Making and testing Breast phantom within Mono-static radar system by using Horn antenna

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Abstract: Breast cancer detection with microwave techniques had been of significant interest for the last two decades, which showed increasing theoretical and practical related research works. This necessity needed to mimic the breast tissues with a phantom. This should be nontoxic, cheap, available, and easy to make. Not only, but also it has stable dielectric properties with time able to simulate real breast. Following earlier successful works, local phantom was produced with similar contents but with the available materials. This local phantom model the different types of tissues (fat, gland, tumor, and skin). It accurately simulates the dielectric properties (conductivity, permittivity, permeability) while providing good contrast of conductivity. This phantom was tested in National Research Centre using a TEM Horn antenna, Vector Network analyzer (VNA). To verify that our phantom simulates normal and abnormal breast tissues, it was illuminated with UWB microwave pulse generated by the antenna with a frequency of 3 GHz to 10 GHz and the collected backscattered signals were analyzed and simulated using microwave imaging algorithms to identify the presence and localization of the tumors. A good relationship between permittivity and the conductivity is obtained by using the improved Debye model. MATLAB and Excel software were used in our results. We have been satisfying our results validity by comparing it with earlier scientific research paper.
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Keywords: Breast Cancer, Local Phantom, Dielectric properties, Tissues parameters, Improved Debye model.

1. Introduction

Recently a large scale study was performed to measure the dielectric properties of breast tissue, including normal and abnormal tumors [1] [2]. Here handmade phantom will be introduced which should be nontoxic, cheap, easily available, easy to make and show minimum change in dielectric properties in time. It should include heterogeneities that are similar to a real breast. One of the challenges is to find materials that can mimic different tissue properties over a wide range of frequencies and show similar dispersive behavior [1] [27]. Our phantom can be used for narrowband and Ultrawideband microwave technologies, such as breast cancer detection and imaging systems.

The phantom was tested in Cairo National Research Centre using a TEM Horn antenna which was available one in our laboratory and which gave the desired results in the frequency range from 3GHz to 10GHz, Vector Network.

Analyzer (VNA) measured the amplitude and phase of the reflection coefficient (the ratio of incoming and outgoing microwave signals in complex form).

A simple experiment has been setup by using mentioned instruments and the collected backscattered signals are analyzed and simulated using microwave imaging algorithms to identify the presence and localization of the tumors. *After this experiment we known the dielectric properties of tissues (conductivity, permittivity, permeability) [2].* The Improved Debye model was used to overcome the difference in permittivity values and to characterize the dielectric properties for four tissues [20]. MATLAB and Excel software were used to assure our practical results. Our results validity has been satisfied by comparing it with earlier scientific research paper [4]. Then we demonstrated that results in this research near to our results.

2. Material and Methods

Traditionally, phantoms that closely mimic the physical properties of various human tissues have been invaluable for the development and testing of medical imaging modalities such as ultrasound, magnetic resonance imaging (MRI), computed tomography (CT) and others(see, for example, Fong et al (2001), Madsen et al (1982a), Madsen et al (1988) and Surry et al (2004). Over the past several decades, with the rapid expansion of cellular phones and other personal devices that emit electromagnetic energy at microwave frequencies, as well as the use of electromagnetic energy for medical imaging and therapy, there has been growing interest and research on the interactions of electromagnetic waves with biological tissues, particularly at microwave frequencies. Therefore, the need for biological phantoms that mimic the electromagnetic properties of tissues at these high frequencies has greatly increased.

The following are the detailed procedures for producing an oil-in-gelatin dispersion for four tissues. Every tissue has its procedures, by using amount mentioned in table I, the steps were for:-

The glandular tissue:-

1. In a bowl, mix 0.3 gm of P-Toulic Acid (powder) *which obtained from outside of the country* with 10 ml from Proplyneghycol. Heating the mixture with stirring until the P-Toulic Acid melted completely.

2. Mixing the previous mixture with 190 ml of deionized water in Pirex pot and water at room temperature.

3. With flipping, add 34 gm from gelatin to the previous mixture at room temperature and must be wet in the mix.

4. Cover the bowl with plastic film which held in place with a rubber band and heat the mixture in a double boiler, note that water must be hot surrounding the vessel from all sides until the mixture is heated well.

