Simulation of holographic radar application in detection of breast tumors

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ABSTRACT

This paper presents the results of experiments and mathematical simulation carried out to confirm the possibility of using holographic radar for the detection of breast tumors. In the work the software designed for the numerical solution of electromagnetic problems using the Finite-Difference Time-Domain Method. The simulation was performed with the three probe frequencies 4, 7 and 15 GHz. The model is a parallelepiped with dimensions 200×200×100 mm - mimicking the normal tissue of the breast, with the inclusion of a sphere - malignant neoplasm of breast tissue, the radius and depth of which have been varied. Frequency dispersion of normal and malignant tissues dielectric properties (conductivity and permittivity) was taken into account.

It was shown both by theoretical and experimental results that it is preferable to use lower-frequency probing signal, namely, 4GHz, which can detect the inclusion of 5 mm diameter up to a depth of 10 mm. While using of probing signals of 7 and 15 GHz the depth limit of detection inclusion is not more than 5 mm, which is caused by the high attenuation in a medium. However, their usage is preferred because of higher resolution.

Keywords: Dielectric inhomogeneity detection, holographic radar, FDTD modeling, tumor.

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[2].

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. 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.

In this paper holographic radar RASCAN is proposed for breast screening. 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 experiments three types of multi-frequency holographic radars RASCAN were used, which specifications are given in paragraph 2. Paragraphs 3 and 4 present results of mathematical simulation and experiments respectively.

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2. APPARATUS AND METHODS

During experiments three types of multi-frequency holographic radar RASCAN designed at Bauman Moscow State Technical University were compared: RASCAN-4/4000, RASCAN-5/7000, RASCAN-4/15000 with the frequency range 3.6 - 4.0 GHz 6.6-7.0 GHz and 14.6 to 15 GHz respectively. They operate at five probing frequencies and two types of polarization (transversal and parallel) and were intended for sounding of building constructions with the high resolution[3].

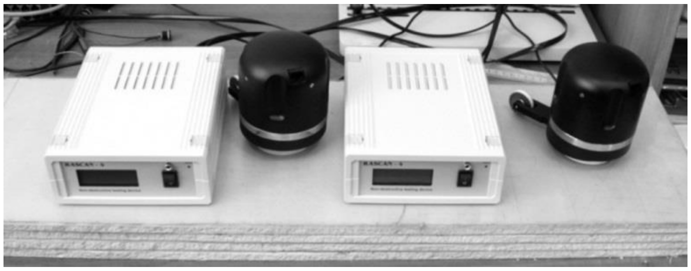

Fig. 1. Radars used in the experiments

The radars had following technical characteristics[5]:

Number of frequencies	5
Number of polarizations	2
Output power, W	< 10
Consumed power from the source, mW	< 3
Supply voltage, V:	
from industrial network at 50 Hz	100-230
from galvanic DC source	12
Overall dimensions, mm:	
control unit	157x63x200
Sensor	95x148x119
Weight, kg	1.9
Productivity, m^2/h	4-6

In the work the software XFdtd[6] 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.

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 parallelepiped with dimensions 200×200×100 mm. It is mimicking the normal tissue of the breast, with the inclusion of a sphere - malignant neoplasm of breast tissue.

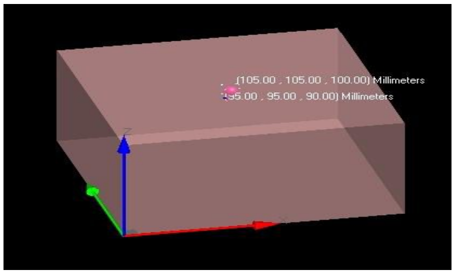

Figure 2. The model geometry

The dielectric properties depend on the frequency of the probe. The following conductivity and relative permittivity were set for the model[1] (Table 1).

