V. F. Manoylov, Dc. Sc. (Eng.), Prof.; L. Y. Nazarchuk

DETERMINATION OF THE DIALECTRIC PERMITTIVITY OF BIOLOGICAL ENVIRONMENT ON THE BASIS OF A FLAT DOUBLE-LAYER MODEL

The paper deals with the method for determining dielectric permittivity of biological objects using frequency dependence of the voltage reflection coefficient on the flat double-layer medium. It is shown that the dielectric constant of the half-space depends not only on the frequency, but also on the type of polarization and the electromagnetic wave incidence angle. This method can be used in the diagnosis of neoplastic diseases of the human body.

Key words: *complex dielectric permittivity, complex voltage reflection coefficient.*

Introduction

The first and main task in the field of radio-wave control of the composition and properties of materials is the dielectric permittivity measurement. The most widely used are microwave techniques that have found application in construction, agriculture and medical diagnostics.

The problem of magnetic field interaction with living organisms attracts attention of scientists by the possibility of its application in medicine, especially in the remote identification of the biological object structure, simulation of artificial objects with electrodynamic characteristics that are maximally approximated to those of real biological objects.

One of the physical quantities, that characterizes the property of environment to absorb electromagnetic waves propagating in it, is complex dielectric constant. The value of this quantity depends on the physical nature of the medium [1]. Most studies are related to measuring absolute values of the dielectric constant of materials and liquids. Thus, determination of the real and imaginary parts of dielectric permittivity of biological fluids and objects is an important task in the study of their structure and characteristics.

Review of the sources

In recent decades, intensive research has been carried out on propagation of electromagnetic waves in forest cover. These studies have acquired particular relevance with the development of remote sensing of the Earth surface. This is due to the significant influence of forests on the parameters of electromagnetic radiation of virtually all ranges that determine the characteristics of wave propagation near the earth surface.

In [2] the method for finding dielectric permittivity of the vegetation environment is considered for the low-frequency part of the very-high frequency range (VHF). According to its electrophysical characteristics, the forest environment is similar to a non-ideal dielectric, so the processes of reflection and refraction of waves at the upper edge of the forest depend mainly on the real part of its dielectric permittivity. The method is based on carrying out direct measurements of the field attenuation in the forest. It was believed that in this frequency range the forest medium is isotropic. Then determination of its dielectric permittivity was reduced to independent measurements of the real and imaginary parts of the scalar value.

During the last forty years GPR technology is increasingly used for a wide range of tasks on assessing the state of the rock mass. This is a technology that uses radar principles for the underground space studies (it is actively developed in the United States, France, Sweden, Russia, etc.). The method of electromagnetic pulse (EMP) ultrawideband (UWB) sensing has been applied in engineering geology and the construction industry as a method of GPR due to the increased depth of the research.

Papers [3 - 4] present a method of subsurface EMP UWB sensing, which is implemented using generators based on drift diodes with a sharp recovery of the reverse voltage for the emission of electromagnetic waves. Considerable depth of signal propagation is caused by the emergence of low-frequency dispersion of the dielectric constant in the medium, the presence of which can be determined by polarization with dipole relaxation mechanism that describes the behavior of moist soil under the influence of strong electromagnetic pulse field.

In the process of low-energy electromagnetic irradiation of biological tissues ionization of a substance molecules and formation of radical pairs occur. Thus, external low-energy electromagnetic fields affect the molecular structure of biological substances and, hence, also their electrophysical properties – the real and imaginary parts of the dielectric constant. These changes lead to the changes in the characteristics of the object under study.

Paper [5] deals with the ultrahigh-frequency electromagnetic field influence on biological objects in agricultural production. Assessment of the state of biological objects was performed using the dielectric radiospectroscopy method. By the level of the biological environment ionization the tendencies in the dielectric constant variations were determined. In this regard, a probabilistic model of the processes occurring in biological media under the influence of external electromagnetic fields was considered, which has made it possible to determine the quantitative changes in electrophysical characteristics of biological tissues.

Paper [6] presents the method of resonance angle and the method of phase measurements of the reflection coefficient, which are used for finding dielectric parameters of biological objects. Also, a sensor is designed for analyzing the composition of biological media. High sensitivity of such sensors is determined by resonance dependence of the sensor output values on the parameters of the medium. The intensity, incidence angle and phase of the reflected wave are used as informational parameters. In the biosensor design a three-layer model was used, namely: medium 1 was a glass prism, medium 2 – a glass or a silver layer with the depth d, medium 3 – a biological medium under study that was assumed to be a semi-infinite space. The method is shown to be a universal one in a wide range of dielectric parameters of the objects under study.

