DESIGN AND FABRICATION OF STACKED APERTURE COUPLED AND CPW FED MICROSTRIP PATCH ANTENNAS FOR WIRELESS COMMUNICATION

A Dissertation Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF ENGINEERING

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Submitted By

GAGANDEEP KAUR

Roll No. 801561008

Under Supervision of

Dr. Amanpreet Kaur
Assistant Professor, ECED

ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY, PATIALA, PUNJAB

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DECLARATION

I, Gagandeep Kaur hereby declare that the work presented in this thesis entitled “Design and fabrication of Stacked Aperture Coupled and CPW fed microstsrip patch antenna for Wireless Communication” in fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering department, Thapar University, Patiala is an authentic record of work carried out under supervision of Dr. Amanpreet Kaur (Assistant Professor, ECED) from 2016 to 2017. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Gagandeep

Date: 15/7/17

(Gagandeep Kaur)

(801561008)

It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

Amanpreet Kaur

Date: 15/7/17

(Dr. Amanpreet Kaur)

(Assistant Professor, ECED)

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Gagandeep Kaur
801561008

ABSTRACT

In the modren world, a high data rate is highly in demand for all wirelwss applications. This requires broadband for those systems .Ultra wide band is a techology that offers many advantages and is also highly in demnd.In addition to these, we need multi-band and wider band antennas to cover the various UWB wireless applications into a similar terminal appliance is aslo required. To obtain better transmitting and receiving rate wide band antennas are required to cover satisfactory operating bands. For miniaturizing the wireless communication system, the antennas must as small enough to be placed within the system. The micro-strip patch antennas have various advantages over other type of antennas that make them a good candidate for the use in wireless communication systems. Among MPA , aperture coupled Stacked MPA offer a high bandwidth of operation that are capable of showing ultrawide band for the desired wirless applications of interest.Thus the resarch work presented in this thesis focuses on the design and simulation of two stacked aperture coupled MPA and two CPW fed antennas. The parametric variations carried out for antenna polarization are also stidied to obatin desired results.

The first antenna that has a U-shaped slot with plus shaped DGS covers a band 4.8 to 10.8 GHz with a bandwidth of 5.92. The second antenna structure has a T-shaped parasitic patch with swastika shpaed DGS covers a frequency band of 6.227 to 14.8 GHz with a bandwidth of 8.57 GHz. The third antenna design has a circular shaped patch with coplanar ground plane covers a band of 1.46 GHz to 6.07 GHz with a bandwidth of 4.61 GHz. The last antenna structure that has a rectangualr shaped patch with coplanar ground plane covers a band of 4.2 GHz to 12 GHz with impedance bandwidth of 7.8 GHz.

All the design and simulations are done in CST MWS version 2014. Two antennas; one stacked aperture coupled MPA and other CPW fed antenna are fabricated using photolithography process and tested on a VNA. The measured results are quite matching with simulated ones, allowing the antennas to be suitable for satellite navigation, telecommunication, Aircraft surveillance, amateur radio, Bluetooth ,Zig-Bee, weather forecasting, SONAR, communications satellites like in microwave ovens, microwave devices, mobile phones , global poisoning system, recreational radio, for long distance radio communication,WLAN,Wi-Fi, military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities or in military actions, satellite communication, radar, space communication ,global broadband system, unpaid radio system, molecular revolving spectroscopy etc.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREIVIATIONS

MPA	Microstrip Patch Antenna
CPW	Coplanar Waveguide
ACMPA	Aperture Coupled Microstrip Patch Antenna
WLAN	Wireless Local Area Network
DGS	Defected Ground Plane
CST MWS	Computer Simulation Tool Microwave Studio
Wi-Max	Worldwide Interoperability For Microwave
IMT	International Moblie Tele Communication
UWB	Ultawide Band
PEC	Perfect Electric Conductor
Wi-Fi	Wireless Fidelity
ATM	Automated Teller Machine
SONAR	Sound Navigation And Raining
RADAR	Radio Detection And Raining
VNA	Vector Network Analysis
PCB	Printed Circuit Board
SMA	Sub Mimiature Vesion A

CHAPTER 1

INTRODUCTION

1.1 MICROSTRIP PATCH ANTENNAS

Wireless communication systems have become important part of human life. Antennas are an indespensible part of any wireless communication system. Many communication systems are use antennas in remote controlled equipment like military radio, cellular phones, satellite communications etc. Microstrip patch antennas have numerous advantages like small size and easy adaptability. Micro-strip patch antenna consists of a radiating patch, dielectric substrate and a ground plane. The dielectric substrate is sandwich between patch and ground plane as shown in Figure 1.1[1-2]. The patch is usually made up from conducting materials like: copper or gold and it can be in any possible shape such as: square, rectangle, circle, triangular and elliptical or some other type of common shape. The patch and the feed lines are generally photo etched on the dielectric substrate [3]. For a rectangular patch as shown in the figure below width of the patch is W and length of the patch is L taken from λ/3 to λ/2 where λ is wavelength and the dielectric constant (ε_r) varies from 2.2 to 12 [4]. MPA (microstrip patch antenna) spread out mainly due to the fringing effects in-between the patch's edge and the ground surface. For good quality antenna, a thick dielectric substrate is advantageous with small dielectric constant because it provides superior efficiency, large bandwidth and improved radiation on the other hand it leads to a large antenna dimensions [5]. To design a condensed MPA higher dielectric constant is mandatory which provides less efficient antenna and narrower bandwidth.

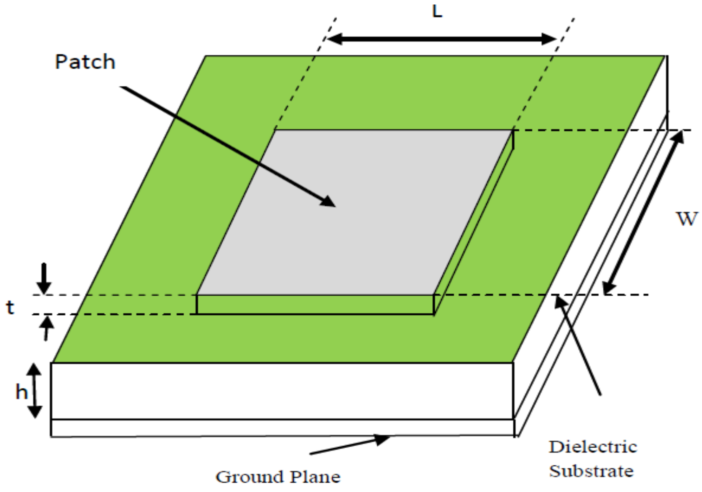


Figure 1.1 Rectangular shaped microstrip patch antenna

The major drawback for microstrip antenna is its narrow bandwidth [6]. The microstrip antenna's bandwidth is directly related with the height of dielectric substrate [7-8]. So many methods are available in literature survey that have been used to enhance the bandwidth as Defected Ground Structure [9-10] (aperture slot in ground plane), fractal antenna [11-12], multi layer stacked substrate [13], change the feed line technique [14, 33], and changing the patch shape [15], increasing the height of substrate [16] and changing the substrate permittivity [17].

The use of an electromagnetically coupled feedline with a stacked geometry can be realized for an improved bandwidth. The advantages and disadvantages of a MPA and the reason for using electromagnetically coupled feedline is discussed in the next sub section of this chapter.

1.2 ADVANTAGES AND DISADVANTAGES OF MICROSTRIP PATCH ANTENNAS

Microstrip antennas posses several advantages as compared to other microwave antennas. Some of the common advantages are specified below [18-19]:

- Light weight and low volume.
- Proficient to several frequency operations.
- Able to provide both types of polarizations i.e. linear and circular with uncomplicated feed.
- Low-cost fabrication using recent printed circuit board techniques thus can be manufactured in large quantities.
- Capability to match with both planar and non planar surfaces.
- Mechanically tough when mounted on stiff surfaces.
- Antennas array can provides high gain and directivity.

With these advantages, micro-strip patch antennas also suffer from some disadvantages which are specified below [7,8,18] :

- Narrow bandwidth of around 5% at the centre of operation.
- Poor efficiency.
- Minimum Gain.
- Irrelevant radiation from feed lines and junction points.
- Low power conducting capacity.
- Responsive to surroundings conditions for example temperature and humidity.
- Undergo surface wave due to high dielectric constant.

A lot of work is available in literatutre for the bandwidth of these MPA. These include the use of defected ground structure [9-10], stacked substrates [13], slotted patches [15, 19] and many more. Gain and the power managing capability of antenna can be enhanced by creation of antenna arrays [20]. Electromagnetic Band Gap structure and meta-material are also used to improve the antenna characteristics [21]. Using a non conducting feeding technique can also enhance the bandwidth of antenna. The five commanly used feedings are mentioned and compared in table 1.1.

Table 1.1 Comparison of Feeding Techniques for MPA [20]

Characteristics	**Microstrip Feed line**	**Coaxial Feed**	**Aperture Coupled Feed**	**Proximity Feed**	**CPW Feed**
Specious feed radiation	More	More	Less	More	More
Dependability	Better	Poor due to soldering	Good	Good	Good
Impedance Matching	Easy	Easy	Easy	Easy	Easy
Bandwidth in percentage	2 to 5	2 to 5	13	21	40

From the above table 1.1 it can be inferred that aperture coupled and CPW feed is more reliable and gives good impedance matching as compaired to other feeding methods. Also the bandwidth offered by it is better than the micro strip feed line and coaxial feed. For these reasons the resarch were presented in this thesis concentrates on the use of aperture coupled feeding technique to improve the bandwidth of operation. The aperture coupled feeding method employees two dielectric material layers that are separated by the ground plane between them. Dielectric constant of bottom material is usually higher than the upper dielectric. Next sub section explaines an aperture coupled feeding method in details. CPW feed has patch fed line and ground layer on same plane as that of the antenna.

1.3 Aperture-coupled micro strip patch antennas (ACMPA)

The ACMPA basically consist two substrates, a patch, feed line and ground plane with slot. Figure 1.2 shows a representative aperture-coupled antenna representation.the patch is printed on upper substrate and ground layer on top of lower substrate with feed line on the bottom of lower substrate. A slot in ground plane allows the electromagnetic coupling to take place from feedline to patch [22]. There are numerous parameters that can influence the performance of an aperture coupled antenna like: substrate's thickness, dielectric constant (ε_r), length of patch, width of patch, and length and width of the aperture slot [22-24].

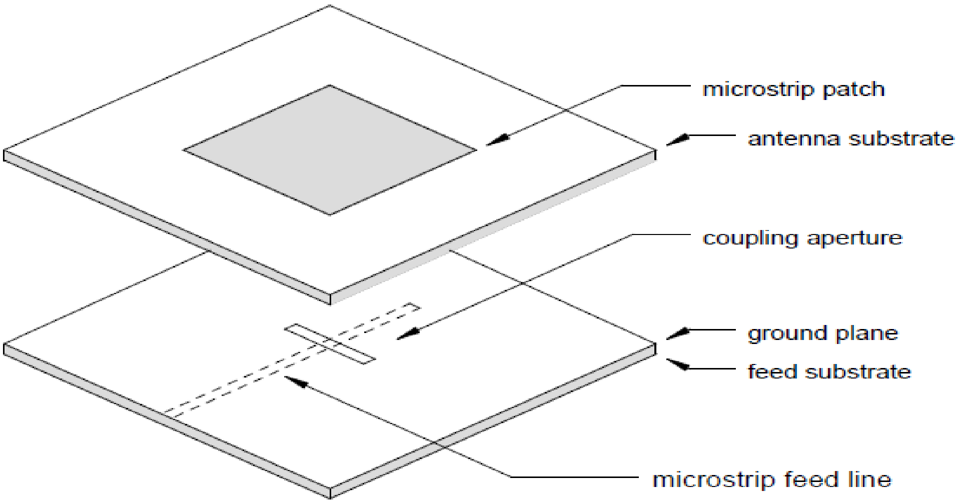


Figure 1.2: Aperture coupled micro-strip antenna

As shown in Figure 1.2, the transmission line delivers the power for the antenna and it is separated from the patch by dielectric substrates and a conductive ground plane. The ground plane is concerning the feed and the patch to force the electromagnetic energy to pass through the dielectric substrate. These allow the energy to direct from transmission line to the patch without actually linking the two conductors. This concept is known as coupling [25].

1.3.1 Optimization factors available with ACMPA

The various parameters are available to improve the performance of an ACMPA which are described below:

- **Aperture slot in ground plane**
  To increase the performance of antenna a hole is creating in the ground plane to let the electromagnetic energy pass from the dielectric substrate towards the antenna. Because there are two disconnected layers of dielectric substrate in this structure, each with a similar/dissimilar permittivity, the electromagnetic energy can be directed from these and radiations from the patch antenna are maximized [26]. The movable collection of the electromagnetic fields in the upper level of substrate support the increased radiation from the patch antenna, which increases the micro strip antenna's overall performance. The coupling level for the antenna is determined by the length of the aperture [27-28]. The slot's length should not made larger than it is mandatory for

impedance matching. The width of the aperture also affects the coupling level, but not too much as aperture length. The ratio of aperture length to width is usually taken as 1/10. It is advantageous to use that type shape for patch which increases the level of coupling for a given size [29-30]. These permit the antenna to be impedance-matched with a smaller aperture (slot). Due to small aperture areas lower back radiation levels are achieved less spurious radiation in the backward section.

By addition of a slot on the ending points of the rectangular aperture, the fields turn out to be nearly regular beside the aperture and hence the coupling increases. The slots with enlarged ends can improve the coupling of the antenna. Therefore there are various types of aperture shapes used to design aperture coupled antenna as shown in figure 1.3.

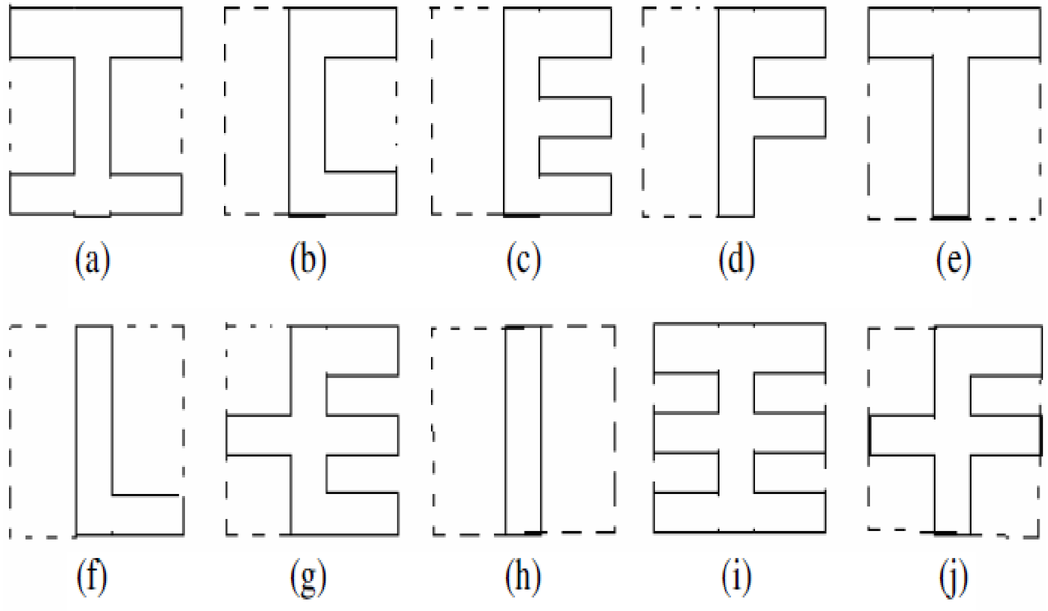


Figure 1.3: Various type of aperture slots in the ground plane [33]

- **Effect of substrate's permittivity**

The lower stage of substrate is normally chosen high dielectric substrate of a very high permittivity, which allows the electromagnetic fields in the lower level to be tightly assembled together. While the fields are strongly grouped with the aperture (slot), more electromagnetic energy is capable to bypass through the hole in the ground surface with the upper layer of substrate. A large value of permittivity in the lower substrate usually reduces the probable losses due to the extent of electromagnetic energy into the ground plane [34]. To evaluate the lower level, the upper level of dielectric substrate naturally features a large amount of lower permittivity value, allowing the electromagnetic fields to be freely grouped within the second layer of dielectric material.

1.3.2 Advantages of ACMPA

The uses of aperture coupled feed with the presence of supplementary substrate permit the antenna to be intended independently from the feed. This means that aperture coupled antennas can be included into a variety of appliances when dimension is not a problem, for the reason that ACMPA shows various advantages such as

- These antennas can be conventional to voltage and power supply in special devices without altering the antenna's possessions. This is a valuable application in the field of communications because aperture coupling can be employ to adjust the same antenna with various different devices [35].
- In ACMPA the radiation pattern formed by the antenna is more symmetric. Here symmetry in radiation pattern provides the reduction in transmission line feed, which make the finest use of the radiation from the antenna. This is essential because it reduces the obstruction and incompatible radiation between the feed line of antenna and dielectric substrates.
- An additional advantage of aperture-coupled antennas is that capability to mount into low contour applications. The plane and rectangular nature of aperture-coupled antennas is superlative for the amalgamation into mobile devices, routers, and other types of communications equipments [35].

Since the height of the substrate changes the output of the antennas. It can be increased by using multiple layers also known as stacking of substrates. Therefore stacked ACMPA are preferred which is explained in the next section.

1.4 STACKED MICRO-STRIP ANTENNAS

Stacking can nullify the limitations associated with the substrate height increment. In stacking a patch is fabricated over the driven patch known as parasitic patch. Both the parasitic and feed patches are electromagnetically couples to each other as shown in figure 1.4.The Figure 1.4 represents stacking of three substrates with different dielectric constant. The size of both the patches can be same or different which depends upon the requirement. The height for all the stacked substrates can be taken as same or different [36]. By optimizing both the patches so that they produce the resonant frequency close to each other, wider bandwidth can be obtained. There are various parameters that are needed to be optimized to have the same [37, 38].

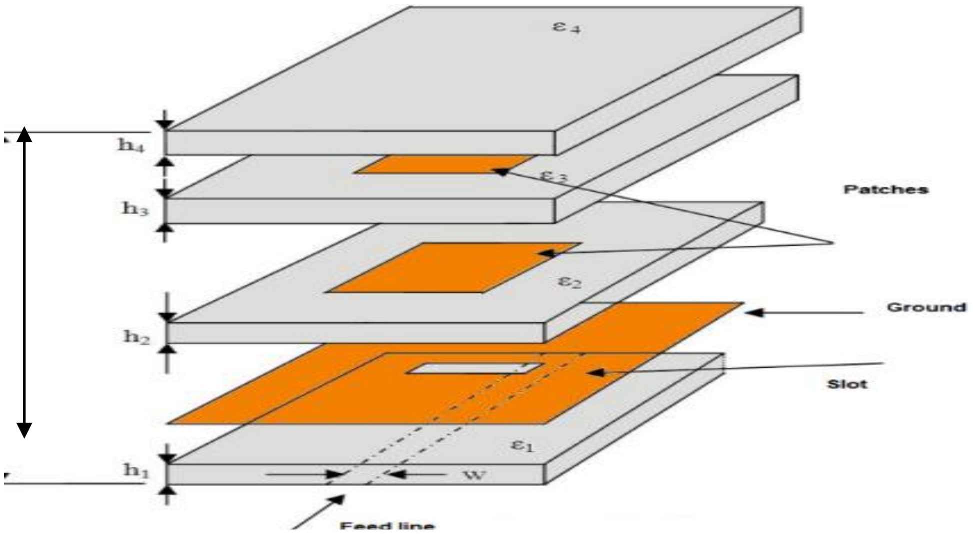
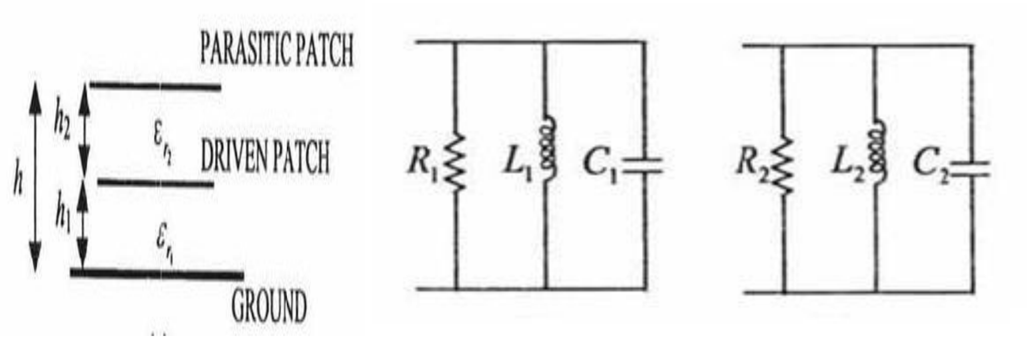


Figure1.4: Stacked ACMPA

1.5 MATHEMATICAL ANALYSIS OF ACMPA

A stacked ACMPA consists of two patches as shown in figure 1.5(a). In the stacked configuration the upper patch is known as parasitic patch and lower patch is known as active patch. The parasitic patch is electromagnetically coupled on top of the driven patch. There are two resonances associated with the structure. One resonance is caused due to the lower patch and the ground plane and it controled the upper resonant frequency and the second resonance is formed due to the parasitic patch and lower patch [39]. Due to the presence of two patches the effective dielectric constant (ε_{ef}) of the structure gets changed and new dielectric constant can determined the new resonant frequency. In figure 1.5 (b) and 1.5 (c) the RLC equivalent circuits of the driven patch and parasitic patch are shown.



(a) (b) (c)

Figure 1.5 (a) Stacked ACMPA (b) Equivalent circuit for active patch
(c) For parasitic patch

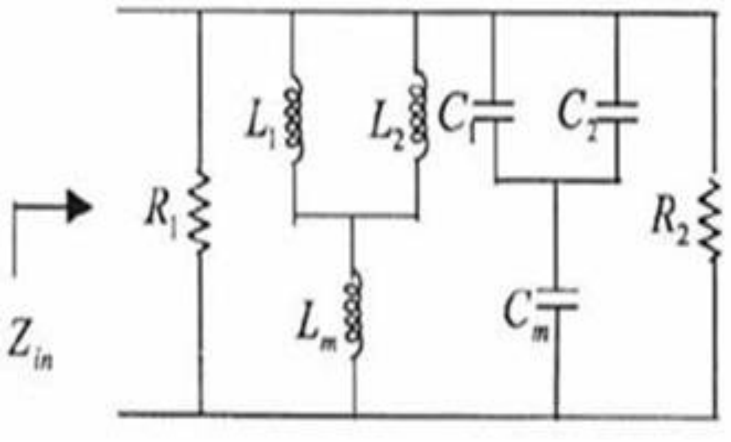


Figure 1.6 Equivalent Circuit of the Stacked ACMPA

Due to the presence of two substrates the effective dielectric constant is given by

$$\varepsilon_{ef} = \varepsilon_{r1} q_1 + \frac{(1-q)^2}{\varepsilon_{r2}(1-q_{1-}q_2)+q_2} \tag{1.1}$$

Where $q_1$is the filling fraction and its value is given by

$$q_1 = 1 - \frac{h_1}{2w_{1e}} \ln\left(\frac{\pi}{h_1} w_{1e} - 1\right) \tag{1.2 }$$

Where w_{1e} is the effective width , its value is given as

$$w_{1e} = w_1 + 2\frac{h_1}{\pi} \ln\left\{17.08\left(\frac{w_1}{2h_1} + 0.92\right)\right\} \tag{1.3}$$

q_2 and $q_3$are also the filling fractions given as

$$q_2 = 1 - q_{1-}q_3$$

$$q_3 = \frac{h_1 - g}{2w_{1e}} ln\left\{\pi \frac{w_{1e}}{h_1} \frac{\cos\frac{\pi g}{2h_1}}{\pi\left(\frac{h}{h_1} - \frac{1}{2}\right) + \frac{\pi g}{2h_1}} + \sin\frac{\pi g}{2h_1}\right\} \tag{1.4}$$

In equation 1.6 the value of g is given by

$$g = \frac{2h_1}{\pi}\left\{\frac{\pi}{\frac{\pi w_{1e}}{2h_1} - 2}\left(\frac{h}{h_1} - 1\right)\right\} \tag{1.5}$$

$h_1$is the height of the lower substrate.