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Table 1. Dielectric properties normal and malignant tissues[1]

	Normal tissue		Malignant tissue	
	Conductivity [Sm/m]	Relative permittivity	Conductivity [Sm/m]	Relative permittivity
RASCAN-4/4000 (4GHz)	0.15	4.6	5	56
RASCAN-5/7000 (7 GHz)	0.26	4.4	8.1	50.8
RASCAN-4/15000 (15 GHz)	0.63	4	23	34

The cell size was selected of 2x2x2 mm, which obviously satisfies the conditions of the maximum size at a given frequencies. Outer-boundaries were set to be absorbing. The model was divided into 51 cells. Parameters of the scattered electromagnetic field were calculated at 12 points imitating receivers (17, 20, 22-29, 31, 34), (Fig. 3).

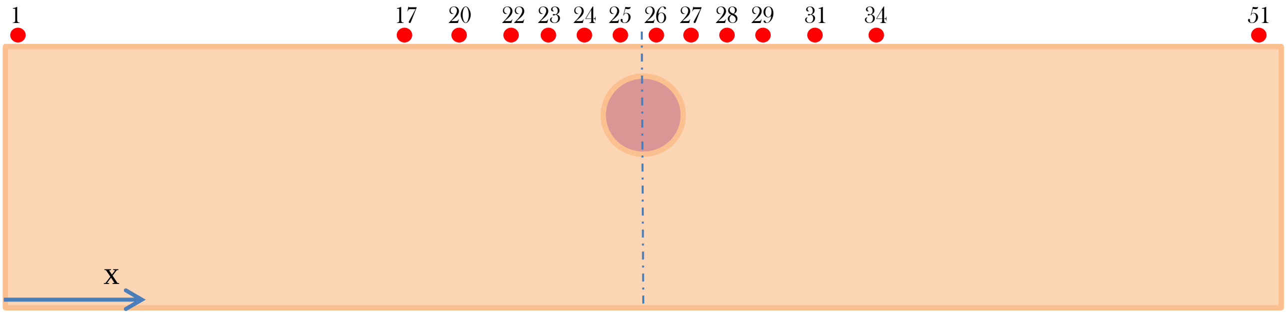

Figure 3. Location scheme points imitating receivers.

Outer-boundaries were set to be absorbing. For each receiver we calculated y-directed vector of electric field $\dot{E}_y$. Results of calculation its absolute values $\left|\dot{E}_y\right|$ for each receiver are presented in the form of graphs in Fig.4 – 7.

Fig.4 presents scattered $\left|\dot{E}_y\right|$ values at points (1–51), Fig. 5 – 7 present scattered $\left|\dot{E}_y\right|$ values at points (17, 20, 22 – 29, 31, 34) at frequencies 4, 15 and 7 GHz respectively.

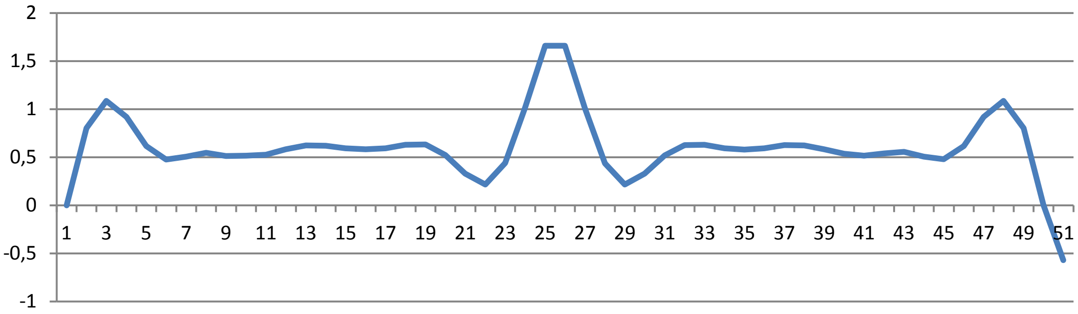

Figure 4. Scattered $\left|\dot{E}_y\right|$ values at 7GHz, inclusion size 5 mm and 2 mm under the surface.

