On-Body Microstrip Patch Antenna for Breast Cancer Detection

Sourav Sinha, Sajidur Rahman, Mahajabin Haque Mili, and Fahim Mahmud

Abstract Breast cancer is the most common invasive cancer for women. It is the second major cause of cancer that causes death after lung cancer in women. This paper portrays an on-body microstrip patch rectangular antenna, which is found to operate at ISM-Industrial, Scientific and Medical band of 2.4–2.4835 GHz after placing it on the surface of the human breast, designed in the CST microwave studio to specify the tumor in narrow bandwidth. Being highly flexible, FR4 is selected as a substrate, and copper is selected for both ground and patch. To guarantee the safety of the patient, a human breast phantom is constructed consisting of two layers-skin and glandular tissue. The tumor is positioned at different locations on the breast phantom model to ensure the efficiency of the device. The S11 value without tumor is −49.405 dB and the voltage standing wave ratio is 1.0067957. Specific absorption rate is 1.18, total efficiency is −6.846 dB and radiation efficiency is −6.846 dB. To make the device biocompatible, all these parameters are experimented by comparing the cancerous tumor's location and without the cancerous tumor.

Keywords Human breast model · Glandular tissue · On-body antenna · SAR

1 Introduction

Breast cancer is a type of disease that occurs when the cells in the breast grow excessively. Most breast cancers initiate in the lobules or ducts. Based on the capacity of extension and growth, tumors are classified into malignant and benign. According to the survey by National Cancer Institute, death rates due to breast cancer among

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women aging between 20 and 49 were more than double that of any other cancer-causing death among women or men from 2012 to 2016. X-ray mammogram, ultrasound, and MRI-magnetic resonance imaging are traditionally implemented for the discovery of breast cancer. These methods possess some limitations as 4–34% of all breast cancers are unidentified due to the differentiation of malignant tissue or poor detection of cells. However, promising results are exhibited by microwave imaging (MI) [1]. The basic technique involved in the MI system is that it transmits and receives the scattered signal for diagnosis. Variant results between the electric and magnetic fields play a major role in recognizing the location of the tumor and its growth [2].

In 1953, microstrip radiators were initially found and extensive researches were made regarding their properties [3]. Ground, substrate, and patch resonator were the elements of this antenna. Being light, low-cost, ease of fabrication, and having a low profile, this antenna is employed for industrial and medical purposes [4]. Its properties would more be increased if substrate thickness, feed line dimension, and patch are optimized [5]. Researches are being continued for the past two decades to mitigate the issue of narrow bandwidth (low factorial bandwidth (FBW $= 7\%$) and to enhance communication and receive more advantages in microstrip antennas [5]. The radiating element can be triangular, semicircular, circular, and square [6].

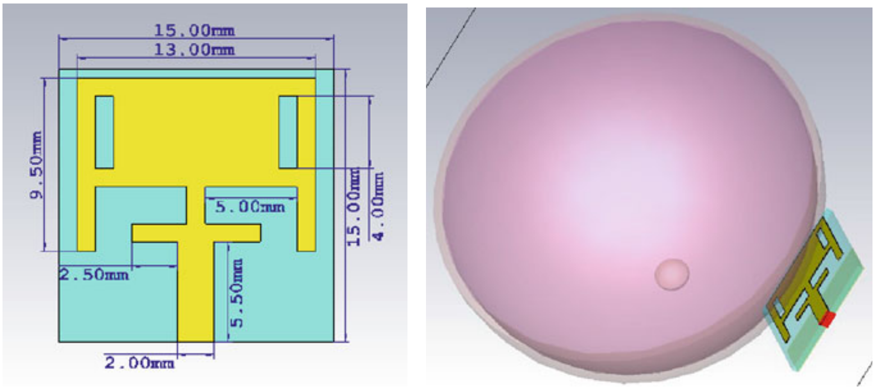
In this research, an on-body microstrip patch antenna is proposed which is to be placed on the surface of the breast skin and operating at ISM band, frequency of 2.4–2.4835 GHz. The antenna is designed for all human beings with flexible and cheap costs to detect the tumor in the early stage if present. Having several advantages, International Telecommunication Union declared radio communication at the frequency of 2.4–2.4835 GHz for the purpose of industrial, scientific, and medical [7]. The fundamental principle is that human organs containing different bio-tissues possess varied characteristics in terms of parameters such as conductivity and dielectric constant [8]. The on-body antenna is composed of ground, patch, and substrate. The dimensions (length, width, and thickness) are considered in such a way that they can be used by all kinds of people. A human breast phantom is designed with skin and glandular tissue being the two layers on the CST microwave studio. The skin encompasses the glandular tissue present inside the breast. All necessary dielectric material properties are maintained using library materials from CST microwave. A spherical-shaped tumor is designed using the above-mentioned software. For precise detection, the location of the tumor was changed and compared with the presence of tumor and absence of tumor. Additionally, return loss, operating frequency, bandwidth, directivity, radiation pattern, gain, voltage standing wave ratio, specific absorption rate, electric and magnetic field are determined. The structure and design method (Sect. 2), antenna characteristics without cancerous tumor (Sect. 3), and antenna characteristics with a cancerous tumor (Sect. 4) are demonstrated, respectively.

