METAMATERIAL BASED COMPACT FLEXIBLE ANTENNA FOR BREAST IMAGING APPLICATIONS

PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electronics and Communication Engineering with specilisation in Communication Systems by the A P J Abdul Kalam Technological University

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CERTIFICATE

Certified that this thesis titled **"METAMATERIAL BASED COMPACT FLEXIBLE ANTENNA FOR BREAST IMAGING APPLICATIONS"** is a bonafide record of the work done by **VIDHYA J S** (Reg. No. TKM20ECCS15) under my supervision, in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Electronics and Communication Engineering with specialization in Communication Systems by the A P J Abdul Kalam Technological University.

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ABSTRACT

Breast cancer is a disease that affects large population of women around the world.Unwanted tumor cells in the breast tissue are the primary cause of breast cancer. Early detection and treatment can improve the survival rates.X-ray mammography, Computed Tomography (CT), Ultra Audio (UA), Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET) are the conventional breast imaging techniques.These approaches do have certain disadvantages, though, like their high cost, ionisation effects, and time-consuming testing procedures.In this thesis a microwave imaging system for detecting breast tumor is introduced.A compact flexible F- slot monopole antenna is designed for Microwave Imaging (MI) of breast cancer.The proposed antenna consists of two flexible substrate materials viz denim and felt having dimensions $10 \times 10\ mm^2$ and $10 \times 15\ mm^2$, respectively. Six metamaterial (MTM) unit cells are placed into the antenna to improve gain, directivity, and band width. This method is innovative, low-cost and has the potential to lead to the development of a portable device that uses an enhanced iterative approach for breast imaging. The simulated results show that the proposed antenna achieves an impedance bandwidth greater than 10 dB from 5.6 GHz to 56.6 GHz. The intended antenna showed a specific absorption rate (SAR) less than 1.6 watts/KG, which is safe for human use. The proposed antenna design can thus be used for breast imaging applications to detect tumor.

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Abbreviations

MWI : Microwave imaging

SAR : Specific absorption rate

FCC : Federal communication commission

FSS : Fequency selective surface

DAS : Delay and sum

FIT : Finite Integration Technique

CST : Computer Simulation Technology

CT : Computed Tomography

UA : Ultra Audio

Chapter 1

Introduction

Breast cancer is the biggest cause of mortality among women globally. Every year, almost 2 million new instances of breast cancer are identified, with a high fatality rate [1].Breast cancer is caused by unwanted cancer cells within the breast tissue.Blood arteries and lymphatics are two ways that breast cancer can spread outside of the breast.Breast cancer tumors mainly form in fibroglandular tissue, including lobules and ducts. Additionally, fatty tissue within the breast can also be affected.The occurance of breast cancer among men is less common. Early identification can improve survival rates among patients.Diagnostic tools for detecting breast cancer [2–3] such as X-ray mammography has several side effects. Exposure to X-ray can have a range of effects such as vomiting, bleeding, hair loss, and the loss of skin and hair.In addition, breast compression is involved in the case of mammography that can cause discomfort to the person undergoing scanning.Strong magnetic fields and radio waves are used in the scanning process known as magnetic resonance imaging to obtain high-resolution images of the inside anatomy of the human body, but this method is highly expensive [4] and cannot be used repetitively for detecting breast tumors. CT scan displays the cross-sectional images of a specific area of the human body. Side effects and risks for a CT scan include discomfort, exposure to ionizing radiation, and allergic reaction to the contrast dye utilized in the procedure.A mixture of injectable radium and active or tracer materials combined with glucose is utilised in PET imaging to monitor how the body uses and synthesises these substances. Cancer cells eat nutrients because they multiply considerably more quickly than healthy cells. Positron emission tomography forms an image based on the absorption of markers for cancer cells. However, it has a low resolution. The limitations presented by these existing methods prompt researchers to device new imaging procedures for breast cancer detection.

Using microwave imaging (MWI), a new technique, breast cancer can be detected early. Microwave imaging works on the basis of radar techniques, it helps to map breast tissue by analyzing the backscattered signals obtained from different dielectric interfaces of the target. Due to the differences in dielectric characteristics between cancerous and healthy breast tissue, microwave breast imaging may be feasible. Less false positives, cheap cost [5], high data rate, low complexity, convenience, and low density are the benefits of MWI. Characteristic data can be extracted from an object via microwave imaging. Such information could be position, shape, size and dielectric properties, as well as information on smaller objects embedded in larger objects. The principle of operation is based on the transmission of electromagnetic waves through the object and thus on the measurement and processing of the scattered waves back and forth. Microwave imaging has been studied for a variety of applications over the past few decades. These applications range from medical diagnostics, such as breast imaging [6], brain imaging [7], kidney imaging, cardiac imaging, and bone density measurements to other fields including geophysical monitoring, civil engineering and industrial engineering. For cancer detection, microwave medical imaging relies on contrasting dielectric parameters between malignant tumor tissue and surrounding normal breast tissue.Despite substantial research into microwave imaging for medical applications since the 1970s, this imaging modality has not yet been widely adopted in clinics.Larsen and Jacobi, who used microwave signals to visualize canine kidneys, introduced one of the first microwave medical imaging systems. Since the 1970s, many microwave imaging groups have built multiple imaging systems, and their drawbacks and limitations have been extensively investigated. In microwave imaging, computational aspects are known as a barrier to the development and usability of technology. In addition to these known challenges, microwave medical imaging has been introduced as an alternative or in addition to conventional imaging systems such as mammography, with recognized reasons being low-cost, harmless, non-invasive and affordable.Furthermore, we present our studies on a recently proposed microwave imaging antenna.In constructing antennas, one important consideration is lowering the amount of electromagnetic energy that the human body absorbs. This functionality is measured using the specific absorption rate (SAR). The SAR of the designed antenna averaged over 1 g of tisste is found out from the simulator. An SAR value is less than 1.6 W/Kg is desirable for a designed antenna to comply with the regulations set by Federal Communication Commission (FCC).

Objectives

This thesis aims at the design and performance analysis of a Metamaterial based compact flexible antenna for breast imaging and head imaging applications.Conventional antennas which may be used for these purposes suffer from many drawbacks such as larger size,bandwidth and gain. The challenge is to get the largest possible bandwidth with a small thickness and small size.This can be achieved by adopting a Metamaterial based design which would also help to increase the antenna performance and gain. The specific objectives of the work include the following:

- Design a compact antenna for breast imaging applications and evaluate its performance.
- Design a compact flexible antenna for breast imaging applications and evaluate its performance.
- Design a low frequency antenna for head imaging applications and evaluate its performance.

Organization of the thesis

This chapter of the thesis introduces the concept of microwave imaging and its applications.The second chapter includes a comprehensive review of literature covering the microwave imaging antennas. The third chapter focuses on the design considerations used for the thesis proposal. The fourth chapter details the results and discusses the interpretations and finding. The last chapter deals with the conclusion and finally,the references and the appendix.

Chapter 2

Literature Review

Many types of antennas have been proposed and developed in terms of their unique properties, structures.This project to design a compact flexible antenna for breast imaging and a design compact low frequency antenna for head imaging applications. In this section, some of the works that are realised in the previous years which are classified in terms of their structures and properties is presented.

In 2022, Md Siam Talukder et al. [6] introduced an antenna for use in head imaging. A nine-antenna focused microwave head imaging system with a rectangular with an interior circular patch, mid-ground-based broadband monopole patch antenna, and diagnoses a tumor inside the head. At a beginning frequency is 1.9 GHz, and with an antenna of 40 x 30 size, the design of a suggested antenna is shown in Fig. 2.1.

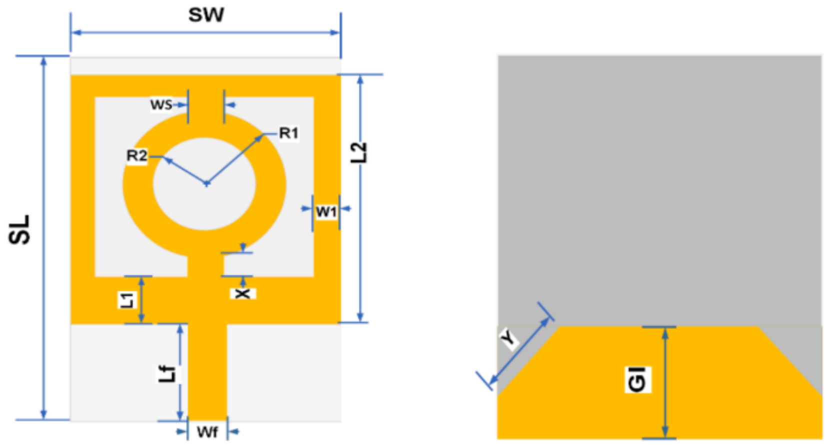


Figure 2.1: The Antenna geometries; (a) Front side , (b) Back side

A realistic 3D head model with a nine antenna array or a redesigned single antenna configuration with a untumorous head and a head-bearing tumour is used to compare the performance of the two antenna types. Finally, utilising open source software, imaging performance is examined with a brain tumour object inside the phantom. Image analysis demonstrates that the proposed imaging configuration based on nine antennas is capable of identifying the tumour item. The Specific Absorption Rate (SAR) is a safety antenna for biomedical usage when it reaches a maximum of 0.7 W/kg.

In 2015, H. Bahrami, et al. [7] employing a non-homogeneous multilayer model of the breast to create dual-polarized and single antennas for breast cancer detection systems. Flexible antennas, including those constructed of felt and denim, are more suited for portable applications. Using a high frequency structure simulator (HFSS), flexible monopolar and tiny spiral antennas were created to make contact with the breast's biological tissues. The proposed antennas have a reflection coefficient (S11) of less than -10dB and are intended to operate between 2 and 4 GHz. Flexible antennas offer a good impedance match, good performance, and good gain, according to measurements. when the breast is curved differently in different positions. The tiny antennas measure 20mm by 20mm in size.They also created two flexible 4x4 ultra-wideband antenna arrays for a radar-based breast cancer screening device (single and dual polarisation). The antenna has a broad band impedance, is reproducible, inexpensive, performs well, and is repeatable.The top view of the antenna array is given in the Fig.2.2.

