Investigation of Dielectric Properties for Various Size Potential Abnormality of Breast Tissues using Non-Ionizing Microwave Technique

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***Abstract*—Microwave imaging is a possible non-ionizing technique to complement existing ionizing mammogram that relies on significant contrast between dielectric properties of cancerous and normal tissues. Early detection of abnormalities in breast anatomy could be the warning sign to breast cancer. This allows the early intervention of treatment, hence increasing the surviving rate of the breast cancer patients. In this paper, a breast phantom of CIRS Model 010A contains various known tissues and sizes are studied. For the purpose of comparison to healthy tissue, the mimic tissues of calcification and the mixture of glandular and adipose were identified as potential abnormality tissues. A measurement of scattering parameter signals has been taken at several points on a breast surface phantom using one-port open-ended coaxial probe. The obtained signals permit the extraction of the dielectric properties of the tissues where the microwave dielectric permittivity and loss factor were obtained. These parameters were compared among the breast tissue types. The results of normal and possible abnormality breast tissues are presented at 2.4 GHz, the narrowband frequency related to microwave biomedical applications. The effective permittivity and loss factor (thus, conductivity) were higher with the size of the possible abnormal grains, masses and more fibrous glands. In conclusion, the dielectric permittivity and conductivity measured via microwave technique have potential ability to detect early possible abnormalities.**

Keywords—microwave technique; dielectric properties; permittivity; conductivity; abnormality; early detection and breast cancer.

I. INTRODUCTION

An accurate imaging technique at early detection is crucial to improve survival rate of breast cancer patients and save more lives. Some breast cancers are related to calcification. Calcification in breast are mostly benign, however some cluster and pattern of calcification might suggest early sign of breast cancer. It was reported majority of detected lesion with calcification during screening were not immediately recalled and the cancer has becoming invasive by the time it was diagnosed [1]. Thus, early detection of the calcification is crucial and could be the key of early treatment intervention.

Currently, X-ray mammography is the most common modality used to detect the disease other than magnetic resonance imaging (MRI), computed tomography (CT-scan) and ultrasound. However, the sensitivity and specificity are compromised due to weak detection in younger age and denser breast women. Normal breast is composed from glandular (glands), adipose (fats) and connective tissues. In mammograms, background image is black, greys indicate adipose composition and some areas showing whites for the glands and connective tissues. A tumour which is denser than fats may show as white due to similar density as glands and connective tissues causing it more difficult to be detected in women with denser breast [2, 3]. As women aging, the density of the breast reduced, more fats dominates, therefore it would be easier to interpret via mammograms.

Microwave imaging offers relatively low cost operation, low levels of power, non-invasive, non-destructive and non-ionizing radiation. It can emerge as one of the potential alternatives to complement existing modalities [4]. This technique relies on substantial contrast in dielectric properties between healthy and cancerous tissues [5, 6]. The primary factors affecting the dielectric properties of a material include the frequency of interest, moisture content and temperature [7]. Prior information about the dielectric properties of breast tissues can be applied in microwave imaging techniques to improve results. Therefore, study on dielectric properties of breast tissue materials is crucial to develop an effective microwave imaging system.

To date, a number of measurement methods have been reported to estimate the dielectric properties in biological tissues such as transmission line [8], multi probe impedance [9], perturbation cavity methods [10] and open-ended coaxial probe (OECP)[5, 11, 12]. These methods have its own limitation and each depends on the frequency of interests, nature of dielectric properties both physical and electrically and degree of accuracy. In microwave frequency range, the OECP has been widely used for liquid and semi-liquid materials such as fresh fruits, foods and biological tissues [11, 13, 14], however limited to small structure.

The objectives of the work presented in this paper are to measure dielectric properties and detect possible abnormality of imitated tissues in breast phantom of CIRS Model 010A. The abnormality of the breast tissues might be characterized by the trend of permittivity rise in microcalcification and glands. The effect of microcalcification grain size containing of 30% glandular and 70% adipose, thickness of hemispheric masses of 55% glandular and 45% adipose imitates the tumour mass, and fibrous glands in the form of percentage variation of glandular in 1cm step wedges in the phantom were analysed.

In this paper, Section 2 describes basic theoretical background of the interaction of electromagnetic (EM) field with materials. Section 3 explains the material composition of breast phantom and the associated methods. Section 4 discusses the results and finally, section 5 concludes the study.

II. Theoretical Background

Breast tissues of a cancer person contains cancer tissue on top of healthy tissues composed of adipose (fat), glands and connective tissues. The interaction of biological materials with electromagnetic radiation can be characterized by their dielectric properties.