2 Structure and Design Method

2.1 Design of Antenna

The fundamental element in microwave imaging is an antenna. The proposed antenna is a rectangular shape with a length of 15 mm and a width of 15 mm to sustain biocompatibility. Radiating rectangular patch of the antenna fed by a rectangular feed line. The antenna consists of substrate, patch, and ground and power is supplied by the feed line. The antenna is experimented with copper in patch and ground of the thickness is 0.1 mm. FR4 was selected as a substrate with 0.8 mm thickness. The propounded antenna thickness is 1 mm. The propounded antenna dimension is ($15 \times 15 \times 1$) mm3. Hence, the CST microwave studio can calculate numerous monitors and have the capability to extract a high resolution of antenna data, the experiment was performed in the CST microwave studio [9]. The propounded antenna is designed for working on the surface of the human breast, therefore it is positioned on the lateral sides of the human breast phantom prototype to check its biocompatibility and performances. The spherical-shaped tumor of 5 mm radius is constructed in the CST microwave studio and positioned within the phantom. The results were compared based on the different locations of the tumor.

Figure 1a demonstrates the propounded antenna's geometrical view. The values which are labeled in Fig. 1a are in the unit of millimeter. Figure 1b shows the antenna along with the waveguide port and breast phantom. The power is supplied in a 2 mm wide feedline by the waveguide port. The red part marked in Fig. 1b represents the waveguide port. In Table 1, all parameters of the propounded on-body antenna are tabulated.



a. b.

Fig. 1 Propounded microstrip patch antenna **a** Dimensions **b** with waveguide port and breast phantom

Table 1 The antenna parameters

Antenna part	Length (mm)	Width (mm)	Thickness (mm)
Feed	5.5	2	0.1
Substrate	15	15	0.8
Ground	5.5	15	0.1

2.2 Equations Employed in Design of Propounded Antenna

Different parameters are calculated using the following equations for the propounded on-body microstrip patch antenna [10].

Width

$$W = \frac{C}{2fr\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Here, fr = Operating Frequency

c = 3 × 10^8 m/s (Speed of light)

ε_r = 3.5 (The dielectric substrate's relative permittivity)

Dielectric Constant (Effective),

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right] \tag{2}$$

W = Patch width

h = Thickness of substrate (0.8 mm)

Length (Effective)

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \tag{3}$$

Length Extension

$$\Delta L = 0.412h\frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{4}$$

Actual length of the Patch

$$L = L_{eff} - 2\Delta L \tag{5}$$

The calculated values obtained from solving the equation are not enough to reach the objective of the design. Therefore, the value of length and width are lessened by keeping the ratio unchanged until ISM band frequency is obtained.

