Flexible Sixteen Monopole Antenna Array for Microwave Breast Cancer Detection

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***Abstract*— Radar based microwave imaging (MI) has been widely studied for breast cancer detection in recent times. Sensing dielectric property differences of tissues over a wide frequency band has been made possible by ultra-wideband (UWB) techniques. In this paper, a flexible, compact monopole antenna on a 100 µm Kapton polyimide is designed, using a high frequency structure simulator (HFSS), to be in contact with biological breast tissues over the 2-5GHz frequency range. The antenna parameters are optimized to obtain a good impedance match over the required frequency range. The designed antenna size is 18mm × 18mm. Further, a flexible conformal 4 × 4 ultra-wideband antenna array, in a format similar to that of a bra, was developed for a radar-based breast cancer detection system.**

I. INTRODUCTION

There has been great demand for a new, nonionizing, reliable, cost-effective, and comfortable approach for breast screening. One such possibility is using microwave imaging methods for early breast cancer diagnosis as a complementary technology to the current method of X-ray mammography [1]. It has been shown that the permittivity and conductivity of breast cancer tissues are higher than those of normal breast tissues, which enables creation of a microwave scattering map of the breast, with the tumor highlighted [2].

There are two approaches in Microwave Imaging (MI): tomography-based and radar-based. The microwave tomography (MT) approach is a narrowband approach where the electrical profile of the breast is reconstructed by solving a nonlinear and ill posed inverse scattering problem [3]. A microwave scattering map can be obtained, from the differences in dielectric properties of the breast tissues, using radar-based imaging [4]. Employing an array (as multi-static radar) has the advantage of avoiding the mechanical issues of a scanning antenna; thus radar-based breast cancer detection systems have been developed [5]. Low frequencies provide deeper penetration (less loss) but the higher frequencies offer better range resolution (smaller antenna and higher number of antennas in array). However, there is a practical limitation in the low-frequency performance of antenna that is mainly determined by its maximum antenna dimension due to the restricted area on the breast surface [6]. The solution to this issue is of great interest for Ultra-Wideband (UWB) techniques [6].

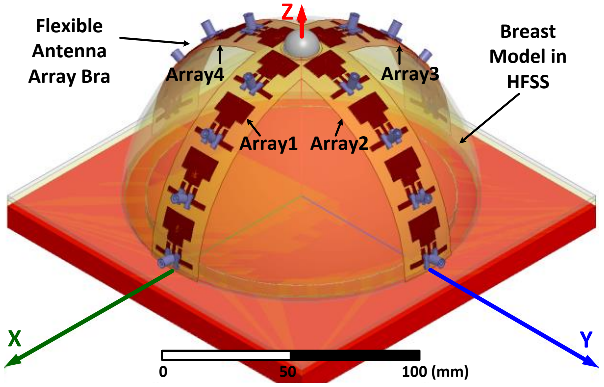

Fig. 1. An overview of a flexible antenna array as a bra for breast cancer detection.

The image quality provided by radar-based microwave imaging techniques is affected by the number and efficiency of the receivers, the synthetic aperture of the antenna array, and the bandwidth of the probing signal. It is very important to obtain a high-performance, broad-band antenna that satisfies these needs. Typical characteristics of the antenna to be used in a radar-based imaging system are: wide impedance bandwidth, small size, and ability to efficiently couple power to the breast [7]. Small antennas reduce the error associated with antenna position, and thus, improve the accuracy of the system. To date, only a few small broad-band antennas for breast cancer detection have been reported [7–15]. Planar printed monopole antennas have been recently considered for breast cancer imaging [13-16] due to the simple structure, broad-band property, relatively small size, and ease of fabrication. However, a multi-static system is able to provide better imaging results than a mono-static system [15] in breast cancer detection, potentially due to the higher number of signals that can be obtained for signal processing and imaging. Hence, it is necessary to build an even smaller antenna, to allow more antennas to be positioned around the breast simultaneously in order to maintain comprehensive radiation coverage over the tissue.

