

# **DESIGN AND FABRICATION OF REFLECTIVE META SURFACE BASED MSPA WITH ENHANCED GAIN**

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

**MASTER OF ENGINEERING**

IN

**ELECTRONICS AND COMMUNICATION ENGINEERING**

Submitted By

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
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**JULY, 2017**

## DECLARATION

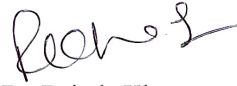
I, Aditi Ary hereby declare that the work presented in this thesis entitled " DESIGN AND FABRICATION OF REFLECTIVE META SURFACE BASED MSPA WITH ENHANCED GAIN" in fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering, Thapar University, Patiala is an authentic record of work carried out under supervision of Dr. Rajesh Khanna (Professor, Thapar University). 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.

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

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## ACKNOWLEDGEMENT

First and foremost, I would like to thank GOD for showering His blessing upon me during the complete work duration and providing me courage and ability to work against all the odds.

Besides, I would like to express my sincere gratitude to my research supervisor Dr. RAJESH KHANNA (Professor), ECED, Thapar University, Patiala for their constant support, patience, motivation, enthusiasm and guidance during my course work. I have been inspired by their conscientious attention to detail and their energetic response to any problem. I value their concern and support at all times, good and bad. They have always emphasis on self-motivation during rough or bad periods and appreciated in good days. The words are not enough to thank them.

I am also thankful to Thapar University for the facilities and healthy environment for study. I also express my sincere thanks to my Head of the Department, Dr. Alpana Aggarwal for providing me decorous environment in carrying the work.

I am highly obliged and wish to owe my sincere gratitude to Dr. Amit Mishra, Assistant Professor, ECE Program Coordinator and Dr. Hem Dutt Joshi, Assistant Professor, P.G. Coordinator, Electronics and Communication Engineering Department, Thapar University, Patiala providing me facilities, learning atmosphere and infrastructure in ECED.

I am very thankful to PhD scholar Miss Deepa negi for their time and patience, being a guiding light all the time.

Finally, I must express my profound gratitude to my parents and friends for providing unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

(Aditi Ary)

## ABSTRACT

Due to increasing interest in gain enhancement of micro strip patch antenna(MSPA) and integration of more than one wireless applications at different bands on a single antenna, concept of reflective meta-surfaces (RMS) comes into account, effectively, keeping the size of the radiating surface small. In this paper, a reflective meta-surface -inspired antenna is proposed for 3.5 GHz and 5.8 GHz band i.e. WiMAX and WLAN. The micro strip patch antenna is having dimension  $50 \times 60 \text{ mm}^2$  and substrate height of 1.6mm, fabricated on Rogers duroid (5880). The antenna has two fine rectangular slots, which helps the antenna to achieve dual band operation at WiMAX (3.5GHz) and WLAN (5.8GHz). Microstrip feed technique is used which gives freedom to optimize impedance matching easily. The RMS surmounted at a height of 15 mm in air, above the radiating patch, mounted. The material used for manufacturing RMS is FR4 with thickness of substrate as 0.25mm. The pattern on the meta-surface is conventional rectangular split ring resonator structure. Parametric analysis and simulation results validate that the reflective type meta-surface (RMS) mounted on micro strip patch antenna enhances the effective gain of antenna in both the band up to 2 dB. It also provides an appreciable impedance bandwidth of approx. 6.6% and 10% and gives a better form-factor. Along with the Gain, different properties of antenna i.e. radiation pattern, front to back ratio, return loss and VSWR are studied. The simulated and measured results of fabricated prototype unveil that the suggested work is suitable for emerging WLAN/WiMAX applications.

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## LIST OF ABBREVIATIONS

ACS	Asymmetric co-planer feed
EM	Electromagnetic waves
MMIC	Monolithic Microwave Integrated Circuit
MSPA	Microstrip patch antenna
NRI	Negative Refractive Index
PRI	Positive Refractive Index
RMS	Reflective meta surface
UMTS	Universal Mobile Telecommunications Service
WLAN	Wireless Local Area Network
LHM	Left Handed Material
SSRR	Square Split Ring Resonator

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# CHAPTER 1

## INTRODUCTION

In RF system, Antenna is the basic requirement for transmitting or receiving the signal into and from, air, acting as medium. It is the transducer used for converting electric signals into EM waves. Antenna also called as Aerial whose plural is antenna has now a day's undergone many alterations as per size and shape requirements. Thus according to size, need and many other parametric necessities different type of antenna can be found accordingly. Main goals to focus is increasing and improving gain bandwidth and varying parameters in order to improve the result of the antenna.

### 1.1 NECESSITY OF ANTENNA

As communication can be either wired or wireless, Antenna suppress the need of wires used in communication system thus make the whole system wireless for the sake of transmitting signal from one place to another with the help of EM waves.

