Indonesian Journal of Electrical Engineering and Informatics (IJEEI)
Vol. 7, No. 2, June 2019, pp. 263~270
ISSN: 2089-3272, DOI: 10.11591/ijeei.v7i2.806

A confocal microwave imaging implementation for breast cancer detection

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Article Info

Article historys:

Received Nov 30, 2018
Revised Apr 30, 2019
Accepted May 23, 2019

Keywords:

Antenna
Breast cancer
CMI
Early diagnosis
UWB

ABSTRACT

Breast cancer affects many women in many ways. Early diagnosis is the most important key for detecting malignant tissue. In this paper, we present the design of a microstrip patch antenna for ultra wide band (UWB) biomedical applications covering the full range of FCC frequencies (3.1 GHz to 14 GHz). We have used a single antenna with various positions to scan the whole breast phantom. A confocal microwave imaging (CMI) algorithm has been implemented and applied to create a 2D image of the tumor. The results obtained suggest the feasibility of using CMI method for detecting small breast tumors with high precision and more safety.

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1. INTRODUCTION

Breast cancer is an anxiety for many women. Early diagnosis is the most important key for a fast and effective treatment before the increase of this disease in the whole body. Currently, the X-ray Mammography is the most technique used for breast cancer screening. While this technique offers clear advantages, it also generates a wide range of limitations and potential risks such as false positive and false negative results, painful breast compression and ionizing radiation. For that reason, many research teams are looking now for ways more safety and efficiency [1-4]. Microwave imaging is the golden diagnostic tool for medical imaging modality developed over the past few years. This technique offers many interesting advantages for breast cancer like low cost, non-invasive, more safety, and high accuracy [5-10]. Confocal Microwave Imaging (CMI) has been proposed as a method to detect tumors by analyzing the scattered signals from the breast. CMI algorithm is based on image reconstruction using multiple signals collected from ultra wide band (UWB) antenna placed at different positions received from the surface of the breast [11-15].

In this paper, we present an image reconstruction algorithm, namely Confocal Microwave Imaging (CMI). In our work, we present an UWB antenna with a wide frequency band according to the Federal Communications Commissions (FCC) standard. A 3D breast model has been prepared which is approximate replica of human breast. In the following section, we will explain the implementation of Confocal Microwave Imaging (CMI) Algorithm by moving a single antenna around the breast to reconstruct images with simulated data.

2. BREAST MODEL

The design of the proposed breast model for this study is shown in Figure 1. It contains different layers such as skin, fatty tissue…. Each layer has different dielectric characteristics that based on different equations developed in [16, 17]. Figure 2 and 3 show the Gabriel model of different breast layers.

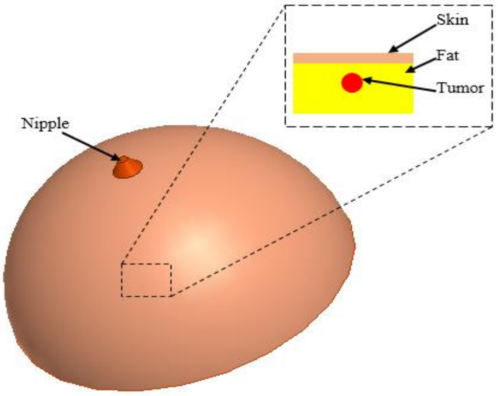


Figure 1. Breast model [8]

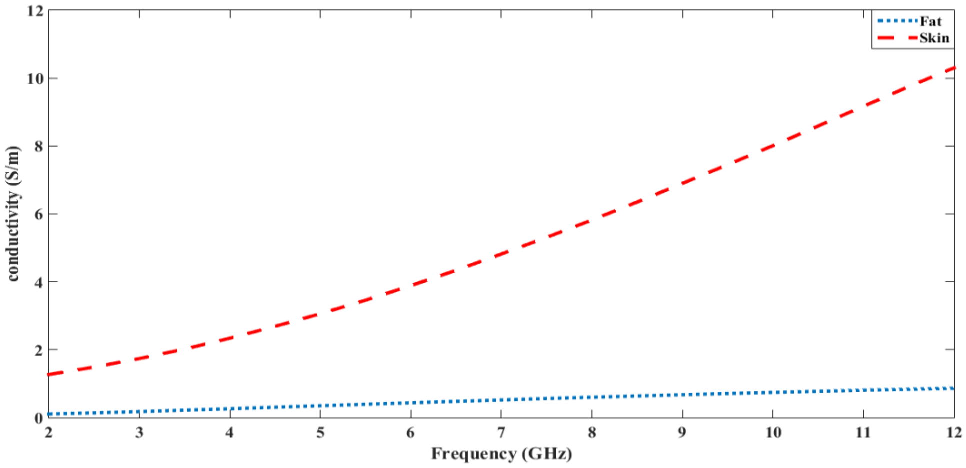


Figure 2. Conductivity of different breast layers [8]

