

## MICROWAVE LOCAL DIAGNOSTICS OF BIOOBJECTS

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Information on the content and changes in the distribution of free and bound water in biological objects allows for the diagnosis of their condition. Microwave diagnostics of bioobjects using resonator transducers with coaxial probe structures provide an opportunity for non-destructive analysis with millimeter and submillimeter spatial resolution. Analytical methods were used to study the nature of the interaction of electromagnetic fields created by coaxial apertures of various configurations with samples. On the basis of the obtained results, directions for the implementation of microwave high-local diagnostics techniques are determined.

### Introduction

In comparison with other electrophysical methods, microwave methods, due to the possibility of measurements in the wide frequency range, which lie in the relaxation frequencies of macromolecules, have significantly higher information capacity. Most of the molecules of bioreactors are electrically neutral. The electrophysical properties of the molecule of bioreactors are acquired when they are bound to molecules of water that have a pronounced dipole moment. Therefore, solving the problem of determining the relationship of water with biological macromolecules and the creation of methods for controlling the state of water in biological substances is a step in the overall problem of diagnosing the state of bio objects.

Therefore, there is a significant set of physical factors that are related to obtaining information on the status of bioobjects on the basis of determining the amount and distribution of free and embedded water in the macromolecule of biological substances using microwave sensors relative to bio objects in vivo and in vitro, as well as in the period external influence on them, and corresponding to these sensors of secondary converters.

With the development of microwave diagnostics there was a need for concentration of efforts on the development of methods and controls for small-scale objects. This determined the use of the so-called near-field interaction of a sensitive element with the object, which led to the construction of primary measuring transducers on the basis of resonators [1].

The need for non-destructive control of objects of arbitrary shape caused, in addition, the advantage of the so-called aperture interaction of the field of measuring resonators with the object [2]. It is these principles that were the basis of most developments with microwave sensors in recent years.

In such a statement, the basic foundations were the base of the necessary alternative solutions to use near-field resonator sensitive elements. Their application allowed to create multi-parameter microwave sensors with wide possibilities of unification, accurate theoretical description of the characteristics of the transformation, dynamic positioning and substantial minimization of requirements to the sizes and form of the object of control.

This complex of properties provided an opportunity to implement the necessary locus of control of the heterogeneity of the distribution of values of parameters on the object surface and multidimensional diagnostics.

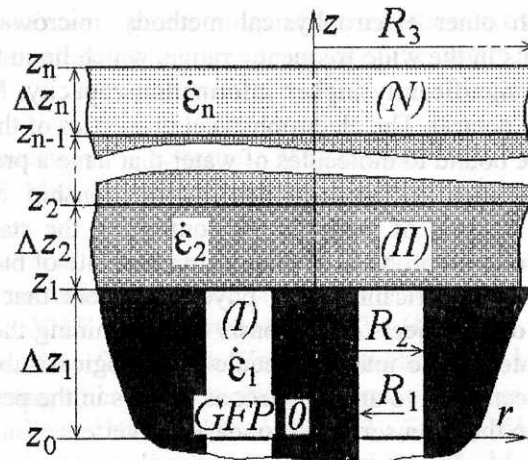
### The main part

The dielectric properties of biopolymers in the field of dispersion of free water are largely determined by the state of water inclusions. As a result, dielectric characteristics are an informative material for obtaining data, first of all, about the state of water in the investigated system. In a number of processes there is a possibility to observe changes in these characteristics in moist specimens and solutions of biopolymers, as well as in cell suspensions.

In this way, the method of microwave dielectrometry, at achieving a certain level of accuracy, provides an opportunity to obtain effective methods of quantitative and qualitative estimates of changes in the state of bound water in the system, which correspond to structural changes in its components. To study the dielectric characteristics of biological objects, there is a method for measuring the complex permittivity of a wide class of biopolymers: solutions and suspensions, gels, films and powders, tissues and cell cultures under various external influences.

For instruments of operational control of the parameters of materials in the microwave range as a sensor, the open end of the coaxial line is very attractive (Fig. 1). It features simplicity, processability, the ability to work in a wide range of frequencies, high field location, easy preparation of samples to measurements. It is not difficult to make changes to the design of an open coaxial sensor (OCS), which opens the possibility of variation of measured samples and areas of application.

To realize the benefits of OCS, a strict assessment of its metrological properties is required. This requires the most accurate calculation of the distribution of the electromagnetic field. Modern software provides an opportunity to accurately calculate it. But to determine the relationship and understanding its properties, it is necessary to develop analytical methods.



