Biological Objects Parameters Meter Based on Microwave Microscope with Coaxial Resonant Sensor

Yuri Gordiyenko, Igor Bondarenko, Nikolai Slipchenko

Abstract – **The possibilities to use methods and tools of the near-field microwave microscopy for studying small-dimension biological objects are analyzed. Methods for optimization of the resonant sensor structure with regard to the objects features are developed, the system of the information signals formation is proposed.**

Keywords – **resonant sensor, biological object, near-field microwave microscopy.**

I. Introduction

Investigations into dielectric characteristics of the biological systems in a wide frequency range make it possible to find different physical parameters of macromolecules and their fragments: the charges distribution on the surface, polarization and characteristics of ion environment in the solution, dipole moments of amino acids and peptides, to single out the dispersion areas practically for all components of biopolymers solutions and molecular complexes [1].

To carry out similar investigations the contactless microwave diagnostics methods are widely used, they are based on the dependence of the biological object's effective dielectric permeability on its molecular structure and also on the contents of the free and bound water.

Taking into account that biological objects and biological media samples are, as a rule, small-dimensional ones the problem arises to create methods and devices for localization of the used microwave electromagnetic fields to increase sensitivity and resolution of the measurements being carried out.

The aim of the given work is to analyze the possibilities to use the near-field microwave microscopy for investigation of the small-dimensional biological objects.

II. Main Part

The basis of the near-field microwave microscopy consists in the use of the microwave microprobe structures, the localized electromagnetic fields, interacting with the objects under investigation, are formed with their help [2]. The spatial resolution is defined in this case not by the microwave radiation wavelength but by the microprobe structure and can reach the desirable nano dimensional level.

As in the case with the traditional methods of contactless microwave diagnostics, the maximal measurements sensibility in the microwave microscopy is attained when using the resonant measuring transducers (RMT). Information about characteristics of the objects under investigation and their variations will be contained in the values and variations of the resonant frequency and quality factor of the transducer.

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Thus, the RMT with a probe structure and the system of its quality factor and resonant frequency measurement will be the devices defining the main metrological characteristics of the transducer as a whole.

The peculiarity of the biological objects microwave diagnostics consists in great losses both in the sample and in the construction layer structure intended for this sample placement; these losses decrease the RMT quality and, as a result, the measurements sensitivity (Fig.1).

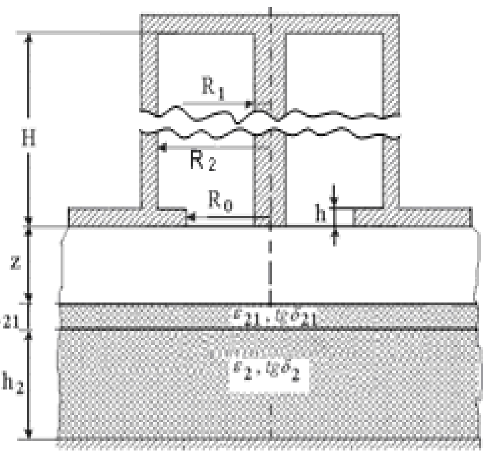

Fig.1. Resonant transducer with a coaxial aperture

The offered RMT with a coaxial aperture is shown in Fig.1 together with the h_2 thick sample substrate having electrophysical parameters $\varepsilon_2, tg\delta_2$ with the h_{21} thick sample layer placed on the substrate having electrophysical parameters $\varepsilon_{21}, tg\delta_{21}$. The RMT construction in the form of the quarter-wave-length coaxial resonator with the placement of the controlled object in the open end face is chosen with regard to the possibility of coverage of the $5 \cdot 10^6 \ldots 10^{10}$ Hz frequency effective range important for investigation of the objects with different relations of free and bound water.

To carry out practical measurements it is important that the electrophysical parameters of the sample exert as much action as possible on the loaded quality of the RMT. In this case the loaded quality should not be less than 100.

The performed digital analysis of the electrodynamic structure shown in Fig.1 with the use of the Maxwell equations solution results with regard to the radiation losses and characteristics of the objects being investigated makes it possible to optimize the RMT design with the coaxial aperture and to choose the required relations of the construction parameters [3].

