Detection of Breast Tumors by Applying FDTD Modelling of Holographic Radar

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Abstract— This paper presents the results of mathematical simulation carried out to confirm the ability of holographic radar to detect breast tumors. The simulation software used the Finite-Difference Time-Domain Method. The simulations were performed for three different scenarios: in the first model the inclusion depth under the surface was varied; for the second model two inclusions were used; while the dielectric properties of malignant tissue were modified in the third model. The model is a 3D block with dimensions $200 \times 200 \times 100$ mm, which mimicked normal breast tissue, with one or two spherical inclusion — malignant neoplasm of breast tissue. Frequency dispersion of normal and malignant tissues dielectric properties (conductivity and permittivity) was taken into account.

The results showed that differences in the dielectric properties allow to use of the radiolocation method for detecting inclusion (diameter 4 mm) on a depth up to 5 mm. The results proved that the greatest impact on the detection of inclusion has a ratio of conductivity values of normal and malignant tissues. Also the proposed method makes possible to distinguish two different objects at the distance between them of 16 mm or more, otherwise they will be identified as one inclusion.

1. INTRODUCTION

Nowadays one of the most topical problems in medical diagnostics is early breast cancer detection. In some countries this pathology is the leading cause of death among the women. Every 9th female in the USA is under the risk of this highly dangerous disease. As a rule, the routine diagnostic procedure consists of individual examination by doctors and mammography or ultrasound screening. Screening for early detection of breast cancer is conducted by these methods at 12–24 month intervals, which cannot guarantee identification of aggressive tumors [1].

In addition, however rarely, such methods as computed tomography, positron-emission tomography, magnetic resonance imaging, all kinds of biopsy are applied. They allow to purposefully look for certain changes in the mammary glands and specify their cause, nature and prevalence [2]. However, none of them is applicable for routine scanning because of high cost, prolonged time of a diagnostic procedure and invasiveness (for biopsy). Therefore, it is advisable to complete a routine diagnostic procedure using a different noninvasive screening method, which could detect tumors at the earliest possible stage [3].

In this paper we describe the results of the mathematical simulation carried out to confirm the possibility of using holographic radar for the detection of breast tumors. It is known that the dielectric properties of normal and malignant breast tissues differ even at the earliest stage of tumor genesis. Thus, frequent scans with a holographic radar could be used for safe early stage breast tumor detection. Although at present there is a growing interest in literature in the usage of ultra-wideband radars for breast malignant tumors detection, these devices have not yet achieved the necessary accuracy and specificity when applied on realistic breast phantoms. During the experiments the software designed for the numerical solution of electromagnetic problems using the Finite-Difference Time-Domain Method was applied, which description are given in paragraph 2. Paragraph 3 presents the results of mathematical simulation for three scenarios: for the first model inclusion's depth under the surface was varied; for the second model two inclusions were placed into a tissue; for the third, dielectric properties of malignant tissue were modified.

2. METHODS

In the work the software XFdtd [4] was used, which is designed for the numerical solution of electromagnetic problems using the Finite-Difference Time-Domain Method, which solves Maxwell's equations for the electric and magnetic fields.

In the experiments is realistic phantoms of a mammary gland, which are planned to be carried put in future, we suppose to use a multi-frequency holographic radar RASCAN-5/7000 designed at Bauman Moscow State Technical University with the frequency range 6.6–7.0 GHz [5]. Therefore simulation, which is described in this article, was carried out at a frequency of 7 GHz for estimating theoretically achievable values of resolution and penetration depth.

3. FDTD MODELLING OF HOLOGRAPHIC RADAR

In the used simulation environment the objects can be created in the graphical editor window using the built-figures, or imported from other systems of automated programming. The fragment of a breast was modeled as a 3D block with dimensions $200 \times 200 \times 100$ mm. It is mimicking the normal tissue of the breast, with a spherical inclusion — malignant neoplasm of breast tissue.

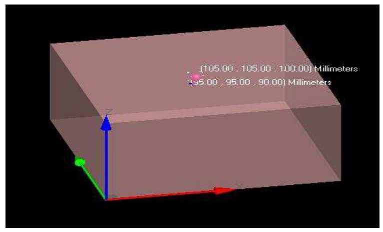

Figure 1: The model geometry.