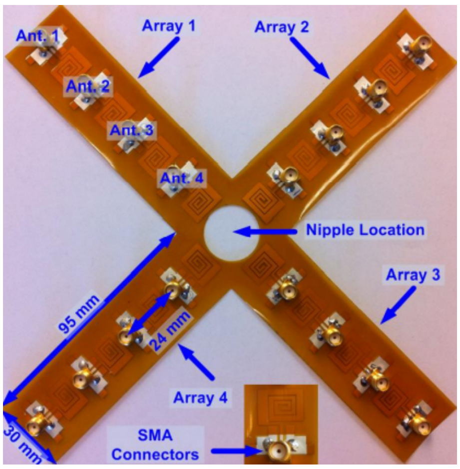


Figure 2.2: Top view of the array

By approving the antenna design process and biological tissue modelling, the suggested antenna achieved its design goals. Finally, it has been demonstrated that using a reflector for arrays can considerably increase the penetration of propagated electromagnetic waves. We calculate the maximum power that the portable antenna can transmit for each set while taking into account the ANSI restriction.

In 2016, A. T. Mobashsher, et al. [41] proposed a compact three-dimensional antenna that is mainly used for microwave-based head imaging systems. The antenna is a folded, slit-loaded dipole structure with four spiral sides, driven by a coplanar waveguide. Due to higher currents in the top layer and reflections from the somewhat larger lower layer, the antenna exhibits directed radiation in the frequency domain in both the near and far fields. Additionally, the antenna's transient response is examined. Investigation of time domain responses demonstrates low distortion directional radiation toward the direction of view of the hole in both the near and far fields, despite the inclusion of several loading and folding slots in the proposed antenna. In comparison to the lowest operational wavelength and bandwidth more than 1.1-2.2 GHz, the antenna is small and has a low profile.The figure 2.3 show that perspective view of the three-dimensional antenna .Due of the antenna's ability to function inside an array. In order to establish an acceptable radiation exposure limit for head imaging, a sixteen-element antenna array is evaluated in a realistic simulation setting.The array is then successfully used in a human head model that is as accurate as possible to locate and identify hemorrhagic brain injury.

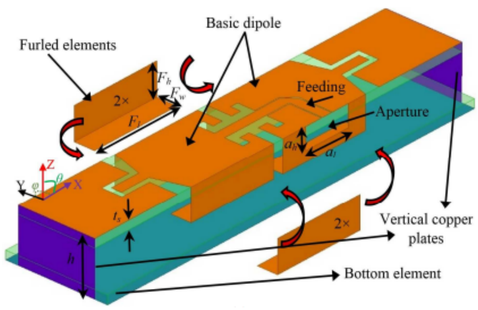


Figure 2.3: Diagrams of the antenna, perspective view

A three-dimensional antenna suitable for the head imaging system. The antenna uses a three-dimensional, folded, slot-loaded dipole. It has a compact size and low profile, compared to the lowest operating wavelength of 0.29 × 0.08 and 0.04, respectively, and broadband coverage of 1.1-2.2 GHz.

In 2014, Xuyang Li, et al. [42] creates a double-layer Bowtie antenna that is small and well-suited for medical diagnostics. More energy will be reflected into the body by this body-mounted antenna, producing clearer reflections for picture processing. using a folded, double-layered staple antenna with microstrip lines wound at the bottom that operates within the same frequency range as the reference antenna. With its specifications optimised, the antenna now has a frequency range of 0.5 to 2 GHz, where low frequencies enable great body penetration and the wide frequency range contributes to a big bandwidth and, as a result, fine gamma resolution.The design of a doubled-layer Bowtie antenna is shown in the Fig.2.4.

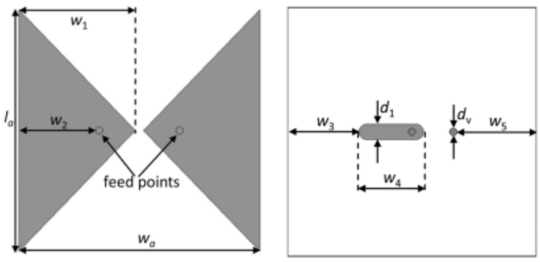


Figure 2.4: Layout of a . (a) Top side . (b) Top view of the connecting layer

In 2019, M.T.Islam1, et al. [43] In this paper, we focus primarily on detecting breast cancer using a new set of portable UWB directional antennas. For microwave imaging, a small side slot conical slot antenna is intended. The recommended imaging system's architecture and numerous components are shown in Fig. 2.5. A set of nine antennas, where one antenna transmits and the other eight receive broadcast signals, a stepper motor-based antenna mounting bracket, a movable suspended platform, a 9-port RF switching to control receivers, and a laptop programme for signal processing and image reconstruction that runs on MATLAB make up the designed MIS. Using the suggested Vivaldi lateral slit antennas, the microwave imaging system may locate the tumor or unwanted cell inside the human breast.

In 2022, Md. Mottahir Alam, et al. [33] Presenting a solid U shape rectangular patch antenna with broadband W slot for microwave based head imaging applications. The slots were used to improve the efficiency, gain and other performance of the antenna. The first frequency of 1.6GHz, the size is 37×56mm as shown in Fig.2.6.A low cost FR4 substrate, 1.6 mm thick is used for printing the antenna which is powered by a transmission line 50 . The frequency ranges from 1.40 to 2.52 GHz and reached

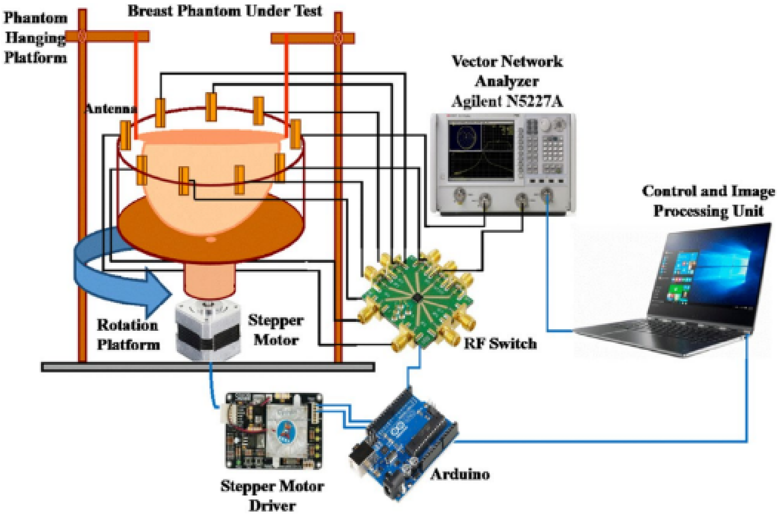


Figure 2.5: The diagram of the proposed breast imaging system

a maximum gain of 3.5 dBi at 2.44 GHz.The SAR value is less than 0.3 W/kg. The antenna's inexpensive substrate content makes manufacturing it affordable and convenient. Antenna sensitivity analysis with a realistic head model is performed using a 9-element antenna array in a 3D head imaging system. This antenna may be the optimal choice for use in many broadband imaging applications, especially the identification of tumors within the human head.

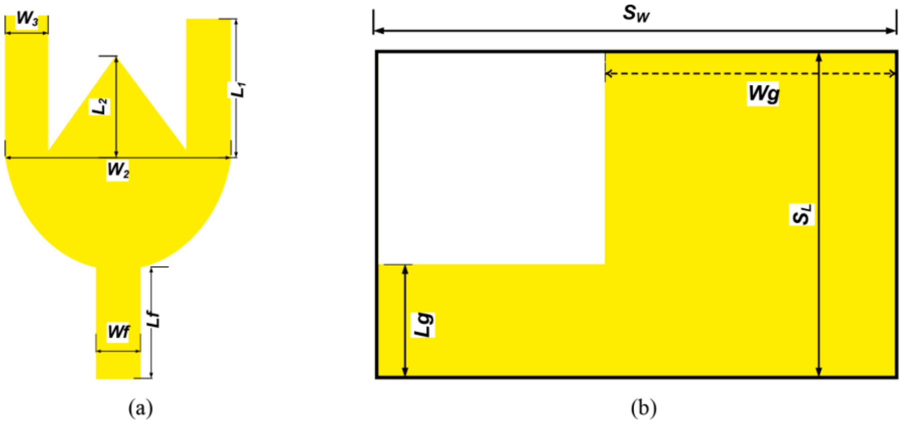


Figure 2.6: The geometry of the final design: (a) Top View, (b) Bottom View

Chapter 3

Design of Antenna

3.1 Metamaterial Based Monopole Antenna For Breast Imaging Applications

This Work introduces a small, unipolar antenna based on metamaterials for the early detection of breast cancer.The antenna's construction uses an inexpensive FR4 substrate with a 4.4 dielectric constant and a 1.6mm thickness.The antenna is connected with a frequency selective surface (FSS) on the rear of the antenna to improve the gain. The proposed antenna achieves a wide bandwidth ($S11 > 10dB$) from 2.9 to 36 GHz, with a maximum gain of 8.5 dBi at 14 GHz. Analysis of the specific absorption rate (SAR) of the antenna with a hemispherical breast phantom modeled in the simulator is made to test the effect of radiation on the human breast.

Antenna design is a crucial step in the case of miocrowave imaging. Many antennas can be used for imaging applications like bowtie antenna, Vivaldi antenna [8] – [9], antipodal antenna [10] – [11], horn antenna and monopole antenna. In this application for breast tumor detection a compact antenna is necessary. Thus we are going for monopole antenna. The designed monopole antenna operates from 2.9 – 36 GHz with a peak gain of 8.5 dBi at 14 GHz. Here, the designed antenna is appended with a Frequency Selective Surface (FSS) to increase performance of the compact antenna [12]. The purpose of any antenna is to throw energy into free space. Conventional antennas which are very small compared to the wavelength reflects most of the signal back to the source. A metamaterial antenna behaves as if it were much larger than its actual size, because its new structure stores and re-radiates energy.

