Investigating Slot Loaded Microstrip Patch Antenna for Breast Cancer Detection

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Abstract

Breast cancer has become a global concern with the highest mortality rate among women. While previously more prevalent in older women, the landscape has shifted significantly. In recent years, breast cancer cases have been increasingly affecting younger women as well. Breast cancer often develops unnoticed and is frequently detected during routine checkups. Microwave imaging offers a potentially more accurate and safer method for cancer detection, which are non-ionizing and do not harm biological tissues when compared to conventional techniques. A two element Slot loaded Microstrip Patch antenna operating in S-band with Rogers RT/duroid 5880 as the substrate material is designed in the HFSS (High Frequency Structure Simulator). A breast phantom was constructed with layers representing skin, fat and fibro-glandular tissues according to their permittivity and conductivity values. Simulation results demonstrate the antenna's suitability for breast cancer detection, showing favorable performance in terms of S11 parameter, directivity, VSWR. The Specific absorption rate (SAR) is a crucial factor in the antenna designed for medical applications. The designed antenna confirms the permissible SAR range, below the FCC recommended limit of 1.6W/Kg.

Keywords Breast Cancer; Microwave Imaging; High Frequency Structure Simulator; Slot loaded Microstrip Patch antenna; Specific Absorption Rate (SAR).

1 Introduction

Breast cancer, akin to other malignancies, originates in the cells of the breast. It stands as one of the most common types of cancers affecting women worldwide, although occurrences in men are less frequent. Typically, breast cancer manifests in the milk ducts (ductal carcinoma) or lobular regions (lobular carcinoma) of the breast. Symptoms may include the presence of a lump or thickening in the breast or underarm, changes in breast size or shape, nipple discharge unrelated to breastfeeding, and alterations in the skin around the breast. When it comes to medical practices for cancer detection, we have various techniques like X-ray mammography, MRI scanning and ultrasonography. X-rays can be effective, but they involve emission of ionizing radiations that can be harmful to the breast tissues. MRI is not affordable as it is costly. To overcome these limitations, researchers have been exploring the use of microwaves for cancer detection in breast tissues.Microwave imaging (MW) is the process of creating visual representations or images of objects, structures using microwaves (~300MHz-30GHz) which are type of electromagnetic radiation.This technique involves an innovative approach to imaging human tissues, utilizing microwave pulses directed towards the tissue and analyzing the backscattered signals, leveraging the knowledge of tissue dielectric properties. By scrutinizing variations in the received signal, tumors, characterized by higher dielectric constants compared to surrounding tissue, can be identified and localized. A crucial component of microwave imaging systems is the antenna, responsible for transmitting and receiving signals through the tissue under examination. These antennas are expected to demonstrate promising characteristics such as high data rate, compact size, high gain, high directivity, and the ability to transmit across a wide range of frequencies.

Microstrip patch antennas have become quite popular in the recent times due to their low profile, small size and simple coupling to planar circuits. These antennas are made up of radiating patch printed on the dielectric substance with a ground plane at the back. Besides their simplicity in design, they are versatile and perform very well which makes them suitable to be used for communication purposes. The use of microstrip patch antennas in detecting breast cancer stems from their non-invasive and highly sensitive ability to interact with biological tissues. Through the utilization of dielectric property difference between healthy and cancerous breast tissues these antennas can locate abnormalities at elevated sensitivity.

2 Antenna Design Consideration

2.1 Antenna Structure

The designed antenna comprises a metallic rectangular patch positioned atop a substrate, which is bolstered by a ground plane beneath it. The radiative component of the antenna is the patch itself, which emits radiation due to the fringing effect occurring between the radiating patch and the ground plane.

Radiating patches can be crafted using various geometric shapes, including squares, rectangles, circles, triangles (equilateral or isosceles), ovals, discs, ellipses, annular patches and more. However, rectangular and circular shapes are commonly favored due to their simplicity in analysis and they require fewer computational resources for mathematical calculations compared to alternative configurations.

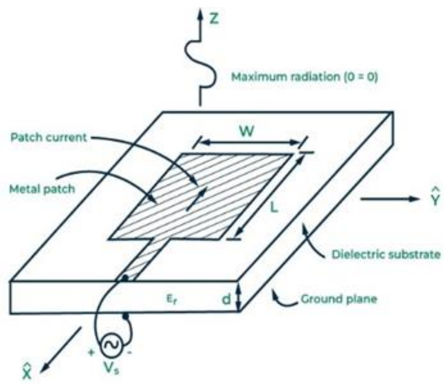

Fig.1 Physical layout of the designed antenna

For the microstrip patch, typical ranges for the height of the substrate (h), patch thickness (t), patch length (L), and substrate's dielectric constant ($\in_r$) are commonly selected as follows.

