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Detection of Breast Cancer by a Circular Microstrip Patch Antenna (CMSA)

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Abstract:

Microwave technologies are important and promising in breast cancer detection, which causes many deaths worldwide annually. These techniques have many ways of diagnosing and detecting breast cancer. In this paper, the Microstrip Patch Antenna (MSA) was presented as a source of microwave signals for use in breast cancer detection. A circular MSA was designed to operate at an operating frequency of 9 GHz, which falls within the ISM frequency range, and some improvements were added to the antenna to raise its efficiency. The antenna is designed in terms of a Rogers RT / Duroid 5880 substrate, with a height of 1.6 mm, to be used in simulating breast cancer detection. Simulation involves designing a breast model (Simulated breast) that simulates a human breast with specific dimensions based on natural breast tissue's electrical and physical properties, such as electrical permittivity and electrical conductivity. By studying antenna parameters such as return losses, directivity, gain, and current density, whose values differ with the presence of a tumor inside the breast, and comparing these values with the absence of a tumor inside the breast, the diagnosis and presence of cancer cells is reached. In this research, the CST STUDIO program was used to design both the antenna and the breast model. The CMSA antenna will be evaluated using a breast model containing a tumor with altered electrical properties. Electrical properties, particularly conductivity (σ) and permittivity (ε), are critical factors in determining the presence of a cancer within the breast.

Keywords: Simulated breast, CST studio, Microstrip Patch Antenna.

1. Introduction

MSA is widely used in many communication and signal transmission technologies due to its easy design and operation on many frequencies, especially high frequencies. This type of antenna has received wide attention in the medical field and is used in many medical applications, including detection, diagnosis, treatment, and monitoring [1,2]. Breast cancer is one of the most common diseases and causes a lot of cases, especially the female element, which suffers from the scourge of this disease. Early detection helps in surviving this disease because

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a cancerous tumor in its early stages can be controlled and cured [3][4]. There are many ways to detect this type of cancer, including ultrasound imaging, magnetic resonance imaging, and X-ray imaging [5][6]. However, these methods suffer from some problems in diagnosis and accuracy of results, especially in some pathological cases of different ages, and the high cost may be one of the reasons for their low availability [7][8]. In this research, the microwave imaging method was used to detect breast cancer by designing a circular MSA (CMSA) to be a source of microwave signals, analyzing its parameters, and using it in the diagnostic process [9][10]. Microwave imaging techniques depend on body tissues' different electrical and physical properties [11]. Cancer cells have different properties from healthy cells, including electrical conductivity (σ), electrical permittivity (ϵ), density, and heat capacity [12][13]. A breast model that simulates the human breast in terms of electrical and physical properties is designed to mimic detecting a tumor inside the breast by exposing the designed antenna to the breast model and studying the antenna parameters with and without a tumor. The difference in the results of the parameters can indicate the presence of a cancerous tumor, and among the parameters used in the diagnosis are return losses, radiation pattern, gain, and directivity. Some research has provided the detection of breast cancer using a pneumatic microstrip patch by simulating the detection process for a single tumor case without exposure to altered conditions of the tumor[14][15][16]. In the process of simulating the detection of breast cancer in this research, an intra-breast tumor was designed with electrical and physical properties, and a comparison was made between the presence of a tumor inside the breast and its absence and the use of variable electrical and physical properties of the tumor in order to take more note of different conditions of the tumor and follow up on cases of its development inside the breast. The antenna was built at the frequency 9 GHz which belongs to the industrial, scientific and medical frequency range, to ensure it is safe for medical purposes. The CST Studio software was chosen to design the antenna, create the breast model, do the simulations and view the study's findings.

2. Circular Microstrip Antenna (CMSA) design

Microstrip antennas are known for their easy design and adaptability, as well as their small dimensions and light weight, which makes them commonly used in the fields of communications and medical applications. It is characterized by its flexibility in design to meet different needs, as it is available in several forms and variations in the Shape of the patch. In this research, a circular microstrip patch antenna was designed to operate at a frequency of 9 GHz, a frequency that falls within the ISM frequency range.

