UWB Microwave Radar Imaging for Detection and Discrimination of Benign and Malignant Breast Tumors Using Circularly Polarized Antennas

Richard Torrealba-Meléndez, José Luis Olvera-Cervantes, and Alonso Corona-Chávez
Electronics Department
Instituto Nacional de Astrofísica, Óptica y Electrónica, INAOE.
Tonanzintla, Puebla, México.
r.torreal@ieee.org

***Abstract*— This paper presents an Ultra Wide Band radar imaging system for detection and discrimination of benign and malignant breast tumors using circularly polarized antennas. The system was tested using a breast phantom with similar dielectric proprieties of a breast. Two tumors were placed inside the breast phantom one malignant and another benign. Furthermore a comparison between linear polarization and circular polarization was carried out. We observed that with circular polarization it was possible to distinguish between the malignant and benign tumors due to its higher sensitivity to small dielectric contrast difference as well as its higher resolution capability compared to linear polarizations.**

Keywords-component; Breasts cancer, circular polarization, dielectric contrast, microwave imaging, ultra wide band.

I. INTRODUCTION

In recent years there has been a great interest in Ultra-wide band (UWB) radar imaging, to detect breast cancer tumors [1]-[3]. In order to improve the tumor detection the Ultra-wide band (UWB) standard (3.1 GHz to 10.6 GHz) offers a good solution as more than 7 GHz of instant bandwidth are available [4]. However all the reported systems suffer from fading cross section (RCS) due to the multiple boundaries of different tissues that compose the breast. The RCS fading problem in a radar imaging system is due to the use of linearly polarized (LP) antennas for transmission and reception. Electromagnetic scattering in LP systems for naturally occurring objects, which often have multiple boundaries of different materials, shapes, and sizes, tend to have a change of polarization at the interfaces. Hence, the receiver antenna does not have a natural alignment to the polarization angle of the scattered wave. To overcome this problem in [1] they applied a rotation of the receiver antennas to change electric field polarization, this implies to take several measurements and an increase in processing time. Therefore, to implement a robust UWB system imaging to detect and discriminate benign and malignant breast tumor, circularly polarized antennas should be included. It is only recently that circularly polarized (CP) antennas can provide good axial ratios (AR) across the full UWB frequency range [5].

This work presents a monastic UWB microwave imaging radar to detection and discrimination between malignant and benign breast tumors using circularly polarized antennas in the full UWB spectrum. It is important to highlight that in the literature does not exist a previous work that uses circular polarization in UWB radar imaging for breast cancer detection. The reported systems [2],[3] were tested using a breast phantom conformed by oil and flour for the fat tissue and a copper pipe for the tumor, this breast phantom provides a simple approximation of the breast. To verify the robustness of the system, it was tested using a breast phantom based on [6], inside this phantom two tumor were placed one benign and the other malignant. The full architecture of the breast phantom will be presented in this paper. It will be experimentally demonstrated that the use of circular polarization enhances the sensitivity to the dielectric contrasts of the UWB compared to vertical and horizontal polarizations.

II. EXPERIMENTAL SYSTEM

The configuration of the proposed UWB microwave is formed by a mechanical system that controls the rotation of the breast phantom with steps of $\Delta\theta=7.2°$. The antenna used in this work is circularly polarized and operates in the full UWB frequency range, the antenna is connected to a vector network analyzer (VNA) which measures the reflection coefficient (S11), with frequency steps of 5MHz. Finally the data processing is performed on a computer. The antenna was placed at 2cm to the breast phantom.

A. Circular polarization antenna

The proposed circularly polarized antenna is composed of a feeding network and an array of four Vivaldi antennas. The schematic of the feed network and antenna array is shown in Fig. 1. The feed network consists of a 90° 3dB hybrid coupler and two Wilkinson power dividers. The proposed circularly polarized antenna is constructed using an array of four linear polarized (LP) elliptically tapered antipodal Vivaldi antennas.

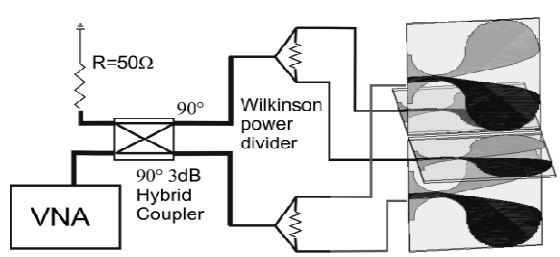

Fig. 1. Schematic of the feed network and antenna array.

978-1-4799-4608-2 / $31.00 ©2014 IEEE

The antenna array is shown in Fig. 1. The substrate used for the design is 1.58-mm-thick Rogers 4003C. The size of one antenna is 8 cm X 8 cm. Fig. 2, shows the measured return loss (S11) in a VNA of the antenna array, which is better than -10dB from 1.4 to 10.6 GHz. The measured axial ratio is illustrated in Fig. 3. The axial ratio is below 3dB in the full UWB frequency range.