The resonance frequency ,fringing length and elective dielectric constant for first antenna resonator of the antenna is calculated by using formula as given in equation 1.6,1.7 and 1.8 respectively

$$f_{r1} = \frac{C}{2(l_1 + \Delta l_1)\sqrt{\varepsilon_{ef}}} \tag{1.6}$$

$$\Delta l_1 = 0.421 l_1 \frac{(\varepsilon_{1e} + 0.3)(\frac{w_1}{h_1} + 0.264)}{(\varepsilon_{1e} - 0.258)(\frac{w_1}{h_1} + 0.8)} \tag{1.7}$$

$$\varepsilon_{1e} = \frac{\varepsilon_{r1}+1}{2} + \frac{\varepsilon_{r1}-1}{2}(1+12\frac{h_1}{w_1})^{\frac{-1}{2}} \tag{1.8}$$

Similarly the resonance frequency,fringing length and elective dielectric constant for first antenna resonator of the antenna is calculated by using formula as given below respectively.

$$f_{r2} = \frac{C}{2(l_2+\Delta l_2)\sqrt{\varepsilon_{ef}}} \tag{1.6a}$$

$$\Delta \mathrm{l}_2 = 0.4212\,\frac{(\varepsilon_{2\mathrm{e}}+0.3)(\frac{\mathrm{w}_2}{\mathrm{h}_2}+0.264)}{(\varepsilon_{2\mathrm{e}}-0.258)(\frac{\mathrm{w}_2}{\mathrm{h}_2}+0.8)} \tag{1.7a}$$

$$\varepsilon_{2\mathrm{e}} = \frac{\varepsilon_{r2}+1}{2} + \frac{\varepsilon_{r2}-1}{2}(1+12\frac{h_2}{w_2})^{\frac{-1}{2}} \tag{1.8a}$$

The two resonators are electromagnetically coupled so mutual capacitance and inductance will be setup between them. When both the resonators are in action we will be able to achieve maximum radiation. At resonance frequency the response of the parasitic element given as

$$\frac{\mathrm{V2}}{\mathrm{V1}} = \sqrt{\frac{\mathrm{L2}}{\mathrm{L1}}\left(\frac{K_1}{K^2+\frac{1}{\mathrm{QT1QT2}}}\right)}$$

Here V1 and V2 are the voltage across fed and parasitic patch
L1 and L2 are the inductance of fed and parasitic patch element
K1 is the actual coupling coefficient and
K is the critical coupling coefficient
When the actual coupling coefficient equal to the critical coupling coefficient such as K1=K.
Then we take

$$\mathrm{K} = \frac{1}{\mathrm{QT\,1QT\,2}}$$

The equivalent circuit of the stacked ACMPA with inductive and capacitive coupling is shown in figure 1.6. The values of mutual inductance (Lm) and mutual capacitance (C_m) are given by

$$\mathrm{Lm} = \frac{\mathrm{K}^2(\mathrm{L1}+\mathrm{L2}) + \sqrt{(\mathrm{K}^2(\mathrm{L1}+\mathrm{L2})^2 + 4\mathrm{K}^2(1-\mathrm{K}^2)\mathrm{L1L2})}}{2(1-\mathrm{K}^2)} \tag{1.9}$$

$$C_m = \frac{-(\mathrm{C1}+\mathrm{C2}) + \sqrt{(\mathrm{C}_1+\mathrm{C}_2)^2 - \mathrm{C1C2}\left(1-\frac{1}{\mathrm{K}^2}\right)}}{2} \tag{1.10}$$

Input impedance (Zin) of the stacked ACMPA can be derived from the Figure 1.6

$$Z_{in} = \frac{\omega 2\mathrm{RL2} + j\omega \mathrm{R2L}(1-\omega 2\mathrm{LC})}{\omega 2(\omega 2\mathrm{R2L2C2} - 2\mathrm{R2LC} + \mathrm{L2}) + \mathrm{R2}} \tag{1.11}$$

Where $R_1 = \frac{\mathrm{R1R2}}{\mathrm{R1+R2}}$,$L = \frac{\mathrm{L1L2}}{\mathrm{L1+L2}} + \mathrm{Lm}$ and $C = \frac{\mathrm{(C1+C2)Cm}}{\mathrm{C1+C2+Cm}}$

These concepts are used to design stacked aperture coupled micro strip patch antennas which are able to achieve broad band frequency operation to cover ultra wide band ,Bluetooth, Zig-Bee, wireless local area network (WLAN) etc. Another configuration that helps in achieving a broadband operation is the CPW structutre. This is discussed in next section.

1.6 COPLANAR WAVEGUIDE FEED STRUCTURE

A coplanar waveguide fed antenna structure consists of a middle metallic strip placed on the surface of FR-4 lossy substrate with two thin slits (S) of ground planes with thickness (t) running nearby and corresponding to the strip on the same surface having dielectric constant (ε) and thickness of the substrate (h) specified in figure 1.7. The transmission line is uni-planar in structure that involve all the conductors are positioned on the same plane of the substrate. As a result, current flowing beside the parallel paths taking place reverse faces of each conductor are subject to the equivalent inductance and the largely current inclines to be alienated uniformly among the two faces [40-41]. On the other hand, the substrate does influence the electric field, so that the substrate side contributes a large capacitance crosswise the slots than does the air side. Electric charge can mount up more readily on the substrate face as compare to the air face. As a result, at those points on the wave where the current reverses direction, charge will spill over the edges of the metallization including the two faces i.e. air face and the substrate face. The secondary current flows above the edges and gives mount to a longitudinal, magnetic field in each of the slots.

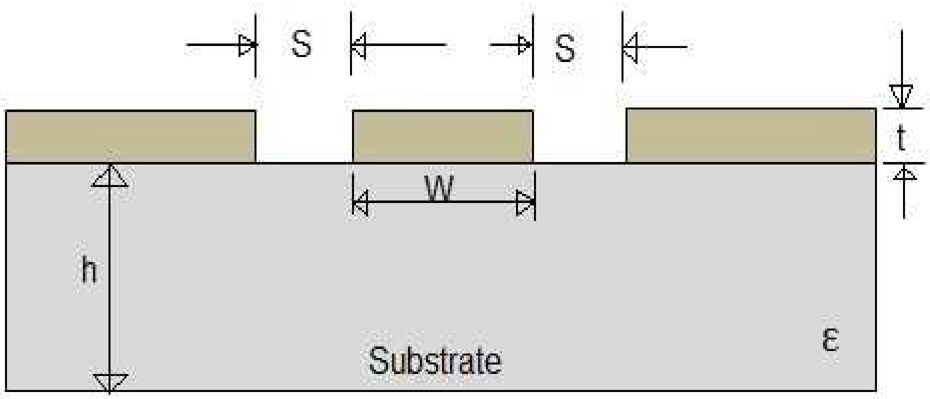


Figure 1.7 CPW feed antenna

1.6.1 Advantages of using CPW

CPW fed antennas have many attractive aspects like

- Low radiation loss, less scattering, less coupling among neighboring components, ease of integration for monolithic integrated circuits, thus these types of antennas have recently become more admirable [42].
- The main advantage of CPW feed is that the slots in antenna are used to provide a simple impedance matching to the CPW line [42-43]. CPW permits both kinds of connections i.e. shunt and series on the same surface of the substrates.
- CPW feed provide the advantages of superior impedance matching, omni-directional patterns, broad bandwidth etc. [45-46]. It is easy to fabricate as compared to the micro strip feed line antennas.
- CPW feed makes it a desirable technique to feed the antenna, getting wider bandwidth, low down radiation outflow, ability to manage the characteristic impedance and to be easily incorporated with other type of active device [46].

Because of the mentioned advantages of ACMPA, stacked MPA and CPW fed antennas the researer work presented in this thesis concentares on the use of ACPMPA and CPW fed antenna to cover various applications like: WI-FI, Bluetooth, WLAN, ultra wide band etc. which are presented in detail in next section.

1.7 WIDEBAND APPLICATIONS COVERED

Micro strip antenna widely used in the defense systems like in missiles, aircraft, rocket and satellite communications.The antennas design with aperture coupled feed and coplanar waveguide feed are used to cover the following frequency bands and used in many applications [48] which are given in below table 1.2.

Table 1.2: Frequency bands covered by proposed antenna structures

Band covered(in GHz)	**Applications**
1 to 2	L-band is mainly used in satellite navigation, telecommunication, Aircraft surveillance, amateur radio
2.4	Bluetooth
2.4	Zig-Bee
2 to 4	S band used in weather forecasting, SONAR, communications satellites like in microwave ovens, microwave devices, mobile phones , global poisoning system, recreational radio
4 to 8	C band used for long distance radio communication
5.15-5.35 and 5.725-5.825	Wireless local area networks

5.2, 5.5 and 5.8	Wi-Fi
5.15 to 5.35 and 5.470 to 5.725	HIPERLAN-2(Used for ATM access and security purpose)
6 to 8	H band is use to recognize the military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities or in military actions
8 to 12	X band is used for satellite communication, radar, space communication ,global broadband system, unpaid radio system, molecular revolving spectroscopy
12 to 15	Ku-band downlink is used from 10.7 GHz to 12.75 GHz for direct broadcast satellite services mainly in Europe

1.8 RESEARCH GAPS

In order to design ACMPA and CPW fed antennas, an extensive literature survey was done in the field of ACMPA and CPW fed antennas. Based on that a few resarch gaps which were found are mentioned below as:

- The antenna bandwidth can be improved by the use of stacked patches, parasitic patches and thick substrate which have low permittivity.
- The size of patch antennas can be reduced without the disturbing the performance of antennas using a novel structure called Defected Microstrip Structure and Defected Ground Structure. Gain and bandwidth can also be increased using DGS. Not much work is presented in literature regarding this.
- UWB applications can be achieved using different shapes of slots in the ground surface called DGS. To attain a single band, dual band and multiband antennas different variables of the slots are varied.
- By the variation of antenna thickness return loss can be improved. We can also use dielectric substrates having different value of permittivities. Since in aperture coupling feedline the upper substrate of low permittivity and lower substrate of high permittivity is used for proper functioning of antenna.

1.9 OBJECTIVES OF THESIS

As we know stacking of antenna is one of the best alternatives available to obtain wider bandwidth at greatly intense space as compared to other conventional MPAs. Also on evaluating the various feeding methods aperture coupled and CPW feeding were found to be superior. Therefore following are the objectives for further research in this regard.

- To design and simulate stacked ACMPA with U-shaped slot in parasitic patch to obtain UWB.
- To design and simulate stacked three layered ACMPA with Swastika shaped DGS for UWB operations.
- To design and simulate circular patch micro strip antenna with CPW feed line technique for UWB operation.
- To design and simulation of design of rectangular patch coplanar ground antenna with CPW feedline.
- Fabrication of U-shaped ACMPA and CPW fed antenna and testing using vector network analyzer.
- Applicability of antennas in practical applications.

This work mainly focuses on the designing of stacked ACMPA and CPW fed antenna for UWB applications. Due to the increasing demand of better gain, return loss and bandwidth, the wireless world requires condense and proficient antenna structures. Due to advantages of MPA along with aperture coupling and CPW feed can be implemented in wireless applications. Firstly theoretical analysis of stacked Aperture coupled antenna and CPW fed antenna is done. Then these antennas are designed and simulated in CST MWS version 2014.Then in the following chapters aperture coupled and CPW fed antennas are designed ,fabricated and tested using VNA and the comparison between simulated and measured results are also shown for applicability of the antenna to practical scenario.

1.10 THESIS ORGANISATION

This thesis is basically divided into following five chapters

- Chapter 1: Introduction about the MPA including aperture coupled feed line and CPW feed line.
- Chapter 2: A brief literature survey about micro-strip patch antenna, aperture coupled MPA, stacked aperture coupled MPA and CPW fed MPA.
- Chapter 3: Theoretical analysis of stacked aperture coupled MPA and CPW fed MPA. Design and simulation of proposed antenna structures in CST MWS version 2014.
- Chapter 4: The optimized antenna designs are fabricated and tested.
- Chapter 5: Conclusion and future work.

CHAPTER 2

LITERATUTR SURVEY

This chapter presents an extensive literature survey carried out on MPA, stacked ACMPA and coplanar waveguide fed MPA. The resarch gaps found out in this chapter help in defining the objective of current researer were presented in this thesis.

2.1 MICROSTRIP PATCH ANTENNAS

David M. Pozar [3] in 1992 proposed a MPA, that have been mostly inventive resarch area in antenna's speculation and design in modern duration.They are widely used in modern microwave systems applications. This resarch paper begins with a brief outline of the essential features of MPAs and then focuses on the considerable expansion in the microstrip antenna expertise.

Ahmed H. Reja [19] in 2009 proposed a MPA with a feed line connector. The antenna was mainly designed to be used for the response of a signal transmitted from an unmanned aircraft and could support many type of applications like: satellite technology and military applications etc. A proposed microstrip patch feed line antenna was used and designed at resonated frequency of 2.5 GHz and wae built efficiently.

Indrasen Singh *et al* [20] in 2011 proposed a MPA as compared to other type of conventional antennas that had benefits and enhanced prospects. Besides this the MPAs could offers two folded circular polarizations, dual-frequency responses, frequency suppleness, wider bandwidth, flexibility of the feedline and omnidirectional pattern.

A.B. Mutiara *et al* [7] in 2011 proposed a wideband MPA for wireless telegraphy system. This proposed rectangular shaped patch antenna was designed for wireless communications that operates at 2.4 GHz frequency and provided a gain of 11 dB.

Patil V. P [15] in 2012 do research in telecommunication, incited the improvement in normal range of antennas which having its own benefits and short-comes. In many appliances in which space is at top and where it is a necessary requirement for an antenna along with tensility to proficiently join the potentiality of multifarious antennas. In rapidly rising marketplace in personal communication systems, MSC, direct broadband television, WLAN recommend that insist for MPAs and array will boost yet further.

Bimal Garg *et al* [21] in 2012 proposed a double band rectangular shaped MPA using an intentive meta-material structure. The antenna was designed at altitude of 3.2 mm above ground surface and be made up of rectangular patch included with C molded arrangement in its surface. The motive of this effort was to increase the hypothetical parameters of MPAs and examine the double band process of the designed antenna.

Pradeep Kumar *et al* [8] in 2013 proposed a small microstrip patch antenna that was intended to operate at 2400 MHz resonance frequency of wireless radio system. It achieved a return loss of -38 dB with FR-4 lossy substrate below the patch .This antenna design had numerous reasonable applications e.g.WLAN,Wi-Fi etc.

Suvadeep Choudhury *et al* [16] in 2014 present that appropriate choice of dielectric material is an important task for antenna designing. In this work, the deviations in resonant frequency, bandwidth, S_{11} parameters of a rectangualr shaped MPA have been considered by varying the substrate thickness and its dielectric constant.

Trupti Ingale1 *et al* [6] in 2015 proposed a rectangular MPA structure which was simulated at 2.34 GHz resonance frequency. The dimension of substrate is 66.7 mm X 53.8 mm, the thickness of substrate is 1.6 mm. It attained a gain of 11 dB and resonates at frequency of 2.21 GHz & 4.45 GHz. A proposed antenna is valuable because of its less price tag, minute size, easy fabrication process, easy to integrate with other cost-effective transceiver systems.

2.2 APERTURE COUPLED ANTENNAS

F. Croq *et al.* [29] in 1991 proposed a study of aperture coupled stacked MPAs. The special effects due to the variation in physical parameters of the structure were examined. Then two patch antennas were simulated and fabricated and deviation was observed inbetween the theoretical and tested results.

Jiri SvaEina [31] in 1992 investigated a multi-layered microstrip transmission lines. The conformal mapping technique was used for the systematic study of effective permittivity of three-layered microstrip patch antennas. The methos was described to cover the solution of multi-layers structures in which individual dielectric layers was linear, homogenous and isotropic.

David M. Pozar [35] in 1996 proposed the existing position of ACMPA. In 1985, the features accessible by the antenna component were confirmed to precious within a extensive applications and adaptability or suppleness for the basic structure that led towards a prevalent quantity of growth. Several historical remarks as regards to the untimely expansion of patch antenna were and initiated its essential characterstics comparative to other types of MPAs feeding methods were discussed.

D. M. Pozar *et al.* [27] in 1997 designed and tested an ACMPA with circular polarization for GPS applications. Antenna operates on two resonances of 1.575 and 1.227 GHz. Then its prototype was fabricated and tested.

S. D. Targonski *et al* [18] in 1998 proposed a deviation of the stacked ACMPA which significantly improve the antenna bandwidth. The impedance behavior of the antenna design is evaluated with other wider band micro strip radiators.

F. Yang *et al* [28] in 2001 presented a novel E-shaped wide band patch antenna. Slots were cut to provide larger bandwidth. Slot parameters like length, width, and position were optimized. Finally, an E-shaped antenna with resonance of 1900 and 2400 MHz was designed, simulated into detail. Comparing to predictable antennas it provided bandwidth increase of 30.3%.

M.K.A. Rahim *et al* [33] in 2006 proposed MPA with aperture coupled feeding techniques. The most important system of power transmits among feed line and its patch was obtained. The two dissimilar structures of an ACMPA are fabricated with dissimilar feed line width, slots dimension, arrangement etc. In these arrangements, the feed width of feedline and aperture location both are varied, whereas maintenaning the rigid three layered formation visible in conventional antennas. The fabricated antenna maintaine improved S_{11} (dB) and bandwidth, although sustaining analogous radiation presentation as evaluated with simulated results.

M. N. Jazi *et al* [26] in 2008 proposed MPAs are simple designs which provide many benrfits. The central frequency was 1.06 GHz and the bandwidth was 250 MHz and observed return loss of below -10 dB in frequency range of 875 MHz to 1150 MHz.The antenna offers some limits : narrow bandwidth, reduce gain and power conducting ability .MPA are used in a multiple range of applications like in military, industry and wireless communication systems. Many type of feeding methods are used to improve the bandwidth. As compare to other feeding method aperture coupled stacked antenna can improve bandwidth more than fifty percent.

Zarreen Aijaz *et al* [17] in 2010 proposed microstrip antennas with slots. The ACMPA consisted of two bounded substrates, with a ground plane in between and provied front to back ration is 13-14 dB. These antennas are minute in size and lighter in weight but they have the trouble of back radiation as a result of these power losses is occurred. To reduce this difficulty a technique is introduces i.e. ACMPA able to reduces the back lobe and provide the wider bandwidth.

Zarreen Aijaz *et al* [25] in 2011 proposed the mechanism of coupling which depends upon the slot, active and parasitic patches and the type of feed. They also improves the radiation property of the antenna. The paper presents some different shapes of aperture slots coupled with ground plane. To increase the impedance bandwidth many changes are done like: change the shape of patch, vary the feed and the slots. The shape of coupling slot in ground plane has great effects which enhance the potency of pairing between line feed and patch.

Tanveer Kour Raina *et al* [36] in 2012 proposed a simple ACMPA which covered band of 5750 to 5850 MHz frequency. The thickness for the substrate was1.57mm and substrates consisted of identical thickness. The optimization for antenna structure is completed using three dimensional electromagnetic simulators tool. This antenna was constructive for several wireless communications.

Justin Obenchain [34] in 2014 proposed a microstrip antenna with aperture coupled fed. MPAs are used in lots of applications like in cellular telephones, military radios, and in other type of communications systems. The intention of the antenna is to evaluate the advantages and negative aspect of ACMPA.

A. Kaur [24] in 2015 presented parametric study of G-shaped MPA. The antenna was designed and optimized in CST MWS version 2010. It showed two resonances frequencies at

3.6 GHz and 5.2 GHz. The proposed antenna structure was fabricated on FR-4 lossy substrate. The tested results were 80% matched with the simulated results.

2.3 STACKED ACMPAs

Stacking is a method in which multiple antennas are layered together. With help of this method the bandwidth and gain of MPA increases. Stacked antennas with aperture coupled feeding can lead to a great improvement in antenna's operational bandwidth.

H. Legay *et al* [30] in 1994 presented a radiating antenna structure which consisted of 4 identical coplanar patches that are electromagnetically coupled with driven patch and engraved on a lower substrate. The antenna structure provides larger bandwidth and very high gain. The antenna structure defeats the troubles of grating lobes. Therefore used in large phase arrays.

A. A. Serra *et al.* [43] in 2007 presented a dual-polarized stacked patch antenna having a wide bandwidth. Antenna showed three resonances from 1920 to 2170 MHz (UMTS), 2.4 to 2.484 GHz (WLAN), and 2500 to 2690 MHz (UMTS II). A prototype was tested for various parameters like impedance bandwidth, gain, and cross-polarization level.

S. Shekhawat *et al.* [39] in 2010 designed and analysed a single-feed stacked rectangular patches antenna with circular polarization. The driven patch was truncated at the corner to provide the circular polarization. It also had a slot at the centre. Parameters like feed point location, size of slot, and the amount of corner truncation were optimized for the optimum results. The proposed antenna provided much greater impedance and axial ratio bandwidth when compared to single layer antenna.

Uma Shankar Modani *et al* [38] in 2014 proposed a stacked aperture coupled antenna which was an E-shaped patch. The antenna was designed for Ultra Wide Band applications having slot at 5-6 GHz frequency. This antenna consisted of an E-shaped top patch and is fed by aperture coupled feed line and recognized the band notching function. The shape of the ground plane was also modified.

A. Agarwal *et al* [37] in 2015 presented an analysis regarding stacked microstrip antenna. Different parameters of stacking were discussed to get high gain and wider bandwidth. The parameters that studied were studied as dielectric constant, stacked patch's dimensions and distance between them.

A. Kaur *et al* [9] in 2015 proposed a multi-layered dual band ACMP antenna with circular polarization. It achieves the bandwidth of 250 MHz from frequency band 2.39 to 2.64 GHz and 370 MHz from frequency band 3.39 to 3.76 GHz. The proposed antenna design able to cover the applications like: WLAN, ZigBee, Bluetooth, Wi-MAX and IMT. The gain observed was 4.08dBi at 2.4 GHz and 5.024 dBi at 3.51 GHz. Simulated parameters are analysis in CST 2014 and gets return loss, smith chart, and gain.

A. Agarwal *et al* [22] in 2015 presented a paper on theoretical study of electromagnetically coupled stacked microstrip antenna. Analysis was conceded out by using equivalent circuit technique. The proposed stacked antenna was designed using CST 2014 which showed 11.7% increase in bandwidth as compared to a single element antenna with 3.27% bandwidth resonating at the same frequency.

Amanpreet kaur *et al* [11] in 2015 presents an ACMPA Sierpinski gasket fractal with a DGS was planned in this resarch for UWB and WLAN applications. The radiating composition of antenna is created by using two Sierpinski gasket fractal antenna layers on FR-4 lossy dielectric substrate mounded over each other. This antenna construction is fed by third layer of FR-4 lossy substrate, having ground layer at top and the feed line and stub at the bottom.

Gagandeep kaur *et al* [10] in 2017 presented a U-shape slotted rectangular micro-strip patch antenna with plus shaped aperture slot in ground plane. The proposed UWB antenna covered frequency band from 4.89 GHz to 10.8 GHz .The antenna is a stacked structure have three substrates of thickness 1.57 mm , material used for each layer is FR-4 lossy having permittivity of 4.4. This antenna structure consisting of a swastika shaped driven patch and U-slotted parasitic patch. The feed-line is aperture coupled attached with rectangular tuning stub.

Gagandeep kaur *et al* [13] in 2017 presents a stacked T-shaped Aperture coupled microstrip antenna designed for ultra-wide band wireless applications. The proposed UWB antenna covers two frequency bands as of 2.49 to 2.9 GHz and 6.85 to 20 GHz and was used for the various applications like Bluetooth, Zig-Bee (2400 MHz), C band (6 -8 GHz), X band (8-12 GHz), Ku band (12-18 GHz) and Satellite communication. The stacked antenna structure has substrates of thickness 1.57 mm and material used is FR-4 lossy having permittivity 4.4. The antenna system is stacked layered structure consisting of two patches like an active patch and a parasitic patch.

2.4 COPLANAR WAVEGUIDE FEED

A. A. Eldek *et al* [5] in 2004 proposed a triangle slit MPA feed by a CPW. It consisted a symmetric triangle shaped slit fine-tuned by a tuning stub and slit hat. This antenna design showed evidence for wider bandwidth i.e. 57 percent for frequency X-band having an average gain 4.5 dB and cross polarization 10 dB. In addition, it was miniature in extent. The coupling among antenna elements was in the order of 15 dB or below it, which made it a good candidate for a phased array system.