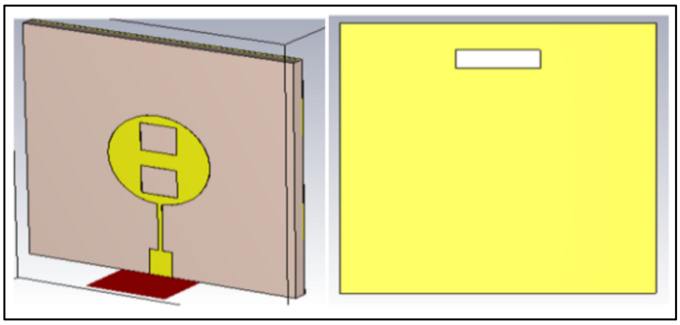

Figure 1: Circular Microstrip Antenna CMSA Design

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The research selected a circular microstrip patch antenna to provide the required microwave signals for detecting breast cancer. The antenna shown in Figure. 1 was designed using the design equations of the circular patch microstrip antenna. Microstrip patch antennas are being developed in multiple ways aimed at improving their efficiency in radio communication applications in general and in biomedical applications in particular. In this research, the method of defective ground structures and slot in a patch was adopted, which is among the methods used to increase the radiation capacity of the microstrip antenna, by enhancing the current density and improving directivity, while at the same time maintaining the antenna's compact dimensions.

The feed type used in the design of the circular microstrip antenna for this research is the "microstrip feed line " type (quarter wave), which is a suitable feed type for her design. To apply the microstrip antenna design equations, we need to know some variables that control the results of these equations [17][18], including the operating frequency (f_0), which is 9 GHz; the substrate (Rogers RT / Duroid 5880 substrate) thickness (h) is 1.6 mm; and the substrate permittivity (ε_r), which is 2.2. The length (L_g) and width (W_g) for both the ground level and the insulating substrate are calculated from (1),(2) respectively:

$$L_g = 6h + L \tag{1}$$

$$W_g = 6h + W \tag{2}$$

Equation (3) illustrates the calculation of the patch radius (a) in the circular microstrip patch antenna. [18][19]:

$$a = \frac{F}{\{1+\frac{2h}{\pi\epsilon_r F}[ln\left(\frac{\pi F}{2h}\right)+1.7726]\}^{\frac{1}{2}}} \tag{3}$$

where F is an intermediate quantity derived from the resonant frequency of the antenna, calculated using (4).

$$F = \frac{8.791 * 10^9}{f_0\sqrt{\varepsilon_r}} \tag{4}$$

Table I shows the design dimensions of the circular microstrip antenna in millimeters, the length and width of the ground and the patch radius, and the height of the insulating substrate. Figure. 1 also shows the upper side of the antenna (patch) and the lower side (ground).

Table I: Circular Microstrip Antenna Design Dimensions

Parameters	**Dimension values(mm)**
width of ground (W_g)	30
Length of ground (L_g)	30
Substrate height (h)	1.6
Radius (a)	5.8

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3. Breast Modelling

In this research, the human breast will be modeled in the CST STUDIO program according to the electrical properties of human cells conductivity and electrical permittivity. A hemispherical breast model is designed with two layers, the skin with a diameter of 50 mm and the fat layer with a diameter of 48 mm, as shown in Figure. 2.

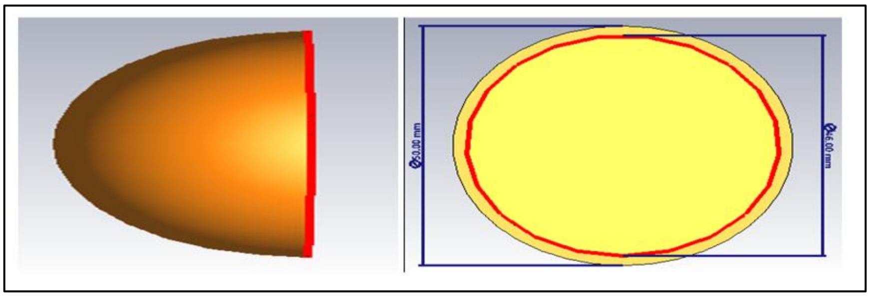

Figure 2: The Shape of Breast Model

The Shape of the tumor was also modeled as a spherical shape with a diameter of 5 mm from a single layer as shown in Figure. 3.

