Asian Research Association
INTERNATIONAL RESEARCH JOURNAL OF MULTIDISCIPLINARY TECHNOVATION

DOI: 10.54392/irjmt26118

Modeling and Designing a Dual-Band Microstrip Patch Antenna Enhanced with CSRR for Breast Cancer Detection

Purnima K Sharma [a], T.J.V. Subrahmanyeswara Rao [b], T.V.N.L. Aswini [c,*], Dinesh Sharma [d], PN Malleswari [b]

[a] Department of ECE, Chitkara University Institute of Engineering and Technology, Chitkara University, Punjab, India.
[b] Department of ECE, Sasi Institute of Technology and Engineering, Tadepalligudem, Andhra Pradesh, India.
[c] Department of ECE, Sri Vasavi Engineering College, Tadepalligudem, Andhra Pradesh, India.
[d] Department of ECE, Chandigarh College of Engineering and Technology, Chandigarh, India
* Corresponding Author Email: aswinivnl@gmail.com

DOI: https://doi.org/10.54392/irjmt26118
Received: 28-01-2025; Revised: 04-01-2026; Accepted: 11-01-2026; Published: 30-01-2026

Abstract: Breast cancer has a significant impact on numerous women and can have fatal consequences if not addressed properly. The cancer detection becomes a critical factor in identifying and intervening with cancerous tissue to facilitate suitable treatment. Early diagnosis and effective therapeutic procedures are to be necessitated to reduce the risk of fatalities and improve the health condition which is accomplished by various diagnostic techniques Several methods are employed to detect breast cancer which includes X-ray mammography, magnetic resonance imaging (MRI), and ultrasound. However, each of these methods comes with its own specific limitations. In this context, a microstrip patch antenna is designed to detect the breast cancer tumors. The proposed antenna resonates for dual-band applications capable of operating at 3.5 GHz and 5.9 GHz frequencies and hence, can be implemented in tumor detection. The suggested design utilizes FR-4 dielectric substrate having slots in radiating patch and modified ground, helps to improve the radiation patterns. The complete antenna design is executed through the utilization of HFSS software. To further validate the design, the antenna was tested on artificially fabricated breast phantom and comparison was made between S11 parameters of healthy and tumorous tissues. The gain parameters indicate that the proposed antenna has promising potential for practical biomedical applications in non-invasive breast cancer detection.

Keywords: High Frequency Structure Simulator, Microstrip Antenna, Return Loss, Patch, Dielectric, Breast Cancer, Cancer Detection.

1. Introduction

Breast cancer is a medical ailment where the breast cells start to proliferate and develop beyond the proportion. These abnormal cells accumulate and eventually form a mass or tumor rather than going through the regular cycle of development and death. The malignant cells may eventually infiltrate the healthy breast tissue around them and, in more advanced stages, spread to other bodily areas such the brain, liver, lungs, lymph nodes, or bones [1]. With an expected 685,000 fatalities in 2020, breast cancer has been identified as one of the major reason for fatalities among the women globally. As per World Health Organization (WHO) records around 19.3 million new cases were reported in 2020 due to which breast cancer is regarded as most common cancers [2-3].

Due to its aggressive nature it emphasizes how vital early identification and the creation of efficient treatment plans are to raising survival rates and enhancing quality of life. A variety of diagnostic and screening methods, including as magnetic resonance imaging (MRI), ultrasound, microwave-based sensors, and X-ray imaging, are used to get early diagnosis. Mammography is still the most used and trustworthy screening method among them. By using low-dose X-rays to find anomalies in breast tissue, it frequently finds possible cancers before clinical signs appear, which is crucial in lowering the number of fatalities from breast cancer. Traditional imaging methods for breast cancer screening are popular, but they have limitations. Mammography and other X-ray-based procedures expose patients to ionizing radiation, which may cause physical injury and marginally raise the long-term risk of secondary cancer development. A common supplementary technique is ultrasound imaging, which is especially helpful in distinguishing solid tumors from fluid-filled cysts. Its efficacy is, however, constrained by its low sensitivity in correctly identifying cancerous lesions and by its inability to image thick breast tissue, which might mask anomalies [4-7]. MRI is especially useful for high-risk individuals since it has a significantly better sensitivity and is excellent at identifying soft tissue abnormalities in the breast. The accuracy and promptness of breast cancer diagnosis are improved by various imaging modalities used together, but their broad use is hampered by high costs, restricted accessibility, and the fact that they frequently work best when disease is already more advanced [8-9].

Researchers are thereby diligently investigating at other diagnostic techniques that make use of developing systems based on electromagnetic radiation. These new technologies have a number of benefits over traditional imaging methods, such as decreased costs, increased accuracy, and increased safety because of less radiation exposure. They are a viable alternative to current diagnostic techniques since they are non-invasive, painless, and easier for people to use while undergoing testing [10-11].

Microwave Imaging (MWI) is a possible substitute for traditional breast cancer screening techniques since it provides a number of noteworthy benefits. First of all, it is an inexpensive method, which is especially important for low- and middle-income nations where high cancer death rates are frequently associated with the inaccessibility and high cost of conventional diagnostic instruments. Second, unlike MRI machines, which are large and stationary, MWI systems are small and light, making them suitable for a variety of uses, including wearable technology, portable units, and even bedside systems [12]. Third, MWI offers patients more comfort since it eliminates the need for breast compression, unlike mammography, and the need to lie for lengthy periods of time within a small scanner while getting contrast injections, unlike MRI. MWI is a desirable and patient-friendly technology for extensive clinical application because of these benefits [13]. The implementation of these patient-friendly technologies is anticipated to improve early detection rates by greatly increasing patient acceptability and involvement in regular screenings. Because therapies may be started before the disease reaches severe stages, early tumor diagnosis is directly linked to better treatment outcomes. In addition to improving patient comfort, the adoption of non-invasive, painless monitoring techniques promotes repeated screenings over time, which is essential for continuous surveillance. When taken as a whole, these elements support quicker and more effective therapy, which eventually raises patients' quality of life and long-term survival rates [14-15].