J. William *et al* [48] in 2010 proposed a coplanar waveguide fed Ultra Wideband (UWB) slot antenna. This design consisted of a rectangular shaped aperture with cross like construction on the front section of the feed line. A size reduction of 66% is obtained compared to the other type of antennas with impedance bandwidth of 4.8 to 12.8 GHz. The CPW feed is designed to achieve 50 ohm impedance matching.

Mohamed A. Hassanien *at al* [41] in 2010 proposed the recital of a rectangular MPA feed by microstrip feed line which was to operate for UWB applications. This antenna mainly consisted of a rectangular shaped patch with U shaped aperture lying on one side of the dielectric substrate and a fixed ground on the other side. The U shaped aperture and ground were used to attain an admirable impedance matching to get wider bandwidth. The proposed antenna was designed to operate over a frequency range from 3.6 to 15 GHz.

Sumandeep kaur *et al* [46] in 2012 proposed an ultra wide band antenna with hexagonal patch and hexagonal slot. The size of antenna was 55×43.5mm. Hexagonal patch's sides were taken as 13 mm and hexagonal slot's sides are taken as 3mm. The proposed antenna was resonates at two frequencies. Due to hexagonal slot cut in hexagonal patch the bandwidth was increased from 6.2 GHz to 8.2 GHz.

S. Krishnan *et al* [45] in 2012 proposed a low profile rectangular slot antenna with CPW feed line effectiving with a wider band resonant at 94 GHz. The antenna was fabricated and tested on ten micrometer silicon diaphragm. It attains return loss of -35.7 dB at 93.6 GHz with bandwidth of over 30% at 94 GHz. To get better bandwidth for conventional slot antenna a material stub is attached which is C-shaped this led to an impedance bandwidth .

M. Bod *at al* [40] in 2012 proposed a novel UWB printed slot antenna which provide 3 extra wirless bands for various applications. The low contour antenna design consisted of an octagonal aperture fed by a beveled and stepped rectangular shaped patch for covering an UWB band of 3.1–10.6 GHz. By joining three inverted U-shaped strips at the upper part of the slit in the ground palne an additional triple linear polarized bands can be recognized.

Dhirgham K. Naji *et al* [47] in 2013 proposed an advance research for wide band CPW fed tapered monopole MPA. It was activated for wireless C-band. This antenna was composed of a CPW-fed monopole antenna having tapered compositions, implanted with symmetric open ended L shaped slots including a tapered shape cut from the crest sides of the ground. By simulating these designs we get (S_{11}) wide bandwidth which was noticeably increased with the help of adjacent three resonance modes, created from antenna. The designed antenna was simulated in CST.

Anil Kr Gautam *et al* [44] in 2013 proposed a coplanar waveguide (CPW)-fed compact microstrip antenna. It was proposed for ultra wide band applications. The proposed antenna possesses a method to reduce the size of monopole antenna by consignment of inverted L-strip above the conventional monopole patch antenna to reduce the height of the antenna. The ground plane was vertically extensive toward two sides of the single radiator. Therefore, space around the radiator is generally wasted could be successfully saved.

Gourav Hans *et al* [42] in 2014 proposed novel monopole planar antenna that was suitable for wireless applications. The proposed antennas showed two resonant modes which are allied with five slots ,these slots match the impedance around the superfluous resonant that provide lower impedance bandwidth 300 MHz (2.4- 2.7 GHz) and upper band width provide a bandwidth of 1009 MHz (5.2-6.3 GHz) which covers applications of WiMAX, WLAN, Bluetooth etc. The CPW feed line was used to get the desired results.

Kirti Vyas *et al* [49] in 2014 proposed a new patch antenna which was CPW fed operating at band of 2700 – 6500 MHz. The dimensions of antenna were 32 x 30 mm^2, thickness of substrate is 1.6 mm , built above FR4-epoxy substrate, permittivity having 4.4. For the improvement of bandwidth the modified ground structure wss used. The antenna design has been optimized and simulated in CST MWS.

A. El Hamdouni *et al* [12] in 2015 proposed a novel fractal microstrip antenna structure. It was planned for UWB applications. The UWB frequency range of 3.1 to 10.6GHz was covered .To get an ultra wide band CPW fed antenna and circular forms were used to satisfy the requirement in fractal antenna. It showed a good matching input impedance with return loss less than -10dB between 2.9 GHz and 11 GHz.

2.5 CONCLUSION

This chapter presented a literature survey carried out in the field of ACMPA, stacked ACMPA and CPW fed MPA. Based upon the research gaps identified the objective of research work were defined and have been covered in the processing chapters.

CHAPTER 3

DESIGN AND SIMULATION OF MICROSTRIP PATCH ANTENNA WITH APERTURE COUPLED AND CPW FEEDLINE FOR UWB APPLICATIONS

3.1 INTRODUCTION

This chapter presents the mathematical analysis of rectangular and circular micro strip patch antennas (MPA).Our main objective is to obtain a wider band and ultra wide band with these micro strip patch antennas. Ultra wide band can be achieved proficiently by two types of feed lines i.e. aperture coupled feed line and CPW feed line which have been covered in first chapter of this thesis. The design and simulation of four UWB micro strip patch antenna has been done in this chapter using CST MWS version 2014. All the proposed microstrip patch antennas are designed on an FR-4 substrate with thickness of 1.57mm and permittivity of 4.4. The material which has been used for the patch, feed line, ground plane and tuning stub is PEC (perfect electric conductor) having thickness 0.035mm.

The proposed antenna designs are namely a design and simulation of stacked ACMPA with U-shaped slot in parasitic patch with a plus shaped DGS, design of stacked three layered ACMPA withswstika shaped DGS, design of circular patch MPA with CPW feed and design of rectangular patch coplanar ground antenna with CPW feedline.The structures of all stacked ACMPA have been calculated with the help of equations which have been mentioned in section 1.4 of chapter 1. DGS (defected ground structures) is a unique technique used to reduce the dimension of antenna at particular operating frequency and play a vital role in bandwidth enhancement and size reduction. DGS disturbs the current distribution on the metal layer of ground shielding depending upon the outline of defect. This current distribution affects the input impedance and the flow of the current of the antenna. It can also organize the excitation and electromagnetic waves propagation through the substrate layer. The equation (3.1) represents the parallel resonance circuit with inductance L and capacitance C as

$$L=\frac{1}{4\pi^2 fo^2 C} \text{ and } C=\frac{fc}{2Zo}\cdot\frac{1}{2\pi(fo^2-fc^2)} \tag{3.1}$$

where fc, fo, and Zo denote the cut off frequency, resonant frequency and characteristic impedance, respectively and the resonant frequency for antenna in term of inductance and capacitance can be calculated with the help of equation (3.2)

$$fr=\frac{1}{2\pi\sqrt{LC}} \tag{3.2}$$

UWB can also be obtained from convential MPAs by using a specific type of feeding technique called coplanar waveguide a feeding (CPW feed).

Therefore third and fourth proposed antenna designs consist of only a single substrate layer microstrip patch antennas with CPW feed line to achieve an UWB. The proposed antenna designs structure is calculated from formulas which are given in equations (3.3) to (3.8)

Calculation of effective permittivity ($\in_{ef}$)

$$\in_{ef} = \frac{\in_{r+1}}{2} \qquad (3.3)$$

Calculation of phase velocity (v_{ph})

$$v_{ph} = \frac{C}{\sqrt{\in_{ef}}} = C\sqrt{\frac{2}{\in_{r+1}}} \qquad (3.4)$$

Calculation of characteristic impedance (Z_o)

$$Z_o = \frac{1}{Cv_{ph}} \qquad (3.5)$$

Relation of elliptical integral, of the first order $K(k'_1)$ with its complement $K^{'}(k_1)$

$$K^{'}(k_1) = K(k^{'}_1) \text{ with } k'_1 = \sqrt{1 - k^{21}} \qquad (3.6)$$

Argument of elliptical integral

$$k_1 = \frac{s}{s+2w} \qquad (3.7)$$

Calculation of capacitance

$$C_1 = 2 \in_o \frac{K(k_1)}{K^{'}(k_1)} \text{and} C_2 = 2 \in_o \in_r \frac{K(k_1)}{K^{'}(k_1)} \qquad (3.8)$$

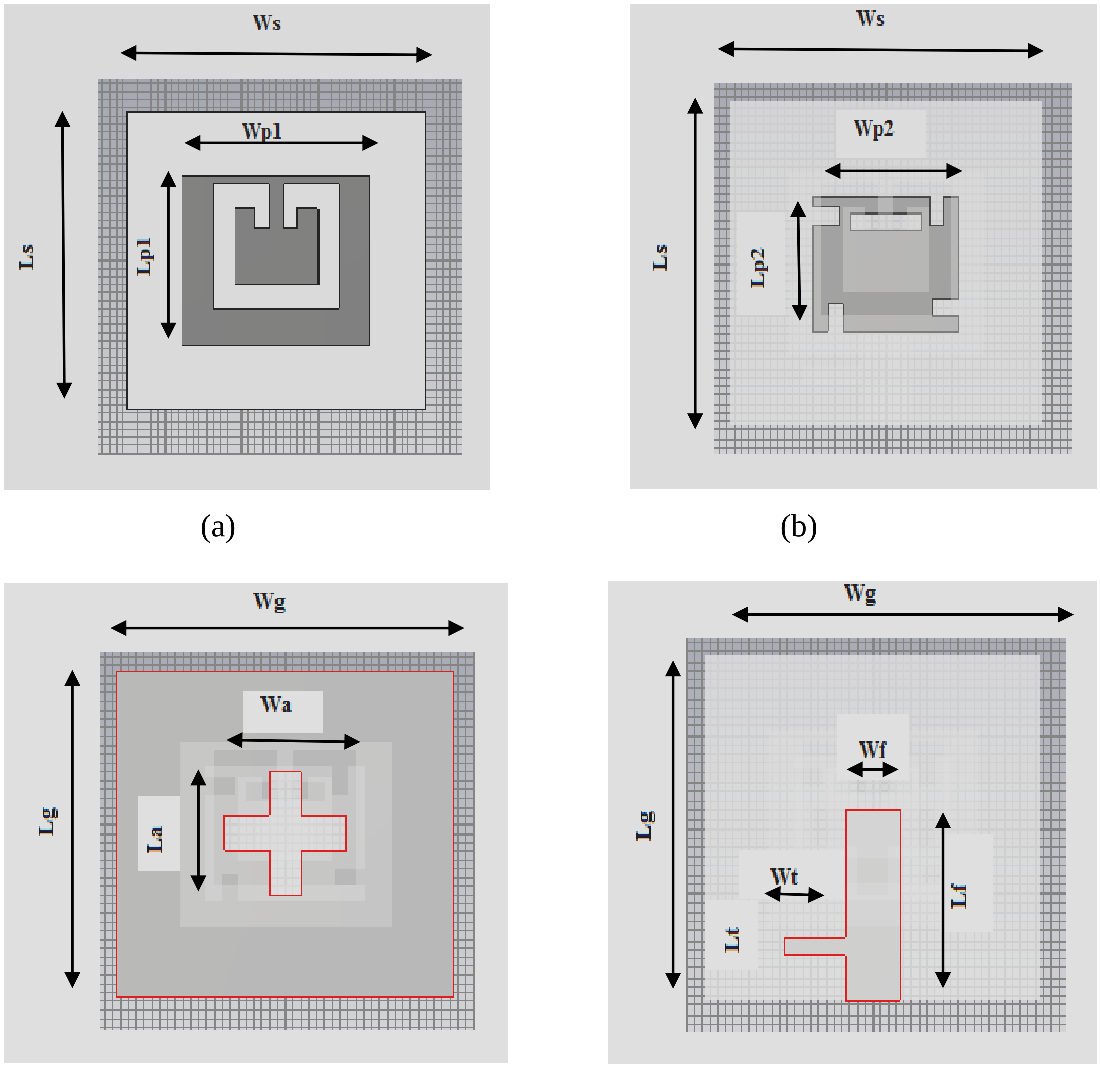
Total capacitance is $C = C_1 + C_2$

Where $\in_r$ is relative permittivity, $\in_o$ is absolute permittivity, s is the gap between CPW-fed line and the ground and w is the width of the feed line, C_1 is the capacitance of first resonant and C_2 is the capacitance of second resonant.

3.2 DESIGN AND SIMULATION OF STACKED ACMPA WITH U-SHAPED SLOT IN PARASITIC PATCH WITH A PLUS SHAPED DGS

The proposed antenna is a three layered structure with three substrates of equal dimensions 37×43 mm^2. The upper patch (27×21mm^2) and lower patch (15.4×20.27mm^2) as shows in figure 3.1 (a) and (b) respectively. Dimension of the upper patch was optimized such that the resonance produced by it comes close to the resonant frequency of active patch. This leads to both the resonance frequencies overlapping to produce a wider bandwidth.The antenna structure consists a rectangular parasitic patch with a U-slot, the middle layer has a swastika shaped driven patch with rectangular slots and the lowermost sunstrate layer has a plus (+) shaped aperture and the feedline is improved with a stub as shown in figures 3.1(c) and

3.1(d). The optimised antenna parameters values are given in table 3.1. The antenna parameters are designed and optimized using the 3-D electomagnetic tool CST MWS version 2014.



(a) (b)

(c) (d)

Figure 3.1 Stacked ACMP antenna (a) upper patch with U-shaped slot (b) lower patch swastika in shape(c) ground plane with plus shape aperture (d) feed line with tuning stub

Table 3.1 Specified and Optimized antenna parameters of the stacked ACMPA

Specification	**Dimension(mm)**
Resonant frequency	5.3 GHz
Dielectric constant	4.4
Tangent loss	0.0024

Substrate (Ls×Ws)	37× 43
Line feed (Lf×Wf)	20.5×7
Ground plane(Lg×Wg)	37×43
Active patch(Lp1×Wp1)	15.4×20.27
Parasitic patch(Lp2×Wp2)	27×21
DGS(La×Wa)horizontal	4×15.6
DGS(Lb×Wb)vertical	15.6×4
Stub with feed(Lf×Wf)	2×9.5

3.2.1 Simulated results

The proposed antenna is designed and simulated in CST MWS version 2014 and obtained the optimized results in terms of return loss, gain, smith chart and surface current distributions are presented in this sud section. The parametric study of antenna design parameters are carried out to achieve optimum UWB operation.

3.2.1.1 *S_{11} (dB) results and improved bandwidth*

S_{11} (dB) represents the amount power is reflected back to the antenna. It is the plot between S_{11}-parameter (dB) along y-axis and frequency (GHz) along x-axis for the ACMPA as shown in figure 3.2. This plot is also useful to calculate the antenna’s impedance bandwidth. The bandwidth of antenna is defined as the range of frequency over which return loss is below -10 dB. The proposed antenna resonant at 5.3 GHz and covers a frequency band from 4.88 to 10.8 GHz and with a bandwidth of 5.92 GHz. The antenna shows peak return losses of -27.93 dB, -30.8dB, -32.24 dB and -27.18 dB at resonant frequencies of 5.01 GHz, 5.65 GHz, 6.13 GHz and 8.5 GHz respectively. The achieved frequency bands are proficient to cover the applications like long distance radio communication ,WLAN, Wi-Fi, recognize the military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities or in military actions, satellite communication, radar, space communication ,global broadband system etc.

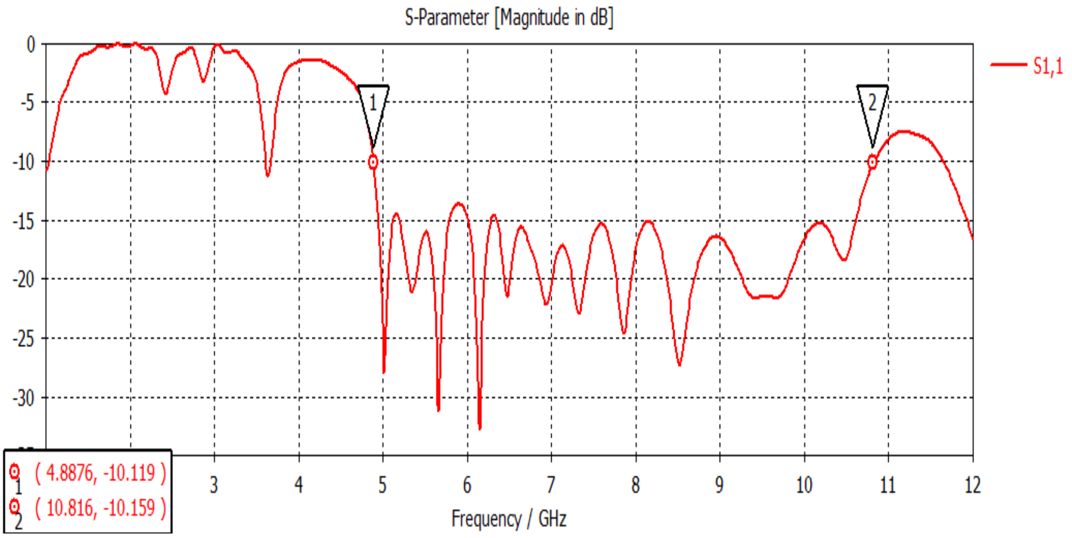


Figure 3.2 Return loss (S_{11}-dB)

3.2.1.2 *Gain*

The gain of an antenna is describes how much power is transmitted in the direction of peak radiation to that of isotropic antenna. The broadband gain of the antenna is given in figure 3.3.The antenna shows a peak gain of 6.06 dB at 9 GHz frequency. Figure 3.4 (a-b) demostrate the 3-D view and polar plot for the peak gain of the antenna. As shown in figure 3.4 (b) the major lobe is directed at an angle of 3 degrees with magnitude of 6.33 dB and half power width of 36.8 degrees.The antenna behavior is more directional, when the gain of the proposed antenna is more than isotropic antenna. A superior gain permits the antenna to be successfully used for long distance applications.

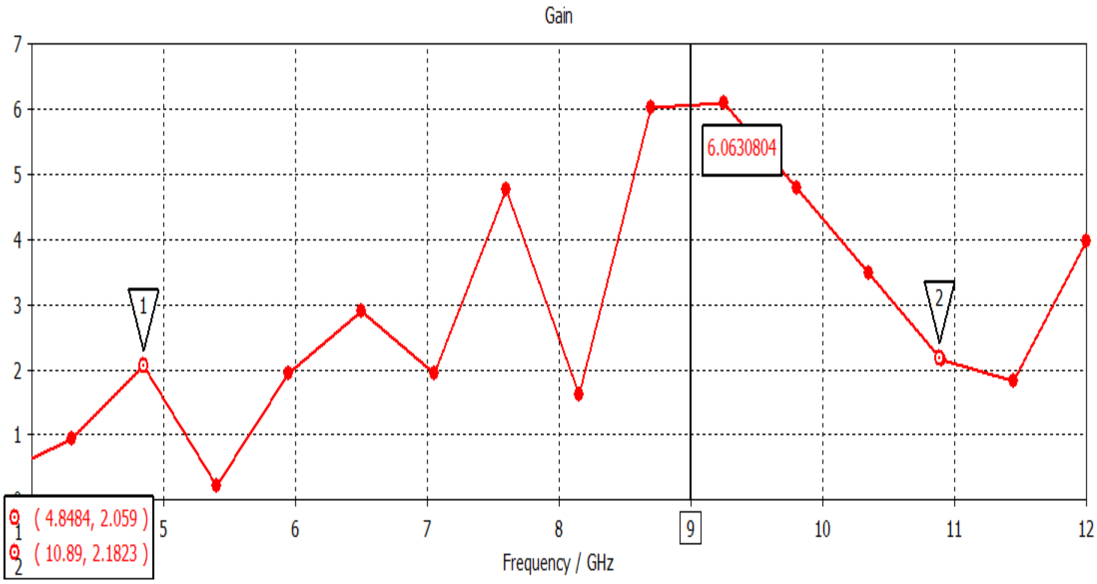
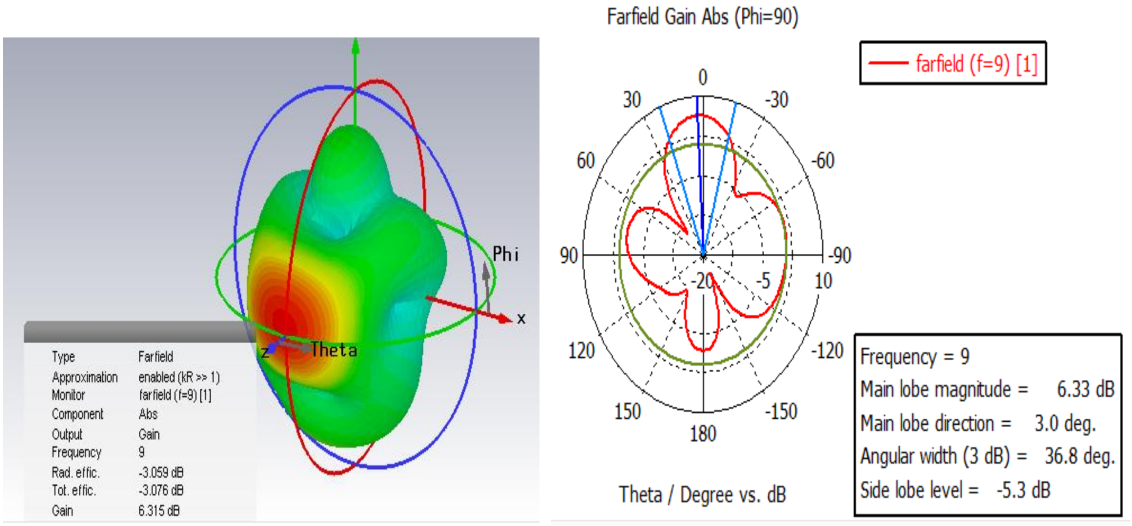


Figure 3.3 Broadband gain of antenna



(a) (b)

Figure 3.4 Gain (a) 3-D view (b) polar plot of Stacked ACMPA at 9 GHz

3.2.1.3 *Smith chart*

Smith chart is used to plot the graph of antenna's impedance as the function of frequency. For proper impedance matching, the locus of the smith chart must pass through its center. The proposed ACMP antenna shows 50 ohm characteristics impedance. The smith chart of the antenna is shown in figure 3.5, and the marker 1 and 2 represents the bandwidth of the antenna.