5. Heat the water until the gelatin temperature rises to about 90°c and becomes transparent, remove any bubbles at the meniscus. Then remove the pot from the burner.

6. Stir the mixture well until you make sure there are no air bubbles.

7. Part of the vessel is covered in cold water at 20 - 25°c, stir the mixture until the temperature is reduced to *50°c.*

8. Remove the bowl of cold water and put 200 ml of the mixture into another bowl and this pot contains 100 ml Olive oil at 50 ° c. Flipping for a good batter with a spoon in the right direction until all the oil mixed.

9. Continue stirring and adding 56 ml of *dish washing liquid detergent* to all 1 ml of oil and the mixture must be consistent after flipping and higher proportions of Ultra Ivory and note that oil will become white color.

10. Cool the mixture to 40° c by dipping the pot partially in cold water with keeping flipping. Using the dropper to put 5 g of Formaldehyde.

11. Cool the mixture again to 34 *°C* then leaving it even hold together and keep them at least 5 days until the Formaldehyde blending with the gelatin.

12. Add 100 ml of oil at 50 ° c *with stirring the mixture until it is consistent.*

The skin, tumor and fat tissue:-

1. Mix oil and dish wash liquid detergent by the amount mentioned in table I.

2. Mix formaldehyde and P-Toluic Acid in a separate beaker and shake it to get a uniform light blue solution.

3. Heat up the water and add oil- dish wash liquid detergent while stirring the solution.

4- Add formaldehyde and P-Toluic Acid to the solution and stir continuously.

5. Add gelatin pinch by pinch and Mix to make a uniform solution.

6. Add Alizarin (any Dye type) to change the color of different parts of phantom.

7. Cover the main container of phantom material with non-stick cooking and baking paper. Make the partitions using different pipe sizes.

8. Pour the cooked materials into the container and put them in the fridge.

Final shape of the practical handmade phantom in fig.1.

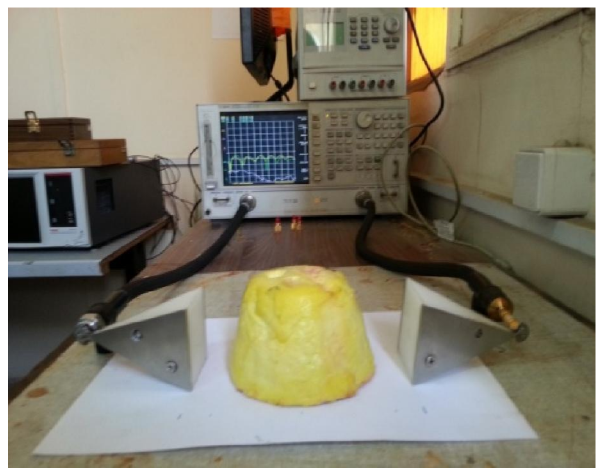


Fig 1: - experiment set up

A. Experiment method

The instruments were used in our experiment as (i) 3 GHz to 10 GHz UWB antenna are used to illuminate the target and collect the reflected signals called TEM Horn antenna. Also, there are various antennas have been proposed for tissue-sensing application [4] [5] [6] [8] [9] [10] [11] [12] [13]. The advantages of TEM horn antenna are that it operates well in the whole UWB frequency band without the need for a coupling medium, also it is placed in a solid dielectric medium, with a specific parameter (conductivity, permittivity, permeability), so that it can be used for direct measurement of the breast tissue without a cooling liquid [14], (ii) our fabricated phantom, (iii) VNA, experiment set up as the fig 1.

Table 1: material weight percentage of Fat, Skin, Tumor, Gland

	Skin	Fat	Tumor	Gland
Water	*67 ml*	*15 ml*	*75 ml*	*190 ml*
Olive oil	*17 ml*	*63 ml*	*8 ml*	*200 ml*
Dish wash liquid detergent	*1 ml*	*12 ml*	*1 ml*	*56 ml*
Formaldehyde	*0.5 g*	*0.1 g*	*0.3 g*	*5 g*
P-toluic acid	*0.1 g*	*0.02 g*	*0.1 g*	*0.3 g*
Alizarin	*0.1 ml*	*0*	*0.1 ml*	*0*
Propylene glycol	*0*	*0*	*0*	*10 ml*
Gelatin	*12g*	*10g*	*14g*	34