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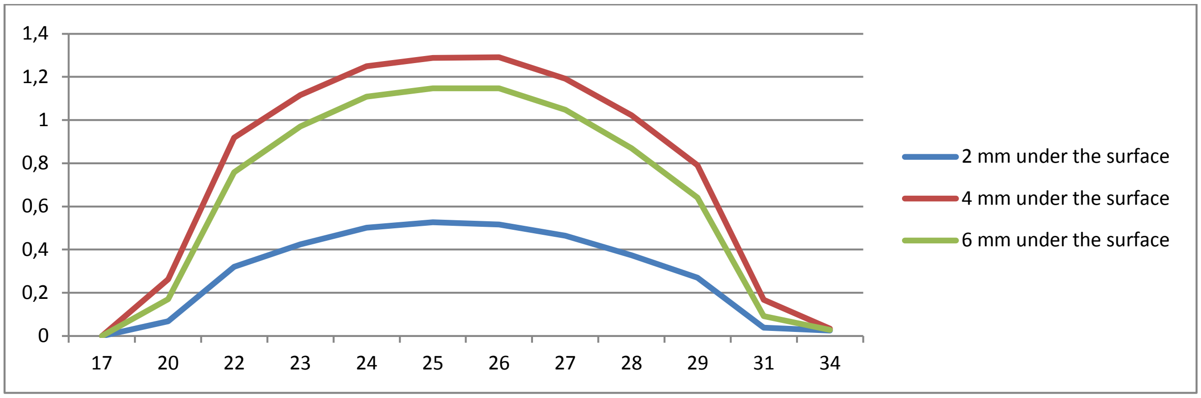

Figure 5. Scattered $\left|\dot{E}_y\right|$ values at 4GHz, inclusion size 5 mm.

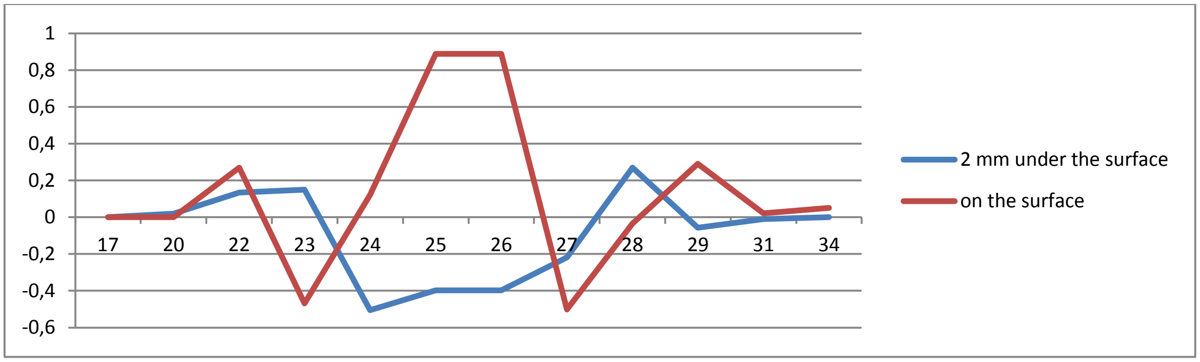

Figure 6. Scattered $\left|\dot{E}_y\right|$ values at 15GHz, inclusion size 10 mm.

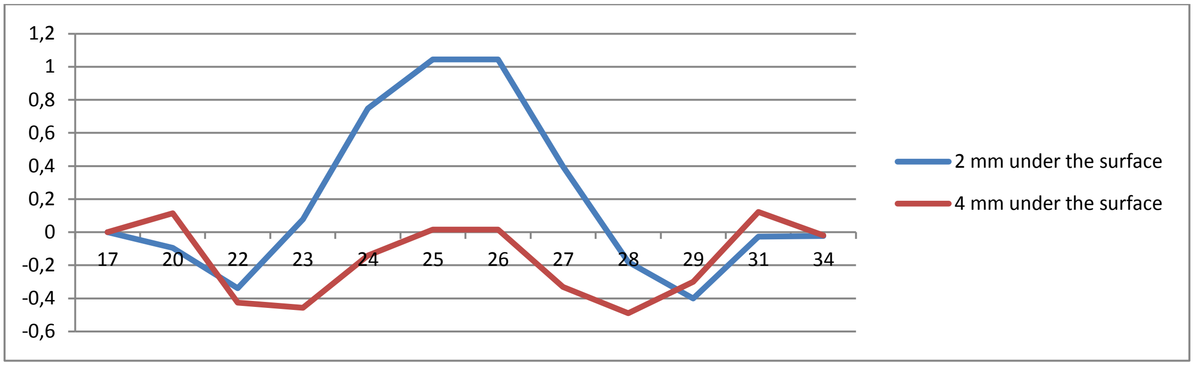

Figure 7. Scattered $\left|\dot{E}_y\right|$ values at 7GHz, inclusion size 5 mm.

