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Complex Dielectric Coefficient of Breast Phantom Prepared for Breast Cancer Detection

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Microwave measurement techniques attract attention due to its practical solutions in breast cancer imaging. Early detection of cancer is the purpose of these imaging studies. For these imaging processes, phantoms which reflect the properties of the area to be imaged are produced. The produced homogeneous phantoms are imaged by stepper frequency of radar technology, as the narrow bands are used for heterogeneous mixtures. Phantoms are used since 70's until today. Different methods are experimented for producing phantoms of tissue, muscle, fat, skin, etc. Iron powder, polymer materials, various oils and gelatins used today are the materials used for producing the phantoms. In this study, phantom breast imaging is aimed. Phantoms breast and breast tumor samples are created. For phantoms and tumor samples, reflection and transmittion measurements are done with Network Analyzer in X-Band (8.2–12.4 GHz). Complex permittivity is calculated with Agilent 85071 Material Measurement Software–Fast Method (NIST–iterative method). It was considered breast phantom with tumor model for 3D imagine at 2–3.5 GHz frequency range.

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1. Introduction

One of the top deaths reason of women in the world is breast cancer. According to researchers in Australia, 1 of 11 women before age of 75 had breast cancer diagnosis [1]. Risk of incorrect diagnosis is high for women with dense breasts, with existing technologies. Phantoms are created to identify the properties of the various tissue types.

In this study, phantoms for breast and tumor are fabricated, S parameters are measured in the experiment setup and permittivity values are calculated. Permittivity results of the phantom models were compared with real breast tissue and tumor.

2. Experimental

2.1. Fabrication of breast and tumor phantom

Materials: white oil (Industrial grade), disponil SLS 101 IS (Cognis), Byk-011 (Byk Chemie), propylene glycol (industrial grade), n-propanol (Merck), HCl (37%, Merck), formalin (37%) and alizarin (industrial grade) were used as received without any purification.

2.2. Preparation of phantom breast model

The breast phantom models have been developed to simulate the real conditions of the human breast tissue (Table). In order to prepare phantom model, white oil is heated at 50 °C in one pot. In another pot, deionized water, propylene glycol and Byk-011 defoamer were mixed and gradually heated at 90 °C. Then, gelatin was slowly added while heating. Next, white oil was poured onto mixture and was cooled gradually until it reaches 60 °C. Then, disponil SLS 101 IS emulsifier was added and stirred for 30 min to obtain homogeneous emulsion. After it, the mixture was cooled at 40 °C and formalin solution was added as a preservative. Finally, the mixture was poured in a mould and left for one day in room conditions (Fig. 1).

TABLE

Materials used in phantom fabrication.

Material	Breast phantom	Tumor phantom
white oil (industrial grade)	x	x
Disponil SLS101 IS (Cognis)	x	x
propylene glycol (industrial grade)	x	
Byk-011 (Byk Chemie)	x	
HCl (37%, Merck)		x
formalin (37%, Merck)		x
alizarin dye (industrial grade)		x

2.3. Preparation of tumor model

In order to prepare tumor samples, deionized water was heated at 40 °C. In another pot, white oil and disponil SLS 101 IS emulsifier were mixed (mixture 1). At the same time, 0.1 M HCl, n-propanol solvent, and formalin mixture was prepared (mixture 2). Then, mixture 1 was poured onto water. HCl was used as a preservative and formalin was used as chemical crosslinker. Next, mixture 2 and agar were added very slowly onto preheated water under vigorous stirring. Then, small amount of alizarin dye was added as pigment. Finally, the mixture was placed in a teflon mould.

3. Results and discussion

Measurement technique for complex permittivity calculation of breast and tumor phantom is the "Transmission-Line" method [2–4] (Fig. 2).

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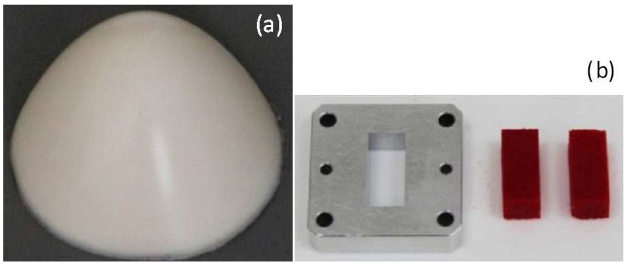

Fig. 1. (a) Breast phantom (diameter 100 mm), (b) tumor phantom.