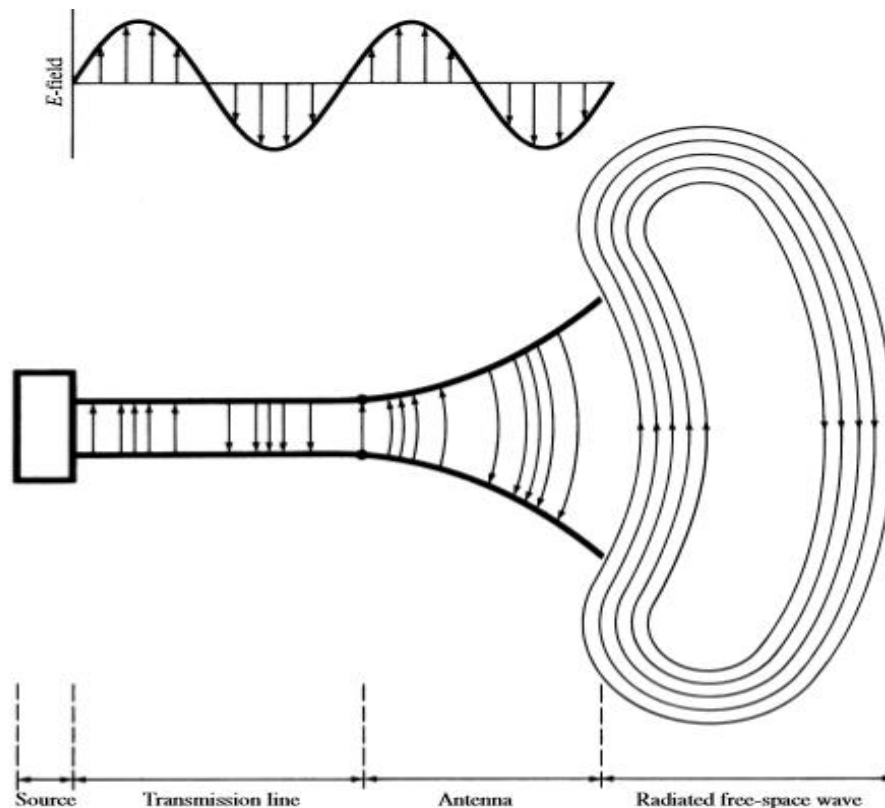


Figure 1.1 Antenna as transmitter in wireless communication [1]

Division of antenna is made-

- On the basis of Physical structure of antenna
  - Aperture antenna
  - Wire antenna
  - Reflector type antenna
  - Lens antenna
  - Micro strip patch antenna
  - Array antennas
- On the basis of operating frequency
  - Very-low frequency (VLF) ranging from 1kHz to 10kHz
  - Low frequency (LF) ranging from 10kHz to 100kHz
  - Medium frequency(MF) ranging from 100kHz to 1MHz
  - High frequency(HF) ranging from 1MHz to 10MHz
  - Very high frequency (VHF) ranging from 10MHz to 100MHz
  - Ultra-high frequency(UHF) ranging from 100MHz to 1GHz
  - Super high frequency(SHF) ranging from 1Ghz to 10GHz
  - Microwave
  - Radio wave
- On the basis of mode of application
  - Point to point communication
  - Broadcasting applications
  - Radar communications
  - Satellite communications

## **1.2 MECHANISM OF RADIATION**

The key role of antenna is Power radiation or reception. Antenna thus connected to the main circuit with the help of transmission lines. Now, if transmission lines allow current to travel inside with uniform velocity and in straight line with infinite extent, radiates NO POWER. Thus, transmission line undergo following requirements to be a WAVEGUIDE and radiate power.

- In order to radiate power, with uniform velocity current conduction, transmission line should be truncated bent or terminated.
- Accelerated or de--accelerated current in transmission line with time varying constant, then it radiates power regardless of straight wire.
- Waveguide is the name given when device or tube is bent or terminated for purpose of getting radiated energy. These are basically used for transmission or reception of microwaves.

### 1.3 PERFORMANCE PARAMETERS FOR ANTENNA

Performance of antenna is based on several measuring parameter which need to be fulfilled in order to resonate antenna on desired frequency effectively and efficiently. Those parameters are discussed below-

#### 1.3.1 Frequency

The rate of repetition of a wave over a specific period of time is termed as frequency.

$$f_0 = \frac{1}{t_0} \quad (1.1)$$

where,

$f_0$  is frequency.

$t_0$  is time period.

#### 1.3.2 Wavelength

The distance between two consecutive crests(maxima's) or two consecutive troughs (minimas) is called as wavelength .

$$\lambda = \frac{c}{f} \quad (1.2)$$

where,

$\lambda$  is wavelength in meters

$c = 3 \times 10^8 \text{ m/sec}$  Is speed of light

f is frequency

#### 1.3.3 Impedance Matching

As per this concept is concerned the approximate value of transmitter's impedance is equal to approximate value of receiver's impedance or vice versa. It is important parameter to achieve

maximum power transfer between antenna and transmitter or receiver.

- Need of Impedance Matching: A resonant device for example Antenna provides better output at certain band of frequencies. Antenna whose impedance if matched, delivers a better Power.
- If antenna matches the free space impedance power radiated by an antenna will be effectively radiated.
- For both transmitter and receiver antennas input impedance or output impedance of antenna should match with output impedance of transmitter amplifier and input of receiver amplifier along with the transmission line impedance.

### 1.3.4 VSWR

Due to impedance mismatching of antenna transmission line and circuitry some power reflects back causing standing waves. Thus ratio of maximum voltage to minimum voltage in standing wave is termed as VOLTAGE STANDING WAVE RATIO. The reflected power is wasted from power radiated. Impedance mismatch is directly proportional to VSWR. Its value ranges from 1 to infinity. Practically,

$$VSWR \geq 2 \tag{1.3}$$

Reflection coefficient is given by:

$$\Gamma_0 = \frac{Z_a - Z_0}{Z_a + Z_0} \tag{1.4}$$

VSWR is related to reflection coefficient as-

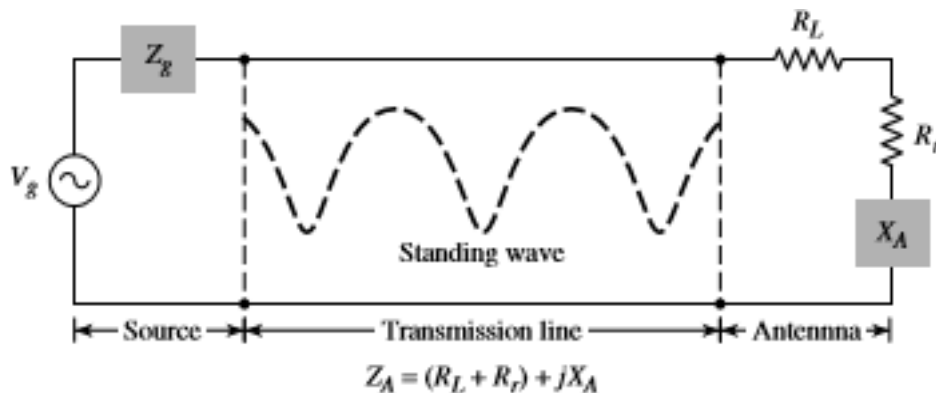


Figure 1.2 Thevenin equivalent of transmission line comprising SWR [1].

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1 + |\Gamma_0|}{1 - |\Gamma_0|} \quad (1.5)$$

### 1.3.5 Bandwidth

It is range of frequencies specified for particular communication. It can be said as band of frequencies between higher and lower one over which signal is transmitted. Further the whole spectrum is divided into bandwidths to be allotted to different transmitters. Graphically, it is calculated by the range of frequency crossing -10dB in return loss plot .

$$\text{percentage bandwidth} = \frac{f_h - f_l}{f_c} \quad (1.6)$$

where,

$f_h, f_l$  and  $f_c$  is higher , lower and centre frequency.

### 1.3.6 Radiation Intensity

It is defined as POWER per unit solid angle. Intense radiation emitted from antenna in particular direction indicates maximum radiation intensity of that antenna.

$$U = r^2 * W_{rad} \quad (1.7)$$

where,

U is radiation intensity

R is radial distance

$W_{rad}$  is power radiated

### 1.3.7 Directivity

The ratio of maximum intensity of radiation in a particular direction by subject antenna to the mean of radiation intensity in all direction which can be obtained by isotropic antenna. The average intensity of radiation is equivalent to overall radiated power by  $4\pi$ .

$$D = \frac{U_s}{U_i} = \frac{4\pi U_0}{P_{rd}} \quad (1.8)$$

where,

$U_s$  is radiation intensity of subject antenna

$U_i$  is radiation intensity of isotropic antenna

### 1.3.8 Front to Back Ratio(FTB)

The Power gain ratio between front and back direction of a directional antenna is (FTB). It is also a measure of Directivity in forward direction with respect to reverse direction.

### 1.3.9 Gain

The ratio of antenna intensity of radiation in one particular side to radiation intensity that we get when power accepted by antenna is radiated isotropically.

- It takes directivity into account but not include losses due impedance mismatch and polarization mismatch.
- Unit of gain is dB.
- Relative gain is power gain in particular direction of subject antenna to power gain by isotropic antenna.

$$G' = \frac{4\pi U(\Theta, \Phi)}{P_{input}} \quad (1.9)$$

where,

$G'$  is gain of antenna(dimensionless)

$U(\Theta, \Phi)$  is maximum power radiated in one particular direction

$P_{input}$  is power accepted by antenna ie lossless isotropic source

Directivity is related to the Gain as

$$G' = \eta_{eff} D \quad (1.10)$$

Designing of antenna plays an important role in working performance of a communication system. A slight change in parameters can make a remarkable change in antenna performance.

### 1.3.10 Radiation Pattern

A graphical representation of radiation properties as a function of space coordinates. Properties include power flux density, field strength, radiation intensity, polarization or directivity phase.

There are three kinds of radiation pattern:

*1.3.10.1 Isotropic Pattern:* The isotropic radiator is hypothetical, it radiates equally in all directions and usually considered as reference antenna for studying the directive properties of actual antenna. Its realistic approach can be seen in quansi-radiating antenna to some extent.

**1.3.10.2 Directional Pattern:** A directional antenna radiates and receives EM waves more efficiently in a particular direction. It has maximum directivity greater than  $\lambda/2$ .

**1.3.10.3 Omni-directional Pattern:** This kind of radiator gives maximum non-directional radiation in one plane and directional pattern in the orthogonal plane .It is thus called a special case of directional antenna.