From the viewpoint of optimum ratio resolution and penetration depth was selected range frequency 6.6-7.0 GHz. For this range simulation was conducted to detect sensitivity of the method to the variability of the dielectric properties of normal tissue. Conductivity and relative permittivity of normal tissue were varied (Fig.8 and Fig.9 respectively) for the following parameters of the model: inclusion size 5 mm and depth 2mm.

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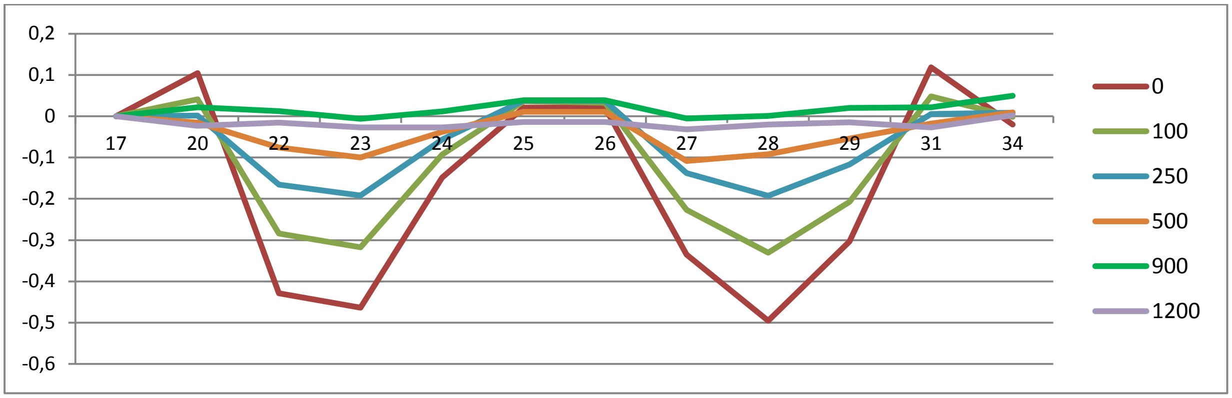

Figure 8. Scattered $\left|\dot{E}_y\right|$ values at 7GHz, inclusion size 5 mm (the conductivity of normal tissue is varied).