Systems for microwave imaging (MWI) work by using the advantage of the difference in dielectric characteristics between breast tissues that are healthy and those that are malignant, namely conductivity and permittivity. various tissues have various dielectric properties because they contain different quantities of water [16]. Compared to normal fatty breast tissue, malignant tumors usually include a much greater water content, which leads to noticeably increased conductivity and permittivity values. Actually, a tumour's dielectric constant might be up to 13 times higher than the fatty tissue around it. This sharp contrast gives MWI systems an excellent basis for identifying anomalies in the breast, allowing them to differentiate between malignant and healthy tissue [17].

Plenty of research is being done in developing appropriate antennas that fulfil the needs of biomedical imaging systems ever since engineers working on these devices first became interested in microwaves. It is possible to create pictures and precisely locate tumours by sending brief pulses into the breast and taking advantage of the dielectric contrast between cancerous and healthy tissues [18].The antenna should be tiny enough to occupy up a small area on the breast, and the cost and complexity of the design needs to be carefully considered. Breast imaging devices should ideally be widely available and reasonably priced, which calls for simple and affordable antenna fabrication. Additionally, certain image reconstruction techniques may be hampered by too complicated designs, which makes precise antenna modelling difficult. Because of its many benefits, including their small size, lightweight, straightforward design, simplicity of manufacture, and affordability, microstrip antennas have attracted a lot of interest in breast cancer detection research, including wearable devices [19-22].

2. Literature Survey

Microwave imaging methods, such as microwave breast imaging and microwave tomography, use antennas to send and receive microwave signals in order to reconstruct images. These antennas use controlled signals to illuminate the body and then record the reactions to create photos of the inside. Wideband operation, directional and concentrated beam patterns, flexible and conformal designs, and compatibility for multiple-antenna configurations are important features of microwave imaging antennas [23-25].

Microwave imaging antennas are designed to function in a broad frequency range, usually in the millimetre-wave or microwave spectrum. Higher resolution, better picture quality, and deeper penetration are made possible by their wideband performance. Depending on the imaging needs and target location, these antennas alter their beam characteristics and frequently use directive beam patterns to improve spatial resolution by focusing the transmitted energy. Antennas used in healthcare facilities are designed to be flexible or conformal to ensure that they can follow the curved surfaces of the body and stay in close proximity, improving picture accuracy and signal coupling. Multiple viewpoints of the body may be obtained using a variety of configurations, such as single- or multi-static setups, which aid in the more precise reconstruction of interior structures.

Depending on the anatomical region of interest, imaging method, and overall system requirements, several microwave imaging antenna designs are used. Phased arrays, metamaterials, adaptive focusing, and other advanced techniques are frequently incorporated to enhance performance and broaden their potential in medical imaging [26-29].

The development of a wearable breast cancer detection system using four circularly polarized (CP) sensor devices is presented in this study. A wearable breast cancer detection system is created by integrating these CP sensors into a smart bra. A CPW-fed trapezoidal monopole antenna and an etched trapezoidal slot are features of the antenna-based sensor, which is built on a flexible Rogers 3003 substrate with a compact dimensions of 0.2 λo × 0.2 λo m² [30].A small, wideband metasurface (MS)-based antenna sensor has been proposed for the detection of breast tumors. A coplanar waveguide (CPW) feed excites a multilayer MS structure that makes up the sensor. Parallel plate capacitors, which increase the operating bandwidth while decreasing the overall profile height, are used by the CPW feed to activate the multilayer MS. Specific absorption rate (SAR) analysis is used to further examine the sensor's functionality and determine how well it detects tumors [31]. In [32], a unique and simple antenna design for the detection, size, and localization of breast cancer is presented. The proposed tiny antenna uses fractal geometry to generate positive gain and operates at an optimal frequency of 7.98 GHz. Its small dimensions are 10 × 10 × 1.6 mm³. The design makes use of two nested folds that are joined by circles, discs, and repetitive lines. The simulation results demonstrate a gain of 1.04 dB, an efficiency of approximately 70%, and a reflection coefficient of −39 dB over a bandwidth of 340 MHz. In the imaging technique, a compact and efficient microstrip patch antenna is utilized to transmit incident signals and capture backscattered responses from a stratified human head model. To further improve antenna performance, an electromagnetic band gap (EBG) structure is incorporated into the ground plane. Both rectangular and circular EBG configurations are investigated for performance evaluation. Results show that incorporating a circular EBG provides notable improvements compared to the rectangular design, achieving a 22.77% enhancement in return loss, a 5.84% increase in impedance bandwidth, and a 16.53% gain improvement [33].

The MSPA is built simply using conventional microstrip fabrication methods. These patch antennas offer versatile attributes like circular polarization, adaptable frequency, and dual-frequency functionality, wide bandwidth, versatile feed line configuration, and beam scanning [34]. On one of the substrate's sides, the MSPA has a ground plane made up of a conducting substance, such as silver, copper, aluminium etc. On the opposite side, there is a patch that is smaller compared to the substrate and is fed by a microstrip line [35]. The antenna's directivity remains unaffected by the substrate thickness. Depending on the application, the substrate may take on a variety of shapes [36], including circular, rectangular, square, and elliptical as shown in the Table 1.

3. Design of proposed Dual Band Antenna

A rectangular shaped antenna has been designed to work over a range of frequencies between 3 to 7 GHz. Further it is used to detect the change in the radiation patterns caused by the cancerous lumps and also look at SAR (Specific Absorption Rate) to see how much energy is absorbed, since tumor cells tend to absorb more [37]. Designing and development of a microstrip patch antenna involves changing its shape using stubs, slots in the main part that sends out signals, and altering the ground to make the signal spread out more widely. This can be accomplished in one of two ways: either by using machine learning algorithms like the Genetic Algorithm or the Jaya Algorithm, or by using various calculations and monitoring the results at each stage of the design process. The antenna's base and the part that sends out signals are both made of copper material [38].

