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A Low-Cost Microstrip Patch Antenna Based Metamaterials for Non-Invasive Breast Tumor Detection

Abdullah Alzahrani

***Abstract:** Microstrip patch antennas have been used extensively in broadband telecommunication applications. Despite their countless promises, their narrow bandwidth and the loss at high-frequency bands have limited their usage in medical applications. The purpose of this work is to design a patch antenna sensor that is a low-cost microstrip sensor which is suitable for biomedical application to detect a breast cancer tumor. The proposed antenna sensor is comprised of three layers namely ground, substrate and microstrip patch sensor that can be easily fabricated by using standard printed circuit board technique. The comparison study between two resonance frequency at 1.8 GHz and 2.9 GHz has been performed and investigated by especially accurate simulation with the presence and absence of tumor cell. Results obtained using computer simulation technology CST Studio Suite 3D EM simulation and analysis software indicates that the design can detect tumor by using phase shift detection and depth of the return loss. The result shows that the antenna return loss is getting lower in -39 dB at 1.8 GHz and -12 dB at 2.9 GHz and the phase shift detected with the presence of the tumor cell. Specific absorption rate has been also calculated (0.746 and 0.934 W/kg) and found to be in acceptable range and not exceed the standard value of <1.6 W/kg, which mean that the patch sensor is compatible for human and biomedical application. The breast phantom models without/with a tumor have been numerically simulated by using the antenna operating as a transceiver for the detection of cancer tumor cells. Two parameters have been observed, the frequency phase shift and the deep amount of reflection return loss. In summary, this study concludes that a lower frequency band will result in higher penetration depth but a lower resolution. Meanwhile, higher frequency band will provide a better resolution, but the penetration depth will be lesser as seen in the comparison study between 1.8 GHz and 2.9 GHz. The proposed work could provide a pathway on the design of electromagnetic sensors for biomedical applications.*

***Keywords:** Antenna; Specific Absorption Rate; Breast Tumor; Phase Shift; Return Loss.*

I. INTRODUCTION

Cancer is the most threatened disease in the last 5 decades and can affect other normal body parts. However, breast cancer is the most common cancer in women worldwide, [1,2].

Approximately 8.2 million people have died from breast cancer [3]. Unfortunately, more than 1.8 million new breast cancer have been reported worldwide each year and breast cancer is expected to rise from 14 million to 22 million people in the next two decades and could increase even more [4,5]. Due to its high incidence, breast cancer is considered one of the most dangerous types of cancer, especially among women, thus women require a routine checking and examinations. One of the most common techniques to diagnose breast cancer is Mammography via X-ray [6], which considered the only method for women with no early symptoms. However, this method could cause the deterioration of the patients' lives due to misdiagnoses and inaccurate results in first checking [7]. Another method to diagnose breast cancer is ultrasound imaging, however, this method suffers from the quality of the images which sometimes cannot be clearly distinguished between a normal cell and an affected cell in its early stage [8]. On of the most advance technique to examine breast cancer is magnetic resonance imaging (MRI), which consider to be more sensitive technique that can be used for women with dense breasts. Despite the sensitivity of MRI, but it is very expensive and complicated. In addition, the tumor cannot be located accurately in this technique, which may lead to mismatch the extraction or could cause other complications [10]. In previous techniques, there are still some limitations such as localization, inaccurate, bulky equipment, complicated and expensive techniques. A new technique has been used as a promising technique with low cost, reduced complexity, high data rate accuracy, non-ionizing nature, and low power density namely microwaves [11,26,27,28,9,8,6]. Microwave imaging (MWI) systems are currently receiving significant attention as an alternative approach to detecting breast cancer [12] and consider to be early diagnosis technique for breast cancer. Survival rates can be reached 97% when the detection of breast cancer is in the early stage. The MWI is a new, reliable, and highly efficient way to detect breast cancer at an early stage [10, 13]. The MWI is based on Metamaterial (MTM), which is an electromagnetic compound with very different properties that are rarely encountered in nature [13]. The Metamaterials are synthesis objects that reveal extraordinary characteristics such as negative permeability ($\mu < 0$), negative permittivity ($\varepsilon < 0$) and negative refractive index [14] in the desired frequency range [15,16]. The MTMs used in a variety of technical applications, including microwave and terahertz applications [16,17, 18], antennas [19], sensors [14-16], sensitive detectors [17], polarization transducers [20, 21], radar [20], absorbers [22] and cloaking [23].

