Proceedings of Asia-Pacific Microwave Conference 2007

A Flexible UWB Elliptical Slot Antenna with a Tuning Uneven U-shape Stub on LCP for Microwave Tumor Detection

Negar Tavassolian, Symeon Nikolaou, Manos M. Tentzeris
Department of Electrical Engineering
Georgia Institute of Technology
Atlanta, GA
negar@ece.gatech.edu

Abstract— **In recent years, pulsed microwave imaging in the gigahertz range has been suggested as a promising complementing methodology to the currently existing detection and imaging techniques. This technique is based on significant electrical contrast between the cancerous and healthy breast tissue in the microwave range. In this paper, we investigate tumor detection capabilities of the CPW-fed Elliptical Slot Antenna with a Tuning Uneven U-shape Stub on flexible liquid crystal polymer (LCP) in the UWB Microwave range of frequencies. This topology features excellent capabilities to detect tumors of different sizes and orientations and could potentially revolutionize the detection of ultra-small tumors through the use of antenna-array conformal diagnostic "pouches".**

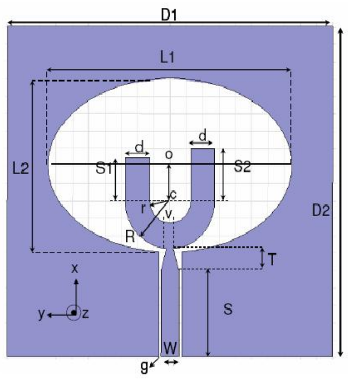
Keywords-microwave tumor detection; breast cancer; gland; UWB antennas; LCP; pulsed microwave imaging

I. INTRODUCTION

The most widely used method in breast cancer detection is X-ray mammography. This method has been in use for over 30 years [1]. However, this method has several limitations, especially when dealing with younger women who have dense breast tissues. These limitations originate from the fact that there is a small contrast between healthy and diseased breast tissue at X-ray frequencies.

Microwave breast cancer detection is primarily motivated by the large contrast between the electrical parameters of breast and tumor tissues. In this method, an antenna element is used to send an ultra-short pulse into the breast and then to collect the backscattered signal. Information about the size and location of the tumor can be obtained from this backscattered signal. Microwave attenuation in breast tissue is low enough for this purpose [2]. Another advantage of this method is that it would be non-ionizing and non-invasive. For breast imaging, we are interested in the 1-11GHz range; which guarantees a balance between the two contradictory needs of better spatial resolution (higher frequencies) and better penetration depth (lower frequencies) [3].

The antenna radiator used in this work is a CPW-fed Elliptical slot antenna on LCP reported in [4]. This uniplanar compact antenna has return loss below -10dB and consistent radiation pattern in the UWB range of frequencies (1-12GHz). The antenna has a relatively high gain of 5dBi at 4GHz, which allows for the directive illumination of specific body areas. The antenna is fabricated on conformal LCP which makes it desirable for this particular application, since our final goal would be to conform the antenna to the breast shape. The fabricated antenna is shown in Fig. 1. The return loss is shown in Fig. 2. The overall size of the antenna is only 40mm× 38mm.



D1	40 mm	r	2.5 mm
D2	38 mm	R	5.5 mm
W	2.2 mm	S1	5 mm
g	0.3 mm	S2	6 mm
v	0.9 mm	d	3 mm
S	9.9 mm	L1	30 mm
T	2.5 mm	L2	20 mm
OC	4.1 mm		

Figure 1. Antenna geometry [4]

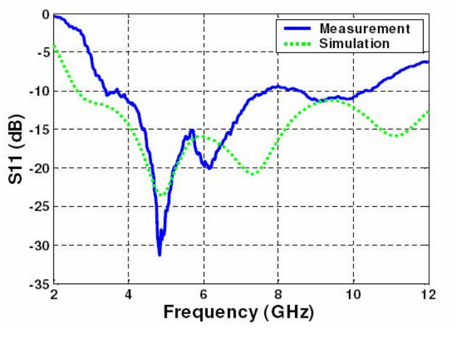


Figure 2. Return loss measurement and simulation [4]

1-4244-0749-4/07/$20.00 @2007 IEEE.