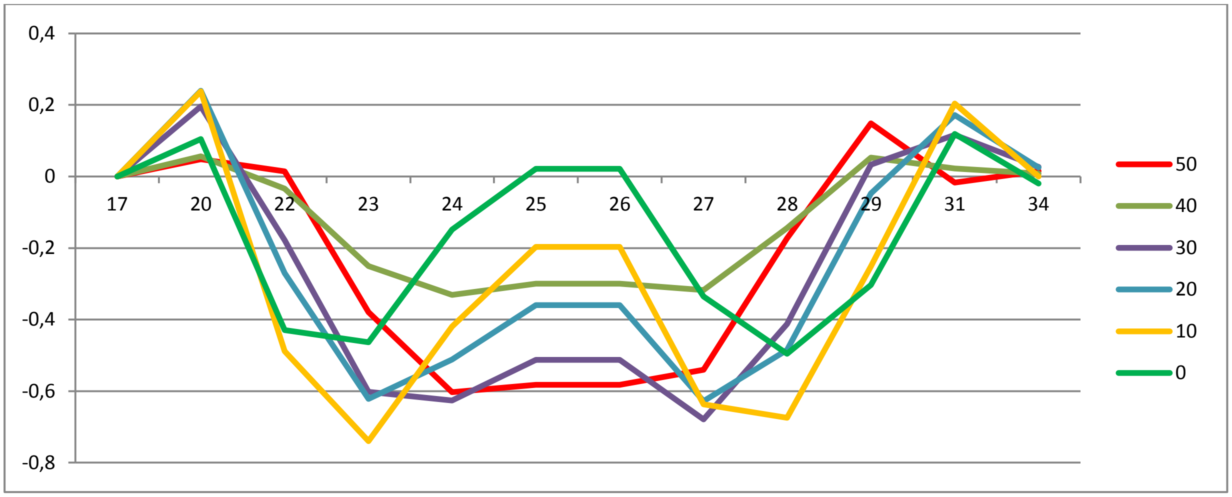

Figure 9. Scattered $\left|\dot{E}_y\right|$ values at 7GHz, inclusion size 5 mm (the relative permittivity of normal tissue is varied).

4. EXPERIMENTAL RESULTS

The reflection of electromagnetic wave radiated by the radar takes place on the boundaries of objects with different dielectric properties. Therefore the device can detect tumors by presence of such re-scattered waves. To prove the fact several experiments were carried out on a special realistic phantom of a breast, which allows creating phantoms with different displacement of neoplasm (Fig.10). In the experimental phantom normal breast tissue was assumed by lard to have the same dielectric properties as adipose tissue (dielectric constant is about 4.4 and conductivity 0.26 Sm/m [7])^1. Neoplasm (dielectric constant is about 50.8 and conductivity 8.1 Sm/m [7]) ^{1} was modeled by pudding. The radar head was connected to a control unit and through it to a PC. After that, a scanning procedure was carried out by moving the radar over experimental model to cover the whole surface of the experimental model.

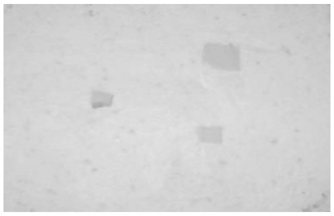

Figure 10. Photo of the experimental model

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To prove the fact several experiments were carried out on the proposed breast phantom, which is an easy-to-use experimental model of the breast.

The experiments were conducted using each of RASCAN models for the following configurations of the breast phantom:

- phantom without inclusion;
- phantom with inclusion on the surface;
- phantom with inclusion 1-2 mm under the surface;
- phantom with inclusion 5 mm under the surface;
- phantom with inclusion 10 mm under the surface;

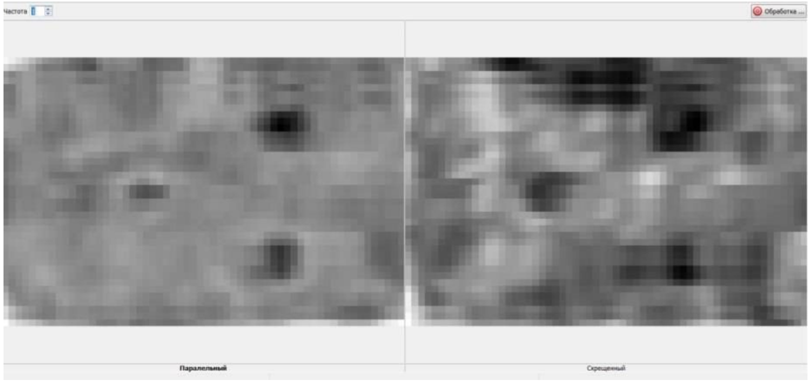

Figure 11. Holographic image of the phantom with tumors on the surface (4 GHz)

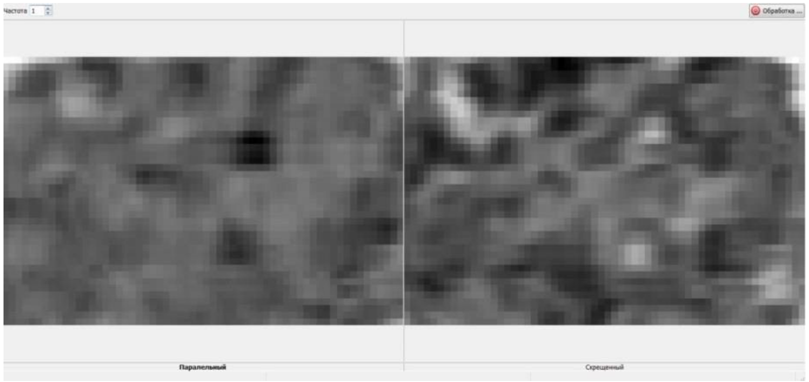

Figure 12. Holographic image of the phantom with tumors 10 mm under the surface (4 GHz)