However, in spite of high sensitivity of these methods, there are certain limitations as to their application: high complexity of the optical circuit for realizing phase measurements of the reflection coefficient, which can be implemented only in the conditions of specialized laboratories..

Near-field location of the ultrahigh frequency (UHF) range is an effective method for investigation of the materials and media with various physical natures and is widely used in microelectronics, material science, defect detection and medical diagnostics. High sensitivity of the antenna to the changes in the dielectric constant of the medium allows performing diagnostics at a certain distance of the area under study from the probe aperture. An important characteristic in this case is a probing depth – a distance inside the object where the changes in the dielectric constant of the medium are still noticeable. In [7, 8] it is shown that the probing depth values for a near-field location could reach several centimeters. Also, a possibility is considered of using the near-field location of UHF range for identification of the malignant formations in biological tissues. Theoretical results are obtained using the theory of plane-layered media. The work presents an electrodynamic model for diagnosing strongly inhomogeneous layered media.

In [9] the effects of radiation interaction during near-field diagnostics of biological tissues are considered. Calculations were performed on the basis of the theory of a plain-layered medium near-field location. The theory was used to determine the probe complex impedance that was changing with the changes in the dielectric constant of biological tissue.

It is known that the emergence and development of many musculoskeletal system diseases of children and adolescents are related to deterioration of the main processes of the living organism activity regulation. Quality of life processes (normal or pathological) changes the electrodynamic parameters of the body, especially the dielectric permittivity of tissues. From this it follows that the dielectric constant estimation can be an indicator of the functional activity of the body.

In [10, 11] the possibility to determine electrodynamic parameters of biological tissues using the remote method is considered. The principal possibility of using such methods for non-invasive diagnosis of biological objects is shown and the capabilities of high-frequency near-field probing are investigated on specific examples connected with the musculoskeletal system of adolescents by measuring the dielectric constant of the living tissue.

Analysis of differences in the properties of biological tissues to absorb and dissipate electromagnetic field is the basis of the waveguide electromagnetic probing method [12 - 14]. The results of the research with the use of this method make it possible to estimate spatial distribution of the biological object dielectric permittivity and to make a conclusion about the degree of the electromagnetic field power absorption in biological tissues. The mathematical model of the method is based on solving the problem of electromagnetic field diffraction on the absorbing object placed into a waveguide. The corresponding boundary value problem is reduced to a Fredholm integral equation of the second kind. The advantage of the method of integral equations is the ability to obtain an overview of the field throughout the volume which includes dielectric inhomogeneity.

In [15] the problem of determining the diffraction pattern of the field using a heterogeneous dielectric sample, simulating a biological object, is considered. Waveguide electromagnetic probing method was used to investigate the effect of electrodynamic and geometric characteristics of the sample on distribution of the scattered electromagnetic field. Also simulation of electromagnetic waves on a layered heterogeneity in the waveguide was performed. Numerical calculations were carried out by the example of a plane waveguide containing a three-layer model of the biological environment. The dielectric constant of the outer layers was assumed to be equal to the dielectric constant of muscle tissue, and that of the inner layer – to the bone tissue

Results of the research on the dielectric properties of weak solutions of glucose in water and saline solution in MM range as well as that on the dielectric properties of the blood and skin are presented in [16]. Investigations were performed using a specially developed method for measuring the complex dielectric constant of a medium with considerable losses, which does not require phase measurements of the complex reflection coefficient. The method makes it possible to determine the level of glucose in blood in real time with a single drop of blood.

Problem statement

Early diagnostics of breast tumors is now one of the most pressing problems. Changes of dielectric constant and temperature are usually observed before the occurrence of structural changes that are determined by standard methods of breast cancer investigation - ultrasonography, mammography.

Therefore, the problem of determining the complex permittivity of biological tissues is a prerequisite for diagnosing structural changes in the human body and, namely, for the tumor process localization. Therefore, the development of a new method for determining the dielectric properties of biological tissues is an important task in diagnosing tumors. The novelty of this radio engineering method lies in finding complex permittivity of biological media using voltage reflection coefficient in the range of frequencies.This method is also improved by introducing a mathematical model of "antenna - biological environment" near-field interaction[17].

