ANTENNA ARRAY SYSTEMS FOR MICROWAVE IMAGING OF BREAST TUMORS *

M.A. Hernández-López[1], M. Quintillán-González[2], S. González-García[3], A. Rubio-Bretones[4], R. Gómez-Martín[5]

[1] Universidad de Salamanca, Dpto de Física Aplicada. Facultad de Ciencias. Pza de la Merced s/n. 37008. Salamanca. Spain.
Phone: 00 34 923 294400; Fax: 00 34 923 294584; E-mail: auximl@usal.es
[2] As (1) above, but E-mail: quinti@usal.es
[3] Universidad de Granada. Dpto de Electromagnetismo y Física de la Materia. Facultad de Ciencias. 18071. Granada. Spain.
Phone: 00 34 958 243224; Fax 00 34 958 242353; E-mail: salva@ugr.es
[4] As (3) above, but E-mail: arubio@ugr.es
[5] As (3) above, but E-mail: rgomez@ugr.es

ABSTRACT

A planar array of four resistively loaded Bow-Tie antennas has been designed to accurately detect and locate early-stage breast tumors. The array, printed on top of a dissipative substrate to improve its robustness and to decrease the mutual coupling between the elements, can freely rotate around the breast. Each single element of the array is excited in turn and the backscattered time signal is recorded in all of them. After transforming these signals into the frequency domain, they are shifted in time for every point inside the breast. They are then added coherently, to obtain a intensity function which is maximum at the points where backscattered signal comes from.

INTRODUCTION

Breast cancer is one of the most common type of cancer and a major cause of death among women. More than 180,000 women are diagnosed with breast cancer each year in Europe. However, nearly 70 % of them can be cured if the tumor is detected in time.

X-ray mammography is currently the most effective method of diagnosis, but this technique presents important limitations (exposure to ionizing radiation, significant false positive-negative rate, etc.). An recent interesting alternative is the use of microwaves [1-4]. The high contrast between the dielectric properties of breast tumor tissue and normal breast tissue allows their image reconstruction from the backscattered signals when they are illuminated with a transient microwave pulse.

In this work we illustrate the use of a four-element planar array of resistively loaded Bow-Tie antennas which are placed in four different locations around the breast to accurately detect and locate the position of a tumor arbitrarily placed inside the breast (Fig. 1).

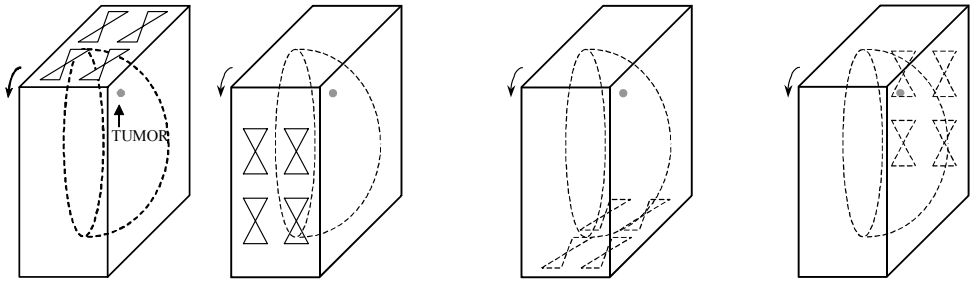

Figure 1. Planar array configuration rotating around the breast

This configuration has been considered instead of a single planar array above the breast, because the mobility of the array permits it to come close to every possible position of the tumor inside the breast.

* This work was supported in part by the spanish Ministerio de Ciencia y Tecnología - FEDER, under the Project TIC 2001-3236-C02-02.

An in-house simulation tool based on the Finite Difference Time Domain method with Perfectly Matched Layer absorbing boundaries (FDTD-PML) has been used to analyze the whole problem [5][6].

PROBLEM DESCRIPTION

The array used in this work consists of four Bow-Tie antennas printed on top of a 4 mm thick dissipative substrate with ε_r =1, σ =10 S/m (Fig. 2).