The dielectric properties depend on the probing frequency. The conductivity and relative permittivity values for the model are listed below [6] (Table 1).

Table 1: Dielectric properties of normal and malignant tissues [6].

Frequency	Normal tissue		Malignant tissue	
	Conductivity [Sm/m]	Relative permittivity	Conductivity [Sm/m]	Relative permittivity
7 GHz	0.26	4.4	8.1	50.8

Outer-boundaries were set to be absorbing. The model was divided into 5 segments. In the area [90; 110] the cell size was 1 mm; in the area [80; 90] and [110; 120]-2 mm, in the area [0; 80] and [120; 200]-4 mm (Fig. 2).

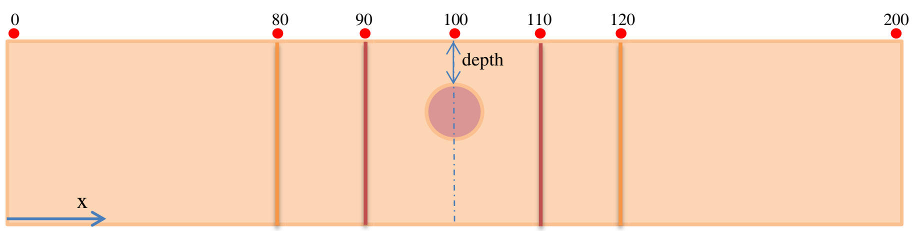

Figure 2: Scheme of the model.

Outer-boundaries were set to be absorbing. For each receiver we calculated y-component of electric field $|\dot{E}_y|$. Results of an absolute values $|\dot{E}_y|$ calculation are presented in Fig. 3.

The peak of $|\dot{E}_y|$ amplitude is located directly over tumor. Side peaks are cased by the edge effects For the further simulation we used only selected points in the central zone from 80 mm till 120 mm.

Three different imaging scenarios were analyzed.

In the first imaging experiment (Fig. 4), $|\dot{E}_y|$ was calculated for the model with the inclusion of 4 mm and its depth of 2, 4, 6 mm.

The results of the simulation (Fig. 4) proved that it is possible to detect a tumor with size of 4 mm at a depth up to 4–5 mm by using a probing frequency of 7 GHz.

In the second imaging experiment, two spherical inclusions were placed inside the block simulating the normal tissue. The distance between inclusions was varied.

As can be seen from Fig. 5 the proposed method do not allow to distinguish two inclusions as separate ones if they are placed closer than 15 mm.

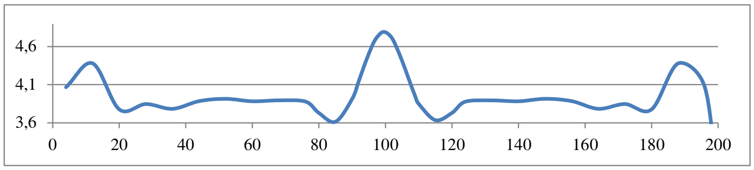

Figure 3: Scattered $|\dot{E}_y|$ values at 7 GHz, inclusion size is 4 mm, depth = 2 mm.

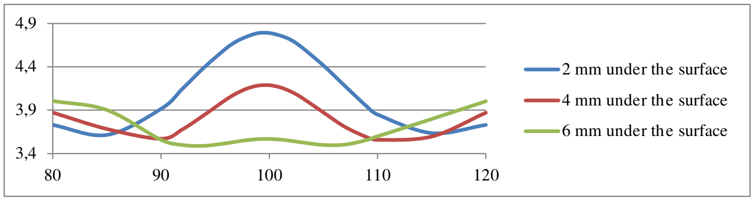

Figure 4: Scattered $|\dot{E}_y|$ values at 7 GHz, inclusion's size is 4 mm.