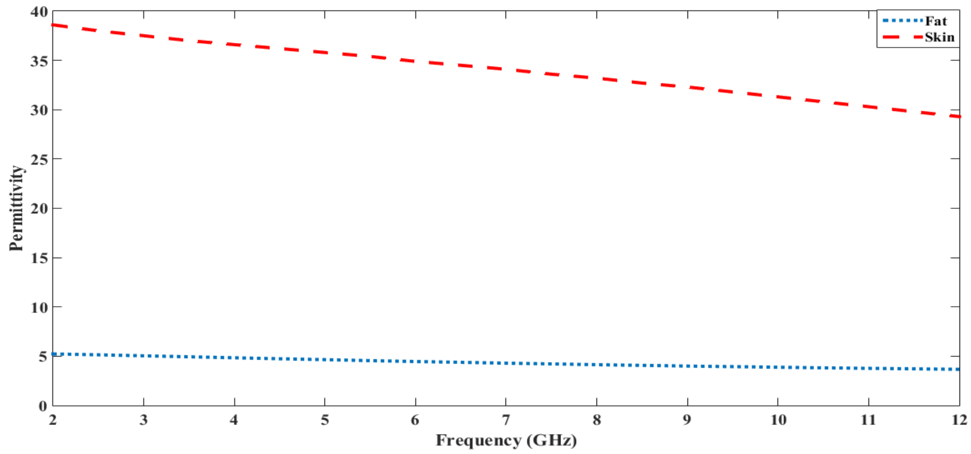
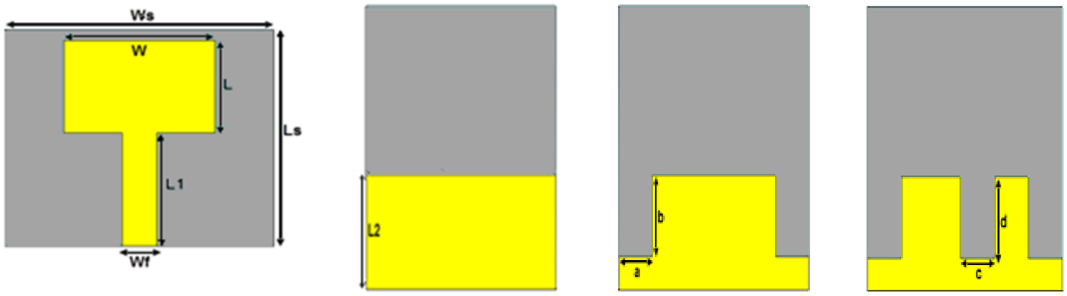


Figure 3. Permittivity of different breast layers [8]

3. ANTENNA MODEL

Figure 4 illustrates the schematic of the proposed UWB antenna. The antenna with a size of Ws x Ls is implemented on FR4 substrate with relative permittivity Ɛr=4.3, loss tangent of δ=0.02 and thickness of t=1.58mm, the final dimensions of the antenna structure and all techniques applied to improve the performances of the proposed antenna are introduced in [17, 18]. Optimal dimension as shown in Table 1.



(a) (b) (c) (d)

Figure 4. (a), Geometry of the proposed antenna (b), (c), (d), Design evolution of the final ground plane

Table 1. Optimal dimensions

Parameters	Value (mm)	Parameters	Value (mm)
Ls	21	Wf	3
Ws	23	t	1.58
L	9	a	4
W	13	b	6.5
L1	11	c	4
L2	8.5	d	6

