METHOD OF MEASURING DIELECTRIC PROPERTIES OF BIOLOGICAL TISSUE AND ITS USE IN MEDICAL IMAGING AND DIAGNOSTICS

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Abstract: Every material has a unique set of electrical charakteristics that are dependent on its dielectric properties. This paper describes a method for dielectric measurements of biological tissue and shows possibilities to use this method in medical imaging and diagnostics. A reflection method on an open ended coaxial line is a nondestructive and noninvasive measurement method which exclusively offers possibilities for ”in vivo” as well as ”in vitro” measurements. The real meausrement situation is modelled in an electromagnetic field simulator. Comparison of simulated and measured date are presented as well.

Introduction

The dielectric properties of biological tissue are determining factors for the dissipation of electromagnetic energy in human body and therefore they are important parameters in hypertermia treatment, microwave detection of tumours and in assesment of exposure doses in basic research on interactions between EM field and biological tissue.

Materials and Methods

1 Dielectric theory

Permittivity in our case describes the interaction of a biological tissue with an electric field and it’s a complex quantity.

$$\kappa = \frac{\varepsilon}{\varepsilon_0} = \varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \tag{1}$$

where κ is dielectric constant, ε_r is relative permittivity and ε_0 is permittivity of free space.

The real part of permittivity is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity is a measure of how dissipative or lossy a material is to an external electric field.

Dissipation factor:

$$tg\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \tag{2}$$

It’s important to note that permitivitty isn’t constant, it changes with frequency, temperature, etc.

2 Frequency dependent of ε_r

Materials can be modeled by the Debye relation (3), which appears as a charakteristic response in permittivity as a function of frequency.

$$\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} \tag{3}$$

where

- ε_∞ is permittivity at $f = \infty$ (optical permittivity)
- ε_s is permittivity at $f = 0$ (static permittivity)
- τ is relaxation time.

Relaxation time is a measure of the mobility of the molecules (dipoles) that exist in a material.

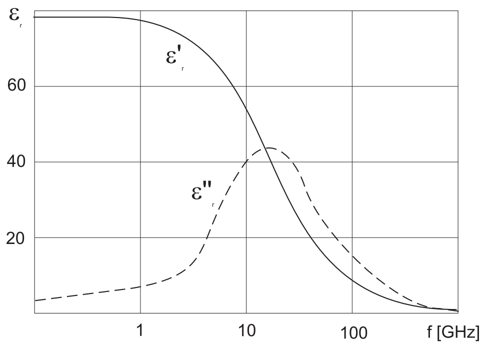

Figure 1: Frequency dependent of ε_r for water (30 °C)

3 Measurement of dielectric properties

There are a several measurement methods for measuring dielectric properties, for example the commercial measurement system of Agilent Technologies.

For hyperthermia purposes we need to describe properties of biological tissue in frequency range approximately from 20 MHz to 2.5 GHz. Sometimes we need measurements ”in vivo”, sometimes measurements ”in vitro”. If we want to use broadband measurement method which is nondestructive and which can offer possibilities for ”in vivo” and ”in vitro” measurements, we should choose reflection method on an open ended coaxial line.

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Measurement method by aid of an open ended coaxial line is based on the reality that the reflection coefficient of an open ended coaxial line depends on dielectric parameters of material which is attached to this one. For calculation of biological tissue dielectric parameters from the measured reflection coefficient it is necessary to use an equivalent circuit of an open ended coaxial line. To determine the values of elements in this equivalent circuit we use calibration by means of material with known dielectric properties.

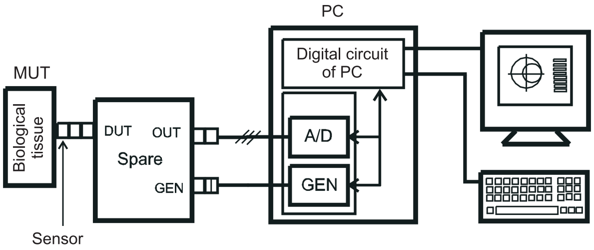

Figure 2: Measurement system

A typical measurement system using a coaxial probe method consists of a network or impedance analyzer, a coaxial probe and software. Our measurement were done by aid of sixport type network analyzer (Fig. 2).

