An Experimental Microwave Imaging System for Breast Tumor Detection on Layered Phantom Model

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Abstract

In this paper, the microwave imaging system currently being developed and realized at the Scientific and Technological Research Council-BILGEM, is introduced. A stacked patch antenna has been designed, fabricated and tested in operation in the experimental setup consisting of a spectrum analyzer (with vector network analysis option) and a planarly layered breast phantom model with tumor. Images are successfully obtained by using scattering electromagnetic waves from the tumor (S_{11}). In the future study, ultrawide-band (UWB) confocal microwave radar-based imaging system with right-handed circularly polarized (RHCP) and left-handed circularly polarized (LHCP) antennas located as an array on a section of a hemisphere, as well as improved and fast imaging algorithms, will be designed and developed in order to minimize mutual coupling between antenna elements, reflections from the skin and mechanical parts of the antenna system for getting better resolution results than similar recent developed microwave imaging systems.

1. Introduction

There are various passive and active microwave techniques which have been proposed as an alternative to the most widely used X-ray mammography for early detection of breast cancer, such as microwave radiometry [1], hybrid microwave-induced acoustic imaging [2], microwave tomography [3] and UWB microwave radar technique [4-6]. X-ray mammography has several limitations, especially when dealing with younger women who have dense breast tissues. Therefore, there is a small contrast between healty and diseased breast tissues at X-ray frequencies [4]. On the other hand, there is a significant contrast in the electrical properties of the normal and the malignant breast tissues [4], which exists in the earliest stage of tumor development. Another advantage of the microwave imaging technique is that it would be nonionizing and it doesn't require painful breast compression.

Currently, there are two main active methods involve illuminating the breast with microwaves and then measuring transmitted or backscattered signals; such as microwave tomography [3], and radar-based imaging [4-6]. In microwave tomography, an inverse scattering problem is solved to reconstruct an image of the dielectric properties in the breast. In contrast to the image reconstruction aim of the microwave tomography technique, UWB radar-based imaging approach solves a simpler computational problem faster dealing with only to identify the presence and location of significant scattering obstacles such malignant breast tumors.

Recent years have shown a dominant interest in a UWB microwave radar-based imaging technique, for a particular technique to detect and locate a breast tumor. This technique specifically uses short duration pulses. Using a mechanical scanning system, measurements are repeated for different locations of an UWB antenna. UWB antenna array with switched elements is also used. The UWB imaging technique offers creation of an image, which can be formed by combining all of the processed results coming from different antennas. In order to improve the tumor detection confocal microwave imaging [4], space-time beamforming [5] or time-reverse wave focusing [6] can be used. However, there exist mutual coupling effects between antenna elements and reflections from the skin and mechanical parts of the antenna system that disturb the resolution.

In this study, UWB microwave imaging technique is used, and we're interested in the 4.6–5.0 GHz frequency range; which also guarantees a balance between the two contradictory needs of better spatial resolution and better penetration depth [7]. A stacked microstrip patch antenna which has been designed, fabricated and tested, in TUBITAK – BILGEM, operating at 4.60-5.25 GHz, is used as an UWB antenna. Swept-frequency measurements

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of magnitude and phase of scattering coefficients (S_{11}) are synthesized for time/space domain analysis via inverse Fast Fourier Transform (FFT). Then, images of the computed backscattered signal energies are created as a function of position.

2. Experimental Microwave Imaging System Setup and Layered Breast Phantom Configuration

In the experimental measurement setup as shown in Fig. 1, the stacked microstrip patch antenna is located 1 cm above the surface of a homogeneous planarly layered breast phantom model with tumor. The stacked patch antenna is connected to a handheld spectrum analyzer (R&S®FSH8, 100 kHz-8 GHz, with tracking generator and internal VSWR bridge) to transmit and receive microwave signals, and it is sequentially scanned in 1 cm increments to 361 different positions in a 19 cm × 19 cm array. The layered breast phantom model is illuminated by the patch antenna, and the backscattered signal (S_{11}) is recorded in the frequency range of 4.6-5.0 GHz. Electromagnetic absorbing materials within a box are located under the experimental setup to reduce ambient reflections (Fig.1).