Normally, the property of interest are dielectric constant, conductivity and reflection coefficient. In biological tissues, the dispersive characteristic depends on water content. The permittivity and conductivity of a cancer tissue are higher than those of normal tissue due to more water content and active cells [15]. When the cancerous tissues are exposed to microwave source, the water content in the tumours causes notably higher scattering effect compared to the normal tissues [16].

The dielectric properties can be obtained from the complex relative permittivity,

$$\varepsilon_r^*(\omega) = \varepsilon'(\omega) - j\varepsilon''(\omega) = \frac{\varepsilon^*(\omega)}{\varepsilon_0} \quad (1)$$

where ε' is the dielectric constant, ε'' is the loss factor, ε^* is the complex permittivity, ω is the angular frequency and $\varepsilon_0 = 8.85419\ 10^{-12}$ F/m is the permittivity of free space. Dielectric constant measures the amount of energy from the external field stored in a material, while loss factor is the amount of energy loss from the material due to the external field. The loss factor is related to conductivity, σ by

$$\varepsilon'' = \frac{\sigma}{\varepsilon_0 \omega} \quad (2)$$

Several methods can be used to convert the S-parameters to dielectric properties such as Nicholson-Ross-Weir (NRW), NIST iterative, non-iterative and short circuit line [17]. Each of the method offers different advantages and limitations. Otherwise, one can use the embedded program offers with the probe kit to extract the conversion.

III. Material and Methodology

The object under test used in the measurement was a Computerized Imaging Reference System (CIRS) Model 010A by CIRS, USA, a tissue equivalent mammography breast phantom. It is a 0.7 kg tissue-equivalent made of epoxy resin-based polymer matrix and calcium carbonate ($CaCO_3$), formulated for performance of mammographic technique in the range of x-ray exposure between 24 to 34 kVp. This model has dimension of 12.5 cm x 18.5 cm with thickness of 5 cm and the schematic drawing is shown in **Error! Reference source not found.**.

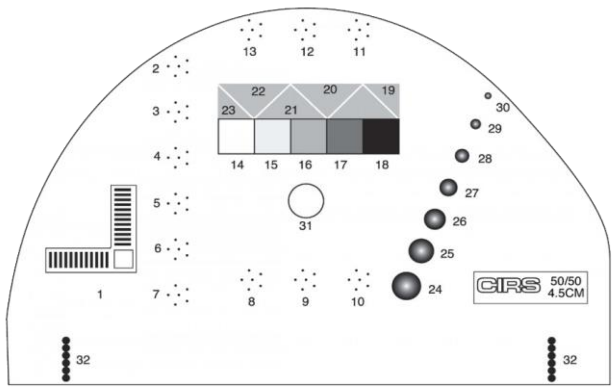

Fig 1. Specification diagram of CIRS Model 010A, tissue equivalent mammography breast phantom.

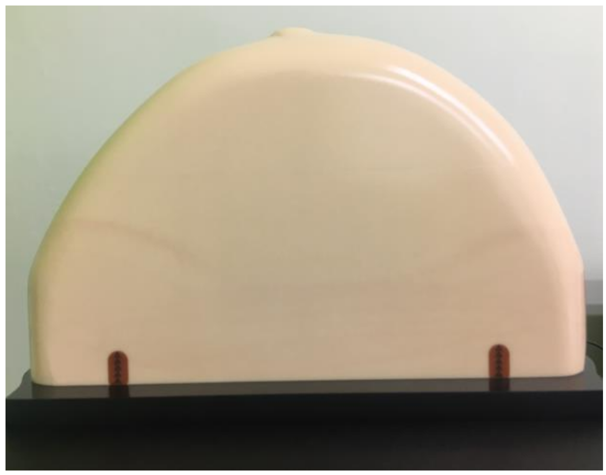

Fig 2. Photo of CIRS Model 010A, tissue equivalent mammography breast phantom.

The phantom as shown in Fig. 2 is implanted with various grain sizes of microcalcifications, adipose and glandular at specified locations. TABLE 1 shows grain size of microcalcifications composed of 30% glandular and 70% adipose (Label 2 to13). Step wedges of 1.0 cm thickness with various percentage of glandular and adipose (Label 14 to 18) are listed in TABLE 2 and the size of the hemispheric masses of 55% glandular and

45% adipose are shown in TABLE 3. Nylon fibers (Label 19 to 23) used as reinforces filler in the phantom are not the subject of interest due to its hollow shaped circle. The phantom was segmented by 1 cm by 1 cm dimension to allow the measurements.

