33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Evaluation of EM Absorption Loss over Breast Mass for Breast Cancer Diagnosis

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***Abstract*— This paper presents electromagnetic (EM) absorption loss over breast mass as a new approach in the detection of breast cancer tumors. A linear curve of absorption loss over breast mass is used to establish acceptable normal absorption loss values. Since tumor-infected breast tissues should have higher absorption loss than normal breast tissues, the measured absorption loss of a tumor-infected breast will be higher than the established normal absorption loss value, and the breast will be diagnosed as infected. EM simulations of normal and infected breast tissues are run at 915, 2450, and 4000 MHz. Results show that 915 MHz presents the best linear curve fit and resolution. Also, the absorption loss for an infected breast, at 915 MHz, is higher than the absorption loss for a normal breast and is least affected by tumor location.**

I. Introduction

BREAST cancer is the second most common cancer among American women, and it infects 1 in 8 women in the United States [1]. Early detection of breast cancer has been an area of active research in past years. Electromagnetic (EM) microwave detection and imaging research has surfaced in past years in hopes of replacing or complementing X-ray mammography and MRI scans, which have some risks and shortcomings. X-rays present the risk of exposure to ionizing radiation. MRI scans are cost prohibitive and have a relatively high false alarm rate [2].

EM microwave imaging area of research is mainly concerned with the reconstruction of an image of a tumor within the breast, whereas microwave detection is mainly concerned with determining if the breast is infected with tumor or not. Both areas of research exploit the difference in dielectric properties of normal and cancerous breast tissues which have different EM signatures. Techniques used for detection are autoregressive (AR) spectral estimation technique [3] and artificial neural networks (ANN) technique [4]. Techniques used for imaging are microwave imaging via space-time (MIST) beamforming [5] and Tissue Sensing Adaptive Radar (TSAR) [6].

This paper presents a novel approach in the detection and diagnosis of breast cancer. First, the amount of EM power absorbed (absorption loss) by normal breasts of different sizes (masses) is determined. This establishes a linear curve by which the normal absorption loss value of any breast mass can be determined using the line equation y=mx+b. Acceptable ranges could be established as an offset around the linear curve for normal absorption loss. For a patient, if the measured absorption loss value falls outside an acceptable range of normal absorption loss values for her breast mass, then the breast is diagnosed as infected. Since breast mass density is different for older women [7], there should also be linear curves for each age group.

Manuscript received April 15, 2011, accepted June 9, 2011.
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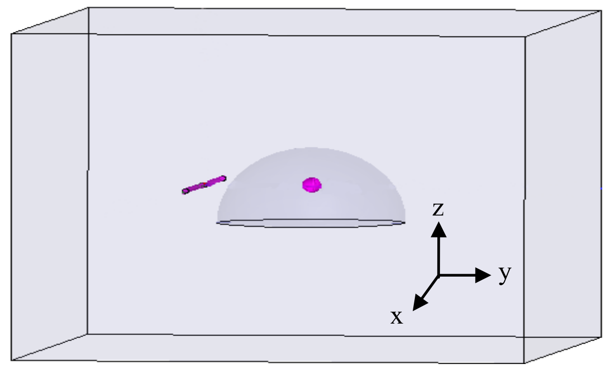

Fig. 1. Ansoft HFSS 3-D simulation model.

In the next section, EM simulation data is presented to determine the frequency which shows the best linear curve with the widest range of absorption loss data thus providing better resolution. Also, simulation data is presented to determine the frequency which has the least varying absorption loss with a varying tumor location.

II. Model And Simulation

The Ansoft HFSS EM simulation package is used to simulate the EM model illustrated in Fig. 1. HFSS utilizes the Finite Element Method (FEM) which uses conformal meshing to solve Maxwell's equations for lossy dielectric objects of arbitrary shapes like human organs [8]. Also, HFSS produces accurate results in comparison to the popular Finite Difference Time Domain (FDTD) method [8].

