American Journal of Electronics & Communication

Dhrubo Ahmad et al, American Journal of Electronics & Communication, Vol. I (1), 69-76

On-Body Circular Patch Antenna for Breast Cancer Detection

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***Abstract*—Breast Cancer is one of the deadliest forms of cancer faced by women every year. Despite having medical methods like Mammography, MRI and ultrasound available, they have various limitations due to poor tissue contrast. This results in misdiagnosis of breast cancer patients all over the world. The purpose of this paper is to detect the presence of breast cancer tumors in women by the variation of S_{11} parameter of a microstrip patch antenna. To reach the desired goal, a circular microstrip patch antenna has been designed in ISM band along with two types of breast phantoms in order to detect the presence of cancerous tumors. The antenna along with the breast phantoms have been created using CST design environment and its various parameters i.e. reflection coefficient, efficiency, SAR have been evaluated to reach the goal set by this paper.**

***Keywords*—ISM band, Microstrip patch, Reflection coefficient, S_{11}, Frequency, Breast tissue, Breast phantom, Farfield, Efficiency, SAR**

I. Introduction

Breast cancer is one of the leading causes of death in women. It is one of the most widespread disease for women around the world. Now a days, a staggering number of women are being affected every year by breast cancer. Breast cancer can also lead to others serious complications in brain, lungs, liver or bones [1]. And so, to ensure critical, proper and effective treatment, early detection of tumors that leads to breast cancer is of utmost importance. To achieve this, locating the exact position and size of the tumor is necessary. Since in the early stage of breast cancer, the tumor remains very small, it is possible for microwave imaging to locate it promptly and precisely.

At present, mammography is the go to method for detecting breast cancer in women. To detect the presence of breast cancer in women who have no apparent symptoms, screening mammograms are routinely administered. The size of the tumor ultimately decides the ability of a mammogram to detect breast cancer. The ability may depend on the breast tissue density, and the skill of the radiologist for reading, administering and performing the mammogram. If the patient is younger than 50 years, it is less likely that Mammography will reveal the presence of breast tumors. The reveal is more likely to happen in older women. This is due to the fact that younger women have denser breast tissue. Due to this, they might appear white in the diagnostic of a mammogram. As a tumor also appear white on a mammogram, this makes the tumor harder to detect in a mammogram [2].

Another method of diagnosing breast cancer is by biopsy [3]. Although biopsy is a really good method of screening breast cancer, there are still some viable issues. The amount of tissue extracted from a needle biopsy may not be sufficient and the biopsy may have to be repeated. Even after samples are extracted from the precise area, there is a possibility of false negative results occurring if the pathologist misdiagnoses the tissue as benign when in reality, cancer is indeed present. Although with surgical biopsy, this is less likely to happen. But even then a misdiagnosis can happen if the tissue of a wrong area is removed [4].

For this reason, recently, research has been going on regarding different types of antenna that uses microwave imaging technique to figure out the presence of a tumor. A patch antenna or microstrip patch antenna is a wide-beam, narrowband antenna. It is also known as printed antenna. Its physical geometry revolves around two dimensions. For fabrication of a patch antenna, on an insulating dielectric substrate like a PCB or printed circuit board, a shaped metal sheet is mounted. At the opposite side of the substrate, a continuous metal layer bonded which forms a ground plane [5]. These types of antenna can either be implantable or on-body. This antenna radiates a microwave signal to the breast and those signals detect the cancerous cells from breast.

In this paper, the proposed antenna was designed in CST Studio Suite (CST) and two types of breast phantom was created in order to simulate the results. From the results, it is seen that the presence of tumors at both of the breast phantoms were detectable.

This paper is presented as, in section II is the modelling of the antenna. In section III, design of the breast phantoms are included. Section IV consists of the simulated results. Lastly, the overall paper has been discussed in section V.

II. Modelling of the Antenna

A microstrip patch antenna was designed which operates at ISM Band in order to detect the presence of cancerous tumors. ISM band works at the range of (2.4-2.48 GHz) [6]. The antenna is working at a resonant frequency of 2.885 GHz for Breast Phantom 1 and 2.3557 GHz for Breast Phantom 2. Copper has been used to create both the ground plane and the patch. To create the substrate, flexible material FR-4 has been used. CST Studio Suite has been used to design the antenna and human body phantom model.