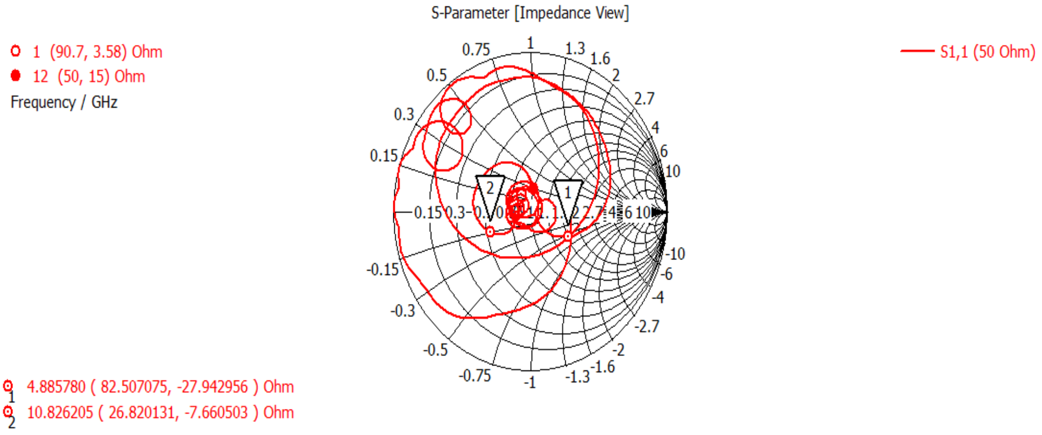
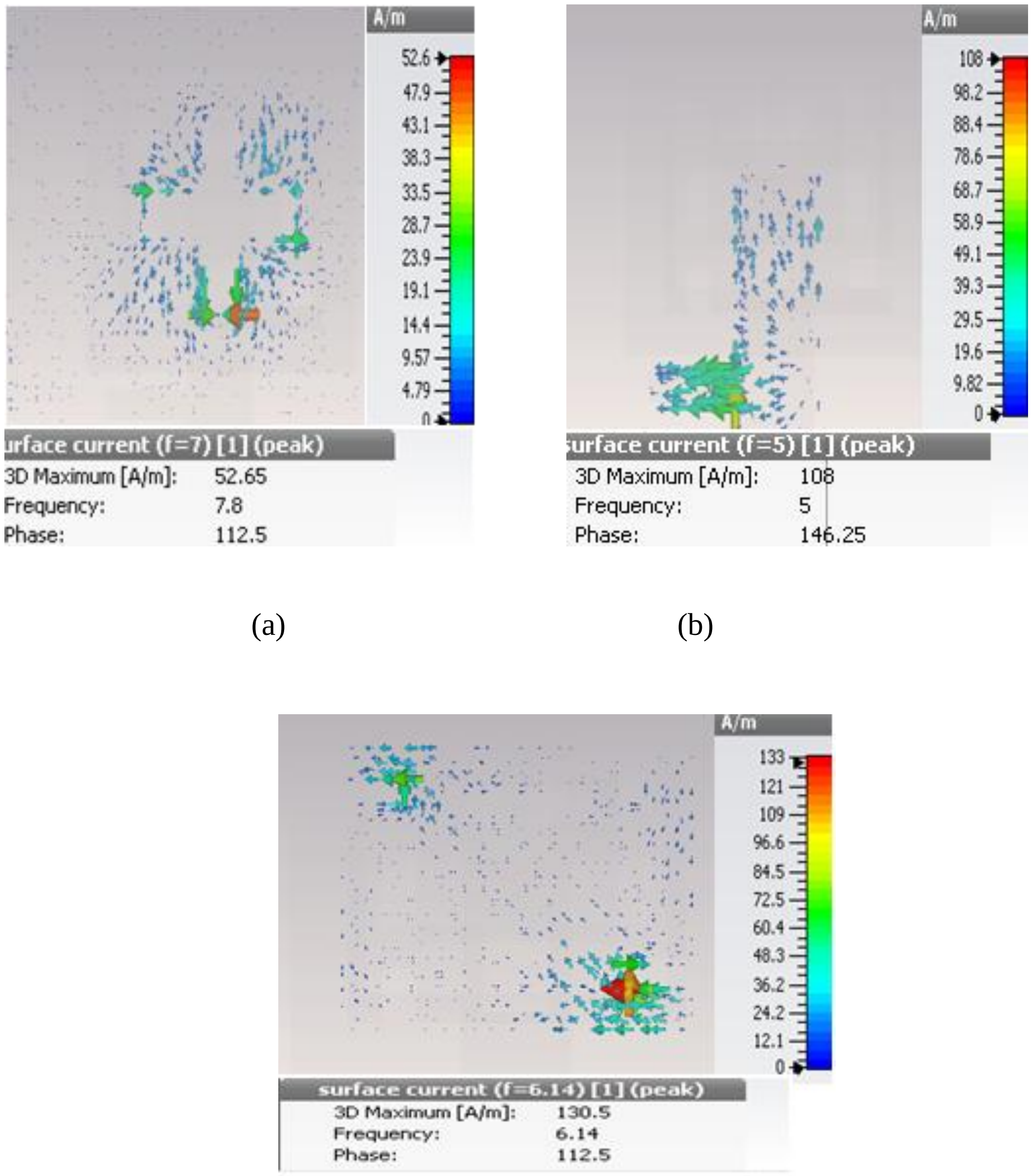


Figure 3.5 Smith chart

3.2.1.4 *Surface current distribution*

The current distribution graphs shows the direction of the flow of current and intensity of the current when the antenna is energised. In Figure 3.6 (a) represents the surface current on the ground plane of antenna. From the figure it can be incidental that the maximum current distribution is achieved at boundaries of the plus slot i.e. 52.65 A/m and it is responsible for the excitation of lower band. Figure 3.6(b) represents that maximum current (108 A/m) is achieved at feed line where stub is attached and figure 3.6(c) shows the current for active patch and maximum current (130.5 A/m) is observed at the patch from upper left to lower right diagonally and it is responsible for upper band excitation.



urface current (f=7) [1] (peak)
3D Maximum [A/m]: 52.65
Frequency: 7.8
Phase: 112.5

urface current (f=5) [1] (peak)
3D Maximum [A/m]: 108
Frequency: 5
Phase: 146.25

(a) (b)

surface current (f=6.14) [1] (peak)
3D Maximum [A/m]: 130.5
Frequency: 6.14
Phase: 112.5

(c)

Figure 3.6 Surface current distributions (a) for ground plane (b) for feed line (c) for active patch

3.2.2 Antenna optimization

The final optimized results were obtained after varying the parametric values of feed line, parasitic patch and DGS etc in CST 2014. The parametric variations that lead to the desired results are presents below:

3.2.2.1 *Effect of variation in feed line width*

Besides controlling the characteristic impedance of the feed line, the width of the feed line also affect the coupling to the slot. To a certain level, thinner feed lines couple more strongly to the slot. Figure 3.7 (black color dotted plot) shows the optimized value of feed line width i.e. 3.3mm when feedline width is varied from 2.4mm to 3.6mm. Since it give the best impedance bandwidth results.

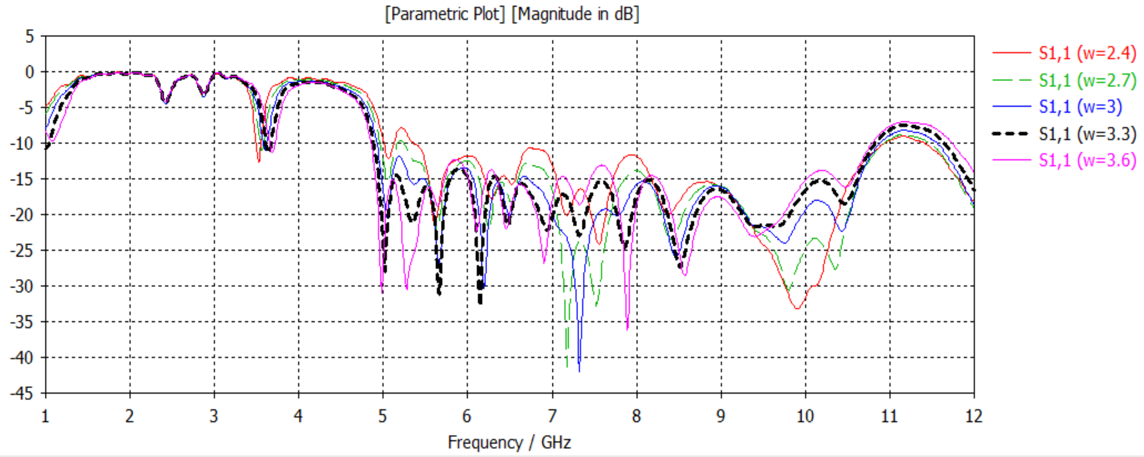


Figure 3.7 Effect due to the variation in feed line width

3.2.2.2 *Variation in the ground plane slot (plus shape)*

The antenna size is reduced for a particular frequency with the help of DGS. The DGS is realized by introducing a shape defected on a ground plane thus will disturb the shielded current distribution depending on the shape of defect. The plus shaped slot is etched from ground plane of the antenna. By varying the slot along its width and length, we are able to obtain a better return loss and wider bandwidth i.e. 5.95 GHz. From figure 3.8(blue color plot) shows that the best optimized results are achieved for w is equal to 8 when w varied from 6 to 9mm.

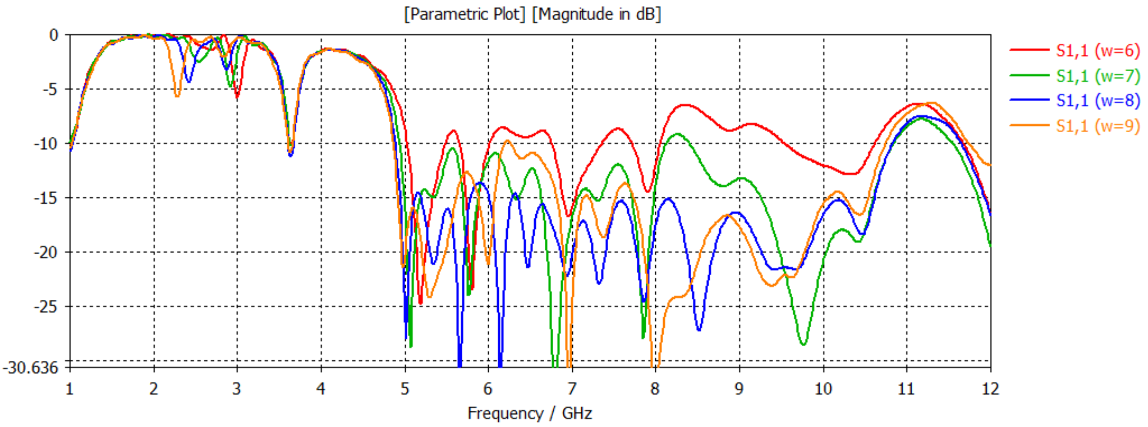


Figure 3.8 Effect due to the variation in DGS

3.2.2.3 *Effect of variation in parasitic patch geometry*

The parasitic patches play a vital role to enhance the parametric results of an antenna. Here U-shaped slot is etched from the top surface of the patch as shown in figure 3.9 (b) and with this modification we are able to achieve better return loss and wider bandwidth. Figure 3.10 shows the comparison results obtained for parasitic patch between without any slot in parasitic patch and with slot in parasitic patch and observed that in first case multiband with frequency bands of 5.45 to 6.5 GHz and 6.89 to 9.95 GHz were achieved. Due to the contribution of the U-shaped slot an ultra wide band with frequency of 4.89 to 10.89 GHz is also achieved.

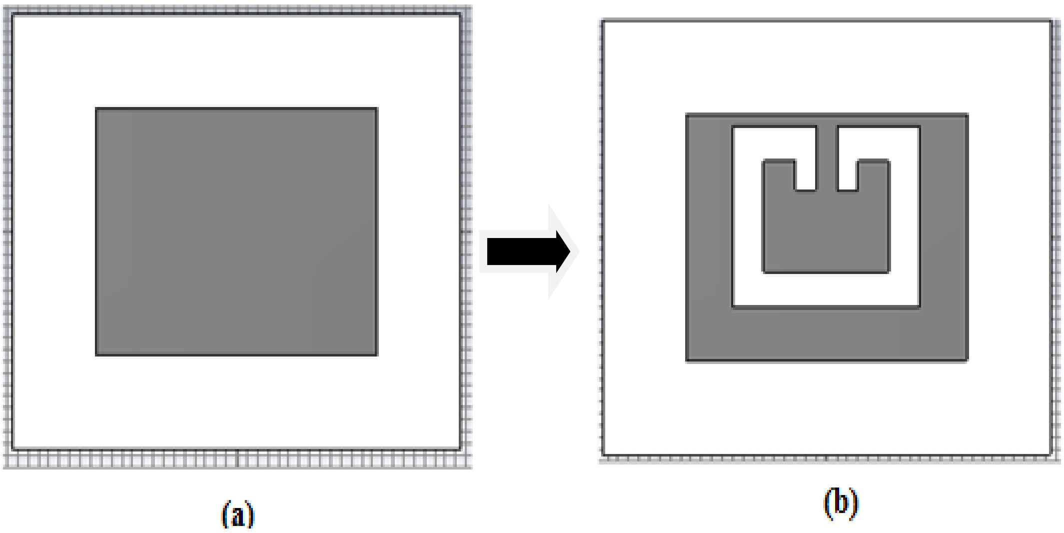


Figure 3.9 Parasitic patch of antenna (a) without any slot (b) with U-shaped slot

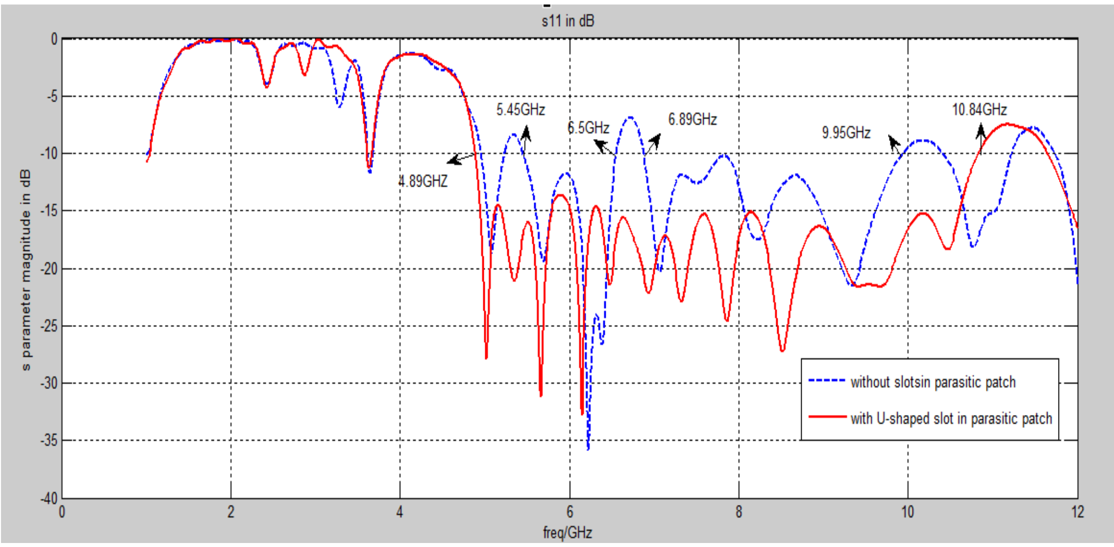


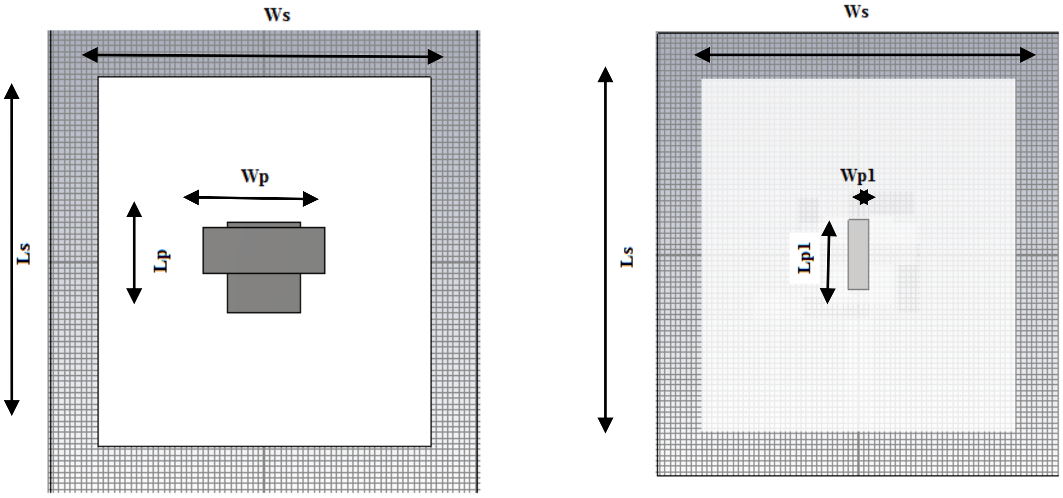
Figure 3.10 S_{11} parameter comparison plot of parasitic patch modification

3.2.3 Wireless applications covered

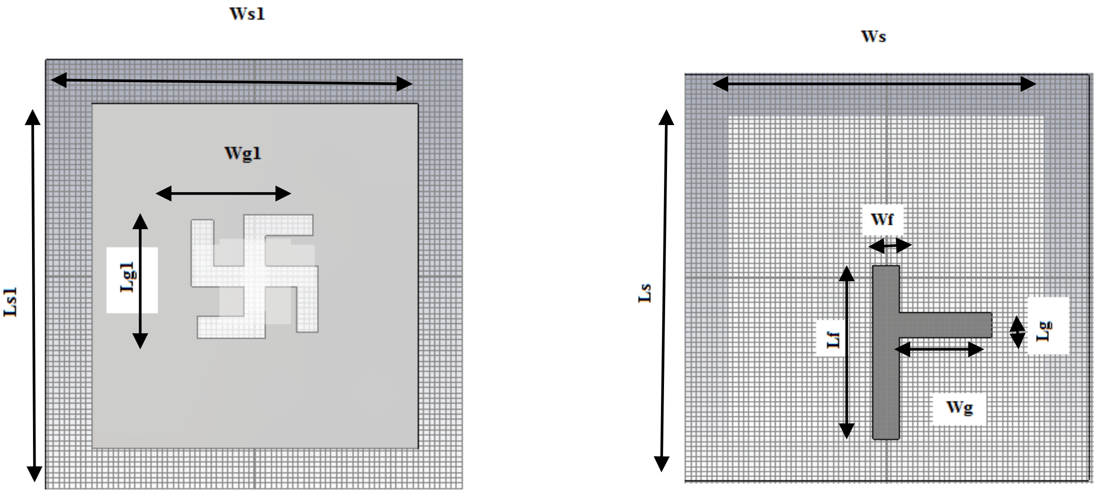
The ACMPA with U-shaped slot in parasitic patch covers the frequency band of 4.89 to 10.8 GHz with bandwidth 5.95 GHz. This antenna design covers many applications- C band in long distance radio communication, WLAN, Wi-Fi, HIPERLAN-2 for ATM access and security purpose , H band for recognize the military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities or in military actions etc.

3.3 DESIGN OF STACKED THREE LAYERED ACMPA WITH SWASTIKA SHAPED DGS

The proposed antenna configuration is a three layered structure with a ‘T’ shaped parasitic patch on the topmost layer and a rectangular driven patch on the middle layer. The ground layer has a swstika shaped defect and on top of lowermost layer and a feedline on bottom of this layer. The three substrates are of equal volumetric dimensions 72.4×72.4×4.85 mm^3. The design of upper patch of size 16×13.2 mm^2 and lower patch of size 13×4 mm^2 of antenna is shown in figure 3.11 (a) and (b) respectively. The antenna has a swastika shaped DGS in the ground plane and rectangular tuning stub is attached to the feedline is shown in figure 3.11 (c) and 3.11(d) respectively. DGS made in the ground to provide the stronger coupling and better impedance bandwidth for proposed antenna. The specified and optimized dimensions values are given in table 3.2 which are simulated in CST MWS version 2014.



(a) **(b)**



(c) (d)

Figure 3.11 Stacked ACMP antenna with DGS (a) T-shaped upper patch (b) vertically placed rectangular shaped lower patch (c) ground plane with Swastika DGS (d) feed line with stub

Table 3.2 Specified Antenna Parameters of the Stacked Aperture coupled Antenna

Specification	**Dimension(mm)**
Resonant frequency	13.15 GHz
Dielectric constant	4.4
Tangent loss	0.0024
Substrate (Ls×Ws)	65× 60
Line feed (Lf×Wf)	35×5
Ground plane	65× 60
Active patch(Lp1×Wp1)	13×4
Parasitic patch(Lp×Wp)	16×13.2
DGS(Lg1×Wg1)	23.2×4
Stair in parasitic patch	8×22
Stub with feed(Lg×Wg)	5×18

3.3.1 Simulation Results

The proposed antenna configuration is designed and simulated in CST MWS version 2014 and obtained the useful results in terms of Return loss, Gain, Smith chart and current distributions which are demonstrated below:

3.3.1.1 S_{11} *(dB) results and improved bandwidth*

The simulated result of S_{11} parameter in dB is plotted against frequency and is shown in figure 3.12. The antenna structure shows resonance frequency of 13.14 GHz and covers the frequency band of 6.227 to 14.8 GHz with bandwidth 8.573 GHz. The antenna shows peak return losses of -26.6dB, -23.4dB, -21dB and -31dB at resonant frequencies of 6.5 GHz, 7.6 GHz, 11.8 GHz and 13.14 GHz respectively. This allows the antenna to be suitable for military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities or in military actions, satellite communication, radar, space communication ,global broadband system, unpaid radio system, molecular revolving spectroscopy etc.

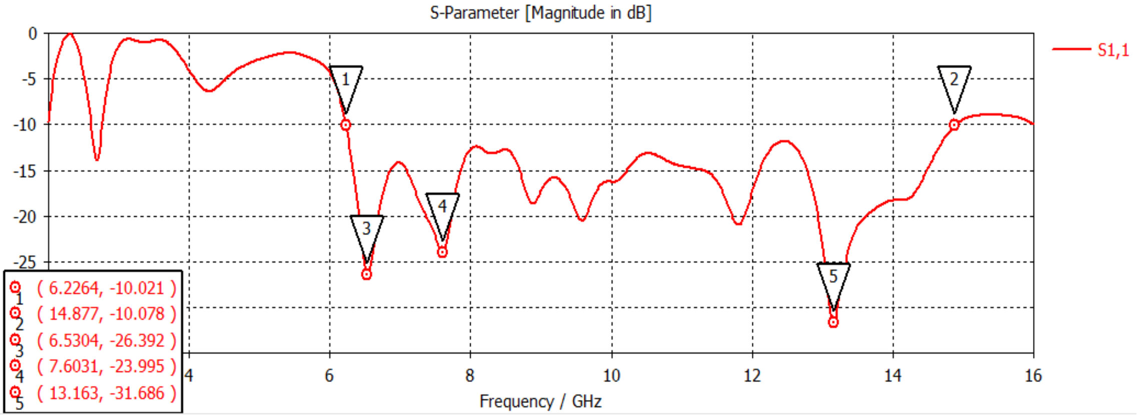


Figure 3.12 Return Loss of UWB antenna

3.3.1.2 *Gain*

In this proposed antenna design structure plus shape DGS is used which helps to increase the gain of the antenna. The broad band gain of proposed antenna in one dimensional is shown in figure 3.13. At a frequency of 9 GHz, maximum peak gain is 4.35 dB. Figure 3.14 demostrate the 3-D view and polar plot for the peak gain of the antenna. As shown in figure 31.4 (b) the major lobe is directed at an angle of 113 degrees with magnitude of 4.15 dB and half power width of 50.7 degrees.

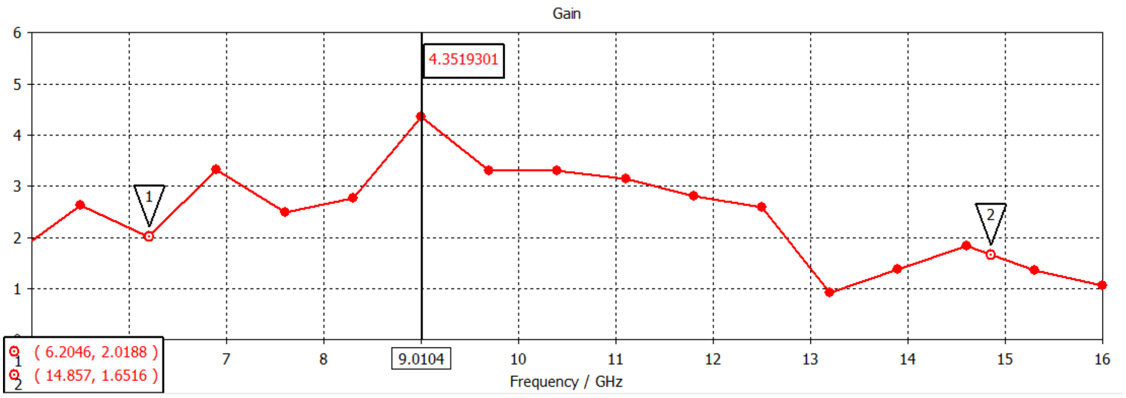
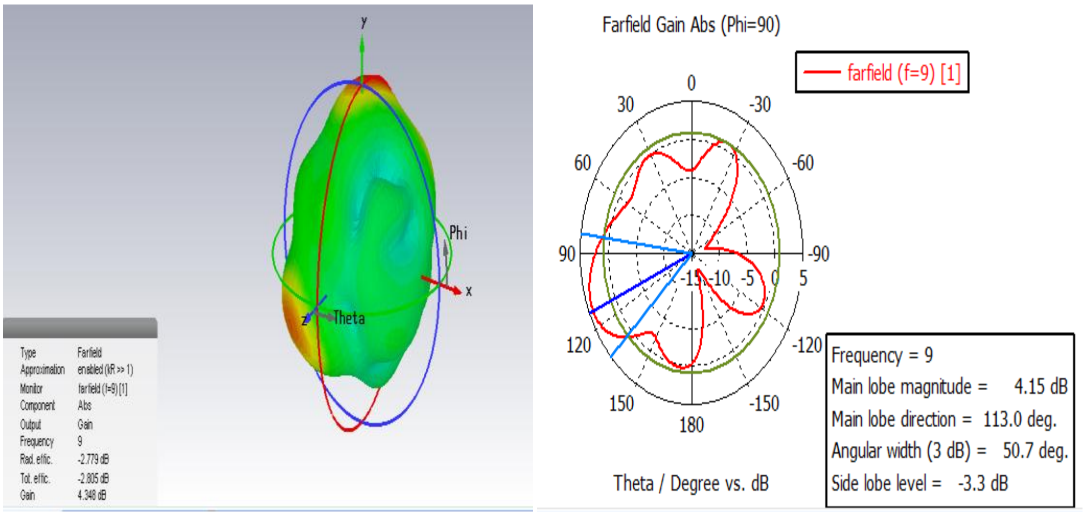


Figure 3.13 Broad band Gain



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=9) [1]
Component Abs
Output Gain
Frequency 9
Rad. effic. -2.779 dB
Tot. effic. -2.805 dB
Gain 4.348 dB

Frequency = 9
Main lobe magnitude = 4.15 dB
Main lobe direction = 113.0 deg.
Angular width (3 dB) = 50.7 deg.
Side lobe level = -3.3 dB

(a) (b)

Figure 3.14 Peak gain at 9 GHz (a) 3-D view (b) polar plot

3.3.1.3 *Smith chart*

Smith chart is used to plot the graph of antenna's impedance as the function of frequency. The proposed ACMP antenna shows 50 ohm characteristics impedance. The smith chart of the antenna as shows in figure 4.5 describes the values at resonant frequency.

