Breast Skin Effect on Scattered Electromagnetic Fields

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Abstract: The effect of various breast skin thicknesses on electromagnetic scattering is explored in this work using the Ansoft High Frequency Structure Simulator (HFSS) package. A coated sphere model is used initially to provide an estimate of the skin effect and is validated using the Mie Theory. A more realistic inhomogeneous breast model is developed based on a magnetic resonance imaging (MRI) scan. This model contains four regions; air, skin, fatty tissue and fibro-glandular tissue. The results of this work indicate that ignoring the skin thickness when receiving in the backscatter direction introduces an error of only 3% compared with ~30% when receiving in the forward direction.

Keywords: Breast cancer detection, Breast skin and Electromagnetic modeling.

1. Introduction

The effect of breast skin on the electromagnetic scattering in the microwave region is of great interest to breast cancer researchers. Microwave imaging techniques can benefit from considerable reductions in computational time when the skin thickness is ignored [1]. Ignoring the skin, however, introduces some level of error into the final result and it is important to quantify this error. A coated sphere is used in previous work to model the breast and skin thickness using the Mie Theory to calculate the scattered fields with an incident plane wave [2]. The theory of electromagnetic scattering by coated sphere was reported Kirker *et al.* [3], [4]. The work in [2] showed that the error can be as low as 3% when receiving in the backscatter direction [2]. The motivation of this work is to confirm these results using a realistic inhomogeneous breast model.

A detailed study of the skin thickness for each region was conducted by Lee *et al.*[5]. The thickness of the skin is not constant at all locations on the breast as reported in [5]. The skin on the outside of the breast, closest to the arm, tends to be the thinnest, with the underside of the breast having the thickest skin layer. Using the nominal ranges of skin thicknesses, 0.5mm-2.7mm, a realistic error analysis will be conducted in this paper.

The process of modeling the breast electromagnetically has been approached from a variety of angles [2], [6], wherein the skin is treated differently or ignored [1]. The focus of this work is to identify the effect that the skin plays in electromagnetic scattering and examine its effect on the signature of the tumor. If the effect of the skin can be ignored, then simplified models can be justified for microwave imaging.

Studies have been conducted on the electrical properties of various regions of the breast. Current research reported new values for the interior makeup of the breast and tumors based on obtained tissue samples in vitro [7]. From the reported data, formulas for the frequency dependent dielectric properties of the breast regions can be obtained. Initial models investigated in this work use the previously reported electrical values of [2] and later models integrate the results of the current research of [7]. The frequency dependence of the electrical properties of the breast tissue is given by [7]:

$$\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0} = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau} - j\frac{\sigma_s}{\omega\varepsilon_0} \quad (1)$$

where the Debye parameters are $\varepsilon_s = 10$, $\varepsilon_\infty = 7$, σ_s(S/m) = 0.15 and τ(ps) = 6.4 for normal breast tissue. For the skin, the real part of dielectric constant ε_r = 36 and the conductivity σ = 4 S/m at 6GHz [7]. The frequency dependence could be incorporated as:

$$\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0} = 36 - j\frac{4}{\omega\varepsilon_0} \ . \quad (2)$$

The thickness of the skin is dependent on a variety of factors; the age, breast size, menopausal and hormonal status can all affect the thickness of each region of the breast [8]. These conditions change over time and thus studying the effect of a variety of skin thicknesses is beneficial. For this work a range between 0-2.5mm is explored. A detailed study of this skin thickness can be found in [5] and [8] with the information outlined in Table 1.

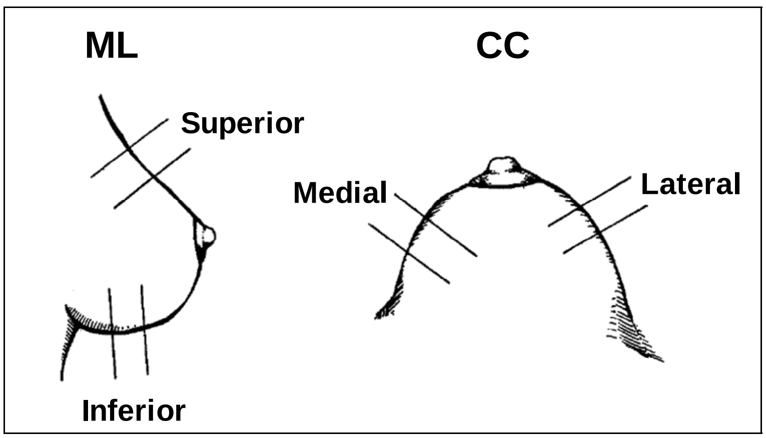

Fig.1. Regions of breast skin [5].

Table 1: Skin thicknesses for each breast region [5].