The reason that copper was chosen was due to the fact that copper is an amazing conductive material and it is very efficient in terms of distributing electrical energy. Also, due to the fact that copper is relatively cheap [7]. FR-4 was chosen primarily because of its availability, high dielectric strength, resistance to moisture, cheap cost and its capability of delivering proper result in higher frequency [8].

TABLE I. Details of Copper Material

No	Copper Material	
	Characteristics	***Value***
01	Type	Lossy Metal
02	Mu	1
03	Electric Conductivity	5.96e+007 [S/M]
04	Rho	8930 [Kg/M^3]
05	Thermal Conductivity	401 [W/K/M]
06	Heat Capacity	0.39 [Kj/K/Kg]
07	Diffusivity	0.000115141 [M^2/S]
08	Young’s Modulus	120 [Kn/Mm^2]
09	Poisson’s Ratio	0.33
10	Thermal Expansion	17 [1e-6/K]

TABLE II. Details of FR-4 Material

No	FR-4 Material	
	Characteristics	***Value***
01	Type	Normal
02	Mu	1
03	Epsilon	4.3
04	Electric Tan.	0.025 (Const. Fit)
05	Thermal Conductivity	0.3 [W/K/M]

Using all the electrical parameters stated above, the final antenna design was created. The dimension of the antenna was measured to be 48.46×42.46×1.6 mm^3.

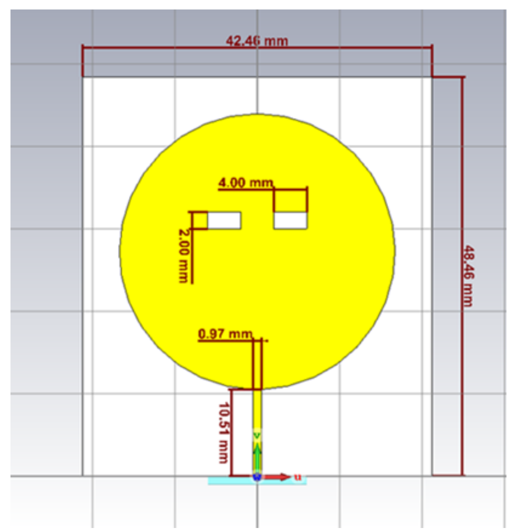

Fig. 1. Dimension of the Created Antenna

TABLE III. Dimension of the Created Antenna

No	Dimension	
	Name of the Parameter	***Size (mm)***
01	Total Length	48.46
02	Total Width	42.46
03	Radius of Patch(a)	16.73
04	Thickness of Patch (yp)	0.035
05	Line Width (ls)	0.97
06	Line Length (ps)	10.5
07	Patch Distance (wg)	4.5
08	Substrate Height (ts)	1.6

After simulating the antenna in free space, 2.465 GHz was found to be the operating frequency with a reflection co-efficient of -31.923577 dB as seen from figure 2.

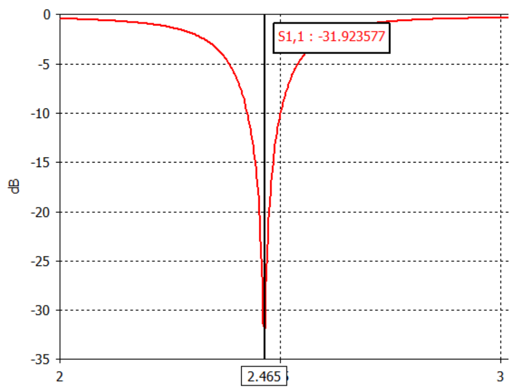

Fig. 2. S_{11} of the Antenna in Free Space

III. Design of the Breast Phantoms

In order to simulate our antenna, at first a breast phantom had to be made with the necessary parameter values. For this, skin and breast tissue were used.