4 Measurement sensor

The coaxial probe is created by an open end of transmission line. The material can be measured by touching this probe to the flat face of a material and determinig the reflection coefficient.

Figure 3: N-connector

For this measurement method we have developed a new type of coaxial measurement probe. This probe was created by adapting the standard *N-connector* from which the parts for connecting to a pannel were removed.

The reflected signal s_{11} can be measured and related (Eq. 4) to permittivity ε_r by using an equivalent circuit of an open ended coaxial line.

$$Y = j\omega\varepsilon_r C + \varepsilon_r^{\frac{5}{2}} G \quad (4)$$

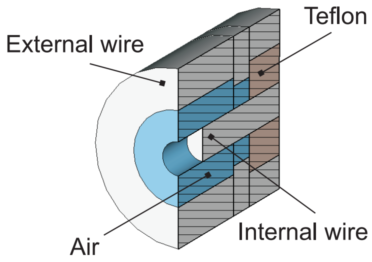

Figure 4: Model of the sensor

This circuit (Fig.5) consists of two elements:

- *C* is capacity between internal and external wire out of coaxial structure and
- *G* is conductance which represents propagation losses.

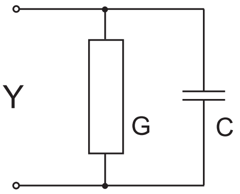

Figure 5: Equivalent circuit

5 EM field simulator

Feasibility study of this measurement method involves also numerical calculations a simulations. The system that we modeled consisted of two parts, i.e. the sensor and the biological tissue. To model the *N-connector* its dimensions were measured and available catalogue data were studied. The biological tissue sample was modeled based on available published data of ε_r, $tg\ \delta$ and σ.

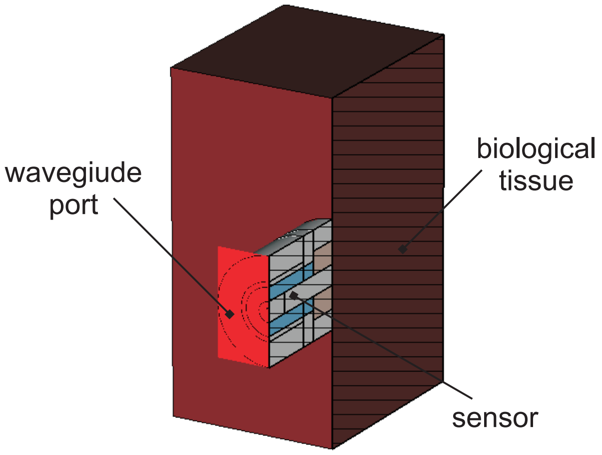

Figure 6: Model

The field at the probe changes as it comes into contact with the material under test. Figures 7 and 8 describe the electromagnetic field distribution at open end of the probe:

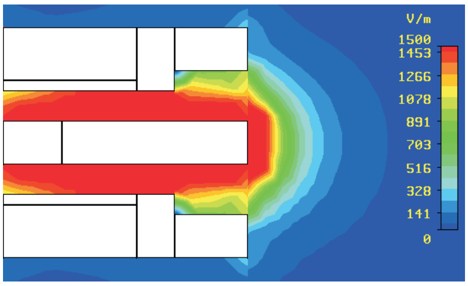

Figure 7: Distribution of EM field

- Fig. 7: distribution of EM field at $f = 434MHz$
- Fig. 8: at $f = 2GHz$

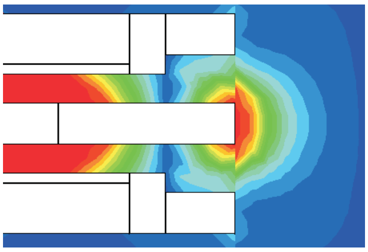

Figure 8: Distribution of EM field

With increasing frequency the wave length of electromangnetic wave decreases. There are two maximum of λ at frequency 2 GHz.