The measurement setup consist of a circular flanged OECP (model: Agilent 85070B), a vector network analyser (VNA, model: HP8720B) and a computer. In this experiment, the OECP was connected to a VNA in order to record the frequency dependent complex scattering-parameter (S-parameter), at 72 locations. The frequency were taken in the range between 1 GHz to 4 GHz and the measurement were done at room temperature of 23°C. Since the measurement was performed with one port terminal, the transmitted and received power signals would flow at the same port. Scattering coefficient or reflection coefficient of S_{11} is a complex entity defined as the ratio of incoming and outgoing power signals measured by the VNA at the aperture plane through port 1.

TABLE 1. Grain size of calcium carbonate.

Label	Grain Size (mm)
2	0.130
3	0.165
4	0.196
5	0.230
6	0.275
7	0.400
8	0.230
9	0.196
10	0.165
11	0.230
12	0.196
13	0.165

TABLE 2. Step wedges of various glandular percentage.

Label	Glandular (%)
14	100
15	70
16	50
17	30
18	0

TABLE 3. Thickness of hemispheric masses of 55% glandular and 45% adipose.

Label	Thickness (mm)
24	4.76
25	3.16
26	2.38
27	1.98
28	1.59
29	1.19
30	0.90

Prior to the data collection, the VNA and OECP were calibrated using calibration standard. A reference liquid of known dielectric properties i.e. distilled water was chosen as calibration standard. In this procedure, the reflection coefficient measurement of reference liquid was performed. This procedure allow all the reflection coefficient measurements to be corrected by determining reference plane for the subsequent measurements. Then, the S-parameter measurements were measured by placing the probe directly on the surface of breast phantom. The measurement has been performed at 72 locations segmented on the phantom. It must be carefully done to assure no air gaps between the end of the probe and phantom.

We have calculated the relative permittivity and loss factor at the frequency of 2.4 GHz, which commonly used in biomedical microwave application [5]. Complex permittivity can be determined from S-parameter (S_{11}) using VNA software embedded package. This software can be straightforwardly extracted the dielectric constant and loss factor, respectively. Whereby, conductivity was established using (2). The obtained results have been fitted with some fitting models accordingly.

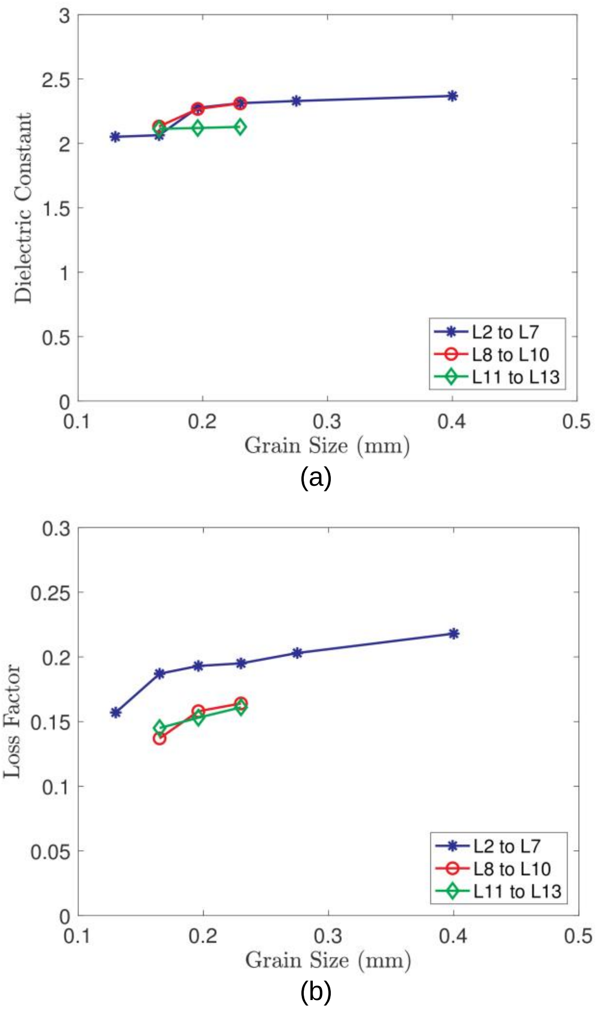

Fig. 3. *Variation of dielectric constant (a) and loss factor (b), respectively with microcalcification grain size.*

IV. Results and Discussions

Microcalcifications are fine and white specks deposit of calcium carbonate similar to grains of salt. They are too small to be felt, however can be detected through imaging. Some microcalcifications have been associated with breast cancer [18] and however the mechanism that induce the generation is still unknown [19]. Normally, breast microcalcifications are noncancerous, however, the area that has more active cells might indicate early sign of cancer.