The parameter used to create the skin of the breast phantom was as below:

Disp. Eps. = Nth order model (fit): N=3
Mue = 1
Rho = 1100 [kg/m^3]
Thermal Conductivity = 0.293 [W/K/m]
Heat cap. = 3.5 [kJ/K/kg]
Diffusivity = 7.61039e-008 [m^2/s]
Blood Flow = 9100 [W/K/m^3]
Metab. Rate = 1620 [W/m^3]

The properties used to create the breast glandular tissue of the breast phantom was as below:

Disp. eps. = Nth order model (fit): N=3
Mue = 1
Rho = 1020 [kg/m^3]
Therm. Cond. = 0.624 [W/K/m]
Heat cap. = 3.6 [kJ/K/kg]
Diffusivity = 1.69935e-007 [m^2/s]
Blood Flow = 360000 [W/K/m^3]
Metab. Rate = 64000 [W/m^3]

The properties used to create the breast cancer tumor was as below: [9]

Electric Conductivity = 4 [S/m]
Dielectric Permittivity = 39

The radius of the tumor used in the design was 6 mm. The first type of model incorporated the whole antenna shown in figure 3 and 4 below. Matching with its dimension. It consisted of 1 mm of skin and 29 mm of breast glandular tissue.

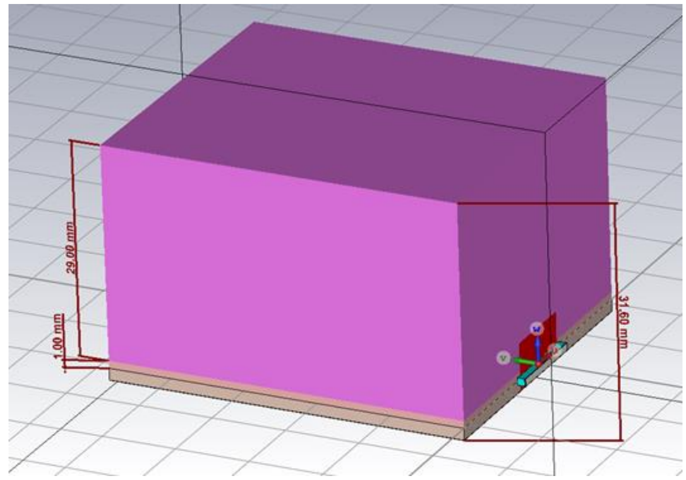

Fig. 3. Breast Tissue model with Skin and Breast Tissue

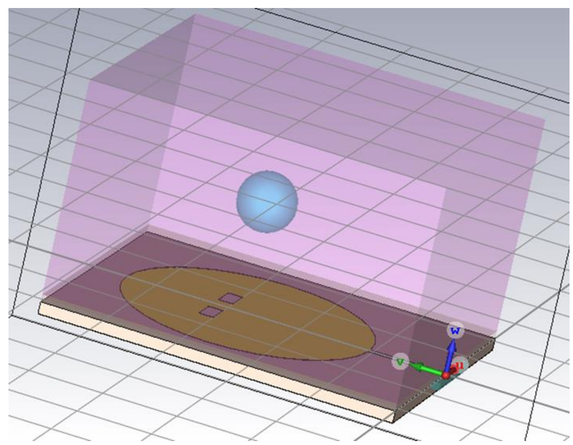

Fig. 4. Breast Tissue model with Skin, Breast Tissue & Tumor

The second model was created to be similar to a real biological model as shown in figure 5 and figure 6. The skin that was created here enveloped the breast tissue. The radius of the skin was 55mm and the radius of the breast tissue was 54mm.

