Near-field interference microwave diagnostics

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Abstract. The article explores the dimensions of the probing region of two coaxial probes during the measurement of the dielectric properties of biological tissues and media at microwave radiation. This region is formed in the overlapping evanescent fields of the probes.

1. Introduction
Microwave electromagnetic radiation has a sufficiently high penetration. With the use of evanescent microwave fields, in a number of cases it is possible to considerably exceed the fundamental Rayleigh criterion. Therefore, near-field microwave diagnostics has become widespread not only in scientific researches, but also in solving practical problems. As the diagnostics has progressed, the possibility of its use in medicine became apparent. However, biological tissues and media are very complex objects for researching. The diagnostics of biological structure is complicated because of the high absorption of radiation into tissue, and the complex structure of tissues.

The described problem required theoretical and experimental studies. These studies were aimed at identifying features in dependence on the frequency of the dielectric properties of biological tissues or their phantoms [1-3]. The studies, shown in [4, 5], had the goal of developing methods for high-precision and non-invasive diagnostics of oncological diseases. The main attention was paid to the definition of the characteristics of breast tissue. A promising technical solution proposes in [6].

Existing models of near-field microwave diagnostics use only a single probe, which mechanically moves above an investigating surface. Our work [7] shows, that the use of overlapping evanescent fields from several active radiators causes the specific interference interaction between the radiators. An investigation of possibility for controlling the interaction due to changing the initial current phases of the probes is the highest interest. This will allow to abandon the system of mechanical movement of the probes above the object, therefore, to reduce errors during investigation.

2. Modeling of sensing biological tissues
The above assumptions were confirming with the electrodynamic simulation by using the CST Microwave Studio software package. The aim of the simulation was showing the presence of an interference interaction arising between two radiators, and demonstrating the possibility to control this interaction by changing the difference of the initial phases of the emitters.
The conical coaxial horns (probes), each 36 cm long, were chosen for the simulation. Diameters of central and external conductors, in the apertures of the horns, were 3 and 7 cm. This model was constructed to demonstrate, how the waves emitted by the probes, propagate in the absorbing medium, the angle between the apertures of the probes was 90° (Figure 1). The excitation of the horns was carried out with waveguide ports, which has the same characteristics. But the signal of the second port was a variable phase shift relative to the signal of the first port. As a result, the calculations of electric and magnetic fields were produced for frequency band from 0.2 to 10 GHz. The cylindrical object was placed between the apertures of the probes. Object’s material has the similar properties to blood. The diameter of the cylinder is 6 cm.

![Figure 1. Model of conical coaxial probes with apertures rotated on 90°.](image)

The simulation results showed that, a changing of the initial phase shifts the region of interference interaction inside the medium from the left edge of the object to its center. The dependence between the position of interaction and the initial phases of the probes (Δφ) at a frequency of 3 GHz is shown in Figure 2.

![Figure 2. Interference interaction](image)

a) Δφ = 0°  
b) Δφ = 15°
Results of the simulation demonstrate that a changing of the difference in phases of the initial currents in the probes makes possible to control the region of field localization in the vicinity of the observation point in the near field zone. This fact provides a possibility to change a probing mode of the region by changing electrical properties, without resorting to the displacement of the elements of a radiating system.

3. The results of studies of biological media

We proposed a simplified scheme of near-field interference probing technology. A model of the device was created and test experiments were started. Experiments aimed at measuring resolution and sensitivity of the model in the diagnosis of phantoms of biological media. The model consists of: PNA-L Network Analyzer (N5230C); two coaxial conical horns (probes), a coaxial power divider; the horn inputs are connected to the outputs of the power divider using the sections of the coaxial transmission lines, which ensures the creation of the required phase shift of the probe fields. The network analyzer recorded the frequency dependence of the normalized complex reflection coefficient (NS11) on the input of the power divider. At that, the frequency band was 10 MHz – 6 GHz, and the sampling step was 250 kHz, measurements were made at 24 000 points.

Figure 2. Near field structure in the model of conical coaxial probes with apertures rotated to 90°.
Figure 3. The frequency dependence of NS11 on the phantom of a biological medium with a spherical inclusion (1 - inclusion is filled with water, 2 - alcohol)

As examples in Figure 3 illustrates the frequency dependence of reflections NS11 for the phantom of biological medium in the dry form (a) and the wet form (b) foam rubber sheet with inhomogeneites. They were two types of hydrogel balls: in the first case the ball was filled with water, and in the other – with alcohol; their diameters ranged from 8 to 12 mm. Inhomogeneites is clearly visible in the entire frequency range. For clarity, the figures show responses in the frequency band not exceeding 0.1 GHz. The shift of the resonance curves in frequency and the change in resonance levels are explained by the significant difference in the dielectric constant between wet and dry foam sheets. It’s worth noting, the inhomogeneites could not be surely detected using only one probe.

4. Conclusion
We confirmed the existence of a pronounced interference interaction, in numerical simulation and in experiments with a model of a near-field interference microwave microscope. It is also shown that the model using two overlapping counter evanescent fields of two coaxial conical probes, is more sensitive than a microscope using only one probe.

Acknowledgments
This research carried out in 2017 was supported by «Russian Science Foundation» grant (No. 16-19-10272).

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