An antenna operating in contact with stacked layers of biological tissues in a detection system, to avoid power reflections (between tissues) caused by inhomogeneities in the breast media, should be designed with an inhomogeneous model to capture all phenomena during the

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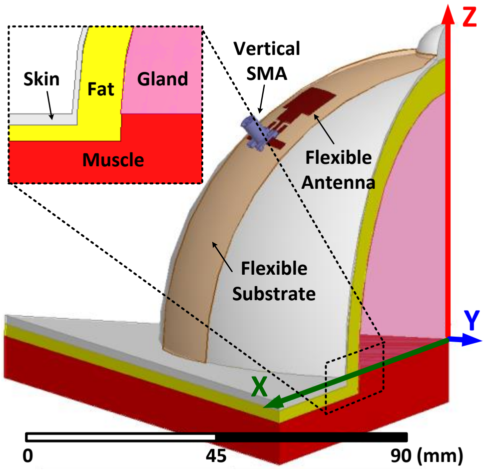


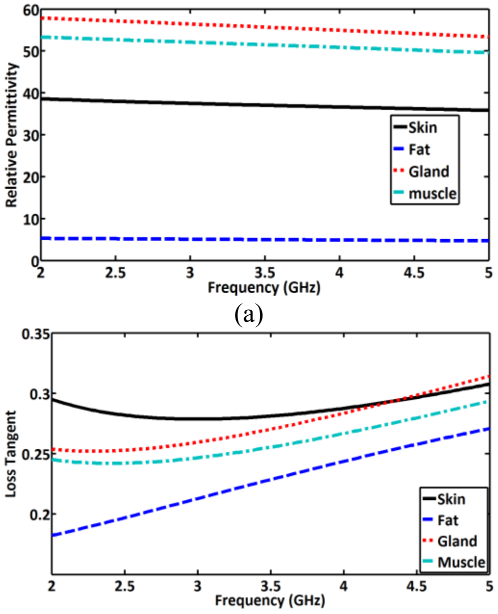
Fig. 2. Multi-layer inhomogeneous model of the breast for designing the flexible antenna array in HFSS .

design process. In this way, the antenna can provide as much energy as possible in order to receive transmitted signals with reasonable strengths from breast tissues. To the best of our knowledge, a flexible antenna array for breast cancer screening has not been presented in the literature to date. Use of a flexible antenna array that mimics a bra has several advantage i.e. light-weight, low cost, ease of fabrication and installation.

This paper reports a flexible monopole UWB antenna array operating in the 2-5 GHz spectrum that meets bandwidth requirement of the breast-cancer microwave-imaging. This work is actually a modified version of an existing system model [16] with the main difference of having the flexible monopole antenna array instead of the bulky, fragile, and expensive traveling wave tapered and loaded transmission line antenna array. Here, to design the flexible monopole antenna, 3D simulations are performed in HFSS by modeling inhomogeneous breast media to capture the real behavior of the antenna propagation in proximity of the breast. The simulated results show that the proposed antenna may be used as an element of a synthetic aperture array for breast cancer detection. Finally, sixteen UWB flexible antennas with the same structure are placed on the same substrate, to compose an antenna array that is expected to form the core of a multi-static imaging system as shown in Fig. 1.

II. INHOMOGENEOUS BREAST MODELING

A miniature antenna in contact with biological tissues will have very different propagation behavior than one in free-space [17]. The antennas must be designed taking into account the impact of the proximity to biological tissues. The multiple biological tissues in breast cancer detection have varying conductivity and dielectric constants leading to complex RF interaction [17]. The breast as a communication media is modeled by several biological tissues and each biological tissue is defined as a dispersive dielectric in a homogeneous medium using three electrical parameters: relative permittivity, loss tangent and mass density. By stacking several homogeneous layers, the inhomogeneous environment is modeled with the HFSS software [18]. The multi-layer model that is used to design the antenna array includes skin, fat, gland, and muscle, and is shown in Fig. 2 [19]. The frequency dependent relative permittivity and loss tangent are plotted in Fig. 3 [20] for the entire 2-5GHz band. The loss tangent quantifies inherent dielectric dissipation when interacting with an electromagnetic wave. The mass density, i.e., the mass of each tissue per volume unit, is reported in [19] for different breast tissues; this parameter is needed for calculation of average specific absorption rate (ASAR). The simulated geometrical parameters of the breast model are presented in Table I.



(a)

(b)

Fig. 3. (a) Relative permittivity and (b) loss tangent of different tissues in the breast.

TABLE I. PARAMETERS OF BREAST TISSUES

Tissue	Breast Parameters			
	Thickness (mm)	*Inner radius (mm)*	*Outer radius (mm)*	*Mass Density (kg/m^3)*
Skin	2	68	70	1010
Fat	8	60	68	928
Gland	120	0	60	1035
Muscle	8	0	0	1040

III. FLEXIBLE ANTENNA ARRAY

There are several single polarization monopole antennas designed for breast cancer in UWB existing in the literature [13-16]. Recently, we have designed an implanted and wearable monopole antenna for neural recording [17]. These antennas have been designed on inflexible substrates that are ill adapted to curvature of the breast. Microwave substrates that are going to be used as wearable on the breast should be biocompatible and as flexible and as soft as possible. In [21], a type of Kapton polyimide substrate that is utilized in this work has been reported that has the two aforementioned properties. We revisit these designs, targeting this flexible substrate to achieve a suitable antenna array for breast cancer.

