DETECTION OF DIELECTRICS ON INHOMOGENOUS AGAR PHANTOM

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Abstract

This paper describes and evaluates a method for determining complex permittivity, and presents results of permittivity measurement of inhomogeneous agar phantom. There are described different approaches for measurement of complex permittivity, in particular the non-invasive method of measuring complex permittivity at the end of the coaxial cable. Vector measurement of the reflection coefficient on the interface between probes and measured samples is performed with the aid of network analyzer in the frequency range from 300 kHz to 2 GHz. The results indicate that using the coaxial probe with dimensions of SMA (subminiature version A) connector is suitable in the frequency range approximately from 300 MHz to 10 GHz. In order to demonstrate the diagnostic potential of this method, measurements were first conducted on artificially created inhomogeneous agar phantom with added mixture of various dielectrics.

1. Introduction

Relative permittivity, loss factor and conductivity are basic parameters for electromagnetic field modeling and simulations. Although these parameters could be found in the tables for many materials, their experimental determination is very often necessary [1]. Dielectric properties of biological tissues are determining factors for the dissipation of electromagnetic energy in the human body and therefore they are useful in hyperthermia cancer treatment.

Measurement of the dielectric parameters of biological tissues is also a promising method in the medical diagnostics and imaging. Knowledge of the complex permittivity in an treated area, i.e. knowledge of the complex permittivity of healthy and tumor tissue, is very important for example in the diagnosing of tumor regions in the human body or in the design of thermo-therapeutic applicators which transform electromagnetic energy into thermal energy in the tissue [2-3].

2. Methods of complex permittivity measurement

The most commonly used method for measuring the complex permittivity is a method of measuring dielectric inserted into a dielectric waveguide. This method is very accurate, but unfortunately requires irreversible changes in the measured material. Another method used for measurement of complex permittivity is RLC measuring bridge. This method is very accurate but there are a few requirements on the quality of the interfaces of the measured material and the capacitor plates [4]. In most cases, this method is used as narrowband. The method of measurement in free space has its limitations in the demand for high-loss dielectrics measured.

Electromagnetic wave through the material must be attenuated by at least 10 dB. Otherwise, standing waves will be created, which contribute significantly to the inaccuracy of this method. The method of measurement in cavity resonators gives us results with good accuracy. On the other hand, it is difficult to produce precise machining of the resonator and the measured material inserted inside [5]. Latest often used method for measuring complex permittivity measurement method is the open end of the waveguide, in our case, the coaxial cable. This method can be considered as very accurate. Moreover, we can achieve a good repetition of the results when we maintain the phase stability of the measuring coaxial cable [6]. In this work, this application was selected for the main method for measuring complex permittivity of biological tissues because of its non-invasive nature.

3. Principle of reflection method

The reflection method represents measurement of reflection coefficient on the interface between two materials, on the open end of the coaxial line and the material under test. It is a well-known method for determining the dielectric parameters. This method is based on the fact that the reflection coefficient of an open-ended coaxial line depends on the dielectric parameters of material under test which is attached to it.

For calculating the complex permittivity from the measured reflection coefficient, it is useful to use an equivalent circuit of an open-ended coaxial line. The probe translates changes in the permittivity of a material under test into changes of the input reflection coefficient of the probe. The surface of the sample of material under test must be in perfect contact with the probe. The thickness of a measured sample must be at least twice of equivalent penetration depth of the electromagnetic wave. This assures that the waves reflected from the material under test interface are attenuated.

4. Measurement Probes

For measurement probes, we have adapted the standard N and SMA RF connectors from which the parts for connecting to a panel were removed. The measurement probes can be described by the equivalent circuit consisting of the coupling capacitance between the inner and outer conductor out of the coaxial structure and radiating conductance which represents propagation losses [7]. These capacitance and conductance are frequency and permittivity dependent.

Probe for measuring the complex permittivity of biological tissues has been adapted from a standard RF connector for coaxial cable, called N-type connector, see figure 1. The original proposed range of application was f_{BW} = 1 GHz, which together with the development of microwave technology is extended until today's f_{BW} = 12 GHz. N connector used in the construction of the probe is normal N 50Ω connector that can be used of frequency f = 5 GHz. The measurements were kept with a high degree of the accuracy and repeatability. The measurement probe based on N connectors had significantly less bandwidth, and f_1 = 100 MHz and f_2 = 1 GHz.

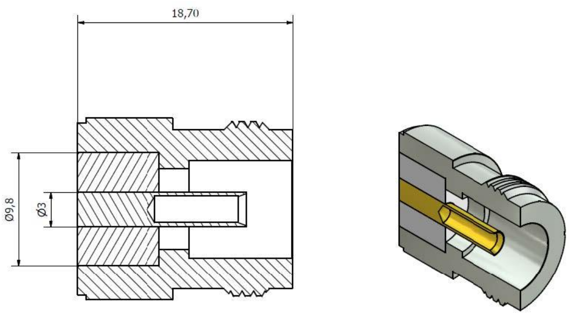

Figure 1. Basic scheme of the N probe's dimensions.

Probe for measuring the complex permittivity based on the SMA-connector was adapted from a standard 50 Ω SMA connector which was developed around 1960 when it was required to create a miniaturized version of the N connector with a higher frequency range of application. Today SMA connectors operate in the band up to f = 18 GHz.

SMA connector used for the production of SMA probes, Figure 2. shows low-cost, standard RF connectors with a usable bandwidth up to f = 12 GHz. This solution is appropriate for the purposes of our measurements because the highest frequency measured is equal to f = 2 GHz.