Table 1 Parameters and their range

Parameter	Range
L	$0.3333\lambda_o < L << \lambda_o$
h	$0.003\ \lambda_o \leq h \leq 0.05\ \lambda_o$
ϵ_r	$2.2 \leq \epsilon_r \leq 12$
t	$t << \lambda_o$

where λo represents the wavelength in free space.

2.2 Parameters for the design

- Resonant frequency (f_r): The antenna is operated in S-band (2-4GHz) frequency. The designed antenna resonates at 3.2GHz.
- The substrate material's dielectric constant (∈r) is selected as 2.2, utilizing Rogers RT/duroid 5880 for the substrate.
- The substrate's height (h) is set at 1.6mm to ensure compact and lightweight antennas, crucial for communication applications.

2.3 Design equations

a) To determine the patch width (W)

$$W = \frac{V_0}{2f}\sqrt{\frac{2}{\epsilon_r+1}} \tag{1}$$

Where V_o = the speed of light in free space = $3*10^8$m/s; ϵ_r = the dielectric constant of the selected substrate; f = resonant frequency

b) To compute the effective dielectric constant

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}[1+12\frac{h}{W}]^{-1/2} \tag{2}$$

Where ϵ_r = the dielectric constant of the selected substrate; h= substrate height

c) To determine the extension length (ΔL)

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

d) To determine the effective length of patch

$$L_{eff} = \frac{V_0}{2f\sqrt{\epsilon_{reff}}} - 2\Delta L \tag{4}$$

e) To determine the length of patch L

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

3 Antenna Structure

3.1 Antenna with inset feeding

A basic antenna with no slots and truncated corners is constructed with Rogers RT/duroid 5880 substrate material. The geometrical configurations of the traditional microstrip patch antenna with inset feeding are contrasted with those employing slot loading.

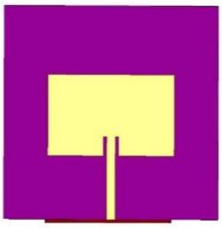

Fig.2 Antenna with inset feeding

3.2 Antenna with L-shaped slit and truncated corner

The design modification involves truncating the top corner of the rectangular patch, which alters the antenna's resonant frequency. Additionally, an L-shaped slit is created at the upper right corner of the rectangular patch. Slots are then incrementally added along the horizontal direction, starting from the corner where the L-shaped slit is located.

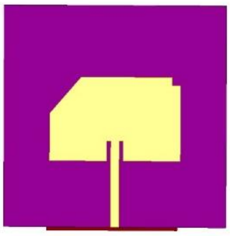

Fig.3 Antenna structure with L-shaped slit and truncated corner

3.3 Antenna with multiple slots arranged serially

Thin rectangular slots, measuring 2.5 by 1.5 units, are sequentially incorporated along the horizontal direction, commencing from the right corner where the L-shaped slit is positioned. Each of these slots maintains an inter-elemnt spacing of 1mm and covers the upper half of the rectangular patch.

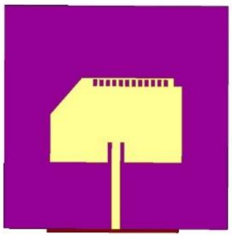

Fig.4 Antenna design with multiple slots arranged in a serial manner

3.4. Designed antenna structure positioned on both sides of the breast phantom model

The designed antenna is replicated and is placed on either side of phantom model representing human breast. The breast model comprises three distinct layers designed to mimic the properties of human breast tissues, incorporating permittivity and conductivity values.

Fig.5 Dual antenna structure placed on either side of the breast phantom model without tumour (front view)

The designed structure is analysed for a case where a tumour is inserted in the breast phantom.