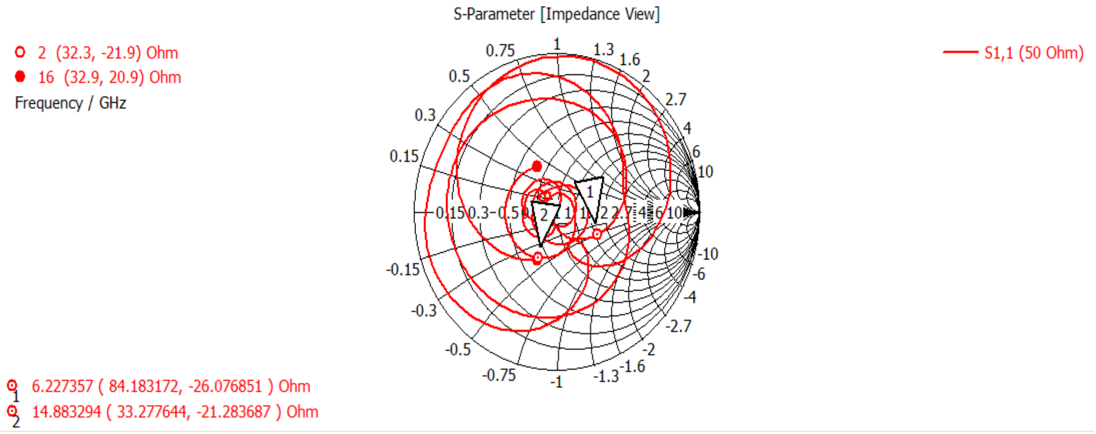
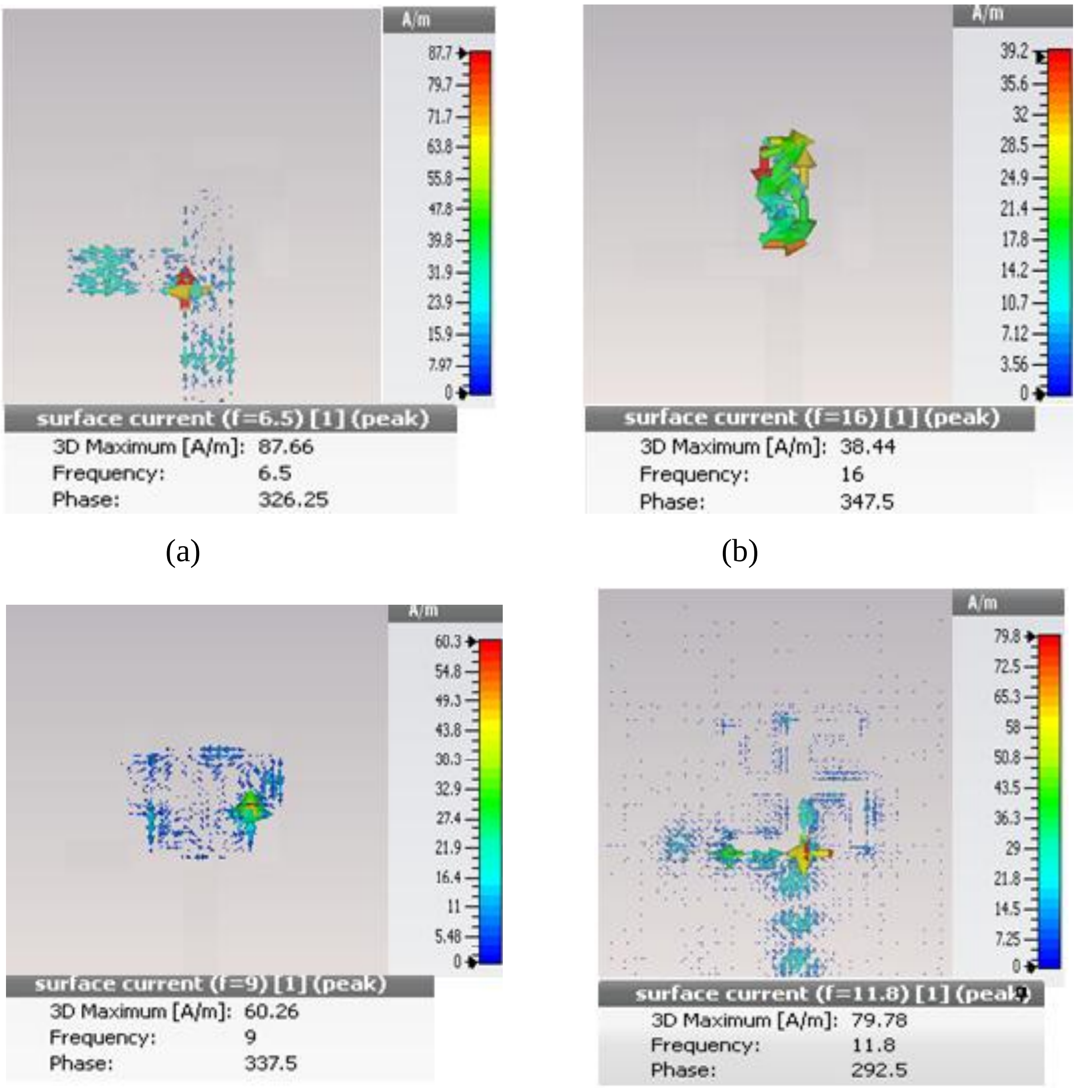


Figure 3.15 Smith chart

3.3.1.4 *Surface current distribution*

Figure 3.16 represents the surface current distribution for different layers of the antenna, from figure 3.16(a) observed that the maximum current (87.66 A/m) is achieved at the centre of the feed line and at that point where stub is attached with it at resonant frequency of 6.5 GHz and it is responsible for the excitation of the lower band. Figure 3.16(b) represents the maximum current (38.44 A/m) for active patch which is small in size. At 9 GHz , maximum current intensity is achieved at the centre of parasitic patch i.e. 60.26 A/m and it responsible for the excitation of the middle band as shown in figure 3.16 (c). For the excitation of the upper band ground plane with DGS play a crucial role thus from figure 3.16(d) observed that maximum current (79.78 A/m) is obtained at the lower edge of the ground plane at resonance frequency of 11.8 GHz.



surface current (f=6.5) [1] (peak)
3D Maximum [A/m]: 87.66
Frequency: 6.5
Phase: 326.25

surface current (f=16) [1] (peak)
3D Maximum [A/m]: 38.44
Frequency: 16
Phase: 347.5

surface current (f=9) [1] (peak)
3D Maximum [A/m]: 60.26
Frequency: 9
Phase: 337.5

surface current (f=11.8) [1] (peak)
3D Maximum [A/m]: 79.78
Frequency: 11.8
Phase: 292.5

(a) (b)

(c) (d)

Figure 3.16 Surface current distributions (a) for feed line (b) for active patch (c) for parasitic patch (d) for ground plane having Swastika shaped DGS

3.3.2 Antenna optimization

The final optimized results were obtained after varying the parametric values of feed line, active patch and stair-case of top most layer etc. The parametric variations that lead to the desired results are presents below:

3.3.2.1 *Effect of variation in feed line width*

Besides controlling the characteristic impedance of the antenna, the width of the feed line also affects the coupling to the slot or aperture. With the variation of feed line we are able to achieve a wider bandwidth at w=2.5mm. Figure 3.17 (blue color dotted plot) shows the optimized value of feed line width i.e. 2.5 mm and better results in terms of bandwidth and return loss are obtained at this value.

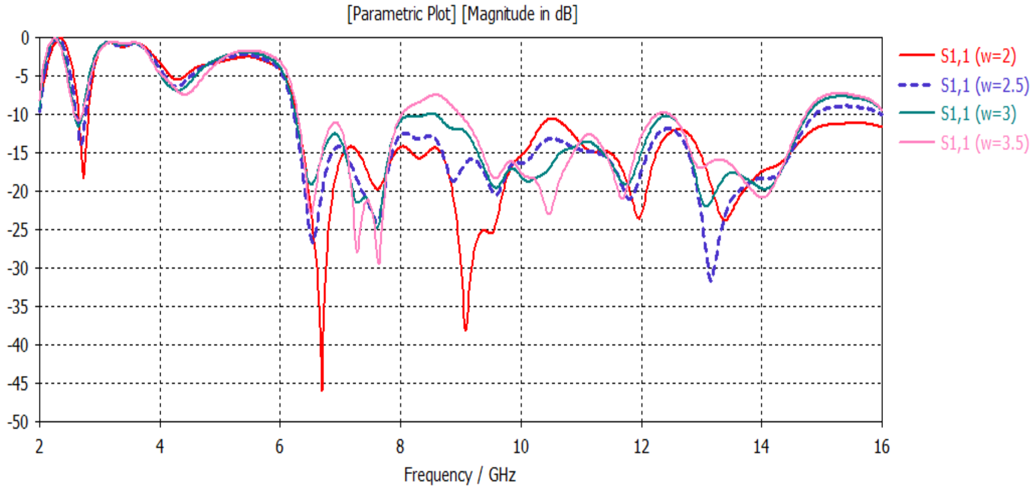


Figure 3.17 S_{11} parameter of feed line variation

3.3.2.2 *Effect of variation in size of the active patch*

The width of the patch affects the resonant resistance of the antenna like a wider patch giving a lower resistance and narrower patch giving higher resistance. The size of the active patch is 13 x $4mm^2$. Hence the dimensions of the active patch with respect to its width , is optimized and obtained optimized value for active patch at 2mm as shown in figure 3.18 (black color dotted plot)

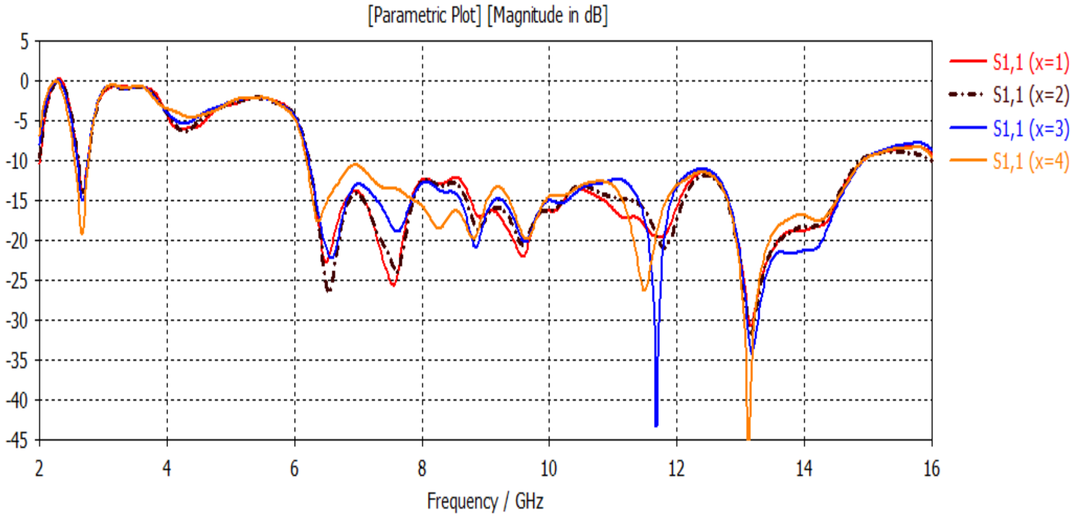
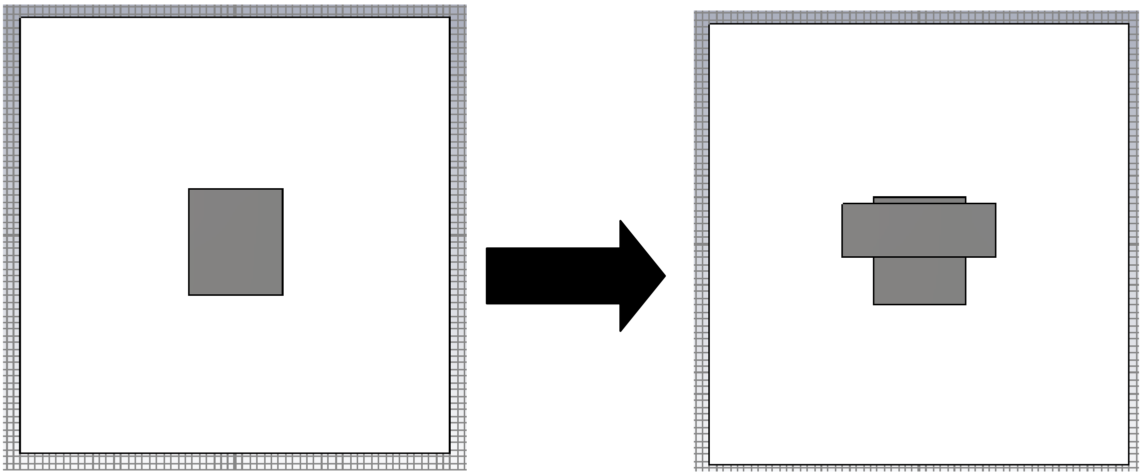


Figure 3.18 S_{11} parameter of active patch variation

3.3.2.3 *Variation in results due to the addition of stair above parasitic patch*

Figure 3.19 shows that with the addition of metallic stair on the parasitic patch give better results in the term of bandwidth and return loss. In case of parasitic patch without stair, we achieve a multiband with bands 6.22 to 8.18 GHz and 8.7 to 14.8 GHz but with addition of metallic stair we are able to achieve an UWB of 6.22 to 14.8 GHz. The combined graph is shown in figure 3.20.



(a) **(b)**

Figure 3.19 Parasitic patch (a) without adding stair (b) with addition of stair

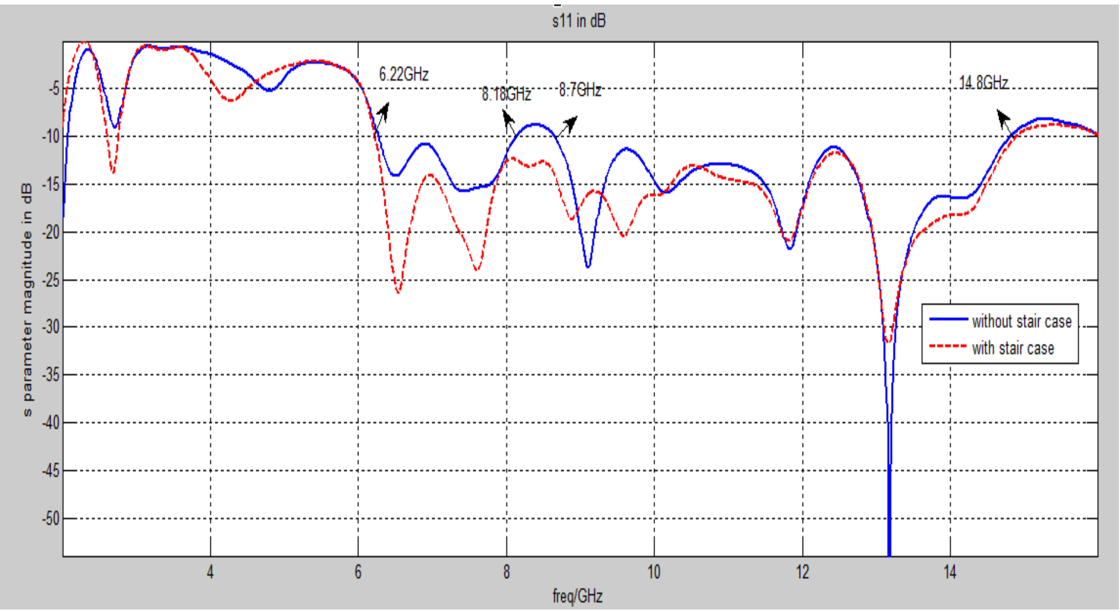


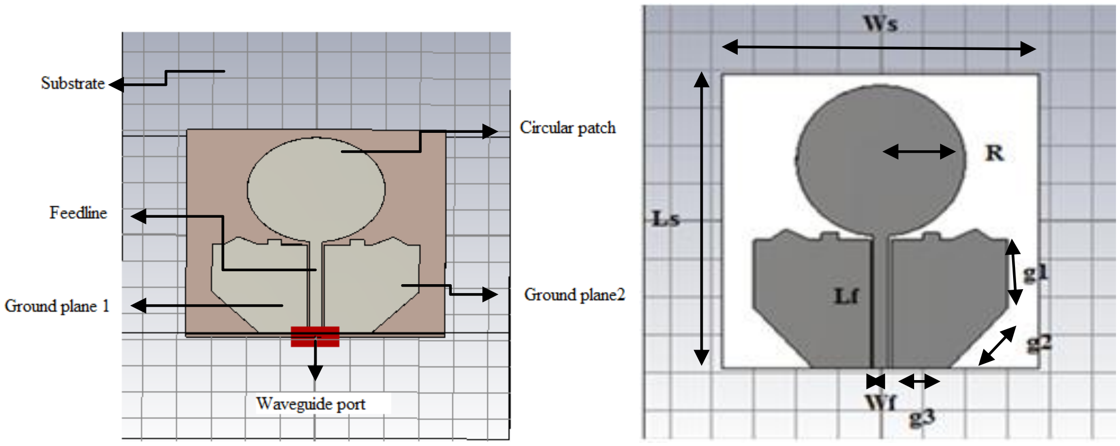
Figure 3.20 Comparison between stair case and without stair case

3.3.3 Wireless applications covered

The ACMPA with swastika shaped DGS covers 6.227 to 14.8 GHz with a band of 8.573 GHz. This antenna design covers applications of H band to recognize the military radio field requirements, in Europe, Ku-band downlink is used from 10.7 GHz to 12.75 GHz for direct broadcast satellite services.

3.4 DESIGN OF CIRCULAR PATCH MICRO STRIP ANTENNA WITH CPW FEED

As discussed in previous chapters, CPW feeding can also be used to achieve a good operational bandwidth from a MPA. Therefore a CPW fed circular patch antenna is presented here. The antenna is a single layered substrate with a circular patch, microstrip feedline and ground on the same layer of substrate. Figure 3.21(a) shows the proposed CPW fed circular patch antenna. Here a coplanar ground plane was placed on the similar plane of the circular monopole patch of radius 20mm (R). The feed length is optimized to a width of 3.66mm. The gap between feed line and ground planes is also optimized to get strong coupling. The value of the gap is 0.57 mm. The basis of monopole radiator is taken in circular shape because the circular patch antenna is able to attain circular polarization characteristics. To further improve the operational bandwidth of antenna, the ground structure is modified from a conventional rectangular design. Two triangular slots of dimensions 16mm, 14mm and 7.07mm are cut from the sides of the coplanar ground. In order to improve the impedance matching at the desired operational bandwidth, a triangle and rectangle are added in to top of this coplanar ground to achieve better impedance bandwidth results. The design parametric values of entire proposed antenna parts are given in table 3.3.



(a) (b)

Figure 3.21 (a) Front view (b) parametric dimensions of proposed antenna design

Table 3.3 Specified and optimized antenna parameters

Parameter	Values(mm)
Resonant frequencies	1.76 GHz, 3.001GHz, 4.049 GHz and 5.16 GHz
Dielectric constant	4.4
Tangent loss	0.0024
Ls ×Ws of substrate	79 ×75
Lf × Wf of feed line	37 × 3.66
R	20
W	27.6
g1	18
g2	16
g3	14

3.4.1 Simulated Results

The design and simulations of proposed antenna structure are carried out using CST MWS version 2014. The optimized results in terms of such as Return loss, Gain, Smith chart and current distributions which are discussed below:

3.4.1.1 S_{11} *(dB) results and improved bandwidth*

The simulation results in terms of Return loss after optimizing the geometrical parameters of antenna like patch, feed line and ground plane are shown in figure 3.22. The antenna covers a bandwidth of 4.61 GHz from 1.46 GHz to 6.07 GHz. The ultra wide band antenna shows peak return losses of -24.4 dB,-28.3 dB,-30.79 dB and -25.4 dB at resonant frequencies of 1.76 GHz, 3.001GHz, 4.049 GHz and 5.16 GHz respectively.

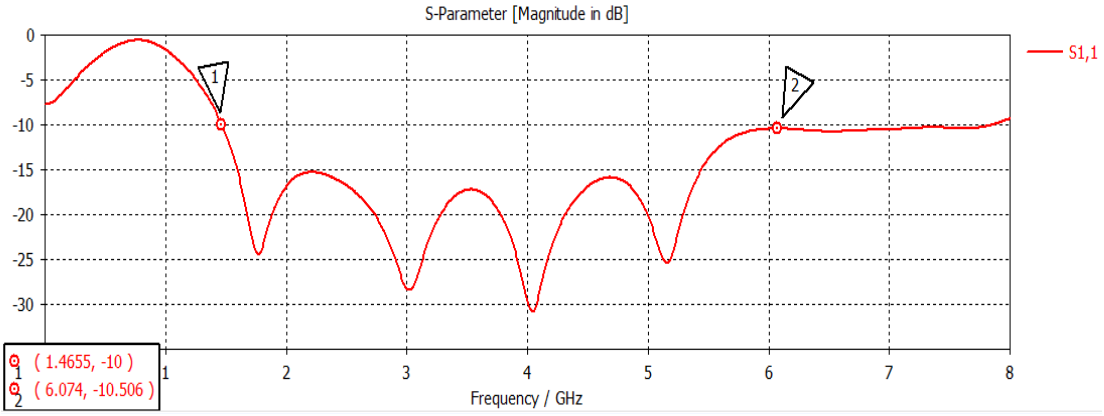


Figure 3.22 Return loss of CPW fed UWB antenna

3.4.1.2 *Gain*

Figure 3.23 shows the broadband gain of antenna. The antenna shows a peak gain of 5.81 dB at a frequency of 6 GHz. In this proposed antenna design , coplanar ground with addition metallic slots is responsible for excellent antenna gain. Figure 3.24 demostrate the 3-D view and polar plot for the peak gain of the antenna. As shown in figure 32.4 (b) the major lobe is directed at an angle of 124 degrees with magnitude of -6.13 dB and half power width of 33.6 degrees.