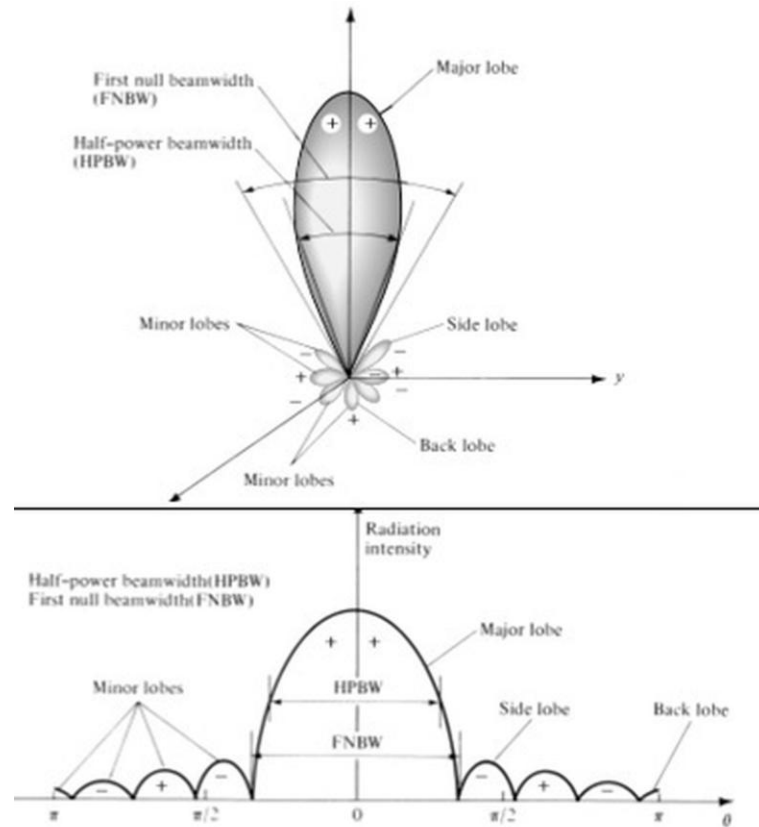


Figure 1.3 Antenna's Radiation lobes (first row), Antenna's Power pattern (second row) [1]

### 1.3.11 Radiation lobes

Radiation Lobe is the part of radiations pattern circumscribed by areas of comparatively weak intensity of radiation.

**1.3.11.1 Major lobe:** This is the main lobe of antenna which is the only required lobe for good result in a directional antenna

**1.3.11.2 Minor lobe:** For a directional antenna this is undesired lobe .For good antenna performance Front to back ratio is calculated which should be high, depends on low minor lobes. Minor lobe categorize into two:

- Side lobe: Lobes other than Major and back lobe.

- Back lobe: Lobe having minimal amount of radiation.

Half power beam width

It is given as angle over which power is reduced to a half of the maximum value of the beam. This is angle between any two points on the pattern, can be the angle between 10 dB.

First null beam width

Angular span between first patterns adjacent to main beam is known as FNBW.

$$FNBW = 2 * HPBW \quad (1.11)$$

### 1.3.12 Return Loss

It is the amount of loss which occurs when EM waves get reflected back due to impedance mismatch in antenna. It is most suitable method to find the resonating frequency of antenna, because maximum power will be transferred over resonating frequency and further we get minimum return loss over those frequencies.

$$RL = 10 \log_{10} \left| \frac{P_{reflected}}{P_{inc}} \right| \quad (1.12)$$

where,

$P_{reflected}$  is power reflected

$P_{inc}$  is incident power

Practically Return loss ratio should be less than -10dB. This is required for impedance matching in order to achieve maximum power transfer.

## 1.4 MICROSTRIP PATCH ANTENNA (MSPA)

MSPA used in wireless communication and other microwave applications is a planar antenna which uses strip line feeding and a patch etched on the top of substrate. Substrate is a layer separating conducting layer on both surface. MSPA are easily fabricated, light weight antenna and can be designed to operate in single band, multiband, broadband applications dual or circular polarization. Due to so many advantages MSPA are important in commercial applications. Due to low cost, thin profile configurations, conformity they are very compatible for embedded antennas in cellphones and many more portable devices. Moreover MSPA can provide broad bandwidth, frequency agility and feed line flexibility. In spite of major advantages and

application low gain and low bandwidth it is still a research hot topic today. To increase gain and bandwidth researchers had proposed probe fed stacked antenna, slotted patch antenna, micro strip patch antenna on electrically thick substrate, stacked shorted patch, DGS and parasitic patch is proposed and investigated.

MSPA using Inset micro strip feed has been studied extensively over many years due to its simplicity. Here, length of MSPA is approximately equal to half wavelength with single resonating frequency of bandwidth around 2%. Some applications require small size. Some requires high gain for efficient working of antenna. Thus we have studied various requirements as per need of antenna.

Now a day's antenna designers are more interested in working on microstrip antennas due to its several merits i.e. compact size, ease of fabrication, high reliability, and simple configuration, easy to use as an array. But in defiance of plenty advantages, patch antenna have some demerits i.e. low gain, narrow bandwidth. These demerits can be prevailed by looking out some parameters in designing of antenna. There are so many design factors that can affect the radiation characteristics of antenna:

- Shape of patch
- Feeding techniques
- Height of substrate
- Substrates dielectric constant and loss tangent
- Introduction of slots on patch
- DGS

In this research work focus is made on how size and gain of a micro strip patch antenna can be optimized to get better results. It covers the ideas trying to solve the problem of improvement of size, bandwidth and gain.

#### 1.4.1 Bandwidth enhancement

Further in thesis different methods have been discussed for enhancement of bandwidth and reviewed the work of authors on the same. Methods include DGS, parasitic patch, air gap etc. which are further used in the work done.

#### 1.4.2 Size miniaturization

In the following work a method of reducing size of MSPA with the help of decreasing the area

used for coplanar feed is proposed.

### 1.4.3 Gain enhancement

Gain enhancement is the important parameter to measure the overall performance of antenna. In the presented work gain enhancement with the help of Meta-surfaces has been discussed reviewed and demonstrated with the help of dual slot antenna design.

## 1.5 PROBLEM STATEMENT

In MSPA major problems are regarding size reduction and gain enhancement along with good performance of antenna. Size of antenna and gain are somewhat related as decrease in size, reduces the efficiency. This happens due to increase in side and back radiation, which causes decrease in main lobe and hence the gain.