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Early diagnosis of breast cancer is considered as the most effective solution to remedy breast cancer [7] and survival rates can reach 97% when the detection of breast cancer is in the early stage. In this paper, the design has numerically presented a new microstrip patch antenna designed for breast cancer detection using microwave. This approach and structure design provides a reliable, and highly efficient way to detect breast cancer at an early stage. It is believed that this study is useful for biomedical applications such as cancer tumor cell detection. The CST Studio Suite 3D EM simulation and analysis software was used to design and simulate numerical results.

II. METHOD

The basic principle of this work is to design microstrip patch antenna which is utilized to analyze and distinguish between changes in the backscattered signal and changes in the properties of different electrical properties of cells and tissues. Normal and cancerous cells can be distinguished depending on changes in the backscattered signal due to changes in the electrical properties of tissues. Patch antenna is the most important component that needs to be considered in the system.

The basic principle is that antenna will generate a microwave electromagnetic and then transmit it into a human cell, part of the signal scatters back to the antenna depending on the dielectric quality value of the cell. According to studies [5, 24], the dielectric quality of a normal cell is smaller than a cancerous cell. Thus, a distinguished backscattered microwave signal evidently indicates a tumorous cell. Furthermore, additional information can be extracted from the scattered back signal that are valuable evidence such as the depth of return loss and phase shift, which reveal the presence of a tumor cell.

The direction of the radiation pattern (directivity), gain, matching feed-in, resonance frequency, efficiency and specific absorption rate SAR radiation are crucial parameters for our design to firmly detect breast cancer cells. All these parameters are considered in the patch antenna.

A. Patch Section Formula

Considering the requirement of antenna in compact design, microstrip patch is chosen due to its thin shape and easy to configure and manufacture. The design uses flame retardant epoxy resin and glass fabric composite (FR4) as substrate with $\varepsilon_r = 4.3$, thickness h = 1.6mm and loss tangent = 0.025. In addition, a copper ground layer is used with the thickness = 0.035 while microstrip line feed is applied as basic feeding technique to match the 50Ω. In terms of patch's dimension, the formula is given as [25]:

Length of patch:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} = = -2\Delta L \qquad (1)$$

Where h is substrate thickness:

$$\varepsilon_{reff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}[1 + 12\frac{h}{w}]^{-1/2} \qquad (2)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \qquad (3)$$

Wide of patch (Wp):

$$w = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (4)$$

where ε_r = dielectic constant of substrate

ε_{reff} = Effective dielectric constant

W_p = Width of the patch

B. Substrate and Ground Planes

Length of substrate plane (Ls):

$$L_s = 6h + L \qquad (5)$$

Wide of substrate plane (Ws):

$$W_s = 6h + W \qquad (6)$$

The width of the ground is identical to the width of the substrate however, the length of the ground is reduced to improve the overall performance and to shift the resonance frequency to the desire frequency range.

C. Antenna Sensor Design

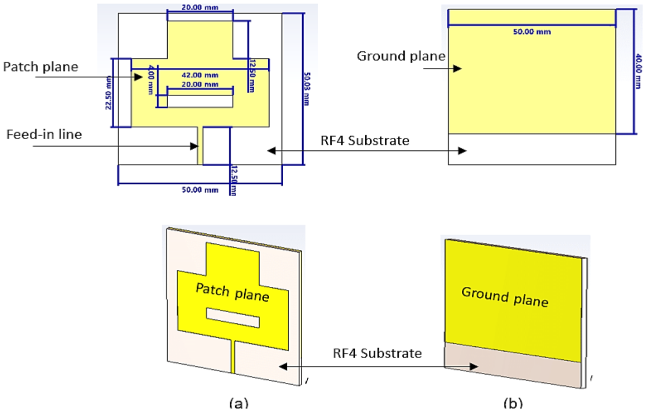


Figure 1. Geometric Structure of the Proposed Microstrip Patch Antenna, (A) Front View and (B) Back View

Figure 1 is presented with layers of microstrip patch antenna design which consists of three layers namely ground, substrate, and patch. The dimensions of antenna sensor (substrate) and patch are 50x50 mm and 42x45 mm respectively. As seen from the figure 1 that the ground plane is changing by removing the small part from the downside as well as introducing a rectangular slot on the patch plane. Following its model, the proposed design was developed in different resonant frequencies which are at 1.8 GHz and 2.9 GHz. All optimizations and modifications in the design (e.g., introducing slot) will enhance the efficiency of the antenna and return loss at specific resonance frequency and all these importance have been considered.