FR-4 glass epoxy stands as a well-liked and adaptable form of high-pressure plastic laminate, crafted from thermoset material. It was chosen for its strong yet lightweight properties. FR-4 is commonly used as an electrical insulator due to its high mechanical strength and very low water absorption. It maintains its strength and insulation capabilities even in different levels of humidity. These qualities make FR-4 suitable for various electrical and mechanical purposes, and its ease of fabrication adds to its usefulness [39]. Copper was chosen because it conducts electricity really well and reacts quickly. It's great at spreading electrical energy. It's also harder than materials like silver or gold, and it's more affordable [40]. The different parameters of the proposed antenna are listed in the Table 2. Figure 1 shows various iterations along with their results that were made and observed to reach the final design with the best results. Following the various studies done previously [41, 42], a patch was modelled. A supplementary T-shape stub has been linked to the non-radiating section of the patch with the intention of enhancing the electrical extension of the configuration. Different steps and stubs are made in order to decrease the return loss and get the resultant design as in Figure. 2. Figure. 3&4 shows the return loss and electrical field radiation patterns of the proposed antenna.

Table 1. Comparison of antenna designs reported in the literature for biomedical and WBAN-based applications.

Ref	Antenna Design	Bandwidth	Gain	Advantages
[43]	Photonic band gap (PBG) structures and substrate integrated waveguide(SIW)	7–28 GHz	10.5 dBi	Achieving quality results on breast-like material, then incorporating it into a WBAN system for breast cancer imaging and monitoring the results.
[44]	all-textile-based slotted triangular antenna loaded with a 2 × 2 textile-inspired artificial magnetic conductor	3.1 to 6.5 GHz	6.71 dBi	Opting for a fully integrated textile antenna within the wristband can enable health monitoring of the user's wellbeing across a variety of frequency channels.
[45]	Flexible sixteen monopole antenna array	2-5 GHz		Variations in the dielectric properties of tissues have been explored across a wide range of frequencies.
[46]	Full ground ultra-wideband (UWB) antenna	7–28 GHz	10.5 dBi	Used to achieve a wide bandwidth while keeping the Specific Absorption Rate (SAR) within acceptable boundaries.
[47]	flexible monopole antennas on a cotton substrate	2.5 to 9 GHz	Average 4dbi	Better tumor detection is provided
[48]	Single Patch with a rectangular slot	8.4-10.3GHz	6.451 dBi	Detailed evaluations of E-fields, H-fields, and current densities have been skilfully conducted
[49]	tapered slot antenna modified by etching nine rectangular side slots	2.80 - 7.0 GHz	>5dBi	Increased electrical length, in addition, produces strong directive radiation

Table 2. Antenna Parameters

Antenna Parameters	Dimensions(mm)
Substrate Thickness	1.6
Substrate Length	25
Substrate Width	20
Patch Length	21
Patch Width	18
Microstrip Length	3.5
Microstrip Width	2

