Two Multiband Uniplanar Antennas for Microwave Breast Imaging

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Abstract – **Two uniplanar monopole antennas are examined as radiating elements for microwave breast imaging. The first uniplanar antenna comprises a printed design with three overlapping ellipses operating at multiple bands over the frequency range from 0.9 to 7 GHz. The second design is based on the first one, features two overlapping ellipses and more compact dimensions, and operates in multiple bands from 1.3 to 9 GHz.**

Index Terms – **multiband antenna, monopole patch antenna, microwave breast imaging**

I. INTRODUCTION

During the last two decades, microwave imaging has been examined as a diagnostic modality for breast cancer, as it offers the possibility for non-ionizing detection of tissue malignancies. Although mammography is a very popular diagnostic tool for breast cancer, its frequent use has been characterized controversial, especially on healthy women without any symptoms. The procedure is uncomfortable, in some cases even painful, and it suffers from false negative and false positive results, that appear in significant rates [1], as the contrast between healthy and malignant breast tissues is not always clear at X-ray frequencies [2].

Microwave tomography for breast imaging involves transmitting and receiving antennas, which illuminate the breast tissue and detect the scattered radiation respectively. Microwave imaging aims to measure the spatial allocation of the permittivity and in some cases the conductivity within the breast tissue [3], [4] by solving the electromagnetic nonlinear inverse scattering problem. The resulted contrast of the microwave breast image is presented as the ratio of the permittivity/conductivity of the scatterers (i.e. tumors) to the permittivity/conductivity of the healthy breast tissue [3].

The antennas of a Microwave Breast Imaging (MBI) system present a fundamental contribution to the imaging efficiency and they should cover a range of requirements. Regarding the operating band, a wide range of frequencies is required: lower frequencies (preferably below 1 GHz) penetrate into the tissue, while higher frequencies improve the resolution. However, high frequencies are significantly attenuated inside breast tissue. Moreover, frequencies higher than 10 GHz are strongly reflected by skin tissue [5]. The lower frequency of operation is also defined by the acceptable size of the antenna that is suitable for the practical application and the compactness of the MBI system.

Different types of antennas have been used for breast microwave imaging in the literature: wideband antennas, ultra wide-band antennas and antennas operating at multiple bands. Generally, Ultra Wide-Band (UWB) antennas for near-field imaging are very attractive candidates for microwave breast imaging systems [6]–[14]. All of the above-mentioned show that the UWB antennas found in MBI literature are operating at frequencies above 2 GHz [6]–[15] with a few exceptions. For example, Al-Joumayly *et al.* [16] immersed in sunflower oil a 29 mm x 28 mm slot-loaded patch antenna and measured resonances at 1.37, 1.95, and 2.90 GHz, whereas Ruvio *et al.* used a 14 cm x 5 cm antipodal Vivaldi antenna operating from 0.8 to 2.75 GHz [5].

In this paper, we propose two multiband uniplanar antennas with wide resonances spanning from 900 MHz to 9 GHz while radiating into a breast phantom. The first uniplanar antenna comprises three overlapping elliptical patches and produces a low frequency resonance at 900 MHz, whereas the second one is designed with smaller dimensions and exhibits its first resonance at 1.3 GHz. An array of such antennas will be placed around a hemispherical and a cylindrical chamber filled with the appropriate matching liquid in order to image the specimen (breast phantom or tissue), as shown in Fig. 1.

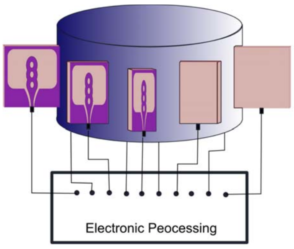

Fig. 1 Cylindrical alignment of the antenna array for the Microwave Breast Imaging System.