III. RESULTS

In this section a comparison study of simulated results of the antenna sensor has been discussed for both resonance frequencies at 1.8 and 2.9 GHz with/without tumor cells as shown in figure 2.

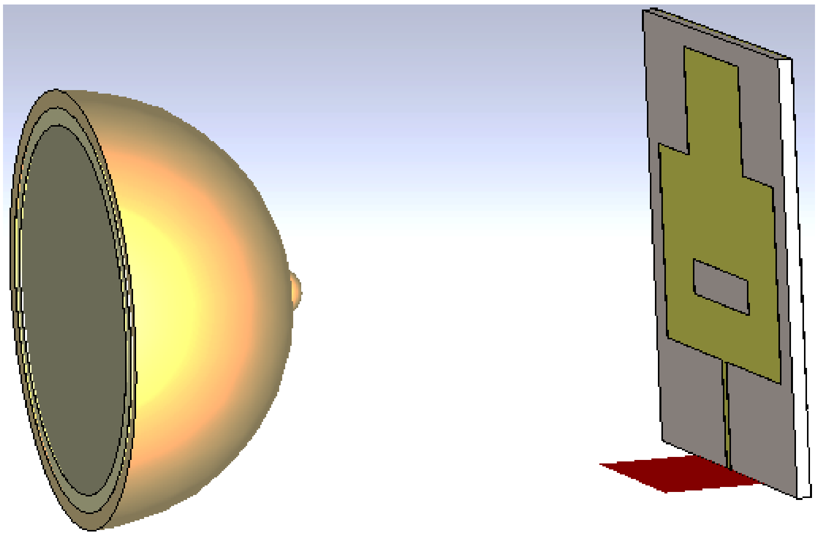


Figure 2. Antenna Patch Sensor with Phantom Breast Model

It can be seen from figure 2 that the phantom breast consists of three layers as outer skin (breast skin), breast fibroglandular and the inner layer which is breast fat. Figure 3 illustrates the breast layers.

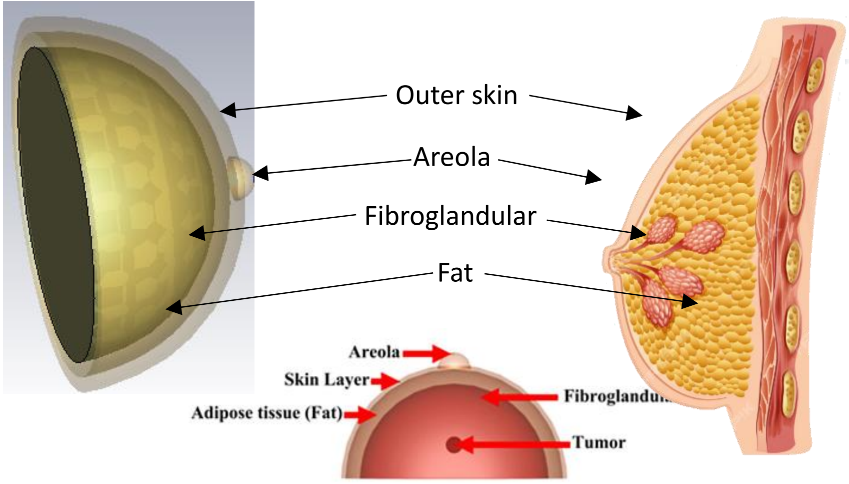
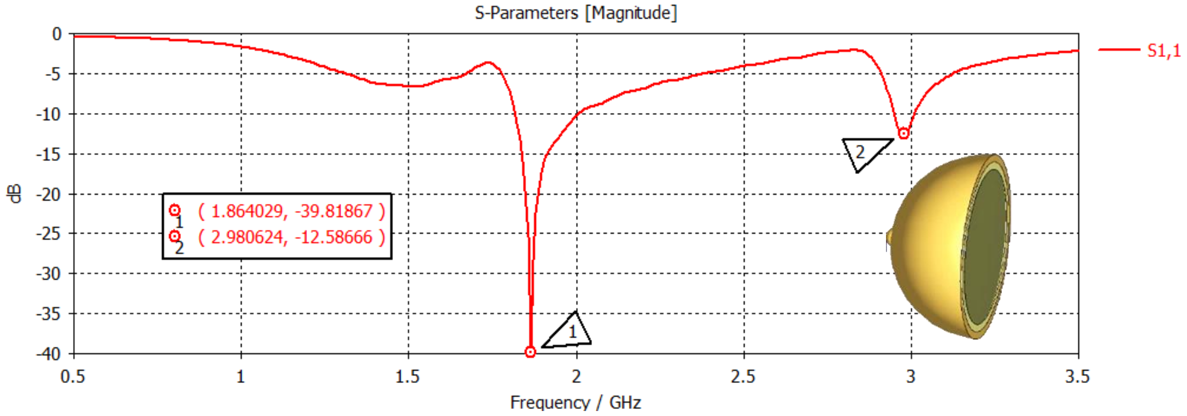