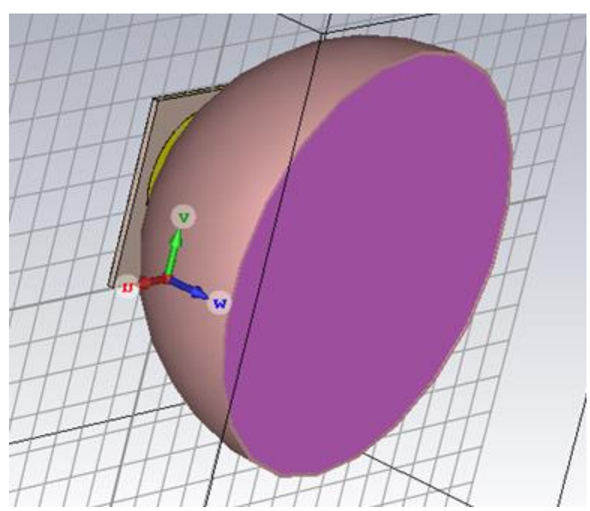

Fig. 5. Breast Phantom model with Skin and Breast Tissue

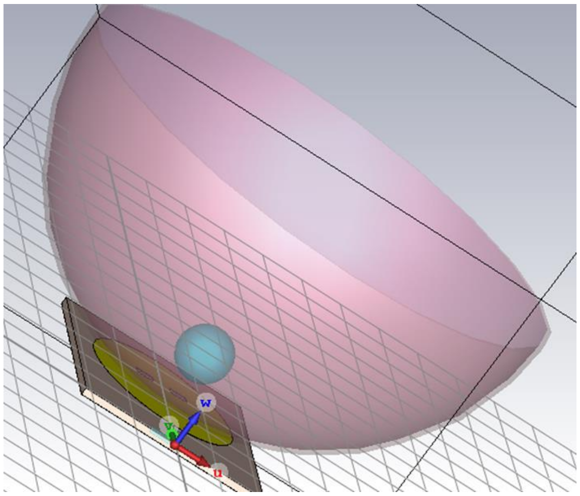

Fig. 6. Breast Phantom model with Skin, Breast Tissue & Tumor

IV. Simulation and Results

S-parameters or reflection coefficients describe the input and output relationship between antenna ports. S_{11} implies the reflected power that the device is trying to deliver to the antenna [10]. After simulating the antenna in free space, resonant frequency was found to be 2.465 GHz with a reflection coefficient value of -31.92 and a VSWR value of 1.052 as seen from figure 7 and 8 below.

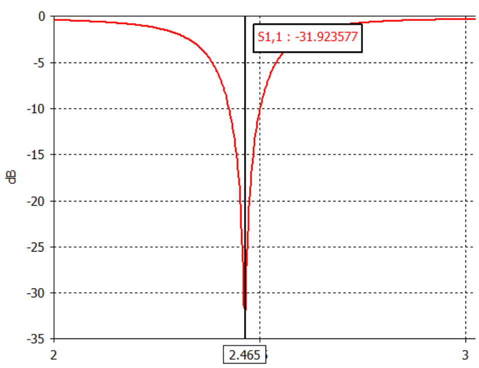

Fig. 7. S_{11} in Free Space

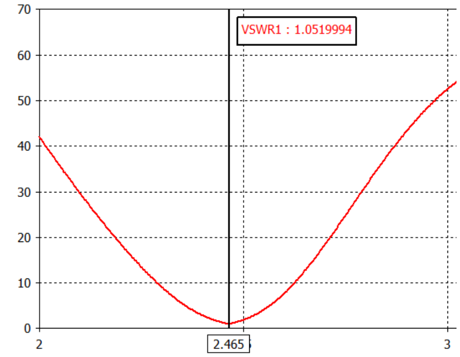

Fig. 8. VSWR in Free Space

A breast tissue region was created and the antenna was simulated by keeping the antenna on top of the skin of the breast. The reflection coefficient had been reduced to -12.470129 while the resonant frequency was found at to 2.885 GHz as shown in figure 9.

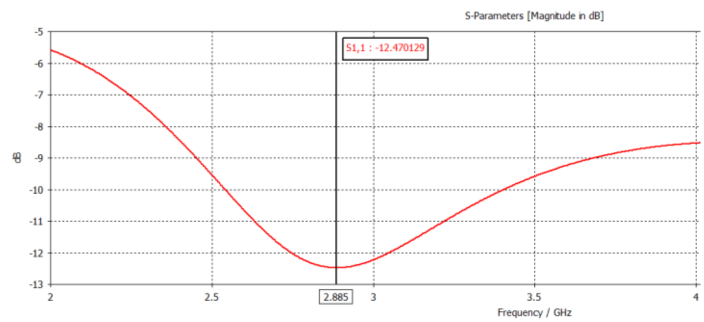

Fig. 9. S_{11} in Breast Tissue model without Tumor

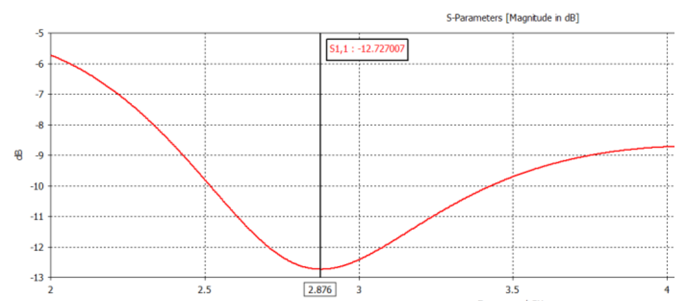

Fig. 10. S_{11} in Breast Tissue model with Tumor

For the analysis of our breast tissue model with tumor from figure 10, we can see that the reflection coefficient drops a bit with the presence of an antenna.