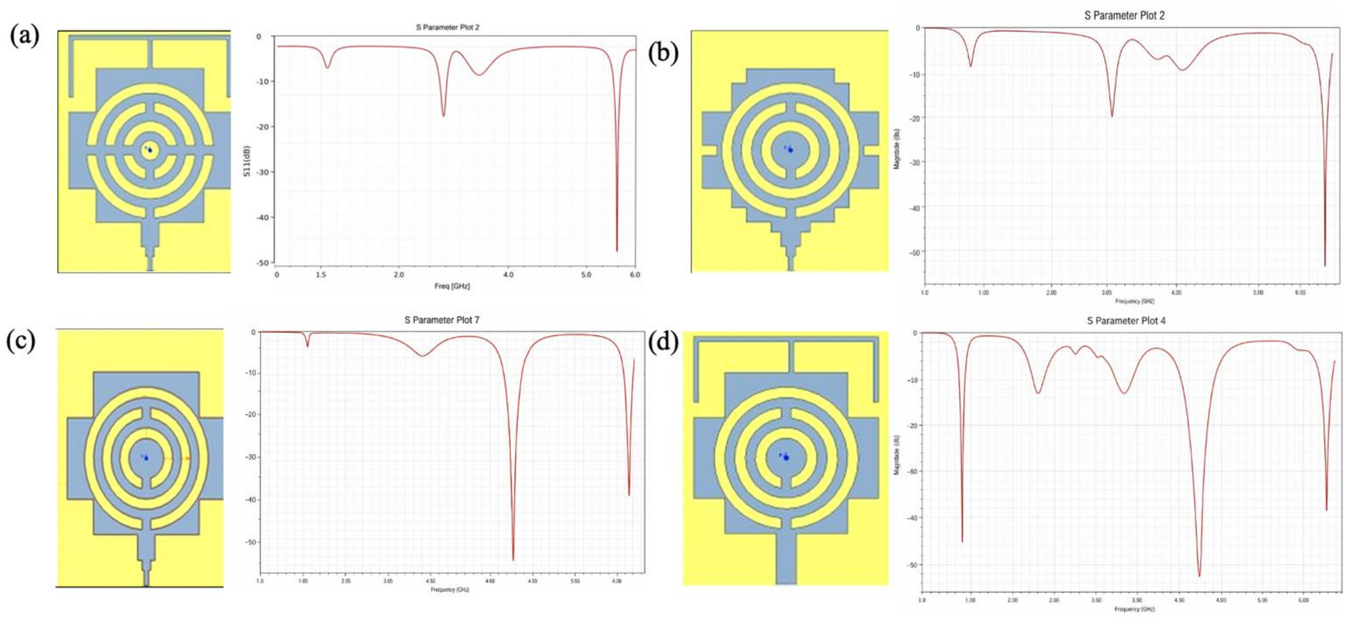


Figure 1. Designed antenna iterations

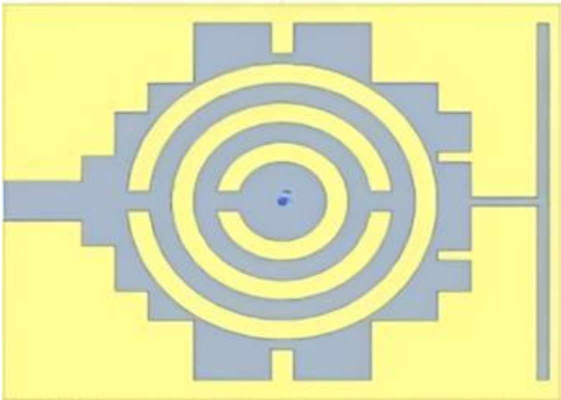


Figure 2. Final proposed design of the antenna

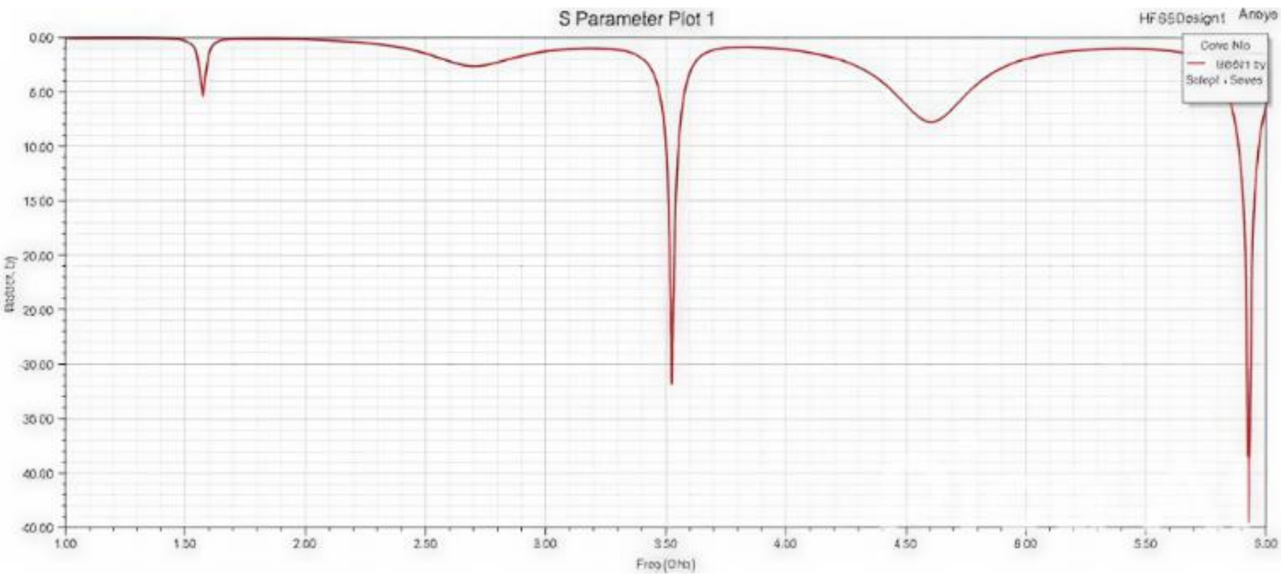


Figure 3. S-parameter plot

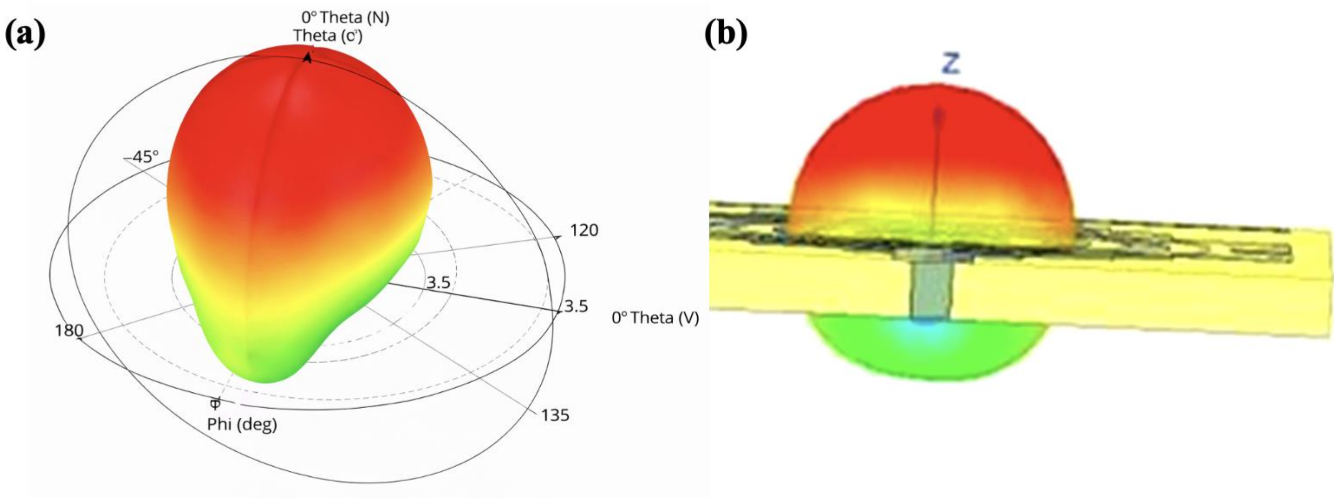


Figure 4. Electric Field Radiation Patterns

4. Experimental Validation of Dsigned Antenna

In order to assess the proposed antenna's performance in the presence of both healthy and malignant breast phantoms, a realistic breast model is created in HFSS, as shown in Figure 5. Skin, fat, and muscle tissue are the three main biological layers that make up the model, with an extra tumour layer included as desired. The proportions of the three-dimensional rectangular blocks used to depict each kind of tissue are carefully chosen to resemble biological features while preserving computing efficiency. In accordance with values acknowledged in the literature, the tissues' dielectric and physical characteristics b such as relative permittivity, conductivity, and thickness are allocated. Table 3 provides a summary of these characteristics as well as information on the geometric dimensions used in the model. The breast phantom offers a useful platform for evaluating antenna performance by integrating these realistic features, making it possible to investigate electromagnetic interactions with tumour inclusions as well as normal tissue [50-51]. The Gain, SAR and Radiation patterns of the proposed antenna can be observed from the figures 6,7,8 respectivel When compared to healthy tissues, breast cancer tumors show notably altered electromagnetic radiation absorption properties. Through the analysis of differences in the specific absorption rate (SAR) between normal tissue and tumor-infiltrated areas, this contrast aids in the identification and location of tumors. The skin, fat, and fibroglandular tissues' SAR values in the tumor-embedded breast model differ significantly from those in the tumor-free model. These variations are trustworthy markers for identifying tumors. Specifically, the SAR is significantly larger in the fatty tissue in the tumor-embedded example, mainly because the tumor's presence within the fat layer increases the absorption of electromagnetic radiation, which raises the SAR [52].