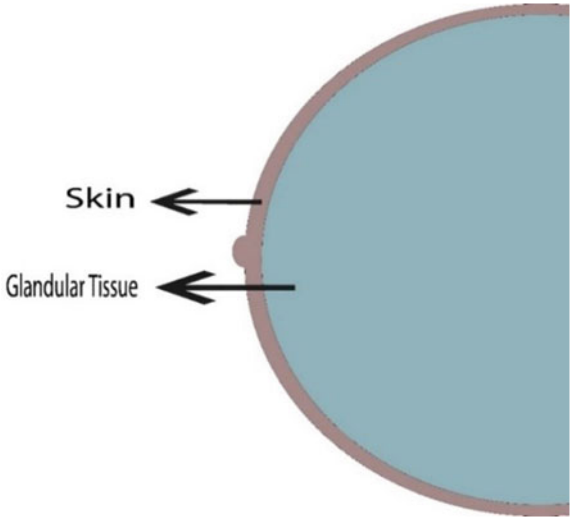


Fig. 2 Human breast phantom (Cross-sectional view)

2.3 Human Breast Phantom Model and Tissue Properties

The human breast phantom is created consisting of skin and glandular tissue. All the dielectric properties are completely regulated, such as conductivity, relative permittivity, density, thickness, and loss tangent. The human breast phantom cross-sectional view is visible in Fig. 2.

The semicircular breast phantom is constructed in the CST microwave studio, which resembles the human breast layout. The layout is shaped as half sphere and the antenna is placed on the phantom surface. A thickness of 1 and 23 mm outer radius is considered for the skin. Inside the skin, breast fatty tissue (fibro glandular) is placed with a 22 mm radius. The defected cell is located inside the fatty tissue with a 2 mm radius (Fig. 3).

3 Antenna Characteristics Without Cancerous Tumor

3.1 Reflection Coefficient or S11 Parameter

Reflection coefficient determines the sum of power reflected or radiated from an antenna [11]. After placing on the surface of the breast phantom, radiation pattern is noted. The x-axis in Fig. 4 defines resonance or operating frequency, which is in the GHz range whereas the y-axis defines the return loss which is in the dB scale. The resonant of the propounded antenna is 2.48 GHz, which falls in the range of the ISM band. The return loss of −49.405 dB proves the performance of the antenna by