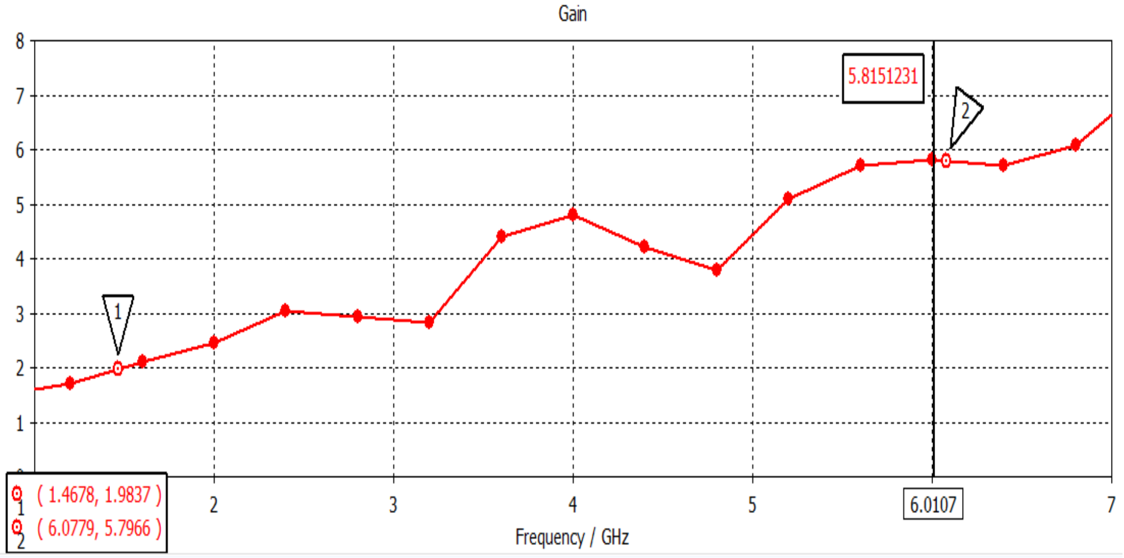
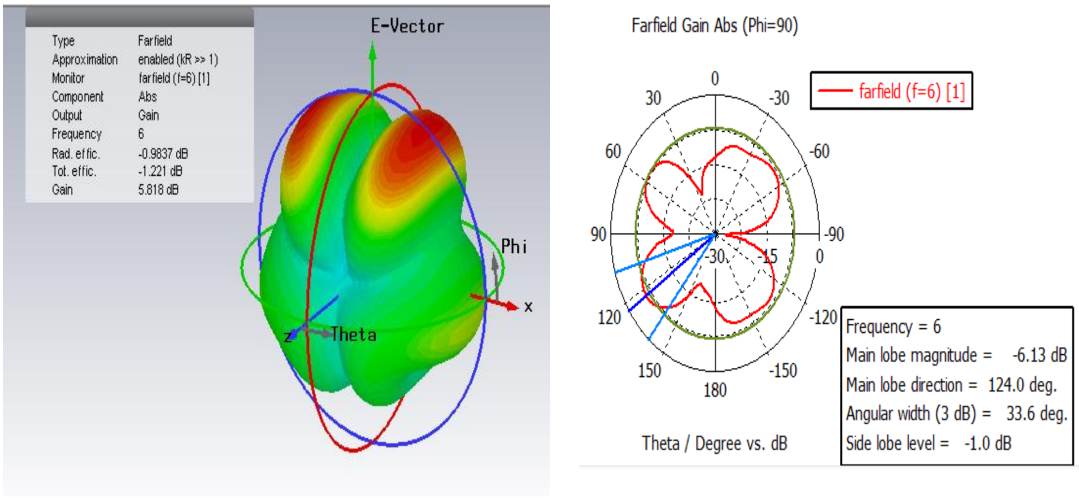


Figure 3.23: Broadband antenna Gain



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=6) [1]
Component	Abs
Output	Gain
Frequency	6
Rad. effic.	-0.9837 dB
Tot. effic.	-1.221 dB
Gain	5.818 dB

Frequency = 6
Main lobe magnitude = -6.13 dB
Main lobe direction = 124.0 deg.
Angular width (3 dB) = 33.6 deg.
Side lobe level = -1.0 dB

(a) (b)

Figure 3.24 Peak gain of proposed antenna at 6 GHz (a) 3-D view (b) polar plot

3.4.1.3 *Smith Chart*

For proper impedance matching the locus of the smith chart must pass out through its centre. The proposed CPW fed antenna shows 50 ohm characteristics impedance. The smith chart of circular patch antenna as shows in figure 3.25 describes the values at the marked frequencies and the curve marker represents the bandwidth of the antenna.

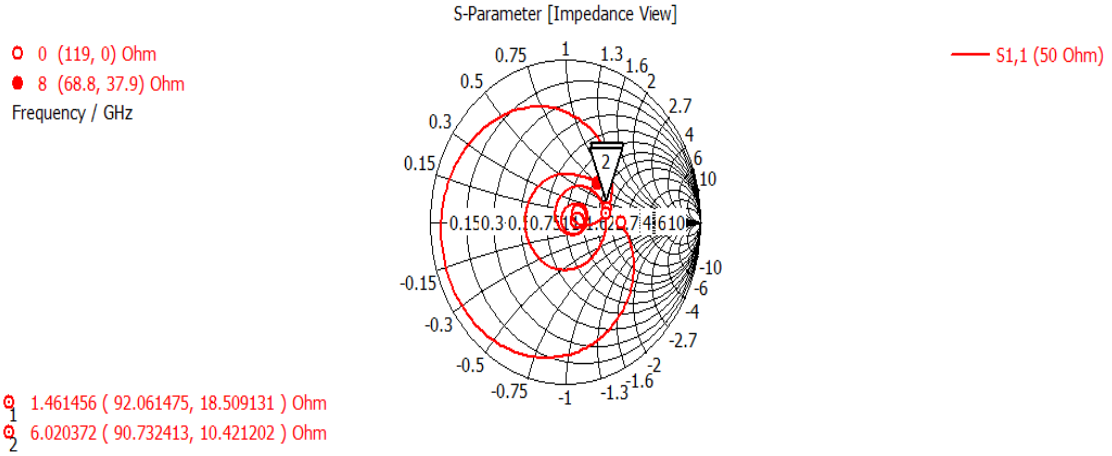
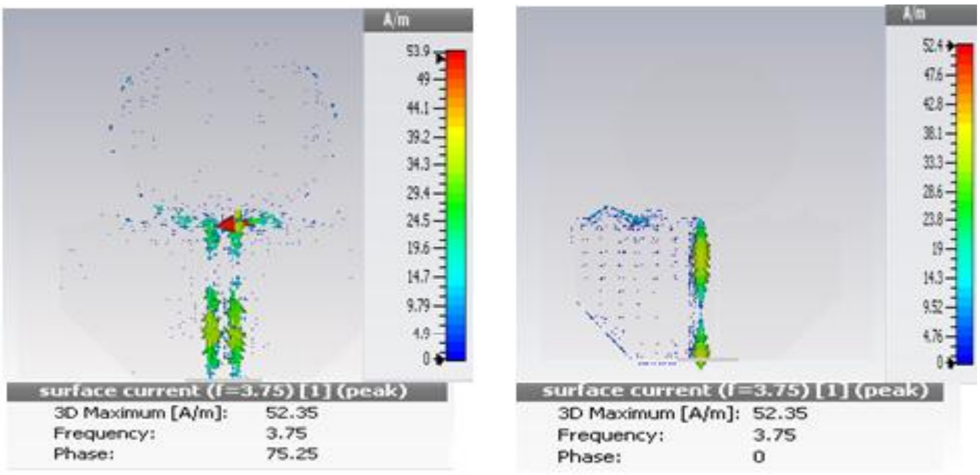


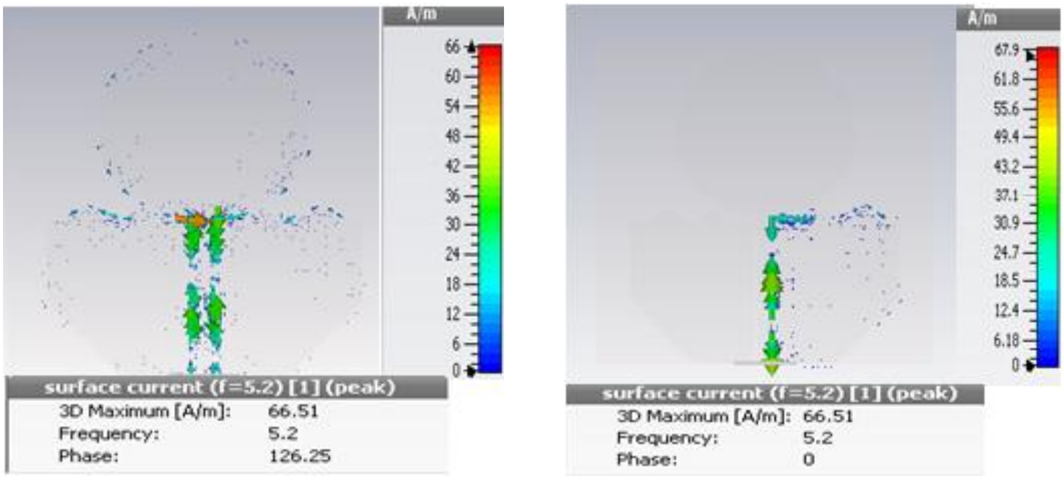
Figure 3.25 Smith chart

3.4.1.4 *Surface current distribution*

It can be observed from the figure 3.26 (a) and (b) that maximum amount of current (52.35A/m) flows at the upper boundary of the right side coplanar ground plane and small amount of current flow in left side ground plane at centre frequency of 3.75 GHz respectively. It is observed that right side coplanar ground is responsible for the excitation of the lower band. Figure 3.26 (c) and (d) shows that maximum amount of current (66.51A/m) flows at the upper boundary of the left side coplanar ground plane and small amount of current flows alone in right side ground plane at resonant frequency of 5.2 GHz respectively. It is observed that left side coplanar ground is responsible for the excitation of the upper band.



(a) (b)



(c) (d)

Figure 3.26 Current distributions comparison at (a) right side ground (b)left side ground for 3.75 GHz(c)left side ground(d)right side ground for resonant peak of 5.2GHz

3.4.2 Antenna Optimization

The final optimized results were obtained in CST MWS 2014 after varying the parametric values of patch, feed line, coplanar ground and spacing between ground and feed line. The parametric variations that lead to the desired results are presents in this section.

3.4.2.1 *Effect of feed line variation*

The feed line is used to control the characteristic impedance of the antenna and affects the coupling to the slot. Therefore the width of feed line is optimized to achieve desired performance of the proposed antenna in terms of impedance bandwidth. The optimized parametric results for different widths of feed line shown in figure 3.27 below. The best optimized results are obtained for feed width of 1.83 mm.

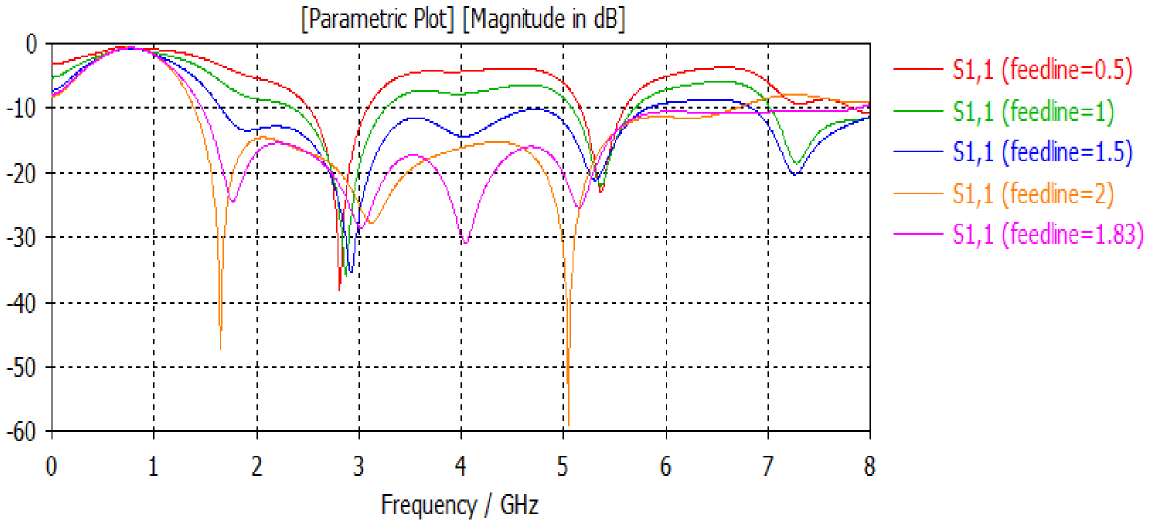
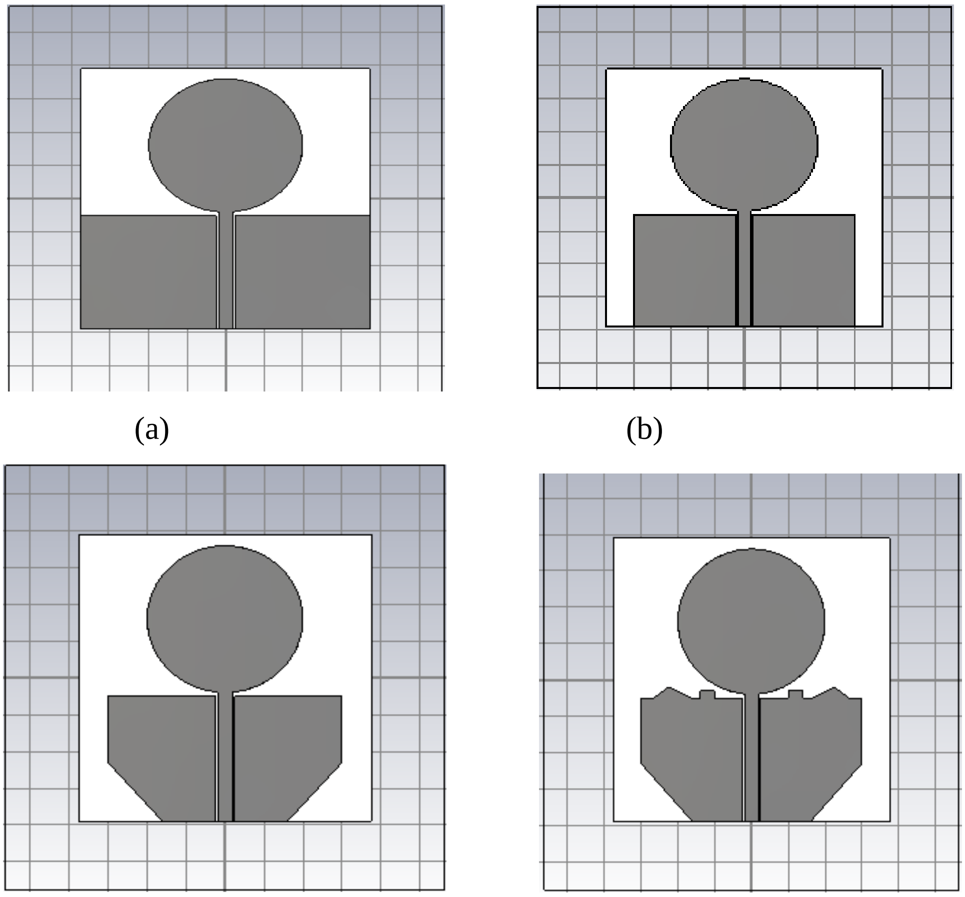


Figure 3.27 Optimized value of feed line at 1.83 mm

3.4.2.2 *Effect of varying the coplanar ground*

The optimization procedure starts with full rectangular ground as shown in figure 3.28 (a). It was observed that since impedance matching was not good for this configuration the impedance bandwidth obtained was 3.3 GHz from 2.6 to 5.9 GHz. A reduction in ground as shown in figure 3.28 (b) from the x-axis that leads to a better impedance matching and hence a broader band of antenna is obtained as shown figure 3.29 (with red color plot). Since the aim is to achieve an ultra wide band from this antenna, two triangular slots are cut from the ground sides as shown in figure 3.28 (c) , these excite resonant frequency near 4.8 GHz and lead to further enhancement in antenna bandwidth as shown in figure 3.29 (violet color plot). Improvement in impedance can be achieved by adding triangular and rectangular sections of metal at the upper boundary of ground as given in figure 3.28 (d). Figure 3.29 shows the combined plot of all these parametric variations. Since geometry of 3.28 (d) shows best results in terms of impedance bandwidth as shown in figure 3.29 (pink color plot), it was selected as the optimized geometry.



(a) (b)

(c) (d)

Figure 3.28 Different antenna geometry (a) Antenna design 1(b) Antenna design 2 (c) Antenna design 3 (d) Antenna design 4

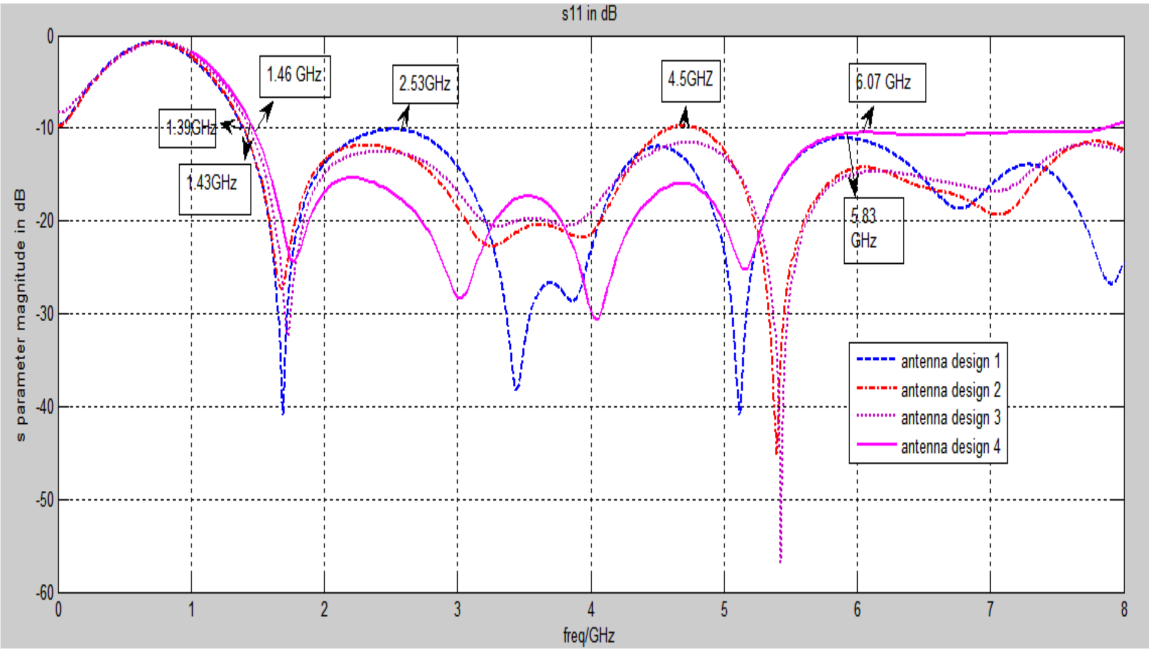


Figure 3.29 Return losses for different antenna structures

3.4.2.3 *Effect of variation in the gap between feed line and ground plane*

In order to optimize the impedance bandwidth results, the value of gap between feed line and coplanar ground is varied from 2mm to 5mm with respect to the length of the antenna. The return loss for the proposed antenna structure with various dimensions as shown in figure 3.30.A superior impedance matching, good return loss and wider bandwidth were obtained at gap width 2.4 mm and therefore it was the selected one for desired applications

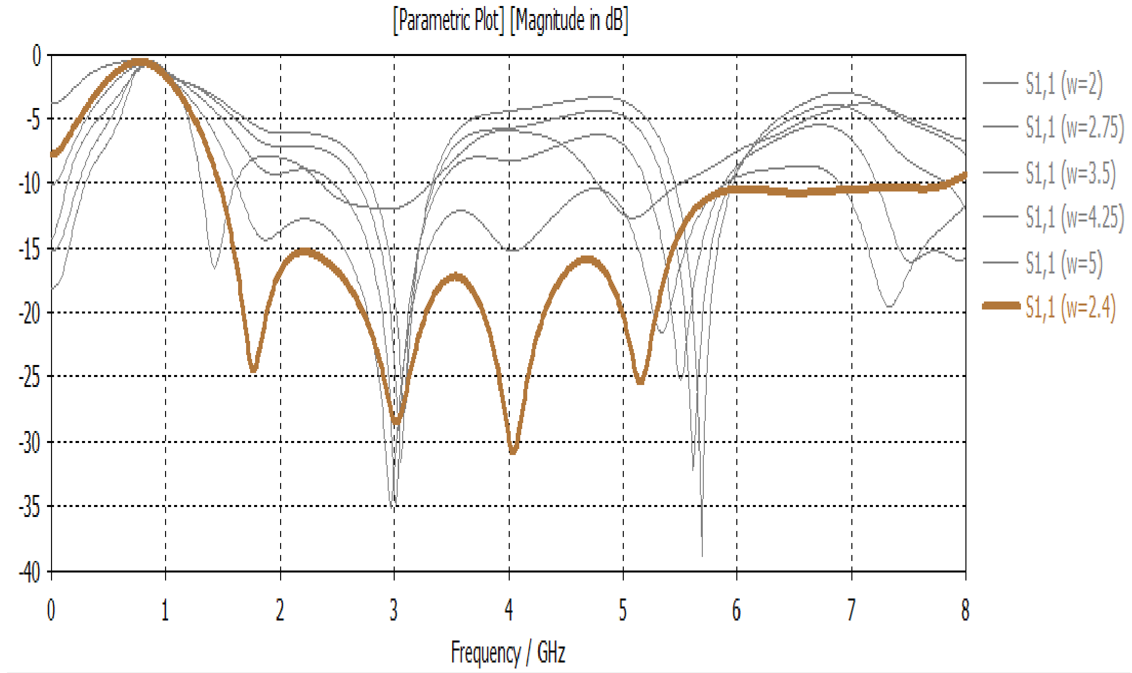


Figure 3.30 Effect of vary ‘the gap between feed line and ground’

3.4.3 Wireless applications covered

The circular patch micro strip antenna with CPW feed covers frequency band of 1.46 GHz to 6.07 GHz with bandwidth of 4.61 GHz. This antenna design covers applications- L band used in satellite navigation, telecommunication, Aircraft surveillance, amateur radio ,Bluetooth, Zig-Bee, S band used in weather forecasting, SONAR, communications satellites like in microwave ovens, microwave devices, mobile phones , global poisoning system, recreational radio, WLAN, Wi-Fi , HIPERLAN-2 used for ATM access and security purpose.

3.5 DESIGN OF RECTANGULAR PATCH COPLANAR GROUND ANTENNA WITH CPW FEEDLINE

The proposed antenna is also a CPW fed antenna that consists of single layer of substrate having material FR-4 lossy with thickness 1.57 mm and dielectric constant 4.4. Two reduced coplanar ground planes and a feedline are placed on the similar plane of the rectangular monopole antenna. Figure 3.31 (a) shows the rectangular patch antenna with CPW feed of dimensions 12×8 mm^2 .A reduced ground layer is made on the same plane of antenna along x-axis for the enhancement of impedance bandwidth and return loss. A rectangular slot is also etched from the center of the patch to attain better return loss. The gap between the feed line and partial ground planes is optimized to obtain strong coupling. The value of the gap is 0.5 mm.The design parametric values of entire specific antenna parameters. and optimized values are given in table 3.4 .

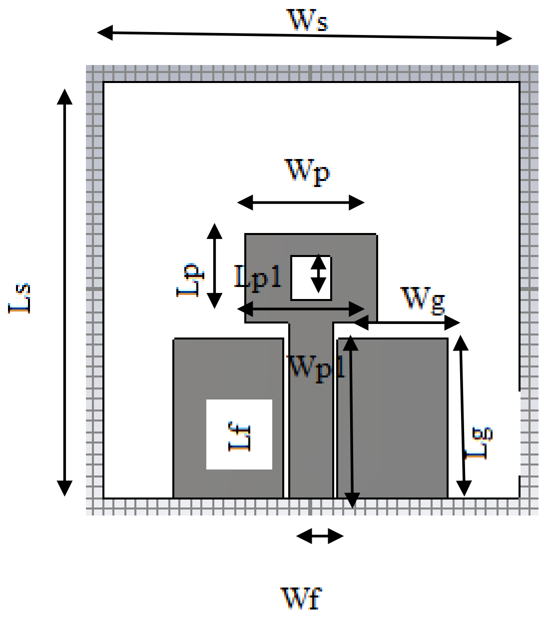


Figure 3.31 Front view of rectangular patch antenna

Table 3.4 Specified and optimized antenna parameters for rectangular patch antenna

Parameter	**Values(mm)**
Resonant frequencies	5.82 GHz and 10.84 GHz
Dielectric constant	4.4
Tangent loss	0.0024
Ls× Ws	38× 38
Lp× Wp	8× 12
Lg×Wg	23.5× 10
Lf× Wf	16× 4
Lp1× Wp1	4×3.6

3.5.1 Simulated Results

The design and simulations of proposed antenna structure are carried out using CST MWS version 2014. The optimized results in terms of such as Return loss, Gain, Smith chart and current distributions which are discussed below:

3.5.1.1 *S_{11} (dB) and impedance bandwidth*

The simulated result of S_{11} parameter in dB is shown in figure 3.32. With repect to the frequency return loss should be as small as possible in the negative range (below -10dB) for maximum power transfer. The antenna resonates at 5.82 GHz and 10.8 GHz covers the frequency band of 4.2 GHz to 12 GHz and an impedance bandwidth of 7.8 GHz allows it to be usable for long distance radio communication, WLAN ,Wi-Fi,military radio field requirements i.e. for disaster executive planning system , welfare activities in military actions, satellite communication, radar, molecular revolving spectroscopy wireless applications. The antenna shows peak return losses of -25.6 dB and -22.196 dB at 5.82 GHz and 10.8 GHz respectively.