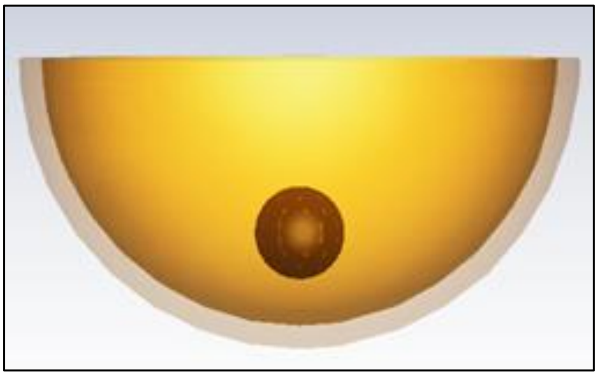

Figure 3: The Shape of the Tumor Equations

Table II and Table III list the values of the electrical and physical properties of each layer of the Breast Model[20][21].

Table II: Electrical Characteristics of the Breast Model and Tumor

Tissue type (Layer)	Electrical permittivity (F/m)	Electrical conductivity (S/m)
Skin layer	36.7	2.34
Fat layer	4.84	0.262
Tumor	50.9	4

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Table III: Thermal and Physical Characteristics of the Breast Model and Tumor

Tissue type (Layer)	Heat capacity (J/K/Kg)	Thermal conductivity (W/K/m)	Density Kg/m^3
Skin layer	3391	0.37	1109
Fat layer	2348	0.21	911
Tumor	3500	0.5	1059

4. Simulation Results of Breast Cancer Detection by Circular Microstrip Antenna

The breast cancer detection process was simulated by exposing the circular microstrip patch antenna to the designed breast model, as in Figure. 4. The breast model designed with electrical and physical characteristics was placed at a distance of 10 mm from the antenna, and the results were monitored through the simulation process.

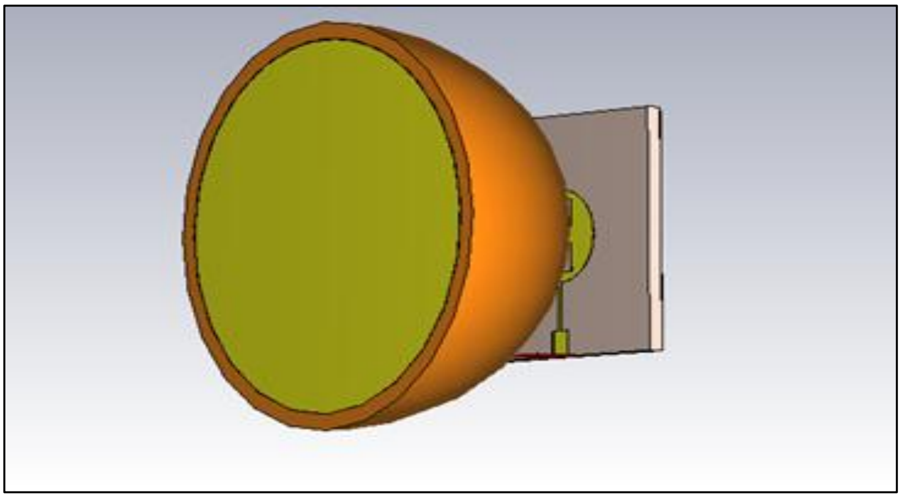

Figure 4: Circular Microstrip Antenna with Breast Model.

