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A Meandered Line Patch Antenna at Low Frequency Range for Early Stage Breast Cancer Detection

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ABSTRACT

Every year a concerning number of women are affected by breast cancer which is one of the deadliest and common types of cancers. Breast cancer is curable at early stages. For detecting breast cancer, there are several methods such as MRI, Mammography, Tomography, Ultrasound, and biopsy are available in medical technology. Still, none of them are as easy and efficient as a microwave imaging technique, in this method, the antenna plays an important role. Therefore, this paper focuses on developing an antenna at a low-frequency range for microwave imaging techniques to detect cancerous tissue inside the breast. For this, the antenna parameters, i.e., return loss, VSWR, directivity, current density, and specific absorption rate were studied, by setting the antenna over without tumor and with tumor breast as up-side-down, to ensure the compatibility of the antenna for the technique as well as for the patient's body. A 5mm radius cancerous tumor was created inside the breast with dielectric conductivity of 4 and relative permittivity of 50. Cancerous cells were detected by reading the antenna parameters' comparison between the healthy breast and the affected breast. The whole study was conducted by using CST MICROWAVE STUDIO SUITE 2020. □

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1. INTRODUCTION

Each year, breast cancer causes an enormous number of death in women. Breast cancer is considered a widespread disease in women. At the final stage breast cancer can lead to other body parts such as the brain, lungs, stomach, and so on to serious complications too [1]. So, it is important to detect breast cancer at an early stage for a remediable treatment. To reach the goal, tracking the exact location and the size of the cancerous cells or tumor is undeniable. As, at the early stages tumor remains in tiny shape so, it is possible to localize the tumor using a microwave imaging technique.

Nowadays, X-ray mammography is one of the methods for breast cancer detection in women. X-ray mammography requires routine administration. This method can detect the existence of cancerous tissue in the breast but sometimes it depends on the patient's breast tissue's density and the experience of the radiologist regarding conducting the test procedure and analyzing the data. Chances are high of revealing the presence of cancerous cells in older women, older than 50 years old, and less in younger women, younger than 50 years

old, due to the denser breast tissue construction. Denser breast tissue may look white as the same as the tumor in the mammography report, which makes it harder to distinguish between healthy tissue and cancerous tissue [2].

Another effective method for tracing breast cancer is a biopsy. Although biopsy is a good method to track out the existence of breast cancer in women, there are still some issues to be considered. In the biopsy method, a needle is used to collect the tissue sample, which may not be sufficient, and therefore, this method may have to be repeated. Although samples are collected from the precise area, there is a chance of wrong results if the pathologist misdiagnoses the tissue as benign, but in reality, cancer may still present there. These types of issues can be avoided with surgical biopsy, but a surgical biopsy is a painful, time-consuming and costly procedure and misdiagnosis may occur if tissue samples are taken from the wrong area [3]. Other methods like ultrasound, tomography, and MRI have some side-effect due to harmful ionized radiation, especially when it comes to young women patients [4].

In recent days, the microwave imaging technique is receiving popularity because of its simple procedure and reasonable cost. In this system, a microwave signal is passed into the breast from an antenna, and in the existence of cancerous cells in the breast, the antenna receives a different back-scattered signal competing with the normal breast tissue [5]. This method does not require any intersection of skin that makes the process stress-free and painless for the patient. In addition, this method can also cover the whole area of the breast as well as any size. For the microwave imaging process, simple and compact types of antennas are required. For this reason, the patch antenna, also known as a printed antenna that fulfills the system's demand is often chosen.

There are several antennas were designed for breast cancer detection purposes, so far. For example, in reference [4], a conventional patch antenna was studied at 2.45GHz for breast cancer detection purposes. This paper only focused on the electrical field distribution of the antenna for detecting the existence of cancerous tissue inside the breast but the most important parameter SAR, which ensures patient safety, was absent in this paper. Also, the breast was not designed with maintaining an exact shape that might lead the results to inaccuracy. A circular shape patch antenna was created in reference [6]. This paper investigated the variations of the S-parameters to indicate the cancerous cells in the designed breast phantom. Although this paper considered patient safety by calculating SAR amount, the authors did not study the antenna performances by varying the tumor's positions. Parameters' data of a ring-shape patch antenna were examined by setting the antenna on a cubic shape breast phantom in [7]. The antenna operated within a wideband frequency range (1.5GHz – 7GHz). This article also did not discuss anything about the antenna's SAR parameter, which makes the antenna questionable for the use of breast cancer detection. Five different shape microstrip patch antennas were studied in [1]. In addition, this paper designed an antenna array using the conventional microstrip patch antenna to check the credibility of their design for use in the microwave imaging system. A 16×16 flexible antenna at UWB frequency was designed in [8] the antenna's performances were checked over a cubic breast phantom which contains skin, fat, glandular tissue, and muscle but the authors did not explore the antenna performances, with a tumor inside the breast which incompletes the investigation of the antenna. An antenna array, using four antennas, was used to detect the cancerous cells in [9] at 1.5GHz. The S-parameter results of the antenna array showed a very uniform pattern for different positions of the tumor. Signal amplification variation versus time curve was studied in [10] for defected breast cell detection where the authors had used a UWB microstrip patch antenna. In addition, the bandwidth range of the antenna was 1.6GHz to 11.2GHz. References [11] and [12] designed two miniaturized antennas at a lower frequency range for breast cancer detection, but none of them discussed the patient safety regulation for their antenna.