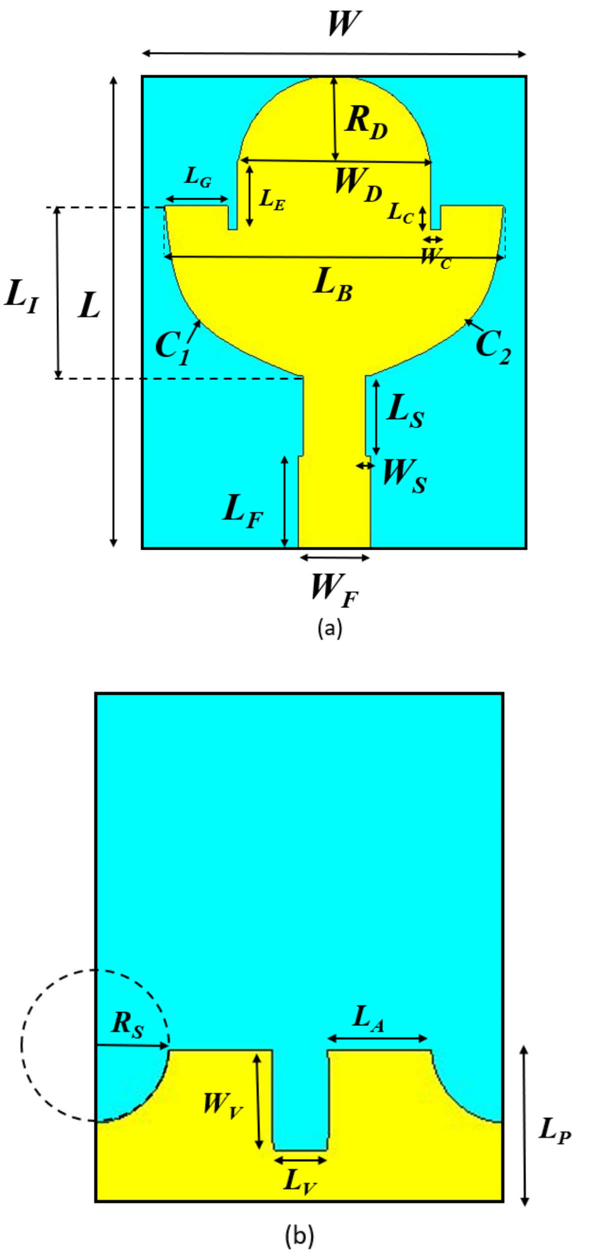


Figure 3.1: The geometry of the proposed antenna. (a) Front View of the antenna, (b) Bottom view of antenna.

The complete geometry of the proposed antenna is displayed in Figure. Fig.3.1 (a) displays the top patch of the designed antenna. Here, the antenna is fed by a rectangular microstrip of dimensions LF × WF. From the edges of this microstrip line feed two curves C1 and C2 are defined using the spline option in the simulator. This curved structures C1 and C2 along with the edge LB on the other side forms a semicircular shaped structure. After this step a rectangular patch of dimension LE ×

WD is attached on top of the previously designed semicircular structure. At last, a semicircular patch formed using the radius RD is made on the patch. To improve the impedance matching performance of the antenna, different slots are etched out from the rectangular patch. They include patches of dimensions LC × WC and LS × WS on the front side of the antenna. Fig.3.1 (b) displays the bottom side of the designed monopole antenna. Here, a rectangular patch of dimension LP × W is designed first. This is followed by etching out two circular sections of radius Rs from the edges of the ground plane as displayed in the figure. The ground plane is further modified by etching out a rectangle of dimension LV × WV from the middle portion of the ground plane.

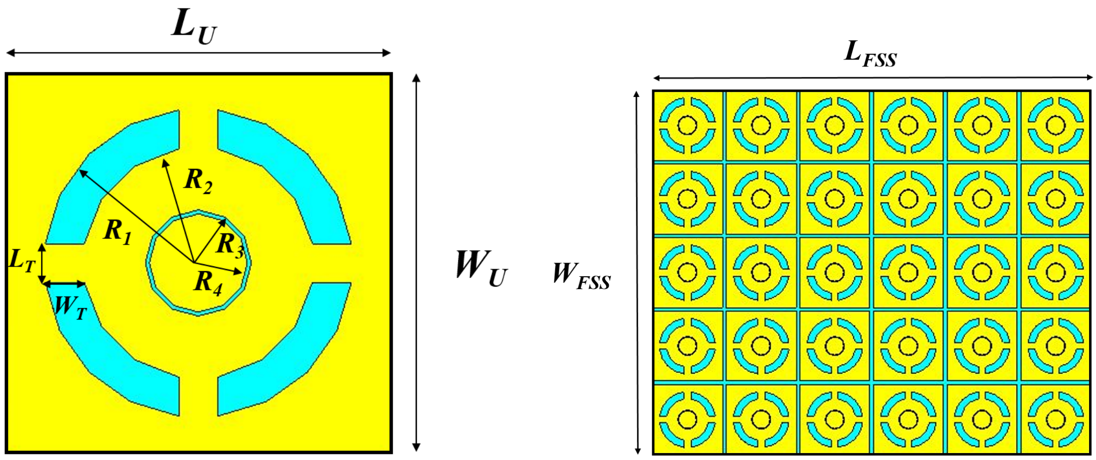
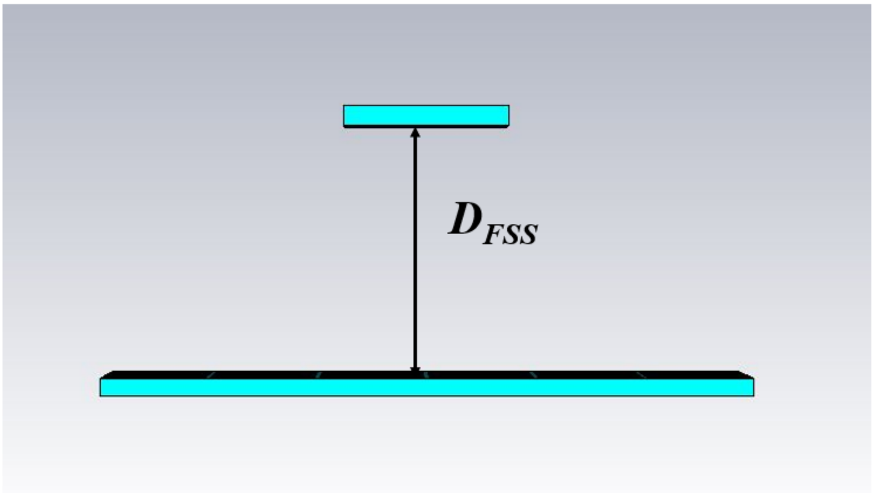
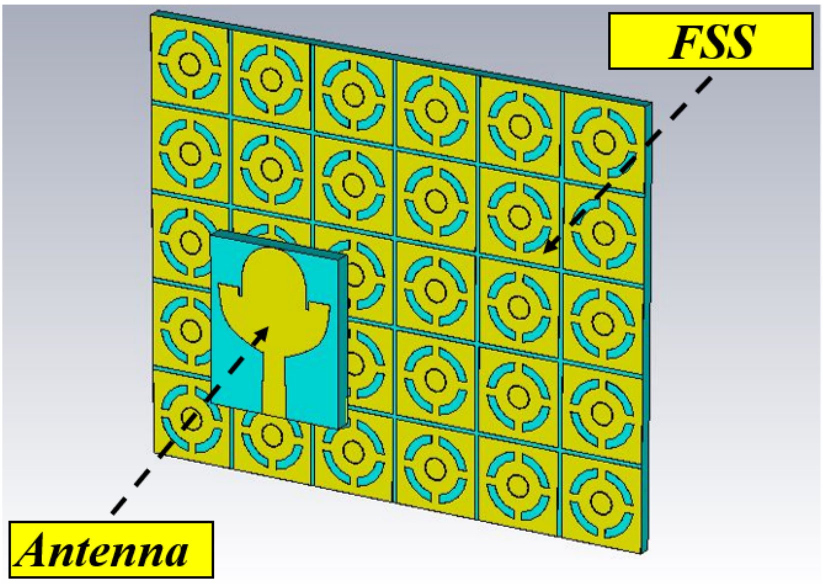


Figure 3.2: (a) designed Unit cell (b) FSS structure.

Fig.3.2 (a) displays the unit cell geometry of the proposed work. The unit cell has the dimensions of LU × WU with two circular slots made by etching out the regions in between the radius R1 and R2 and similarly the region between R3 and R4. The circular slot obtained by the radius R1 and R2 are covered on the top, bottom. left and the right sides by a patch of dimension LT×WT. The unit cell is repeated in the horizontal and vertical direction with a gap of 0.5 mm in between to form the complete FSS structure as displayed in Fig.3.2. (b). The complete dimension of the FSS structure is LFSS × WFSS.



(a)



(b)

Figure 3.3: (a) optimized distance between the antenna and FSS and (b) perspective view of the complete structure.

The complete dimension of the FSS structure is LFSS × WFSS. The distance in between the antenna and FSS is optimized to achieve the best performance as displayed in Fig.3.3 (a). The perspective view of the complete structure with the antenna and FSS is displayed clearly in Fig.3.3. (b). All the optimized dimensions of the designed antenna are tabulated in Table 3.1 for completeness.

Table 3.1:Proposed antenna functional parameters

W	L	L_I	L_G	R_D	W_D	L_C	W_C	L_B	L_F
16	19.5	6.9	2.6	3.5	8	1	0.4	14	3.8
L_S	W_S	W_F	R_S	L_A	L_V	L_P	W_V	R_1	R_2
3.3	0.2	3	3	3.9	2	5.7	3.8	4	3
R_3	R_4	L_U	W_U	L_T	W_T	L_{FSS}	W_{FSS}	D_{FSS}	L_E
1.37	1.27	10	10	1	1	62.5	52	24.3	2.86

All dimensions are in “mm”

3.2 A Compact Monopole Antenna For Brain Tumor Detection

In this Work, a star shaped patch structure with a outer ring is designed in the simulator for microwave head imaging applications. The designed antenna operatres from 1.47 GHz – 4.3 GHz with an impedance matching greater than 10 dB. The antenna also attains a peak gain of 5 dBi at 2 GHz. The Specific Absorption (SAR) rate of the designed antenna is checked to evaluate the effect of the antenna on the human head. This is done by separately designing a 7 layered head phantom. The antenna is also utilized to image brain tumor by introducing a small cancer inside the brain phatom and imaging. The brain tumor is obtained successfully after imaging using the widely popular Delay and Sum (DAS) algorithm.
The development of a rectangular monopolar antenna that satisfies the requirements and broadband requirements of the medical imaging system Numerous geometrical adjustments are performed to a straightforward unipolar antenna in order to increase bandwidth while minimising size.A three-dimensional realistic head model with an embedded tumor is created in the simulator to test the developed antenna’s functioning. The designed head model is intrgrated with multistatic antenna setup to image the embedded tumor. The analysis of imaging shows that the tumor object is identified through the imaging setup and the widely used delay and sum algorithm (DAS).