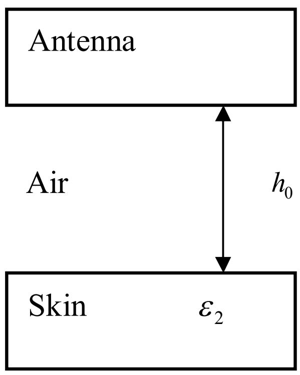

Fig. 1. Simulation of the human body biological environment using a double-layer model, h_0 – height of the antenna location over the structure

Paper [18] presents a method for finding dielectric parameters of the plane three-layer model (including air) of a biological medium with relative dielectric permittivity of the layers ε_1, ε_2, ε_3 by analyzing the frequency dependence of reflection coefficient $R(f)$ in the range of 1,4 ... 1,6 GHz.

Double-layer models of media is a special case of plane three-layer models where biological medium is considered as a dielectric half-space (Fig.1).

In this case the dielectric permittivity of biological environment has the following depth dependence:

$$\varepsilon(y) = \begin{cases} \varepsilon_1 = 1,\ 0 < y \le h_0, \\ \varepsilon_2, y > h_0. \end{cases}$$

The aim of the work is to consider the method for determining complex dielectric constant of the medium through analyzing the frequency dependence of the function of the radio wave voltage reflection coefficient *R(f)*. To do this, let us consider the case of the electromagnetic wave (EMW) incidence on the double-layer structure.

Arbitrary incidence of EMW with perpendicular polarization

Let us consider the case of arbitrary incidence of EMW with perpendicular polarization on the double-layer structure (Fig. 2).

Considering only absolute values of the vectors of EMW components, i.e. projections of EMW vectors on Oy axis, let us write expressions for the incident and reflected waves in the first medium:

$$E_1 = E_{1m} e^{\gamma_1 y \cos a_1},\ H_1 = \frac{\cos a_1}{Z_1'} E_{1m} e^{\gamma_1 y \cos a_1},$$

$$E_2 = E_{2m} e^{-\gamma_1 y \cos a_1},\ H_2 = \frac{\cos a_1}{Z_1'} E_{2m} e^{-\gamma_1 y \cos a_1},$$

where E_{im} is a complex amplitudes of the electromagnetic field vectors, $\gamma_1 = -\frac{2\pi f}{c}$ – propagation constant for the first medium.

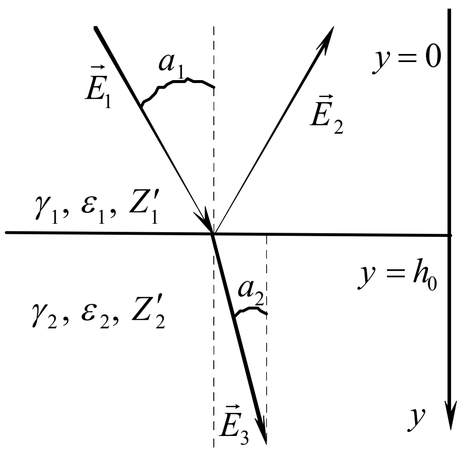

Fig. 2. Incidence of EMW with perpendicular polarization at an arbitrary angle *a 1* to the media interface

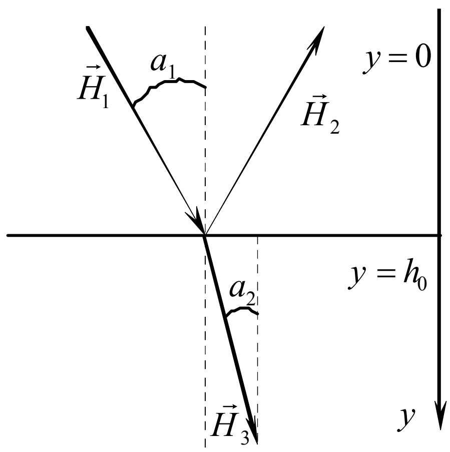

Fig. 3.3. Incidence of EMW with parallel polarization at an arbitrary angle *a 1* to the media interface

where γ_1, γ_2 are complex constants of propagation in the media, $\varepsilon_1, \varepsilon_2$ – complex relative dielectric constants of the media, $Z_i' = \dfrac{Z_o}{\sqrt{\varepsilon_i}}$, $Z_o = 377\ Ohm$ – free-space wave resistance, h_0 – the height of the antenna location above the medium.