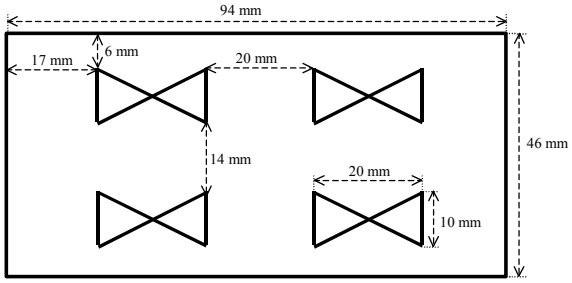

Figure 2. Planar Array geometry

In order to eliminate unwanted reflections from the ends of the antennas and, therefore, enhance their broadband characteristics, each element (Fig. 3) has been loaded with a linear resistive profile whose conductivity is given by

$$\sigma(x_c) = 10\left(1 - \frac{x_c}{h}\right) \qquad S/m \tag{1}$$

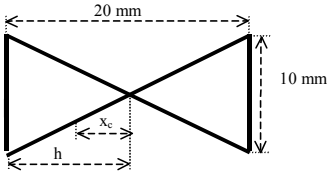

Figure 3. Bow-Tie antenna.

Each antenna is individually fed at its center by means of a coaxial line with a differentiated Gaussian pulse with a frequency range between 1.5 GHz and 10.5 GHz (full-width half-maximum).

The computational model of the breast consists of an 80 mm diameter semisphere, on top of a half-space, covered by a 2 mm-thick layer of skin. The tumor is a 4 mm diameter sphere, arbitrarily located inside the breast. The plane of the array, which can freely rotate around the breast, is maintained 6 mm separated from the skin. Both the breast and the antenna array are in free space.

A Debye model in the frequency domain is assumed for the breast tissue and the tumor

$$\vec{D}(\omega) = \left(\varepsilon(\omega) + \frac{\sigma}{j\omega}\right)\vec{E}(\omega) \quad , \quad \varepsilon(\omega) = \varepsilon_0\varepsilon_{r\infty} + \varepsilon_0\frac{\varepsilon_{rs} - \varepsilon_{r\infty}}{1 + j\omega\tau} \tag{2}$$

The electrical parameters for the normal breast and the half space are [3] ε_{rs}=10, $\varepsilon_{r\infty}$=7, σ_s=0.15 S/m and τ=6.4 ps, and for the tumor ε_{rs}=40, $\varepsilon_{r\infty}$=4, σ_s=0.7 S/m and τ=6.4 ps. The skin is modeled as a lossy dielectric with ε_{rs}=$\varepsilon_{r\infty}$=36, σ_s=4 S/m.

DETECTION ALGORITHM

In order to obtain a microwave image of the breast, each antenna is fed individually and the voltage drop across its feed created by the backscattered response is recorded at all the antennas, for the four scan positions shown in Fig. 1, obtaining a total of N=64 signals. These signals are subsequently calibrated by subtracting the signal recorded when the tumor is not present [3].

The low coupling between the antennas (less than –50 dB in the whole frequency range) which is further reduced when the dissipative substrate is employed (up to -70 dB for some frequencies), ensures that the signal recorded in an element when a different one is excited mainly comes from the scattering structure and not from the excited element.

To locate the tumor position, the N recorded callibrated signals $\Psi_i(t)$ are transformed into the frequency domain $\psi_i(\omega)$, and each harmonic component $\psi_i(\omega)\ \exp[j\omega t]$ is delayed at each point inside the breast $\vec{r}$, by a time $t_{\max} - t_{i,ret}(\vec{r},\omega)$, obtaining

$$\psi_i(\omega)\ \exp\left[j\omega\left(t-(t_{\max}-t_{i,ret}(\vec{r},\omega)\right)\right] \quad , \quad i=1,...,N \tag{3}$$

where $t_{i,ret}(\vec{r},\omega)$ is the time needed for a signal *i* to make the round-trip from point $\vec{r}$ inside the breast to the recording antenna at each frequency, which depends on the frequency because of the breast dielectric dispersivity, and where $t_{\max} = \underset{\forall i,\forall \vec{r},\forall \omega}{Max}\left\{t_{i,ret}(\vec{r},\omega)\right\}$

