Error Analysis of Breast Tumor Signature versus Skin Thickness at Microwave Frequencies

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Abstract: The effect of breast skin thickness on electromagnetic scattering is explored in this work using the Ansoft High Frequency Structure Simulator (HFSS) package. The signature of a spherical tumor of 1cm in diameter is compared to the skin effect. A more realistic inhomogeneous breast model is used based on a magnetic resonance imaging (MRI) scan. This model contains five regions; air, skin, fatty tissue, fibro-glandular tissue and the malignant tumor. The preliminary results of this work indicate that the tumor signature is larger than the effect of the skin in the backscatter for the case presented.

Introduction

The breast skin has large dielectric values and conductivity compared to fatty breast tissue but with values comparable to a malignant tumor. The thickness of the skin, however, makes its effect on electromagnetic scattering unclear compared to a breast tumor. Microwave detection and imaging techniques can benefit from reductions in computational time when the skin layer is ignored [1]. When the signature of the tumor is on the same order of the skin effect, or smaller, imaging algorithms that ignore the skin will have reduced accuracy upon applied to a realistic breast model. On the other hand, when the tumor signature is larger than the skin signature, then models ignoring the skin thickness will be considered efficient due to anticipated robustness. The motivation of this work is to investigate the signature of the tumor to the skin signature of various thicknesses.

Previous work has shown that ignoring the skin when receiving in the backscatter can introduce an error as low as 3% in the scattered electromagnetic fields [2]. In this work the signature of the tumor is defined as the difference, in complex numbers, between the scattering parameters (S-parameters) of the breast configuration with and without a tumor. The effect of the skin thickness was determined by subtracting the S-parameters of the breast with and without skin layer.

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 [3]. From the reported data, formulas for the frequency dependent dielectric properties of the breast regions can be obtained. The frequency dependence of the electrical properties of the breast tissue is given by [3]:

\[
\epsilon_r - j\frac{\sigma}{\omega \epsilon_0} = \epsilon_\infty + \frac{\epsilon_s - \epsilon_\infty}{1 + j \omega \tau} - j\frac{\sigma_s}{\omega \epsilon_0} \quad (1)
\]
where the Debye parameters are $\varepsilon_s = 10$, $\varepsilon_\infty = 7$, $\sigma_s (\text{S/m}) = 0.15$ and $\tau (\text{ps}) = 6.4$ for normal breast tissue and $\varepsilon_s = 5.573$, $\varepsilon_\infty = 34.57$, $\sigma_s (\text{S/m}) = 0.524$ and $\tau (\text{ps}) = 9.149$ for the fibro-glandular region [3]. For the skin, the real part of dielectric constant is assumed $\varepsilon_r = 36$ and the conductivity $\sigma = 4 \text{ S/m}$ at 6GHz [3]. The frequency dependence could be incorporated as:

$$\varepsilon_r - j \frac{\sigma}{\omega \varepsilon_0} = 36 - j \frac{4}{\omega \varepsilon_0}$$

(2)

**Methodology**

The breast is modeled as five regions; air, skin, fatty breast tissue, fibro-glandular tissue and the malignant tumor. The model is constructed in Ansoft HFSS using contours taken from a breast Magnetic Resonance Image (MRI) [4]. The model can be seen in Fig. 1. Previous work utilized plane wave excitations and the fields received at a point receiver to quantify the effect of the skin thickness [2]. In this work, planar broadband antennas are employed for the source and the receiver. Fig. 1 shows the position of the antennas, the tumor, and the breast configuration.

The scattering parameters are calculated to determine the skin and tumor signatures as will be shown in the numerical results. To allow for the calculation of the S-parameters over a large range of frequencies, a broadband antenna was designed based on the Fourpoint antenna [5]. This modified Fourpoint antenna is shown in Fig. 2 with the associated $S_{11}$ parameter. Figure 2 shows that the antenna operates between ~5-10GHz with a return loss of less than -10dB, with an input impedance of 100Ω. The modified Fourpoint antenna allows for a dual linear polarization based on the ports excitation.

![Fig. 1. Realistic breast model with interior fibro-glandular tissue](image1)

![Fig. 2. Modified Fourpoint antenna and $S_{11}$ parameters](image2)
To accurately represent the skin in the breast model of Fig. 1, measured thickness values from mammography scans are used [6]. The thickness of the skin is dependent on a variety of factors such as age, breast size, menopausal and hormonal status which change over time. Utilizing various skin thicknesses allows the model to represent the breast of various patients. A summary of the results from [6] is outlined in Fig. 3 and Table 1.

![Fig. 3. Regions of breast skin [6].](image)

Table 1: Skin thicknesses for each breast region [6].

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<th>ML</th>
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<tbody>
<tr>
<td></td>
<td>Superior</td>
<td>Inferior</td>
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<tr>
<td>Normal Thickness (mm)</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Range (mm)</td>
<td>0.75-2.3</td>
<td>0.7-2.7</td>
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<tr>
<td>Standard Deviation (mm)</td>
<td>0.25</td>
<td>0.32</td>
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**Numerical Results**

Figure 4 shows the signatures of the tumor and the skin in the operating band of the antenna. The results exhibit an oscillator behavior as demonstrated in [2] using the Mie Solution. Both signatures exhibit maximum magnitude at 5GHz, which is the center frequency of the antenna.

![Fig. 4. Signatures of the skin and tumor in the backward scatter](image)
Additional results using the forward scatter, cross-polarization, various tumor sizes and positions are currently under investigation.

Conclusions

The tumor signature for a spherical shape of 1cm diameter was calculated and compared to the skin signature of normal thickness as defined in Table 1. The preliminary results show that tumor signature is more dominant than the skin signature when receiving in the backscatter direction. Smaller tumor size and non-spherical tumor shapes could lead to different results. These factors will be investigated and results will be presented in the conference.

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References