As in a typical active microwave imaging scenario, microwave power is radiated via an antenna and the scattered power is picked by one or more antennas. The scattered signals are then analyzed to detect and evaluate significant scatters (targets). Microwave detection of breast tumors is based on the significant contrast in the dielectric properties, which is estimated to be greater than 1:2 between normal and abnormal tissue. The sequence of the experiment operation as the fig 2, first we measured the dielectric properties of the phantom materials using a coaxial probe described in Popovicet al (2005) in conjunction with VNA. The probe-VNA system was calibrated at the connecting plane of the probe, to set the offset signal to be equal or nearly equal zero or on the other meaning be matched with the point of origin of axes to reach as possible as the smallest value of error [16].

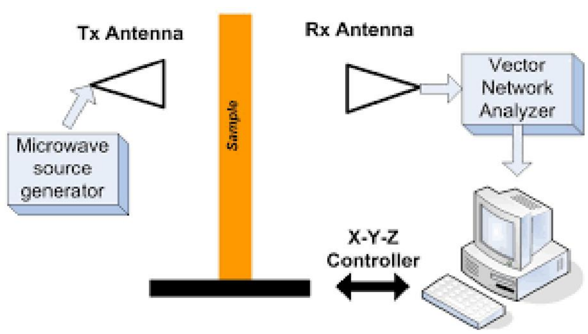


Fig 2: - Experiment operation

The measurements were performed at room temperature (approximately 22 ° C). We placed the tip of the probe on the flat bare surface of the phantom sample, taking care not to puncture the surface or compress the gel excessively. The distance between two antennas (transmitter, receiver) was 16 cm, phantom at in the center of this distance. Measurements were taken at all ranges of frequency 3GHz to 10GHz. The probe was held stationary against each sample for about 15–30 min before recording each measurement. The samples were kept sealed in the glass jars between measurement periods.

3. Results

Figure 3 shows the signal paths (S_{11}, S_{22}, S_{21}, S_{12}) between transmitter and receiver, During the experiment the reference's path between two antennas as in fig 4.

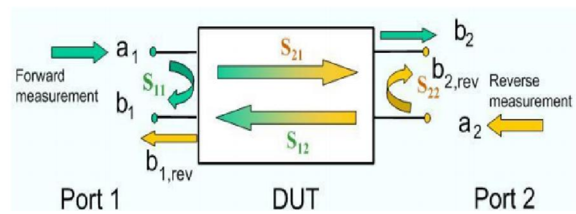


Fig 3: - Signals path S_{11}, S_{22}, S_{21}, S_{12}

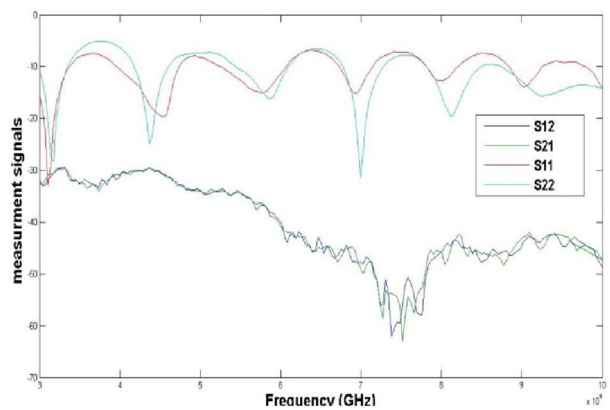


Fig 4: - The measurement signals S_{11}, S_{22}, S_{21}, S_{12} with a vector network analyzer.

Where four different scattering parameters of two-port system are described as (2) (3),

$$s_{11} = \frac{b_1}{a_1} | a_2 = 0 \ \& \ s_{21} = \frac{b_2}{a_1} | a_2 = 0 \rightarrow \qquad (2)$$

$$s_{12} = \frac{b_1}{a_2} | a_1 = 0 \ \& \ s_{22} = \frac{b_2}{a_2} | a_1 = 0 \rightarrow \qquad (3)$$

The abbreviation of S-parameters are s_{11} denotes the forward reflection in which the signal is propagated from port 1 and reflected back to port 1, s_{21} denotes the forward transmission in which the signal is propagated from port 1 and reflected back to port 2, s_{12} denotes reverse transmission in which the signal is propagated from port 2 and reflected back to port 1, s_{22} denotes reverse transmission in which the signal is propagated from port 2 and reflected back to port 2 [17].