Initial simulation through HFSS comprehensively analysed the antenna's return loss, impedance matching and bandwidth. The simulations were followed by the fabrication of an antenna prototype as shown in Figure. 9 with its measurements.

The fabricated antenna was then experimentally tested in a controlled laboratory environment. To evaluate the antenna's resonance frequencies and bandwidth, Vector Network Analyzer and Spectrum Analyzer were connected to it. Additionally, the antenna was tested using artificially fabricated breast phantoms to simulate actual breast cancer detection scenarios as shown in Figure.10. Through this comprehensive testing approach, the performance of the dual-band CSRR loaded microstrip patch antenna was thoroughly evaluated, providing valuable insights into its potential for practical application in breast cancer detection systems [42].

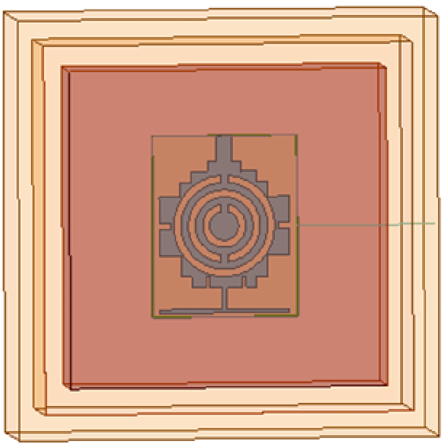


Figure 5. Proposed Antenna inside Phantom model

Table 3. Electrical Properties of skin, fat and muscle at various frequencies

	Electrical Permittivity (ε_r)		**Electrical Conductivity** (σ)	
Frequency(GHz)	3.5	5.9	3.5	5.9
Skin	38.0	35.0	1.46	3.72
Fat	5.28	4.89	0.16	0.32
Muscle	52.7	48.2	1.73	4.92
Tumour Tissue	59.1	56.6	3.6	4.7

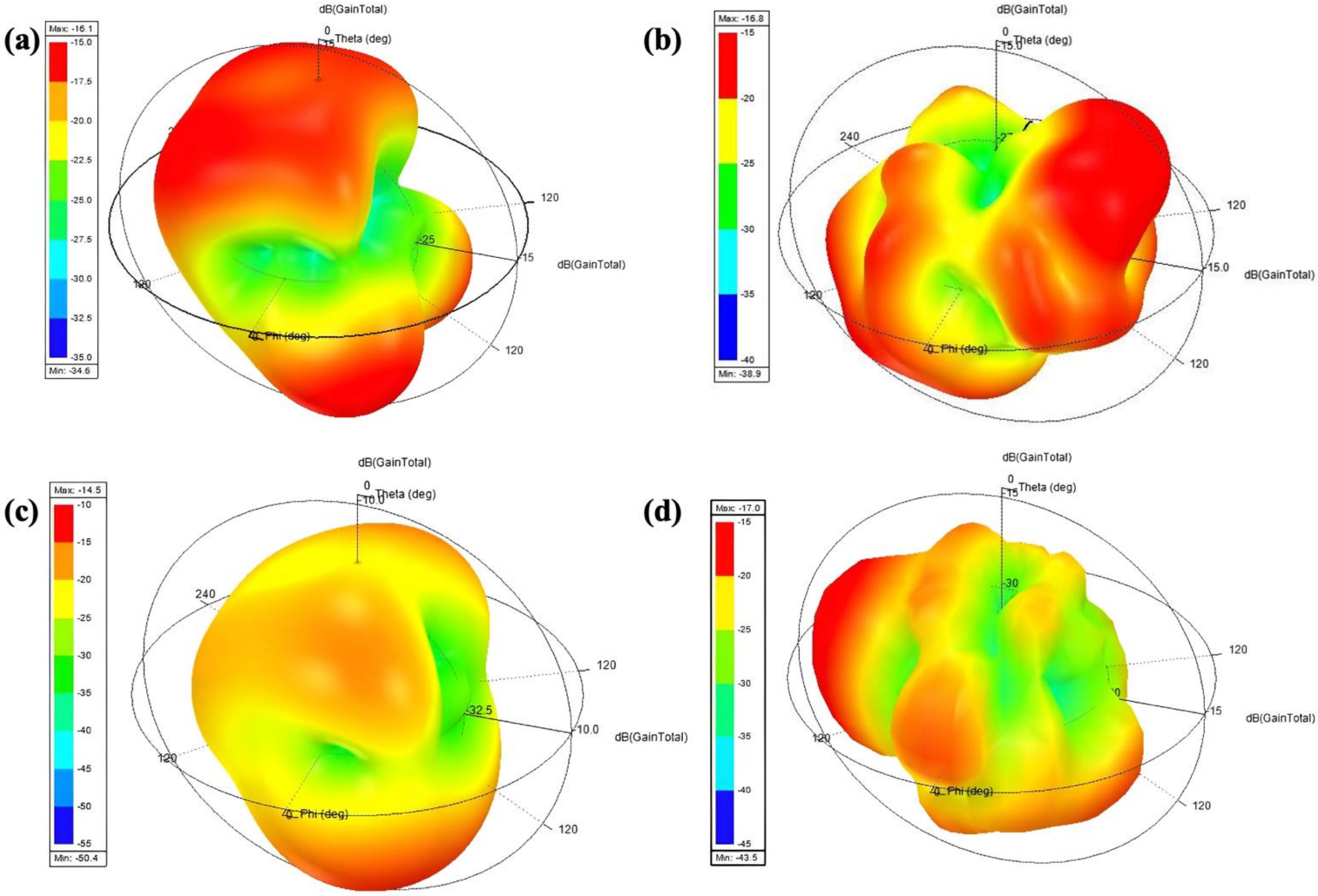


Figure 6. Gain of proposed antenna at various frequencies with and without tumour, (a) Gain at 3.5 GHz without tumour, (b) Gain at 5.9 GHz without tumour, (c) Gain at 3.5 GHz with tumour, (d) Gain at 5.9 GHz with tumour