5. Measurement setup

A typical measurement setup using the reflection method on an open-ended coaxial line consists of the network analyzer, the coaxial probe and software. Our measurements were done with the aid of Agilent 6052 network analyzer in the frequency range from 300 MHz to 3 GHz.

First the calibration of the vector network analyzer is performed. Then the calibration using a reference material is done. Finally, the reflection coefficient of material under test is measured. The complex permittivity of material under test is evaluated by the MATLAB.

6. Measurement on inhomogeneous agar phantom

T he initial measurements on the inhomogeneous agar phantom were performed, fig. 3. As the simulations shows that the effective penetration depth in both cases, for N probe and SMA probe, is an interval of 4 mm to 2 mm depending on the frequency of measurement. Therefore, in this model of inhomogeneous agar phantom, strange dielectric immersion depths lies in the range from 4 mm to 1 mm.

Thus, the purpose of this measurement was to detect strange dielectrics that are covered with an agar layer in terms of simulating the electrical parameters of human skin and soft tissue. Inhomogeneous agar phantom was covered with a regular square grid (30 points x 30 points), with the 900 points of measurement. Subsequently, measurements were taken at these points by the N probe and SMA-probe.

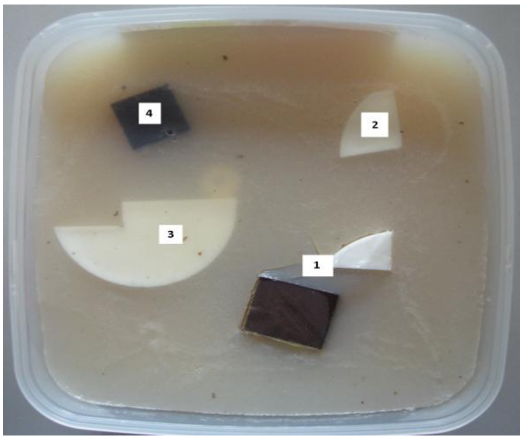

Figure 3. Inhomogeneous agar phantom setup, the number shows the depth of strange dielectrics submersion.

7. Results

For the measurement on inhomogeneous agar phantom was designed with a submerged object of Teflon $\varepsilon_r = 2.1$ and Bakelite $\varepsilon_r = 4.1$, immersed in a variable depth of 4 mm to 1 mm into the agar phantom. After solidify of the agar surface was applied spatially equidistant grid (30 x 30) with 900 data points. Measurements were performed by the SMA probe. Obtained values of the real part of complex permittivity have been rewritten into MATLAB and displayed as a contour graph image, see figure 6. The results of the measurement on the inhomogeneous agar phantom have shown the potential of imaging usability of this method for further investigations on real living tissue.

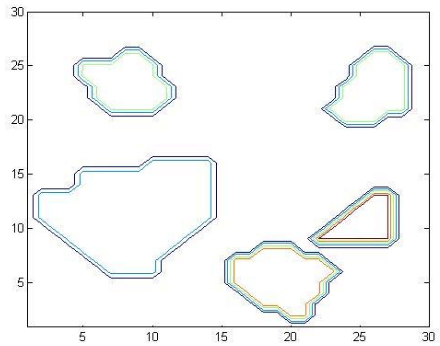

Figure 5. Results of the measurement on inhomogeneous agar phantom (contour graph of real part of complex permittivity on frequency f = 500 MHz).

8. Conclusions

Measurements on inhomogeneous agar phantom showed the potential of this imaging method, because the strange dielectrical materials were detectable beneath the surface of agar. Based on this result, the measurement of the left upper extremity of the author was performed, and the contour map of the real part of complex permittivity shown the detectable difference between the tissues.

The contour graphs of the real part of complex permittivity of biological tissue give us the hope for the future development that this method may be used as a imaging method. After proving more interaction on the pathological changes in tissues, such as growth of tumor tissue, we can consider this method for diagnostic purposes.

Acknowledgement

Research described in the paper was financially supported by Grant Agency of the Czech Republic, project: ,,Non-standard application of physical fields - analogy, modeling, verification and simulation"(102/08/H081).

References

[1] Hippel, A. (1954). Dielectric Materials and Applications. *Technology Press of MIT*, Cambridge, 1954, pp. 71-75.

[2]Choi, J.; Cho, Y. Lee, J. Yim, B. & Kang, K. et al. Microwave detection of metastasized breast cancer cells in the lymph node; potential application for sentinel lymphadenectomy. *Breast Cancer Research and Treatment*, Vol. 86, No. 2, 2004, pp. 107-115. ISSN 0167-6806

[3] Williams, T. Sill, J. & Fear, E. Breast surface estimation for radar-based breast imaging systems. *IEEE Transactions on Biomedical Engineering*, Vol. 55, No. 6, 2008, pp. 1678-1686. ISSN : 0018-9294

[4] Thompson, A. M.; A bridge for the measurement of permittivity. *Proceedings of the IEE - Part B: Radio and Electronic Engineering*, Vol.103, No.12, pp.704-707, November 1956.

[5] Ramachandraiah, Munikoti S.; Decreton, Marc C.; A Resonant Cavity Approach for the Nondestructive Determination of Complex Permittivity at Microwave Frequencies. *Instrumentation and Measurement, IEEE Transactions on Instrumentation and Measurement*, Vol. 24, No.4, (December 1975), pp.287-291, ISSN: 0018-9456

[6] Tanaba, E. & Joines, W. T. A nondestructive method for measurement of the complex permittivity of dielectric materials at microwave frequency using an open-ended coaxial line resonator. *IEEE Trans. on Measurement and Instrumentation*, Vol. 25, 1976, pp. 222-226. ISSN: 0018-9480