The results of the antenna parameters will be displayed: return losses, directivity, gain, and current density in the process of simulation. The results will be reported and compared with the microstrip antenna parameters with and without a tumor in the breast model.

A. Return Losses

The return losses of the antenna are a measure of the electromagnetic energy reflected from the antenna. The electrical and physical properties affect the results of the return losses for the antenna, and due to the difference in these properties between infected and healthy cells, the presence of a tumor can be diagnosed.

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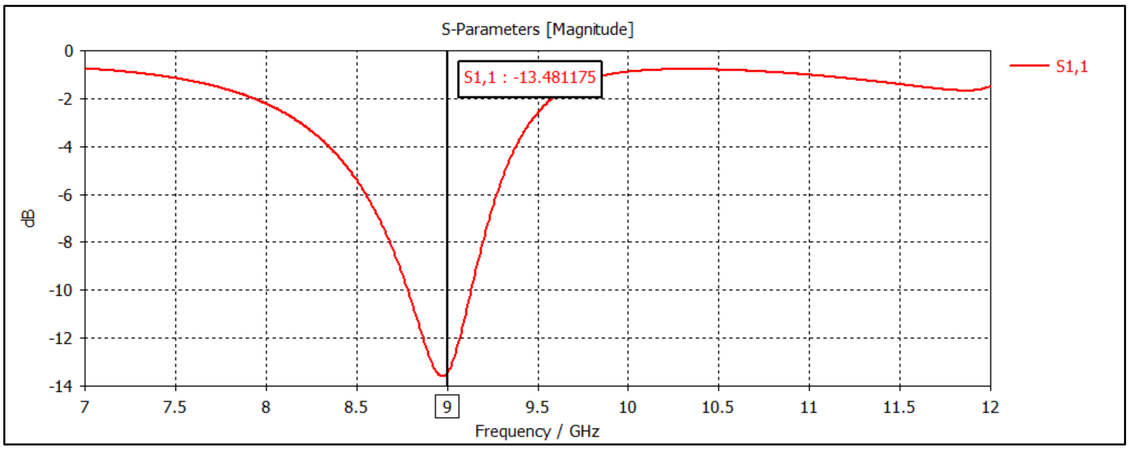

Figure 5: Return Loss of Antenna on Breast Model without Tumor

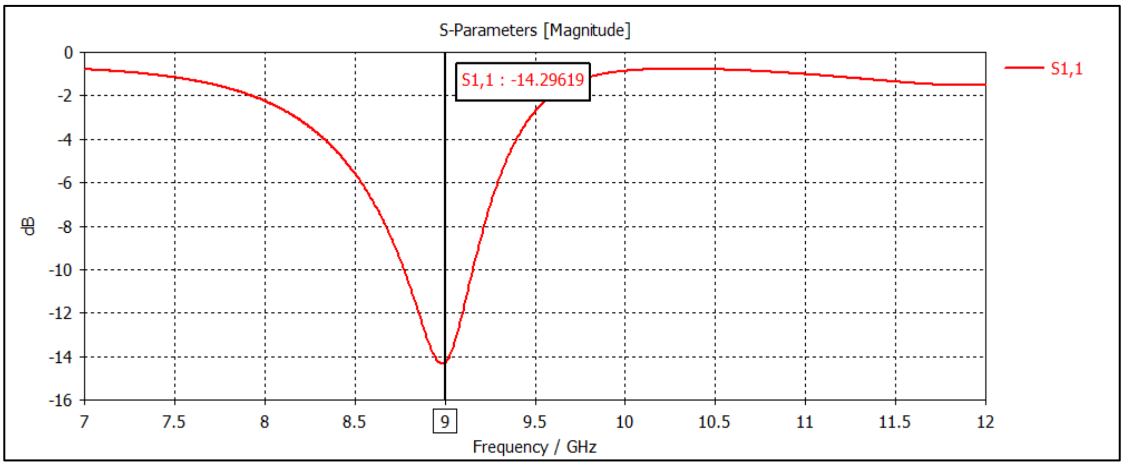

Figure 6: Return Loss of Antenna on Breast Model with Tumor

As part of the procedure for detecting a tumor inside the breast, Figure. 5,6 show the S11 scale, which shows the results of the return losses of the circular microstrip antenna. Figure. 5 records a value of -13.481 dB, which is the return loss value of the antenna without a tumor, and this value rises to -14.296 dB in Figure. 6 after exposing the antenna to the breast model with a tumor. It is this difference between the two results for return losses that gives a diagnosis of the presence of a tumor inside the breast.