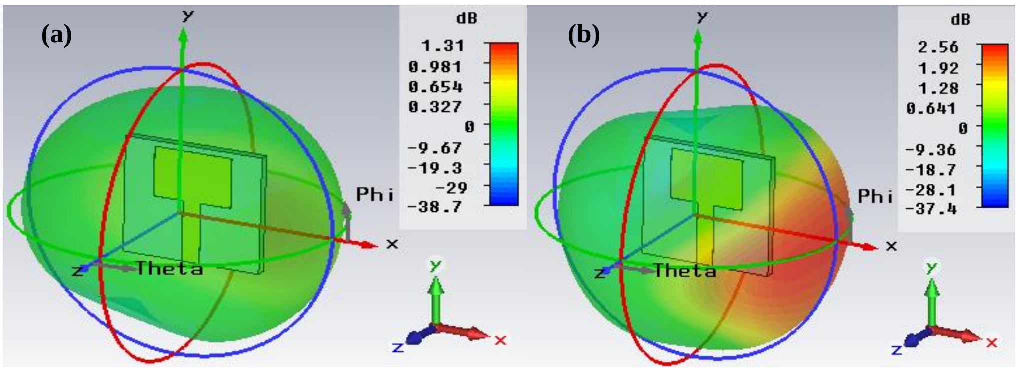


Figure 5. Radiation pattern 3D of the basic antenna at (a) : 3.65 GHz and (b) : 8.64 GHz

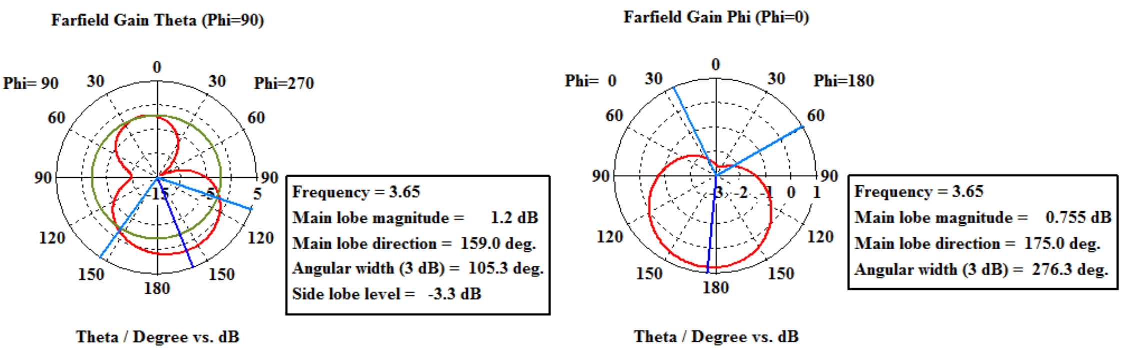


Figure 6. Radiation pattern 2D of the basic antenna at 3.65 GHz

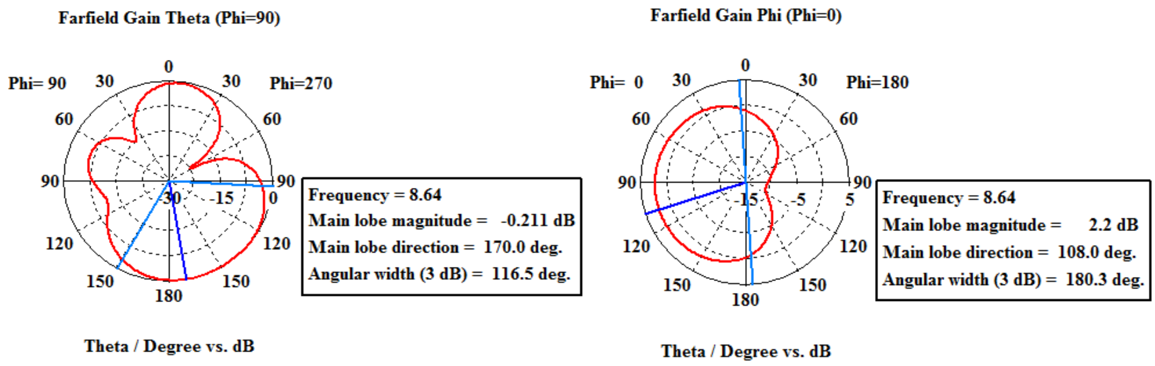


Figure 7. Radiation pattern 2D of the basic antenna at 8.64 GHz

Radiation patterns of the proposed antenna is approximately omnidirectional, as shown in Figure 5-7. It is observed that the antenna has good radiation characteristics for all resonance frequencies. The photograph of fabricated UWB antenna prototype is shown in Figure 8.