The EM model consists of a hemispherical breast phantom with variable radii of 50, 55, 60, 65, and 70 mm. The breast model has been simulated with 3 different frequencies (915 MHz, 2450 MHz, and 4000 MHz) to study the effect of frequency on the absorption loss and find the frequency which presents the best linear curve. The frequencies 915 MHz and 2450 MHz are part of the Industrial, Scientific, and Medical (ISM) band. The frequency 915 MHz also happens to be an ideal frequency for breast cancer thermotherapy [9]. A spherical tumor with 5 mm radius is simulated at 5 different locations within the 50 mm radius breast model to study the effect of tumor

TABLE I
DIELECTRIC PROPERTIES OF BREAST FAT AND TUMOR TISSUES AT DIFFERENT FREQUENCIES [10]

Frequency (MHz)	Conductivity, σ (S/m)		Relative Permittivity, ε_r		Loss Tangent		Penetration Depth (m)	
	Breast Fat	Tumor (muscle)	Breast Fat	Tumor (muscle)	Breast Fat	Tumor (muscle)	Breast Fat	Tumor (muscle)
915	0.049523	0.94809	5.4219	54.997	0.17944	0.33866	0.14015	0.043577
2450	0.13704	1.7388	5.1467	52.729	0.19535	0.24194	0.053684	0.016731
4000	0.26229	3.0155	4.8393	50.821	0.24357	0.26665	0.033823	0.010423

location on the absorption loss and to find the frequency which is least affected by tumor location.

The simulated breast model is homogeneous and consists of breast fat tissue. Breast skin was ignored in this preliminary model to avoid its effect and to decrease the complexity of the model and hence the simulation computation time. Additionally, in [11], it is demonstrated that skin introduces only 3% error in the backscatter direction versus 30% error in the forward scatter direction. This simulation uses only one half-dipole antenna which is excited by an impedance matched lumped port source with 2W input power. According to [12], the maximum isotropically radiated power that is allowed to be sent through the human body varies between 1W for 915MHz and 4W for 2450 MHz. For easier comparison of absorption loss data between the 3 different frequencies, one input power (2W) was used. The antenna is located 5 mm away from breast to allow for good wave penetration through the breast model. This agrees with a similar breast model presented in [13].

Benign and cancerous tumors have similar dielectric properties as muscle [9]; hence we used muscle tissue to simulate a breast tumor in this study. The dielectric properties of breast fat and tumor are presented in Table I. The masses of breast only model and breast+tumor model were calculated using known volumes of hemispherical breast and spherical tumor, and their densities. The breast fat density is 928 kg/m^3, and tumor density is 1041 kg/m^3 [9].

Specific Absorption Rate (SAR) represents the rate of energy absorbed by an object and has units of W/kg. SAR is expressed by [14] as:

$$SAR = \frac{\sigma}{\rho} |E|^2 \tag{1}$$

where σ is the conductivity of dielectric, ρ is the mass density of dielectric, and E is the electric field.

The skin depth or penetration depth is defined as the distance into the object at which the electromagnetic fields attenuate to 1/e of their values. It has units of meter and is expressed by [14] as:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \tag{2}$$

where ω is the radian frequency, μ is the permeability of dielectric, and σ is the conductivity of dielectric.

The absorption loss in breast and tumor tissues is derived from the volume loss density calculation expressed by [15] as:

$$p_V = \frac{1}{2} \Re\left(E \cdot \tilde{J} \; - \; curl\, E \cdot \tilde{H} \right) \tag{3}$$

where E is the electric field, J is the conjugate of the volumetric current density and H is the conjugate of the magnetic field. It has units of watts (W).

Antenna radiation loss is given by equation (4), in which $P_{accepted}$ is power accepted by antenna after return loss and $P_{radiated}$ is power radiated by antenna. It has units of watts (W).

$$Antenna\ Radiation\ Loss = P_{accepted} - P_{radiated} \tag{4}$$

III. RESULTS AND DISCUSSION

Table II summarizes the volume loss density and antenna radiation loss data for 5 different breast masses at the 3 different frequencies. First, it is observed that the calculated volume loss density data, which corresponds to the absorption loss in breast tissue, correlates well with the antenna radiation loss data. This indicates that the majority of non-radiated power was absorbed by the breast tissue. Accepted and radiated powers are measurable values. This allows for the use of absorption loss over breast mass as a method for breast cancer diagnosis.