A close look at the curves shown in figure 9 and figure 10 above suggests that the curve goes a little downwards in comparison to the one having no tumor. The new value of reflection coefficient is -12.727007 dB.

Afterwards, the simulation was done for different positions and size of the tumor. At first placing the tumor in the upper part of the antenna provided the same exact operating frequency. But the noticeable change was in the reflection coefficient value.

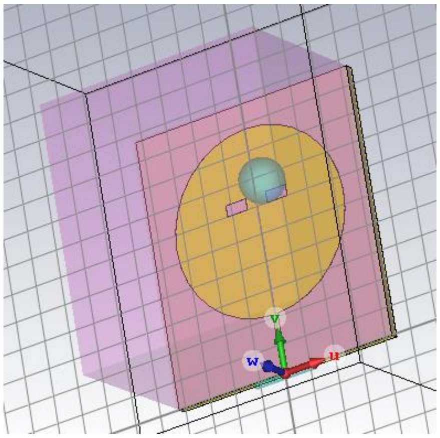

Fig. 11. Breast Tissue model with Tumor Position Right

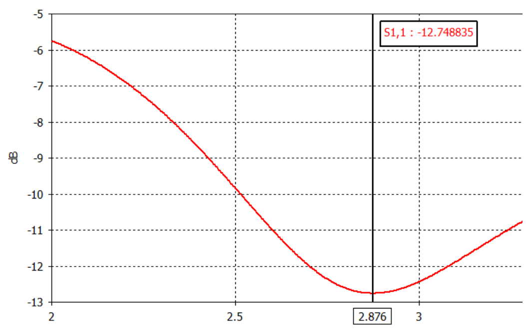

Fig. 12. S_{11} in Breast Tissue model with Tumor Position Right

As seen from figure 11 and figure 12, putting the tumor to the right from the center provided us with a reflection coefficient value of -12.748835 dB. While putting the tumor to the left provided us with a reflection coefficient value of -12.73303 dB as shown in figure 13 and 14 below. So it was understood that a decrease in the coefficient value had indicated that the position of the tumor had moved from the center of the antenna.

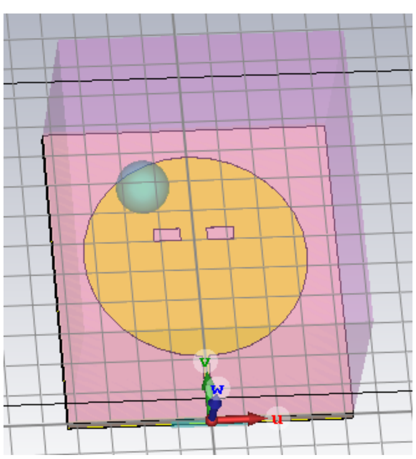

Fig. 13. Breast Tissue model with Tumor Position Left

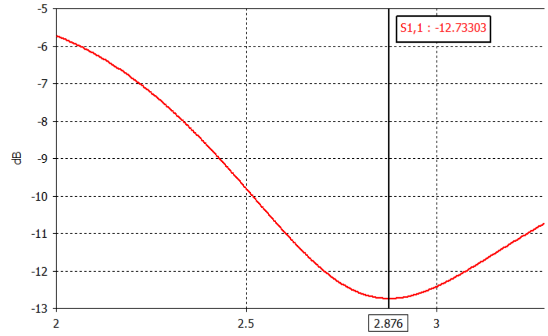

Fig. 14. S_{11} in Breast Tissue model with Tumor Position Left

This time, the simulation was done for different size of the tumor. Increasing the tumor radius to 8 mm, the simulation was done again as seen from figure 15.

