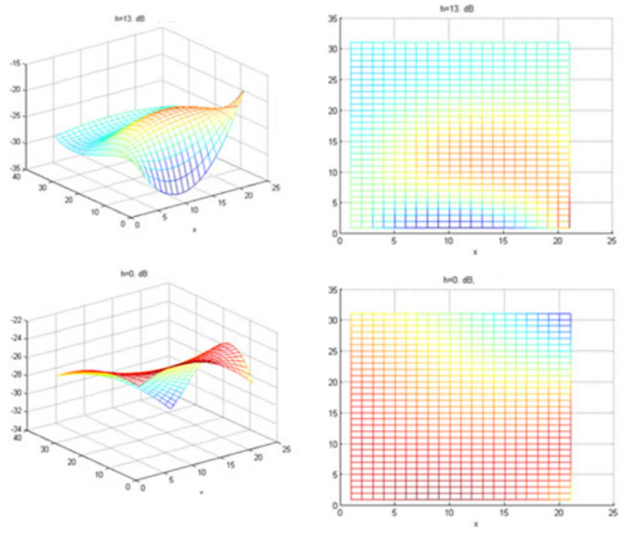

Fig. 9. Results of measurements of the distribution of power attenuation in the box, expressed in dB: bottom row - on the floor of the cage, top row - at a height of 13 cm from the floor

## VII. CONCLUSION

Analysis of the data obtained from the modeling results showed that the electromagnetic field in the experimental stand is distributed extremely unevenly both in the selected reference planes, the choice of which was carried out in accordance with the requirements of the planned research, and within the planes themselves. The maximum areas of radiation are concentrated along the axis (line of antenna placement), the radiation pattern is an elongated torus. The intensity is minimal near the grounding point.

The plane that is of the greatest interest for placing living objects on it is the level of 13 cm from the router, since it is on this plane that the maximum values of the power radiated by the antenna system occur.

The area in space in which the values of the power emitted by the router reach their greatest value within the experimental stand are spaces located on both sides of the antenna placement line, which makes it logical to place living objects in such places.

Based on the analysis of the modeling results, the following recommendations are given for further experimental studies:

- A plane of 13 cm from a wireless communication device seems to be the optimal area for placing living objects on it in order to consider the influence of the electromagnetic field on living organisms.
- Placing living objects in order to study the influence of EMF exposure is advisable in areas located on both sides of the line of antenna placement.

## ACKNOWLEDGMENT

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