The complete view of the proposed antenna is displayed in Fig.3.4. The front

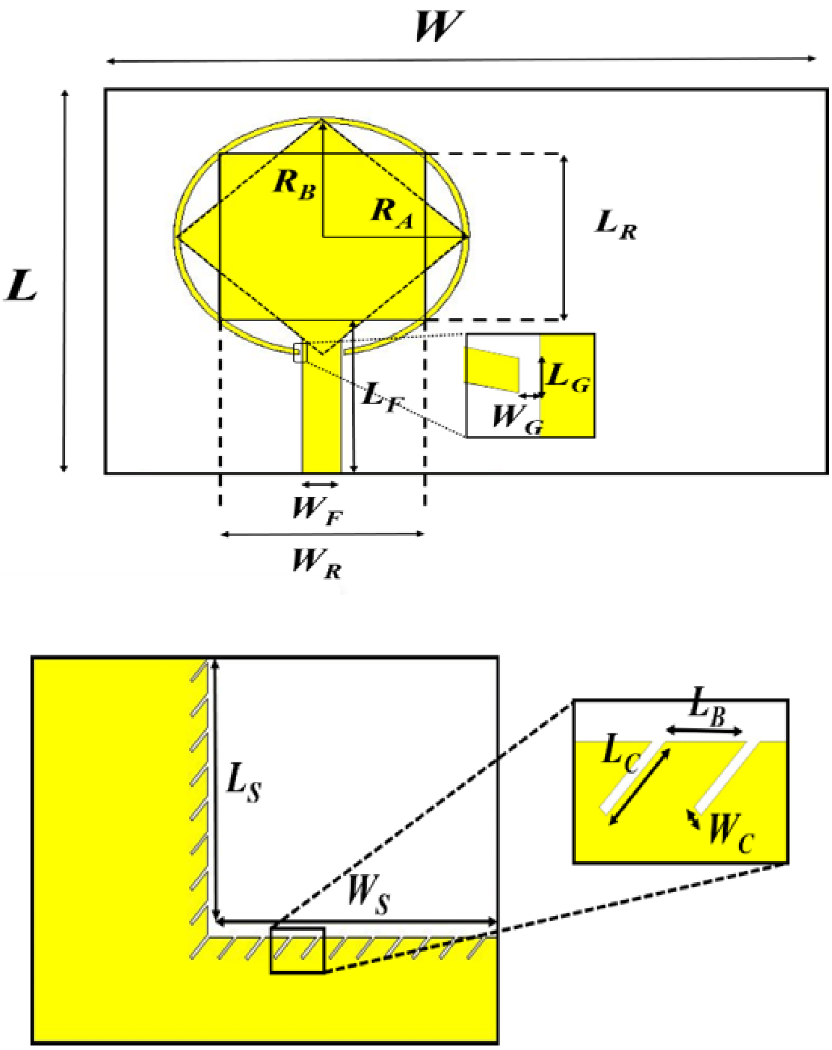


Figure 3.4: The geometry of the proposed antenna. (a)Front view of monopole antenna, (b) Back view of proposed antenna.

view of the designed antenna is displayed in Fig.3.4. (a). Initially a rectangular patch of dimension LR × WR is placed on top of the substrate. This is followed by placing another patch of the same dimension on the initially designed structure, after rotating it by 45 degrees. Further, a circular ring is placed around the star shaped structure. This structure is designed by initially designing a circle of radius RA and RB. Then, the circle formed by RB is etched out from RA to get the ring design. A slot of dimension LG × WG is also cut out from the ring on either side of the feed structure. The antenna is fed by a feed line of dimension LF × WF to match the 50-ohm characteristic impedance. The back view of the designed antenna is displayed in Fig.3.4. (b). Here, a copper layer of dimension L × W is initially designed. This is followed by etching out a slot of dimension LS × WS. After this step, rectangular slot of dimension LC × WC is made at the edges of the slot. This is done by initially designing the rectangular structure of appropriate dimension and then rotating it by 45 degrees. This is followed by repeating the slot edge with a distance of LB between the slots. The entire structure is designed on a FR4 substrate of L × W dimension, with dielectric constant of 4.4, loss tangent of 0.025 and thickness of 1.6 mm. All final optimized dimensions of the designed antenna are tabulated and shown in Table 4.1 for completeness.

Table 4.1:Proposed antenna functional parameters

Ws	Hs	L_g	W_g	L_{star}	W_{star}
56	37	35	27	16	16
Fh	**Hr**	**Or1**	**Or2**	**SemiC**	**Trih**
15	12	11.5	11	8	8
L1	Lre	TriB	CUT	W1	SD
5	4	4	0.035	0.3	0.9
All dimensions are in “mm”					

3.3 Metamaterial-Based Compact Flexible F-Slot Antenna For Breast Imaging Applications

This work presents a flexible and compact single pole F-slot antenna for microwave (MI) imaging applications. The proposed antenna consists of two flexible materials. One material is denim and the other material is felt with dimensions of 10 × 10 mm2 and 10 × 15 mm2 respectively. The antenna is integrated with six metamaterial cells (MTM) to improve gain, directivity and bandwidth over the entire operating band. The proposed F-slot flexible antenna operates between 5.6 GHz and 58.6 GHz with a return loss greater than 10 dB. The proposed antenna also achieves a maximum antenna gain of 3.03 dBi at 30 GHz. The proposed antenna also achieves a specific absorption rate (SAR) value of less than 1.6 W / kg. The designed antenna is also used to obtain images of a tumor made in a phantom breast. The tumor profile is successfully obtained with the Delay and Sum Technique (DAS).

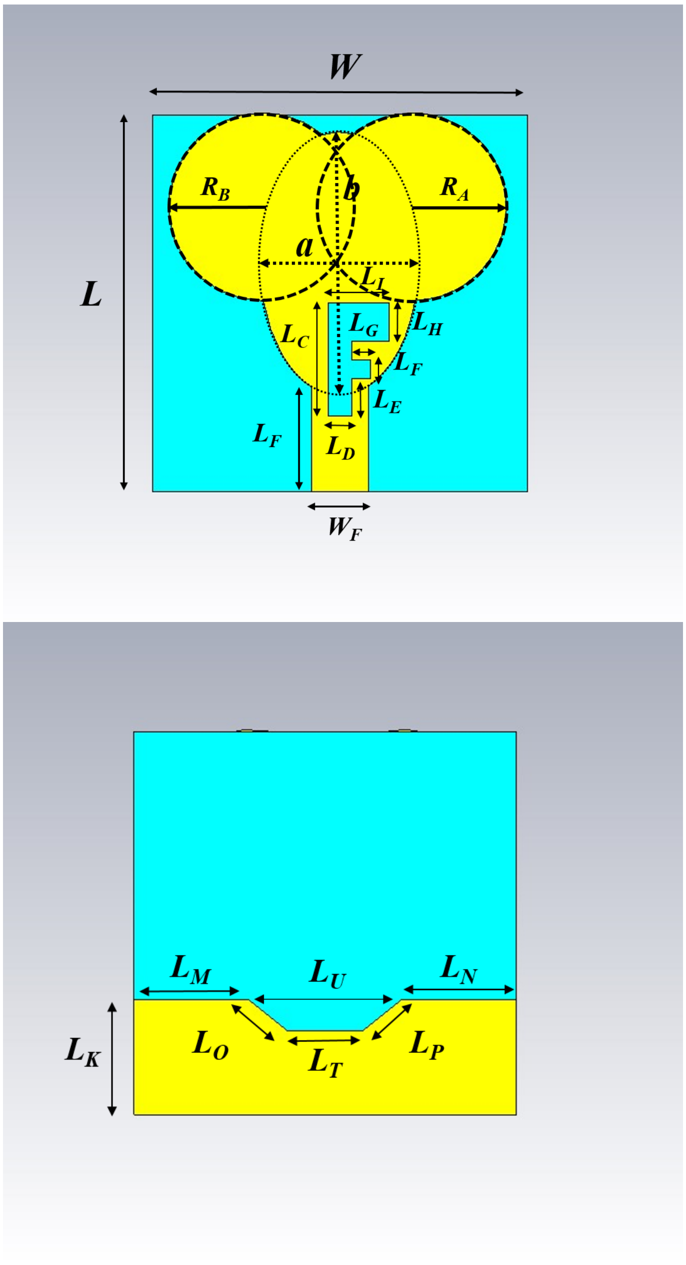


Figure 3.5: The geometry of the proposed antenna. (a)Flexible F-slot antenna, (b) back view.

A multistatic MI antenna arrangement is one in which multiple antennas are enclosing the targeted body part and each of these antennas act as the transmitters and receivers. In MI of a realistic breast phantom, the multistatic antenna arrangement is preffered for imaging. This is due to the observation that, in this type of arrangement, more number of backscattered signals are obtained from the target image which produces a clear image of the concealed tumor. Multistatically arranged antennas have the further advantage of eliminating the mechanical problems of a scanning pattern [13]. The quality of the reconstructed image depends on the number of antennas used, the directionality of the antenna and the bandwidth of each antenna. Additional antenna features required for the imaging system include low profile, low manufacturing cost, and the ability to efficiently couple energy to the breast [14,13].