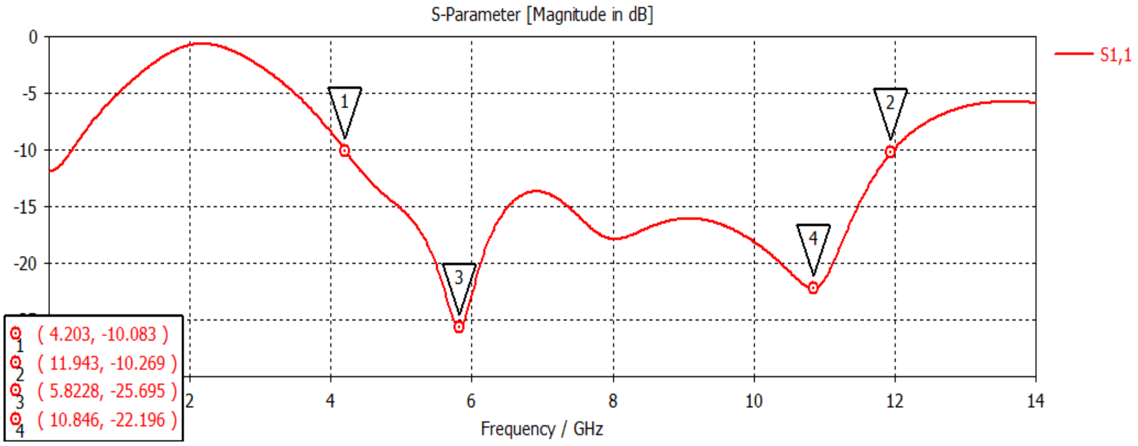


Figure 3.32 Return loss

3.5.1.2 *Gain*

Antenna gain at transmitter determines the how well the antenna converts the input power into the radio waves moving in a particular direction and vice versa at the receiver. It should be greater than 3dB for practical applications. Figure 3.33 demonstrates the broad band gain of the antenna and shows maximum gain 6.154 dB at a frequency of 11.92 GHz frequency. Figure 3.34 demostrate the 3-D view and polar plot for the peak gain of the antenna. As shown in figure 33.4 (b) the major lobe is directed at an angle of 174 degrees with magnitude of -3.87 dB and half power width of 62.5 degrees.The three dimension plot of the proposed UWB antenna shows in figure 3.34.

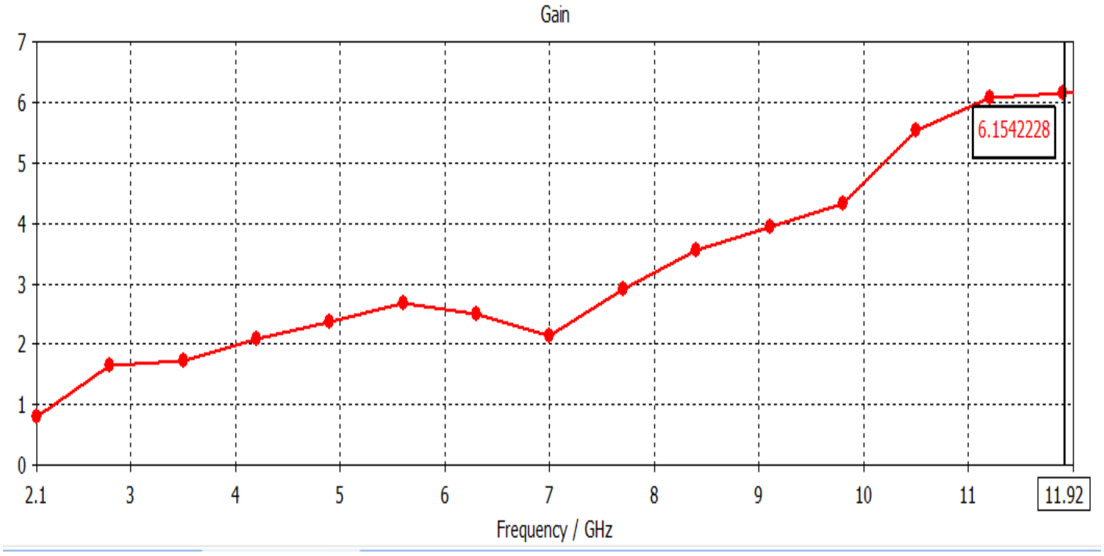
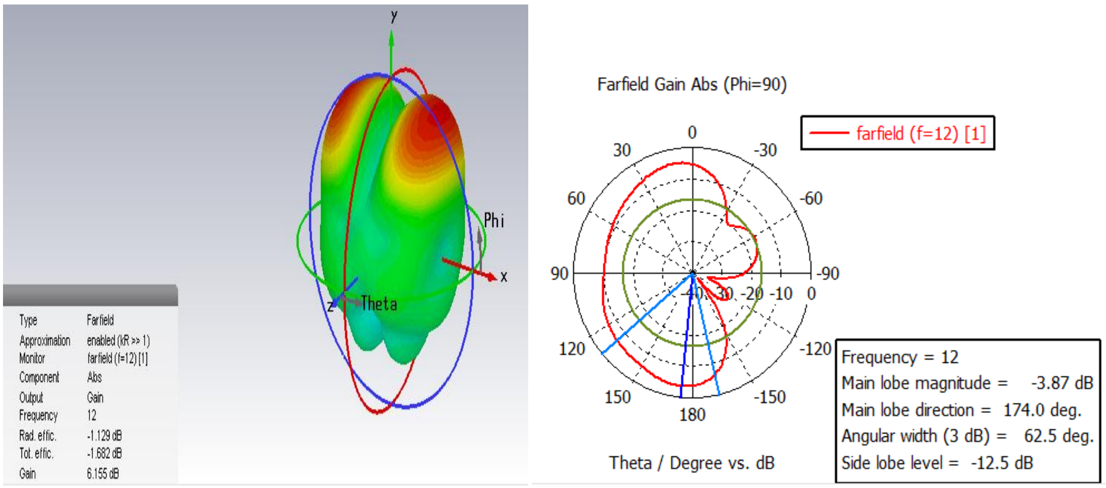


Figure 3.33 Broadband gain of proposed antenna



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=12) [1]
Component Abs
Output Gain
Frequency 12
Rad. effic. -1.129 dB
Tot. effic. -1.682 dB
Gain 6.155 dB

Frequency = 12
Main lobe magnitude = -3.87 dB
Main lobe direction = 174.0 deg.
Angular width (3 dB) = 62.5 deg.
Side lobe level = -12.5 dB

(a) (b)

Figure 3.34 Peak gain at 12 GHz (a) 3-D view (b) polar plot

3.5.1.3 *Smith chart*

Smith chart is used to plot the graph of antenna’s impedance as the function of frequency. The proposed antenna shows an impedaance 50 ohm at the marked frequencies. The smith chart of the rectangular patch CPW fed antenna is shown in figure 3.35. Markers 1 and 2 express the bandwidth of 7.8 GHz for the frequency range from 4.2 GHz to 12 GHz. Hence the proposed antenna exhibits good impedance matching characteristics at the desired band of 4.3-11.9 GHz.

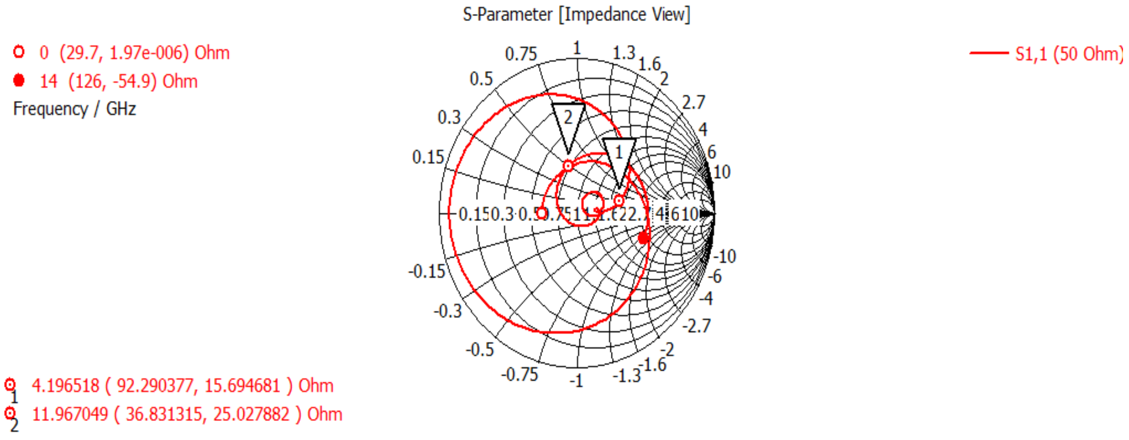
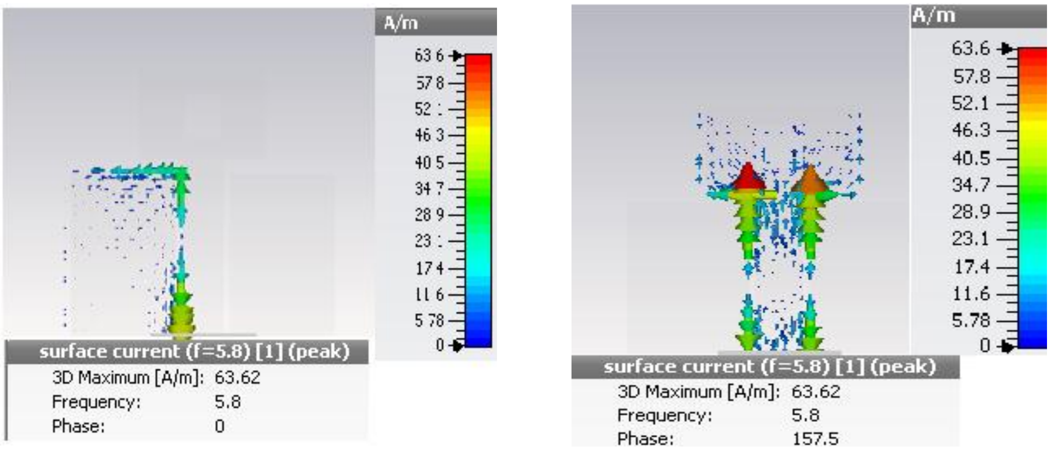


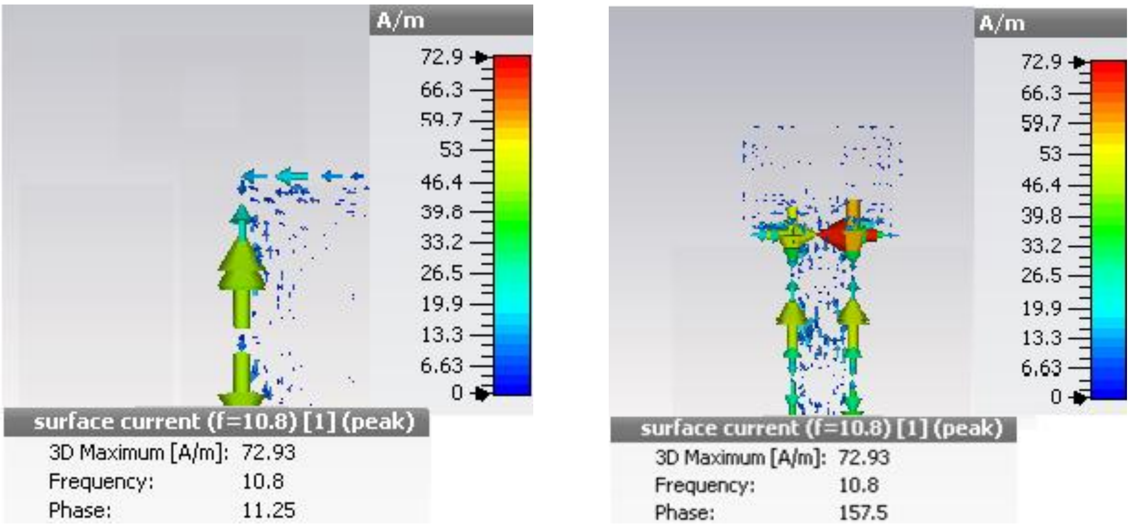
Figure 3.35 Smith chart

3.5.1.4 *Surface current distribution*

The proposed antenna design resonates at two frequencies i.e. 5.8 GHz and 10.8 GHz. Figure 3.36(a-b) shows that rectangutar patch and feedline are responsible for the excitation of the lower band with maximum current 63.62 A/m. For the excitation of higher band, the left side coplanar ground plane is responsible which shows maximum current (72.93A/m) as shown in figure 3.36(c-d).



(a) (b)



surface current (f=10.8) [1] (peak)
3D Maximum [A/m]: 72.93
Frequency: 10.8
Phase: 11.25

surface current (f=10.8) [1] (peak)
3D Maximum [A/m]: 72.93
Frequency: 10.8
Phase: 157.5

(c) (d)

Figure 3.36 Current distribution for (a) Left side ground plane (b) patch at 5.8 GHz (c) right side ground plane (d) rectangular patch along with feed line at 10.8 GHz

3.5.2 Antenna optimization

To get an UWB, final optimized results were obtained by varying the parametric values of antenna like: feed line, modifying in the ground plane etc. The parametric variations that lead to the desired results in terms of bandwidth and return loss are presented in the next subsection.

3.5.2.1 *Effect of variation in feed line width*

The width of the feed line affects the coupling to the slot. Up to a certain level, feed lines with small width couple more strongly to the slot. Figure 3.37 (red color dotted plot) shows the optimized value of feed line width i.e. 2 mm and obtained better results in terms of bandwidth.

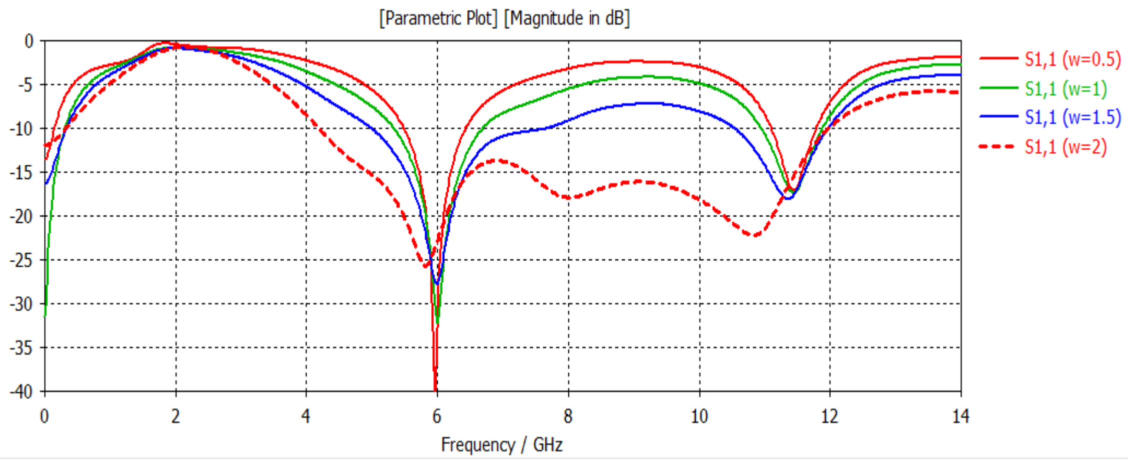
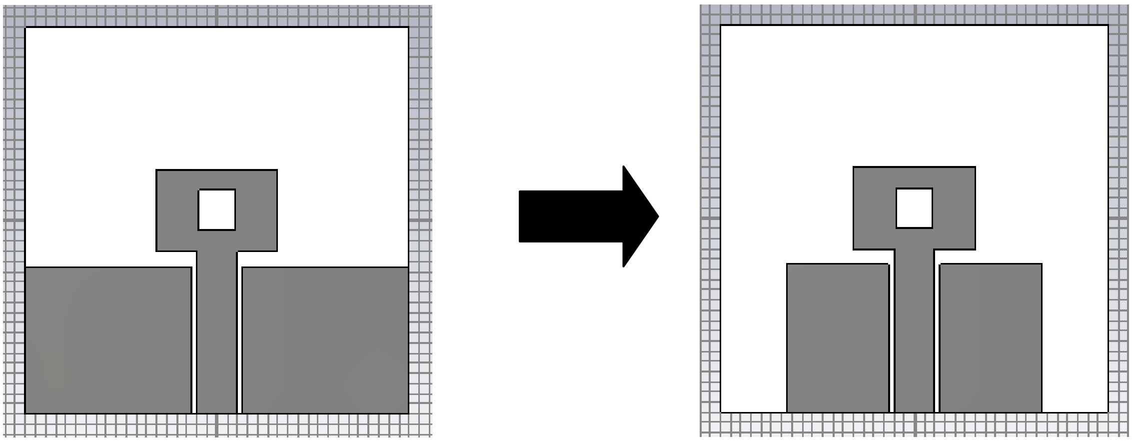


Figure 3.37 S_{11} parameter of variation in feedline width

3.5.2.2 *Effect of ground plane variation*

In order to achieve optimized results a full rectangular ground is taken on as shown in figure 3.38 (a). From figure 3.39 observed that the impedance bandwidth obtained 3.3 GHz from 2.6 to 5.9 GHz. since impedance matching was not good for this configuration. A reduction in ground along its width is made from the x-axis as shown in figure 3.38 (b) which leads to a better impedance matching and good return loss. The value of ground plane along x-axis is varied from 11.5 to 14.5mm. Since optimized results in terms of impedance bandwidth are obtained for a value of 12.5mm. It is selected as the best one



(a) (b)

Figure 3.38 Coplanar ground plane modification

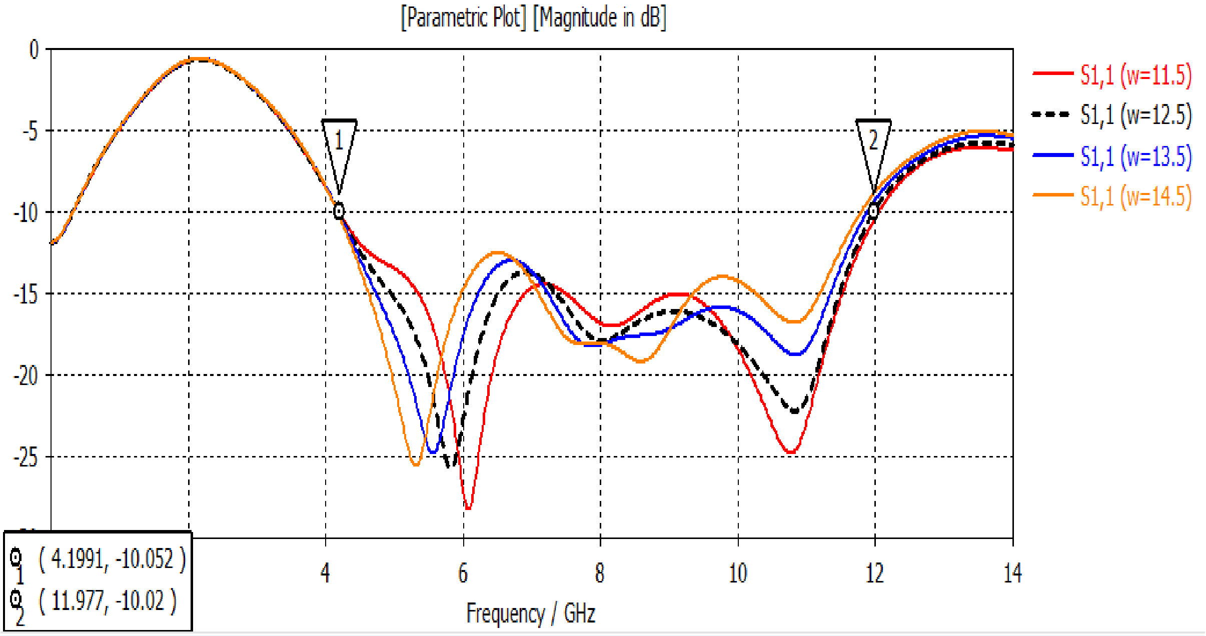


Figure 3.39 Return loss of full ground and reduced ground plane

3.5.3 Wireless applications covered

The rectangular patch antenna with coplanar ground using CPW feed covers 4.2 GHz to 12 GHz of frequency band with bandwidth 7.8 GHz. This antenna design covers applications- C band used for long distance radio communication, WLAN, Wi-Fi, HIPERLAN-2 used for ATM access and security purpose, H band is use to recognize the military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities or in military actions, X band used for satellite communication, radar, space communication, global broadband system, unpaid radio system, molecular revolving spectroscopy etc.

3.6 CONCLUSION

This chapter presents the design and simulation of four UWB antennas for wireless applications. Two antennas are stacked ACMPA and two are coplanar waveguide fed MPAs.

The first antenna that has a U-shaped slot with plus shaped DGS covers a band 4.8 to 10.8 GHz with a bandwidth of 5.92.

The second antenna structure has a T-shaped parasitic patch with swastika shpaed DGS covers a frequency band of 6.227 to 14.8 GHz with a bandwidth of 8.57 GHz.

The third antenna design has a circular shaped patch with coplanar ground plane covers a band of 1.46 GHz to 6.07 GHz with a bandwidth of 4.61 GHz.

The last antenna structure that has a rectangualr shped patch with coplanar groung plane covers a band of 4.2 GHz to 12 GHz with ipedance bandwidth of 7.8 GHz

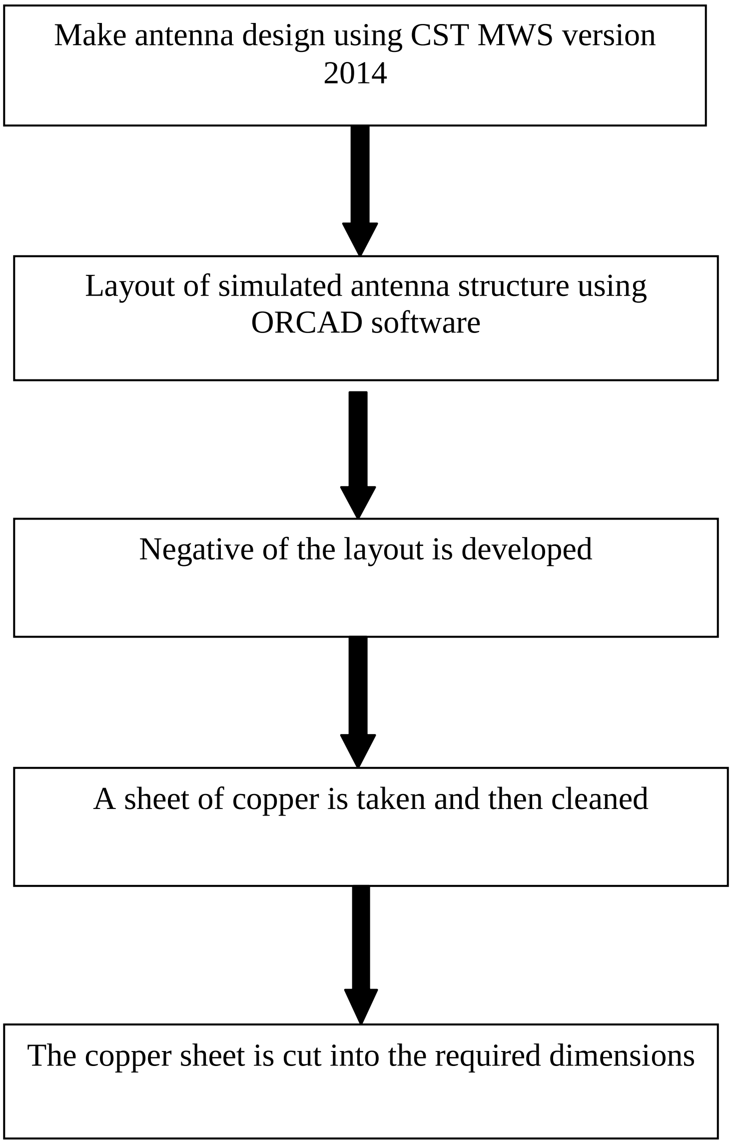
CHAPTER 4

FABRICATION AND TESTING OF STACKED APERTURE COUPLED MICROSTRIP PATCH ANTENNA AND CPW FEED ANTENNA DESIGNS

This chapter presents the fabrication and testing of two antennas that are designed and simulated in chapter 3. The chapters explains fabrication process in a flow chart and the two antennas are tested using a VNA E5063 (Agilent) to evaluate the antenna’s performance for practical wireless applications.