$R_1$  – inner radius of coaxial line;  $R_2$  – external

[1] **Fig. 1** – Geometric measurement scheme using OCS

Microwave control can be an effective addition to traditional methods for monitoring the status of bio objects, in particular, in clinical examination of patients. This requires the creation of specialized diagnostic equipment, the development of new and development of known methods of research. When creating a specific, small-scale equipment, a significant role is played by reducing the cost of development. Thus, there was a need to conduct a series of studies to answer a number of specific issues.

Among them it is especially important to note the following:

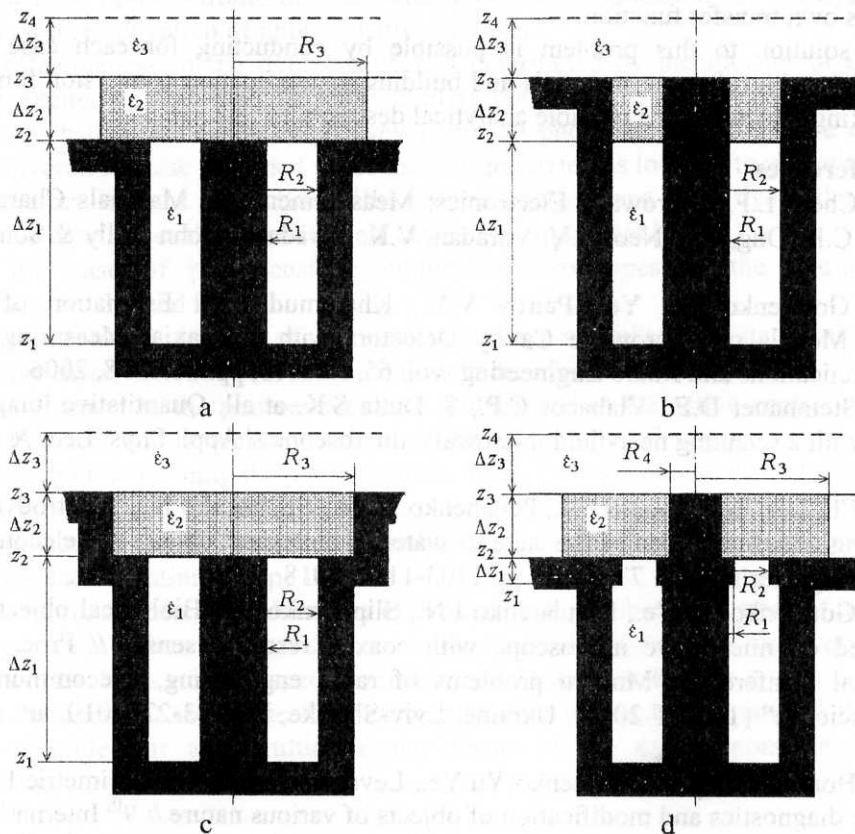
1. Justification and selection of the type and design of the microwave meter, which allows to increase the informativeness of the measurements and reduce the volume of biological samples.
2. Provision of measurements over a wide frequency range, which lies in the region of relaxation frequencies of free and bound water.
3. Development of a technique ensuring the elimination of the main errors of the theoretical calibration, in particular, guided by the criteria of hardware errors and the necessary accuracy of measurements in clinical conditions.
4. Conduct an analysis of the procedure for obtaining the final results and themselves for the creation of a model that allows the calculation of the properties of a microwave meter with a complex structure. Create a perfect model that provides further upgrades to sensors.

5. Development of procedure and algorithm of numerical solution of the problem of calculating the parameters of the microwave meter.

Resonator methods are most sensitive to changes in the parameters of samples of small sizes while preserving the necessary accuracy of measurements. Bulk resonators provide high accuracy, but require internal placement of the sample, which is inconvenient for current measurements. Quarter-wavelength coaxial resonator measuring transducers (RMT) through a coaxial measuring aperture (CMA) are coupled to the surrounding space. In doing so, they also provide sufficient accuracy of measurements [3]. In addition, the theoretical calibration of sensors based on RMT with CMA, estimation of their parameters is possible. They have the ability to localize the field in a given volume of the sample, a wide frequency range.

