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Breast Cancer Detection Based on Multi-Slotted Patch Antenna at ISM Band

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Abstract

The present work designed and investigated a 3D basic model for breast cancer detection at the ISM band. The model consists of two multi-slotted rectangular patch antennas and a three-layer breast phantom containing two tumors. A multi-slotted antenna was designed at 2.45 GHz using CST STUDIO SUITE 2018, where the simulated results showed a return loss better than −35 dB and attended more than 77 MHz bandwidth. The diagnosis approach is based on exploiting the electrical properties (frequency dependent) of breast tissues, *i.e.*, mass density, relative permittivity, and conductivity. Once the proposed slotted antenna radiates electromagnetic signals toward the breast model (with and without tumors), the radiation properties in terms of the scattering parameters (S_{11} and S_{21}), the electrical field, the power flow, the current density, and the power loss density were altered. As a result, the values of these radiation parameters increased when tumors were implanted inside the breast model, informing the presence of cancerous tissues. Moreover, the specific absorption rate (SAR) was estimated as a function of input powers, where the proposed antenna showed a set of low SAR values compared to the IEEE standard of 1.6 W/kg, validating its potential use for diagnosing purposes. The simulated results indicated the prospective use of two slotted antennas (in the first instance) to detect multiple tumors which could be a challenging task using a single-element antenna, where the ultimate goal is to realize a compact antenna array to detect multi-tumors.

Keywords

Antenna Array, Breast Cancer, Cancer Detection, Microstrip, Tumor Detection

1. Introduction

By 2040, it is predictable to be more than 27 million new cancerous cases as informed by Cancer Research UK [1]. In 2020, it was accounted worldwide to be around 10 million deaths caused by different cancer types, where breast cancer was the most common one with 2.26 million cases and 685000 deaths as reported by World Health Organization [2]. Thus, a preliminary diagnosis is a prerequisite, as a significant number of women under 40 years old suffer from this uncontrollable disease [3]. On the whole, different approaches have been employed to recognize breast cancerous cells such as magnetic resonance imaging, tomography and mammogram, ultra-sound, and X-ray [4]. However, these methods are bulky, ionizing, inconvenient, expensive, and more painful, which are not preferred for some age groups [5]. At present, microwave breast imaging (MBI) is considered an alternative tool characterized as non-invasive, non-ionizing, cost-effective, and convenient to detect and distinguish tumor cells (benign or malignant) inside the women's breast [6] [7]. The MBI approach depends on the variances of electrical features for both cancerous and normal breast tissues [8] [9]. The crucial element of the MBI is an applicator (antenna) to send and/or receive EM signals at which such an antenna should be low in terms of its profile and cost. Even if various designs of antennas have been advanced in the literature [10] [11] [12] [13] [14], there is a need to improve the return loss and simplify the antenna structure for more potential use in medical applications.

In this paper, the investigation was achieved by considering two multi-slotted patch antennas operating at 2.45 GHz, where the proposed multi-static approach was based on the S_{21} parameter to estimate the performance by applying an electromagnetic (EM) signal at one antenna and observing the outcome at other one. This gave the potential to identify multiple tumors compared to other mono-static methods exploited S_{11} of a single-element antenna. Further study was presented to evaluate the tumor effects on the radiation parameters such as the electrical field, the power flow, the current density, and the power loss density. Moreover, the specific absorption rate (SAR) was simulated and estimated for the proposed slotted antenna to attain a low SAR level compared to the IEEE standard of 1.6 W/kg. The exploration here is to initially confirm the concept, however, the ultimate objective is to design a well-organized antenna array at low return loss to detect multiple smaller tumors.

The rest of the current paper is prearranged over sections in order: Section 2 presents a schematic of the proposed multi-slotted antenna in a CST environment, where the design terms alongside the antenna results are also well discussed. Section 3 characterizes the planned breast model along with the designed antenna. Section 4 explores the potential performance of the entire proposed model in terms of the scattering parameters (S_{11} and S_{21}), the radiation properties, and the SAR parameter while Section 5 concludes the whole presented work and draws some future lines.