B. Directivity

Antenna directivity is the extent to which the antenna can concentrate the radiations in a given direction, as opposed to equal radiation in all directions. This makes it an important measure in this research, particularly when comparing the results with and without a tumor during the process of intra-breast tumor detection.

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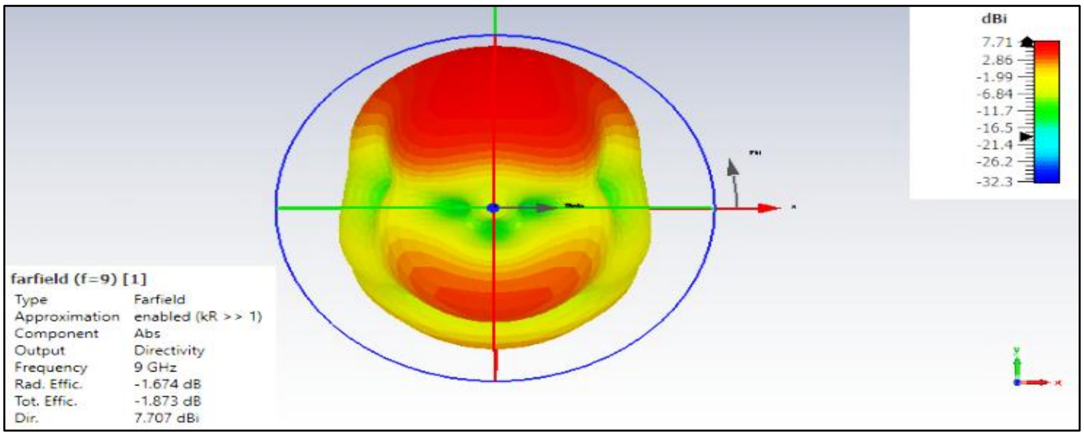

Figure 7: Directivity of the Antenna and Breast Model without Tumor

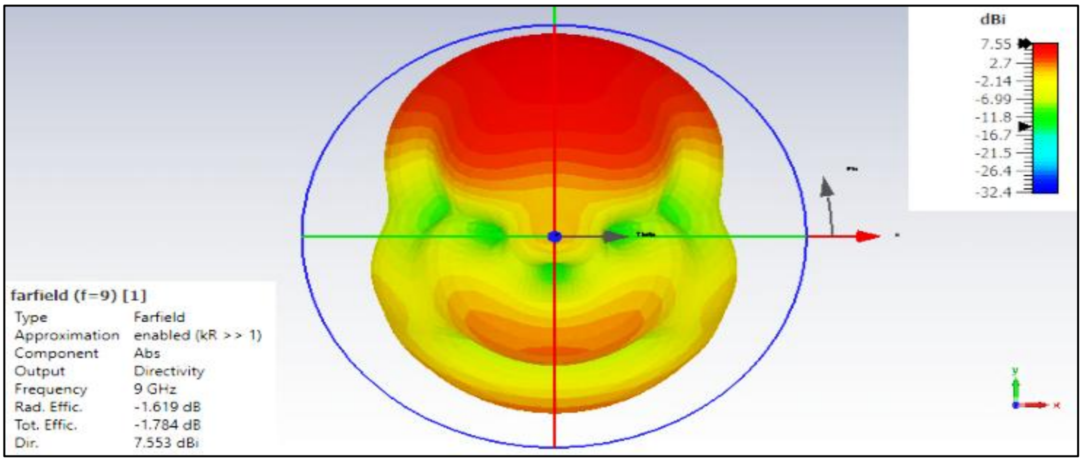

Figure 8: Directivity of the Antenna and Breast Model with Tumor

Figure 7 shows the directivity result of the antenna without a tumor, 7.707 dB, and Figure 8 also shows the directional value of the antenna, which records a value of 7.553 dB. We observe a decrease in the directivity value with the presence of a tumor, which leads to a difference in the directivity result in the absence of a tumor; the difference in the directivity results is what determines the presence of a tumor inside the breast.