The quarter-wave RMT is a transitional link between open and closed types of resonator meters. They are most consistent with the requirements of minimizing sample volumes while maintaining high sensitivity. Execution of the open end of the RMT in the form of a coaxial measuring aperture of small size makes it possible to concentrate the electric field of the resonator in a small volume. This ensures a maximum change in the resonance frequency of the RMT, depending on the dielectric properties of the object. At the same time, the size of such a work area is determined not by the wavelength, but by the size of the CMA. In addition, the semi-open system is convenient for current measurements.

To solve problems of microprobe structures, the method of a given field was convenient. This method allows the integral parameters of the RMT (resonance frequency  $f$  and  $Q$  factor) to be replaced by the complex value of the equivalent concentrated CMA  $C$  capacitance. In this case, the electromagnetic wave base of the solution is preserved. The method of a given field greatly simplifies analytical calculations, but gives an approximate solution. Nevertheless, it has a fundamental opportunity in all the most important cases to provide the necessary precision.



**Fig. 2** – Examples of geometrical circuits of RMT with CMA and variants of placement of cuvettes with biomaterial into the working area

If we take into account that the relaxation properties of free water are most pronounced at frequencies near 10 GHz, and for the frequency bound in the macromolecules this will be lower than the design of such RMT will have acceptable dimensions, and the required volume of samples will be determined only by biological criteria.

An adequate mathematical model and the creation of an efficient calculation algorithm open the possibility of determining the distributions of an electric field inside the sample, which is necessary to take into account the characteristics of heterogeneous biological samples.

The geometric schemes of some variants of the performance of the CMA and the placement of the sample cuvette ( $\Delta z_2, \varepsilon_2$ ) are presented in Fig. 2, a-d. Only a sample (layer  $\Delta z_2$ ) is shown. The effect of possible gaps and cuvettes for placing the sample can be taken into account with further refinement of the model.

### Conclusion

The use of analytical methods for describing the processes of interaction of electromagnetic fields formed by coaxial measuring apertures with the studied structures of various types, combined with numerical methods of mathematical modeling, make it possible to more clearly visualize the nature of the processes and even define a number of requirements for measuring instrument designs.

Moreover, the results obtained in this case can be applied to the already existing and used in practice RMT based on different types of resonant structures, since in all of them the working body providing the local measurement is a coaxial probe [4 – 6].

At the same time, for calibration of RMT, it is necessary to determine the transfer function, which relates the change in the electrophysical characteristics of the local areas of the objects under study with the measured changes of the quality factor and the resonant frequency. It should be borne in mind that for each specific design RMT and the sample placement options will have its own transfer function.

The solution to this problem is possible by conducting for each case a series of measurements with reference materials and building approximation conversion functions based on them taking into account a possible analytical description.

### References

1. Chen, L.F. *Microwave Electronics: Measurement and Materials Characterization* / L.F. Chen, C.K. Ong, C.P. Neo, V.V. Varadan, V.K. Varadan – John Willy & Sons, Ltd, 2004. – 537 p.
2. Gordienko Yu. Ye., Petrov V.V., Khamud F.M. Estimation of Numerical-Analytical Models of Microwave Cavity Detectors with a Coaxial Measuring Aperture // *Telecommunications and Radio Engineering*. vol. 65, № 9-10, pp. 789-798, 2006.
3. Steinhauer D.E., Vlahacos C.P., S. Dutta S.K. at all. Quantitative imaging of sheet resistance with a scanning near-field microwave microscope // *Appl. Phys. Lett.* № 72. pp. 861–863, 1998.
4. Ch. Lin, Bondarenko I.N., Panchenko A.Yu., Slipchenko N.I. Electrodynamic sensor for assessing transformations of the state of water in biological objects // *Telecommunications and Radio Engineering*. vol. 77, № 12. pp.1103-1112, 2018.
5. Gordienko Yu.Ye., Bondarenko I.N., Slipchenko N.I. Biological objects parameters meter based on microwave microscope with coaxial resonant sensor // *Proc. of the 10-th International Conference “Modern problems of radio engineering, telecommunications and computer science” (TCSET 2010)*, Ukraine. Lviv-Slavske, Feb. 23-27, 2010. art. no. 5446176, p.137-138.
6. Bondarenko I.N., Gordienko Yu.Ye., Levchenko A.V. Submillimetric localization of microwave diagnostics and modification of objects of various nature // *9<sup>th</sup> International Kharkiv Symposium on Physics and Engineering of Microwaves, Millimeter and Submillimeter Waves (MSMV'2016)*, Kharkiv, Ukraine, 2016. № 7538014.