

Evaluating the Impact of Tissue Dielectric Property Variability on Microwave Imaging for Breast Cancer Detection

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Breast cancer has become the most diagnosed cancer and the leading cause of cancer-related death among women. Early detection is crucial to ensure the highest chance of positive health outcomes. Currently, the preferred method for cancer screening is X-ray mammography, but this modality requires uncomfortable compression of the breast and exposes the patient to ionizing radiation which limits how often screenings can occur. Microwave imaging techniques using tomography or radar have been proposed as a promising tool to aid in early cancer detection. Because these imaging systems do not emit ionizing radiation, more frequent screenings are possible allowing the system to track small changes in the breast over time that could be indicative of cancer. These imaging systems are used to create a spatial dielectric mapping of the tissues of the breast. Malignant tissues have been shown to have larger dielectric properties compared to surrounding healthy tissues creating a ‘hot-spot’ on reconstructed images. However, measurement campaigns of these dielectric properties have documented significant variations in the measured permittivity and conductivity of both healthy and malignant tissues that indicate the contrast between malignant and benign tissues can be significantly reduced in some cases (N. AlSawaftah, S. El-Abed, S. Dhou, and A. Zakaria, “Microwave Imaging for Early Breast Cancer Detection: Current State, Challenges, and Future Directions,” *Journal of Imaging*, vol. 8, no. 5, pp 1-31, May 2022). This reduced contrast impedes the ability of the microwave imaging system to detect tumors.

Other groups have proposed microwave imaging techniques that attempt to circumvent this issue by enhancing the contrast between tumors and surrounding tissues. These include the use of magnetic nanoparticle contrast agents, advanced beamforming algorithms, and hybrid microwave-acoustic imaging systems. While these techniques have improved the robustness of microwave imaging systems, there is a knowledge gap in accurately predicting how variations in dielectric properties affect imaging performance. A better understanding of the statistical variation of dielectric properties is needed. Currently, the average dielectric properties are widely reported over a broad frequency range (K. Sasaki, E. Porter, E. A. Rashed, L. Farrugia, and G. Schmid, “Measurement and image-based estimation of dielectric properties of biological tissues —past, present, and future—,” *Phys. Med. Biol.*, vol. 67, no. 14, pp. 14-39, Jul. 2022), but variability is less often reported. In addition, a tool is needed to predict how different breast compositions – light, medium, and dense breast tissues, and their variability, affect imaging performance.

In this work we propose two major contributions. The first is a comprehensive review of the variability of tissue dielectric properties relevant to the breast cancer research community including benign tissues such as adipose, glandular, and fibroconnective tissues and different types of malignant tissues including invasive and non-invasive ductal and lobular carcinomas. This review also includes transition tissues such as skin and muscle. The second contribution is the development of a stochastic finite-difference time-domain (S-FDTD) solver originally proposed in S. M. Smith and C. Furse, “Stochastic FDTD for Analysis of Statistical Variation in Electromagnetic Fields,” *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 7, pp. 3343–3350, Jul. 2012. This technique augments the traditional FDTD solution (which provides the mean fields) to include the standard deviation of the fields in time and space. The S-FDTD solver provides a useful predictive tool for understanding how the variability in tissue properties affects the variability of the fields and can potentially be used to bound the performance of microwave imaging algorithms and approaches.