2. Slotted Antenna Design

This section presents the design of a slotted rectangular patch antenna operating at the industrial, scientific, and medical (ISM) band using CST STUDIO SUITE 2018. To efficiently design a patch antenna, three key parameters should be well-specified. These prerequisite factors are the resonant frequency, the substrate thickness, and the type of substrate material. In that, the operating frequency is intended at 2.45 GHz where biological tissues have a well-being interaction with EM fields. The substrate height is 1.6 mm, assuring a favored light antenna for medical applications. For reducing the antenna dimensions, the cost-effective substrate is planned as an FR-4 with a lower permittivity of 4.3 and a loss tangent of 0.025.

The layout of the proposed antenna is schematically shown in Figure 1, labeling the optimized parameters which are listed in Table 1. The dimension for both the substrate and the backed ground is 50 mm^2. The width and length of the 50 Ω power feed line are in respective of 2.80 mm and 27.45 mm, whereas the gap width, the depth of the inset fed, the patch length, and the patch width are 1.57 mm, 6.85 mm, 29.10 mm, and 40 mm, respectively. To enhance the performance at the resonant frequency, three different slots are introduced on the patch as S_1 (length of 2.68 mm and width of 1.47 mm), S_2 (length of 2 mm and width of 4 mm), and S_3 (length of 3 mm and width of 1.47 mm).

The return loss (S_{11}) is the foremost parameter to explore the performance of the designed antenna, which is estimated in Figure 2 where the simulated results

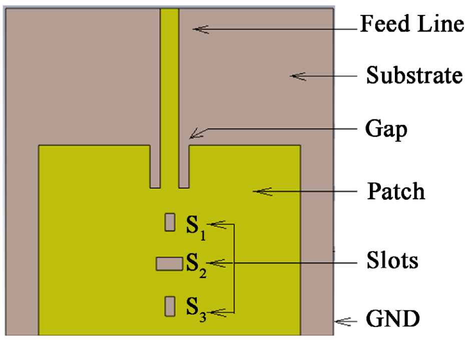

Figure 1. A configuration of the designed multi-slotted antenna.

Table 1. Optimized parameters of the proposed antenna.

Parameter	Width (mm)	Length (mm)
Feed Line	2.80	27.45
Substrate	50	50
Gap	1.57	6.85
Patch	40	29.10
Slot S_1	1.47	2.68
Slot S_2	4	2
Slot S_3	1.47	3
GND	50	50

not only present a good performance better than −35 dB of the S_{11} at 2.45 GHz but attend more than 77 MHz bandwidth (below −10 dB) at the preferred frequency as well. This result indicates a reasonable impedance matching, resulting in efficient radiation via the designed multi-slotted patch. Hence, this performance will be further exploited for tumor detection as introduced in the next sections.

3. Breast Model Design

In the current section, the entire model including the designed antenna and the breast phantom comprising tumors is designed using CST STUDIO SUITE 2018. A three-layer breast phantom represented as skin tissue, fat tissue, and glandular tissue is characterized by means of electrical properties such as mass density, relative permittivity, and conductivity at which their frequency-dependent values are listed in Table 2 [15]. The 3D basic breast is constructed physically as a hemisphere with a diameter of 140 mm as a skin layer and 130 mm as a fat layer, where their thicknesses in respective are 5 mm and 15 mm. Likewise, the glandular tissue and the tumor are modeled as spheres with radii of 50 mm and 10 mm, respectively.