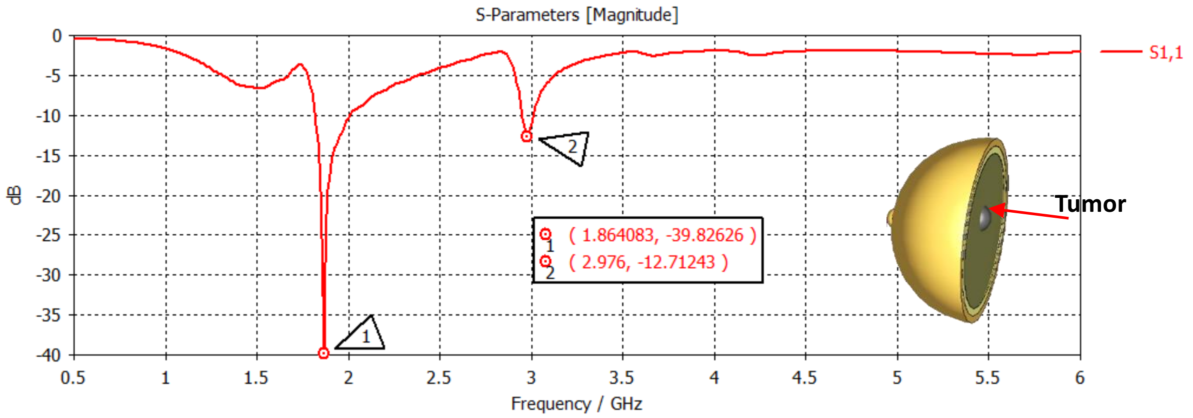
Figure 3. Phantom Breast Model and Layers

A. Return loss:

The first parameter that considered and analyzed is return loss (S11) at resonance frequency of 1.8 GHz and 2.9 GHz. Each reflectance shows below -10 dB which complies with criteria. Figure 4 shows the graphs of return loss profile for reflector (S11) antenna sensor on both normal breast figure 4 (a) and affected cancerous breast figure 4 (b).



(a)



(b)

Figure 4. Return Loss Profile for Reflector (S11) Antenna Sensor, (A) Without Tumor and (B) with Tumor Cell.

It can be seen from figures 4 that at resonance frequency of 1.8 GHz, the phase shift between a normal and affected cell is very small around 54Hz, whereas at 2.9 GHz, the phase difference is around125 MHz. Even though the return loss at 1.8 GHz is -39dB which is much better than the S11 (-12dB) at 2.9 GHz by around -27dB, however the resolution of higher band frequency is significantly better. In addition, the depth value of return loss is another parameter that can be used as a reliable indicator of tumor cells present. At lower band frequency of 1.8 GHz, the depth deference between both measurements (without/with tumor cell) is 0.0076dB whereas at resonance frequency of 2.9 GHz is 0.13dB.

B. The Voltage Standing Wave Ratio (VSWR)

The VSWR is an indication of the amount of mismatch between an antenna and the feed line connecting to it and can be obtained at a minimum level in the permissible range (i.e.) below 2 for the desire resonance frequency. Hence, the simulated results of the antenna sensor shown in the below Figure 5.