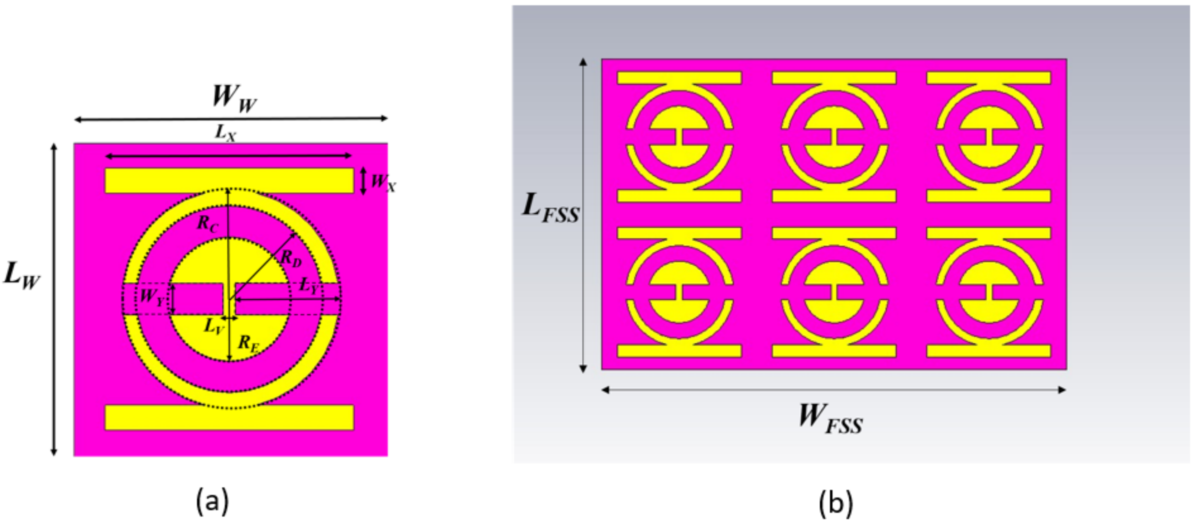


Figure 3.6: (a)designed metamaterial unit cell (b) Six metamaterial cells

The complete geometry of the proposed antenna is shown in Fig.3.5.The proposed flexible F-slot antenna is designed first as shown in Fig.3.5. (a). In this structure, the feed structure of dimension LF × WF is designed first. This is followed by the addition of an elliptical structure with major axis of length a and minor axis of length b. After this step an F shaped slot is introduced in the elliptical designed structure as displayed in Fig.3.5.(a). For this modification, initially a slot of dimension LC × LD is introduced in the elliptical patch. This is followed by further etching out slots of dimensions LF × LG and LI × LH at approporiate locations on the elliptical patch, forming the F-shaped slot. Finally, two circles of radius RA and RB are placed at appropriate locations to get the complete designed front part of the proposed antenna as displayed in Fig.3.5. (a). The bottom view of the proposed antenna is displayed in Fig.3.5. (b). Here, initially a patch of dimension W × LK is introduced. This is followed by etching out a trapezium of sides LU, LT, LO and LP. This completes the design of the proposed antenna.

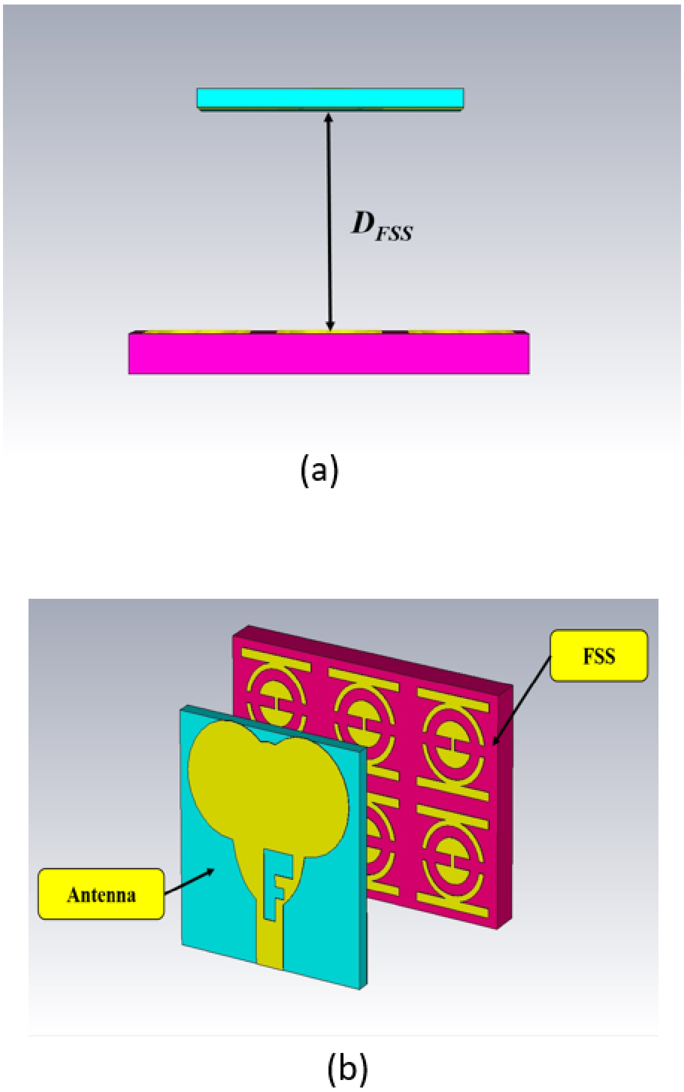


Figure 3.7: (a) optimized distance between the antenna and the metamaterial cells and (b) perspective view of the proposed Flexible antenna with FSS.

The designed metamatertial unit cell in the proposed work is displayed in Fig.3.6. (a). The proposed unit cell is made on a felt material with dimension WW × LW and and thickness h. In this case, initially a circle of radius RC is designed, followed by another ciecle of radius RD. Then The former circle is subtracted from the latter to get a circular ring. This is followed by introduction of a new circle of radius RE. Two rectangular structures of dimension, LX × WX are introduced in the top and bottom of the circular ring. Finally rectangular slots of dimension LY × WY are etched out from the unit cell to obtain the proposed structure. The designed unit cells are multiplied horizontally and then vertically to obtain the structure displayed in Fig.3.6.(b).

The distance between the antenna and the FSS is optimized for best DFSS performance and is shown in Fig. 3.7. (a). Finally, the perspective view of the proposed structure is shown in Fig.3.7.(b).All optimized dimensions of the designed antenna are tabulated in Table 5.1 for completeness.

Table 5.1:Proposed antenna functional parameters

W	L	W_f	L_f	L_C	L_D
10	10	1.5	2.7	3	0.6
L_E	L_F	LG	L_H	L_I	R_A
1	0.5	1	1	1.6	2.5
R_B	L_M	L_U	L_N	L_O	L_T
2.5	3	4	3	1.2	2
L_P	L_K	L_{FSS}	W_{FSS}	L_W	W_W
1.2	1.2	10	15	5	5
All dimensions are in "mm"					

Chapter 4

Results and discussion

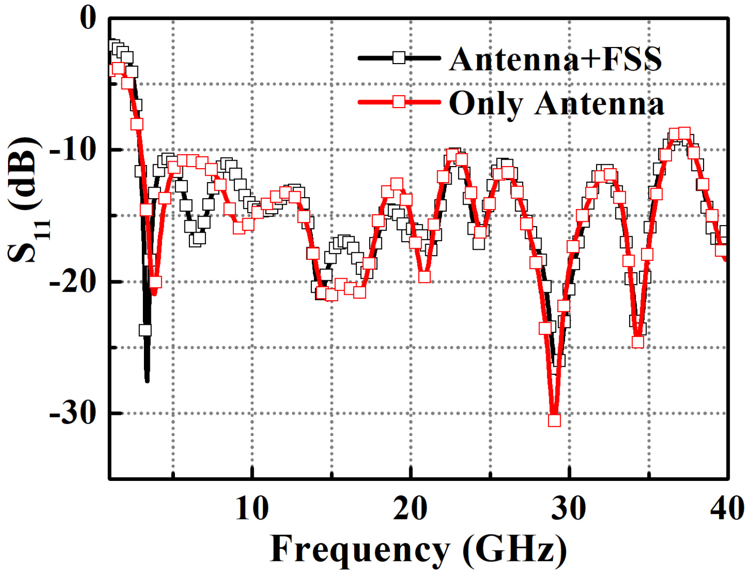
4.1 Metamaterial based Monopole Antenna

A metamaterial-based monopolar antenna is designed for breast cancer detection. The designed antenna operates from 2.9GHz to 36GHz with an impedance match greater than 10dB. The antenna also achieves a maximum gain of approximately 8.5 dBi at 14 GHz. The designed antenna is further tested for its applicability for biomedical applications by finding the SAR value.

Performance analysis

The return loss of the designed antenna with and without the addition of the FSS structure is plotted and shown in Fig. 4.1. (a). It shows that the proposed design operates from 2.9 to 36 GHz with good impedance matching performance. It can be seen that the overall performance of the designed structure has improved with the addition of the FSS.
The gain graph of the designed antenna with and without the FSS structure is shown in Fig.4.1. (b). It can be seen that the gain improves dramatically with the addition of the FSS structure. Furthermore, the average gain of the designed antenna is also improved by the addition of FSS. The 3D radiation diagram of the designed antenna is extracted from the simulator and shown in Fig.4.2. The radiation pattern is observed at 8 GHz, 9 GHz, 12 GHz and 16 GHz. It can be seen that the proposed structure obtains a directional radiation pattern at these frequencies. The directional radiation

pattern along with the broadband response is critical for breast imaging applications. All simulations are performed in the electromagnetic solver (EM) based on the finite integration technique (FIT) Microwave Studio 2016. Table 6.1 shows the comparison of the proposed antenna performance with similar works.