The chosen breast phantom simulates calcifications, fibrous calcification in ducks (by the percent of glands) and tumour masses. Microcalcification in CIRS 010A contains 30% gland and 70% adipose. The grains with different sizes ranging from 0.13 mm to 0.40 mm were arranged in three groups (L2 to L7, L8 to L10 and L11 to L13). In the model, some of the grains were the same size located at different positions (groups). Basically, the dielectric constant and loss factor (thus conductivity) increase with grain size as shown in Fig. 3. The grains that were arranged near the top of the breast (L11 to L13) however has only slight increase with grain size. There are several possible explanations for this result. It might be due to low scattering effect near the top of the breast and less amount of scattered grains implanted in the area, therefore holding less volume of water content.

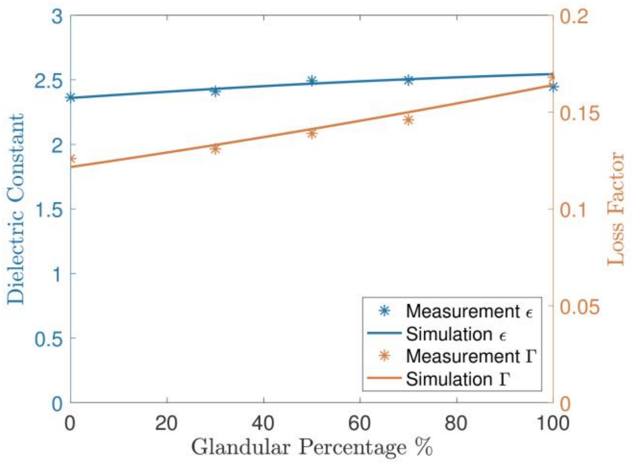

Fig. 4. *Variation of dielectric constant and loss factor with glandular percentage.*

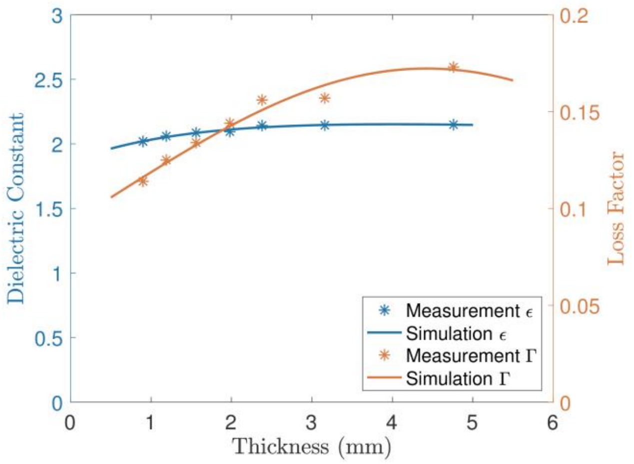

Fig. 5. *Variation of dielectric constant and loss factor with hemispheric masses thickness.*

Glandular with high percentage has been associated with denser breast and more possible fibrous calcification. Denser breast has been associated with high risk of breast cancer due to the difficulties to detect via mammogram. We have studied the 1 cm wedges influenced by different percentage ranging from 0 to 100% gland. As the percentage of glandular increases, the dielectric constant slowly increases while the loss factor shows definitive increment as shown in Fig. 4.

As for the effect of size in tumor masses in the form thickness from 0.9 mm to 4.76 mm in the hemispheric masses containing 55% gland and 45% adipose, both dielectric constant and loss factor increases with thickness, whereby the loss factor, hence conductivity have given more prominent increase. The trend indicated the loss factor increase linearly up to 2.5 mm, then followed by slow increase.

The results of this study did not show the appearance of cancer. However, the increment trends of dielectric properties in bigger size microcalcification grains and masses as well as density in more fibrous glands could possibly be an indicator to the increase of activity in the breast. The results have also shown that the technique was sensitive enough to the size as small as 1 mm and 0.130 mm for hemispheric mass and grain microcalcification, respectively.

V. Conclusion

A breast phantom Model 010A by CIRS, USA, a tissue equivalent mammography breast phantom was examined using one-port open-ended coaxial probe in the frequency range between 1 to 4 GHz. The study found that the dielectric properties increase with grain size in microcalcifications, thickness of hemispheric masses and the amount of glands. The results has been presented at frequency 2.4 GHz.

The study indicates that the relative permittivity were found in the range of 2 to 2.5 where the values were low, indicating all the imitated tissues are noncancerous. Even though the tissues were not cancerous, the technique is however capable to detect small changes in tissue's activity. Increment of activities could be a warning sign of abnormality, hence early intervention for monitoring and further testing could be planned.

The phantom was claimed to best used for mammographic simulation and might not be suitable for microwave technique. Further works are necessary such as fabrication of homogeneous and heterogeneous breast phantoms with similar component, sizes and locations to testify the reliability of the technique before applying to microwave imaging system.

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