In this paper, a 14×14 compact antenna is assigned to localize the cancerous tumor inside the breast at a low-frequency range due to safety concerns as the antenna is about to operate in the on-body condition. A similarly structured breast to a real human having radius of 20mm is designed for the sake of error-free results. In addition, tissue properties are considered accordingly as the microwave imaging process works based on tissue contrast in the aspects of electrical properties. The antenna was performed for two conditions, such as with tumor and without tumor, of the breast. Furthermore, the data are analyzed for various positions of the cancerous tumor. The paper is organized as follows: in section II, the designing methods of the antenna & the breast phantom and the simulation set-up of the antenna are discussed. Section III describes the results of the antenna parameters for the breast without any tumor and with a tumor. Then in section IV, the antenna's performances with other reported works were compared. Lastly, in section V, the paper was concluded with a brief overview of this work.

2. RESEARCH METHOD

This part deals with the antenna and breast phantom designing. Also, with the simulation set-up for the parameter readings of the antenna.

2.1. Antenna Designing

To design the meandered line microstrip patch antenna, which is shown in Figure 1, the worksheet of the CST MICROWAVE STUDIO SUITE 2020 is utilized. First of all, a $14 \times 14 \times 0.5$ square shape brick is created as a substrate where Rogger R030100 is employed as the material because of its flexible nature [13]. Then another brick of $12 \times 12 \times 1$ dimension is built as the antenna patch or radiator on one side of the substrate. Due to the amazing conductivity and electrical energy distribution ability, copper is chosen for the patch material as well as for the ground too [6]. Furthermore, the measurement of the ground is $14 \times 14 \times 1$, which is designed to be the opposite of the patch, on the substrate plate. Dimensions of the antenna plates can be visualized from Table 1. The patch is cut accordingly to get the desired frequency at a low range.

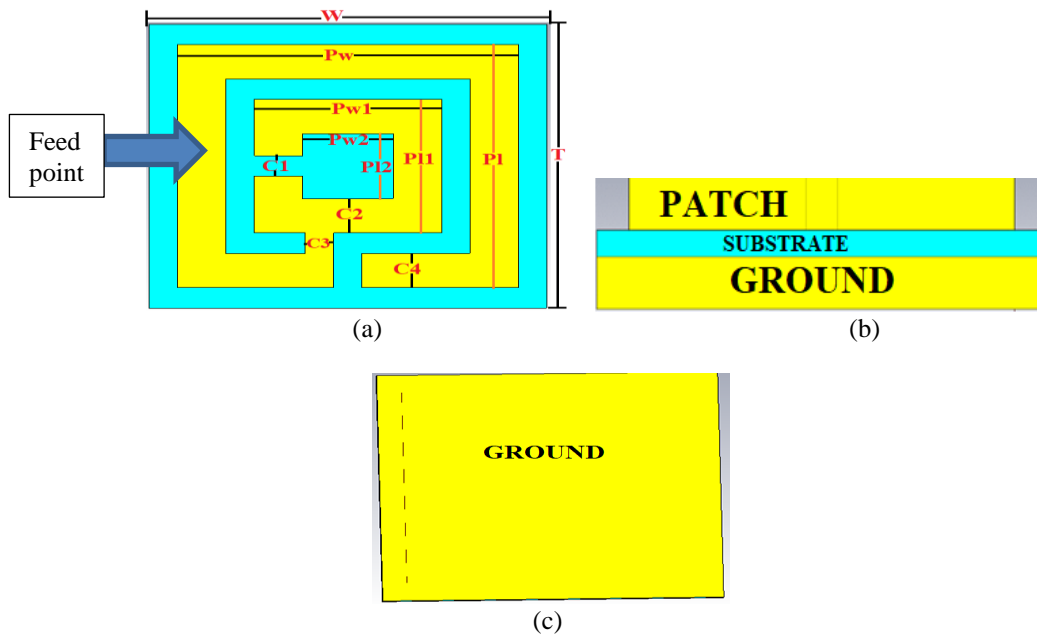


Figure 1. Antenna's view: (a) Frontal (b) Side (c) Back

Note that the operating frequency of the antenna can be changed by varying the length, width, and number of the patch slots. Used Materialistic properties' values of Copper and Rogger R03010 are listed in Table 2.

Table 1. Details of the antenna plates

Layers	Material	Parameters in mm
Patch	Copper	Pw=12, P1=12, Pw1=6.60, P11=6.60, Pw2=3.20, P12=3.20, C1=1, C2=1.70, C3=1, C4=1.70
Substrate	Rogger R01030	W=14, T=14
Ground	Copper	W=14, T=14

Table 2. Detail physical property of Copper and Rogger R03010

Material	Property value with unit
Copper (Lossy metal)	Mu or dielectrical conductivity = 1, electrical conductivity = 5.96×10^7 (s/m), Rho = 890 (kg/m^3), Thermal Conductivity = 401 (W/K/m), Specific Heat = 390 (J/K/kg), Diffusivity = 0.00011541 (m^2/s), Young's Module = 120 (kN/mm^2), Poisson Ratio = 0.33, Thermal Expansion = 17 ($1\text{e}-6/\text{k}$)
Rogger R03010 (Normal)	Epsilon or permittivity = 10.2, $\tan \delta$ or loss tangents = 0.0022, Thermal conductivity = 0.66 (W/K/m)

2.2. Breast Phantom Designing

To get accurate and closer to the practical value of results, it is important to design the breast as similar to the real human breast for simulation. Therefore, in this paper, a breast with actual shape and tissue construction is designed. The tissue properties of the breast are maintained properly during the creation.