The cancer diagnosis is investigated by considering three different cases as shown in Figure 3; breast excluding tumor, breast including a single tumor, and

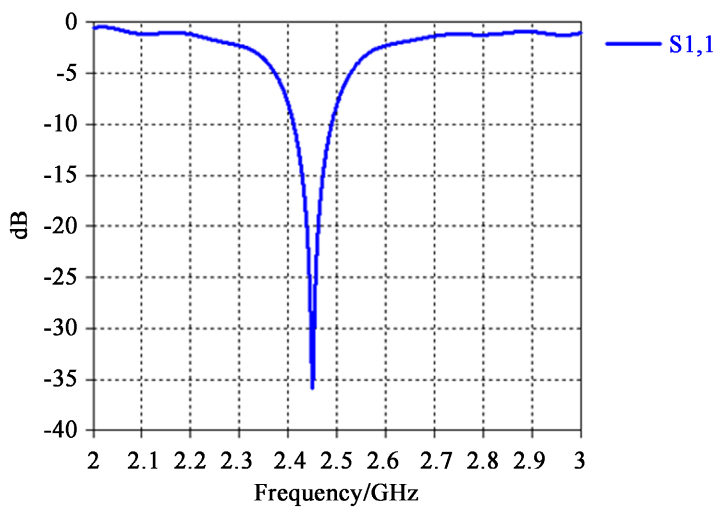

Figure 2. The return loss performance at 2.45 GHz.

Table 2. Electrical features of breast tissues at 2.4 5GHz.

Breast Layer	Mass Density (kg/m^3)	Relative Permittivity (unit-less)	Conductivity (S/m)
Skin	1100	36	4
Fat	900	9	0.4
Glandular	1040	14	0.45
Tumor	1040	50	4

breast including two tumors. Once the proposed antenna radiates EM signals toward the breast model, the changes in terms of radiation properties, such as the return loss, the electrical field, the power flow, the current density, and the power loss density, could be observed. The three different scenarios are explored and the associated results are in the next section.

4. Detection Results

The results could be evaluated by inspecting the differences in the radiation characterization as mentioned above, once two designed antennas are individually placed 15 mm distant from the breast model as shown in Figure 4. The simulated performance of the S_{11} for three different cases is demonstrated in Figure 5. In the case of the breast without a tumor, the S_{11} showed a slightly different result when compared to the other cases comprising tumors. In the case of a single tumor and two tumors, it was expected that the S_{11} presents an equivalent performance as the antenna-1 still has similar conditions. As an alternative, the S_{21} could be a favored parameter to further distinguish the potential results. Figure 6 explores the S_{21} results for the three different scenarios. In that, the S_{21}

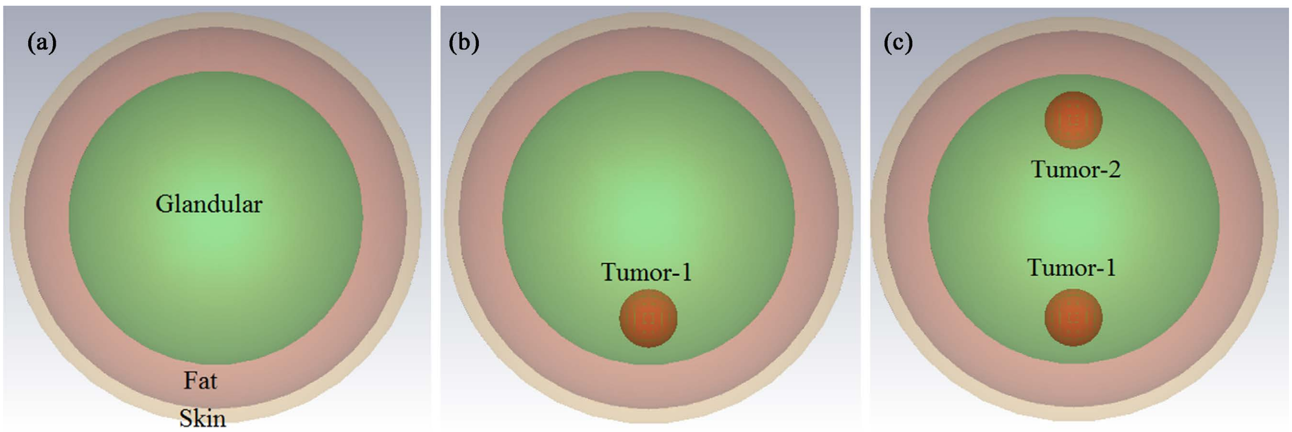

Figure 3. A breast phantom: (a) without tumor; (b) with one tumor; (c) with two tumors.