So after our experiment, curves which describe dielectric properties of breast tissues are obtained. In fig 4, we noted that the average permittivity values of normal tissue had constantly changed over a frequency range and there wasn't a linear relationship between permittivity and frequency, which caused a problem, As this problem didn't let us to determine the correct dielectric properties of normal and abnormal breast tissues. This problem was solved by suitable mathematic model (improved Debye model).

B. Dielectric properties of breast tissues

Each tissue type has their respective dielectric properties which are used by the biomedical engineers to make the artificial models or phantoms. Hence phantoms must be developed with correct dielectric properties [22-24]. From earlier scientific research [19], we found that there are two theoretical models (cole-cole model and Debye model) with a gap between analytical and practical values [25-27]. So Improved Debye model and a polynomial fitting approach were used to mend this gap.

$$\varepsilon^* = \varepsilon_\infty + \frac{(\varepsilon_s-\varepsilon_\infty)}{1+(\omega\tau)^\wedge 2} - j\left[\frac{(\varepsilon_s-\varepsilon_\infty)\omega\tau}{1+(\omega\tau)^2} + \frac{\sigma_s}{\omega\varepsilon_0}\right] \qquad (4)$$

Where ε_0= 8. 854 x10^{-12} (F/m) is the free space Permittivity, $\boldsymbol{\varepsilon_\infty}$, $\boldsymbol{\varepsilon_s}$, $\boldsymbol{\sigma_s}$, and $\boldsymbol{\tau_0}$ are, respectively, the relative permittivity at infinite and zero frequencies, the conductivity at zero frequency and the relaxation time constant.

We used Debye parameters set of the human breast tissues from (4) for skin, fat, glands and tumor at 6 GHz UWB center frequency to calculate their respective absolute permittivity values see figure (5). These values are shown in Table 2 with associated parameters accordingly.

Table 2:- Debye Parameters at 6GHz UWB Centre Frequency

Medium	**Debye Parameter Values**				AbsolutePermittivity
	$_\infty\varepsilon$	$_s\varepsilon$	$_s\sigma$	(ps)τ	ε
Gland	5	35	0. 5	7	35
Tumor	4	55	0.8	7.	53
Fat	7	17	0.2	7	16
Skin	4	37	1	7.5	37

Table 3: Porter Parameters at 6 GHz UWB Centre Frequency

Medium	**Absolute Permittivity**
	E
Skin	34
Tumor	50.5
Fat	14
Gland	33.5

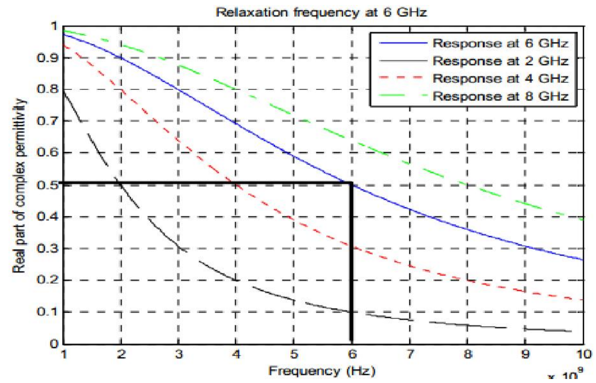


Fig 5: - Absolute permittivity

From Table 2 and 3 note the gap between them, so we need to determine the statistical correlation between the permittivity results to mend this gap.

Correlation coefficients have been found by Pearson correlation (5) using MATLAB or Excel Pearson correlation coefficient, Γ_{xy} between two sets of data x and y.

Here we used just one frequency value 6 GHz (the center of frequency range) to satisfy (5).

$$\Gamma_{xy} = \frac{\mathrm{cov}(x,y)}{\sigma_x\sigma_y} \qquad (5)$$

Where, Cov (x, y) is the covariance of x and y, σx is the standard deviation in x, σ_y is the standard deviation in my. Equation (5) can be equally used to calculate correlation coefficient between similar sets of data, i.e. between x and x, Γ_{xx} or you and you, Γ_{yy}.