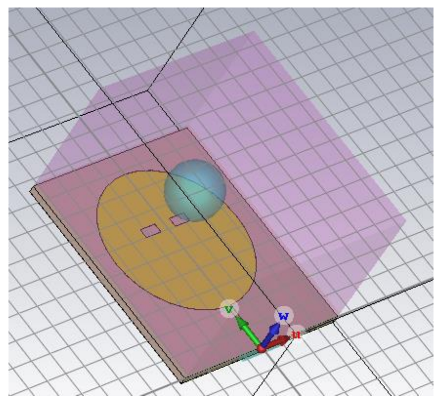

Fig. 15. Breast Tissue model with Bigger Tumor (8mm)

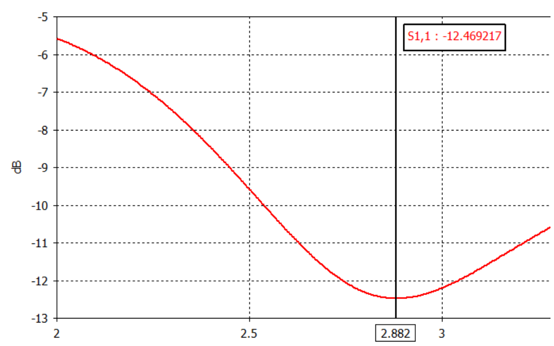

Fig. 16. S_{11} in Breast Tissue model with Bigger Tumor (8mm)

Changing the tumor size provided an increase in the operating frequency which was 2.882 GHz. There was also noticeable change was in the reflection coefficient value. The value of the reflection coefficient was -12.469217 dB as seen in figure 16.

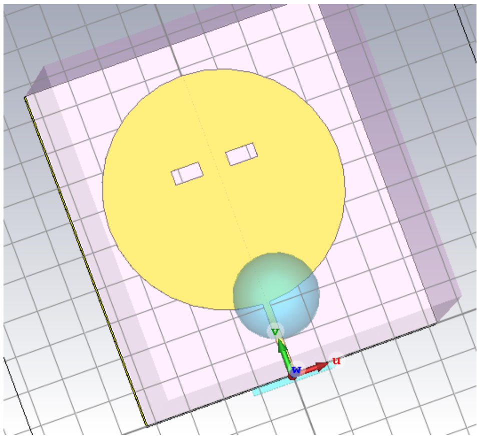

Fig. 17. Breast Tissue model with Bigger Tumor (8mm) – Different Position

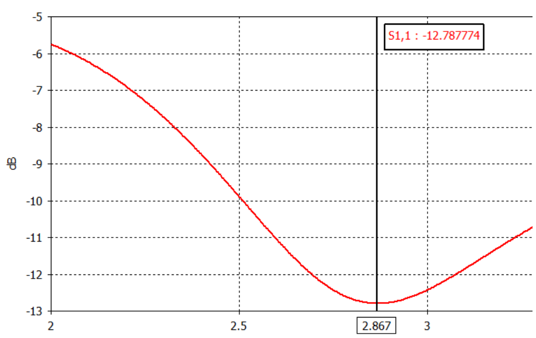

Fig. 18. S_{11} in Breast Tissue model with Bigger Tumor (8mm) – Different Position

Putting the tumor to the bottom side provided us with a frequency 2.867 GHz and a reflection coefficient value of -12.787774 dB as observed from figure 17 and figure 18. So we can say that an increase in the size of the tumor decreases the value of reflection and further nether region placement of the tumor decreases it a lot more as observed from figure 16 and figure 18.

This time, the simulation was done for the design of the breast phantom. This provided an updated value of operating frequency at 2.357 GHz. This also provided us with a reflection coefficient value of -8.4932765 dB as seen from figure 19.