II. MATERIALS AND METHODS

The first antenna is a rectangular uniplanar antenna measuring 6 cm x 7 cm and was built on a 1.57 mm–thick substrate. The monopole is 5.3 cm long and it was designed as three overlapping ellipses with a smaller elliptical gap inside each one of them. This design has been chosen in order to introduce a smooth flaring of the CPW transmission line, and at the same time perturb the currents in a way that extends the operating bandwidth towards higher frequencies. The lower resonance was generated by extending the ground plane around the elliptical element in the form of a "window". The function of the window can be explained in two ways: (a) since both element and ground currents radiate, by extending the path traversed by the ground currents, lower order characteristic modes of the PCB chassis are excited, and (b) the window essentially transforms the antenna into a wide-slot antenna, which is larger than the initial monopole and hence resonates at a lower frequency. The geometrical configuration of the antenna is shown in Fig. 2.

The second uniplanar antenna was designed to have a more compact size: 4 cm x 5 cm and 1.57 mm thickness, whereas the monopole, which is composed by two ellipses with small elliptical gaps inside, is 3.7 cm long (Fig. 3).

The metallic parts of the antennas were simulated as perfect conductors. Alumina was chosen as the antennas substrate with a dielectric permittivity ε_r = 9.4 and loss tangent tanδ = 0.006.

Each antenna was tested radiating in free space (FS) and in the vicinity of a breast phantom. The breast phantom was modeled as a cubic segment of 1 mm skin layer and a 30 mm breast tissue layer with dielectric properties found in the literature [17]–[19]. The edge of the antenna was placed against a 4 mm layer of nylon (PA2200, ε_r = 3.8 and tanδ = 0.07). This material is used for constructing the chamber where the antennas will be attached to. Between the nylon layer and the breast phantom, a 10 mm–thick layer of matching liquid with electrical permittivity ε_r = 13 and tanδ = 0.01 was inserted.

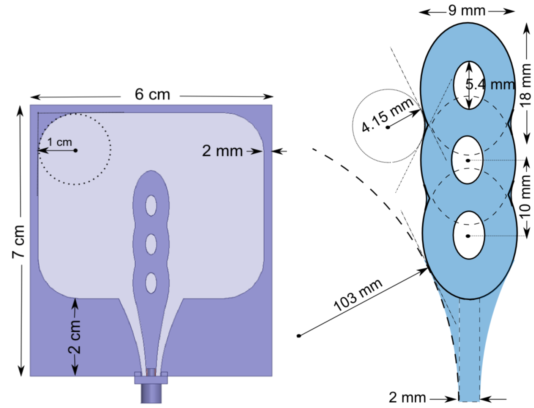

Fig. 2 Geometrical configuration of the triple-elliptical multiband patch antenna designed with three overlapping ellipses and a "window" with curved corners.

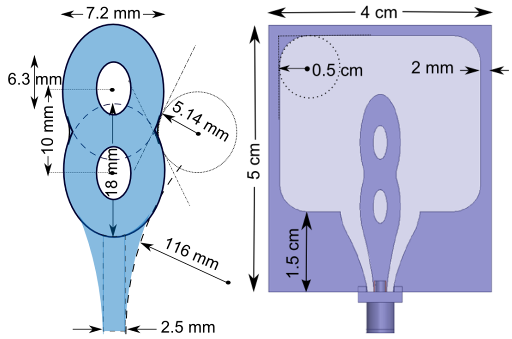

Fig. 3 Geometrical configuration of the double-elliptical multiband patch antenna designed with two overlapping ellipses and a "window" with curved corners.

III. SIMULATION RESULTS

The antenna was designed and simulated in ANSYS HFSS. The port impedance was set to Z_{port} = 50 Ω.

A. The triple-elliptical uniplanar antenna

The first antenna presents multiple operation bands when radiating against the breast phantom (Fig. 4): 0.9-2.4 GHz, and 4.0-6.0 GHz. Under FS conditions the resonances are shifted, whereas the first resonance at 900 MHz vanishes. The first resonance of the antenna in free space lies at 1.5 GHz.

The radiation efficiency of the antenna when radiating against the breast phantom is: from 0.5 to 0.8 in the first operating band (0.9- 2.4 GHz) and around 0.6 in the second operating band (4.0-6.0 GHz) (Fig.4). Its radiation pattern is a torus at the lower operating band (Fig. 6.a), whereas side lobes are formed along the y-axis at higher frequencies (Fig.6.c).