Created healthy breast mainly has four biological tissue layers, namely, skin, fat, gland or glandular tissue, and muscle [12] (Figure 2). The total radius and total height of the breast are 20mm and 36mm, respectively. Detailed dimensions and properties of the used tissues for breast designing are mentioned in Table 3.

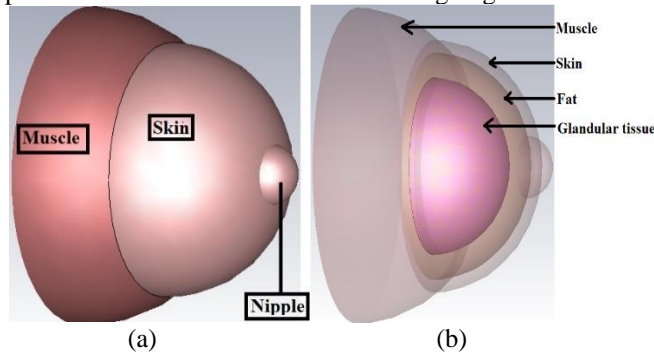


Figure 2. Designed healthy breast’s view: (a) solid and (b) transparent

Table 3. Details of breast tissue

Tissue	Outer radius (mm)	Thickness (mm)	Property (unit)
Skin	20	2	Epsilon = 43.75 , Mu = 1, Electrical Conductivity =0.856 (s/m), Rho = 1100 (kg/m ²), Thermal Conductivity = 0.3 (W/K/m), Specific Heat = 3500 (J/K/kg), Diffusivity = 7.7921e-08 (m ² /S), Blood flow = 9000 (W/K/m ³), Metabolic Rate = 2000 (W/m ³)
Fat	18	4	Epsilon =3 , Mu =1 , Electrical Conductivity = 0.4 (s/m), Rho = 910 (kg/m ²), Thermal Conductivity = 0.201 (W/K/m), Specific Heat = 3500 (J/K/kg), Diffusivity = 8.8356e-08 (m ² /S), Blood flow = 1700 (W/K/m ³), Metabolic Rate = 300 (W/m ³)
Glandular	14	-	Epsilon = 68.81, Mu = 1, Electrical Conductivity = 0.794 (s/m), Rho = 1040 (kg/m ²), Thermal Conductivity =0.6 (W/K/m), Specific Heat =3600 (J/K/kg), Diffusivity = 1.6025e-07 (m ² /S), Blood flow = 400000 (W/K/m ³), Metabolic Rate = 60000 (W/m ³)
Muscle	25	7	Epsilon = 3 , Mu = 1 , Electrical Conductivity = 0.3 (s/m), Rho = 1041 (kg/m ²), Thermal Conductivity = 0.53 (W/K/m), Specific Heat = (J/K/kg), Diffusivity = (m ² /S), Blood flow = (W/K/m ³), Metabolic Rate = (W/m ³)

2.3. Simulation Set-up

At first, the antenna was designed and investigated in free space, the resonance frequency of the antenna at free space was found at 2.452GHz. But as the antenna is about to use for breast cancer detection so the antenna is set over the designed healthy breast (Figure 3 (a)) as well as over the affected breast (Figure 3 (b)) as up-side-down. For affected breast designing, a tumor (dielectric conductivity = 4 and relative permittivity = 50 [4]), with a 5mm radius is fitted inside the breast’s glandular tissue. The antenna is investigated for six different positions such as No-tumor, Middle, Down-side, Up-side, Right-side, and Left-side of the cancerous cells inside the breast as is shown in Figure 4. The co-ordinates of the tumor are recoded as (0,0,-20) for Middle, (0,-10,-20) for Down-side, (0,9,-20) for Up-side, (10,0,-20) for Right-side and (-10,0,-20) for Left-side.

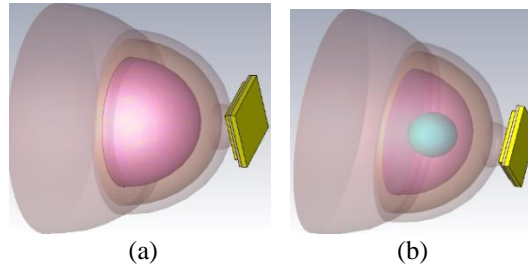


Figure 3. The antenna is set up as up-side-down over: (a) the healthy breast phantom and (b) the affected breast phantom with a tumor inside gland tissue