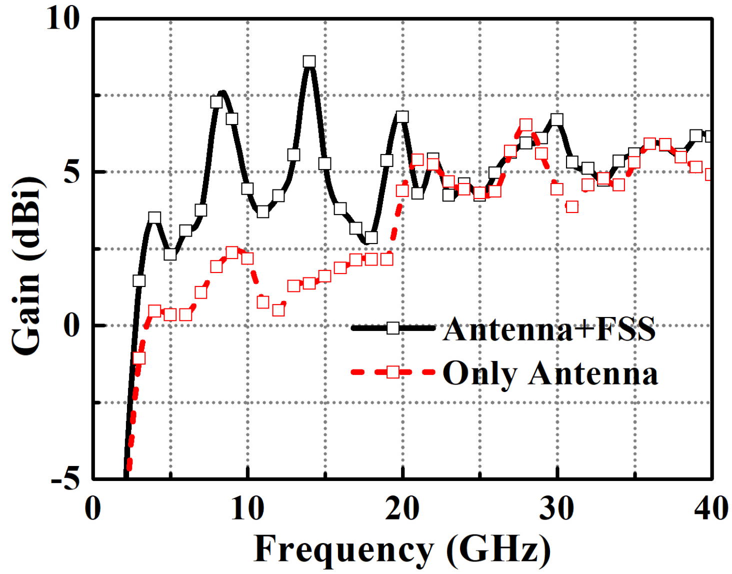


Figure 4.1: (a) The simulated antenna return loss (b) The simulated gain plot of the proposed antenna

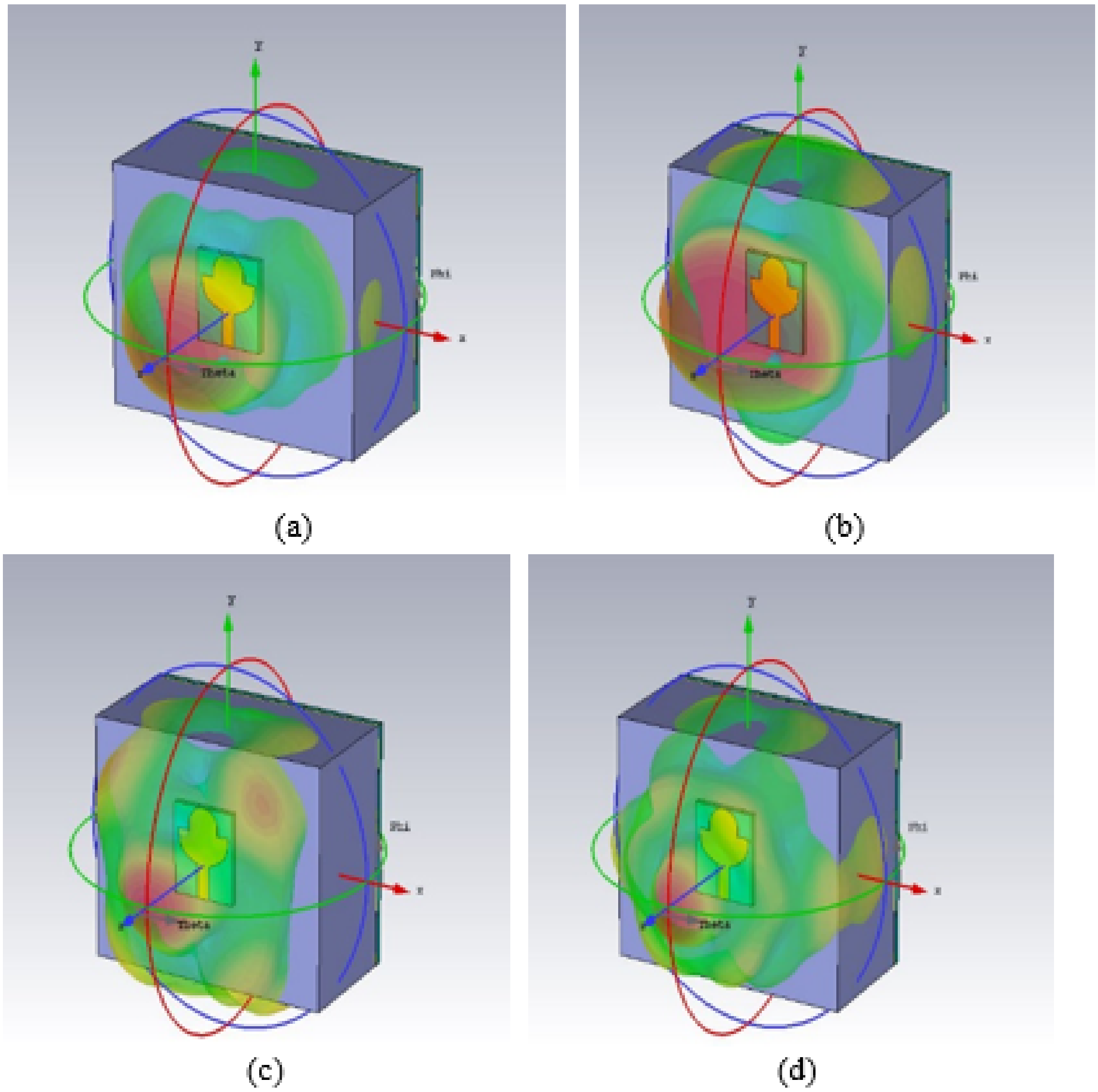


Figure 4.2: The Three dimensional radiation pattern of the designed antenna at (a) 8 GHz, (b) 9 GHz, (c) 12 GHz and (d) 16 GHz.

4.2 A Compact Monopole Antenna For Brain Tumor Detection

It was created a unipolar antenna appropriate for head imaging systems. In comparison to the lowest operational frequency, which is between 1.5 and 4.5 GHz, the properties of the antenna include high gain, efficiency, front-to-back ratio, small size, and low profile. Low frequencies enable greater penetration into the human body.

Table 6.1:Comparison of the performance

References	Size of the antenna(mm^2)	FSS unit cell size (mm^2)	Bandwidth (GHz)	No. of FSS Layers	Gain (Without FSS)	Gain (With FSS)	Approach
[15]	115 x 115	13.5 ×13.5	3 – 8	1	Around 6	Around 9.7	Dual polarized radiator mounted on a backing reflector
[16]	34 × 26	14 × 14	2.7 – 13.9	1	4.9	8.9	Compact unilayer FSS with UWB antenna.
[17]	35 × 30	10.8 × 10.8	3 – 13.4	2	2.5 - 5	5.5 – 8.5	Umbrella shaped UWB antenna with FSS as reflector
[18]	17.5 × 14.5	5.4 × 5.4	6.1 – 20.88	2	2 - 4	3.5 – 6.5	CPW fed printed UWB antenna with FSS
[19]	32 × 30	11 × 11	3.8 – 10.6	1	Around 5	Around 8.5	UWB antenna with FSS
[20]	32 × 32	-	3.1-10.6	-	1.7-4.2	-	Two open L shaped slots and narrow slots on the ground plane
[21]	24 × 28	-	2.91-11.4	-	NR	-	Y-shaped strips to annular ring
[22]	24.5 24.5	-	2.95-12.1	-	3.39	-	Asymmetrical rectangular patch with the U-shaped open-slot structure
[23]	Antenna 20 × 27 Antenna + FSS 84 × 84	14 × 14	4.7-14.9	1	4.2	8.7	Ultra wide stop band FSS
[24]	Antenna 63 × 63 Antenna + FSS 119 × 119	17 × 17	3-12	2	6	9.8	Multioctave FSS reflector
[25]	30 × 60	22.4 × 6.5	3.2 - 12	2	Around 5	Around 9	Slotted ground microstrip antenna with FSS reflector
This Work	**Antenna 16 ×19 Antenna + FSS 52 × 62.5**	**10.5 × 10.5**	**Only Antenna** **3.1 – 26** **Antenna+FSS** **2.9 - 36.14**	**1**	**2.27 @ 5 GHz 3.71 @ 7 GHz 1.73 @ 15 GHz 4.32 @ 20 GHz**	**2.3 @ 5 GHz 3.74 @ 7 GHz 5.3 @ 15 GHz 6.1 @ 20 GHz**	**Modified U-shaped slot patch with FSS**

Performance Analysis

The simulated return loss of the proposed antenna is plotted and shown in Fig. 4.3. (a). It can be seen that the proposed antenna operates from 1.5 GHz to 4.7 GHz with a return loss greater than 10 dB. The antenna also achieves a fractional bandwidth of 103.2 %.

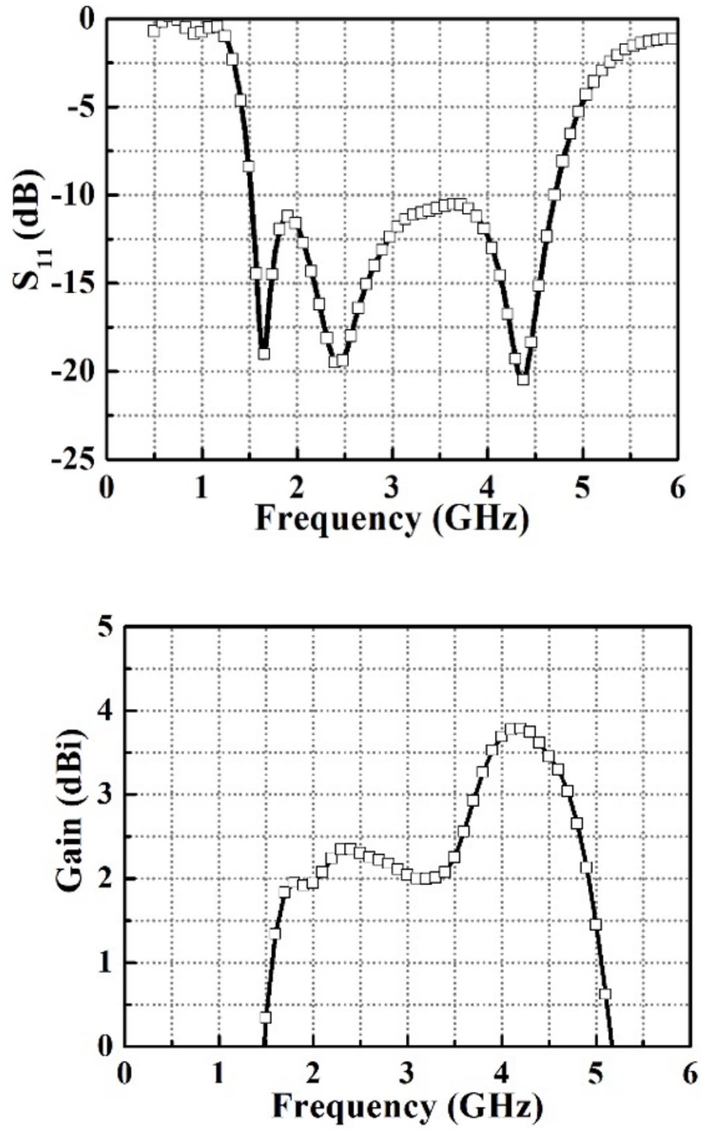


Figure 4.3: (a) The simulated antenna return loss (b) The simulated gain plot of the proposed antenna

The graph of the designed antenna gain is shown in Fig.4.3. (b). It can be seen that the proposed antenna achieves a maximum gain of 3.8 dBi, which is the highest reported maximum gain among the compact antennas currently used for head imaging applications.