The linear fit of volume loss density data in Table II for the 3 different frequencies are presented in Fig. 2, 3, and 4. The coefficient of determination (r^2), which provides a statistical measure of how well a regression line approximates data points, is calculated and presented on Fig. 2, 3, and 4. An r^2 value closer to 1 means the data has a good linear fit. From the figures, it is observed that the absorption loss data at 915 MHz has a better linear fit (0.9972) than at the other frequencies. Although the absorption loss data at 4000 MHz has just as good a linear fit (0.9970) as at 915 MHz, it is observed from Table II that 915 MHz has better data range than 4000 MHz. Data range is calculated by subtracting the smallest value of volume loss density from the largest value of volume loss density in Table II. The wider the data range the better the resolution of the system to

TABLE II
BREAST VOLUME LOSS DENSITY AND ANTENNA RADIATION LOSS FOR DIFFERENT BREAST MASSES AND FREQUENCIES

Breast Mass (kg) / Breast Radius (mm)	Frequency = 915 MHz		Frequency = 2450 MHz		Frequency = 4000 MHz	
	Breast Volume Loss Density (W)	Antenna Radiation Loss (W)	Breast Volume Loss Density (W)	Antenna Radiation Loss (W)	Breast Volume Loss Density (W)	Antenna Radiation Loss (W)
0.24295 / 50	0.23412	0.1999	0.84785	0.8300	0.73240	0.7165
0.32337 / 55	0.32884	0.2949	0.86221	0.8361	0.71960	0.6983
0.41982 / 60	0.44391	0.4126	0.87814	0.8586	0.70341	0.6840
0.53376 / 65	0.57061	0.5427	0.87491	0.8542	0.68792	0.6692
0.66665 / 70	0.69397	0.6831	0.87528	0.8543	0.67052	0.6553
Range	0.45985	0.4832	0.03029	0.0286	0.06188	0.06120

TABLE III
TOTAL VOLUME LOSS DENSITY AND ANTENNA RADIATION LOSS FOR DIFFERENT TUMOR LOCATIONS WITH SAME BREAST+TUMOR MASS (0.24301KG)

Tumor Location	Frequency = 915 MHz		Frequency = 2450 MHz		Frequency = 4000 MHz	
	Total Volume Loss Density (W)	Antenna Radiation Loss (W)	Total Volume Loss Density (W)	Antenna Radiation Loss (W)	Total Volume Loss Density (W)	Antenna Radiation Loss (W)
Leftmost	0.23789	0.2028	0.85999	0.8452	0.67856	0.6590
Center	0.23635	0.2027	0.84546	0.8317	0.73281	0.7195
Rightmost	0.23506	0.2084	0.84963	0.8329	0.73243	0.7143
Center Top	0.23430	0.2026	0.84968	0.8340	0.73211	0.7160
Center Bottom	0.23632	0.2058	0.84310	0.8296	0.73126	0.7186
Std. Deviation	0.00137	0.00258	0.00646	0.00610	0.02397	0.02606

detect breast tumors for various breast sizes. The volume loss density data at 915 MHz (0.45985) has 7.5 times better resolution than at 4000 MHz (0.06188). This nominates 915 MHz as the frequency of choice for establishing the linear curve of known normal breast mass values and their measured absorption loss.

Table III summarizes the total volume loss density, which is the sum of the breast and tumor volume loss densities, and antenna radiation loss data for 5 different tumor locations at the 3 different frequencies. First, we note that all the values for the total volume loss density at 915 MHz are larger than the volume loss density value of breast without tumor (0.23412) at 915 MHz in Table II. This indicates more absorption loss was present for a breast with tumor. The same cannot be said about the other two frequencies as the volume loss density data for 2450 MHz and 4000 MHz in Table III have larger and smaller values than the volume loss density value of breast without tumor in Table II. Therefore, the absorption loss of an infected breast is better detected at 915 MHz. Also, we note that the volume loss density data for the 5 different tumor locations at 915 MHz has the smallest variation compared to the data for the other two frequencies. The standard deviation of the volume loss density data at 915 MHz is the lowest compared to the standard deviation of the volume loss density data at the other two frequencies. This indicates that, at 915 MHz, the absorption loss is not significantly affected by the different tumor locations as much as with the other two frequencies. This is easily explained when noting that the penetration depth, presented in Table I, at 915 MHz is much higher than the other two frequencies. Also, in Table I, we observe that, at 915 MHz, the loss tangent for tumor is relatively higher (0.33866) than the loss tangent at the other two frequencies. The combination of better penetration depth and better lossy behavior of tumors at 915 MHz leads to better absorption by tumors regardless of their location within the breast.