## 1.6 OBJECTIVE OF THESIS

As discussed above decrease in size cause decrease in efficiency and hence decrease in gain. In this thesis reflective Meta-surface concept is used for dual band micro strip patch antenna resonating at 3.5 GHz and 5.8 GHz simultaneously. The conventional antenna works on right hand rule. metamaterial mounted antenna adopt property of metamaterial and work on left hand rule. Thus, metamaterial antenna can radiate while having small size of antenna with improved gain. It allows antenna size to be same. Work emphasis on obtaining the good results using meta surface with the optimized parameters of NRI behaviour where both permeability and permittivity co-exist simultaneously in region of desired frequency.

Thus, the objectives can be summed up by:

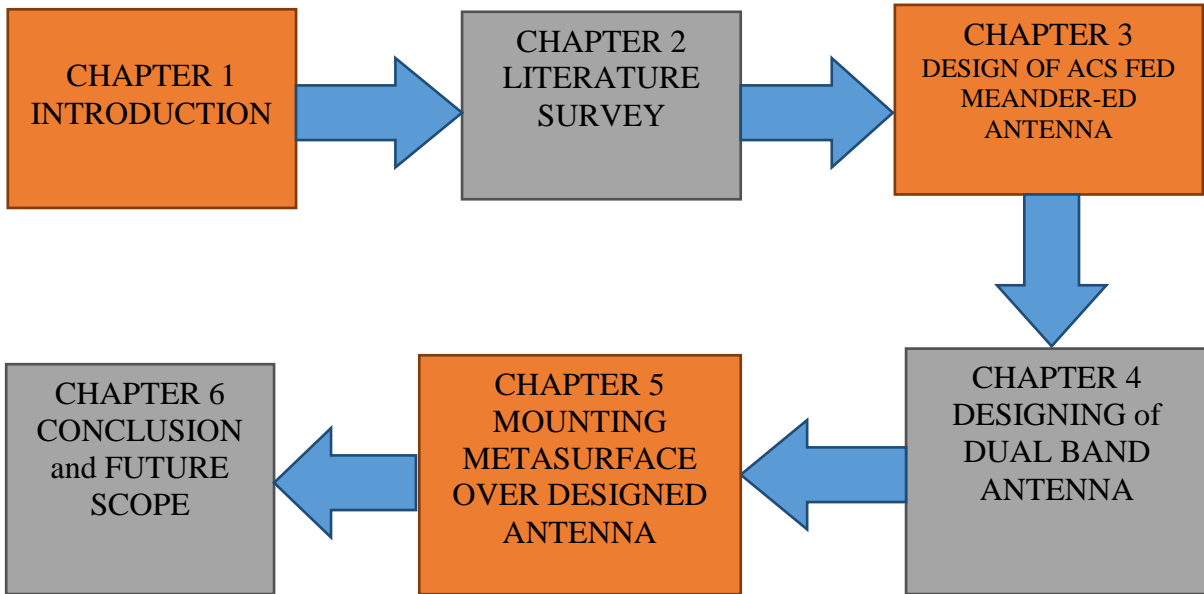
- To utilize the concept of metamaterial.
- To optimize dual band rectangular micro strip patch antenna surmount metamaterial unit.
- To compare the gain of dual band microstrip patch antenna before and after Implying metasurface.

## 1.7 SCOPE OF WORK

This thesis comprises of two concepts and accordingly designing two different antennas. First antenna includes size reduction using asymmetric coplanar feed with meandered structure antenna resonating at 2.5 GHz frequency i.e. suitable for Bluetooth application [33].

Other part comprises of manufacturing of dual slot antenna resonating in the dual band at operational frequency 3.5 GHz and 5.8 GHz covering WLAN and WiMAX band which further consists RMS reflective metasurface enhancing the properties of the antenna.

### 1.8 ORGANIZATION OF THESIS



## CHAPTER 2

### LITERATURE SURVEY

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The chapter contains brief introduction of work done in field of microstrip patch antenna to improve its size, gain and bandwidth as per required application and also it gives detailed study by various researchers on the concept of metamaterial and reflective metasurfaces.

#### 2.1 BANDWIDTH ENHANCEMENT

Impedance bandwidth is an important characteristic of antenna which can be improved significantly by various methods including introduction of multilayer dielectric configuration and many other methods. Earlier different techniques of bandwidth and gain enhancement are given. There are different feeding techniques and other methods to improvise the bandwidth of MSPA. Design parameter such as patch height, feeding substrate used in designing can cause degradation as well as enhancing of the desired result [11]. The micro strip feed and coaxial feed are the simplest technique to design and implement. Whereas aperture and proximity coupled techniques provide wider bandwidth but are difficult to implement as they are aligned between two substrates. Some other methods were discussed in the literature such as:

##### 2.1.1 Parasitic Patch

The technique is applied to enhance the gain-bandwidth properties of antenna. It has two different configurations such as:

- Coplanar technique: Here two different patch incorporated on single plane above dielectric substrate. Main patch is given excitation.
- Stacked technique: One patch is stacked over another with superseding a layer of dielectric in between allowing more than one patch to share common aperture area [12]. In this configuration, parasitic stacks with lower dielectric constant are added above the radiating patch which minimizes the overall effective permittivity of the multilayered antenna and enhance the gain of antenna [13]. Multilayering microstrip antennas also maintain the size and helps in reducing the effect of surface waves [14].

##### 2.1.2 Air gap

The air has a lowest permittivity as a dielectric thus using it as a dielectric between radiating patch and reflecting ground gives low Return loss and effective radiation pattern as well. This can be interpret as maximum amount of power is converted into electromagnetic waves [16-

17]. Air gap helps to provide resonance at two frequencies simultaneously. And by increasing the gap the resonating frequency come closer and hence gap in between them becomes zero which means enhancement in bandwidth take place [18].