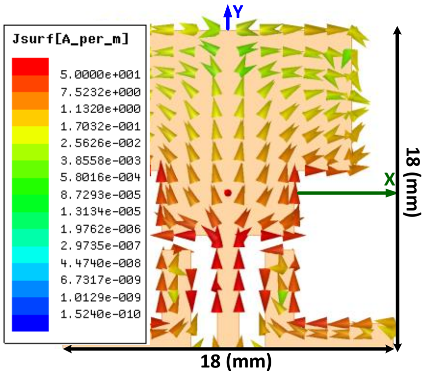


Fig. 4. The induced current on the flexible single polarization antenna.

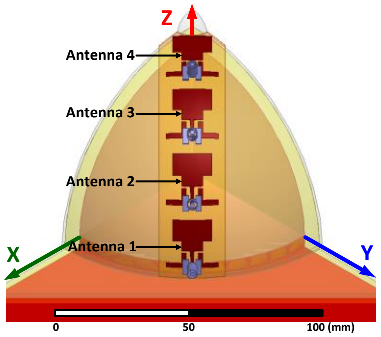


Fig. 5. Different positions of the flexible antenna in the flexible array.

The first step is to design a transmission line having 50 ohm impedance over the frequency range of interest while being fed with a vertical SMA connector. The dimensions of the transmission line are a function of the electrical properties of the substrate as well as the environment surrounding the substrate. The transmission width is calculated for the flexible antenna while it is in contact with the breast. In the single polarization antenna, current induced on the antenna should follow a single axis of propagation. The antenna propagator with a rectangular shape has highest linearity of induced current. As the rectangular propagator is much wider than the transmission line, the return loss will tend to be narrowband. Therefore, the propagator is tapered to couple to the transmission line at the widest bandwidth [17]. In order to achieve reflection coefficients (S_{11}) below -10 dB in the entire frequency range of interest, the physical dimensions of the antenna are optimized. Fig. 4 shows the induced current on the antenna (TX). This figure clearly shows that most of the induced currents on surface of the antenna are aligned with the Y direction. The S_{11} of the designed single antenna should be checked at different positions in the array to confirm that it is still below -10 dB as shown in Fig. 5.

IV. SIMULATION RESULTS

A. *S-parameters*

The simulation results for reflection coefficients (S_{11}) are shown in Fig. 6 for different positions of the antennas in the array as shown in Fig. 5. The reflection coefficient is below -10 dB from 2 GHz to 5 GHz for each position. As is shown from results, the flexible antenna is not sensitive to bending and thus, this antenna is a good candidate for use in this type of array configuration. The simulated S_{21} (transfer function) between antenna 1 of array 1 and antennas 1 to 4 of array 2 (array layouts shown in Fig. 1, antenna numbering in Fig. 5) is shown in Fig. 6-b. Also, the simulated S_{21} results between antenna 1 of array 1 and antennas 1 to 4 of array 3 are plotted in Fig. 6-c. From the S_{21} results, it is concluded that antennas that are further apart communicate with higher insertion loss. Additionally, as shown in Fig. 3-b, because the biological tissues have higher loss tangent in higher frequencies, the S_{21} results follow this behavior (less insertion loss in lower frequency). The worst case of insertion loss is around 80 dB for the mentioned thicknesses in Table I.