Then, for every point inside the breast, we build a time function of the form

$$\Psi_i^{\ shift}(\vec{r},t) = F^{-1}\left\{\psi_i(\omega)\ \exp\left[-j\omega\left(t_{\max}-t_{i,ret}(\vec{r},\omega)\right)\right]\right\} \quad , \quad i=1,...,N \tag{4}$$

where F^{-1} stands for the inverse Fourier transformation. These functions $\Psi_i^{\ shift}(\vec{r},t)$ will contribute coherently to their total sum $\Psi^{added}(\vec{r},t) = \sum_{i=1}^{N}\Psi_i^{\ shift}(\vec{r},t)$ if the point $\vec{r}$ is actually the point where the tumor is located. An intensity function $I(\vec{r})$ can be assigned to each point as

$$I(\vec{r}) = \frac{1}{T}\int_{t_{\max}}^{t_{\max}+T}\left[\psi^{added}(\vec{r},t)\right]^2 dt \tag{5}$$

where T is the time width of the incident signal. The intensity (5) is maximum at the tumor region and allows us to map both the breast and the tumor.

RESULTS

Two different positions of the tumor have been used to test our detection system. In the first case, the tumor was located in a symmetrical position 36 mm under the skin (at (x, y, z) = (70, 40, 70) mm). In the second case, the tumor was located in a non-symmetrical position at (x, y, z) = (60, 42, 88) mm. Figures 4 and 5 show 3D colormaps of the above defined intensity function (5), where the position of the tumor can be precisely observed. For the first case, the maximum of the intensity function is obtained at (70, 42, 70) mm and for the second case it is obtained at (62, 42, 82) mm, which closely matches the real positions, taking into account that the tumor radius is 2 mm.

CONCLUSIONS

A planar array of four resistively loaded Bow-Tie antennas has been used to accurately detect and locate malignant breast tumors at microwave frequencies. Since the mutual coupling of the antennas is very low, we have been able to excite every element in turn and record the backscattered signal in all of them. By recording the response in four different positions rotated around the breast, it is possible to accurately locate the position of the tumor, by summing up coherently all the responses, and taking into account the different phase speeds of each frequency of the incident field inside the breast.

REFERENCES

[1] S. C. Hagness, A. Taflove, and J. E. Bridges, "Two-Dimensional FDTD Analysis of a pulsed Microwave Confocal System for Breast Cancer Detection: Fixed-Focus and Antenna-Array Sensors", *IEEE Trans. on Biomedical Eng.,* vol.45. pp. 1470-1479, Dec. 1998. Correction, p. 364, March 1999.

[2] E. C. Fear, and M. A. Stuchly, "Microwave System for Breast Tumor Detection", *IEEE Microwave and Guided Wave Letters*, vol.9, Nov. 1999.

[3] X. Li, and S. C. Hagness, "A confocal microwave imaging algorithm for breast cancer detection ", IEEE Microwave and Wireless Components Letters, vol. 11, pp. 130-132, March 2001.

[4] M. Fernández Pantoja, S. González García, M. A. Hernández-López, A. Rubio Bretones, R. Gómez Martín, "Design of an Ultra-Broadband V-Antenna for microwave detection of breast tumors", *Microwave and Opt. Techn. Lett.* (In press)

[5] K. S. Yee,"Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media", *IEEE Trans. Antennas Propagat.*, vol. 14, pp. 302-307, May 1966.

[6] J.P. Bèrenger, "A Perfectly Matched Layer for Absorption of Electromagnetic Waves", *IEEE Trans. Antennas Propagat.*, vol. 44. pp. 110-117, Jan. 1996.