	ML		CC	
	Superior	Inferior	Medial	Lateral
Normal Thickness (mm)	1.5	1.7	1.5	1.3
Range (mm)	0.75-2.3	0.7-2.7	0.6-2.4	0.5-2.1
Standard Deviation (mm)	0.25	0.32	0.31	0.26

2. Methodology

The Ansoft High Frequency Structure Simulator (HFSS) is used to simulate the scattering of waves from three different models. The HFSS uses a Finite Element Solver and is able to approximate irregular geometries. An MRI scan of a patient's breast is used as the basis for the creation of a realistic breast model as shown in Fig. 2 [9]. This model allows the complex shape and interior structure of the breast to be taken into account. In this model the skin layer can be controlled for each side of the breast which allows for the various skin thicknesses shown in Table 1 and discussed in [5].

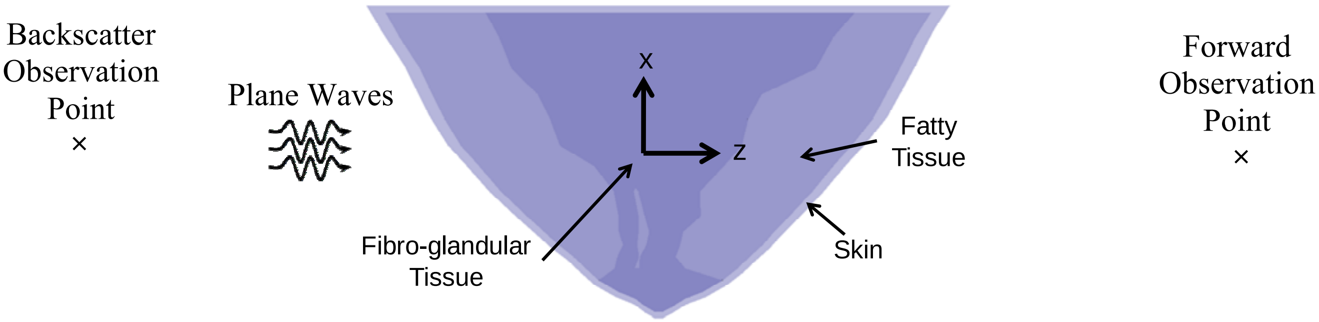

Fig. 2. Realistic breast model with interior fibro-glandular tissue.

Figure 2 shows a four region model representing air, skin, fatty tissue, and interior fibro-glandular structure. The electrical properties for the skin and fatty tissue are obtained from the previous models [2], while the fibro-glandular region is described by equation 2 with ε_∞=5.573, $\Delta\varepsilon$=34.57, τ(ps)=9.149, α=0.095 and σ_s(S/m)=0.524 [7].

An x-polarized plane wave excitation travelling in the z-direction is used here although realistic antenna sources can be incorporated as well [6]. An observation point 20cm measured from the origin is chosen to allow for the far field calculations. The frequency is swept from 3GHz to 18GHz in this work.

3. Numerical Results

Prior to using the realistic model shown in Fig. 2, validations are conducted with two simple breast models. A simplified planar model and a coated sphere are used for validation [2]. This step is important to validate the HFSS results. The planar three-region model with an incident plane wave is shown in Fig. 3a. Region 1 models the air, region 2 represents the skin and region 3 is the interior breast tissue. Calculating the reflection coefficient, $\boldsymbol{\Gamma}$, for various thicknesses of region 2 in the frequency range of 3-18GHz gives an initial impression of the effect of the skin. The reflection coefficient is plotted for skin thicknesses ranging from 0 to 2mm as shown in Fig. 3b.

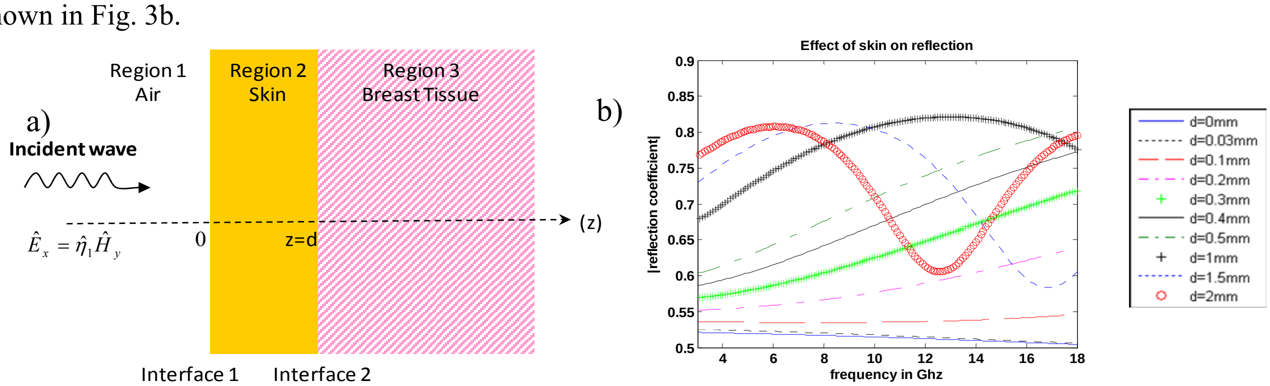

Fig. 3. a) A planar structure b) HFSS calculated reflection coefficient.