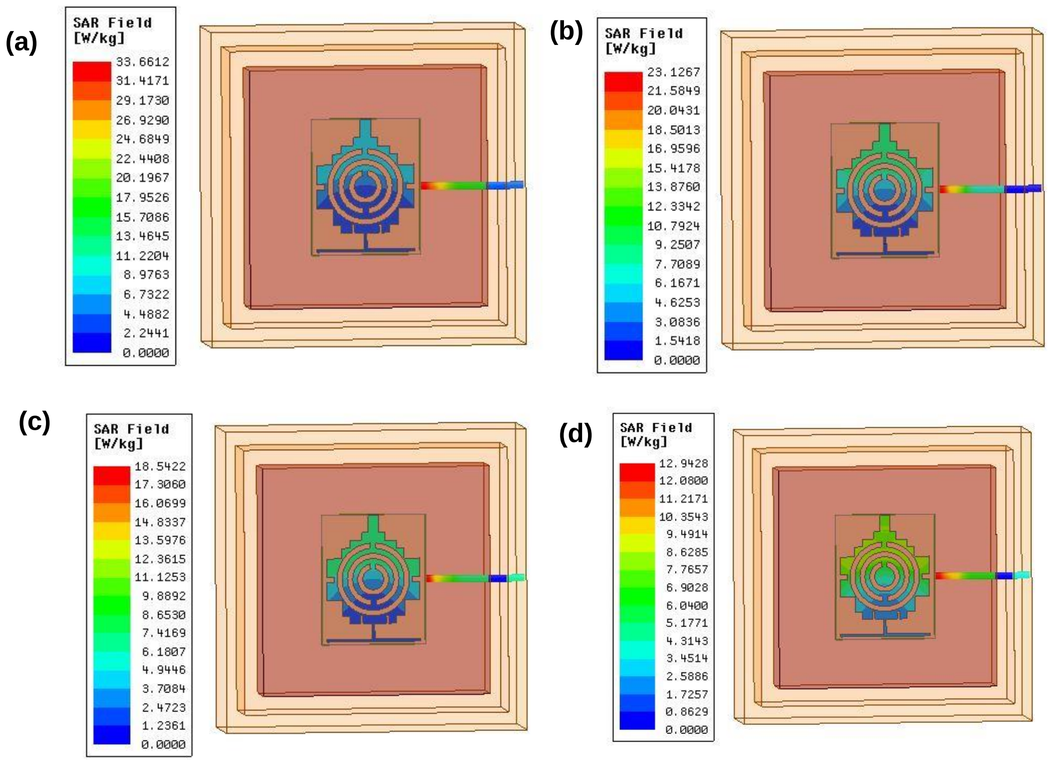


Figure 7. SAR of proposed antenna at various frequencies with and without tumour, (a) SAR at 3.5 GHz without tumour, (b) SAR at 5.9 GHz without tumour, (c) SAR at 3.5 GHz with tumour, (d) SAR at 5.9 GHz with tumour

(a) (b) (c) (d)

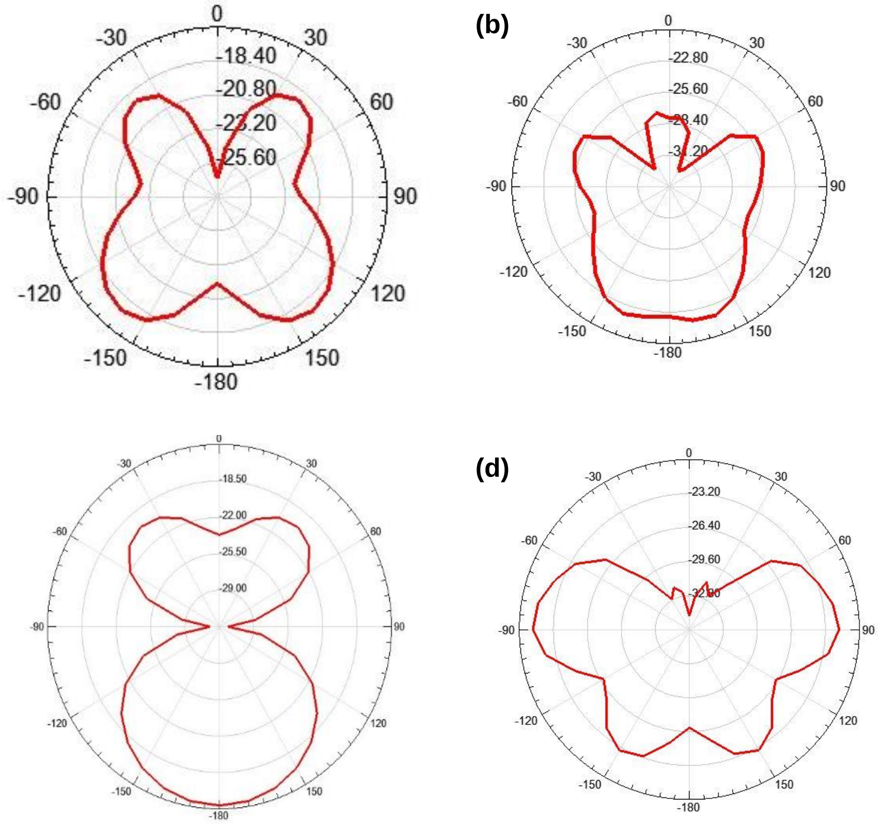


Figure 8. Radiation Pattern of proposed antenna at various frequencies with and without tumour, **(a)** Radiation Pattern at 3.5 GHz without tumour, **(b)** Radiation Pattern at 5.9 GHz without tumour, **(c)** Radiation Pattern at 3.5 GHz with tumour, **(d)** Radiation Pattern at 5.9 GHz with tumour

(a) (b)