Electromagnetic field inside the first layer is determined by the incident and the reflected waves in the following way:

$$E(1) = E_1 + E_2 = E_{1m}e^{\gamma_1 y \cos a_1} + E_{2m}e^{-\gamma_1 y \cos a_1},$$

$$H(1) = H_1 - H_2 = \frac{\cos a_1}{Z_1'}E_{1m}e^{\gamma_1 y \cos a_1} - \frac{\cos a_1}{Z_1'}E_{2m}e^{-\gamma_1 y \cos a_1}.$$

Electromagnetic field inside the second layer is determined only by the presence of the penetration wave, namely:

$$E(2) = E_3 = E_{3m}e^{\gamma_2 y \cos a_2},$$

$$H(2) = H_3 = \frac{\cos a_2}{Z_2'}E_{3m}e^{\gamma_2 y \cos a_2}.$$

Using the boundary conditions of the electromagnetic field continuity at the media interface [19]

$$\text{for } y = h_0 \quad \begin{cases} \varepsilon_1 E(1) = \varepsilon_2 E(2), \\ H(1) = H(2), \end{cases} \tag{1}$$

let us write the equation system for the complex amplitudes of the electromagnetic field of the first and the second media:

$$\begin{cases} \varepsilon_1(E_{1m}e^{\gamma_1 h_0 \cos a_1} + E_{2m}e^{-\gamma_1 h_0 \cos a_1}) = \varepsilon_2 E_{3m}e^{\gamma_2 h_0 \cos a_2}, \\ \dfrac{\cos a_1}{Z_1'}(E_{1m}e^{\gamma_1 h_0 \cos a_1} - E_{2m}e^{-\gamma_1 h_0 \cos a_1}) = \dfrac{\cos a_2}{Z_2'}E_{3m}e^{\gamma_2 h_0 \cos a_2}. \end{cases} \tag{2}$$

Solving system (2) for the ratio of the complex amplitudes E_{2m}/E_{1m} of the electromagnetic field, we obtain the following expression for the complex reflection coefficient:

$$R = \frac{E_{2m}}{E_{1m}} = \frac{\sqrt{\varepsilon_2} - a\sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + a\sqrt{\varepsilon_1}}e^{2\gamma_1 h_0 \cos a_1}, \tag{3}$$

where $a = \dfrac{\cos a_2}{\cos a_1}$ is a real number**,** a_1 – the incidence angle**,** $a_2 = arc\cos\sqrt{1 - \dfrac{\sin^2 a_1}{|\varepsilon_2|}}$ – the refraction angle.

Taking into account $\varepsilon_1 = 1$ (air is the first medium) and the propagation constant, relation (3) is written in the following way;

$$R = \frac{\sqrt{\varepsilon_2} - a}{\sqrt{\varepsilon_2} + a}e^{-\frac{4\pi h_0 f \cos a_1}{c}}. \tag{4}$$

From expression (4) we find the complex relative dielectric permittivity ε_2 of the medium

$$\varepsilon_2 = a^2\left(\frac{e^{-\frac{4\pi h_0 f \cos a_1}{c}} + R}{e^{-\frac{4\pi h_0 f \cos a_1}{c}} - R}\right)^2. \tag{5}$$

As R, ε_2 are complex values, from expression (5) it follows that the real and imaginary parts of the complex numbers are equal. Thus, let us write the equation system for finding the real and imaginary parts $\varepsilon_2 = \varepsilon_2' + i\varepsilon_2''$

$$\varepsilon' = \mathrm{Re}\left[a^2 \left(\frac{e^{-\frac{4\pi h_0 f \cos a_1}{c}} + R}{e^{-\frac{4\pi h_0 f \cos a_1}{c}} - R} \right)^2 \right], \ \varepsilon_2'' = \mathrm{Im}\left[a^2 \left(\frac{e^{-\frac{4\pi h_0 f \cos a_1}{c}} + R}{e^{-\frac{4\pi h_0 f \cos a_1}{c}} - R} \right)^2 \right].$$

Arbitrary incidence of EMW with parallel polarization

Let us consider the case of the arbitrary incidence of EMW with parallel polarization on the double-layer structure (Fig. 3).