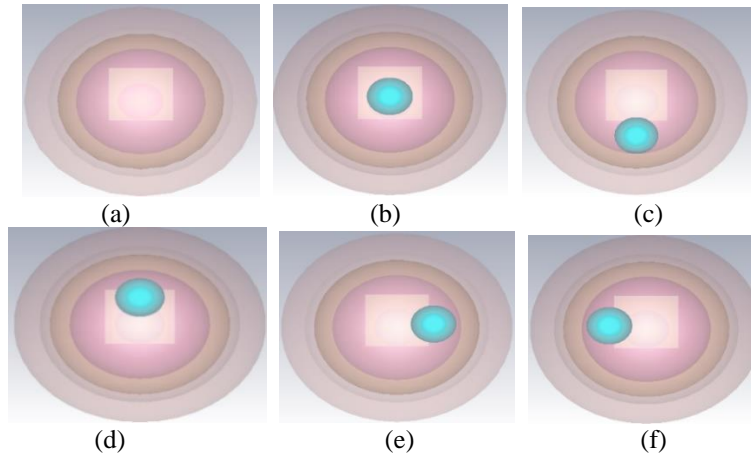


Figure 4. Tumor positions inside the braest: (a) No tumor, (b) Middle, (c) Down-side, (d) Up-side (e) Right-side and (f) Left-side

3. RESULTS ANALYSIS

This section deals with the antenna’s obtained results for the simulation environment as shown in Figure 4.

3.1. S-parameter or Reflection Coefficient

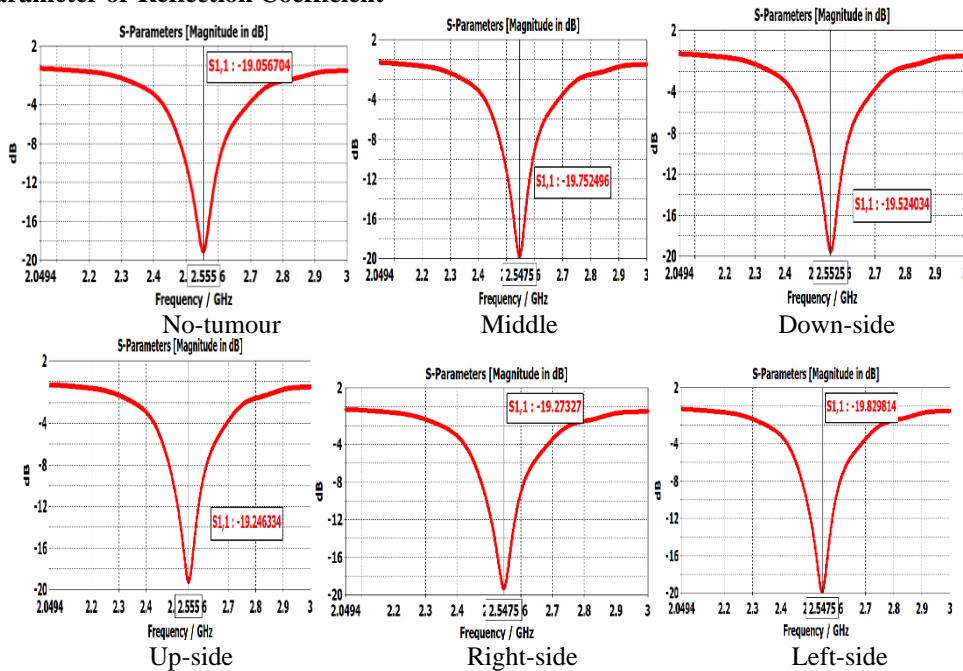


Figure 5. Antenna’s S11 or Return loss values for different positions of the tumor inside the breast

Return loss also familiar as S-parameter mainly denotes the amount of power reflected from the antenna [14]. In this study, S-parameter is used to distinguish between cancer-affected breast and healthy breast. In the absence of cancerous cells inside the breast phantom, The S11 or S-parameter is found -19.057 at 2.555GHz, wherein the existence of the tumor at any position in the breast the antenna provides lower values of S-parameter that can be observed from Figure 5. Also, Table 4 clearly explains the S11 values and tuning frequencies for different positions of the tumor. In addition, the table shows that the antenna has the same resonance frequency for no-tumor and up-side condition of the tumor but the S-parameter values are not equal. Therefore, S-parameter can be utilized as a tumor and non-tumor indicator for this design.

Table 4. Variations of S-parameter values and frequency for different positions of the tumor

Tumor position	S11 (dB)	Frequency (GHz)
No tumor	-19.057	2.555
Middle	-19.753	2.548
Down-side	-19.524	2.553
Up-side	-19.246	2.555
Right-side	-19.273	2.548
Left-side	-19.83	2.548

3.2 Voltage Standing Wave Ratio (VSWR)

Voltage Standing Wave Ratio or VSWR parameter represents the antenna matching-capability with the system. An antenna VSWR value needs to be less than 2 and VSWR value 1 is considered as ideal VSWR value [15]. From Figure 6, it is clear that the antenna is well matched with the system, as for all of the statuses such as with tumor and without tumor of the breast the antenna’s VSWR values are less than 2. VSWR values are 1.251, 1.230, 1.236, 1.245, 1.25 and 1.227 for No-tumor, Middle, Down-side, Up-side, Right-side and Left-side position, respectively.