The results of Fig. 3b show that the reflection, **Γ,** increases with the increase in thickness due to the high conductivity of the skin layer. The results show that at 6 GHz, the difference between the reflection coefficients for the case of no skin and that of a thickness of 2mm is ~30%. Also the **Γ** plots for each thickness show resonance behavior depending on the skin thickness. This shows very good agreement with the results of the Mie Solution presented in [2]. Thus this simple model gives us an idea of how the presence of skin layer may affect the scattered field.

A coated sphere is used as the second validation. A sphere with a shell of skin is shown in Fig. 4 where, region I represents air, region II represents skin layer and region III represents healthy tissue. The difference between *a* and *b* gives the thickness of the skin. [2]. Utilizing this model allows for rapid calculations and exact answers due to the closed Mie Solution forms.

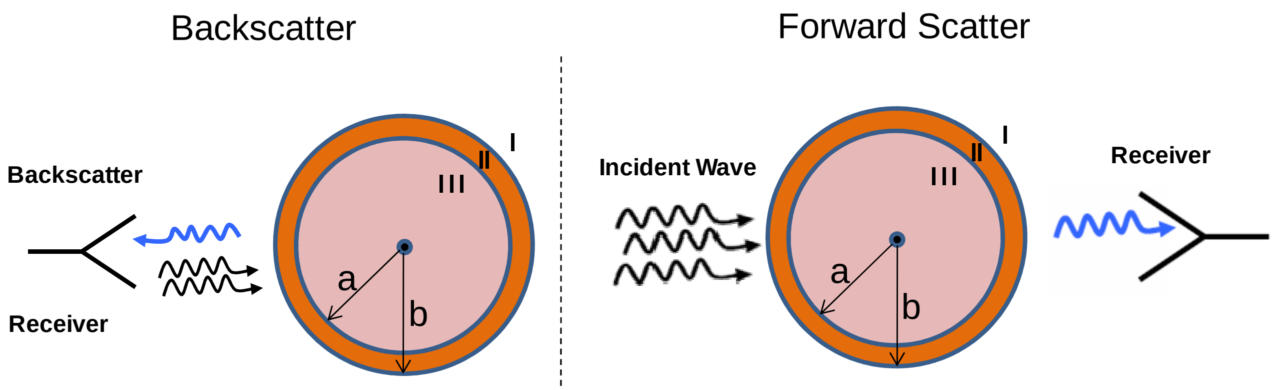

Fig. 4. Model of the coated sphere.

The scattered fields are calculated using the HFSS at every 10° around the sphere. Of particular interest are the results when receiving the backscattered fields (θ=0°) and the forward scattered fields (θ=180°). These results are shown in Fig. 5. These results are in good agreement with Mie Solution results presented in [2].