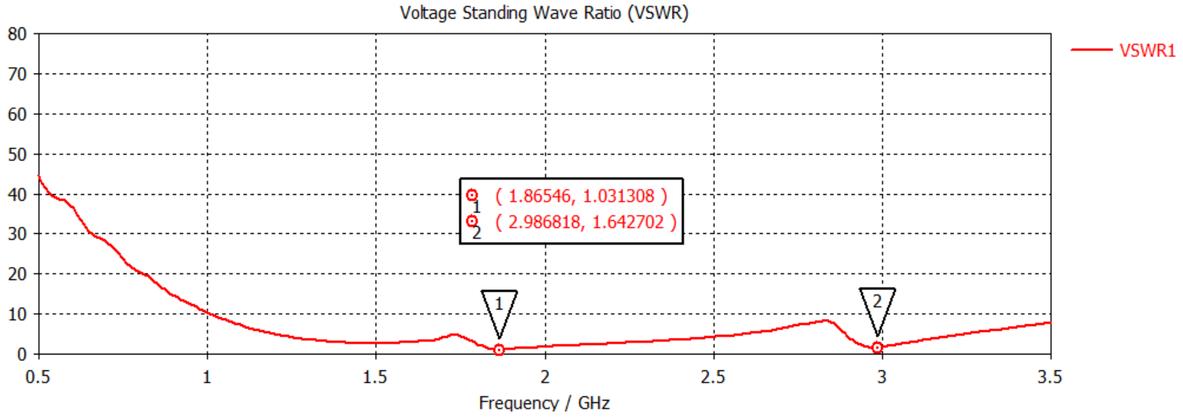
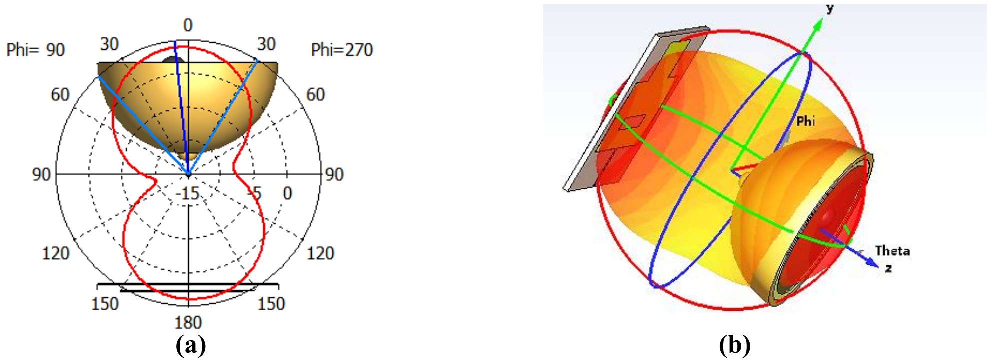


Figure 5. The Voltage Standing Wave Ratio (VSWR)

At two resonance frequencies 1.8 and 2.9 GHz, the VSWR values are 1.03 and 1.64 respectively. A VSWR value under 2 is considered suitable for most antenna applications. The antenna can be described as having a “Good Match” and when the VSWR value exceeds 2 for a frequency of interest, it means that the antenna is poorly matched. However, in our design both values of VSWR are less than < 2 which indicate that the values in acceptable range and good match.

C. Radiation Pattern

Theta and phi spherical coordinate tables record the measurements. The following is how the spherical coordinates relate to the Cartesian axes: Theta = 0 for 360 and Phi = 0 for x-z Cut, Phi = 90 for y-z Cut, and Theta = 90 for x-y Cut. The x-z plane (ϕ = 0) and the y-z plane (ϕ = 90) are referred to as the E and H planes, respectively. The radiation pattern of proposed antenna in E-plane (x-z plane) and H-plane (y-z plane) is shown it in the figure 6 (a), and also the 3-Dimensional radiation pattern is shown in Fig 6 (b). The E-plane and H-plane beams are preferred because the orientation of the primary lobes is stable with broadside beams.



(a) (b)

Figure 6. Radiation Pattern at 1.8 Ghz in E-Plane (X-Z Plane), and H-Plane (Y-Z Plane)

From figure 6 (a), the main lobe magnitude = 3.94dBi, the main lobe direction = 6 deg. and the angular width (3dB) = 74.4 deg. The simulated gain and directivity plotted and calculated for all resonance frequencies. The observed shows that the directivity at 1.8 GHz and at 2.9 GHz are 3.773dBi and 3.264dBi respectively. Whereas the gain at 1.8 GHz is 0.995dBi and at 2.9 GHz is 1.804dBi. All above calculations with presence of tumor cell.