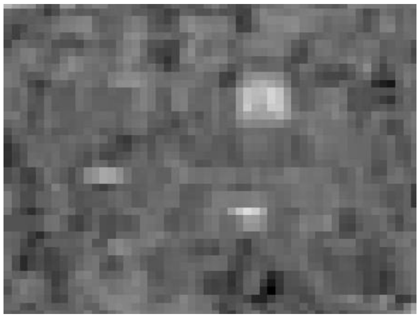

Figure 13. Holographic image of the phantom with tumors 5 mm under the surface (7 GHz)

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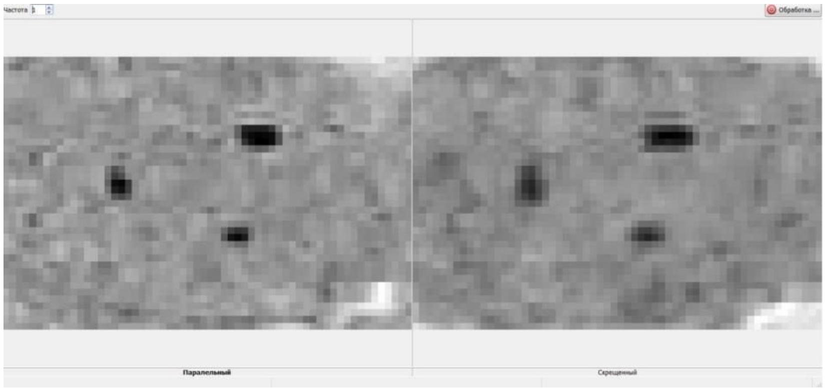

Figure 14. Holographic image of the phantom with tumors on the surface (15 GHz)

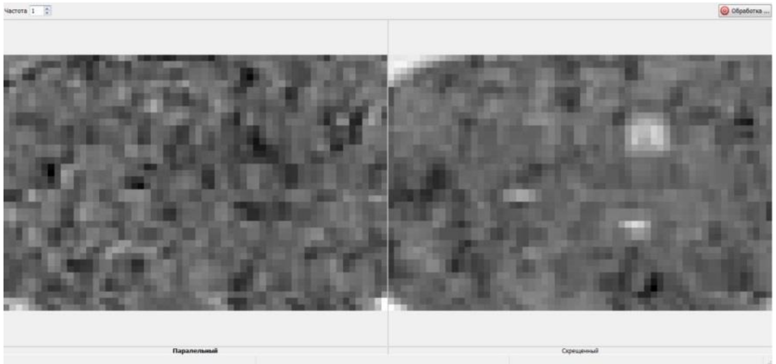

Figure 15. Holographic image of the phantom with the tumors 1-2 mm under the surface (15 GHz)

5. CONCLUSION

Experimental results showed that holographic radars RASCAN used in the experiments allow detection of dielectric inhomogeneity in biological tissues, e.g. tumor in normal breast tissue, due to significant differences in dielectric properties. It was found that holographic radars operating at 4, 7 and 15 GHz can detect a tumor at the depth of 10, 5 and 2 mm respectively. Such low values of depth are caused by non-uniformity of the material structure, which imitates the fatty tissue of the breast. By using the results obtained with the help of FDTD modeling following conclusions could be made. As expected from theoretical considerations it is preferred to use lower-frequency probing signal, namely, 4GHz, which can detect the inclusion of 5 mm diameter up to a depth of 10 mm. While using of probing signals of 7 and 15 GHz the depth limit of detection inclusion is not more than 5 mm, which is caused by the high attenuation in a medium. However, their use is preferred for higher resolution. In further work it is proposed to develop an algorithm that allows to subtract from the received signal the signal reflected from the surface of the model. This will increase the maximum depth on which the inclusions can be detected.

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