The 3D radiation diagram of the designed antenna is shown in Fig.4.4. The radiation pattern at 2 GHz, 3 GHz, 4 GHz and 4.5 GHz is plotted and observed. It can be seen that the designed antenna is directional at these frequencies. All simulations are performed in the EM solver based on FIT CST 2016. Fig. 6.6 shows that the comparison of the proposed antenna performance with similar works.

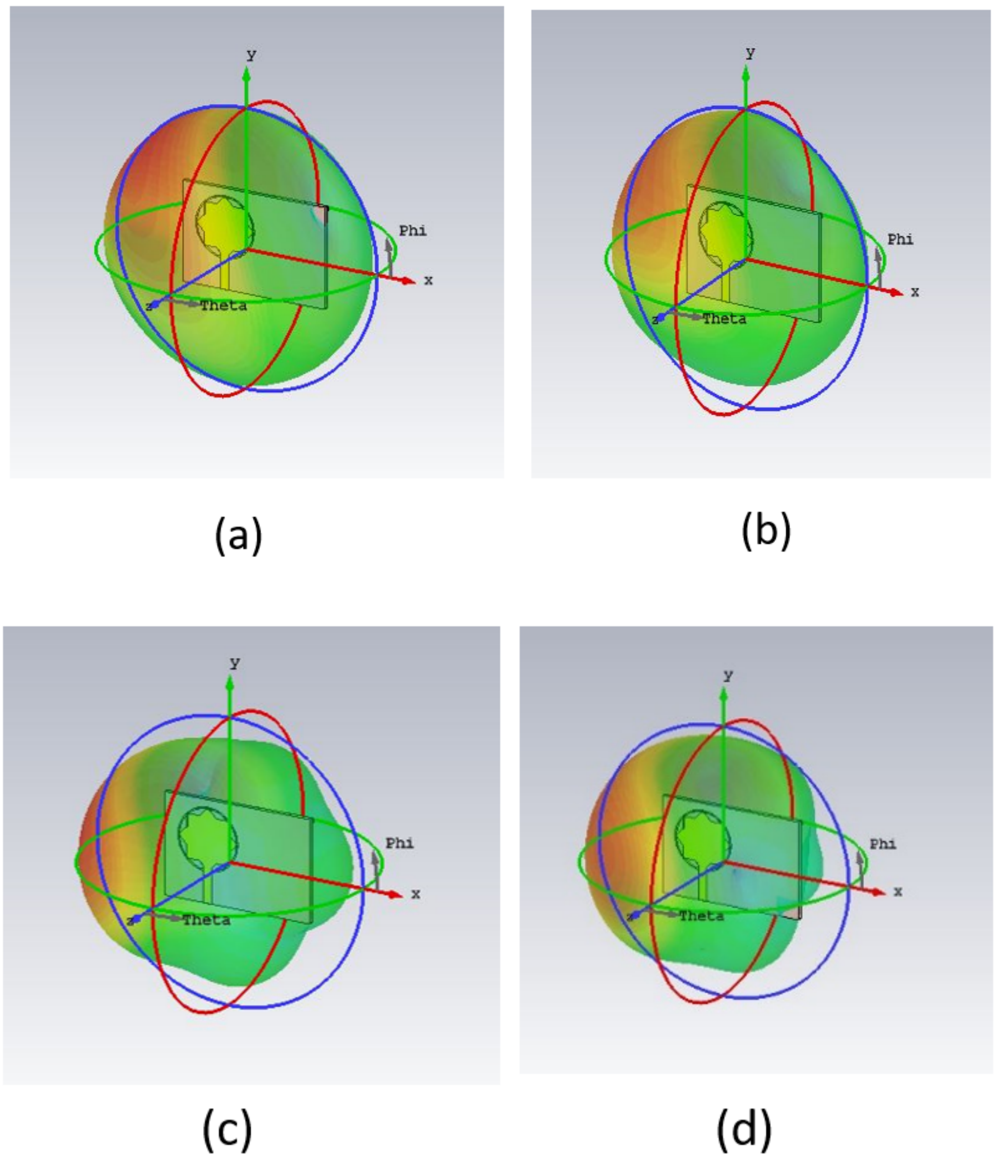


Figure 4.4: The simulated 3D radiation of the proposed antenna. (a) 2 GHz, (b) 3 GHz, (c) 4 GHz and (d) 4.5 GHz.

4.3 Metamaterial-Based Compact Flexible F-Slot Antenna For Breast Imaging Applications

The creation of a small, flexible, monopolar antenna based on metamaterials that is appropriate for breast imaging systems. The antenna's features include a high gain, front-to-back ratio, efficiency, compact size, and low profile, with the lowest operating frequency falling between 5.6 and 58.6 GHz.

Table 6.2:Comparison of the performance

Ref. Number	Dimension (mm)	Substrate	Substrate Layer	Fractional bandwidth (%)	Gain(dBi)	Scanning elements	EM field penetration	Maximum SAR (W/kg)
[26]	50 × 60 × 1.5	Rogers RO4350B	1	23.55	2.45	Single antenna	Not mentioned	Not mentioned
[27]	59 × 59 × 1.5	Rogers R04003C	2	80	3.10	10-antenna	Not mentioned	Not mentioned
[28]	85 × 60 × 4.0	PDMS	5	50.30	Not mentioned	8- antenna	Half portion	0.500
[29]	56 × 37 × 1.6	FR4	1	52	2.4	Not mentioned	Not mentioned	Not mentioned
[30]	29.99 × 29.99 × 0.59	FR4	1	2.84	<3	Single antenna	Not mentioned	0.332
[31]	50 × 44 × 1.52	Rogers RO4350B	1	74.3	<4	12-antenna	Half portion	0.298
[32]	79 × 68.28	FR4	1	10	Not mentioned	Single antenna	One-third portion	0.26
[33]	37 × 56 × 1.6	FR4	1	51.2	>3.5	9-antenna	Two-third portion	0.26
Proposed	33.3 × 50.4 × 1.6	FR4	1	103.2	3.8	Not mentioned	Not mentioned	Not mentioned

Performance Analysis

The suggested antenna's predicted return loss is plotted and displayed in Fig. 4.5. (a). It is clear that the suggested antenna has a return loss of more than 10 dB and works between 5.6 GHz and 58.6 GHz. It is evident that the incorporation of the FSS has enhanced the proposed structure's overall performance.

Figure 4.5 displays the gain graph for the planned antenna (b). As can be shown, the suggested antenna has the greatest reported maximum gain among the tiny antennas currently being employed for breast imaging applications, with a maximum gain of 3.03 dBi.

The 3D radiation diagram of the designed antenna is shown in Fig.4.6. The radiation pattern is plotted and observed at 10 GHz, 20 GHz, 30 GHz and 40 GHz. It can be seen that the designed antenna is directional at these frequencies. All simulations are performed in the EM solver based on Finite Integration Technique (FIT) of Computer Simulation Technology (CST), 2016. Table 6.3 shows that the comparison of the proposed antenna performance with similar works.

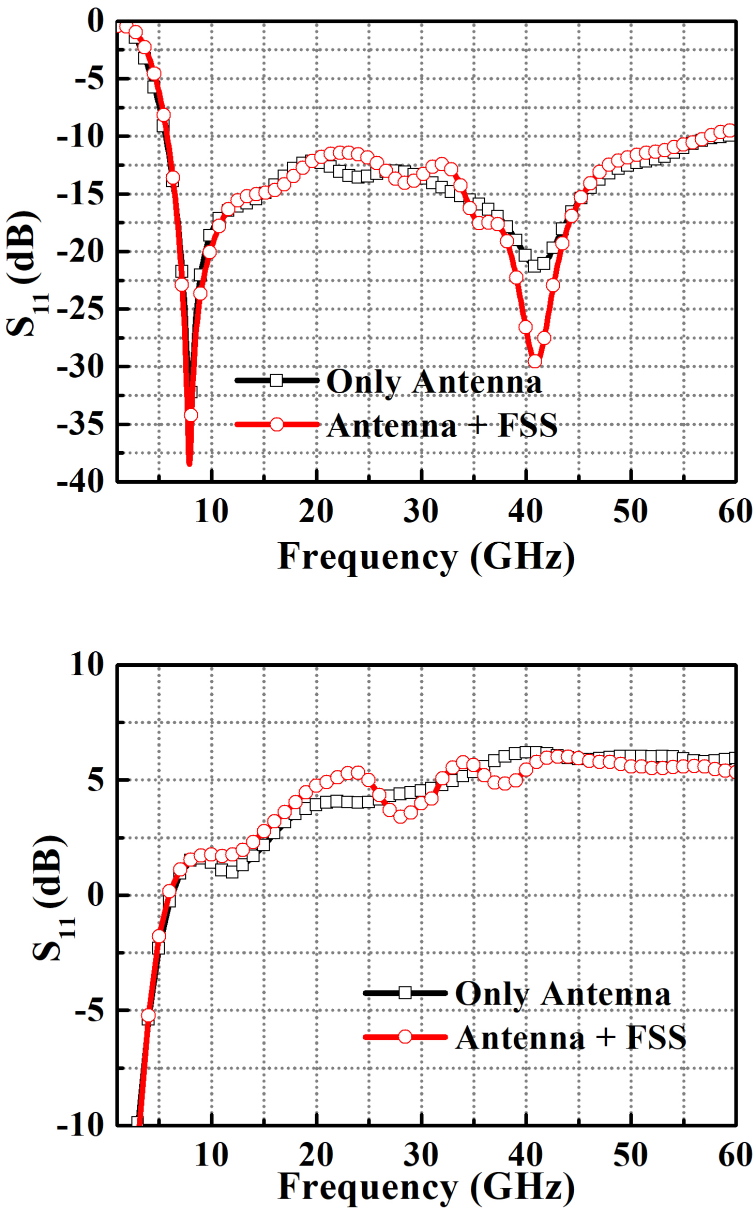


Figure 4.5: (a) The simulated antenna return loss (b) The simulated gain plot of the proposed antenna