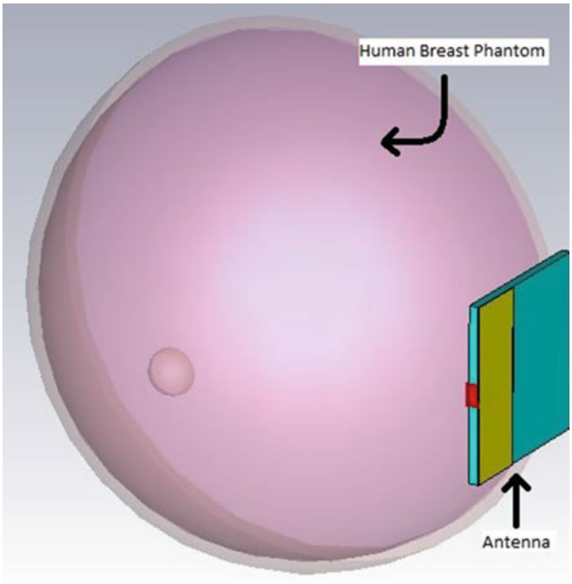


Fig. 3 Antenna on the human breast phantom surface

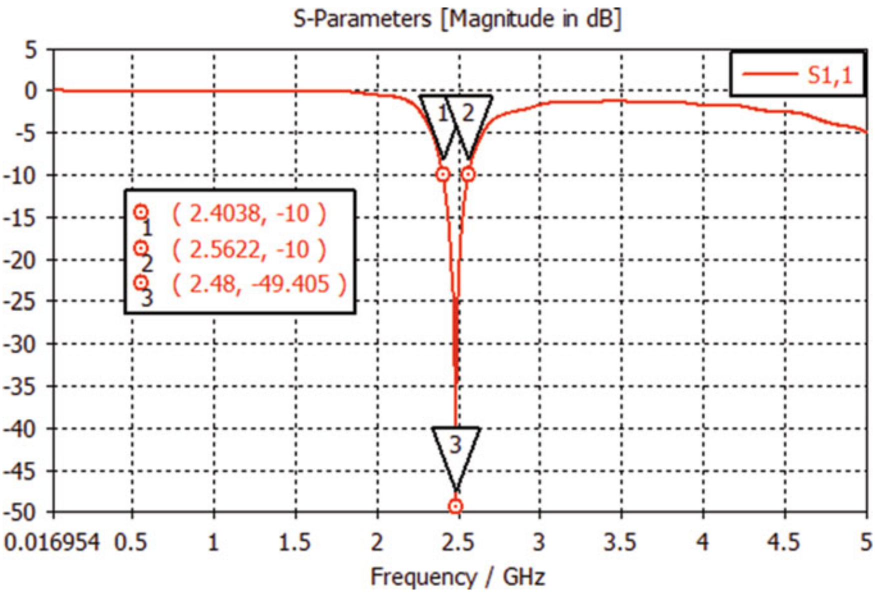


Fig. 4 S11 parameter or return loss of the antenna (without cancerous tumor)

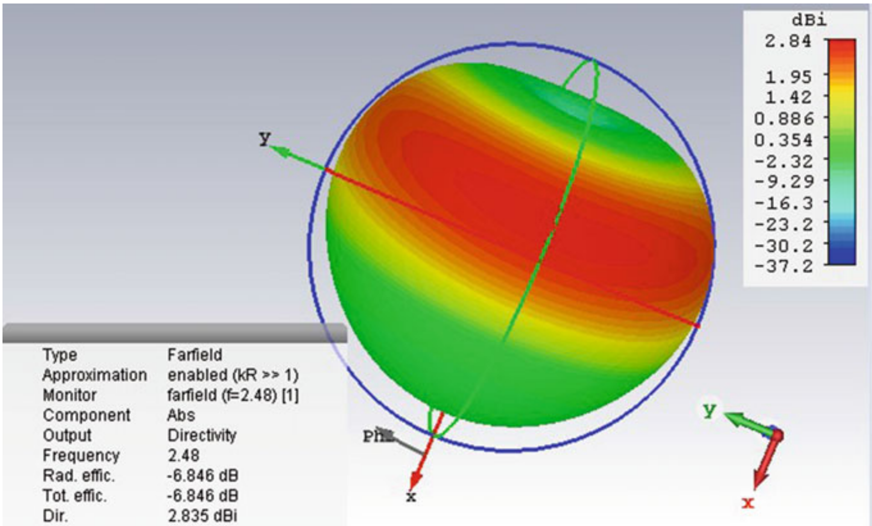


Fig. 5 Far-field radiation pattern (3D view) of the propounded antenna (healthy tissue)

showing the maximum radiation. The bandwidth of the propounded design is noticed at 158.4 MHz (2.4038–2.5622 GHz), thus ensuring safety for all users.

3.2 Far-Field Radiation Pattern

In Fig. 5, the radiation pattern of the propounded antenna is elucidated. Since the antenna is made to detect the cancerous tumor, therefore the directivity maintained is unidirectional. Despite being unidirectional, the radiation spreads throughout the organ part is as shown. Practically, the user can also rotate the antenna in all possible sides. Parameters such as directivity is 2.835 dBi, radiation efficiency is −6.846 dB, and total efficiency is −6.846 dB, respectively.

Figure 6 is showing the polar view of the far-field radiation pattern of the propounded antenna with 2.61 dBi main lobe magnitude.

3.3 VSWR—Voltage Standing Wave Ratio

It is basically a function of measurement of the power radiated from the antenna [12]. The propounded antenna's VSWR is 1.006 at an operating frequency of 2.48 GHz. This specifies that the antenna's impedance is matched perfectly with the transmission