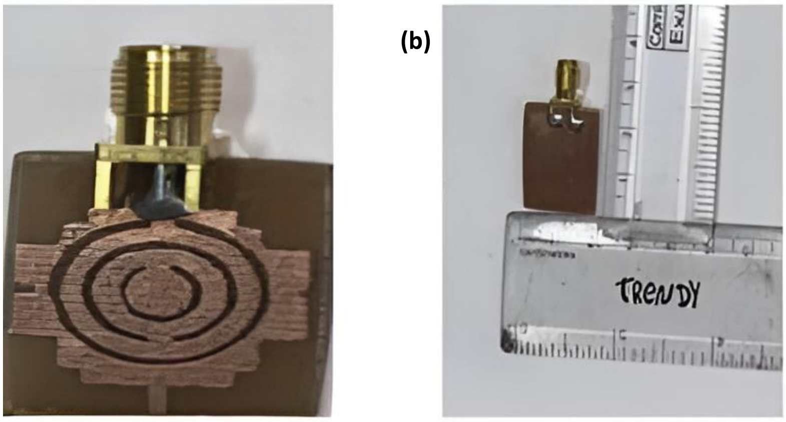


Figure 9. Fabricated Microstrip Patch Antenna

(a) (b)

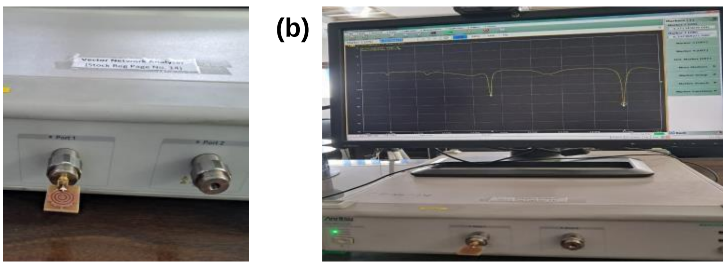


Figure 10. Experimental setup for the fabricated Antenna

5. Experimental Setup and Testing of the Antenna with the Breast Phantom

There are variety of techniques and mixture types to replicate the breast phantom as demonstrated in numerous papers and articles. Long-term research has been done to determine how the breach in these electrical properties affects the outcomes, specifically in the microwave frequency for a healthy breast phantom and a malignant breast phantom. The breast and tumor models in the proposed study are made using the recipe reported in [53-54], as can be seen in Figure 11. In the breast phantom, the first three layers consist of skin, fat, and glandular tissue. Additionally, a fourth layer representing a tumor is introduced during the antenna testing phase. Table 4 lists the materials used in the fabrication of the breast phantom's various tissue layers.

The breast phantom, as prepared artificially for the experimental purpose, is positioned between the transmitter and receiver antennas to simulate the antenna on the breast phantom. The breast phantom is approximately 60mm wide and 40mm tall. As depicted in the Figure. 12, it is kept at a certain height, and both antennas are positioned on either side of the phantom. The Spectrum Analyzer and Function Generator are connected to the antennas. The results and path loss are observed.

6. Results and Discussion

The comparison of S11 parameters between the antenna's response to healthy and tumorous breast tissue yielded insightful results which can be seen in the Figure. 13. The S11 parameter, representing the antenna's reflection coefficient, is a crucial indicator of its impedance matching and signal transmission efficiency. The research revealed distinct differences in the S11 values when the antenna was exposed to healthy versus tumorous breast tissue. Specifically, the S11 values exhibited noticeable shifts in magnitude and resonance frequencies for the two cases. These variations in S11 parameters signify the antenna's sensitivity to detect abnormalities in breast tissue and highlight its potential as a diagnostic instrument for detecting breast cancer. The findings emphasize the antenna's ability to differentiate between healthy and tumorous tissue, highlighting its promising role in non-invasive, early-stage breast cancer screening and contributing to advancements in medical imaging technology for improved patient outcomes. However, further investigations and validation with clinical data are necessary to solidify the antenna's efficacy and establish its practical application in real-world breast cancer detection scenarios.

Table 4. Materials Used For The Fabrication of Breast Phantom

Material	Skin	Fat	Gland	Tumor
Sodium Chloride (NaCl)	5g	4g	68	-
Distilled Water	20ml	-	50ml	-
Pure petroleum jelly	-	24g	-	-
Wheat Flour	10g	30g	30g	-
Olive oil	-	30ml	-	-
Coal	-	-	-	10g
Powder dyes	Yellow	Brown	Red	Black