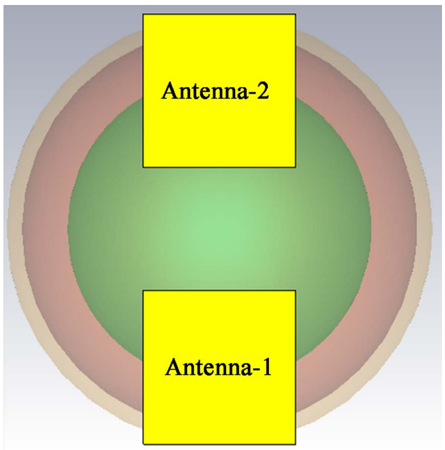

Figure 4. Two antennas placed on the breast model.

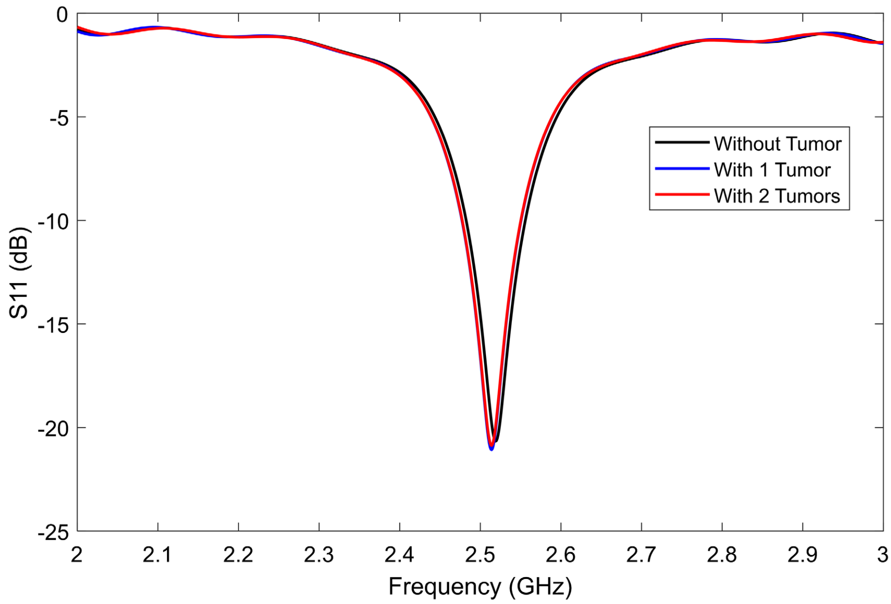

Figure 5. The S_{11} performance with and without tumors.