D. Specific Absorption Rate (SAR)

One of the critical parameters is SAR absorption rate of radiation. In order to avoid adverse health effects, the specific absorption rate of an antenna must not exceed 2 Watts per kilogram. Since 1998 this value is recommended as a limit by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The SAR is obtained by dividing the total power absorbed in the human body by the full body weight. The SAR Calculation requires entering the electric field (V/m), conductivity of the material (S/m) and Mass Density (Kg/m3) and these calculations are measured by CST simulation.

A local SAR is calculated and given as a numerical value per volume element and becomes a space distribution function. For this function, the mass mean value in arbitrary tissue volume is called local SAR. Typical local SAR values are averaged in tissue masses of around 10g specified by the Telecommunication Technology Council Agenda No. 89 and CENELEC 1995, whereas the value of 1g is adopted by ANSI/IEEE C95.1-1992 of the United States. A cuboid averaging volume is used. Thus, in this work a 10g and 1g of mass have been calculated and given the maximum SAR of 0.746 W/kg for 10g, and for 1g the maximum SAR is 0.934 W/kg.

The SAR in simple terms refers to the rate at which the body absorbs RF energy. The SAR limit is 1.6 watts per kilogram in countries that set the limit averaged over 1 gram of tissue, and 2.0 watts per kilogram in countries that set the limit averaged over 10 grams of tissue. So, the antenna design in this work is suitable for biomedical applications since both SAR at 10g and 1g do not exceed 1.6 W/kg.

IV. DISCUSSION

The proposed design was simulated using CST-studio; the design was completed and contained layers of antenna with a full ground plane and patch with no slot. By using the full ground plane, the return loss was excellent and more -30dB but on the other hand the SAR radiation was more than standard value of 1.6 w/kg. However, after removing 10 mm from one side of the ground plane, the SAR radiation became in acceptable range less than < 1.6 w/kg.

In addition, the resonance frequency was around 6 GHz and distant from lower band frequency which is valuable for biomedical applications. Then, the antenna was enhanced by introducing a rectangular slot with 20 mm width and 4 mm length. The resonance frequency moves to lower band frequency around ~3 GHz, and we obtained two resonance frequencies at 1.8 GHz and 2.9 GHz. A lower frequency will result in higher penetration depth but a lower resolution. Meanwhile, higher frequency will provide a better resolution, but the penetration depth will be lesser as seen in the comparison study between 1.8 GHz and 2.9 GHz. Low frequencies band provide deeper penetration (lower loss), although higher frequencies band offer better resolution range in terms of phase shift and deference depth value: hence, the choice of 1.8 and 2.9 GHz as an appropriate operating frequency ensuring internal views of normal/tumor breast cells in the depth of 3-5cm.

In brief, a high band frequency provides resolution even with less penetration. Thus, more than one antenna sensor can be mounted around the breast to overcome the penetration issue. So, in the case of one patch antenna sensor is far away from the tumor, the other one could be closer and can detect it easily. The difference is attributed between return loss and its depth value as well as the frequency phase shift measurements due to the absence (normal cell) and presence of tumor cell. These results are acceptable and require further investigation for practical use.

V. CONCLUSION

In summary, a new structure and low-cost antenna sensor were designed and simulated for microwave breast cancer at 1.8 and 2.9 GHz frequencies. CST software was used to design and simulate the structure. The realized of the antenna design at the resonance frequencies (return losses at the lowest frequency) were -39dB while at higher band frequency is around -12dB. It also observed from work that even though the higher band frequency is less than a lower band frequency in terms of return loss depth, but the higher band frequency provides identifiable detection and higher resolution (recognizable phase shift and depth value) more than the lower band frequency.

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A comparison study of antenna performance at two resonance frequencies was conducted. Phantom models with and without tumors were considered to validate the approach. Important parameters such as gain, directivity, VSWR and SAR were considered in this design, and all values are recommended and meet the requirements and organizations standard. The proposed design is a safe candidate for biosensor applications and microwave breast cancer.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material	Not relevant.
Authors Contributions	I am only the sole author of the article.

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