In Table II, we observe that the volume loss density data at 915 MHz is significantly lower than at 4000 MHz. This is due to the fact that conductivity of breast and tumor tissues increases with frequency as seen in Table I. According to equation (1), SAR is proportional to conductivity; therefore SAR will increase as frequency increases.

In Fig. 2, we observe that, at 915 MHz, volume loss density increases as breast mass increases, whereas, in Fig. 4, at 4000 MHz volume loss density decreases as breast mass increases. This is in accordance with equation (2) which states that penetration depth is inversely proportional to $\omega\sigma$. As $\omega\sigma$ increases with frequency, penetration depth will decrease. As the breast mass increases, larger frequencies will penetrate less into the tissue and hence less power is absorbed.

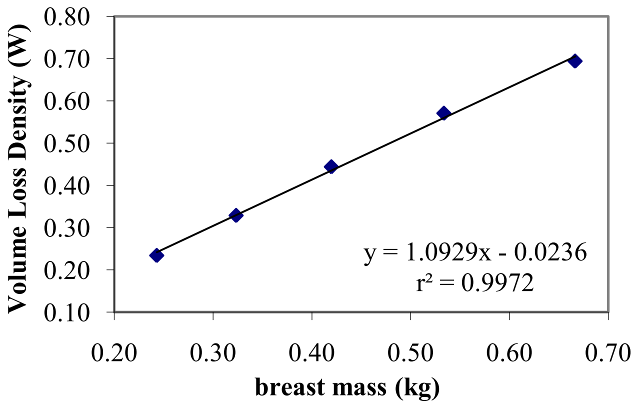

Fig. 2. Linear fit of volume loss density data for different breast sizes at solution frequency 915 MHz.

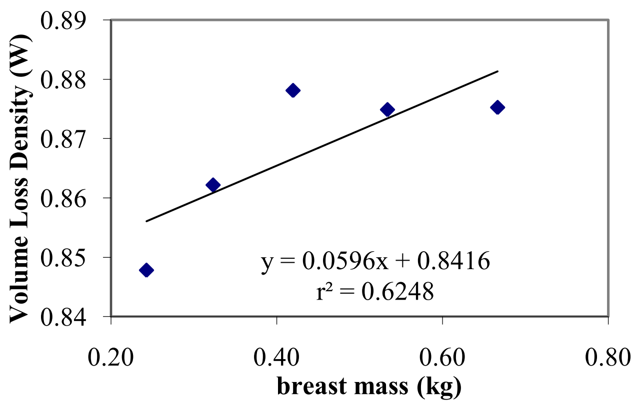

Fig. 3. Linear fit of volume loss density data for different breast sizes at solution frequency 2450 MHz.

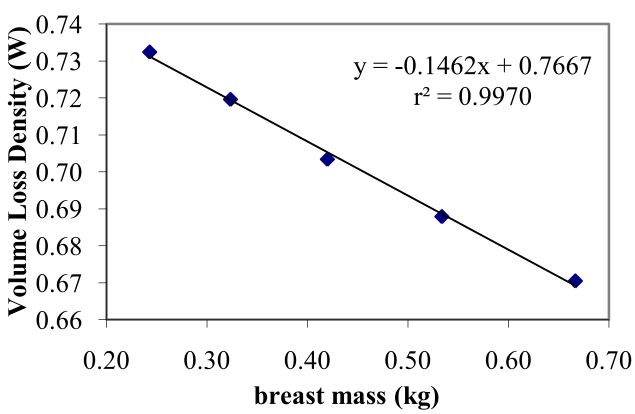

Fig. 4. Linear fit of volume loss density data for different breast sizes at solution frequency 4000 MHz.

IV. CONCLUSION

Above simulation data clearly show that the ISM frequency, 915 MHz, has the best linear curve fit and resolution. Also, the absorption loss for a tumor-infected breast at 915 MHz is higher than the absorption loss for a normal breast and is the least affected by tumor location.

Other EM microwave imaging and detection methods have to outweigh the benefits of higher frequencies for better detection of small tumors and lower frequencies for deeper tissue penetration. The proposed approach in this paper is unaffected by this issue since it relies on tumors having higher absorption loss than normal breast tissue and thus will be detectable if they fall outside the established acceptable absorption loss range by the linear curve.

Further experiments are needed to determine the acceptable absorption loss range as an offset around the linear curve accounting for possible errors due to other radiation losses. Also, future experiments will focus on improving the resolution of the system and its independence of tumor location.

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