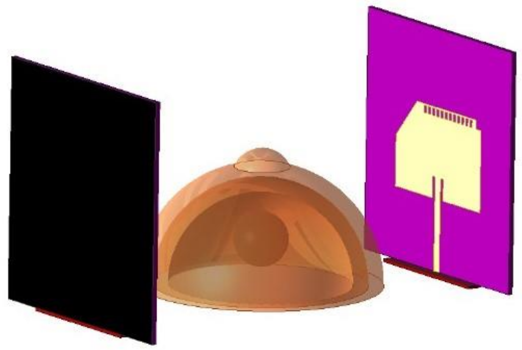

Fig.6 Dual antenna structure placed on either side of the breast phantom model with tumour

3.5. Final antenna structure placed on either side of the phantom model

The ultimate antenna structure is analysed in HFSS software both with and without tumour respectively.

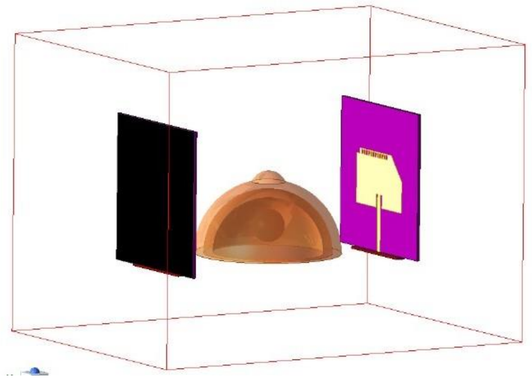

Fig. 7 Ultimate configuration of the antenna placed alongside with the phantom model of breast

4 Antenna Design Parameters

The antenna is crafted for operation within the S-band frequency range (2-4 GHz), utilizing Rogers RT/duroid 5880 as the substrate material, which possesses a dielectric constant of 2.2.

Table 2 Dielectric properties of breast tissues

Tissue	Relative permittivity ϵ_r	Conductivity (S/m)
Skin	33	0.15
Fat	11	0.1
Fibro glandular	28	0.1
Tumour	57	2.07

Table 3 Design parameters of Antenna

Design parameter	Value
Operating Frequency	3.2 GHz
Dielectric constant	2.2
Substrate Height	1.6mm
Feeding Technique	Microstrip feeding
Length of Patch (L)	30.2mm
Width of Patch (W)	47mm
Depth of the Feed	7.16mm
Width of the Feed	2.98 mm
Length of slot	2.5 mm
Width of slot	1.5mm

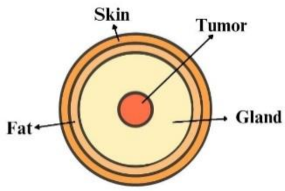

Fig.8 Various layers of breast tissue model.

The following figure depicts the ultimate structure of the designed antenna, detailing all dimensions in millimetres.

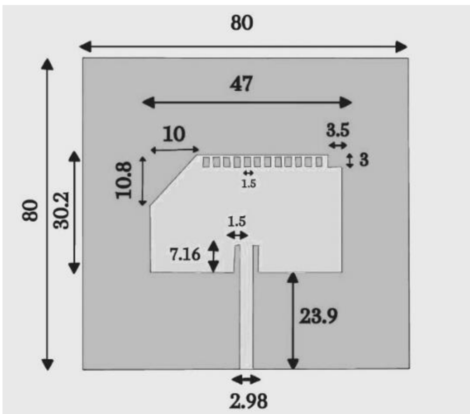

Fig.9 Structure of the designed antenna with dimensions.

5 Results and Discussions

The antenna structure is simulated using High-Frequency Structure Simulator (HFSS) and the analysis is performed with and without tumour considerations, examining various parameters like S_{11} parameter, VSWR, SAR value, E-field, H-field. To ensure effective radiation of any antenna, it is essential to aim for a return loss value below -10 dB and VSWR less than or equal to 2.

The designed antenna is simulated in S band (2-4 GHz) and offers a return loss minimum at frequency of 3.2 GHz. The figure below illustrates that the designed antenna resonates with a return loss (S11) of -18.0689 dB, corresponding to a VSWR of 1.2, at the central frequency of 3.2 GHz.