Expressions for the incident and reflected waves in the first medium will have the following form:

$$E_1 = \cos a_1 E_{1m} e^{\gamma_1 y \cos a_1}, \ H_1 = \frac{E_{1m}}{Z_1'} e^{\gamma_1 y \cos a_1},$$

$$E_2 = \cos a_1 E_{2m} e^{-\gamma_1 y \cos a_1}, \ H_2 = \frac{E_{2m}}{Z_1'} e^{-\gamma_1 y \cos a_1}.$$

Electromagnetic field inside the first layer is determined by the incident and the reflected waves as follows:

$$E(1) = E_1 - E_2 = \cos a_1 E_{1m} e^{\gamma_1 y \cos a_1} - \cos a_1 E_{2m} e^{-\gamma_1 y \cos a_1},$$

$$H(1) = H_1 + H_2 = \frac{E_{1m}}{Z_1'} e^{\gamma_1 y \cos a_1} + \frac{E_{2m}}{Z_1'} e^{-\gamma_1 y \cos a_1}.$$

Electromagnetic field inside the second layer is determined only by the penetrating wave in the medium

$$E(2) = E_3 = \cos a_2 E_{3m} e^{\gamma_2 y \cos a_2},$$

$$H(2) = H_3 = \frac{E_{3m}}{Z_2'} e^{\gamma_2 y \cos a_2}.$$

Using the boundary conditions of the electromagnetic field continuity at the media interface (1), we write the equation system for the complex amplitudes of the electromagnetic field in the media.

$$\begin{cases} \varepsilon_1 \cos a_1 (E_{1m} e^{\gamma_1 h_0 \cos a_1} - E_{2m} e^{-\gamma_1 h_0 \cos a_1}) = \varepsilon_2 \cos a_2 E_{3m} e^{\gamma_2 h_0 \cos a_2}, \\ \dfrac{1}{Z_1'} (E_{1m} e^{\gamma_1 h_0 \cos a_1} + E_{2m} e^{-\gamma_1 h_0 \cos a_1}) = \dfrac{E_{3m}}{Z_2'} e^{\gamma_2 h_0 \cos a_2}. \end{cases} \quad \textbf{(6)}$$

Solving system (6) for E_{2m} / E_{1m}, we obtain the following expression for the complex reflection coefficient:

$$R = \frac{\sqrt{\varepsilon_1} - a\sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + a\sqrt{\varepsilon_2}} e^{2\gamma_1 h_0 \cos a_1}. \quad \textbf{(7)}$$

For $\varepsilon_1 = 1$ relation (7) we write in the form of

$$R = \frac{1 - a\sqrt{\varepsilon_2}}{1 + a\sqrt{\varepsilon_2}} e^{-\frac{4\pi h_0 f \cos a_1}{c}}. \quad \textbf{(8)}$$

From expression (8) we find complex dielectric permittivity of medium ε_2

$$\varepsilon_2 = \frac{1}{a^2}\left(\frac{e^{-\frac{4\pi h_0 f \cos a_1}{c}} - R}{e^{-\frac{4\pi h_0 f \cos a_1}{c}} + R}\right)^2.$$

Thus, the system for finding the real and imaginary parts $\varepsilon_2 = \varepsilon_2' + i\varepsilon_2''$ we write in the form of

$$\varepsilon' = \mathrm{Re}\left[\frac{1}{a^2}\left(\frac{e^{-\frac{4\pi h_0 f \cos a_1}{c}} - R}{e^{-\frac{4\pi h_0 f \cos a_1}{c}} + R}\right)^2\right],\ \varepsilon_2'' = \mathrm{Im}\left[\frac{1}{a^2}\left(\frac{e^{-\frac{4\pi h_0 f \cos a_1}{c}} - R}{e^{-\frac{4\pi h_0 f \cos a_1}{c}} + R}\right)^2\right].$$

Incidence of EMW with perpendicular polarization at right angle

Let us consider the case of incidence of EMW with perpendicular polarization at right angle on a two-layer structure (Fig. 4).