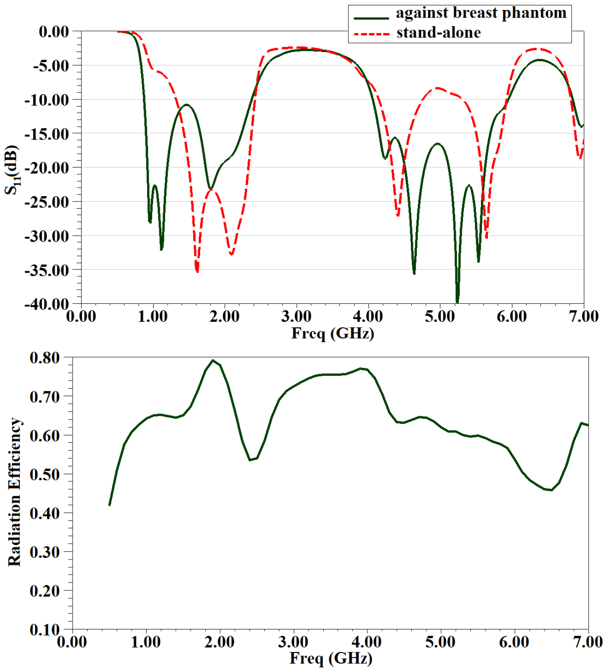

Fig. 4 Reflection coefficient of the triple-elliptical uniplanar antenna when radiating in free space and in the vicinity of the breast phantom and radiation efficiency of the antenna in the vicinity of the breast phantom.

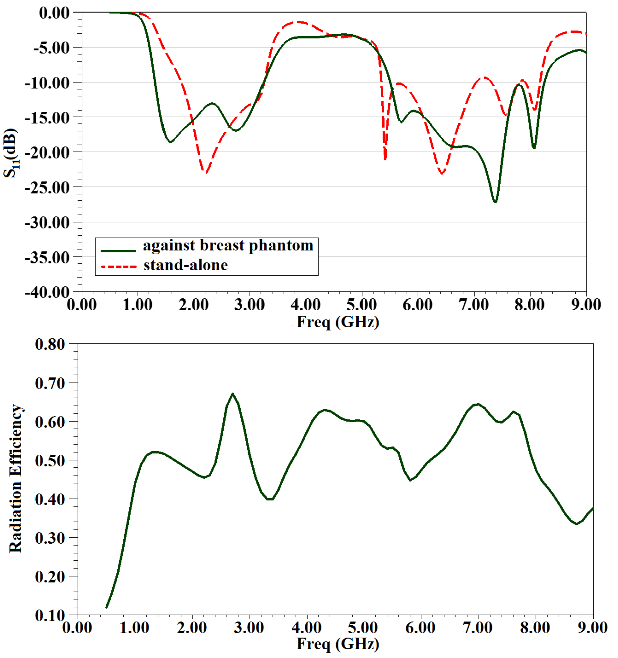

Fig. 5 Reflection coefficient of the double-elliptical uniplanar antenna when radiating in free space and in the vicinity of the breast phantom and radiation efficiency of the antenna in the vicinity of the breast phantom.

B. *The double-elliptical uniplanar antenna*

The double-elliptical antenna operates at 1.3-3.2 GHz and at 5.5-8.3 GHz (Fig. 5). Under FS conditions the first operating band becomes narrower with a resonance at 2.1 GHz.

The radiation efficiency of the antenna when radiating against the breast phantom is varying from 0.5 to 0.7 for the abovementioned operation bands (Fig. 5). Its radiation pattern is a torus in the lower operating band (Fig. 6.b) and side lobes along the y-axis are formed at higher frequencies (Fig.6.d).