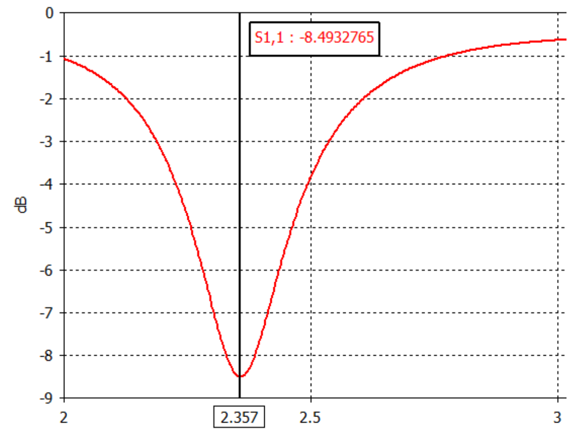

Fig. 19. S_{11} in Breast Phantom model – Without Tumor

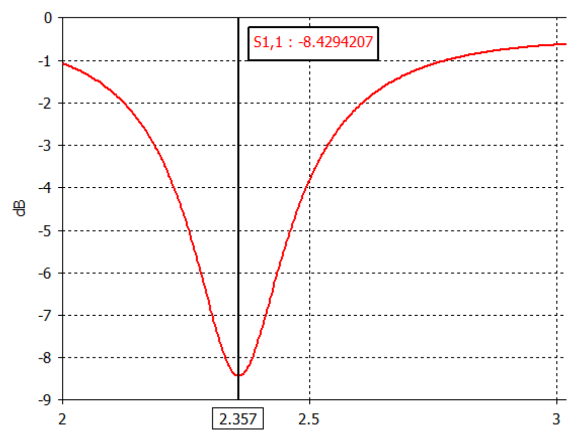

Fig. 20. S_{11} in Breast Phantom model – With Tumor

In the presence of a tumor provided us with a reflection coefficient value of -8.4294207 dB as per figure 20 above. So, we can say that an increase in the reflection coefficient value indicates that there is an inconsistency present in the breast phantom from figure 8 and figure 9. S_{11} below -10 dB would mean that reflected power is less than 10% and at the very least, 90% input power is delivered to the antenna. So this means that the values that we had gotten were fairly reasonable.

Maximum voltage ratio denoted to the standing wave as minimum is called VSWR or Voltage standing wave ratio. It is also called SWR. Power will not be released proficiently if the antenna impedance and its transmission line do not match each other. In other way some of the power returned back. VSWR is the term of the indication of impedance mismatch. The higher value of the VSWR means the higher value of impedance mismatch.

Simulating the antenna with breast phantom gives a VSWR value of 1.6245145 shown in figure 21.

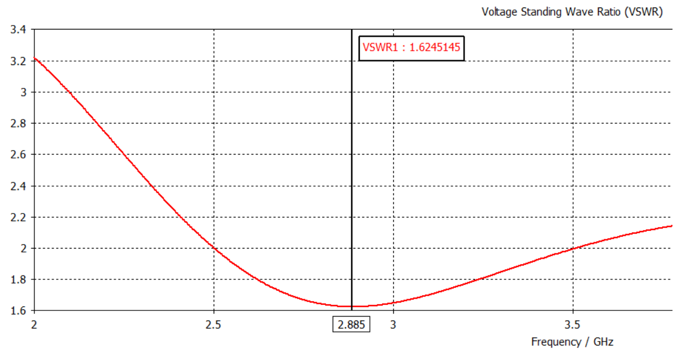

Fig. 21. VSWR in Breast Phantom model

TABLE IV. COMPARISON CHART

State	**Comparison Chart**		
	Characteristics	***Breast Phantom 1***	***Breast Phantom 2***
Without Tumor	Resonant Frequency	2.885 GHz	2.357 GHz
	Reflection Coefficient (dB)	-12.470129	-8.4932765
With Tumor	Resonant Frequency	2.876 GHz	2.357 GHz
	Reflection Coefficient (dB)	-12.727007	-8.4294207

The efficiency of an antenna is known as the ratio of the power that is delivered to the power which is radiated from the antenna [11]. From figure 22 below, it can be observed that the directivity of the antenna was found to be 6.776 dBi.

Also, for this antenna, radiation efficiency was measured to be -8.009 dB and the total efficiency was found to be -8.496 dB. The gain of the antenna was found to be 2.453 dB.

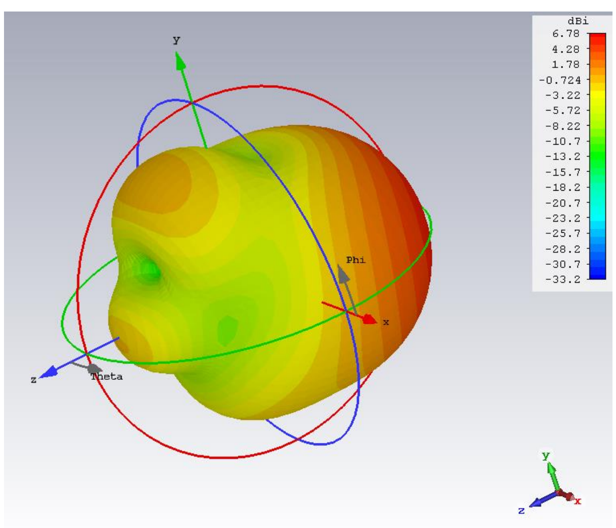

Fig. 22. Farfield Analysis (3D)

From the farfield firectivity (Phi=90) view of the antenna, the magnitude of the main lobe was found to be -28.4 dBi and the magnitude level of the side lobe was observed to be -3.5 dB.