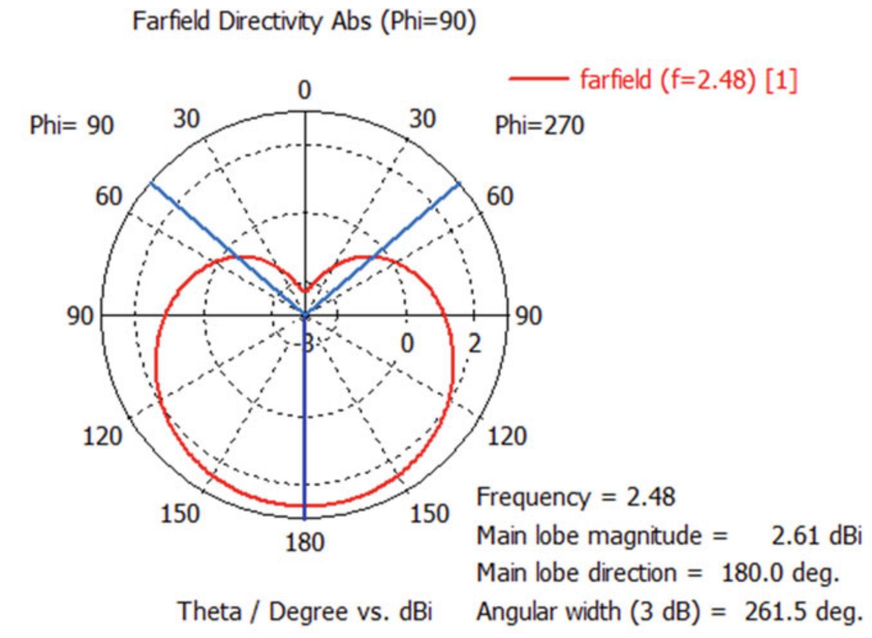


Fig. 6 Far-field radiation pattern (polar view) of the propounded antenna

line. For efficient performance, the value of VSWR should be between 1 and 2. The x-axis in Fig. 7 represents frequency in the range of GHz and the y-axis represents VSWR.

3.4 SAR—Specific Absorption Rate

The radiation given out by the surrounding tissue is called SAR. It checks the safety level for all users [13]. According to FCC, the specific absorption rate should be less than 2 W/kg to meet the standard [14, 15]. SAR for the propounded antenna is noted 1.18 W/kg at the resonant frequency for 10 g tissue for 1mW of input power (Fig. 8).

4 Antenna Characteristics with Cancerous Tumor

To examine the performance of the antenna, a spherical-shaped tumor is constructed in the CST studio suite with a 2 mm radius, and antenna is placed on the surface of the breast phantom. The dielectric property is followed by electric conductivity and permittivity are 0.7 S/m and 55, respectively. By placing it on the varied position of

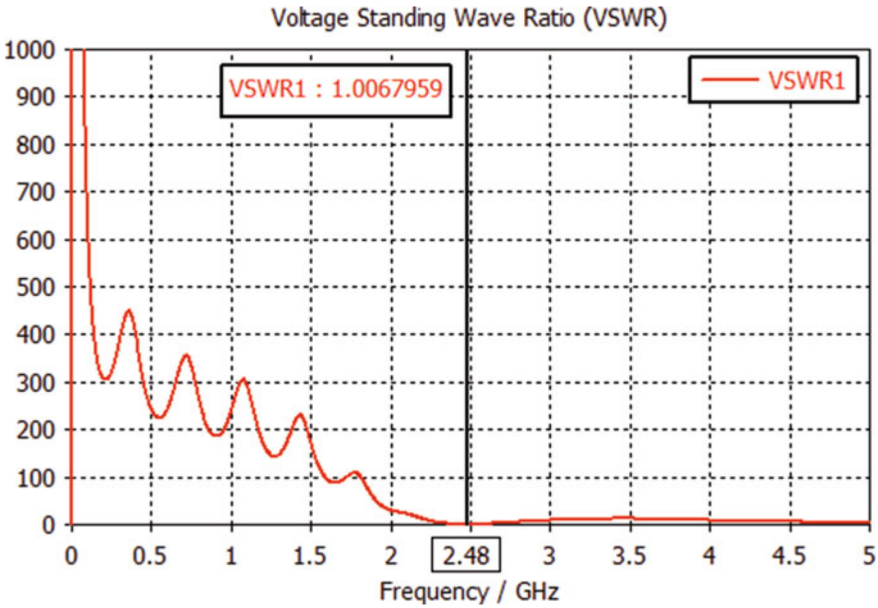


Fig. 7 VSWR of the antenna (healthy tissue—without cancerous tumor)