### 2.1.3 Slots

Slots are made on the patch to basically improve impedance matching at specific frequency. As slots increase and somewhat change the current path causing change in impedance at input point [19]. Also adding more slots create more resonant frequency and hence enhanced bandwidth.

### 2.1.4 Dual feed

Dual feed is yet another method to enhance bandwidth. Double feeding configurations are used to enforce vertical current mode, preventing asymmetric and horizontal current modes from being excited simultaneously. Because the horizontal and vertical mode degrade the polarization property and reduce input impedance and gain performance of antenna.

### 2.1.5 Shorting Pin

To decrease the resonating frequency without affecting the size of antenna [21]. Again it is said that to attain high impedance matching location of shorting pin should be nearer to feed point. It can also act as feed line of antenna as it is considered as inductive part parallel to resonant LC circuit. Larger inductive part correspond to smaller resonance frequency. That ultimately augmented the level of miniaturization attained for fix operating frequency. [20]

### 2.1.6 Dielectric substrate

It is important part to choose dielectric substrate in designing of antenna. Some critical parameters ie bandwidth efficiency, gain and directivity can be improved by using appropriate dielectric material. Choosing appropriate substrate can also reduce the propagation of surface wave which degrades the electrical property by extracting some parts of total power available for radiation.

### 2.1.7 Deflective ground structures

The concept includes engraving simple defect of any shape in the ground plane. This finally results in handling excitation of radio waves and propagation of them across substrate layer. This configuration can also change the parameters of transmission line [22]. It also has advantages in field of transmission lines, couplers, dividers, power amplifiers etc [15].

P.H Rao *et al.* (2007) highlighted recent trends in MSA technology. It proposed that use of reflect array antennas enhance the bandwidth of antenna which has been obtained by electromagnetic bandgap structures. Work includes application of various algorithms to optimize the bandwidth [2].

Aaron *et al.* (2003) proposed many designs for small size wide band width patch antenna. Design includes combination of L probe fed patches and U slot with various size reduction techniques. Utilizing a microwave substrate material adding a shoring pin and shorting wall. Resultant of design concluded that resonant length of patch can be reduced to as small as  $0.1 \lambda_0$  maintaining bandwidth greater than 20% [3].

A. Deshmukh *et al.* (2013) elaborates broadband rectangular microstrip patch antenna, cutting a half U-slot. This includes effect of rectangular slot on patch edges. The proposed work results in increasing the bandwidth of antenna by 50%.also,gain is obtained over 7dB [4].

K. Y. Hui *et al.* (2006) given a coaxial fed rectangular antenna loaded by a folded patch. Bandwidth is made to increase by introducing a foam layer between dielectric resonator and the metallic patch. Above antenna incremented bandwidth from 2.2% to 6.3% and provide 5 dB gain [5].

Shing Lung Steven Yang *et al.* (2008) proposed MSA which could excite four polarizations. MSPA was fabricated with various thicknesses and studied. The system configuration can be improved with the help of polarization diversity and results in further increment of bandwidth and other parameters [6].

Wei Xing Liu *et al.* (2011) presented work on Compact U slot antenna for the requirement of bandwidth enhancement. In which an Asymmetrical rectangular radiating patch having U-shaped open kind of slot structure is developed using multiple resonances, by cutting two bevels on the patch impedance matching was achieved. Thus the manufactured antenna gives a wider impedance bandwidth of 122 % with 10dB return loss. Impedance BW was enhanced dramatically from 28 to 122 % by using different antennas is shown in this paper. Moreover, the size of slot antenna is small i.e. in mm, while maintaining the ultra-wideband performance [7].

J. S. Kuo *et al.* (2003) proposed circularly polarized micro strip patch antenna having equilateral triangular single feed with enhancement in gain of antenna. Here, three slots of triangular shape

are created below the triangular radiating patch on the ground plane to design and obtain the circular polarization. One of the triangular slots is created and adjusted such that the lengths of sides will remain slightly greater. Due to circular polarization we get two resonating modes. Antenna gain thus measured incremented by 3.3 dB. Substrate material and resonant frequency gets affected only with the use of triangular patch MSA The results are compared and optimized [8].

W. L. Chen *et al.* (2009) proposed printed microstrip wide slot antenna fed by microstripline having fractal shaped slot resulted in increasing bandwidth. Relation between all three bandwidth iteration factor and iteration order was studied providing 2.4 GHz bandwidth at 4GHz operating frequency and also 2dB gain is achieved. The future scope include enhancement of gain as well [9].

S. B. Yeap *et al.* (2010) gave a method of enhancing gain of microstrip antenna by removing substrate partially surrounding the patch. This partial removal helps in decrement of surface wave losses. Effect was studied resulted in increase in gain up to 2.7dB. Conclusion is when effective dielectric constant is decreased the gain increment depends more on decrement of losses occurred because of surface waves and substrate than the enlarged patch dimensions [10].

## **2.2 SIZE MINIATURIZATION**

This section includes study of antenna based on concept of ACS feeding and its need in order to miniaturize the size.

Liu and Chen *et al.* (2004) designed a  $20 \times 30 \text{ mm}^2$  dimension meandered dual band resonating patch antenna. The prototype consists of uniplanar rectangular conducting element with CPW feeding. This antenna gives a resonating bandwidth of about 260 MHz from 1.92GHz to 2.18 GHz and also another is 710 MHz from 4.99 GHz to 5.7 GHz at-10dB, respectively, supporting both, the WLAN as well as UMTS bands. Although this reported structure was quite simple, it was unable to operate at 3.5 GHz i.e. WiMAX band [23].