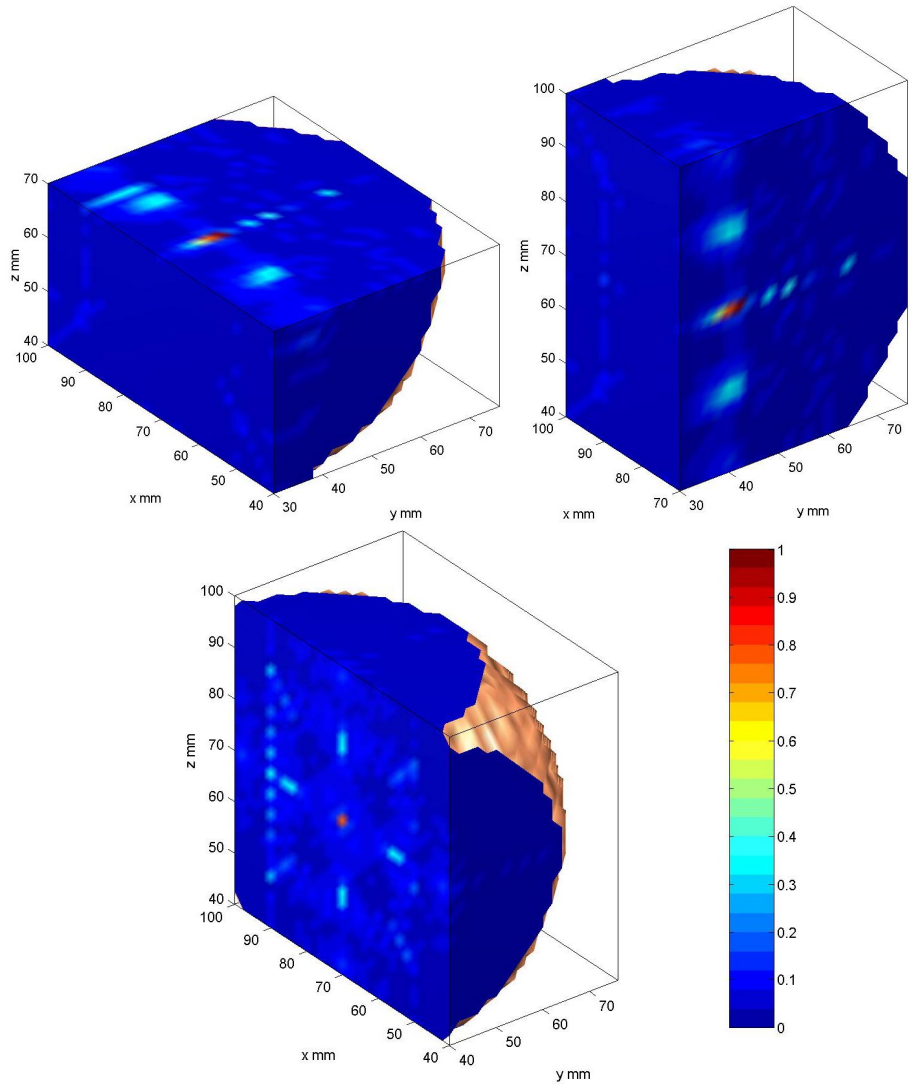

Figure 4. 3D Breast image (three different sections). Tumor position (x, y, z) = (70, 40, 70) mm.

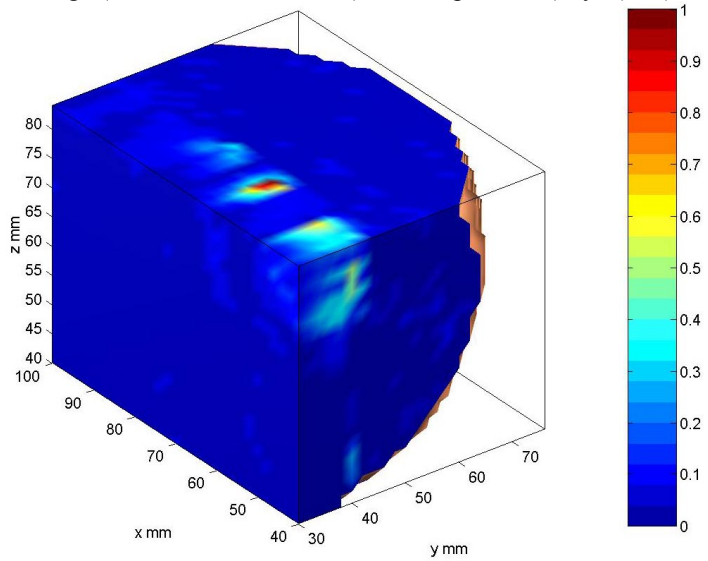

Figure 5. 3D Breast image. Tumor position (x, y, z) = (60, 42, 88) mm.