The correlation test result in terms of matrix is shown in (6).

$$\boldsymbol{\Gamma} = \begin{bmatrix} \boldsymbol{\Gamma_{xx}} & \boldsymbol{\Gamma_{xy}} \\ \boldsymbol{\Gamma_{yx}} & \boldsymbol{\Gamma_{yy}} \end{bmatrix} \qquad \textbf{(6)}$$

We fit these data sets and evaluate the polynomial equation of the regression curve using polyfit commands in Matlab shown in (7).

$$\boldsymbol{p(x) = 0.9978x - 2.06\ 87} \qquad \textbf{(7)}$$

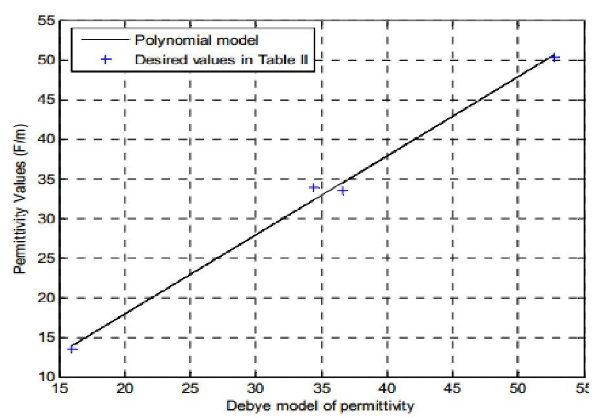


Fig 6: - Polynomial fit to provide an approximation of the Debye data

Where *p(x)* is the proposed permittivity value (the new realistic one), *x* is the Debye model value in Table I.

The regression curve of (7) is shown in Fig (6).

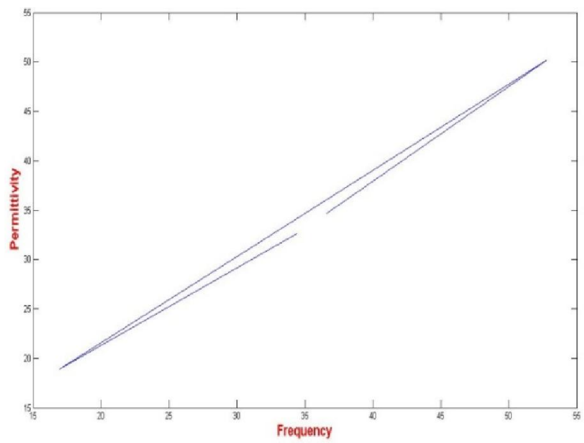


Fig 7: - Simulated Polynomial fit to provide an approximation of the Debye data

Note here that this new polynomial fitting model efficiently reduces the gap by reducing the relative error approximately 5.9%.

Also, from Excel and MATLAB programs, we obtained a simulation of the relationship between the frequency, conductivity and permittivity for the parameters in table 2 and table 3 as shown in fig (7).

C. Phantom results evaluation

To evaluate our phantom results we compared it with earlier scientific research paper [4]. The results of earlier scientific research paper as the following:-

The parameters used in this paper are given in Table (4), the tumor permittivity is about 10% higher than glandular tissue.

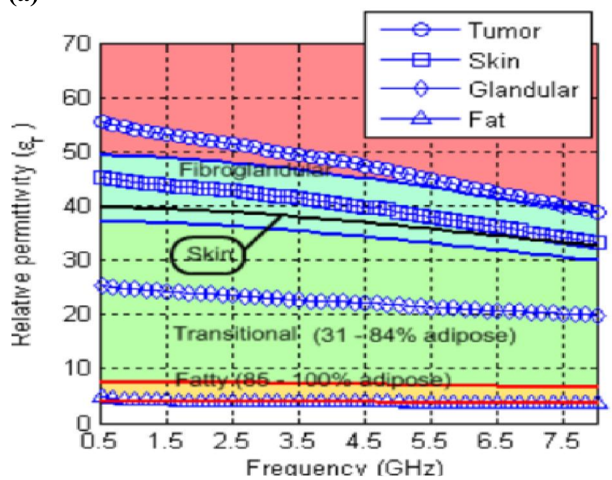
Table 4. Debye parameters

	ε_∞	ε_s	σ_s	τ_0
Skin	16	40	0.9	13
Gland	14	50	0.7	13
Transitional	13	37	0.5	13
Fat upper	4	7.5	0.1	13
Fat lower	3	4	0.01	13

The measured dielectric properties of assembled phantom vs. the Debye estimate of dielectric properties of real breast tissue are depicted in Fig 7.