Song *et al.* (2007) presented a CPW-fed triangular shaped patch multiple band antenna for WiMAX applications. To enlarge the impedance bandwidth in the upper frequency band adjustable strips were used. Even though the studied and presented antenna covers more bandwidth, it has disadvantage of occupying a very large area of  $840 \text{ mm}^2$  [24].

Krishna *et al.* (2008) fabricated a fractal monopole antenna having size of  $28.5 \times 33.5 \text{ mm}^2$  antenna for dual band WLAN and WiMAX applications. Thus acquired impedance bandwidth includes 2.38GHz to 3.95 GHz and 4.95GHz to 6.05 GHz [25].

Lee *et al.* (2009) presented a dual band U-shaped open stub antenna having size  $40 \times 35 \text{ mm}^2$  to resonant the 2.45 GHz WLAN and the 3.1–5.2 GHz DS-UWB applications [26].

Liu WC *et al.* (2010) presented the triband monopole antenna with dimensions  $22 \times 41 \text{ mm}^2$  size suitable for WiMAX and WLAN applications. In the presented paper, inserting an U-geometry strip in monopole antenna, dual resonances were observed for the WLAN band and by combining two L-geometry symmetrical slits in DGS, another resonating frequency at WiMAX band was obtained. Limitations of these were large dimension and complex structure [27].

Liu W.C. *et al.* (2010) designed a  $30 \times 25 \text{ mm}^2$  size monopole shape antenna, having simple and compact rectangular radiating patch. Two resonating frequency at 2.4-5.0 GHz covering WLAN and 4–8 GHz covering C-band were acquired by properly choosing an optimized electrical length of the slots. Again, it demerits the large area [28].

Huang CY *et al.* (2011) presented a new monopole slot antenna with an embedded parasitic rectangular elements for WLAN and WiMAX application. The structure provides wider impedance bandwidth but limits large size i.e.  $30 \times 50 \text{ mm}^2$ . A slot monopole type antenna with tri-band operating frequency at WiMAX and WLAN was obtained. The obtained frequency range was from 2.34 GHz to 2.82 GHz, 3.16 GHz to 4.06 GHz, and 4.69 GHz to 5.37 GHz, separately, covering WiMAX and WLAN bands [29].

Lin *et al.* (2012) presented the  $50 \times 50 \text{ mm}^2$  rhombus shaped slot antenna operating in double band. By carefully inserting the rectangular strips and feed structure, dual separate resonant frequencies at  $-10 \text{ dB}$  is around 607 MHz resonating at 2.45 GHz and also 1451 MHz resonating at 5.5 GHz had been acquired. It covers RFID (1-10 GHz) band along with WLAN band [30].

Teng XY *et al.* (2012) fabricated this CPW uniformly fed triangular geometry antenna with a size of  $28 \times 26 \text{ mm}^2$ . Designing includes a  $\Pi$ -geometry, slot and a T-geometry strip in order to produce two frequency ranges i.e. from 2.36 GHz to 2.50 GHz and also from 5.01GHz to 6.33 GHz, respectively. This geometry was compact and simple but did not cover 3.5 GHz i.e. WiMAX band [31].

Tsai LC *et al.* (2014) presented a bow tie shaped CPW-fed slot antenna to meet the WLAN and WiMAX application. In this design, an M-shaped patch is used as a conducting element. The prototype resonates on two frequencies ranging from 2.26 GHz to 2.57 GHz and also 4.81GHz to 6.56 GHz and having dimensions  $60 \times 45 \text{ mm}^2$ . This reported antenna has demerit of large dimension and narrow bandwidth [32].

Even though this CPW feed has many merits such as

- Uniplanar structure
- Simple geometry
- Low cost of fabrication (as one side printing)

All above studied antennas are having same drawback of large dimensions limited frequency of operation and narrow bandwidth. Hence designing small size with large impedance bandwidth becomes the need.

Naidu *et al.* (2015) et al. uses the asymmetric coplanar strip feed(ACS). An ACS-fed antenna results in reduced dimension (~44 % size reduction) as it considered only one half of ground plane as that of CPW-fed structure. The measured impedance bandwidth (with return loss  $\leq -10$  dB) using ACS was about 320 MHz ranging from 2.2 GHz up to 2.52 GHz and also 900 MHz from 3.3 GHz up to 4.2 GHz respectively [33].

### **2.3 GAIN ENHANCEMENT THROUGH METAMATERIAL**

Major disadvantage associated with MSPA is low gain. Many methods were studied for the purpose of gain enhancement i.e. arrays of micro strip antenna, the superstrate structure, change of the dielectric material and hence partial removal of substrate. These methods enhance gain of MSPA is thus being approved by field researches. Here in this thesis focus is on gain enhancement through metasurfaces.

Jackson *et al.*(1987) investigated the fundamental effects of superstrate on antenna. Superstrate-substrate resonance cases are maintained that enhanced the gain of antenna, radiation resistance, and also radiation efficiency. This criteria was redefined for dimensions and properties of material for which surface waves are being eliminated and a radiation efficiency of 100percent due to superstrate substrate effects is obtained. And finally general criterion was presented for using a superstrate to optimize the efficiency for cases of nonmagnetic layers having the antenna at the interface. Using the superstrate should be taken care of as it can effect adversely to

antenna. By choosing the parameters of antenna properly, a significant improvement in gain, radiation resistance and efficiency can be noticed. By the selection of thicknesses properly, a resonance condition can be maintained, and thus gain and radiation resistance are essentially improved upon a denotative bandwidth. It is possible to achieve maximum of 100% efficiency, without power of the surface wave being excited. A remarkable enhancement may be obtained by working on superstrate having an optimum thickness measured by the switching onto the TE<sub>z</sub> mode, for the cases of nonmagnetic layers consisting of dipole at its interface [34].