4.1 ANTENNA FABRICATION PROCESS

Various steps are followed to fabricate the antenna structure which is shown via low chart given in figure 4.1



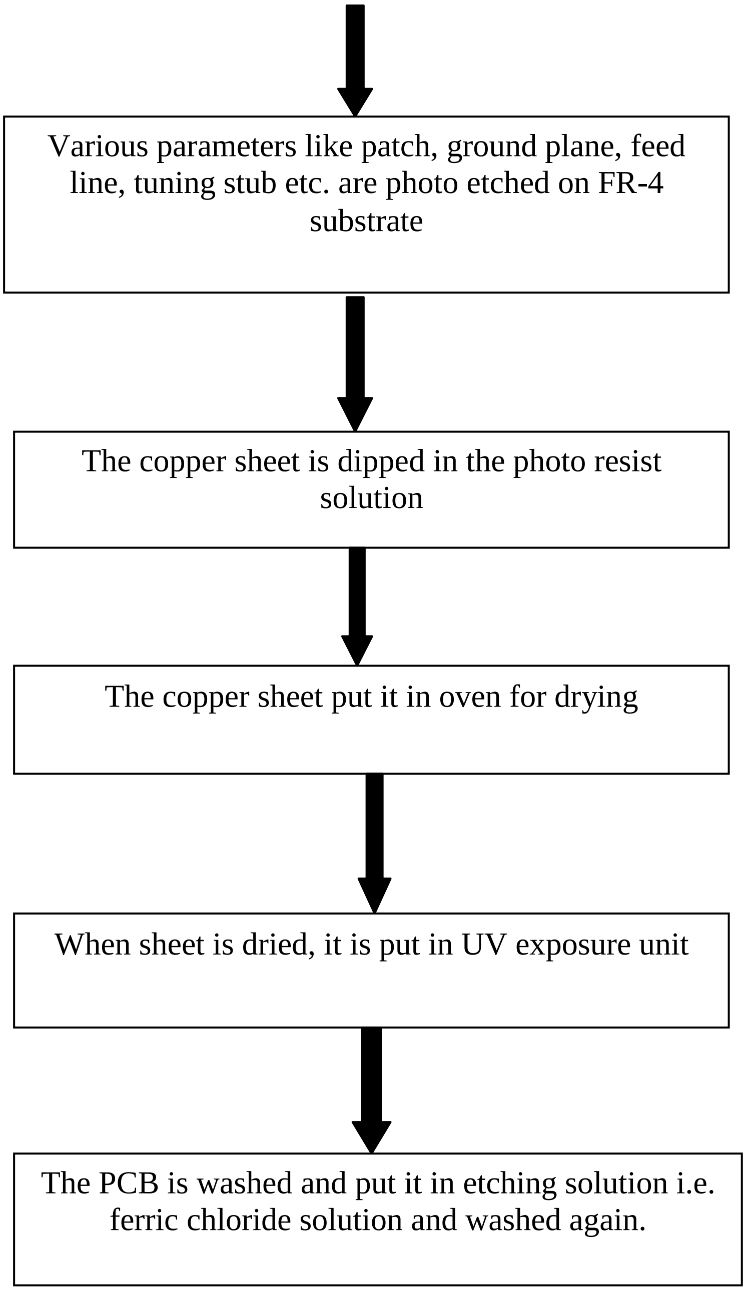


Figure 4.1 Flow Chart of Fabrication Process

4.2 INSTRUMENTS USED FOR ANTENNA FABRICATION AND TESTING

The hardware used to design antenna mainly consists two processes i.e. PCB designing and testing of antenna. The steps used to design are explained as:

- Firstly negative of layout is developed by ORCAD software and print out is taken out.
- The PCB cutter is used to cut the copper sheet in desired dimensions as shown in figure 4.2.

Figure 4.2 PCB cutter

- Now the PCB is dipped in to photo resist solution and dried by placing in an oven for 3-5 minutes. The oven unit contains the paint on the layer that protects the copper sheet. Thus, the oven dries the PCB at 140-150 degree temperature. The Oven Unit is shown in figure 4.3.

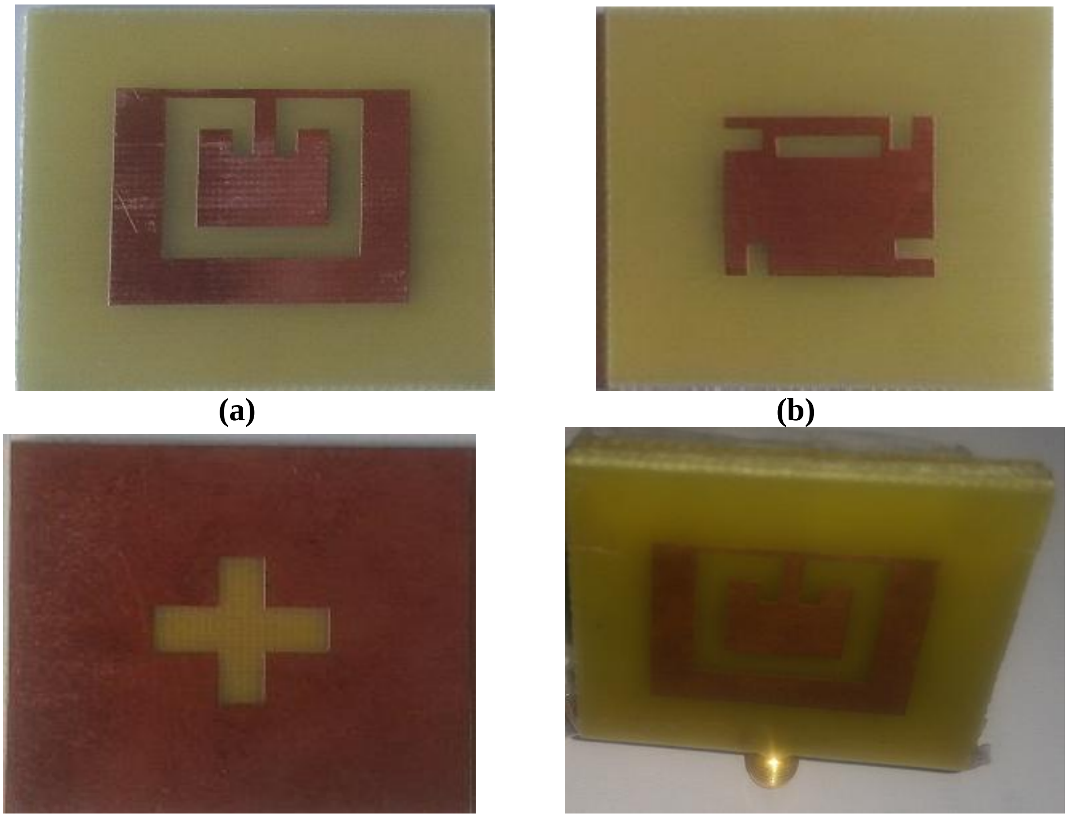
Figure 4.3 Oven unit used for drying process

- The antenna was tested for S_{11} parameter measurements with the help of VNA model no. E5063A with frequency range is from 100 kHz to 18 GHz, for validation of impedance bandwidth as shown in figure 4.4. The SMA (Sub Miniature version A) female connector is used to provide the supply to the antenna. This connector has impedance of 50 ohms.

Figure 4.4 VNA used for antenna testing

4.3 FABRICATED STACKED ACMPA

The layout of stacked ACMPA is prepared by using ORCAD software and the PCB of antenna is prepared using the process mentioned in flowchart figure 4.1. The proposed antenna design consist four layers and each layer is fabricated individually. Figure 4.5(a-d) shows the stacked ACMPA.



(a) **(b)**

(c) **(d)**

Figure 4.5 Fabricated antenna (a) Parasitic patch (b) active patch (c) ground plane with plus shaped DGS (d) Assembled antenna design

4.3.1 Comparison between simulated and measured results for stacked ACMPA

Figure 4.6 shows the comparision between simulated and measured S_{11} (dB) of stacked ACMPA. The proposed antenna shows simulated peak return losses of -27.88 dB, -30.96 dB, -32.75 dB and -27 dB at resonant frequencies of 5.01GHz, 5.65GHz, 6.14GHz and 8.53GHz respectively and covering the frequency band from 4.89 GHz to 10.8 GHz with bandwidth 5.91 GHz. The measured results shows peak return losses of -32.43 dB and -25.78 dB at resonant frequencies of 5.5 GHz and 8.55 GHz.

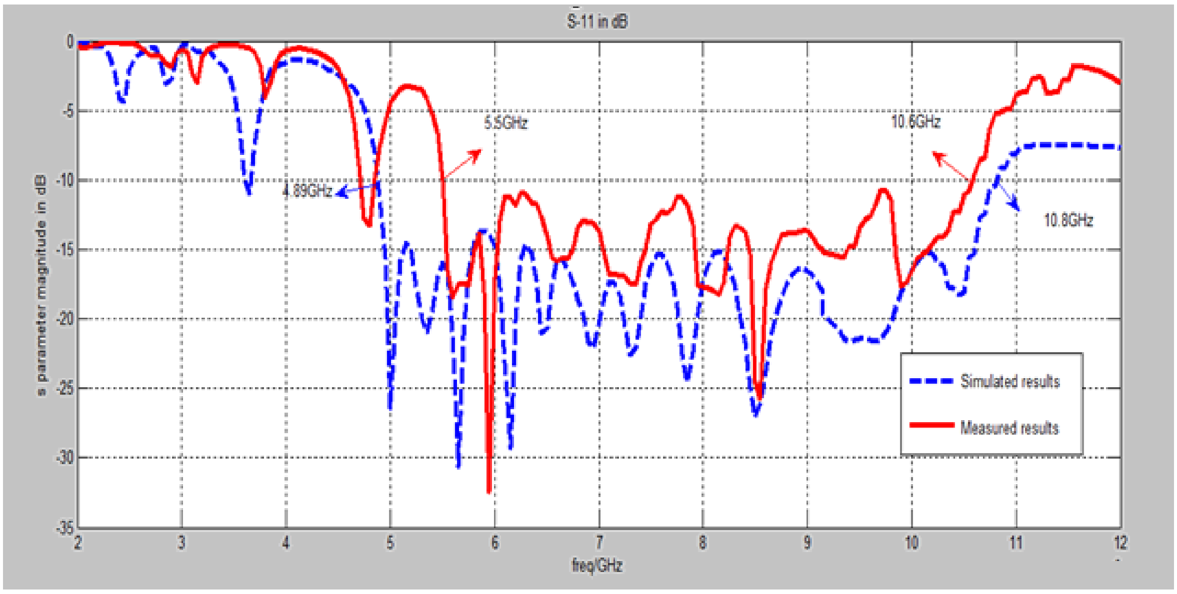


Figure 4.6 S_{11} parameter's comparison between simulated and measured result

Table 4.1 Comparison of Simulated and Fabricated Results of Stacked ACMPA

Parameters	**Simulated results**	**Fabricated results**
Resonating frequencies	5.01 GHz, 5.65 GHz ,6.14 GHz and 8.53 GHz	5.95 GHz and 8.55 GHz
Band covered	4.89 to 10.8 GHz (with bandwidth 5.91 GHz)	5.5 to 10.6 GHz (with bandwidth 5.1 GHz)
Return loss observed at resonant frequency	-27.88 dB, -30.96 dB ,-32.75 dB and -27 dB	-32.43 dB and -25.78 dB
Application covered	Satellite communication, radar, terrestrial broadband communication , amateur radio	Satellite communication, radar, terrestrial broadband communication , amateur radio

Table 4.1 shows that the mesured and simulated results are slightly varying. The frequency band is little shifted towards right. This could be because of misallignment of antenna layers while antenna testing. The measured results also show that the impedance matching has

reduced, this could be because of air gap arising between antenna layers that were not modelled using software. The applications that can be practically covered by the antenna are satellite communication, radar, terrestrial broadband communication, amateur radio etc.

4.4 FABRICATED CPW FEED ANTENNA DESIGN

The circular patch CPW feed antenna is fabricated by the same process mentioned in the flow chart 4.1. This antenna design consist only a single layer of substrate as shown in figure 4.7 and was fabricated using photo-lithography process. The antenna was tested for S_{11} (dB) measurments using the VNA E5063 services. The comparision of simulated and measured results is done in next subsection.

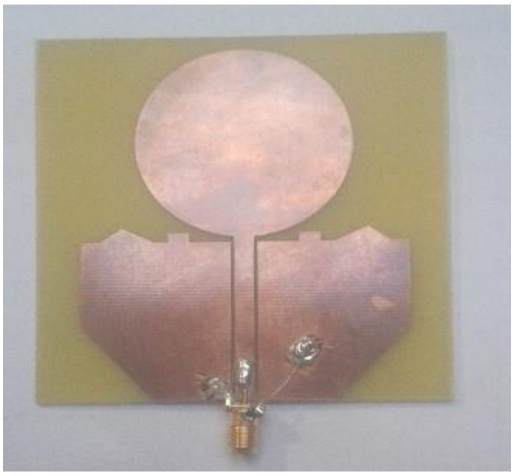


Figure 4.7 Fabricated circular patch antenna with CPW feed

4.4.1 Comparison between simulated and fabricated results for circular patch antenna with CPW feed

Figure 4.8 shows the comparision of simulated and measured return loss (S_{11} parameter) of circular patch antenna with CPW feed. The proposed antenna shows a peak return losses of -24.4 dB,-28.3 dB,-30.79 dB and -25.4 dB at resonant frequencies of 1.76 GHz, 3.001GHz, 4.049 GHz and 5.16 GHz respectively and covering the frequency band from 1.45 GHz to 6 GHz with bandwidth 4.55 GHz. The antenna shows a measured retun loss of -29dB and -22.5dB with frequency 2.25 GHz and 3.7 GHz respectively.

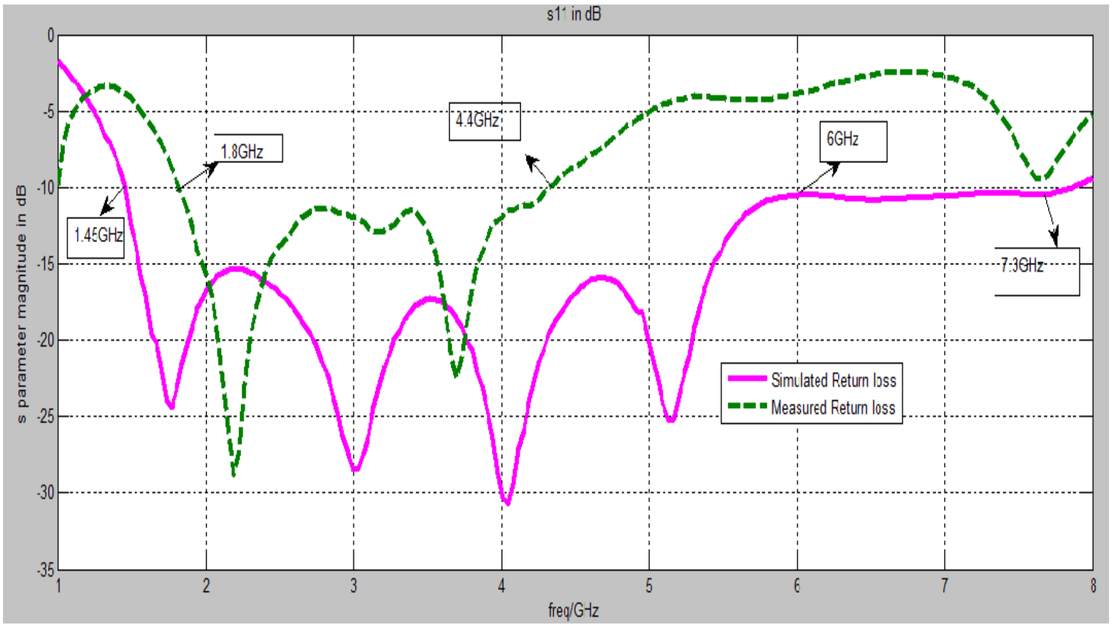


Figure 4.8 Comparison of simulated and measured return loss

Table 4.2 Comparison of Simulated and Fabricated Results of CPW fed antenna

Parameters	Simulated results	Fabricated results
Resonating frequencies	1.76 GHz, 3.001GHz, 4.049 GHz and 5.16 GHz	2.25 GHz and 3.7 GHz
Band covered	1.45 GHz to 6 GHz (with bandwidth 4.55 GHz)	1.8 GHz to 4.4 GHz (with bandwidth 2.6 GHz)
Return loss observed at resonant frequency	-24.4 dB,-28.3 dB,-30.79 dB and -25.4 dB	-29dB and -22.5dB
Application covered	weather radar, microwave oven, mobile phone, WLAN, Bluetooth ,Zig-Bee and in the long distance radio telecommunication systems	Weather radar, microwave oven, mobile phone, WLAN, Bluetooth ,Zig-Bee .

Table 4.2 compares the simulated and measured results. It shows that the proposed antenna can be sucessfully applicable to the wireless application of Weather radar, microwave oven, mobile phone, WLAN, Bluetooth ,Zig-Bee etc.

4.5 CONCLUSION

The chapter presents the fabrication and testing of two antennas designed in chapter 3. These are stacked ACMPA with U slot and circular patch CPW fed antenna. Both the antennas were tested using VNA E5063. The simulated and measured results are matching closley but a slight variation can be attributed to the fabrication and testing errors.

CHAPTER 5

CONCLUSION AND FUTURE WORK

The resarch work presented in this thesis aims at the design and implementation of ACMPA and CPW fed UWB antenna as for current wireless senario.

5.1 CONCLUSIONS

- The mathematical analysis of stacked aperture coupled microstrip antenna and coplanar waveguide microstrip antenna has been explained in Chapter 1 and with help of this analysis, four micro-strip patch antennas were designed and simulated in CST MWS version 2014.
- The chapter 2 presents the literature review done in this thesis regading four antennas are designed and two of them are fabricated and tested for practical applications.
- The chapter 3 presents the four antenna designs. In first design, a stacked three layered micro strip patch antenna with plus shaped aperture was designed which resonates at 5.3 GHz and covers frequency bands of 4.89 to 10.8 GHz having bandwidth 5.95 GHz. Various parameters optimized to obtained most favorable result like-feed line width variation, making slots in active and parasitic patch, optimize the plus shape aperture in ground plane for maximum coupling. The proposed antenna simulation is done in CST MWS 2014 and obtains the results in terms of return loss, gain, smith chart and surface current distributions.
- Second design consists of a stacked ACMPA with T-shaped parasitic patch and rectangular driven patch with swastika aperture in the ground plane. A rectangular tuning stub is attached to the feedline. The proposed antenna is designed and optimized in CST MWS version 2014. The antenna structure resonates at 13.15 GHz and covers the frequency band of 6.227 to 14.8 GHz.
- In third antenna design, a single layer circular patch antenna with CPW feed was designed in CST MWS 2014. The ground plane was modified from a conventional rectangular design for bandwidth improvement. The antenna covered a bandwidth of 4.61 GHz from 1.46 GHz to 6.07 GHz. This ultra wide band antenna shows peak return losses of -24.4 dB,-28.3 dB,-30.79 dB and -25.4 dB at resonant frequencies of 1.76 GHz, 3.001GHz, 4.049 GHz and 5.16 GHz respectively.
- The last antenna design consists of a single layer substrate, rectangular patch, CPW feed line and coplanar ground plane. A rectangular slot is etched from the centre of the patch to attain improved return loss. The antenna resonates at 5.8 GHz covers the frequency band of 4.2 GHz to 12 GHz. The antenna shows peak return losses of -25.6 dB and -22.196 dB at 5.82 GHz and 10.8 GHz frequency respectively.

- In Chapter 4, stacked aperture coupled antenna with plus shaped aperture and circular patch antenna with CPW feed were fabricated. The comparision of simulated results results shows little variation. This variation is due to fabrication and testing errors. Table 5.1 shows the comparision of simulated results of all the antennas.

Table 5.1 Conclusion of simulated and fabricated result for all proposed antenna designs

Proposed Antenna designs	**Resonant frequency in GHz**	**Return loss in dB**	**Bandwidth in GHz**	**Peak gain in dB**	**Fabricated results in terms of return loss**
Stacked aperture coupled antenna with U- shaped slot in parasitic patch	5.01 ,5.65, 6.13 and 8.5	-27.93, -30.8, -32.24 and -27.18	5.92	6.06 dB at 9 GHz	-32.43 dB and -25.78 dB at 5.95 GHz and 8.55 GHz respectively
Stacked aperture coupled antenna with swastika shaped DGS	-26.6, -23.4, -21 and -31	6.5 , 7.6 , 11.8 and 13.14	8.573	4.35 dB at 9 GHz	----
Circular patch antenna with CPW feed	-24.4, -28.3, -30.79 and -25.4	1.76, 3.001, 4.04 and 5.16	4.61	5.81 dB at 6 GHz	-29 dB and -22.5 dB at 2.25 GHz and 3.7 GHz respectively
Rectangular patch antenna with CPW feed	-25.6 and -22.196	5.82 and 10.84	7.8	6.15 dB at 12 GHz	----

The antennas can be successfully used for satellite navigation, telecommunication, aircraft surveillance, amateur radio,Bluetooth, Zig-Bee, weather forecasting, SONAR, communications satellites like in microwave ovens, microwave devices, mobile phones , global poisoning system, recreational radio,long distance radio communication,Wireless local area networks,Wi-Fi,ATM access and security purpose,recognize the military radio field requirements i.e. for disaster executive planning system and its training, electronics welfare activities ,direct broadcast satellite services wireless applications

5.2 FUTURE SCOPE

Different methods can also be used in future to design antenna which are specified below:

- **Metamaterials:** There are type of materials in which properties depend upon the inter-atomic structure rather than atom’s composition. A metamaterial can be a metallic substance or semiconductor substance. It has negative value for both relative permittivity (ε_r) and relative refractive index(μ_r). There are various types of metamaterials out of which some are able to twist the visible ray and IR (infrared ray) from conventional refractive medium. Due to this behavior used in many applications like- optical communication system, medical diagnostic apparatus, spectrometry, optical wrapping devices etc.

- **Different shapes of aperture slots (DGS):** For the improvement of return loss, gain, bandwidth different shapes of aperture slot is etched from the surface of ground plane like H-shape, U-shape, I-shape and E shape etc. The slots with broaden ends can also improve the coupling of the antenna.
- **Different feeding techniques:** In future instead of aperture coupled feed and coplanar waveguide (CPW) feed many other feeding techniques can be used. The various types of feeding methods used to design MPA are inset microstrip, coaxial and proximity feed line.
- **Patch Antennas with Switchable Slots:** When MPA used with switchable slots shows attractive features because of its easy structure, single feedline and single layer design. This makes them compatible for wireless communication systems. MPA with single switchable slot used to obtained dual frequency band. While to get dual band along with circular polarization two switchable slots can be used.
- **Use of UWB antennas for cancer detection**: The UWB MPAs can be used for the detection of tumors and cancer using radar based microwave imaging technology. Here the signalas atr trasmitted and back scattered signals are recorded. A back scattered signal from a tumor cell show more reflection as the water content of tumor is more.

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