As a first-order benchmark, we tested the detection performance of this antenna for different orientations close to a realistic hemispherical breast model. The commercial software "Microstripes" [5] -based on the Transmission Line Matrix (TLM) method- was used to develop the breast model and to calculate the tumor response of tumors with different diameters located inside a gland. The excitation pulse is a wideband pulse centered at 6GHz with a bandwidth of 10GHz (1-11 GHz). Based on this model, we ran 3 sets of simulations. First, we rotated the antenna around the breast to view the effect of different gland arrangements on tumor response. The simulation was repeated for two different tumor diameters (2mm and 4mm). Next, we placed the antenna at a fixed position and changed the electrical parameters of the tumor-containing gland to examine the sensitivity of the tumor response to gland parameters. Finally, a preliminary study of an array configuration consisting of three antenna elements was performed.

II. Geometry of the Problem

The breast model used is based on previous work [6], [7]. However, it is expanded based on recent biological images and data from the breast [8],[9]. The model is shown in Fig. 3. More tissue types are included in this model with realistic geometries and configurations. The breast inhomogeneity is more pronounced compared to the previous models. Also, updated electrical parameters for the tissues are used based on [10],[11]. The electrical parameters for different tissue types are listed in Table I. The breast model is considered to be a hemisphere with a base diameter of 14cm. The skin is a 2mm thick layer. The glands are randomly scattered throughout the fat tissue and resemble real-case fibroglandular tissue in shape and location. Ducts are assumed to be cylindrical with realistic configuration.

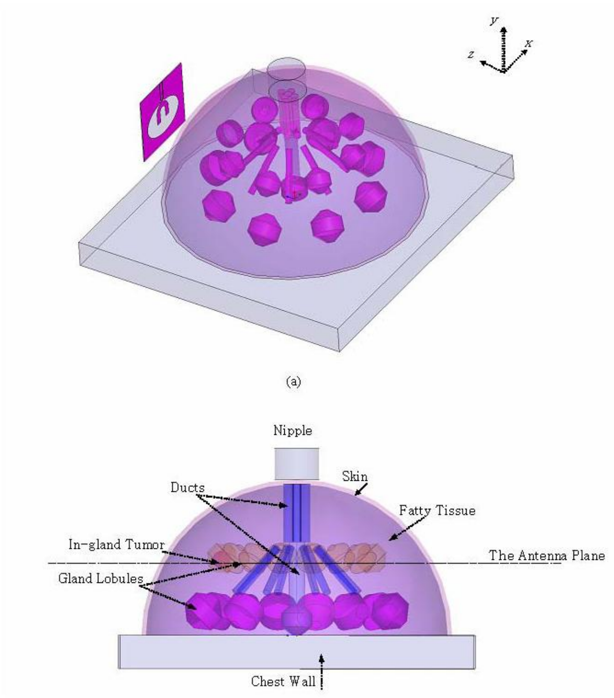


Figure 3. Hemispherical breast model. (a) general view showing the antenna near the model (b) side view.

Table I: Dielectric parameters of breast tissues [10],[11].

