Microwave breast cancer detection via space-time beamforming: A computational and experimental study of breast phantom and sensor design parameters

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We have recently proposed a method of microwave imaging via space-time (MIST) beamforming for detecting and localizing backscattered energy from small malignant breast tumors (E. Bond, X. Li, S. C. Hagness, and B. D. Van Veen, *IEEE Trans. Antennas and Propagation,* April 2003, in press). In our MIST approach each antenna in an array sequentially transmits an ultrawideband microwave pulse into the breast and receives the backscatter. Robust space-time beamforming algorithms are applied to the recorded signals to provide an image showing backscattered energy as a function of location. Malignant tumors produce localized large backscatter energy in the image due to their significant dielectric-properties contrast with normal breast tissue. In our previous computational studies, we applied the beamforming algorithms to simulated backscatter waveforms generated from 2-D MRI-derived FDTD breast models. In previous experimental studies, we tested the MIST approach using a simple first-generation breast phantom comprised of a water-based synthetic tumor suspended in a homogeneous normal breast tissue simulant. The imaging results demonstrated the theoretical and experimental feasibility of the MIST breast cancer detection method.

In this paper, we present in-depth computational and experimental investigations of the MIST beamforming approach using a second-generation breast phantom. Here, a layer of skin simulant is introduced at the surface of the breast phantom and alternative materials are used for the synthetic tumors to more realistically represent the predicted dielectric contrast between normal and malignant breast tissue. 3-D FDTD models of the improved breast phantom including the ultrawideband transmitting/receiving antenna are also developed. The simulated time-domain tumor response observed a single antenna location is compared to the measured tumor response for several cases where the dielectric-properties parameters of the synthesized tumors are varied. The excellent agreement between the simulated and measured tumor responses confirm the accuracy of the FDTD models.

We have conducted a comprehensive parametric study using both measurements and simulations for a variety of breast phantoms. Tumor response strength and signal-to-clutter-ratios of the images are presented as functions of breast phantom parameters, such as the dielectric properties of the breast-tissue simulants and the tumor shapes and sizes. The results of this study provide guidelines for determining dynamic range requirements of the imaging system, as well as image quality for detecting malignant tumors in these different scenarios. The impact of the sensor design on the observed tumor response is also investigated through simulation by changing the antenna geometry and immersion medium in the FDTD models of the system.