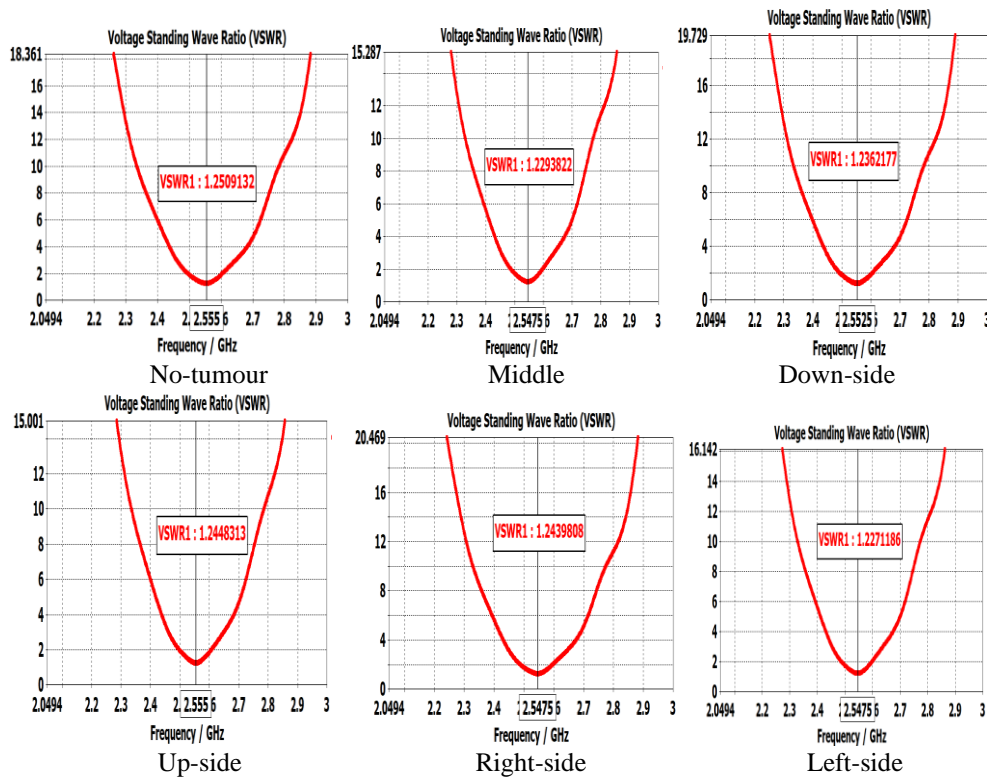


Figure 6. VSWR values of the antenna for different statuses of the breast

3.3 Analysis of Electrical Properties to Locate the Positions of the Tumour

The antenna’s electrical field intensity (Figure 7) and current density (Figure 8) are scrutinized for all of the positions of the tumor at their particular frequency in search of the location of the defected cells. Table 5 makes a clear understanding of the electrical field intensity and current density of the antenna for the variations of the tumor’s position. From Table 5, it can be seen that the current density and electric field intensity of the antenna are higher for the Middle, Right-side, and Left-side positions of the tumor than in

normal conditions (No-tumour). However, these values are lower than normal conditions while the breast contains a tumor at Down-side and Up-side.

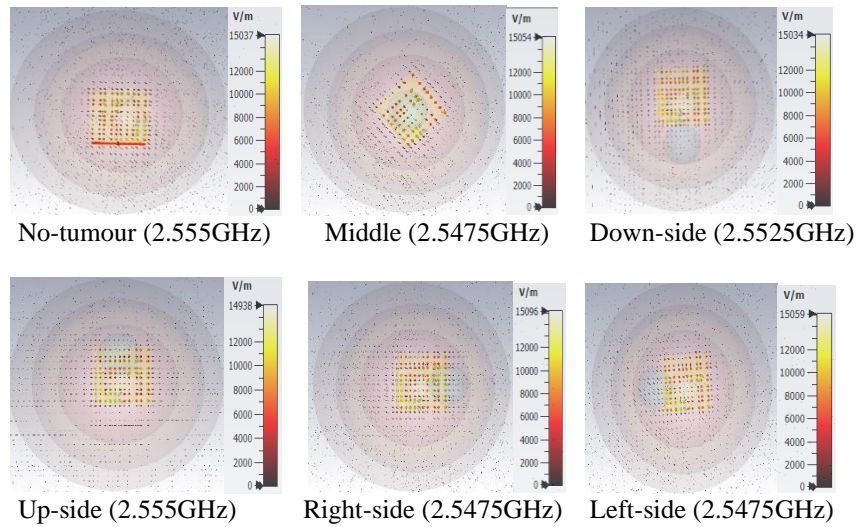


Figure 7. Electrical Field Intensity of the antenna for diverse conditions of the breast at a different frequency