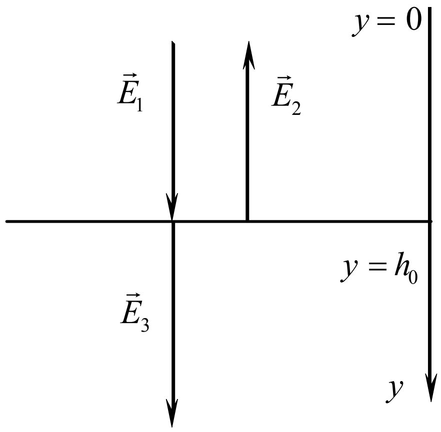

Fig. 4. Incidence of EMW with perpendicular polarization at right angle to the media interface

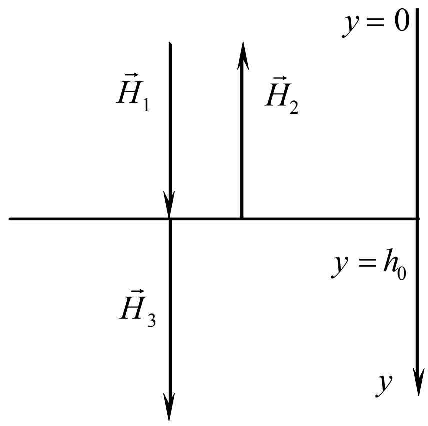

Fig. 5. Incidence of EMW with parallel polarization at right angle to the media interface

Let us write the expression for the incident and the reflected waves in the first medium

$$E_1 = E_{1m}e^{\gamma_1 y},\ H_1 = \frac{E_{1m}}{Z_1'}e^{\gamma_1 y},$$
$$E_2 = E_{2m}e^{-\gamma_1 y},\ H_2 = \frac{E_{2m}}{Z_1'}e^{-\gamma_1 y}. \qquad \textbf{(9)}$$

Electromagnetic field inside the first layer is determined by the incident and the reflected waves in the first medium

$$E(1) = E_1 + E_2 = E_{1m}e^{\gamma_1 y} + E_{2m}e^{-\gamma_1 y},$$
$$H(1) = H_1 - H_2 = \frac{E_{1m}}{Z_1'}e^{\gamma_1 y} - \frac{E_{2m}}{Z_1'}e^{-\gamma_1 y}.$$

Electromagnetic field inside the second layer is described by the expression for the penetrating wave in the second layer

$$E(2) = E_3 = E_{3m}e^{\gamma_2 y},$$
$$H(2) = H_3 = \frac{E_{3m}}{Z_2'}e^{\gamma_2 y}. \qquad \textbf{(10)}$$

Using the boundary conditions of the electromagnetic wave continuity (1), we write the equation system for the complex amplitudes of the electromagnetic field:

$$\begin{cases} \varepsilon_1 (E_{1m} e^{\gamma_1 h_0} + E_{2m} e^{-\gamma_1 h_0}) = \varepsilon_2 E_{3m} e^{\gamma_2 h_0}, \\ \dfrac{1}{Z_1'} (E_{1m} e^{\gamma_1 h_0} - E_{2m} e^{-\gamma_1 h_0}) = \dfrac{1}{Z_2'} E_{3m} e^{\gamma_2 h_0}. \end{cases} \quad \textbf{(11)}$$

Solving system (11) for E_{2m} / E_{1m}, we obtain the expression for the complex reflection coefficient

$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}} e^{2\gamma_1 h_0}. \quad \textbf{(12)}$$

For $\varepsilon_1 = 1$ we write expression (12) as follows:

$$R = \frac{\sqrt{\varepsilon_2} - 1}{\sqrt{\varepsilon_2} + 1} e^{-\frac{4\pi h_0 f}{c}}. \quad \textbf{(13)}$$

From expression (13) we find relative dielectric permittivity ε_2:

$$\varepsilon_2 = \left(\frac{e^{-\frac{4\pi h_0 f}{c}} + R}{e^{-\frac{4\pi h_0 f}{c}} - R} \right)^2.$$

Thus, the equation system for finding the real and the imaginary parts $\varepsilon_2 = \varepsilon_2' + i\varepsilon_2''$ we write in the form of

$$\varepsilon' = \mathrm{Re}\left[\left(\frac{e^{-\frac{4\pi h_0 f}{c}} + R}{e^{-\frac{4\pi h_0 f}{c}} - R} \right)^2 \right], \; \varepsilon_2'' = \mathrm{Im}\left[\left(\frac{e^{-\frac{4\pi h_0 f}{c}} + R}{e^{-\frac{4\pi h_0 f}{c}} - R} \right)^2 \right].$$

Incidence of EMW with parallel polarization at right angle

Let us consider the case of incidence of EMW with parallel polarization on the double-layer structure (Fig. 5).