the phantom and replacing the position of the tumor, the effects are examined and compared. Figure 9a shows the condition where the tumor is absent. Figure 9b shows the condition where the tumor is in the center (position 1). Figure 9c represents the condition for position 2 (x = 45, y = 0, z = 0) and Fig. 9d represents the condition for position 3 (x = 90, y = 0, z = 0).

4.1 Reflection Coefficient or S11 Parameter

Figure 10 depicts a vivid comparison of the S11 parameter by placing the tumor on a different position. Table 2 reflects the resonance frequency and return loss of all positions.

From Table 2, it can be summarized that the operating frequency is identical during the absence and presence of a tumor. However, there is a major change in S11. Return loss or S11 is raised rapidly in presence of a tumor and inversely proportional with the distance of antenna and breast surface.

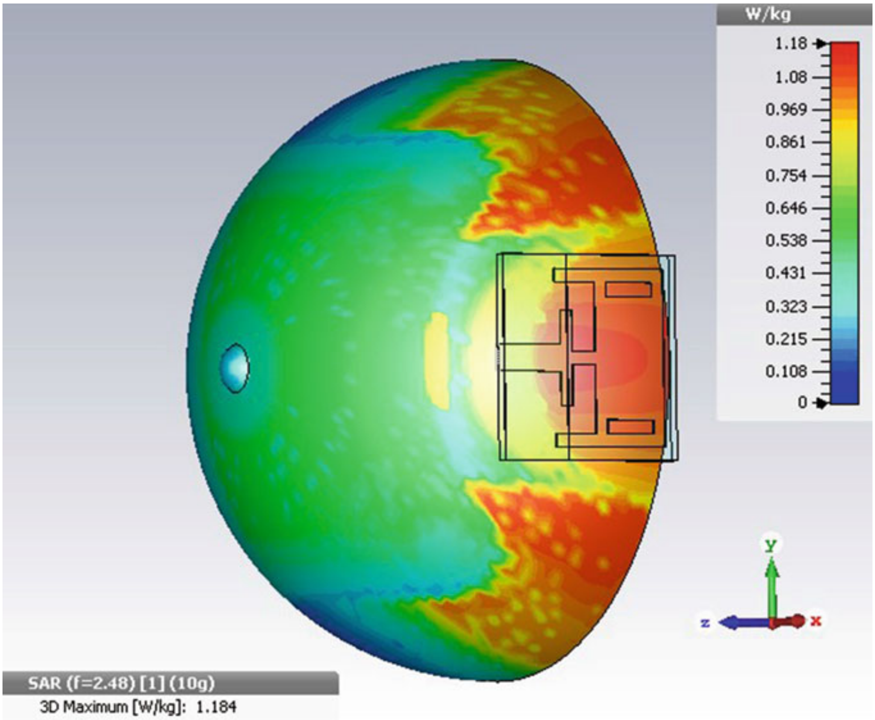


Fig. 8 SAR (Specific Absorption Rate) for 10 g tissue for 1mW of input power

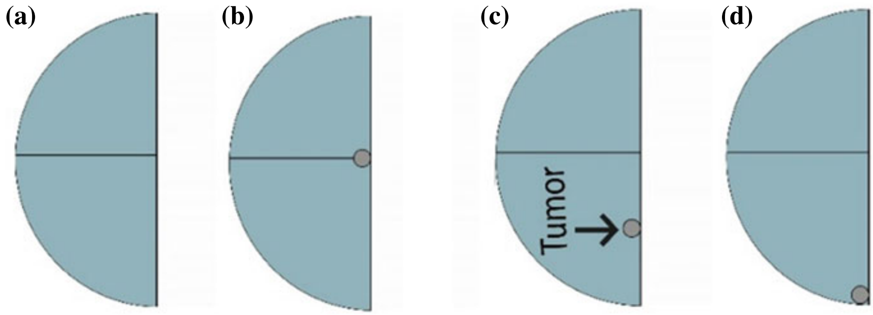


Fig. 9 Cancerous tumor (malignant) inside human breast in **a** Without tumor, **b** Position 1, **c** Position 2, **d** Position 3