B. Breast Phantom characteristics.

The breast phantom is composed of a mixture of 80% oil and 20% of aqueous gelatin solution which correspond to adipose fat tissue (ε_r=9). Moreover the malignant tumor is made with a mixture of 10% oil and 20% of aqueous gelatin solution (ε_r=55). And the benign tumor (fibro glandular tissues) is made of a mixture of 10% of oil and 90% of aqueous gelatin (ε_r=45) [6]. According to [6] dielectric contrast difference between malignant and benign tumor is close to 10.

The phantom has a diameter of 10 cm, and height of 14cm, the tumors have a diameter of 1.8cm. Considering a cartesian reference system, the breast phantom is centered at (x = 0cm, y = 0cm), the location of the malignant tumor is (x = 4cm, y = 1cm) and the benign tumor location is (x = -3, and = 1). Fig. 4 shows a photograph of the constructed breast phantom and the location of the tumors.

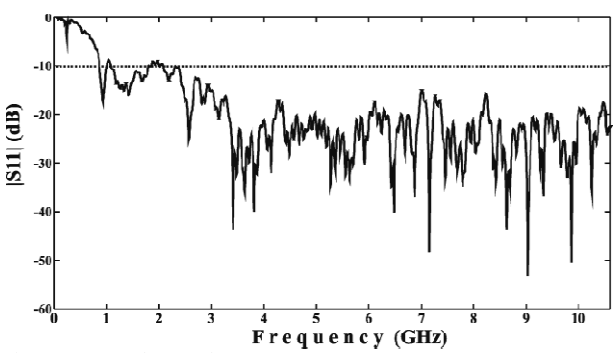

Fig. 2. Measured return loss.

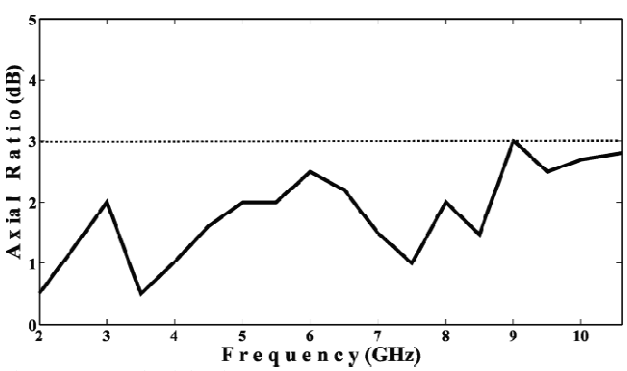

Fig. 3. Measured axial ratio.

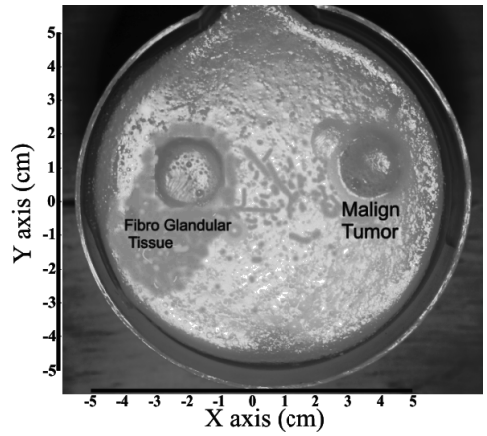

Fig. 4. Breast phantom with a benign and malignant tumor

C. Imaging algorithm.

Firstly all the measures need to be calibrated by subtracting the measurement registered when only the antenna is present [6]. With this calibration we can remove undesired reflection caused by cables, the feeding network and antenna. Subsequently a Hamming window is applied to every measurement, which eliminate undesired reflections. Finally the inverse Fourier transform (IFT) is used to transform the measured reflection coefficients in the time domain. The reflection coefficients in the time domain are grouped in an image matrix *I* with dimensions ($M \times N$), where M denotes the points used to compute the IFT and N is the number of measurements.

III. MEASUREMENT RESULTS

In order to demonstrate that circular polarization improves the resolution of the system, three images were obtained, one with circular polarization (CP) one with vertical (VP) and one horizontal polarization (HP). The images with vertical and horizontal polarization were obtained using one Vivaldi antenna. Fig. 5 shows the resulting images. In the image obtained with VP and HP, (Fig. 5.a and 5.b), we can see the presence of two tumors, but it is difficult to see the contrast difference (CD) between benign and malignant tumor, this difference contrast between malignant and benign tumor is only about 0.05 for vertical and horizontal polarization. In a real case scenario where no information about the tumors is available, these results would not be helpful to determine which would be the malignant or benign tumors However for circular polarization (Fig. 5.c) we can distinguish without difficulty the CD between the two tumors, this is over 0.2 more than double than horizontal and vertical polarization. In this case the location and shape of the tumors are close to the real ones. A way to quantify the error location of the tumors is calculating the distance between the right location of the tumors and the measurement location. The calculation of the error location is present in Table I, where we can see that the circular polarization has the minor error location compared with the other polarizations.