Expression for the incident and the reflected waves in the first medium is determined by the equality (9). Electromagnetic field inside the first layer is determined by the incident and the reflected waves in the first medium as follows:

$$E(1) = E_1 - E_2 = E_{1m} e^{\gamma_1 y} - E_{2m} e^{-\gamma_1 y},$$

$$H(1) = H_1 + H_2 = \frac{E_{1m}}{Z_1'} e^{\gamma_1 y} + \frac{E_{2m}}{Z_1'} e^{-\gamma_1 y}.$$

Electromagnetic field inside the second layer is determined by the expression (10).

Using boundary conditions of the electromagnetic field continuity (1), we write the equation system for the complex amplitudes of the electromagnetic field:

$$\begin{cases} \varepsilon_1 (E_{1m} e^{\gamma_1 h_0} - E_{2m} e^{-\gamma_1 h_0}) = \varepsilon_2 E_{3m} e^{\gamma_2 h_0}, \\ \dfrac{1}{Z_1'} (E_{1m} e^{\gamma_1 h_0} + E_{2m} e^{-\gamma_1 h_0}) = \dfrac{1}{Z_2'} E_{3m} e^{\gamma_2 h_0}. \end{cases} \quad \textbf{(14)}$$

Solving system (14) for E_{2m} / E_{1m}, we obtain the expression for the complex reflection coefficient

$$R = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} e^{2\gamma_1 h_0}. \quad \textbf{(15)}$$

For $\varepsilon_1 = 1$ expression (15) takes the form of

$$R = \frac{1 - \sqrt{\varepsilon_2}}{1 + \sqrt{\varepsilon_2}} e^{-\frac{4\pi h_0 f}{c}}. \quad \textbf{(16)}$$

From expression (16) we find relative dielectric permittivity ε_2 in the following way:

$$\varepsilon_2 = \left(\frac{e^{-\frac{4\pi h_0 f}{c}} - R}{e^{-\frac{4\pi h_0 f}{c}} + R} \right)^2.$$

Then we write the equation system for finding the real and imaginary parts $\varepsilon_2 = \varepsilon_2' + i\varepsilon_2''$ as

$$\varepsilon' = \mathrm{Re}\left[\left(\frac{e^{-\frac{4\pi h_0 f}{c}} - R}{e^{-\frac{4\pi h_0 f}{c}} + R} \right)^2 \right], \ \varepsilon_2'' = \mathrm{Im}\left[\left(\frac{e^{-\frac{4\pi h_0 f}{c}} - R}{e^{-\frac{4\pi h_0 f}{c}} + R} \right)^2 \right].$$

Thus, with a given value of the reflection coefficient and the corresponding frequency we have found complex relative dielectric permittivity ε_2 .of the medium.

Conclusions

The paper proposes a mathematical model of the method for restoring the parameters of biological media according to the function of the radio wave reflection coefficient. Frequency dependence of the reflection coefficient has been investigated on the basis of considering the double-layer model of the biologic medium for four cases of the electromagnetic wave incidence on the media interface.

For the case of a double-layer model, determination of dielectric permittivity of the medium is shown to be possible for the known frequency value. From the relationships presented above it is evident that value of the complex reflection coefficient for the voltage depends not only on the parameters of the medium under study, but also on polarization and on the electromagnetic wave incidence angle.

This method can be applied in the diagnosis of tumors as it does not require surgery and is completely safe. In the future we plan to develop a mathematical model of the method for determining the temperature distribution in biological tissue, where the results of this study will be used.

REFERENCES

1. Черепнев И. А. Биологические эффекты при воздействии электромагнитных волн. / И. А. Черепнев // Системи управління, навігації та зв'язку. – 2007. – № 3. – С. 118 – 124.

2. Басанов Б. В. Метод определения эффективной диэлектрической проницаемости лесного полога. / Б. В. Басанов, А. Ю. Ветлужский, В. П. Калашников // Журнал радиоэлектроники. – 2010. – № 4. – С. 34 – 40.

3. Болтинцев В. Б. Определение диэлектрических свойств сложных грунтов при электромагнитном импульсном сверхширокополосном зондировании подстилающей среды / В. Б. Болтинцев // Промышленное и гражданское строительство. – 2011. – № 11. – С. 25 – 28.

4. Болтинцев В. Б. Метод электромагнитного импульсного сверхширокополосного зондирования подстилающей среды / В. Б. Болтинцев, В. Н. Ильяхин, К. П. Безродный // Журнал радиоэлектроники. – 2012. – № 1. – С. 1 – 39.