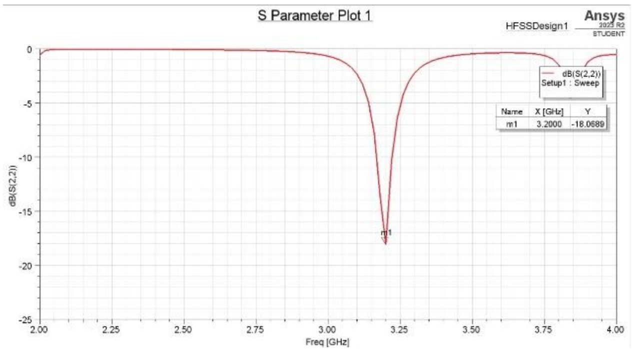

Fig.10 Return loss of the antenna

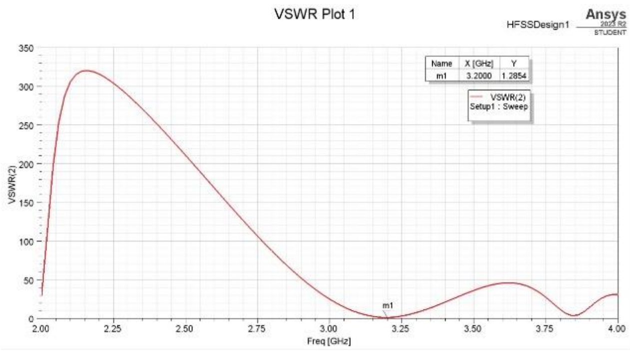

Fig.11 VSWR of the antenna

Specific Absorption Rate (SAR):

The Specific Absorption Rate (SAR) denotes the pace at which the human body absorbs energy per unit mass when exposed to electromagnetic fields of radio frequency. SAR is quantified in watts per kilogram (W/kg) and serves as a metric for assessing the potential health hazards linked to electromagnetic radiation exposure.

Table 4: Limit of SAR levels for various countries

Country	**Association**	**SAR value(W/kg)**
United States	FCC (Federal Communications Commission)	1.6 Watts per kilogram
India	TEC (Telecom Engineering Centre)	1.6 Watts per kilogram

The Federal Communications Commission (FCC) specifies that maximum SAR limit for a human body exposure to electromagnetic radiations without harmful effects is 1.6 W/kg. SAR value obtained when the designed antennas are positioned around the breast phantom without the tumour is 0.364 W/kg, which is in the permissible range given by FCC.

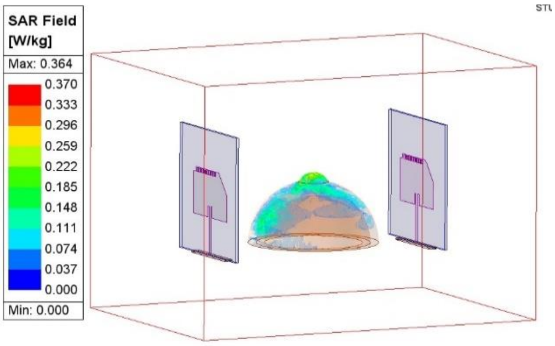

Fig 12 SAR value of the designed structure without tumour

Similarly, the designed antenna structure is simulated with a tumour of multiple radius, the SAR values obtained for 3 mm, 6 mm, 9 mm radii are 0.427 W/kg, 0.433 W/kg and 0.492 W/kg respectively.

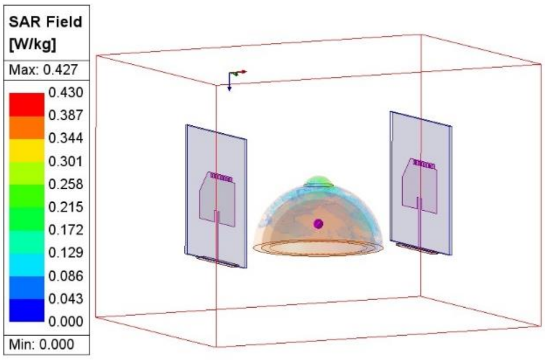

Fig.13 SAR value of designed structure with tumour of 3mm radius

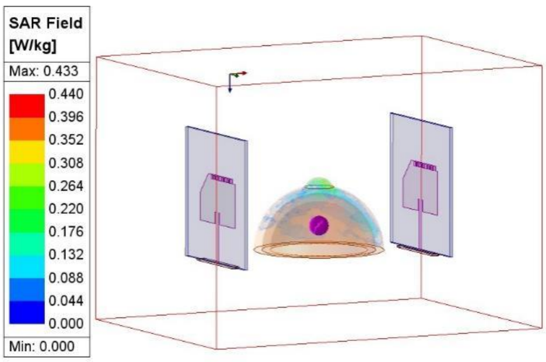

Fig.14 SAR value of designed structure with tumour of 6mm radius

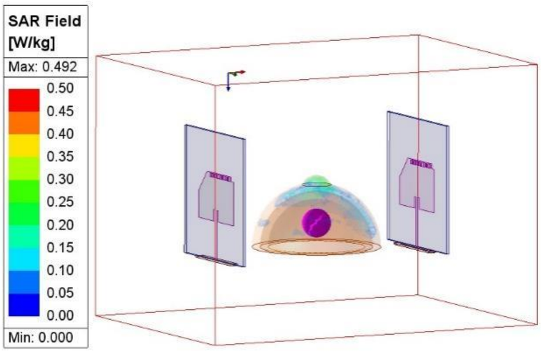

Fig.15 SAR value of designed structure with tumour of 9mm radius

S_{11} Parameter:

The S11 parameter, commonly referred to as the return loss or reflection coefficient, quantifies the extent of signal reflection from a component, typically expressed in decibels (dB). It represents the ratio of the power of the reflected wave to the power of the incident wave at a specific port within a network or device.

The less the S_{11} value is, the better the impedance matching in between the source and the load, and thus leads to less reflection and more efficient power transfer.

The graph below shows the return loss of the proposed antenna structure without tumour which is below -10dB (a value of -18.3523dB at centre frequency of 3.2GHz).

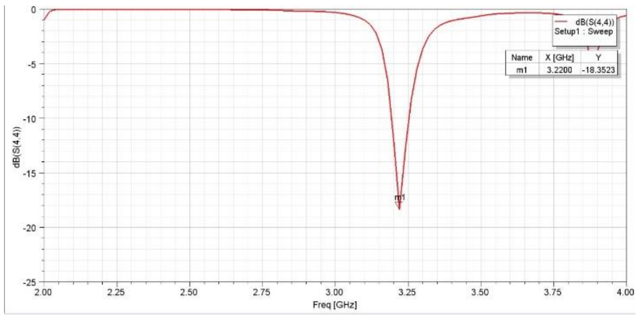

Fig.16 S_{11} parameter of designed antenna structure without tumour

The following figure shows the variation of return loss of the designed antenna structure in presence of tumour with multiple radii.

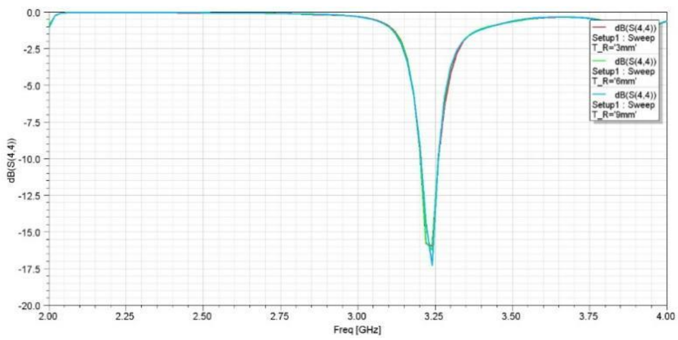

Fig.17 S_{11} parameter of designed antenna structure with multiple tumours

The above-mentioned figures show that the return loss values with the tumour are higher than the values without tumour, which indicates more reflection of signals in presence of the tumour.

The change in the reflection coefficient values in presence of tumour and absence of tumour determines the presence of abnormalities in breast phantom.

Far field patterns:

The directivity value of the proposed antenna obtained is 8.25dB at 3.2GHz which specifies the effectiveness of slot loaded microstrip patch antenna in directing its radiated power towards its desired target.

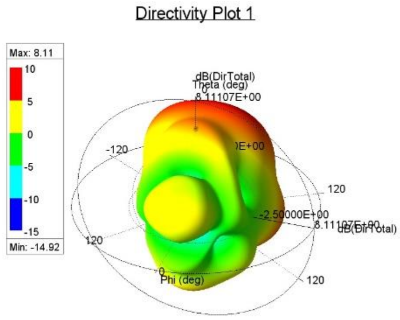

Fig.18 Directivity of designed antenna structure without the tumour

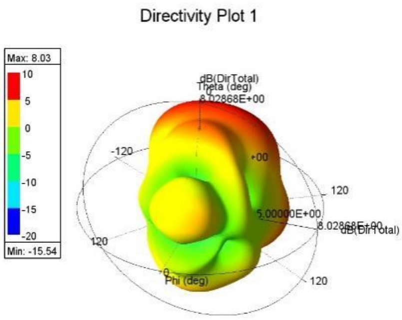

Fig.19 Directivity of designed antenna structure with tumour

The illustration below depicts the distribution of electric and magnetic fields for the designed antenna.