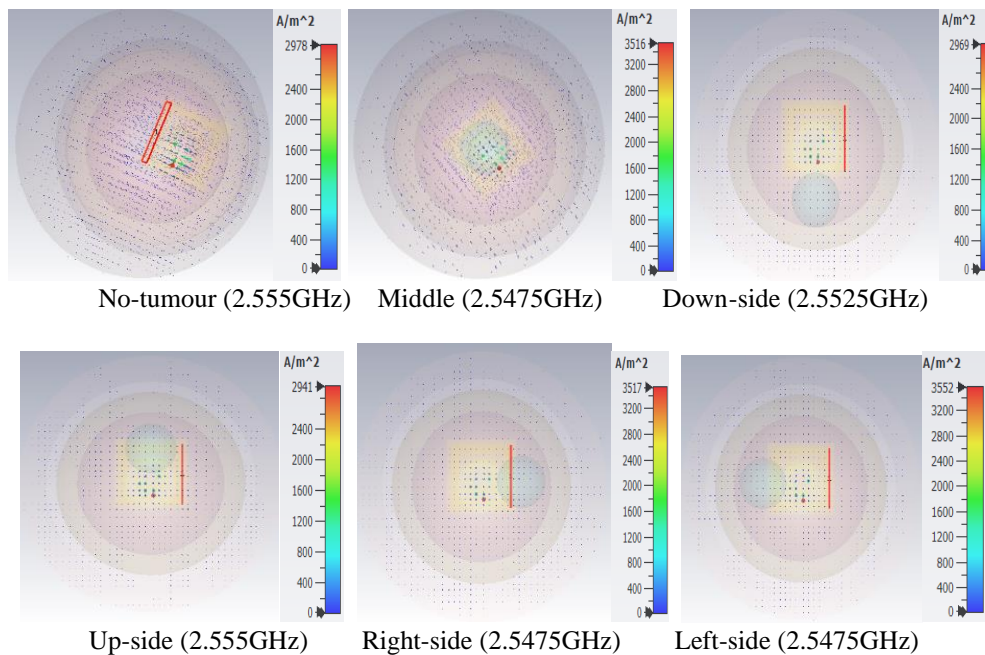


Figure 8. Current Density of the Antenna for different situations of tumor

Table 5. Summary of antenna's E-field intensity and current density with frequency for various positioning of the tumor

Tumour position	E-field Intensity (V/m)	Current Density (A/m^2)	Frequency (GHz)
No-tumour	15037	2978	2.555
Middle	15054	3516	2.5475
Down-side	15034	2969	2.5525
UP-side	14038	2941	2.555
Right-side	15096	3517	2.5475
Left-side	15059	3552	2.5475

In Table 6, an estimation chart is stated for a better understanding of the tumor’s area. If the achieved electrical properties match with the normal condition of the electrical properties, that means the breast is cancer-free, but if the obtained value does not match then, cancerous cells are present.

Table 6. Estimated tumor’s area depending on antenna’s electrical property

Status	Tumour area
Achieved Electrical Property = Standard Condition Electrical Property	No tumor
Achieved Electrical Property > Standard Condition Electrical Property	Middle, Right-side, Left-side
Achieved Electrical Property < Standard Condition Electrical Property	Down-side, Up-side

3.4 Radiation Pattern Analysis

Antenna’s radiation patterns are presented in Figure 9 and Figure 10 as 3-D and 1-D view, respectively. Theoretically, an antenna directivity can be 0 dBi, when the antenna has equal radiation to all of the directions [16]. Figure 9 depicts that the antenna directivity values are between 2.89 dBi to 2.79 dBi for any of the conditions of the breast, such as affected and unaffected, which means the antenna can cover the breast from any direction. At 2.555GHz, the highest radiation efficiency is -21.72 dB, and the highest total efficiency is -27.27 dB, of the antenna are observed when the tumor locates at Down-side in the breast, and the lowest values are -27.50 dB for radiation efficiency and -27.09 dB for total efficiency at 2.548GHz, which is recorded when the tumor’s position is at the Right-side in the breast.