Results

We measured two samples of biological tissue:

- *sample A:* biological tissue of beef
- *sample B:* values measured on author's arm

1 Comparison of Permittivity

Relative permittivity is heavily frequency dependent quantity. Because of particles decreasing ability folow fast changes of electrical field, relative permitivity decreases with increasing frequency.

For muscle tissue is at low frequencies the real part of relative permittivity about value of 200 $[-]$ and with increasing frequency it goes down to value of 50.

2 Comparison of Loss Factor

Loss factor $tg\ \delta$ is a frequency dependent parameter too.

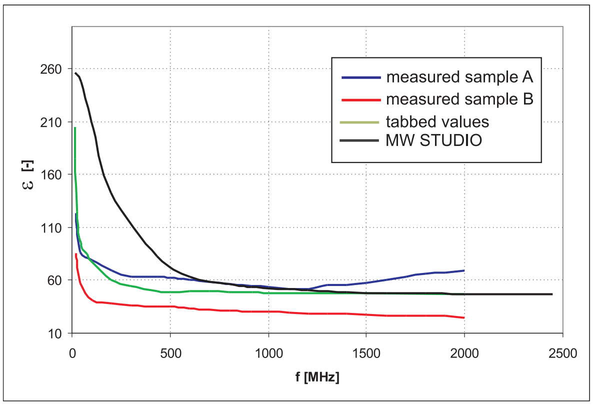

Figure 9: Relative permittivity for biological tissue

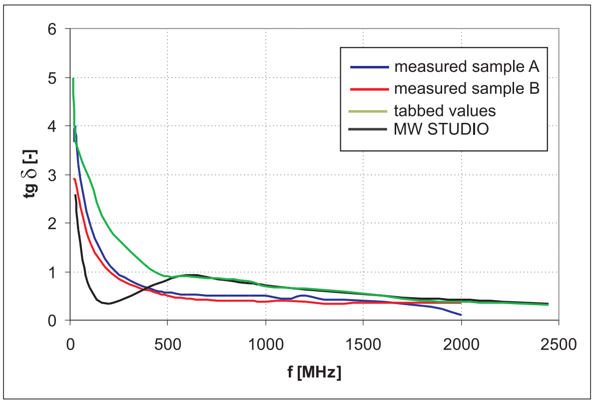

Figure 10: Loss factor for biological tissue

At low frequencies is for muscle tissue $tg\ \delta$ about value of 5 [-] and with increasing frequency it goes down to value of 0.35.

Discussion

Reported measurement method has inconvenient step in calibration by means of materials with known dielectric parameters. From accuracy of knowledge of this dielectric parameter description results total accuracy of final determination of complex permittivity. We very often use alcohol as a calibration material. Alcohols are hygroskopic liquids so they are time unsteady calibres. Additional their parameters are known from table only for 100% virgin alcohols. Their use in calibration makes measurements not very precise.

Conclusions

The measurement of complex permittivity is perspective method for medical diagnostics and preparation of treatment by using the electromagnetic field. Knowledge of the complex permittivity in a treatment area is important for design and matching of applicators for microwave thermotherapy.

The reflection method on an open ended coaxial line is suitable method for determination of dielectric parameters of biological tissue. We will continue in new study of relation between the dielectric constant of the biological tissue and the reflection coefficient. By exploring of the mathematical and physical model of the reflection coefficient measurement on the interface between biological tissue and measurement sensor we can make measurements more accurate.

We would like to verify the possibility to increase resolution of our measurements by inserting transformation layer between the probe and biological tissue. The measurement will be thus more sensitive and hence precise.

We will construct and compare the probes for various frequency bands. Finally it will rationalize total accuracy of determination of relative permittivity.

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