A model for wave propagation in biological tissues is developed and tested for stability using the Finite Difference Time Domain (FDTD) method. For a lossy, dispersive (frequency-dependent) tissue, it is important to model the behavior of electromagnetic waves in the time domain for applications such as breast cancer detection. In order to apply FDTD techniques, discretized conductivity models are necessary. The Four Zeros Conductivity Model provides a single-pole, rational function of the C3 transform variable well suited for this application. A real average dielectric constant for the tissue is used with the modeled conductivity to calculate theoretical propagation constant to be compared with propagation constant calculated from measured conductivity and permittivity. This comparison shows good agreement between measured and theoretical attenuation rates and phase constants for high-fat breast tissue. The stability condition, derived using von Neumann analysis, is examined in the frequency domain. Stability in the time domain is then tested for the model parameters using 1D FDTD with a modulated Gaussian wave excited in breast fat tissue. For this type of tissue, simulated electromagnetic transmission obtained shows expected attenuation and forward propagation of the wave.

State of the Art

- The Four Zeros Conductivity model is better suited to application in time domain modeling than the traditional Cole-Cole expression. This model significantly reduces the number of model parameters.
- Time domain modeling of wave propagation in complex realistic media can be used to develop imaging systems for use such as breast cancer detection, classifying the work as a 3S system level project.
- This work is classified under NSF R1 and R2 research thrusts because it involves computational modeling and develops a model that can be used in various applications.

Developing the Model

Measured data for conductivity and permittivity are fit to the Four Zeros Conductivity model by solving simultaneous equations for \( b_0, b_1, b_2, \) and \( b_3 \), and making an initial estimate for \( a_1 \).

A final value of \( a_1 \) is selected in the stability analysis and the propagation constant is calculated for the measured data and modeled conductivity and average dielectric constant.

Stability Analysis

- Von Neumann analysis of Maxwell's Equations yields the stability condition equation. All of the roots of the stability equation must lie within the unit circle at a given value of \( a_1 \) over a sufficient range of \( \Delta z \) for a stable model.

The four roots are calculated and the maximum magnitude of the roots at each for each combination of \( a_1 \) and \( \Delta z \) is plotted. Values of \( a_1 \) and \( \Delta z \) are selected at uniformly spaced discrete points around an initial estimate of \( a_1 \) and between \( \Delta z_{\text{min}} \) and \( \Delta z_{\text{max}} \).

Testing the Model

A Gaussian Excitation was applied to the simulated breast fat using FDTD and the tissue parameters from the model.

References