Microwave Imaging for Breast Cancer Detection using Vivaldi Antenna Array

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1. Introduction

The radar based UWB microwave imaging techniques have shown great potential for the localization of embedded dielectric targets in breast phantoms [1], [2]. In practical UWB microwave imaging systems, antennas play a key role in determining the characteristics of the received signals. The antennas behave as spatial-temporal filters as they have to radiate narrow pulses and thus the radiated signal may be distorted. Besides, the multipath effects and dispersion can also affect the reconstruction process. With this aim, in this paper, we investigate the effects of UWB antenna array on the image reconstruction for early stage breast cancer detection. A full-scale radar based microwave imaging system was reported in the literature that employed a small slot antenna with copper cage that was positioned into a hemispherical array to illuminate the breast [1]. Different types of horn antennas were also investigated for breast imaging [2], [3]. In this paper, we investigate the problem of breast tumor detection in an inhomogeneous breast phantom using a Vivaldi antenna array. We first investigate the experimental UWB characterization of the prototype-Vivaldi antenna element. Later, we perform FDTD simulations with a 7-element Vivaldi antenna array that is placed in a semi-circle arc around the numerical 3-D breast phantom. We employ the time-of-arrival calibration [6] and use the signal processing methods to reconstruct suspicious regions to localize the presence of tumor. We present results on image reconstruction using FDTD simulations.

2. Antenna Performance

The end-fire directional Vivaldi antenna reported in [4] is employed in our study with some modifications. The antenna has the aperture dimension of 44 by 6 mm. We have modified the design in [4] to improve the ease of fabrication by having the thickness of the four layers to be the same. Also, we have done away with the bonding film as the antenna will be immersed in a coupling liquid that has a dielectric constant close to that of the substrate on which the antenna is printed. A simple SMA connector is used to easily connect it to the strips as well as to the ground appropriately. Both FDTD simulations and prototype experiments verified that this simplified design performs reasonably well.

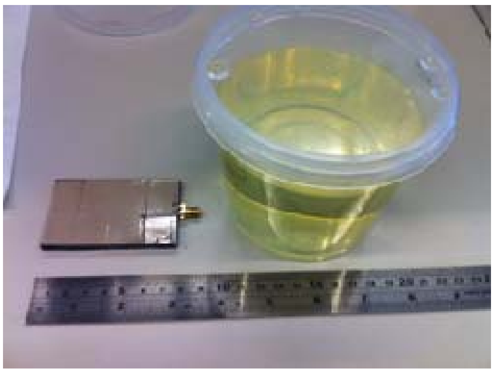

Figure 1: Vivaldi antenna and coupling oil

The fabricated antenna and the coupling liquid are shown in Fig.1. The coupling liquid used here is cooking oil whose dielectric constant is similar to that of fatty breast tissues. The simulated and measured results of return loss as shown in Fig. 2. It clearly indicates that the-10 dB return loss bandwidth is very wide spanning from 2.5 GHZ to 18 GHz. We have only included the results up to 8.5 GHz as higher frequency signal content cannot penetrate deep into the breast phantom. In Fig 2, the red line refers to measured data and blue line refers to simulated data using FDTD. The UWB microwave imaging requires antennas to radiate narrow pulses to illuminate the embedded target and hence the fidelity is important criterion for such antenna design. Fidelity measures the distortion of the radiated pulse from the excitation pulse. It is calculated by the maximum magnitude of the cross correlation between the normalized observed response and an ideal response. We calculated the fidelity of our designed Vivaldi antenna at distances ranging from 5 to 55 mm placing two similar antenna elements face to face and the results are shown in Fig. 3. The results show that the fidelity is very high and is independent of the distance and this antenna has fidelity larger than 0.98. The fidelity at 50 mm separation is 0.996. The excitation pulse at the transmitting antenna and radiated pulse at a distance of 50mm separation are illustrated in Fig. 4 where the blue dotted line shows excitation pulse and red line shows radiated pulse by the chosen Vivaldi antenna. The results indicate that the Vivaldi antenna element does not significantly distort the signal.