The comparison between the S parameter measured with two different electromagnetic solvers is shown in Figure 9. A good agreement is found between the simulations in the whole band, but we remark some differences due to the fact that they are based on two different meshing techniques and solving algorithms (FIT, FEM). Even with the small difference in the S parameter, the results confirm that, the bandwidth of the antenna is from 3.1 to 14 GHz, which covers the full range of FCC frequencies from 3.1 to 10.6 GHz.

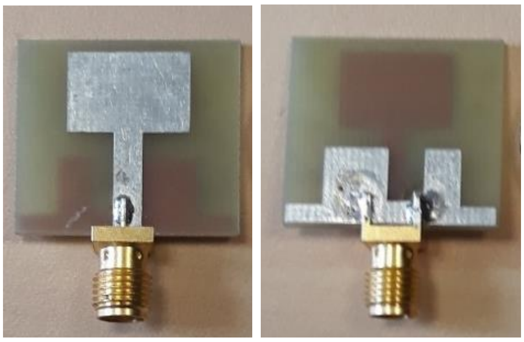


Figure 8. The photograph of fabricated UWB antenna prototype

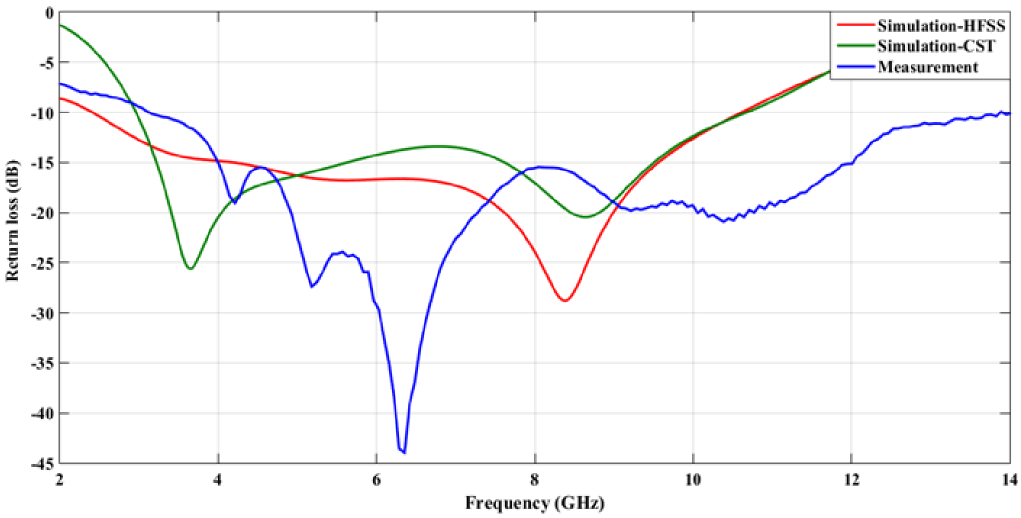


Figure 9. Simulated and measured S_{11} for the proposed antenna

A good agreement is found between simulation and measurement results. The proposed antenna has a good performance in the whole band ranging from 3.1 to 14 GHz, as noted in Table 2.

Table 2. Comparison of previous designs with the proposed antenna

Antenna	Substrat (Ɛr)	Antenna Area (mm)	Bandwidth (GHz) (< -10dB)
[19]	4.3	73.4x41.9	5-10
[20]	Not reported	45x40	6-10
[21]	3.38	42x19	3-8
This work	4.3	21x23	2.96-10.68

4. THE CONFOCAL MICROWAVE IMAGING ALGORITHM

The objective of our breast imaging system is to detect tumors at their early stage and ensure a fast and effective treatment in order to reduce women mortality. In this part, we present our algorithm of the confocal microwave imaging (CMI) introduced in [22], [23]. The frequency domain data is obtained with a monostatic radar, which consists of an UWB antenna used for transmitting and receiving signals. The goal of this technique is to place our antenna at different X-Y positions and transmits microwaves over a wide band of frequencies to give us more accuracy and precision for a complete reconstruction of the image, as illustrated in Figure 10. The positions are distributed in a grid of 121 points (11x11), covering the size of the whole model.