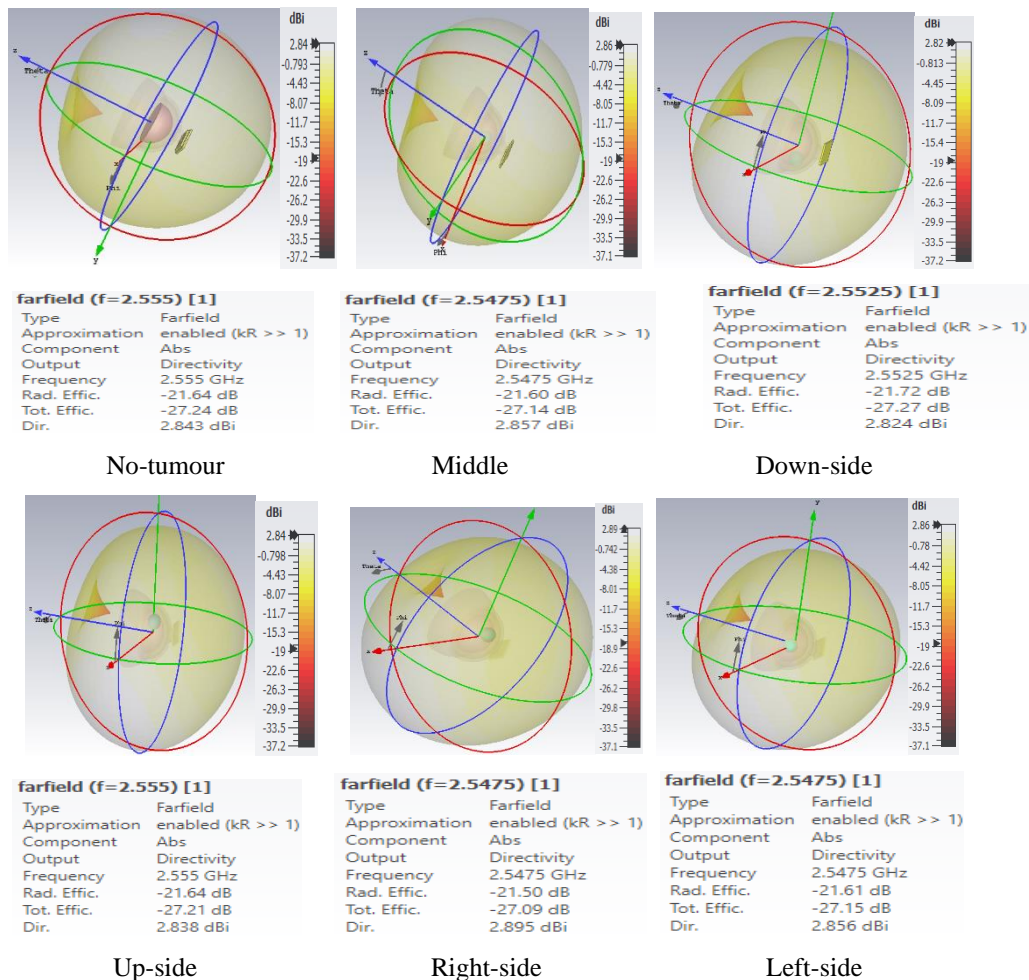


FIG. 9. 3-D Radiation Patterns of the antenna for different positions of the tumor inside the breast

Antenna’s radiation patterns in the polar form are represented in Figure 10, which explains the antenna radiation in terms of degree. The main lobe magnitude, which is 2.23 dBi at 2.5475GHz, of the antenna is maximum when it operates over the breast with a tumor at Right-side in it and minimum, which is 2.16 dBi at 2.555GHz and 2.5525GHz, for both No-tumour and down-side conditions of the tumor. The parameters of the

3-D and 2-D far-field radiation patterns for different positions of the tumor at their respective center frequency are codified in Table 7.

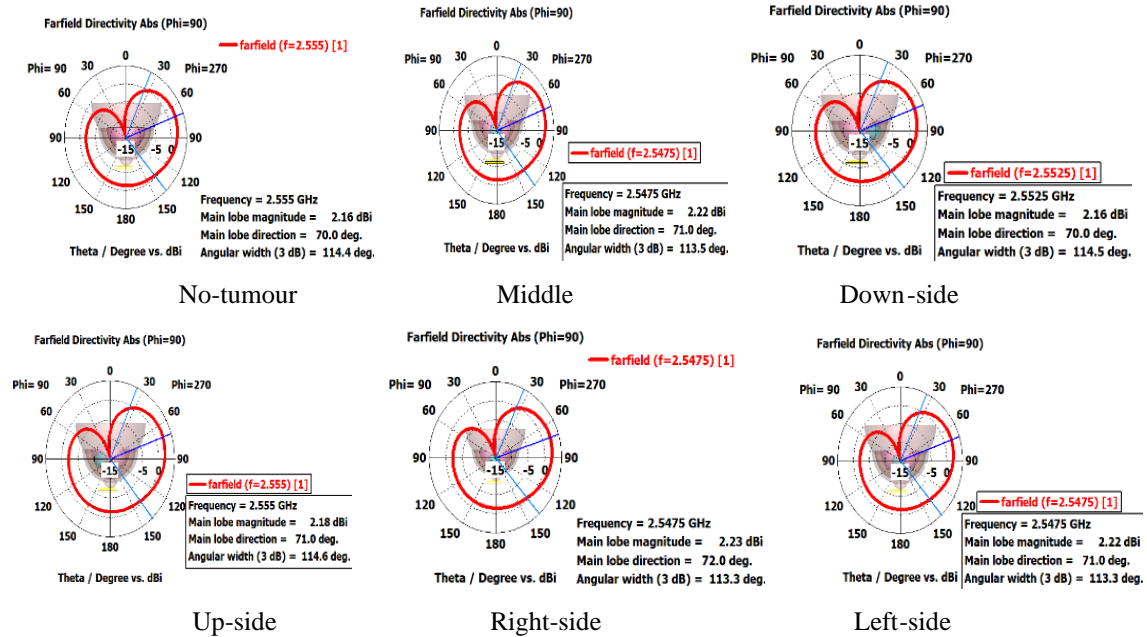


Figure 10. 1-D (Polar view) Radiation Patterns of the antenna for different positions of the tumor inside the breast

Table 7. Parameters' summary of the antenna's 3-D and 2-D Fairfield view

Tumour position	Frequency (GHz)	Directivity (dBi)	Radiation Efficiency (dB)	Total Efficiency (dB)	Main lobe magnitude (dBi)	Main lobe direction (Degree)	Angular width (Degree)
No-tumor	2.555	2.84	-21.64	-27.24	2.16	70.0	114.4
Middle	2.5475	2.86	-21.60	-27.14	2.22	71.0	113.4
Down-side	2.5525	2.82	21.72	-27.27	2.16	70.0	114.5
Up-side	2.555	2.84	-21.64	27.21	2.18	71.0	114.5
Right-side	2.5475	2.89	-21.50	-27.09	2.23	72.0	113.3
Left-side	2.5475	2.86	21.61	-27.09	2.22	71.0	113.3

3.5 Specific Absorption Rate (SAR)

Specific Absorption Rate, in brief SAR, is the essential parameter to consider as it is an exhibitor of patient safety. It mainly indicates the amount of antenna's radiated electromagnetic energy that is absorbed by the near side body tissue [15]. The antenna's SAR values for the breast with diverse positioned tumors are calculated at their center frequencies due to patient safety purposes. The SAR values are measured for 10 grams of body tissue while the antenna input power is fixed at one milli-watt. All the obtained values of SAR are found within the maximum tolerable range (2 W/kg), which is set by the International electro-technical Commission (IEC) [14], which can be checked from Figure 11. Maximal SAR value (1.27 W/kg at 2.5475GHz) is encountered for the Right-side positioning of the tumor in the breast. SAR values and frequencies concerning tumor positions are given in Table 8.