C. Gain

The gain of an antenna is defined as the ratio of electromagnetic radiation emitted in a specific direction and serves as a key parameter in assessing the efficiency of a microstrip patch antenna. This parameter was utilized in the detection of breast cancer by analyzing the variation in the antenna's gain. Specifically, the difference in gain values between a breast model without a tumor and one with a tumor was evaluated.

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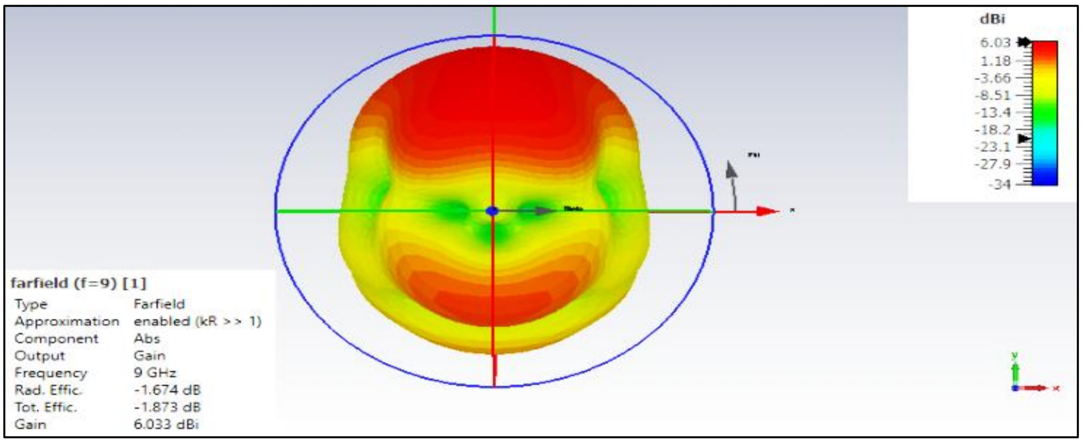

Figure 9: Gain of the Antenna and Breast Model without Tumor.

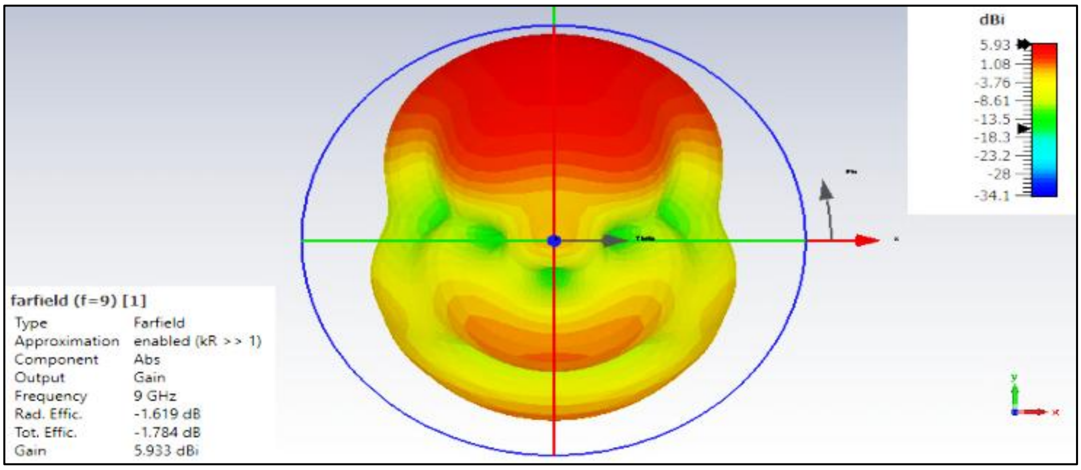

Figure 10: Gain of the Antenna and Breast Model with Tumor.