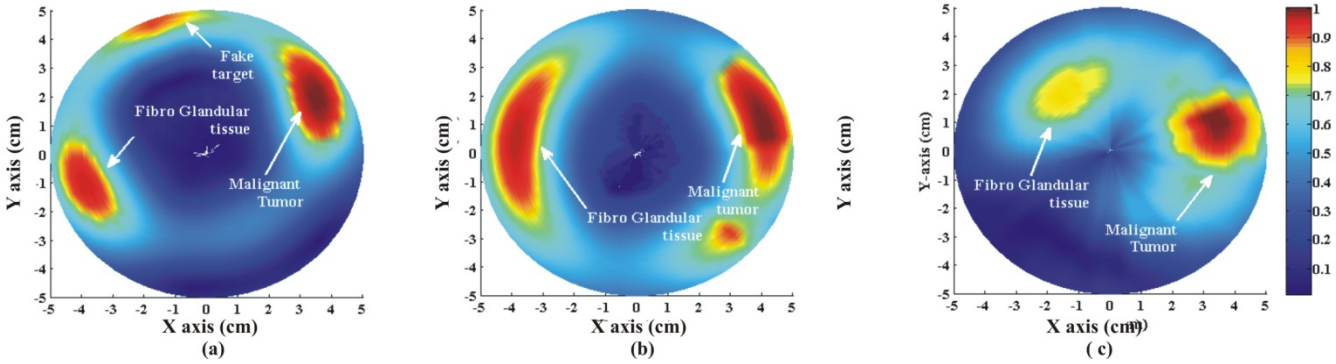

Fig. 5. 2D imaging results. (a) Image with VP (b) Image with HP, (c) Image with CP.

TABLE I. MEASUREMENTS OF SIZE, LOCATION AND DIFFERENCE CONTRAST

Polarization	Size (cm)		Location (x_r, y_r)		Error Location (cm)		CD
	M	*B*	*M*	*B*	*M*	*B*	
VP	2	2	(4.5,1)	(-5,-1)	0.25	2	0.05
HP	4	3	(4.5,1)	(-4.5,1)	0.25	1.5	0.05
CP	2	2	(4,1)	(-2,1)	0	1	0.2

TABLE II. COMPARISON OF UWB RADAR SYSTEMS FOR BREAST CANCER DETECTION.

Reference	Polarization	Frequency Range	Antenna Rotation	Detection of malignant and benign tumor
This work	Circular	3.1-10.6 GHz	No	Yes
[1]	Linear	1-9 GHz	Yes	Yes
[2]	Linear	2.4-12 GHz	No	Not reported
[3]	Linear	3.1-6.3 GHz	No	Yes

From the images we can obtain the dimensions and locations of the tumors, as well as their contrast difference (Table I.). This experiment shows that circular polarization; improves resolution of the system and can provide a good diagnostic for breast cancer compared with the linear polarization. We can say that the circular polarization enhances the sensitivity of the microwaves to dielectric contrast difference; this would be helpful when the contrast difference between objects or tissues is small.

IV. CONCLUSION

An UWB microwave imaging radar with circularly polarized antenna for breast cancer detection has been presented. The system is capable to detect and distinguish with clarity between malignant and benign tumor .Furthermore we have shown that the circular polarization enhances the sensitivity of the UWB radar system to small dielectric contrast difference.

REFERENCES

[1] J. E Bridges, S. Hagness, A. Taflove, and P. Evanton., “Microwave discrimination between malignant and benign breast tumor” United Stated Patent 6,421,550 B1. 2002.

[2] S. A. AlShehri, S. Khatun, A. B. Jantan, R. S. A. Raja Abdullah, R. Mahmud, and Z. Awang, "3D experimental detection and discrimination of malignant and benign breast tumor using nn-based UWB imaging system," *Progress In Electromagnetics Research*, Vol. 116, 2011, pp. 221-237,. doi:10.2528/PIER11022601 .

[3] S.M. Salvador, and G. Vecchi, , "Experimental Tests of Microwave Breast Cancer Detection on Phantoms," *Antennas and Propagation, IEEE Transactions on* , vol.57, no.6, Jun 2009, pp.1705-1712, doi: 10.1109/TAP.2009.2019901.

[4] Federal Communications Commission FCC 02-48, 2002.

[5] X.L. Bao and M.J. Ammann, "Printed circularly polarized antenna with ultra-wide axial-ratio bandwidth," IET *Microwaves, Antennas Propag.,* vol. 5, no .9, Jun 27 2011, pp.1089-1096, doi: 10.1049/iet-map.2010.0493.

[6] M. Lazebnik, E. L. Madsen, G. R. Frank and S. C. Hagnnes, “Tissue-mimicking phanthom materials for narrowband and ultrawideband microwave applications” Phys. Med. Biol. Vol 50, pp 4245-4258, doi:10.1088/0031-9155/50/18/001.