a b c

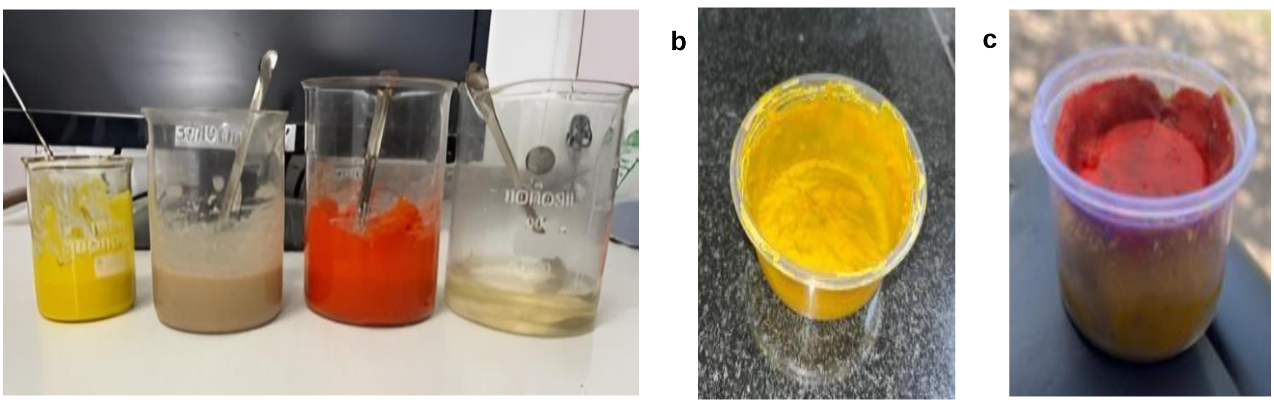


Figure 11. The steps needed to make the breast phantom

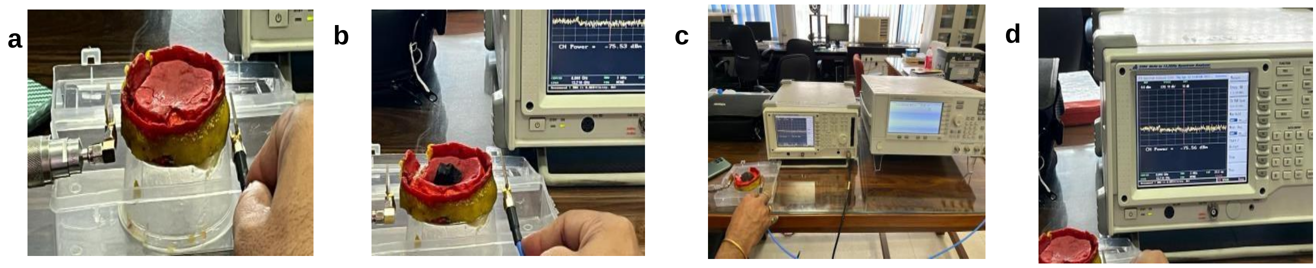


Figure 12. Testing of antenna on the Breast phantom

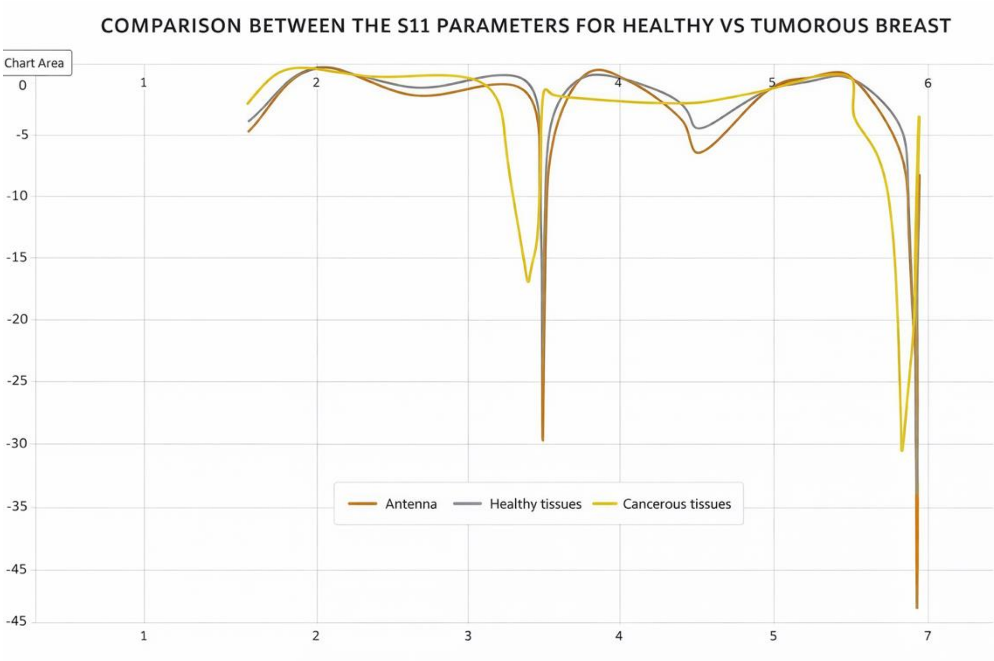


Figure 13. Comparison between S11 parameters for healthy vs tumorous tissue

Table 5. Comparison Between Existing And Proposed Antennas

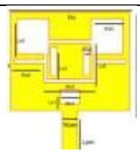
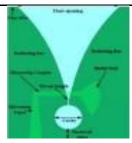
Ref No	[51]	[52]	[53]	[54]	Proposed work
Patch					
Dimension	20x25x1.6	50×50×2	27.76x23.3x1.56	51×42x1.57	20x25x1.6
Substrate material	FR4	Cotton	FR-4	Rogers RT/duroid 5870	FR4
Bandwidth/ Operating frequency	2.4 GHz	1.8 to 9 GHz	8.41-10.29 GHz	2.80 –7.00GHz	3 to 7 GHz
Gain	10.5 dB	Avg 4dBi	6.451dBi	>5dBi	-
Efficiency	96%	-	-	>70%	-
Results		1.16 (W/Kg) in 10g	Return loss ≤10dB and voltage standing wave ratio (VSWR) of less than 2	DAS for one tumor was 5.0645	Provides very high return loss and has small size.

Table 5 shows the comparison various existing antennas and the proposed antenna which can be used as a reference to understand the plus points of proposed work as well as for future modifications for improvement.

7. Conclusion

In this paper, a dual-band CSRR (Complementary Split Ring Resonator) loaded microstrip patch antenna for breast cancer detection is discussed and tested on artificially fabricated breast phantom. The CSRR structure was used in the antenna design to achieve dual-band operation, which allows it to resonate in two distinct frequency bands 3.5 and 5.9 GHz. The likelihood of an early diagnosis and a favourable course of treatment is increased by improved sensitivity and accuracy in identifying abnormal tissues within the breast. It was shown that the proposed antenna achieved the desired characteristics for efficient breast cancer detection through a thorough analysis of the antenna's performance metrics, including return loss, bandwidth, and path loss. The importance of this study lies in its potential contribution to biomedical engineering and healthcare, specifically in the early detection of breast cancer.

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Authors Contribution Statement

Purnima K Sharma: Conceptualization, Methodology, Investigation, Formal analysis, Validation, Writing original manuscript. T.J.V. Subrahmanyeswara Rao: Methodology, Investigation, Formal analysis. T.V.N.L. Aswini: Validation, Writing original manuscript. Dinesh Sharma: Writing Review and Editing, PN Malleswari: Writing Review and Editing. All the authors read and approved the final version of the manuscript.

Funding

The authors declare that no funds, grants or any other support were received during the preparation of this manuscript.

Competing Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

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