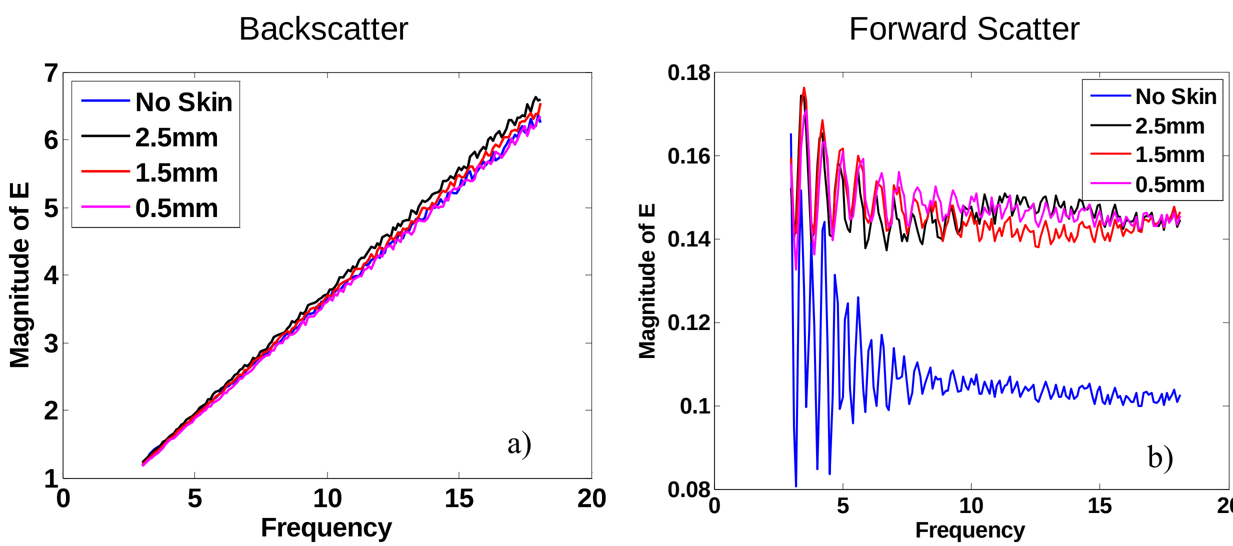

Fig. 5. Magnitude of the scattered fields at 20cm from the origin for a) the backward and b) forward directions.

The magnitude of the backscattered fields is almost the same for all the different skin thicknesses as shown in Fig. 5a. The results show an error of ~30% when receiving in the forward scatter direction while only a ~3% is observed error when receiving in the backscatter direction.

After these validations were completed, the realistic breast model shown in Fig. 2 is used. The incident plane wave remained the same as well as the observation points. The magnitude of the scattered fields is calculated and is shown in Fig. 6.

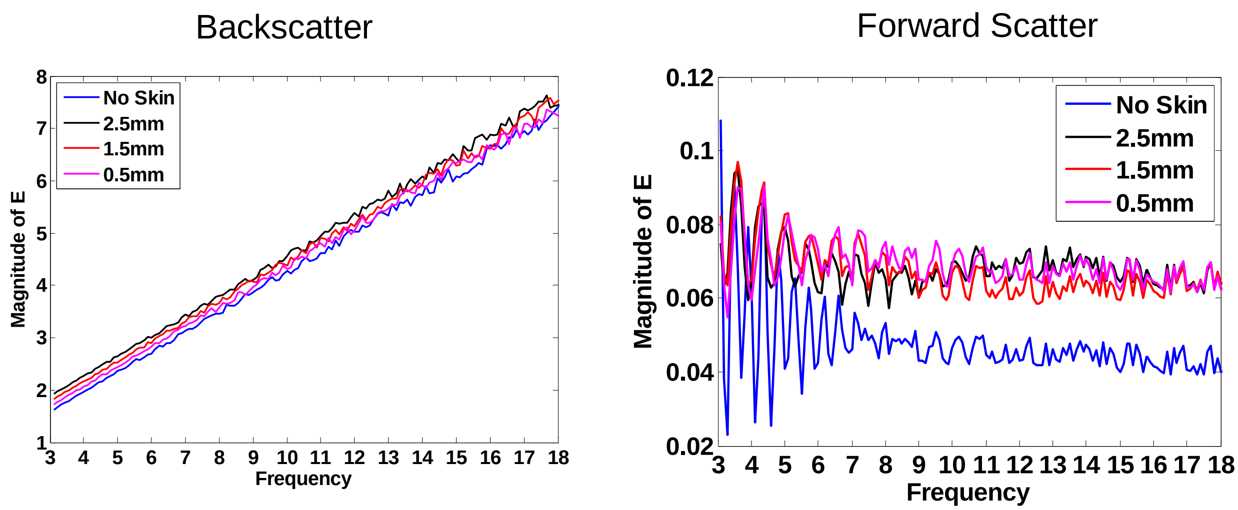

Fig. 6. Magnitude of the scattered fields for the backward and forward directions for realistic breast model.

The results of Fig. 6 are similar to those presented for the coated sphere model in Fig. 5. The difference between the no skin case and 2.5mm of skin is larger in this model, on the order of 10%, however, the typical skin thickness is around 1.5mm which introduces ~3% error. At higher frequencies the plots show oscillations that could be due to meshing accuracy.

The above work will be extended to using realistic antennas. The scattered fields in the near field will be examined to determine the effect of the skin on the tumor signature. An analysis of the tumor signature in relation to the error caused by ignoring the skin layer is currently in progress. Although the percentage difference in the magnitude of the scattered electric field is small in the backscatter direction, the signature of the tumor itself could be on the same order or smaller depending on its size. If this is the case then ignoring the skin layer may have a large effect on tumor detection and imaging which will be investigated further.

4. Conclusions

Various breast models are used to analyze the effect of the skin on scattered electromagnetic data. This effect has been quantified for the realistic breast model and found to be approximately 3% when receiving the backscatter. A tumor signature will be analyzed using the HFSS package and will be compared to the error introduced by ignoring the skin layer. Understanding this effect is important for the development of future breast models and their applications.

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