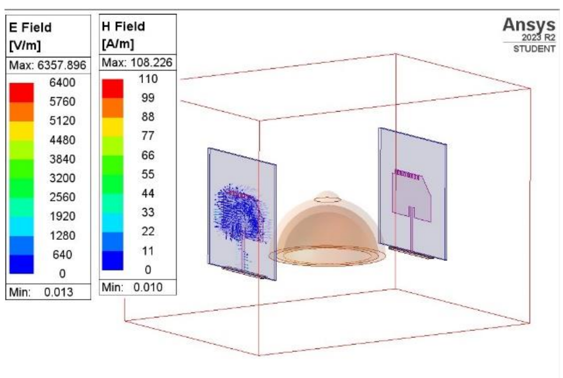

Fig.20 H-field and E-field in absence of tumour

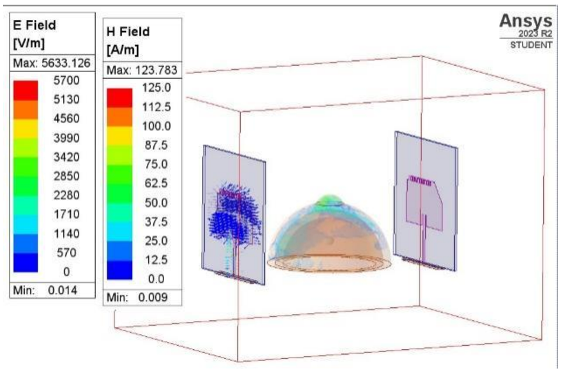

Fig.21 H-field and E-field for a tumour of 3mm radius

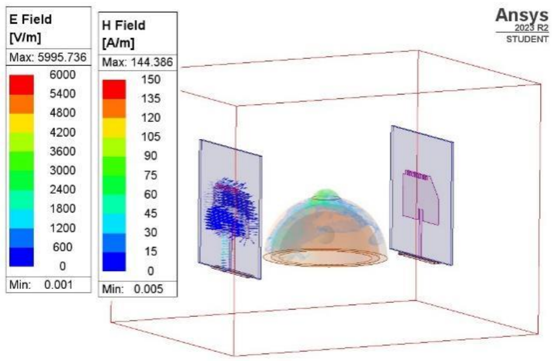

Fig.22 E-field and H-field for a tumour of 6mm radius

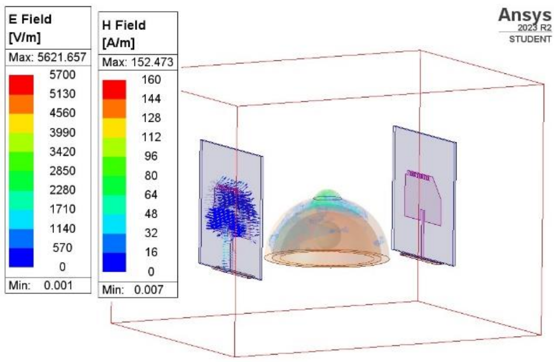

Fig.23 E-field and H-field for a tumour of 9mm radius

Summary:

The comparison among various parameters for the proposed antenna structure with and without the tumour in terms of directivity, SAR, E-field and H-field is done to show that antenna works well in S-band (2-4GHz) frequency range that is well suited for biomedical applications.

Table.5: Comparison of different parameters

Breast Phantom model	**Directivity (dB)**	**SAR (W/Kg)**	**E-field (V/m)**	**H-field (A/m^2)**	**Reflection coefficient (dB)**
Without tumour	8.11	0.36	6357.89	108.22	-18.35
With Tumour 3mm	8.03	0.42	5633.13	123.78	-15.96
6mm		0.43	5995.74	144.38	-16.24
9mm		0.49	5621.66	152.47	-17.27

6 Conclusion

This paper presents the successful design and simulation of a slot-loaded microstrip patch antenna using HFSS within the S-band frequency range. The antenna achieves a return loss below -17 dB, with a directivity of 8.25 dB and a VSWR of approximately 1.2.

The antenna shows satisfactory output parameters that are well suited for biomedical applications. For further scope, the received signals can be applied to signal processing algorithms to generate 2D or 3D images of the breast. It also renders the images of cancerous cells with their size, location and density. The designer must choose a proper antenna with appropriate materials and dimensions to obtain optimum performance.

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