As is shown in Fig 7, the permittivity of the phantom follows the permittivity of the real breast tissues. While there is a good contrast between the conductivities of the various phantoms materials [28-31]. The measured conductivity has a different frequency response and is significantly higher than real breast tissues. Before we used the results of this paper, we proved that it is true enough to be used by using MATLAB program and Excel to simulate the results in the paper. See the figures:

(a)



(b)

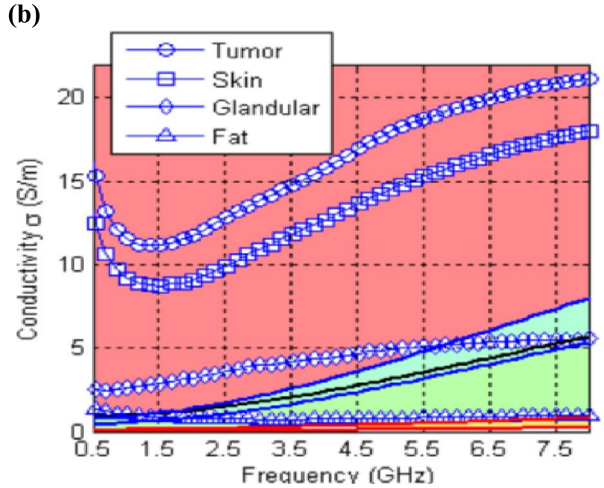
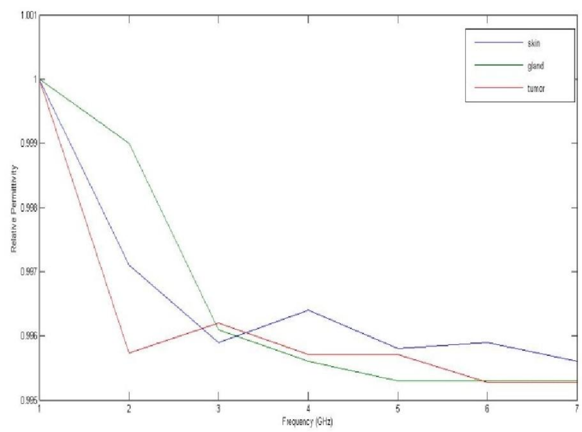
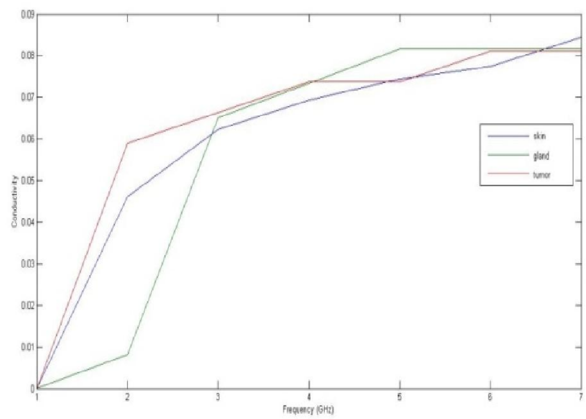


Fig 7:- (a) Relative permittivity of phantom materials (b) Conductivity.

From fig 8, the results from practical experiment in [4] and fig 5, the results from simulation with MATLAB program, it is clear that the practical results near to the simulated one.



(a)



(b)

Fig (8): - show simulated results of (a) relative permittivity (b) conductivity.

4. Discussions

Local handmade breast phantom was fabricated for four tissues, skin, gland, tumor and fat. It was illuminating with UWB microwave pulse generated by a TEM Horn antenna with a frequency of 3GHz -10GHz. Using the improved Debye model to know the dielectric properties of breast tissues permittivity and conductivity to determine malignant and normal tumor. Finally, Our results validity has been satisfied by comparing it with earlier scientific research paper.

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