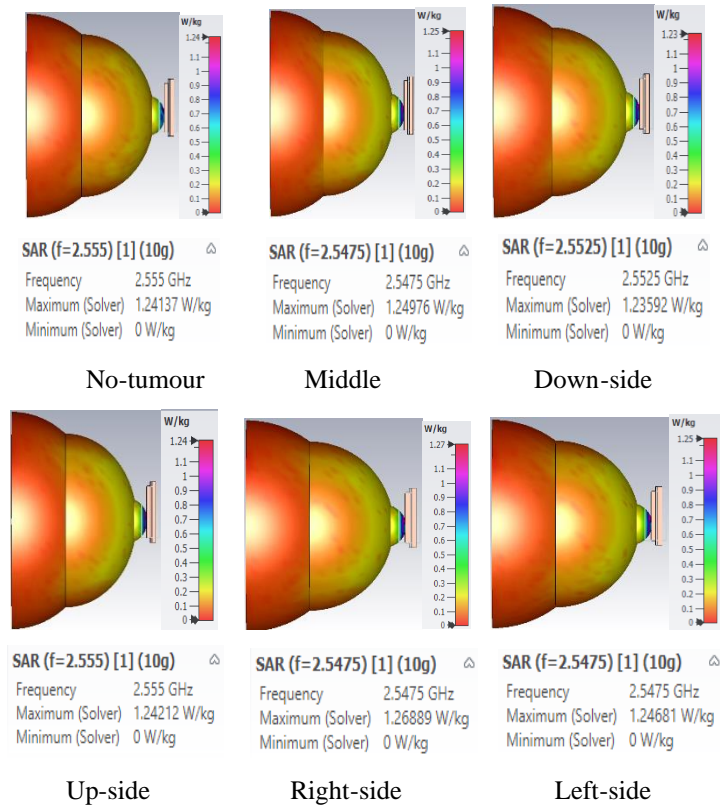


Figure 11. Simulated SAR values of the antenna at different states of the tumor in the breast

Table 8. Antenna’s SAR values with respect to tumour positions

Tumour’s region	SAR value (W/kg)	Frequency (GHz)
No-tumour	1.24	2.555
Middle	1.25	2.5475
Down-side	1.23	2.5525
Up-side	1.24	2.555
Right-side	1.27	2.5475
Left-side	1.25	2.5475

3.6 Comparison Analysis with Similar Published Works

This antenna is one of the compact antennas comparing with previously reported works, which is illustrated in Table 9. Although researchers from [6] and [9] investigated patient’s safety regarding contact with the antenna, others did not, which makes those designs impractical to use in the real system. Ref. [18] evaluated its antenna in free space and claimed that the antenna can detect cancer. Also, all of the papers (without Ref. [9]) presented data for only one position of the tumor. On the other hand, we consider five different positions of the tumor for presenting the data. Moreover, this paper considers patient safety from harmful electromagnetic radiation energy by measuring SAR-parameter and found the values within the accepted range according to IEC. Furthermore, this paper uses the most realistic simulation environment, comparing with other mentioned references in Table 9, for errorless and precise results as it is proven by Ref. [6] that shape may affect the results. Though Ref. [6] and [1] designed their breast maintaining actual shape, they did not consider the nipple part, and reference [17] created a hollow breast. So, considering the simulation set-up, antenna’s whole volume, and safety measurement, from Table 9, this antenna will be more suitable than other works for breast cancer detection in the practical field.

Table 9. Comparison of this work with other similar works

Ref.	Breast shape	Antenna Volume (mm^3)	Tissue Safety Consideration
[4]	Cubic shape phantom	9244.36	No
[6]	Actual shape Phantom	3497.94	Yes
[7]	Cubic shape phantom	3393.84	No
[1]	Actual shape phantom	9253.72	No
[8]	Cubic shape phantom	512	No
[9]	Cubic shape phantom	1545.48	Yes
[17]	Hollow actual shape phantom	2862	No
[11]	Pyramid shape phantom	400	No
[18]	No breast is designed	763.14	No
This paper	Actual shape phantom	401.8	Yes

4. CONCLUSION

In this article, a tiny-shape meandered line microstrip patch antenna is presented at a low-frequency range for breast cancer detection. For examining the antenna performances and parameters' result, the antenna has set over a cancer-free breast as well as the cancer-affected breast with maintaining their all-important properties. Good outcomes have been found for simulation results such as return loss, VSWR, radiation pattern, current density, electrical field intensity, and SAR calculation for both states of the breast (affected and healthy). For cancer detection, S-parameter or return loss values mainly help as an indicator as they are reduced by a considerable value in the presence of a tumor. Besides, fluctuations of the antenna's electrical properties' values, which mainly happened due to the variations of the tumor's position, assist in tracing the location of the tumor. Lastly, SAR reveals patient safety in contact with the antenna. So, keeping in mind the antenna performances, it would be fruitful to use this antenna to detect breast cancer in practical life.

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