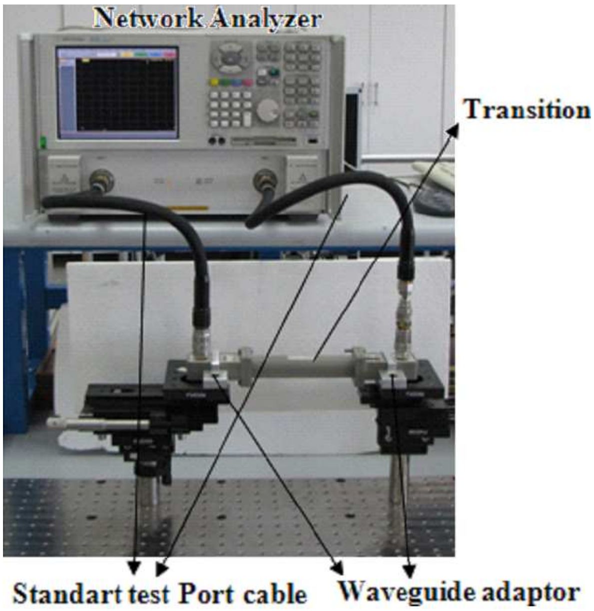

Fig. 2. Measurement system.

For the calculation technique 85071E Agilent Material Measurement software — Fast Method is used [5, 6].

The NIST iterative technique uses the Nicholson Ross Weir (NRW) technique to obtain the initial guess. According to NRW technique, S_{11} and S_{21}, and derived explicit formulae are used for the calculation of permittivity and permeability [7]. However, if users do know the approximate permittivity value of the material, then it can be deduced from the following Eqs. (1)–(5). The difference of fast method is that the measurement was less affected by systematic uncertainties to determine epsilon from the NIST iterative method (Fig. 3)

$$\Gamma = \frac{\gamma_0/\mu_0 - \gamma/\mu}{\gamma_0/\mu_0 + \gamma/\mu}. \tag{1}$$

The propagation constant in air can be determined as

$$\gamma_0 = j\sqrt{\left(\frac{w}{c}\right)^2 - \left(\frac{2\pi}{\lambda_c}\right)}. \tag{2}$$

The propagation constant in material can be defined as $\varepsilon = \varepsilon_0\varepsilon_r$ and $\mu = \mu_0\mu_r$ [9]:

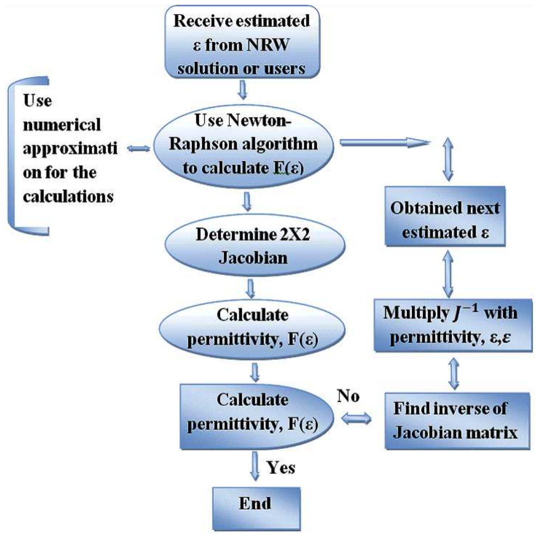

Fig. 3. NIST iterative method [8].

$$\gamma = j\sqrt{\left(\frac{w^2\mu_r\varepsilon_r}{c^2}\right)^2 - \left(\frac{2\pi}{\lambda_c}\right)^2}, \tag{3}$$

$$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}. \tag{4}$$

Replacing Eq. (3) into (4) will yield the following equation with $\mu_r = 1$:

$$\gamma = j\sqrt{\varepsilon_r\varepsilon_0\mu_0 w^2 - \left(\frac{2\pi}{\lambda_c}\right)^2}. \tag{5}$$

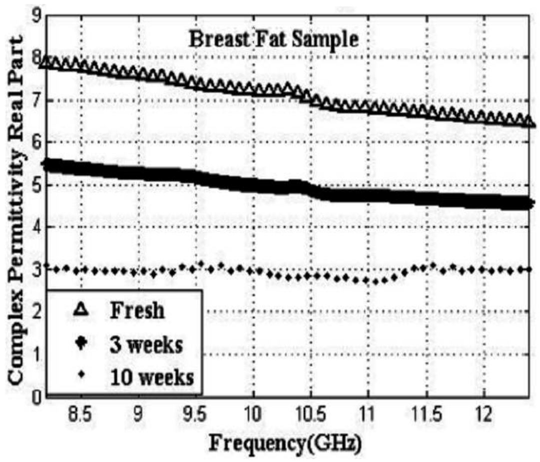

Fig. 4. Complex permittivity of real part calculation values of breast phantom for different periods of time.