The moisture content in the biological objects is characterized by the range of ε variations from 3 to 10 and of

$tg\delta$ — from 0,01 to 0,4. Thus, it is expedient to perform the numerical investigation in the given range of variations of electrophysical parameters of the sample being tested.

Figs. 2 and 3 show the curve of Q and resonance frequency dependence for the RMT with the following parameters: $H/\lambda = 1,25$; $R_2/\lambda = 0,17$; $z = 0$; $h_{21} = 0$; $h_2/\lambda = 0,14$; $h/H = 0,01$; the walls conduction $\sigma = 5,8 \cdot 10^6$; $\lambda = 3$ cm, with the aperture size variation R_0/R_2 from 0,29 to 1 are given Figs.2 and 3.

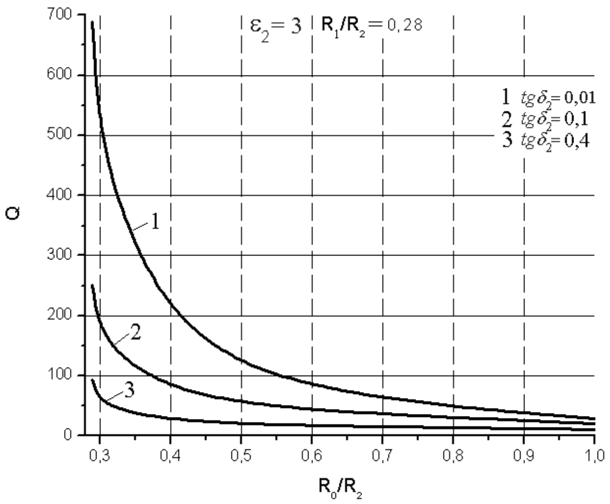

Fig.2. Dependence of Q on the aperture and sample parameters

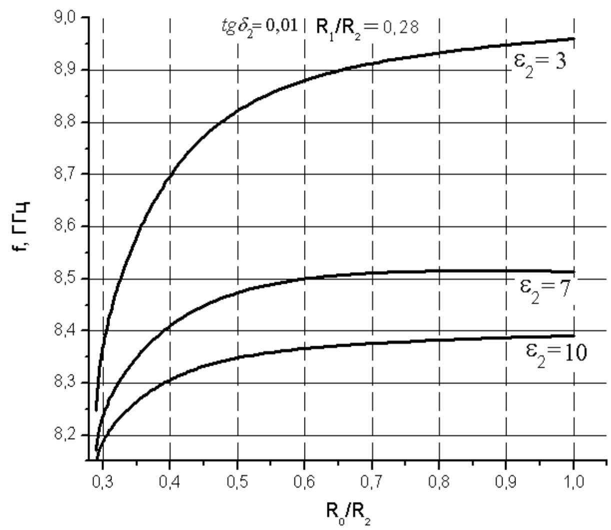

Fig.3. Dependence of f on the aperture and sample parameters

As can be seen from the figures the aperture size significantly affects the information parameters of the RMT. In this case the following requirements should be taken into account: the initial Q of the RMT should be sufficiently high ($Q \geq 10^3$) to maintain the needed sensitivity of measurements; the field energy in the aperture area should be sufficient for the efficient interaction with the object being investigated; the radiation losses should be minimal ones.

Figs. 4 and 5 show the dependences of Q and the resonant frequency on the sample parameters.