	ε_r	σ (S/m)
Skin	34.7	3.89
Fatty Tissue	9.8	0.4
Fibro-glandular Tissue	21.5	1.7
Ducts	37.96	4.5
Chest wall	55.56	6.5
Nipple	45	5
Tumor	50.7	4.8

III. Sensitivity to Gland Arrangements

Without loss of generality, we assume that the antenna is located at mid-breast plane, 5mm away from the skin and is rotated (azimuth) to eight different locations on this plane defined by increments of 45° in the angle φ (Fig. 4). The tumor is located inside a gland on this plane, 3.5 cm off the center of the breast. In all of this work, the tumor is considered to be inside a gland, since this is what happens in real cases (ductal carcinoma). Tumor responses for different antenna locations and for two different tumor sizes (diameters of 2mm and 4mm) are shown in Fig.5. The tumor response is defined and calculated in the following manner: First the complete model with the tumor present is radiated, and the back-scattered signal is collected at the antenna location. Next, the breast model without the tumor present is excited and the back-scattered signal is again collected. The second signal is subtracted from the first, and the maximum absolute value of the resulting signal is normalized to the incident power and defined as the tumor response (in dB). It is seen that the tumor response level for this antenna is much higher than for similar antennas [7]. The response seems realistic even for a tumor with a 2mm diameter (a tumor in a very early stage). The tumor response decreases as the antenna moves away from the tumor, although the return variation between the extreme cases of φ=0° (closest to the tumor) and φ=180° (furthest distance from the tumor) do not differ more than 10dB for all tumor sizes, showing that the antenna indeed has the ability to detect tumors at all locations.

IV. Sensitivity to Gland Parameters

In this part, we examine the sensitivity of the tumor response to variations in electrical parameters of the breast tissues. This variation in generally observed in different breast models.

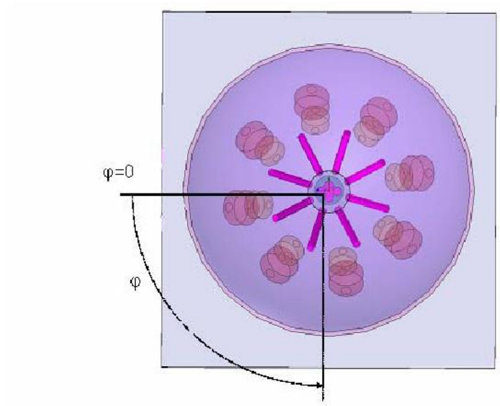
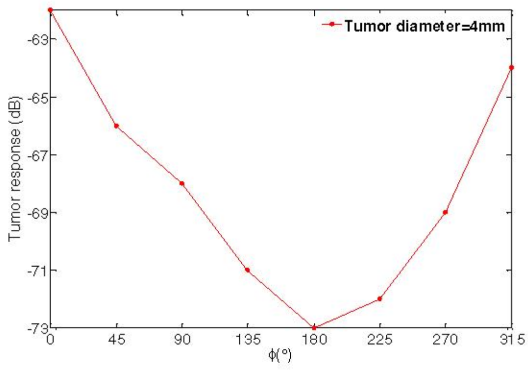
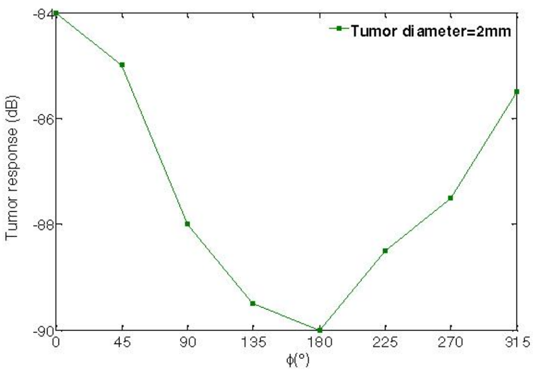


Figure 4. Top view (x-y plane) of the breast model shown in Fig.3. The antenna is rotated to eight locations, defined by increments of 45° of the angle φ.



(a)



(b)

Figure 5. Tumor response levels for different antenna locations. (a) Tumor diameter=4mm. (b) Tumor diameter=2mm.

