Eccentric Annular Slot Antenna for Breast Cancer Detection Based on the Finite-Difference-Time-Domain Method

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ABSTRACT
This paper investigates the effect of the surrounding medium (i.e., the human tissue) on the performance of the eccentric annular microstrip slot antenna when used in breast cancer detection. The finite difference time domain (FDTD) method is used to analyze the antenna characteristics. The results show that the performance of the antenna changes when used in biological applications.

I. INTRODUCTION

The cause of breast cancer disease remains unknown, however, significant progress has been accomplished for the treatment only if the cancer is detected in early stages. Different techniques are currently used to detect breast cancer, e.g., X-ray mammography, ultrasound, magnetic resonance imaging (MRI), microwave imaging, etc. Microwave-imaging modality proves to show a potential for detecting malignant tumors in the breast since at microwave frequencies the contrast of the electrical properties between normal and malignant breast tissue becomes significant. For example, at 6 GHz, the relative dielectric constant of malignant tissue is almost five times larger than of normal breast tissue [1]. The basic idea of using microwave imaging system for breast cancer detection is to transmit electromagnetic waves from a transmitting antenna to the breast and receive the scattered waves at a receiving antenna [1-2]. These received waves contain vital information regarding the tumor location, shape, size, and electrical properties.

The main advantage of microstrip line fed slot antennas is its wide bandwidth and it has small size suitable to use on the human breast. The technology and characteristics of slot antennas are well established in the literature (e.g. [3]). As a novel application we used the wideband eccentric annular slot antenna to analyze and investigate the characteristics of malignant breast tumors. A FDTD based model is implemented to include the normal breast tissue, breast skin, malignant tumor and the transmitting/receiving antenna [1, 3-8]. The geometry of the antenna is shown in Fig. 1. This investigation will help in understanding the change that occurs in the antenna performance when used in biological applications.

II. FORMULATIONS

As well known, the FDTD method is based on the Maxwell's equations:

$$\nabla \times \overline{E} = -\frac{\partial \overline{B}}{\partial t} \tag{1a}$$

$$\nabla \times \overline{H} = \overline{J} + \frac{\partial \overline{D}}{\partial t} \quad (1b)$$

$$\overline{B} = \mu \overline{H} \quad (1c)$$

$$\overline{D} = \varepsilon \overline{E} \quad (1d)$$

Where, $\overline{B}$ is the magnetic flux density in Tesla, $\overline{D}$ is the electric flux density in C/m^2, $\overline{E}$ is the electric field intensity in V/m, $\overline{H}$ is the magnetic field intensity in A/m, $\overline{J}$ is the current density in A/m^2, μ is the magnetic permeability in H/m, and ε is the electrical permittivity in F/m. Upon representing equation (1) in Cartesian coordinate system and applying the central difference formula for the derivatives with respect to the time and space we obtain six finite difference equations representing H_x, H_y, H_z, E_x, E_y and E_z following the notations in [4-6]. The realistic model of the human breast generated using the FDTD should include the normal breast tissue, the skin layer and the tumor as shown in Fig. 2.

A Gaussian pulse is applied at the feed point of the antenna as a plane of E_z fields between the microstrip line and the ground plane following the work in [7]. The Gaussian pulse is given by:

$$E_z(t) = e^{-(t-t_0)^2/T^2} \text{ (V/m)} \quad (2)$$

Where, T = 15 ps, t = $n\Delta t$, t_0 = $3T$, n is the number of time steps and Δt is the time increment (Δt = 0.833ps).

Following the work in [7], the reflection coefficient of the antenna (S_{11}) is given by:

$$\Gamma = S_{11} = 20 \log_{10} \frac{FFT[E_{z-ref}]}{FFT[E_{z-inc}]} \text{ dB} \quad (3)$$

Where FFT represents the Fast Fourier Transform, E_{z-ref} is the reflected E_z field from the antenna observed at port 1 on the microstrip line and E_{z-inc} is the incident E_z field (Gaussian pulse) observed also at port 1 of the microstrip line.

III. NUMERICAL RESULTS

Two scenarios are investigated here; defined as the matched and the mismatched cases. Both cases use the same antenna geometry of Fig. 1. The matched case model includes normal breast tissue, skin layer of 1mm thickness, matching medium above the antenna that has the same electrical properties of the normal breast tissue as shown in Fig. 2. A malignant tumor of diameter 5.28 mm is present in the breast at depth of 1.265 cm measured from the skin interface. The antenna is placed at 2.65mm below the breast to avoid direct contact with the human tissue. A matching solution (e.g. gel used in medical application) is placed between the slot antenna and the skin layer as shown in Fig. 2. This matching solution is used to minimize the reflection that occurs due to the contrast between the air and normal tissue. In the mismatched case, the gel medium is not used between the antenna and the skin leaving this region as air gap. The computational domain shown in Fig. 2 is surrounded by 12 cell of the perfectly matched layer (PML) following the work in [5, 6]. The antenna is used to transmit the electromagnetic waves towards the breast and to receive the scattered fields at port 1 as depicted in Fig. 1.