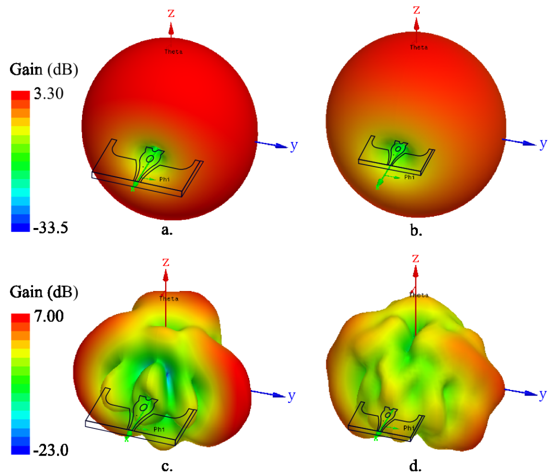

Fig. 6 Radiation patterns at 2 GHz of (a) the triple-elliptical antenna with 3.3 dB gain, and (b) the double-elliptical antenna with 2.86 dB gain. (c) Radiation pattern at 6 GHz of the triple-elliptical antenna with 7.00 dB gain. (d) Radiation pattern at 8.2 GHz of the double-elliptical antenna with 5.58 dB gain.

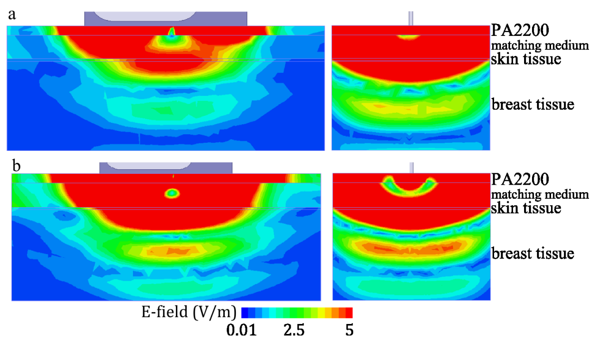

Fig. 7 E-field distribution inside the breast phantom of (a) the triple-elliptical antenna, and (b) the double-elliptical antenna. A layer of PA 2200 and a layer of matching liquid are placed between the breast phantom (skin and breast tissue) and the antennas.

C. *Antennas loaded by the breast phantom*

Since the antennas are intended to be used for microwave breast imaging, the penetration of the electromagnetic field into the breast tissue is examined. In Fig. 7, the distribution of the E-field inside the breast tissue caused by the antennas is presented. The electric field is normalized to 5 V/m and the input power of the antennas is 1 W. For the triple-elliptical multiband antenna the field decreases to 2.5 V/m at 2.9 cm inside the breast tissue measured from the skin tissue surface at 1.0 GHz, while for the double-elliptical multiband planar antenna the field decreases to 2.5 V/m at 2.5 cm at 1.3 GHz. At the antennas' higher operating bands the field decreases to 2.5 V/m at a depth of approximately 1 cm measured from the skin tissue layer.

IV. CONCLUSION

In this paper, we presented a multiband monopole antenna, which exhibits its first resonance below 1 GHz: the triple-elliptical uniplanar antenna fundamentally resonates at 900 MHz. This property is important for Microwave Breast Imaging, since a rough scanning of the breast tissue is required by the algorithms that solve the inverse scattering problem. Also, a more compact antenna with operating bands at 1.3-3.2 GHz and 5.5-8.3 GHz was presented.

Both the antennas are intended to be placed vertically on a spherical setup surrounding the breast phantom. Taking into consideration the antennas' mutual coupling, the vertical placement allows a 16 to 24 antenna array around the breast phantom. In addition, if needed, the small dimensions of the double-elliptical uniplanar antenna permit also positioning of the antennas "facing" the phantom, presenting similar performance characteristics. This setup, i.e. the antenna's large surface lying on the PA 2200 non-conductive chamber, shortens the distance between the antenna and the breast phantom.

The next step to our research involves the construction of these antennas for testing using a breast phantom. Their performance will be compared with various designs of tapered-slot antennas, which are more commonly used at microwave breast imaging, and the most efficient will be chosen for the under-development MBI system.

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