We first vary the dielectric constant of the tumor-containing gland within ±25% of its nominal value ($16<\varepsilon_r<26$) to see the effect on the tumor response for a tumor diameter of 4mm Results are shown in Fig. 6. Tumor response changes only about 7dB for the permittivity ranges above, and decreases (as expected) as the permittivity of the gland approaches that of the tumor. For comparison, we then vary the dielectric constant of all the breast glands within ±25% of their nominal values. Fig. 6 also shows the results for this case. It is seen that the tumor response variation follows similar pattern is both cases. When changing the permittivity of all the glands, variation in tumor response is larger (almost 12dB overall). However, the tumor-containing gland by itself has a considerable effect on the variation of the tumor response.

Next, we examine the effect of conductivity variation on the tumor response. We change the conductivity of the tumor-containing gland within ±25% of its nominal value ($1.2<\sigma<2.2$) and observe the tumor response for a tumor diameter of 4mm. Results are shown in Fig.7. Tumor response decreases as the conductivity increase (as expected). However, only 2.55 dB change in tumor response is observed over the whole range. For comparison, the same graph shows tumor response variation when changing the conductivity of all breast glands. Tumor response varies about 4.6 dB. These results show that the tumor response is not affected considerably by variations normally seen in the electrical parameters of glands.

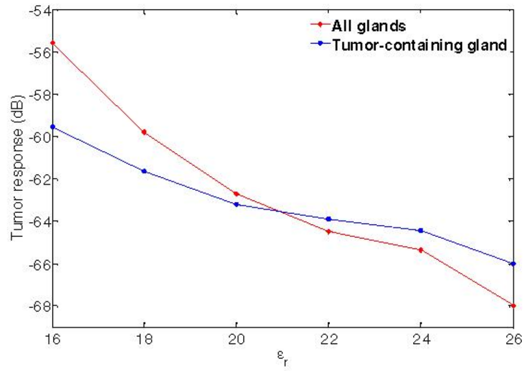


Figure 6. Comparison of tumor response variation with permittivity of all glands and permittivity of tumor-containing gland only (σ=1.7 S/m)

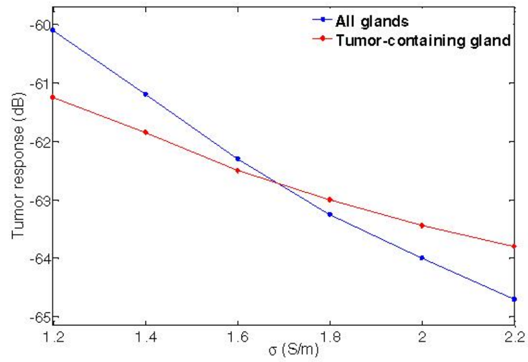


Figure 7. Comparison of tumor response variation with conductivity

V. PRELIMINARY STUDY OF A 3-ELEMENT ARRAY

In order to examine the mutual effect between antennas forming an array, we place 3 antennas around the breast with an angle of 45° between neighboring elements. Array configuration is shown in Fig. 8. Antenna (1) is excited and antennas (2) and (3) are passive. We record the tumor response for all antennas. The tumor is a sphere with a diameter of 4mm.

Table II shows tumor responses for all antennas. For comparison, we also show the tumor response for the case where each antenna is active and alone.

TABLE II: TUMOR RESPONSE DETECTED BY THE ANTENNAS SHOWN IN FIG. 6.

Antenna #	Tumor response of the antenna alone (active) (dB)	Tumor response (dB) Antenna 1: active Antennas (2) and (3): passive
1	-62	-64.23
2	-66	-97
3	-65	-95

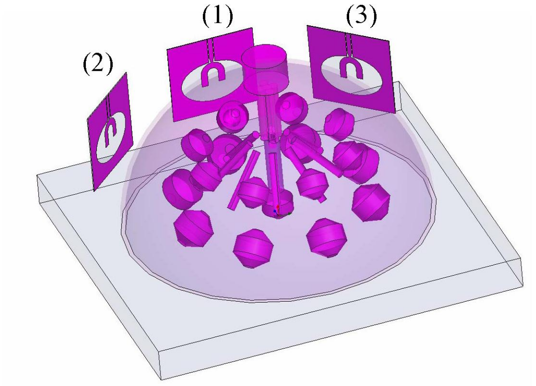


Figure 8. Array configuration for three antennas. (1) is excited, while (2) and (3) are kept passive. Tumor diameter is 4mm.