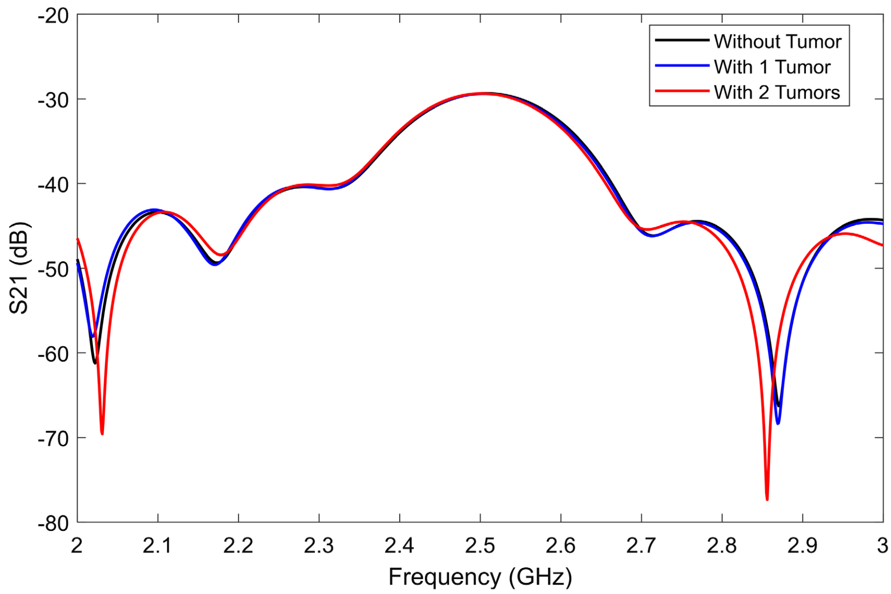

Figure 6. The S_{21} performance with and without tumors.

presented an altered performance when two tumors were included, whereas it attained an equivalent result in the case of the breast without a tumor or with one tumor.

Table 3 shows the radiation parameters of the designed antenna with respect to the tumor's existence and nonexistence inside the breast phantom. It is obvious from Table 3 that the parameters slightly increased when the tumors were considered inside the breast model, signifying the presence of abnormal breast tissues as their higher water contents leading to different dielectric properties compared to healthy ones.

There is a strict level of the absorbed power within the human body, expressed as a specific absorption rate (SAR). According to IEEE reference [16], the maximum SAR is 1.6 W/kg for 1 g mass of tissue. Figure 7 exhibits the maximum

Table 3. Radiation characterization of the proposed antenna at 2.45 GHz.

Tumor	E-Field (V/m)	Power Flow (V.A/m^2)	Current Density (A/m^2)	Power Loss Density (W/m^3)
Considered	91.85	19.28	41.34	212.55
Not-Considered	89.44	18.44	40.74	203.70