4.2 Other Characteristics

Table 3, represents the compared values of maximum main lobe magnitude, maximum E-field intensity, maximum H-field intensity, and surface current density

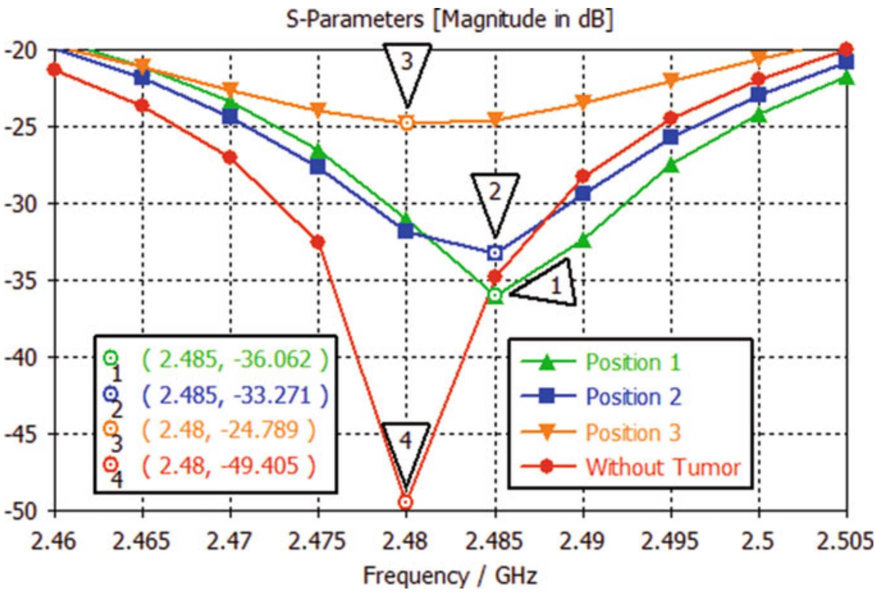


Fig. 10 Reflection Coefficient or S11 parameter with and without cancerous tumor of the antenna

Table 2 Resonance frequency and return loss analysis

Parameter	Without tumor	With cancerous tumor		
		Position-1	Position-2	Position-3
Resonance frequency (GHz)	2.48	2.485	2.485	2.48
Return loss or S11 (dB)	−49.405	−36.062	−33.271	−24.79

Table 3 Comparison analysis of different characteristics

Parameter	Without tumor	With cancerous tumor		
		Position 1	Position 2	Position 3
Main lobe magnitude	2.61	2.67	2.7	2.75
Max. E-field intensity	73659	80138	79755	77259
Max. H-field intensity	560	576	570	562
Surface current density	317	332	329	321

between cancerous tumor and without cancerous tumor. It is identified that the value slightly increases in main lobe magnitude. The numbers of maximum E-field and H-field intensity increase with the presence of tumor and proportion with the distance of tumor [16]. But the surface current density slightly decreases.

5 Conclusion

In this research, a rectangular structured microstrip patch antenna with improved parameters has been presented. The purpose of designing the antenna is served in terms of efficiency, size, return loss along with making it functional at a resonant frequency of 2.48 GHz. The propounded design is more improved from the rest of the work in the field of frequency, SAR, radiation pattern, H-field, and E-field. The variation of the frequency curves shows an enormous response in identifying the cancerous and non-cancerous tissue. The VSWR of 1.007 proves that the impedance of the antenna is matched well with the transmission line. Besides, there are significant changes when the results are compared in the presence and absence of the tumor in both electric and magnetic fields. Considering the well-being of the user, SAR is computed as 1.18 W/kg at the operating frequency of 2.48 GHz for 10 g tissue. Hence, it can be said that the devised system is well efficient for the early diagnosis of breast cancer.

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