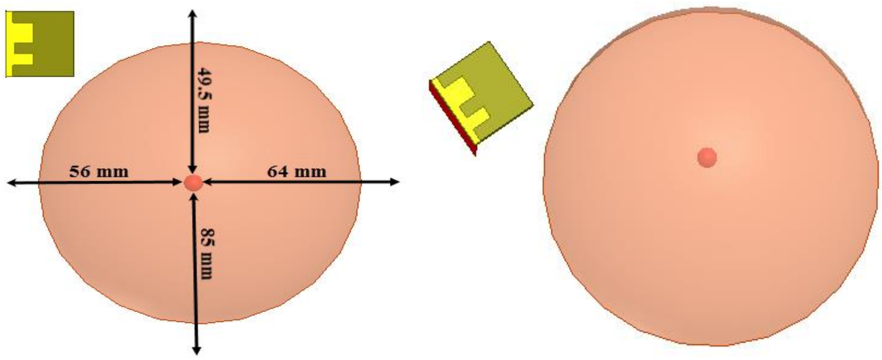


Figure 10. Antenna positions covered the whole model

In this part, we will explain the implementation of CMI algorithm. Five steps were applied to create an image of the tumor.

- Hamming Window: A Hamming window is applied to the signals (with and without tumor) to reduce the level of side lobes (H: Hamming window, SH: environment without tumor, STH: environment with tumor).

$$SH_{XY}(f) = S_{XY}(f) * H \quad (1)$$

$$STH_{XY}(f) = ST_{XY}(f) * H \quad (2)$$

- Inverse Fast Fourier Transform: The obtained signals were transformed into the time domain by taking the Inverse Fast Fourier Transform (IFFT), as shown in Figure 11-12 for environment with and without tumor, respectively.

$$SH_{XY}(f) \underset{IFFT}{\Longrightarrow} SH_{XY}(t) \quad (3)$$

$$STH_{XY}(f) \underset{IFFT}{\Longrightarrow} STH_{XY}(t) \quad (4)$$

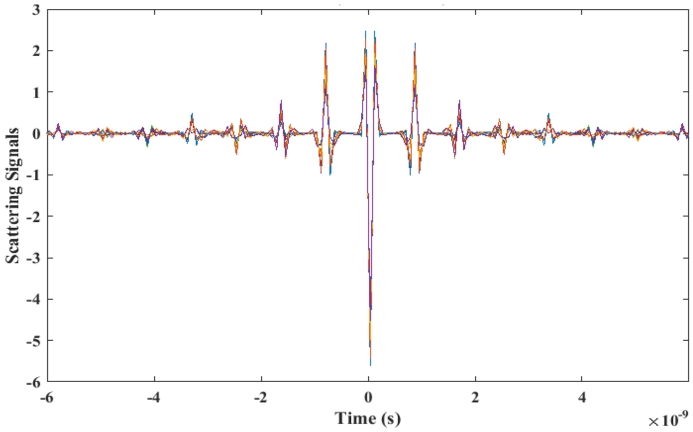


Figure 11. IFFT for the environment with tumor

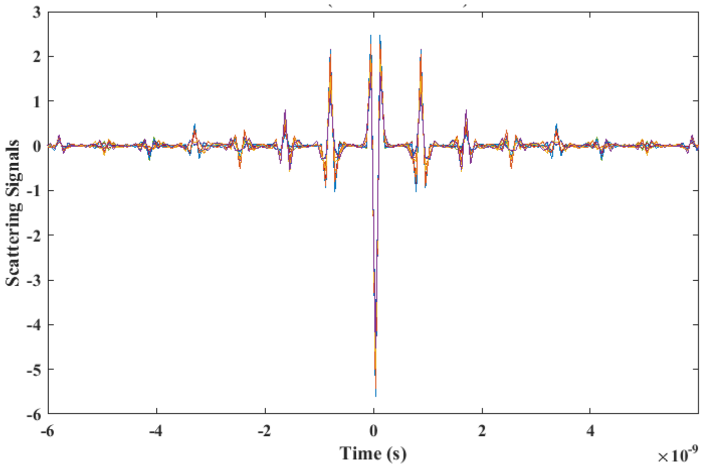


Figure 12. IFFT for the environment without tumor

– Calibration: This technique was used to remove the environment signals and keep only the reflections of the tumor. We subtract the signals SHXY(t) (environment without tumor) from the signals STHXY(t) (environment with tumor), as shown in Figure 13:

$$S_{XY}(t) = STH_{XY}(t) - SH_{XY}(t) \quad (5)$$

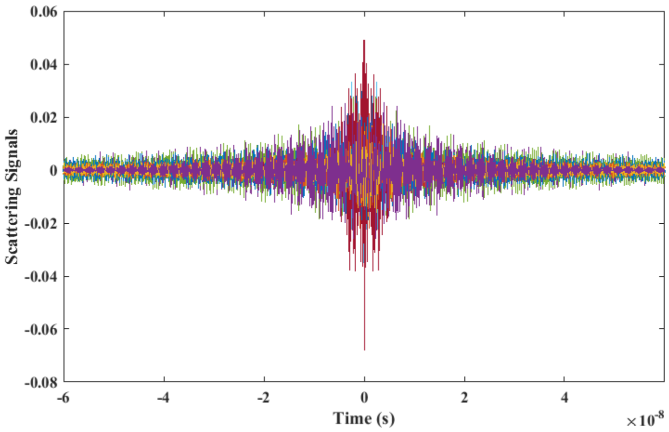


Figure 13. Calibration between two environments

– Clutter Removal: The obtained signals always contain a mixture of noises due to antenna and environment. This noise is removed by subtracting the averaged signals from each received signal:

$$EM(t) = \frac{\sum_{Y=1}^{N} S_{XY}(t)}{N} \quad (6)$$

$$E_{XY}(t) = S_{XY}(t) - EM(t) \quad (7)$$

where N represents the number of rows and columns of the grid of 121 positions of the antenna. The result is shown in Figure 14.

– Generate Pixel points: In this section, we evaluate the distance of each antenna position XY to each pixel covering an area of (118mm x 126mm) in order to calculate the round-trip time. After calculating the time values, The final image is generated by different intensity values for all antenna positions XY (Figure 15).

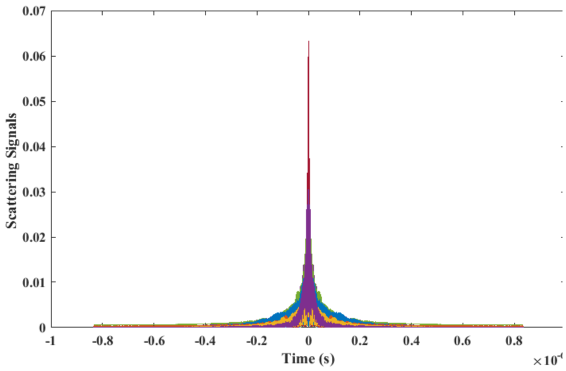


Figure 14. Clutter Removal

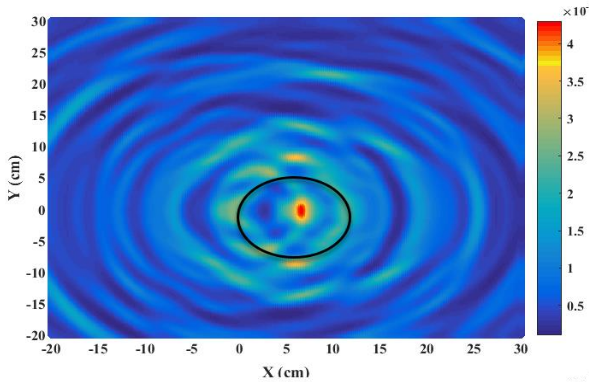


Figure 15. Image result of CMI algorithm

The imaging results are shown in two dimensions by using a single antenna moving around the breast. It is shown that the normal and malignant tissue are easily differentiated. The tumor have very different dielectric properties (high conductivity and relative permittivity), which makes it possible to be detected by analyzing the scattered signals.

The image reconstructed demonstrates the feasibility of using confocal microwave imaging (CMI) algorithm from a monostatic UWB radar system for breast cancer detection.

5. CONCLUSION

The results presented in this paper show that it is feasible to detect and localize breast tumors in two dimensions. We proved the validity of our confocal microwave imaging (CMI) algorithm for breast cancer detection. For the first step, An UWB microstrip antenna is designed and fabricated for UWB applications especially for biomedical applications. The measured results show that the antenna can cover a bandwidth ranging from 3.1 GHz to 14 GHz (according to FCC). As a next step, we placed our antenna at different X-Y positions, and we applied the CMI algorithm proposed to create a 2D image of the tumor. This technique is able to detect tumors breast with many advantages such as low cost, non-invasive radiation compared to the worldwide screening systems.

ACKNOWLEDGEMENTS

We thank the members of the laboratory (I + D + i of Telecommunications) in the engineering department of communication, University of Cantabria in Spain for their cooperation.

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