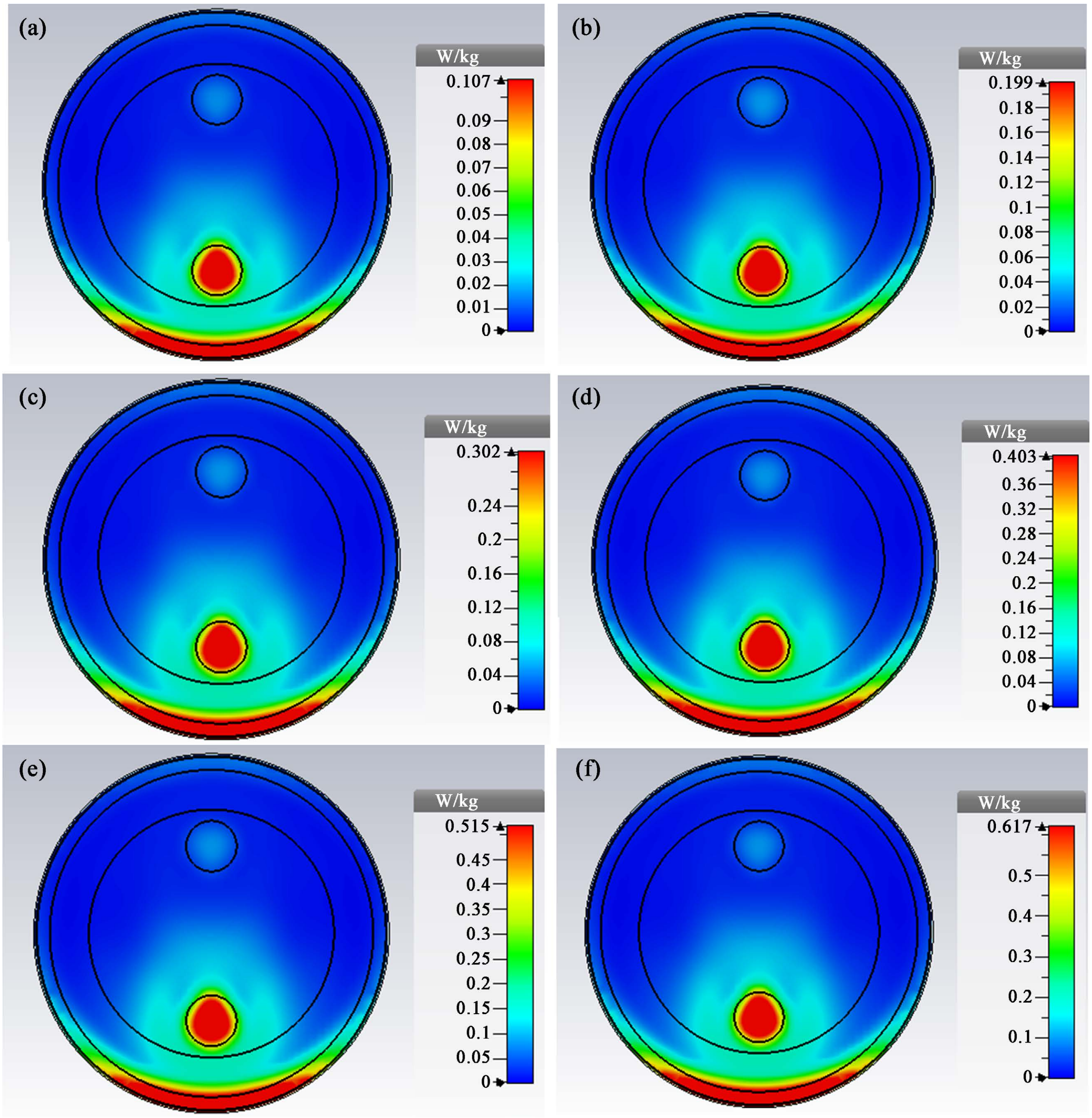

Figure 7. Maximum SAR value as a function of input powers. (a) At 0.5 W applied power; (b) at 1 W applied power; (c) at 1.5 W applied power; (d) at 2 W applied power; (e) at 2.5 W applied power; (f) at 3 W applied power.

SAR value as a function of applied powers at the center of the tumor-1 when antenna-1 emits EM energy. From **Figure 7**, it is evident that the SAR value increased by 10% as the input power increased by 50%. In other words, the maximum SAR levels were 0.10, 0.19, 0.30, 0.40, 0.51, and 0.61 when the input powers were 0.5 W, 1 W, 1.5 W, 2 W, 2.5 W, and 3 W, respectively. Thus, the maximum input power should be retained below 8 W to avoid any hazard to the healthy tissues. It should be noted that the skin tissue was exposed to a relatively high SAR, however, this could be maintained through a water bolus separating the skin layer and the antenna.

5. Conclusion

The investigation of using two multi-slotted patch antennas to detect cancer tissues was achieved in this paper. The suggested multi-static approach using S_{21} to estimate the results by sending an EM signal from antenna-1 and receiving a part of the signal by antenna-2, resulting in a significant difference in the S_{21} assisting to identify multiple tumors compared to mono-static methods based on S_{11}. Further analysis was introduced by examining the tumor effects on the radiation parameters of the designed antenna. It concluded that the values of the electrical field, the power flow, the current density, and the power loss density were increased once the tumors were considered within the breast phantom, indicating the tumor's existence. Moreover, the simulated performance of the SAR gave a convenient range to apply powers up to 8 W, satisfying the IEEE Standard of 1.6 W/kg. A step to fabricate and measure the proposed slotted antenna is planned in the next phase, where the ultimate purpose is to design a compact antenna array with low return loss to detect multiple tumors inside the breast tissues.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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