The main lobe direction was at 167.0 deg and angular width (3 dB) was at 83.3 deg as seen from figure 23.

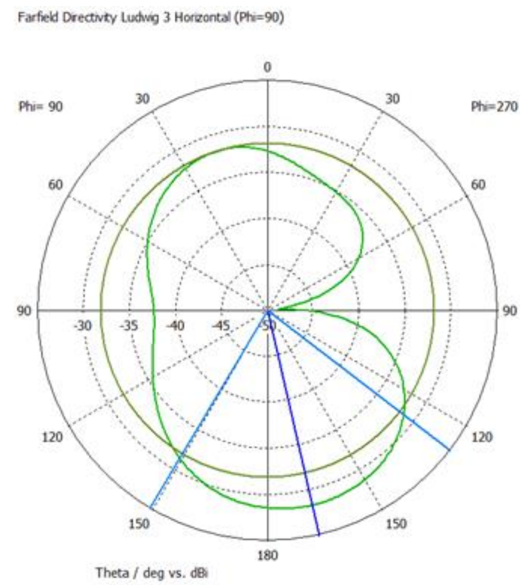

Fig. 23. Farfield Directivity Ludwig 3 Horizontal Analysis (Phi=90)

The maximum SAR for 1g of tissue was calculated. The W/kg bar at the figure below shows the level of intensity for SAR. The maximum SAR value was found to be 0.0603 W/kg for 1g of tissue as seen in figure 24 below.

According to Federal Communications Commission (FCC) which refers patient's safety, the value of SAR should be under 1.6 W/kg for 1g of tissue as per American Standard [12].

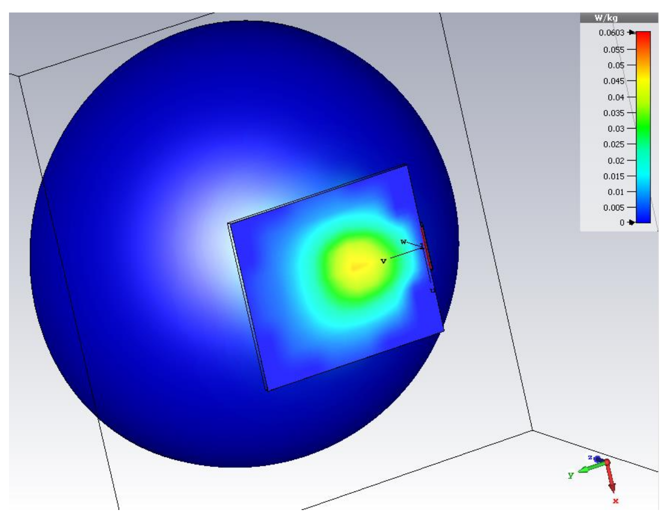

Fig. 24. SAR Distribution (1g Tissue)

V. CONCLUSION

In this paper, a circular microstrip patch antenna was designed in the ISM band and simulated. The compact size and easy accessibility of on-body design makes the antenna a preferable method to the rest. Two different types of breast phantoms were created for analyzing the results. Various simulated results were observed with tumor and without tumor. From these results, it was concluded whether there were any presence of cancerous tumors or not. For the first type of phantom model, the presence of tumor changed the resonant frequency from 2.876 GHz to 2.885 GHz. It was also observed that the reflection coefficient (S11) value had changed from -12.73 dB to -12.47 dB. For the second type of breast phantom, the change was rather observed only in the change of reflection coefficient as the value changed from -8.49 dB to -8.43 dB indicating the presence of cancerous tumor in the created breast phantom. Different tumor position and placement were simulated to observe the change in antenna characteristics. Directivity, radiation efficiency and total efficiency were found to be 6.776 dBi, -8.009 dB and -8.496 dB. The main lobe and the side lobe magnitude were found to be -28.4 dBi and -3.5 dB. The main lobe direction was 167.0 deg and angular width for 3 dB was at 83.3 deg. Maximum SAR were found to be 0.0603 W/kg for 1g of tissue in the simulated environment. Lastly, from all the findings, it was understood that the antenna was capable of detecting cancerous tumors in the virtually created breast phantoms.

VI. ACKNOWLEDGEMENT

The authors of this paper would like to thank the department of EEE of American International University-Bangladesh for their tremendous support throughout this work.

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