It is seen that the tumor response of the active element decreases less than 3dB when the passive elements are present. This shows the small effect of the passive elements on the detected tumor response of the active antenna. The passive elements receive a response which is almost -30dB less than their received response in active mode. These results suggest that mutual coupling, for an angular distance of 45° between adjacent antennas, has little effect on tumor response levels of this antenna. Also, this conclusion sets the foundation for the development of a conformal "pouch" of UWB antennas around the breast that would enhance the sensitivity of detection.

VI. CONCLUSION

The UWB elliptical slot antenna with tuning Uneven U-shape Stub on LCP shows realistic and detectable tumor response levels for all tumor sizes tested. The antenna shows low sensitivity to variations in gland electrical parameters and to different tumor orientations with respect to the antenna, demonstrating unique detection capabilities even for tumors below 2mm. This type of antenna elements have low mutual effect in the configuration analyzed in this work and could potentially lead to the development of "ultra-sensitive" diagnostic pouches around the breast, revolutionizing the breast detection capabilities.

ACKNOWLEDGMENT

The authors would like to thank GEDC and NSF Career Award for their support of this work.

REFERENCES

[1] http://www.breastcancer.org/

[2] C. Hagness, A. Taflove and J. E. Bridges, "Three-dimensional FDTD analysis of a pulsed microwave confocal system for breast cancer detection: Design of an antenna array element", IEEE Transactions on Antennas and Propagation, vol. 47, pp. 783–791, May 1999.

[3] X. Li, S.K. Davis, S.C. Hagness, D.W. van der Weide and B.D. Van Veen, "Microwave Imaging via Space-Time Beamforming: Experimental Investigation of Tumor Detection in Multilayer Breast Phantoms," IEEE Transactions on Microwave Theory and techniques ,vol.52, no.8, Aug. 2004.

[4] S. Nikolaou, G.E. Ponchak, J. Papapolymerou and M.M. Tentzeris, "CPW-fed Elliptical Slot UWB Antenna with a Tuning Uneven U-shape Stub on Liquid Crystal Polymer (LCP)", Proc. Of the 2006 ACES Conference, Miami, FL, March 2006.

[5] http://www.flomerics.com/microstripes/

[6] E.C. Fear and Michael Okoniewski, "Confocal Microwave Imaging for breast tumor detection: application to a hemispherical breast model", Microwave Symposium digest, 2002 IEEE MTT-S International, vol. 3, 2-7 June 2002, pp. 1759-1762.

[7] N. Tavassolian, H. Kanj and M. Popovic, "The Effect of Breast Glands on Microwave Tumor sensing with Dark Eyes Antenna", IEEE AP-S International Symposium, Albuquerque, New Mexico, July 2006.

[8] Leon Schlossberg, George D. Zuidema, *The Johns Hopkins Atlas of Human Functional Anatomy*, JHU Press, 1997.

[9] Manfred Kaufmann, Jean Y. Petit, Ishmail Jatoi, *Atlas of Breast Surgery,* Springer, 2006.

[10] M. Converse, E. J. Bond, B. D. Veen, and S. C. Hagness, "A computational study of ultra-wideband versus narrowband microwave hyperthermia for breast cancer treatment", IEEE Transactions on Microwave Theory and Techniques, May 2006.

[11] M. Lazebnik, L. McCartney, D. Popovic, C. B. Watkins, M. J. Lindstrom, J. Harter, S. Sewall, A. Magliocco, J. H. Booske, M. Okoniewski, and S. C. Hagness, "A large-scale study of the ultrawideband microwave dielectric properties of normal breast tissue obtained from reduction surgeries," *Physics in Medicine and Biology,* Jan. 2007