The value of 6.033 dB shown in Figure. 9 is the gain value of the microstrip antenna without a tumor, and the value of 5.933 dB shown in Figure. 10 is the gain value of the antenna. when the antenna was exposed to a breast model with a tumor in Figure. 10, the value was relatively reduced because of the existence of the tumor within the breast, which caused the disparity to the gain value of the antenna in the breast model without a tumor. It is this difference that is used to identify the existence of a tumor within the breast.

D. Current Density

The term current density refers to the distribution of electric current through the antenna structure. This criterion is influenced by the presence of objects close to the antenna. Therefore, the current density was used in the simulation process to detect breast cancer by analyzing its values and comparing them within the breast model.

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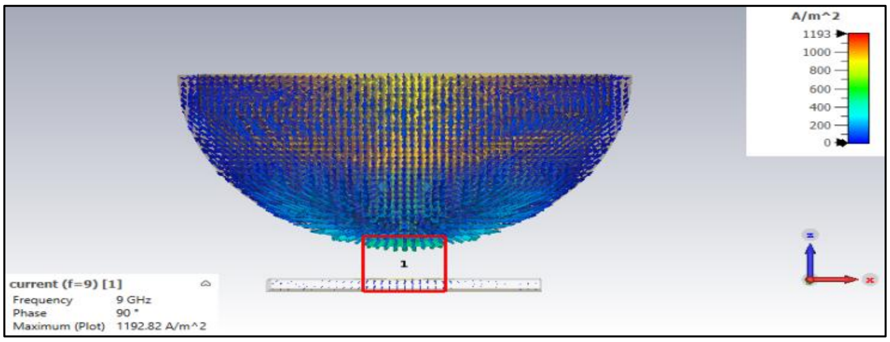

Figure 11: Current Density of the Antenna and Breast Model without Tumor

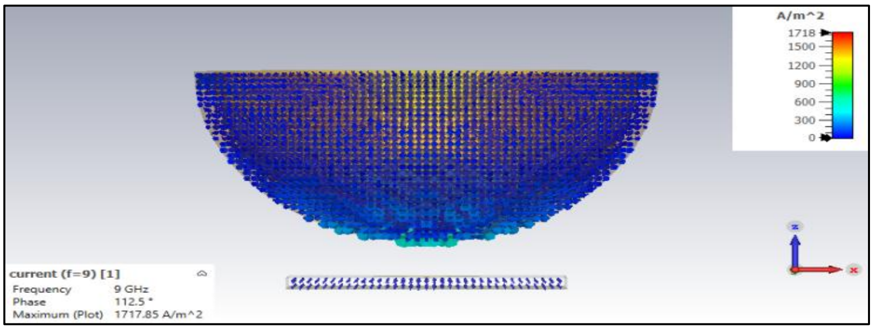

Figure 12: Current Density of the Antenna and Breast Model with Tumor

Figure. 11 presents the current density of the breast model without a tumor, measured at 1192.82 A/m². In contrast, Figure. 12 illustrates the current density with the presence of a tumor, recorded at 1717.82 A/m². The difference in the distribution of current density between the results in the two Figure.s 11,12 shows a marked increase in the result of current density with the tumor in the breast model, and from this it is possible to diagnose the presence of a tumor inside the breast by comparing the results of current density.

The results of the parameters of the circular microstrip patch antenna were displayed by the CST STUDIO program, which was used in the simulation of breast cancer detection. These results showed a marked contrast and difference when exposing the antenna to the breast model without a tumor and the antenna with the model without a tumor. This difference is because of the different electrical and physical properties of infected and healthy breast cells. Table VI shows a comparison of the breast cancer detection simulation process. The table shows the values of the antenna parameters, where a difference is shown between these values in the presence of a tumor and the absence of a tumor inside the breast.