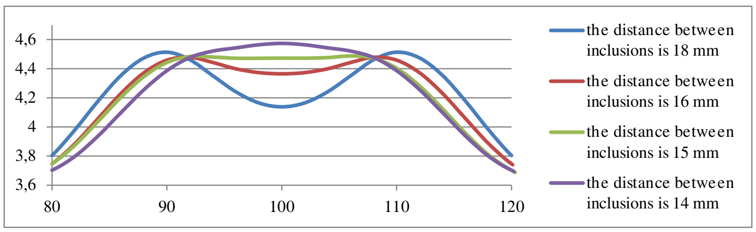

Figure 5: Scattered $|\dot{E}_y|$ values at 7 GHz probing frequency, inclusions' size are 4 mm.

Table 2: Dielectric properties of malignant tissues.

Malignant tissue			
Conductivity [Sm/m]		Relative permittivity	
Scale factor	Value	Scale factor	Value
1.0	8.10	1.0	50.80
0.7	5.67	0.9	45.72
0.5	4.05	0.7	35.56
0.4	3.24	0.5	25.40
0.3	2.43	0.3	15.24
0.1	0.81	0.1	5.08

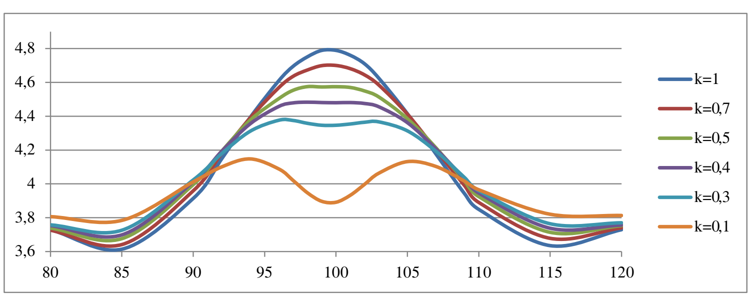

Figure 6: Scattered $|\dot{E}_y|$ values at 7 GHz, inclusion's size is 4 mm (the conductivity of malignant tissue is varied).

In the scientific literature there are no data on the effect depending on a fat/fibrous tissue ratio in the breast, which changes with age and depends on the physiological state of each woman. In this work mathematical modeling of a situation in which the ratio in the structure of breast increases was carried out. Table 2 shows the values of the dielectric properties of malignant tissue of the breast, which we used in simulation. Table 2 uses data from a large-scale study of the ultrawideband microwave dielectric properties of normal, benign and malignant breast tissues obtained from cancer surgeries conducted by Lazebnik, et al. [6].

Results of the simulation revealed that it is impossible to detect the tumor if the conductivity value for the malignant tissue decreases for more than 50%. However even if the relative permittivity of malignant and normal tissue are equal, it is still possible to detect the tumor (Figs. 6, 7).

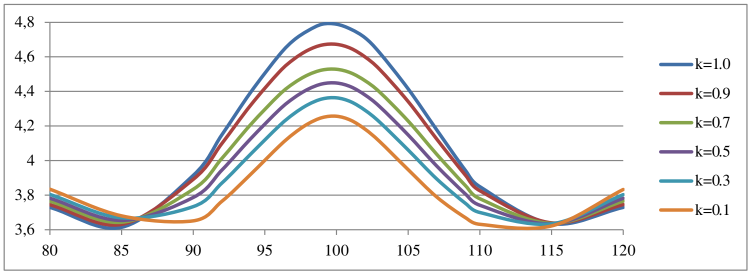

Figure 7: Scattered $|\dot{E}_y|$ values at 7 GHz, inclusion's size is 4 mm (the relative permittivity of malignant tissue is varied).

4. CONCLUSION

Experimental results showed that the maximum depth of the inclusion (diameter 4 mm) detection by the proposed method does not exceed 5 mm, it is due to the strong attenuation of electromagnetic radiation in the medium. This depth limit can be increased by using lower frequencies at the expense of resolution and by using matched antennas. The proposed method allows to distinguish two different inclusions at the distance of 16 mm or more, otherwise they will be identified as one. Variation of biological tissue conductivity in physiological adequate limits has stronger influence on the possibility of an inclusion detection compared to the same parameter for relative permittivity.

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