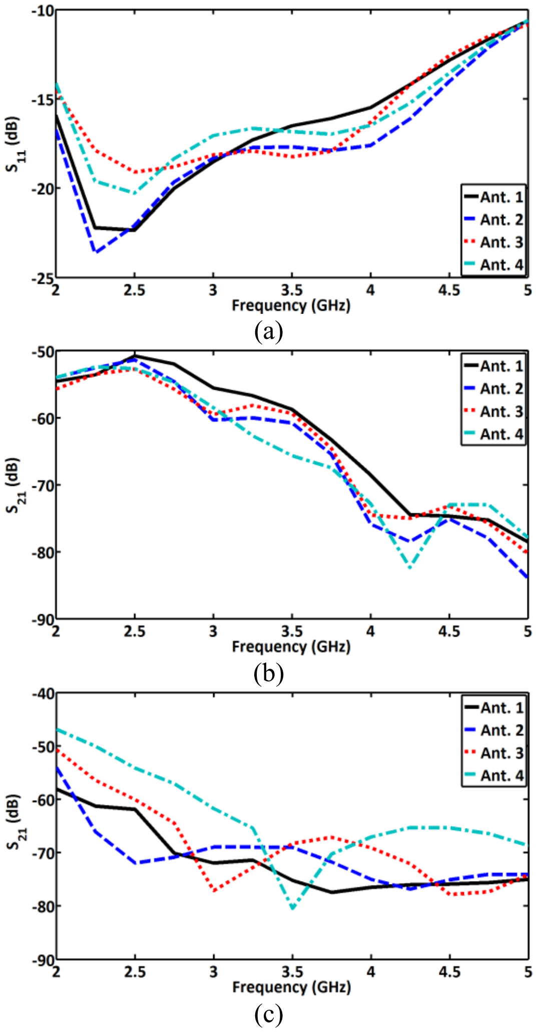


Fig. 6. Simulated S-parameters for flexible antenna array (a) S_{11} for the flexible antenna in different positions in the array, (b) S_{21} of antenna 1 of array 1 and antennas 1 to 4 of array 2 (c) S_{21} of antenna 1 of array 1 and antennas 1 to 4 of array 3.

B. *Average Specific Absorption Rate (ASAR)*

ASAR (Average Specific Absorption Rate) is a critical parameter for assessing the tissue safety of wireless communications. The peak 1-g ASAR distribution versus frequency is simulated with HFSS for the wearable antenna array and is presented in Fig. 7. The delivered power would have to be 2.6 mW for each antenna in the array to have the

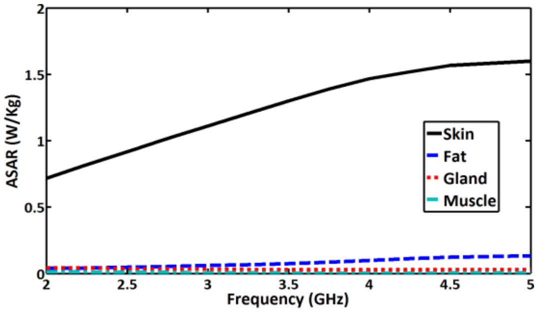


Fig. 7. The Simulated ASAR of the wearable antenna for different tissues when the average transmitted power is 2.6 mW.

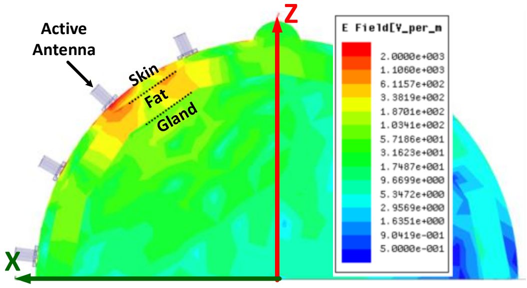


Fig. 8. Propagation behavior of E- field intensity of the array when the antenna 3 is active in Z-X plane.

maximum peak 1-g ASAR near 1.6 W/kg to meet the ANSI limitations in the 2-5 GHz frequency range [22]. Sending more power could damage the breast tissues. Fig. 7 shows that most of transmitted power is absorbed by the skin.

Additionally, HFSS provides a three dimensional numerical solution for the electrical field intensity across all tissues. A planar cross section (Z-X plane) of the intensity is plotted in Fig. 8; a color bar indicates that maximum intensity in red and minimal values in blue. This plot allows us to visualize two important aspects of the EM propagation: 1) the highest intensity of E-field and the highest absorption of breast tissues which are close to the wearable antenna, 2) the propagation behavior of EM waves while penetrating the breast inhomogeneous media. The plotted electrical field shows that when electromagnetic waves are propagating through the breast, they will be attenuated. Therefore, for women with bigger breast sizes, the detection of the pulse will be challenging considering maximum allowable power of 2.6 mW (ANSI limitation).

V. CONCLUSION

In this paper, a methodology for designing a wearable flexible single polarization antenna array for breast cancer detection has been presented. The new array improves on previous microwave radar imaging systems in that it is highly flexible, cost-effective to fabricate, and light-weight. Simulations were carried out with HFSS, exploiting a layered (inhomogeneous) model with different dielectric constants and loss tangents to capture the effect of surrounding tissues. Finally, the maximum power allowed to be transmitted from the wearable antenna, by taking into account the limitation imposed by the ANSI, has been determined to be 2.6mW.

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