Table VI: Parameters Values of the Antenna with Breast Model without and with Tumor

Parameters of antenna	Breast Model without Tumor	Breast Model with Tumor
Return Loss	-13.481	-14.296
Directivity (dB)	7.707	7.553
Gain (dB)	6.033	5.933
Current Density (A/m^2)	1192.82	1717.85

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E. The use of CMSA Antenna in the Detection of Breast Cancer Tumor with Variable Electrical Characteristics

Breast cancer tumors show different electrical properties compared to other breast tissues, and these differences in electrical properties allow the detection of tumors inside the breast. Electrical permittivity (ε_r) and conductivity (σ) are the specific electrical characteristics that we use to detect breast cancer, which makes the study of these characteristics important. To make the breast cancer detection simulation process more effective, we will expose the circular patch microstrip antenna to tumors with different electrical permittivity and electrical conductivity values to study tumor behavior under different electrical properties and analyze the results for each case. The antenna will be exposed to three states, (case 1, case 2, and case 3), each of which has specific values of permittivity and conductivity, as presented in Table V.

Table V: Breast cancer Tumors with Varying Electrical Characteristics Detected by the CMSA Antenna

Parameters of CMSA antenna	**Case 1** $\varepsilon_r = 10$, $\sigma = 0.5$ S/m	**Case 2** $\varepsilon_r = 50$, $\sigma = 4$ S/m	**Case 3** $\varepsilon_r = 100$, $\sigma = 8$ S/m
Return Loss	-13.691	-14.289	-14.253
Directivity (dB)	7.019	7.541	7.571
Gain (dB)	5.253	5.912	5.956
Current Density (A/m^2)	1118.01	1724.14	3338.72

Some values show an increase with increasing permittivity and conductivity values. This trend is observed in parameters such as directivity, gain, and current density. On the other hand, we observe a variation in the value of the return loss gradually as the electrical characteristics change in each case. It can be concluded that the change in the electrical properties of the tumor affects the propagation of antenna radiation inside the breast.

An important aspect of tumor behavior was addressed by covering the results of the detection of a cancerous tumor with variable electrical characteristics. This is a crucial aspect in studying the behavior of a tumor and monitoring its growth in various situations. Investigation of the antenna response to variable values of the electrical permittivity and conductivity of the tumor is important because it helps in early detection of the tumor and monitoring the stages of its progression inside the breast.

5. Conclusion

The microstrip antenna is used in many applications due to its small size, high efficiency, and ease of design, and (MSA) is widely used in the medical field. A CMSA is designed for an operating frequency of 9 GHz. Several modifications were made to it to improve the quality and range of antenna performance (slot patch and defective ground). The circular microstrip patch antenna is characterized by its ease of design, its ability to operate at multiple frequencies, and the ease of optimizing its performance. Fine-tuning the size of the patch leads to noticeable improvements in the performance of the model, which is why it was chosen for this project. The process of detecting a tumor inside the breast was simulated through the CST STUDIO program

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by exposing the designed antenna to a breast model designed with electrical and physical characteristics of real breast cells. To perform the simulation, a 5 mm spherical tumor was added to the breast model, with different electrical and physical characteristics from normal breast tissue. The antenna was tested in two cases: a breast model without a tumor and another containing a tumor, and the results were compared. The antenna parameters differed significantly between the two studied cases. The values of recoil loss, directivity, gain, and current intensity were not identical when studying the tumor-affected breast model and the tumor-free model. The variety of antenna parameters supports the identification and diagnosis of cancer cells in the breast, which allows diagnosing the presence of a tumor inside the breast. For a deeper understanding of various tumor states, the tumor detection process was simulated within the breast model by subjecting the antenna to three characteristic states, each of which is characterized by electrical characteristics varying in the values of electrical properties, including conductivity and permittivity. These tests aim to better understand the conditions of tumors and study them in their early stages to facilitate their treatment.

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