Five different simulations of the S_{11} parameter are plotted in Fig. 3. This provides a thorough comparison of the antenna performance when it is present in air (i.e., the original antenna); when a matching medium exists between the antenna and skin layer (matched case) with and without the presence of a tumor in the breast, and when an air gap exists between the antenna and the skin layer (mismatched case) with and without the presence of the tumor. The bandwidth of the slot antenna in air is almost 3.87 GHz with center frequency equal to 5.167 GHz, as shown in Fig. 3 [3]. The bandwidth is obtained at –10dB. The electric fields obtained at port 1 for the matched and mismatched cases did not show appreciable variations when the tumor was present. This is due to the high attenuation of the waves inside the human breast and to the small size of the tumor as well. In other words insignificant variation in the S_{11} parameter is observed upon comparing the two cases with and without the tumor for both the matched and mismatched cases. The results also show significant change in the antenna performance especially for the matched case. The bandwidth of the antenna in the mismatched case becomes almost 2.446 GHz. For the matched case, the S_{11} becomes larger than –10dB in the shown frequency band.

IV. CONCLUSION

The reflection coefficient (S_{11}) of the eccentric slot antenna is investigated in this work. A wideband Gaussian pulse is used to excite the antenna. The performance of this antenna is also compared with the bowtie and patch antenna (not presented here). The results show that the performance of the slot antenna significantly changes when used in biological applications.

ACKNOWLEDGMENTS

This research was sponsored by the Arkansas Biosciences Institute award no. ABI-103, and in part by the National Science Foundation Center for Subsurface Sensing and Imaging Systems (CenSSIS) at Northeastern University in Boston award No. EEC-9986821.

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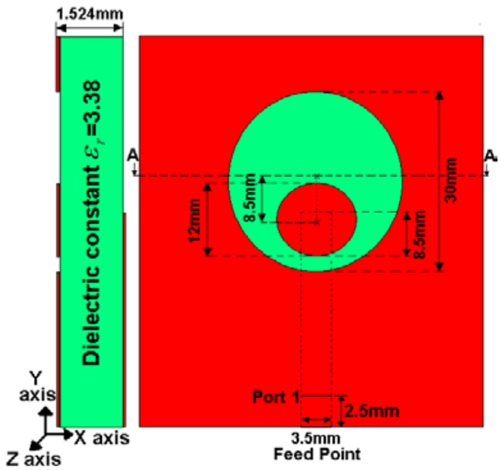

Fig.1 Eccentric annular slot antenna

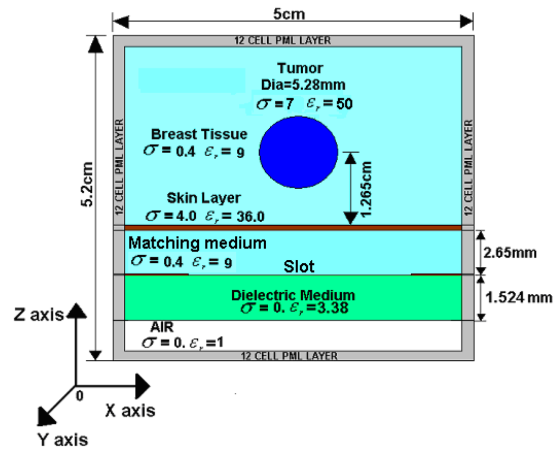

Fig. 2: The matched case shown at the A-A cross section

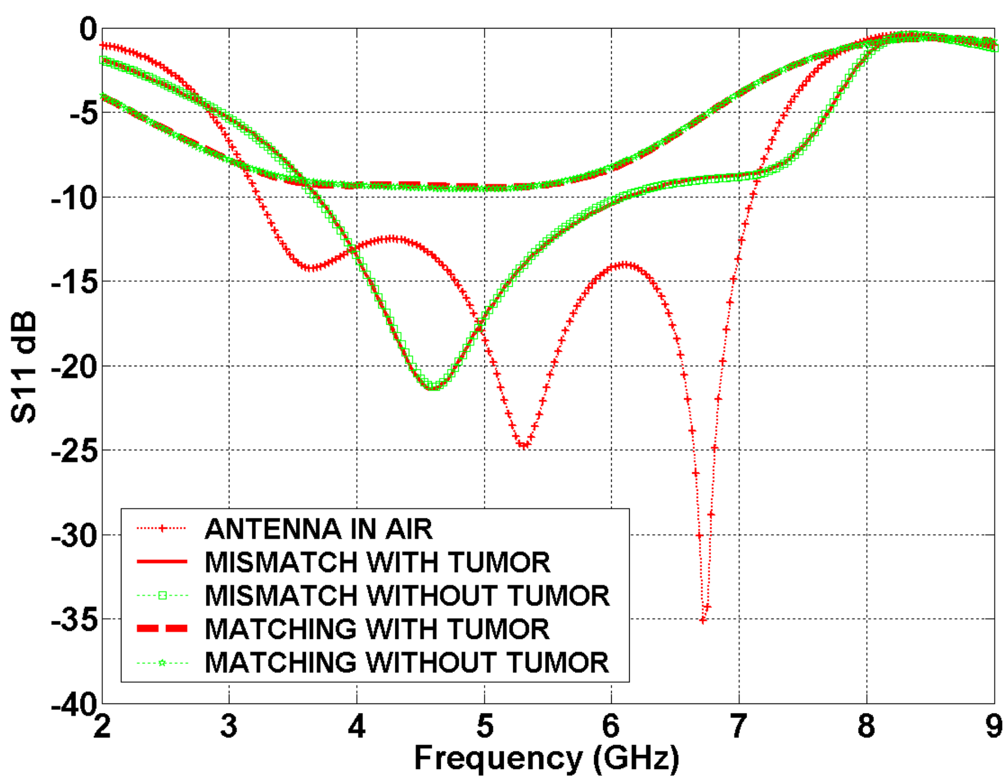

Fig. 3: S_{11} comparison