5. Мутнян В. О. Теоретичний аналіз впливу низькоенергетичного електромагнітного випромінювання на стан біооб’єктів / В. О. Мутнян, О. В. Лисенко, Д. М. Коваль // Праці ТДАТУ. – 2011. – Т.3. – № 11. – С. 14 – 19.

6. Плахотник В. Ю. Сенсоры на основе поверхностного плазмонного резонанса и контроль диэлектрических свойств биологических сред / В. Ю. Плахотник, Г. А. Поляков, Г. А. Долинский // Вісник СевНТУ. – 2009. – №. 99. – С. 82 – 85.

7. Резник А. Н. Ближнепольная СВЧ томография биологических сред / А. Н. Резник, Н. В. Юрасова // Журнал технической физики. – 2004. – Т. 74. – №. 4. – С. 108 – 117.

8. Резник А. Н. Обнаружение контрастных образований внутри биологических сред при помощи ближнепольной СВЧ діагностики / А. Н. Резник, Н. В. Юрасова // Журнал технической физики. – 2006. – Т. 76. – № 1. – С. 90 – 104.

9. Резник А. Н. Радиационные эффекты в ближнепольной сверхвысокочастотной диагностике / А. Н. Резник, И. А. Шерешевский, Н. К. Вдовичева // Радиотехника и электроника. – 2008. – Т. 53. – № 6. – С. 656 – 664.

10. Арсеньев А. В. Применение метода ВЧ–ближнепольного зондирования в диагностике биообъектов / А. В. Арсеньев, А. Н. Волченко, Л. В. Лихачева, В. И. Печерский // Научно-технический вестник Санкт-Петербургского государственного университета информационных технологий, механики и оптики. – 2011. – № 2 (72). – С. 154 – 157.

11. Балошин Ю. А. Метод диагностики функциональной активности тканей и органов биообъектов / Ю. А. Балошин, А. А. Сорокин, А. В. Арсеньев, М. Г. Дудин, А. Н. Волченко // Изв. ВУЗОВ. Приборостроение. – 2011. – Т. 54. – № 3. – С. 37 – 43.

12. Моденов В. П. Волноводно-резонансный метод в СВЧ диэлектрометрии / В. П. Моденов // Вестник новых медицинских технологий. – 1996. – Т. 3. – № 1. – С 17 – 19.

13. Моденов В. П. Метод интегральных уравнений в задаче волноводного электромагнитного зондирования биообъектов / В. П. Моденов, И. К. Трошина // Вестник новых медицинских технологий. – 1998. – Т. 5. – № 3 – 4. – С. 106 – 108.

14. Моденов В. П. Метод Галеркина в задаче волноводного электромагнитного зондирования биообъектов / В. П. Моденов, В. В. Конюшенко // Электромагнитные волны и электронные системы. – 1998. – Т. 3. – № 4. – С. 43 – 46.

15. Моденов В. П. Математическое моделирование волноводного электромагнитного зондирования биологических обьектов / В. П. Моденов, И. К. Трошина, В. В. Конюшенко // Биомедицинские технологии и радиоэлектроника. – 2002. – № 5 – 6. – С. 67 – 72.

16. Мериакри В. В. Диэлектрические свойства растворов глюкозы в миллиметровом диапазоне волн и проблема контроля ее содержания в крови / В. В. Мериакри, Е. Е. Чигряй, И. П. Никитин, М. П. Пархоменко // Международная конференція Крымико. – 2005. – С. 853 – 854.

17. Манойлов В. П. Ближньопольова НВЧ–взаємодія «антена–середовище» / В. П. Манойлов, Л. Ю. Назарчук // Вісник ЖДТУ. – 2005. – № 2 (33). – С. 75 – 79.

18. Назарчук Л. Ю. Відновлення параметрів біологічних середовищ за функцією коефіцієнта відбиття / Л. Ю. Назарчук // Вісник ЖДТУ. – 2006. – № 1 (36). – С. 65 – 74.

19. Гольдштейн Л. Д. Электромагнитные поля и волны / Л. Д. Гольдштейн, Н. В. Зернов. – М.: Сов. Радио, 1971. – 664 с.

Manoylov Viacheslav **–** Dc. Sc., Prof., Head of the Department of Radio Engineering and Telecommunications, Lnazarchuk@rambler.ru.

Nazarchuk Lesia **–** applicant for the Cand. Sc. degree, Lnazarchuk@rambler.ru.
Zhytomir State Technological University.