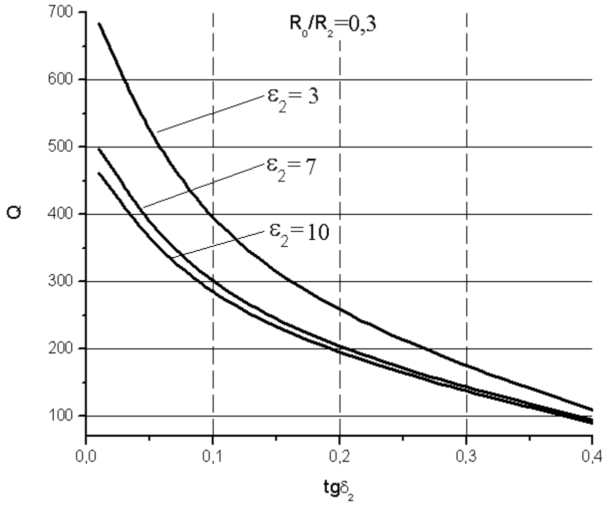

Fig.4. Dependence of Q on the sample parameters

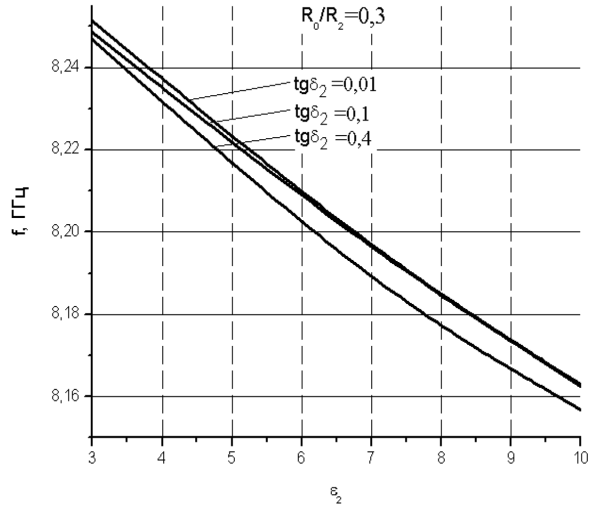

Fig.5. Dependence of f on the sample parameters

From the curves it will be obvious that Q is influenced both by the sample permittivity and its losses, and the contribution from the dielectric loss tangent to the resonant frequency variation depending on the ε value is insignificant.

The AFC system of the test microwave oscillator is used as a system for information signals formation by the resonant measuring transducer (RMT) with the microwave oscillator frequency modulation [4]

The signals related to $\delta f/f_0$, are singled out as an error signal after the phase detector.

Its value is defined in the general phase by the expression

$$\frac{\delta f}{f_0} \cong \frac{\delta f_r}{f_0} \cong \frac{\delta U(\delta f_0) \cdot S}{f_0}, \qquad (1)$$

where $\delta U(\delta f_0)$ – is the error signal voltage used for the test oscillator frequency control; S – the test oscillator frequency sensitivity.

The signal related to $\delta Q/Q$, is singled out as a voltage on the frequency microwave detector on a frequency of 2Ω, amplified by a narrow-band amplifier and then it arrives to the processing system.

In this case

$$\frac{\delta Q_{н}}{Q_{н1}} \approx \frac{\delta U_{д}^{2\Omega}}{2U_{д}^{2\Omega}}. \qquad (2)$$

The relative variation value of Q, as well as for $\delta f/f_0$ (1), can be normalized by the calibrated variation of Q for the standard object of the investigation.

III. Conclusion

Methods are offered and tested for simulation of the microwave microscope with coaxial resonant sensor making it possible to optimize its structure with regard to particularities of diagnosing the biological objects, the system for the information signals' formation based on the AFC system by the resonant measuring transducer with the test FM oscillator is also offered.

References

[1] E.N. Grant, R.J. Sheppard, G.R. South. Dielectric behavior of biological molecules in solution. – Oxford: Clarendon Press. – 1978. – 234 p.

[2] L.F. Chen, C.K. Ong, C.P. Neo et al. Microwave Electronics. Measurements and Materials Characterization − John Wiley & Sons, Ltd., 2004. P - 537p.

[3] Yu.Ye. Gordienko, Yu.I. Gud, D.A. Poletaev. Oscillation and radiation losses contribution to the characteristics of microwave converters with coaxial measurement aperture// Radiotekhnika: All-Ukr. Sci. Interdep. Mag 2009. № 157. P. 108 - 114.

[4] I.N. Bondarenko, Yu.Ye. Gorgienko, S.Yu. Larkin. Scanning signals formation in the microwave microscopy with a resonant microprobe // Radiotekhnika: All-Ukr. Sci. Interdep. Mag. 2009. № 158. P. 59 - 67