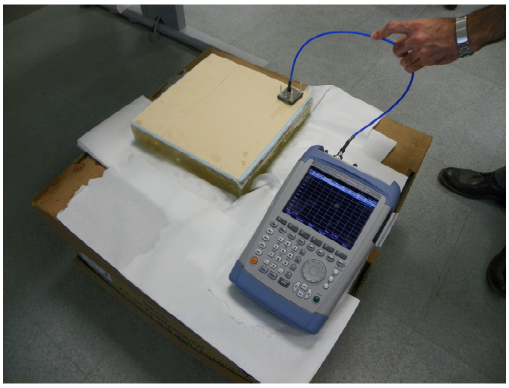


Fig.1. Experimental setup of the microwave imaging system.

2.1 Stacked Microstrip Patch Antenna

Microstrip antennas have been studied for many years because of their low cost, thin profile, light weight, ease of fabrication, their capability of being mounted on curved surfaces and being integrated in active devices. The most important drawback of microstrip antennas is narrow bandwidth. Various methods have been studied to overcome this drawback. Stacked patch antenna concept is one of the methods to increase the bandwidth of the antenna. Stacked patch antenna generally consists of a parasitic patch on another layer so that bandwidths of about %25 can be achieved. In this study, a stacked microstrip patch antenna has been chosen as a good candidate for UWB microwave imaging of breast tumor detection. The measurement result of the antenna is shown in Fig. 2 (b).

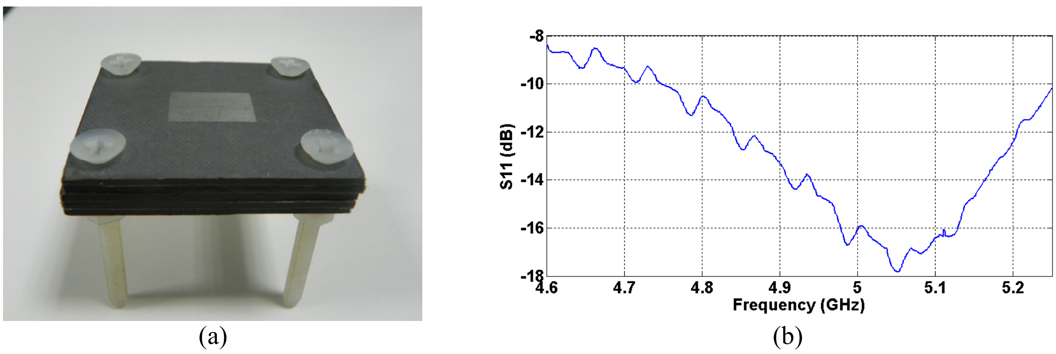


Fig. 2. (a) Stacked patch antenna, (b) Measurement of return loss of the stacked patch antenna.

2.2 Layered Breast Phantom Model

The layered breast phantom consists of a container (Plexiglass) filled with planar layers of breast fat tissue simultant, skin tissue simultant, and also spherical objects embedded at the bottom of the breast fat tissue simultant (Fig. 3). For the experimental tests, appropriate materials for the layered breast phantom model with tumor have been determined based on the proposed phantom model studies in [8-10]. Soybean oil is used as the breast fat tissue simultant [8]. The soybean oil is contained in the 30 cm × 30 cm × 5 cm tank. The skin layer in the phantom is created using a simple moisturising lotion [9]. These breast fat and skin simultants are inexpensive and nontoxic with dielectric properties that mimic roughly those of actual tissues [8, 9]. Two spherical objects both with 2 cm diameters are used, such that one of them is simulating tumor, and the other is chosen as perfectly electrical conducted (PEC) object for distinguishing them in the imaging results. The tumor simulating one is elastic and it's constructed based on the procedure suggested for preparing tumor tissue-mimicking materials in [10].