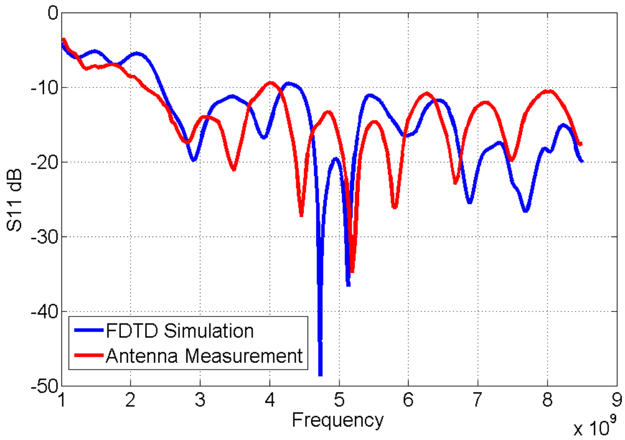

Figure 2: Return loss

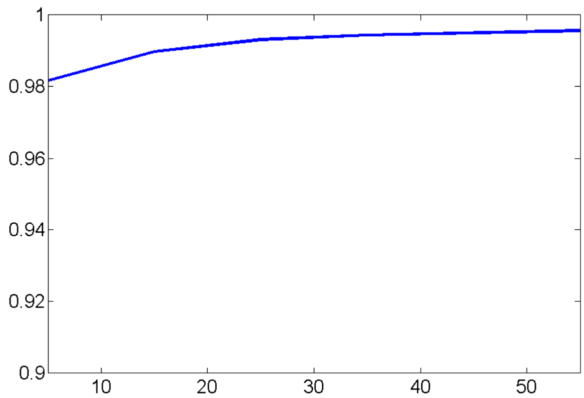

Figure 3: Fidelity vs distance

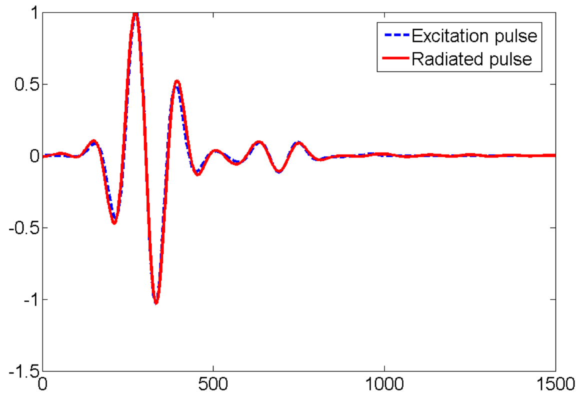

Figure 4: Radiated pulse distortion by the Vivaldi element at 50mm separation.

3. Breast Phantom

We employ a 3D hemi-spherical breast phantom using FDTD method as illustrated in Fig. 5. The tumor is assumed to have 10 mm diameter and is placed 40mm away from the central Vivaldi antenna element of the arc array which is positioned at 0 degree azimuth angle. The other two types of breast tissues included in our phantom represent the glandular tissues and medium adipose tissues respectively. The background tissues content of the phantom consists of fatty tissues. The antennas are placed about 15mm away from the skin layer which is assumed to be 2mm thick. A transmit UWB pulse illuminates the breast from the central antenna of the 7- element Vivaldi array and the rest of the antennas are used as receivers to collect the scattered pulses. Every antenna element has 30 degree angular separation from its neighbour. The chosen 7-element arc array can cover only one half of the phantom since placement of antennas at the other half of the phantom can make the early time signal removal difficult. A 20mm thick chest wall is also assumed. All the breast tissues use the dielectric parameters published in [5].

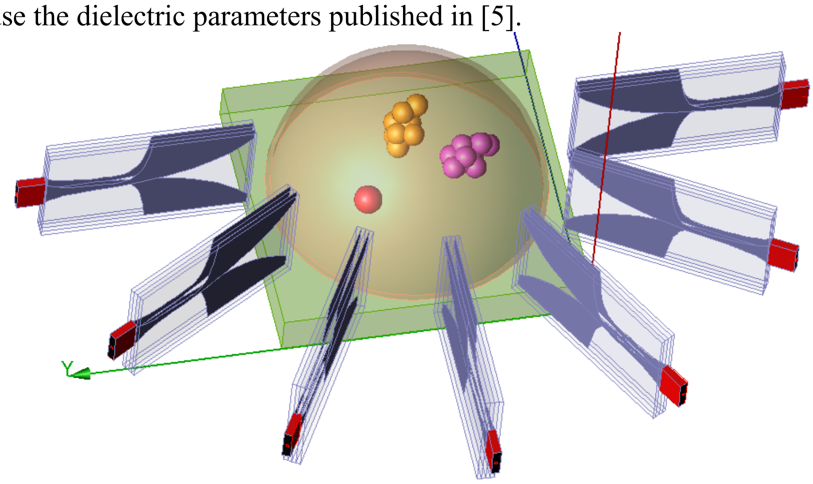

Figure 5: Breast phantom and antenna array

4. Imaging of suspicious regions

The pre-processing for the removal of early time content includes the antenna excitation and skin reflection. The pre-processing and image reconstruction are conducted based on [6]. The tumour is placed in (34, 74, 35)mm and the centre of reconstructed tumour location is (36, 70, 35). The reconstructed tumour image is illustrated in Fig. 6 which is obtained from FDTD simulations. The figure indicates that the expected tumour location is well reconstructed using realistic antenna array.

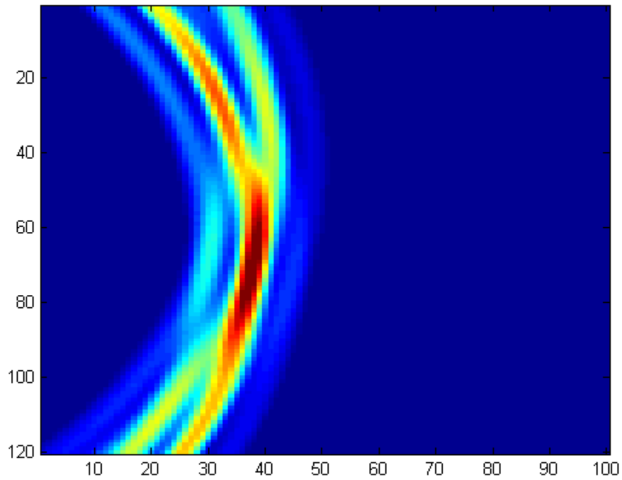

Figure 6: Reconstructed tumor image

5. Conclusions

The measured results on return loss and simulation results on fidelity of the chosen Vivaldi antenna element indicate that the distortion is very small for pulse transmission. The selection of 7-element Vivaldi array in simulations has helped to properly remove early time content and improve the reconstruction process with the 3-D inhomogeneous breast phantom. The reconstructed image demonstrates that the suspicious region indicating the possible presence of tumour can be accurately localized when employing the Vivaldi antenna array. To improve the localization performance, smaller antennas will be developed in future for practical measurements.

Acknowledgments

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