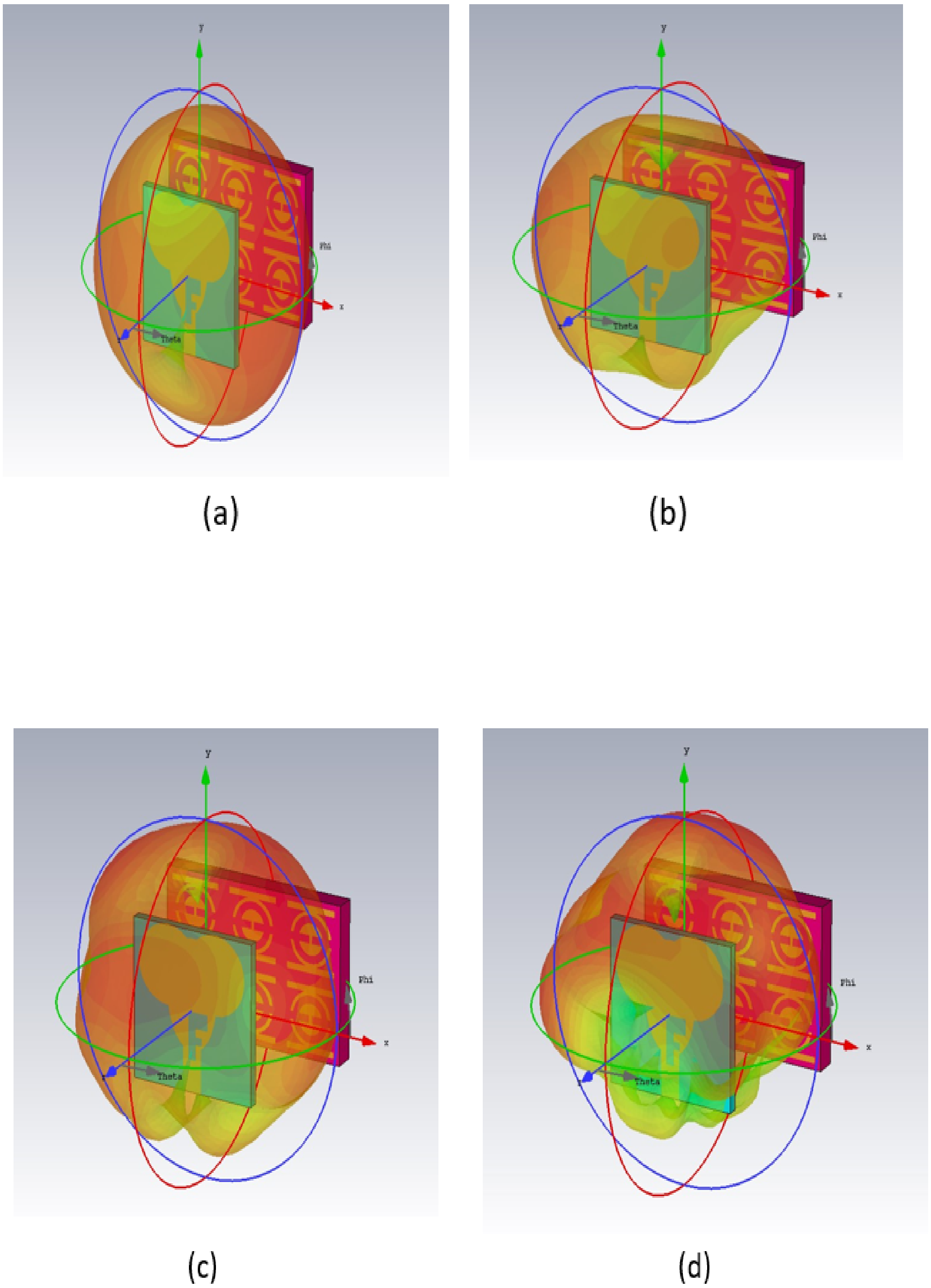


Figure 4.6: The simulated 3D radiation of the proposed antenna. (a) 10 GHz, (b) 20 GHz, (c) 30 GHz and (d) 40 GHz.

Table 6.3:Comparison of the performance with similar works in literature

References	Dimensions (mm^2)	BW (GHz)	Max gain (dBi)
[34]	20 × 20	2-18	>-2.65
[35]	28.6 × 28.6	2-27	....
[36]	16 × 16	26-40	7.44
[37]	50 × 40	2.2-25	4.5
[38]	26 × 16	18-44	1.45
[39]	50.8 × 62	1.3-20	10
[40]	10 × 15	6.5-35	8.85
proposed	10 × 10	5.6-58.8	3.03

Chapter 5

Conclusion

A metamaterial-based monopolar antenna is designed for breast cancer detection. The designed antenna operates from 2.9GHz to 36GHz with an impedance match greater than 10dB. The antenna also achieves a maximum gain of approximately 8.5 dBi at 14 GHz. The designed antenna is further tested for its applicability for biomedical applications by finding the SAR value. It is noted that the SAR value is less than 1.6 W / Kg in the selected frequencies, which demonstrates that the proposed design complies with FCC guidelines. The proposed antenna will be used at a later stage to visualize tumors in a cancerous breast phantom.

The designed antenna is of low frequency and suitable for head imaging applications.The features of the antenna are high gain, efficiency and front-to-back ratio, compact size and low profile.The operating frequency of antenna is ranging from 1.5 GHz to 4.5 GHz, where low frequencies allow high penetration into the human body. In conclusion, this small antenna will positively contribute to improve the performance of the microwave imaging system for medical diagnosis, such as head tumor detection.

A flexible metamaterial based F-slot antenna is designed for breast cancer imaging applications. It is integrated with six MTM arrays, where the MTM unit cell consists of a split ring resonator to improve gain, directivity and bandwidth.The operating frequency of the antenna ranging from 5.6 GHz to 58.6 GHz and the gain of antenna 3.03 dBi at 30 GHz. The proposed antenna may be able to detect a tumor. In conclusion, the proposed metamaterial-based flexible F-slot antenna system is a proven method suitable for breast imaging applications.

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Appendix

COMPUTER SIMULATION TECHNOLOGY (CST)

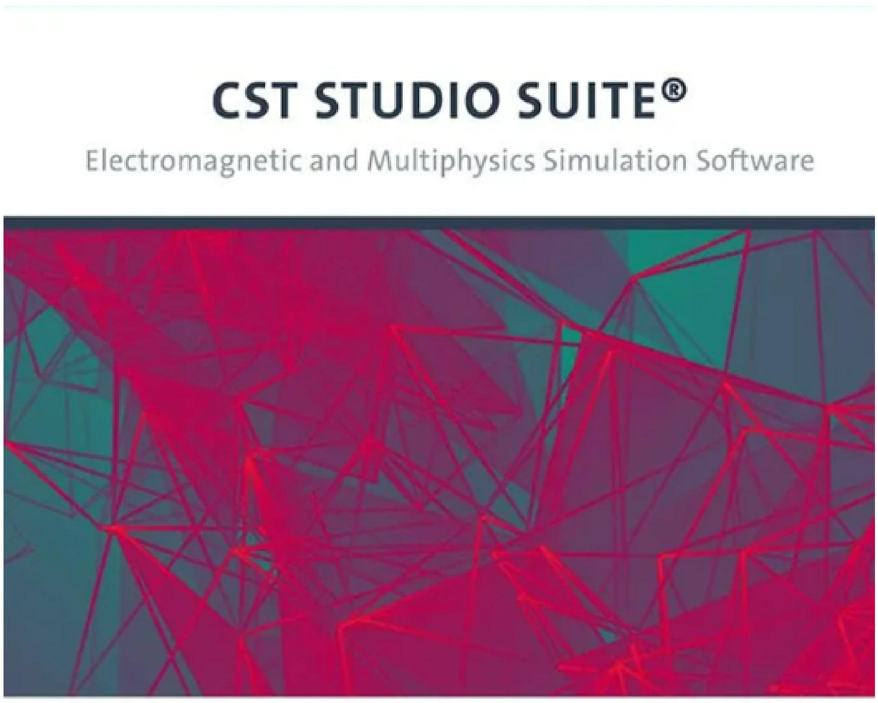

Figure 5.1: CST Studio Suite

CST Studio Suite is a high-performance 3D EM analysis software package for the design, analysis and optimization of electromagnetic (EM) components and systems. CST MICROWAVE STUDIO is a specialized tool for 3D EM simulation of high frequency components. CST promotes comprehensive 3D EM technology and enables fast and accurate analysis of high frequency (HF) devices such as antennas, filters, couplers, planar and multilayer structures, and SI and EMC effects. CST is based on Finite Integration in Technique (FIT). CST Studio Suite is 3D electromagnetic (EM) simulation software for the design and simulation of high frequency electronic products such as RF or microwave components, antennas, antenna assemblies, high speed interconnects, filters and connectors. No other full-wave EM 3D simulator can cover the capacitance, dimensional range and density of geometric details in a fully coupled full-wave electromagnetic simulation. Parallel Multi-Mesh technology significantly accelerates the speed and ability to solve complex systems while maintaining standard accuracy. Each CST solver incorporates a powerful and automated solution process, so we only need to specify the geometry, material properties and desired output. One of the most useful outputs of CST is the S parameter. Once a simulation is complete, the S parameters can be plotted at a single frequency or a frequency sweep. S parameters can be easily plotted with the CST result editor. However, depending on the type of gate, the S parameters are generalized or normalized.

The electromagnetic field solvers for applications across the EM spectrum are contained in a single user interface in the CST Studio Suite. Solvers can be paired to run hybrid simulations, giving sengineers the flexibility to analyze entire systems made up of multiple components efficiently and directly. Additional features of CST Studio Suite are:

• Navigate the general layout of the CST Studio Suite interface.

• Generate CAD geometry within the native modeling interface.

• Set the project environment with desired units, frequency settings, base materials and boundary conditions.

• Understand the various types of existing materials and how to define them.

• Configure units using grouped elements and waveguide ports.

• Set output monitor to get 2D / 3D field data.

• Choose and configure the most suitable solver and algorithm for high frequency applications.

• Run time domain (FIT) and frequency domain (FEM) simulations, including parametric sweeps and optimizations.

• Analyze simulation results as S-parameters, voltages, currents, near fields and far fields in 3D.

• Extract data from standard result set using post-processing templates.