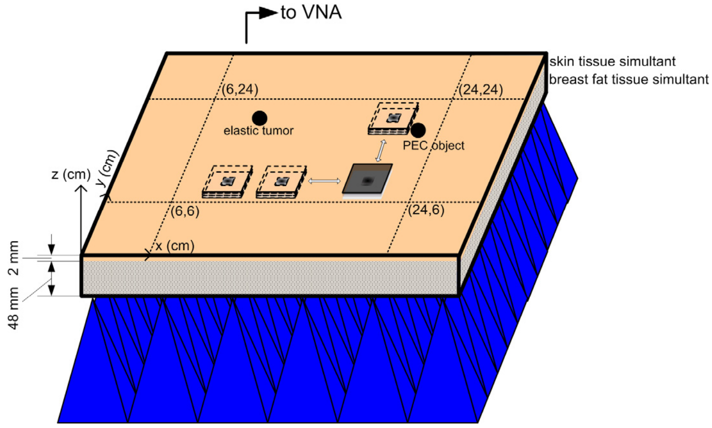
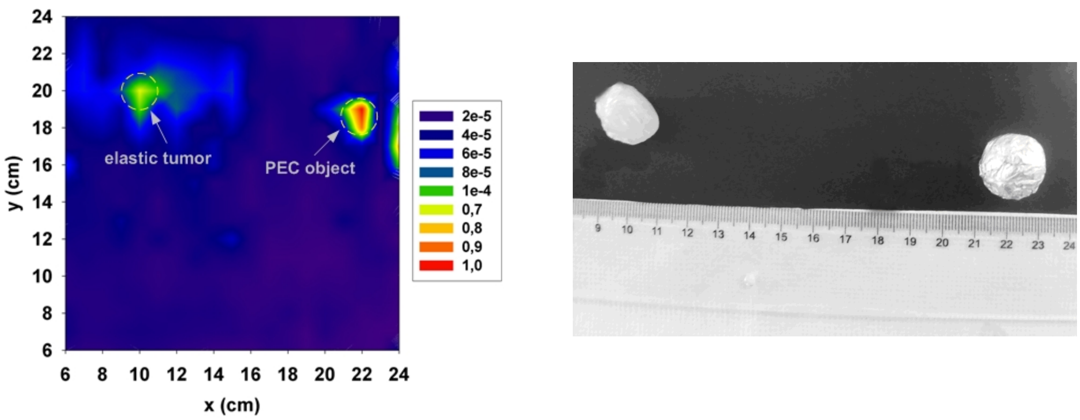


Fig. 3. Schematic representation of layered breast phantom model.

3. Imaging Results

In UWB microwave radar system, signal processing algorithms such as delay-and-sum (DAS) beamforming, penalized least-squares optimal beamforming, a generalized likelihood ratio test, time-reversal techniques are generally applied to the recorded backscattered microwave signals to localize and characterize malignant breast tumors [11]. In this study, a simpler microwave imaging method is used. The designed stacked microstrip patch antenna is sequentially scanned in 1 cm increments and the backscattered signal (S_{11}) is recorded in the frequency range of 4.6–5.0 GHz. Measured frequency-domain datas are recorded at 631 frequency points, and its time/space domain equivalent is obtained by using inverse FFT. Images of the computed signal energies are created as a function of position. The tumor is successfully detected (Fig. 4).



(a) (b)

Fig. 4. (a) Color image of the backscattered energies with actual locations of tumor and PEC object drawn by yellow circles, (b) Real dimensions of tumor and PEC object.

4. Conclusion

Experimental feasibillty of the UWB microwave imaging system currently being developed and realized at the Scientific and Technological Research Council-BILGEM is demonstrated using an initial imaging setup and a layered breast phantom. The antenna designed for the microwave imaging system is measured. We were able to detect the elastic tumor model with 2 cm diameter by using so many frequency and position dependent raw datas, although dielectric properties of tumor and breast are close to each other compared to the PEC object. Initial imaging results are promising, however more extensive work is required with more realistic phantom models, improved and fast imaging algorithms. In the future study, RHCP and LHCP antennas will be designed and located as an array on a section of a hemisphere in order to minimize mutual coupling between antenna elements, reflections from the skin and mechanical parts of the antenna system for getting better resolution results than similar recent developed confocal microwave radar-based imaging systems.

5. References

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