In the study of breast fat, the real part of complex permittivity, calculated at the beginning, is 6 through 8 at the first week while that of real permittivity are 4 through 6, at the 3rd week and 3 at the 10th week (Fig. 4). The imaginary part of complex permittivity is 4 through 5 at the beginning, 2 through 3 at the 3rd week, and is decreased to 1 at the 10th week (Fig. 5).

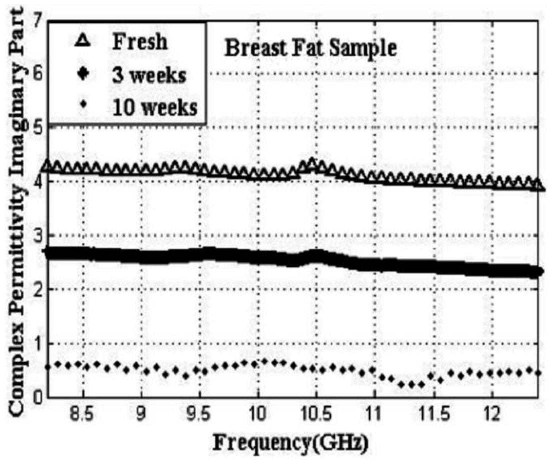

Fig. 5. Complex permittivity of imaginary part calculation values of breast phantom for different periods of time.

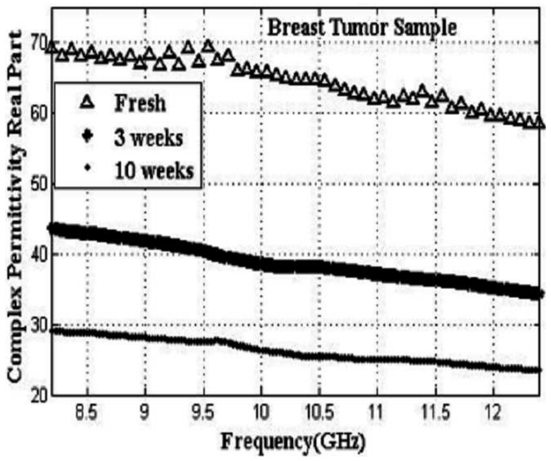

Fig. 6. Complex permittivity of real part calculation values of tumor phantom for different time of periods.

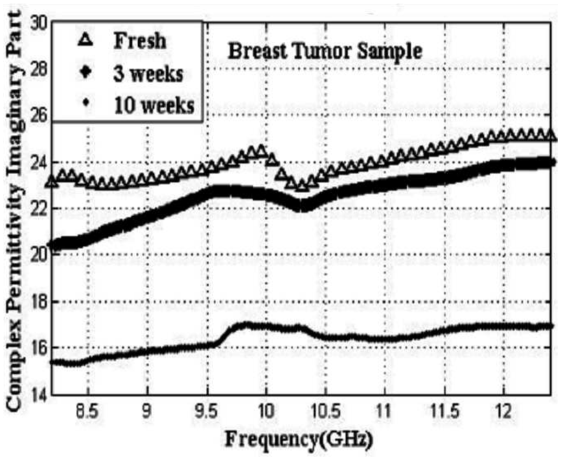

Fig. 7. Complex permittivity of imaginary part calculation values of tumor phantom for different time of periods.

The real part of frequency-varying permittivity value of breast tumor sample is 55 through 75 at the beginning, 30 through 50, at the 3rd week and 20 through 30 at the 10th week (Fig. 6). Imaginary part is 26 at the beginning, 20 though 24 at the 3rd week, and 14 through 16 at the 10th week (Fig. 7).

4. Conclusions

In this study, phantom model breast and tumor were prepared and their complex permittivity were calculated in X-band region at certain periods (initial, after 3rd, and 10th weeks) and the values were compared with the real breast and tumor results from the literature.

The complex permittivity of breast phantom is well-matched with that of the real breast while the complex permittivity of tumor phantom is higher than that of real tumor [9]. These results allow providing microwave medical diagnosis.

The time-varying results of the complex permittivity of breast and tumor phantom which will be used in the study of microwave breast cancer imaging were monitored at initial, 3rd week, and 10th week periods.

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