Yang H *et al.* (1987), described that Reciprocity and a transmission line model are required to obtain the radiation properties of microstrip patch antenna in a multilayered material configuration. It was observed that extremely high directive gain was resulted at any scan angle, with practical materials, if the thickness of the substrate and superstrate was chosen properly. This model is also used to analyze the radiation characteristics of printed circuit antennas in inhomogeneous substrates [35].

Chaimool *et al.* (2010) proposed the use of reflective metasurface (RMS) as a superstrate to increase the gain and bandwidth of antenna. The work compares two different kinds of RMS i. e. DCR (Double closed ring shaped resonator) and DSR (double split-ring shaped resonator). The two different antenna prototypes were fabricated and experimentally studied. The results ensures that these RMS mounted MPAs acquires huge-gain along with bandwidth improvement. The designed antenna with the RMS type superstrate has a huge-gain of 9.0dBi and a wide bandwidth of approximately 13%. This RMS uses a very thin antenna having 6 mm cavity height, which is approximately equal to  $\lambda/21$  at the centre frequency of 2.45GHz [36].

Duran *et al.* (2012) reviewed the electrically very small size resonators used mostly for the manufacturing of metamaterials and metamaterial inspired microwave antennas and circuits. The intrinsic circuit modelling of these resonators also the transmission line coupled to them are studied. This kind of transmission lines with electrically very small size resonators are the intermediate cells for the mechanically robust design of many MW components. Thus, we get comparative analysis with resonator's size, bandwidth, and compatibility with certain applications, has been researched [37].

Malik *et al.* (2012) proposed metamaterial inspired radiating patch antenna having l-shaped slot loaded on ground plane for dual band. CSRR loaded on patch i. e. metamaterial inspired antenna

gives a resonance at the WLAN band in accumulation with the L-shape slot loaded ground causes resonance in WiMAX band. The CSRR loading causes reduction in the physical size of the patch and make the antenna suitable to be operated in upper WLAN band. A gap couple feed technique is used in the paper allows direct feeding of the structure without using any overcomplex impedance transformer and microstrip taper. This prototype thus fabricated, upon simulation gives a bandwidth of 200MHz, as well as improved radiation pattern and also gain for both the band of operation. This design thus can be integrated to MW circuits and are made compatible with MMIC technology for implementing practically [38].

D. Rao *et al.* (2011) proposed the antenna design consisting of multi-layered dielectric along with partial substrate removal which gives a bandwidth of 314MHz and gain of 4.035dB at 6.646 GHz operating frequency. This is a remarkable improvement in bandwidth obtained using MSPA over single-layer silicon or glass substrate. These broadband characteristics to next level attained multiple-layer dielectric substrate which helped in lowering of the elective dielectric value while reducing the size. The designed antenna provides a gain of 4.035dB [39].

Numan *et al.* (2013) presented paper in which a structured procedure was employed for attaining the material parameters and to oversimplify the method for designing the metamaterial structures with the use of commercially available software. S parameter is studied by plots in order to measure the curves for permeability and permittivity of the metamaterial based on a unit cell. HFSS is used to extract the S parameter. In HFSS itself there are two methods to extract the S parameter first is using magnetic as well as electric (TE-TM) boundary conditions, and the other is by implementing the master-slave boundary conditions. Fouquet ports as well as wave ports are used to feed the structure [40].

Ullah *et al.* (2014) proposed a double sided metasurface reflective surface circular loop patch antenna resulting in enhancement of both the gain and bandwidth. Initially, bioplastic-ceramic-bioplastic dielectric substrate was used to design antenna on it having a high-permittivity and obtained desired resonant frequencies. Afterwards, a dual-sided metasurface had been fabricated and mounted on circular conducting patch of the antenna having an air gap of 4mm. A parametric study was thus done in order to analyze the side effects of each the patch structure, the air gap between RMS and also patch and the ground plane reflection coefficient. A prototype of the present antenna having incorporated RMS has been constructed as well as measured for practical deductions. According to the studied results, addition of the RMS, VSWR, gain and

bandwidth had been enhanced and improved significantly in multiple bands along with minimal boost of 6mm in the height. For this antenna, symmetric radiation patterns with low effect of cross-polarization had been noticed at the tri-resonant frequencies [41].

Mehrabramzan *et al.* (2015) presented the design methodology of miniaturized square patch antenna for 5.15 GHz (ISM band). CSRR employed in between the ground plane and patch helps to miniaturize the size of antenna. Thus overall reduction in size is given by .25 times of conventional patch. The presented antenna provided 78% of antenna efficiency and bandwidth of 0.4% [42].

Ridhasahli *et al.* (2017) proposed a design the design of a dual-band MSA mounted metamaterial reflective surface. A MRS array is mounted on the MSA separated by an air gap of 7 mm leading to improved performance of designed antenna. The result provides a simple and a low-cost design and is suitable for WLAN, WiBro (wireless broadband), Bluetooth and WiMAX applications [43].

## **2.4 SUMMARY**

The literature survey of different methods for enhancement of various properties including gain and size reduction are studied in detail. Survey provides ease of understanding what can be required specifically to improve the properties of MSPA. The literature survey was divided into 3 parts. Firstly methods of bandwidth enhancement with the help of parasitic patch shorting pins, air gaps, DGS has been studied. Second section includes the methods of size minimization with the help of reduction of feed space. Last section contains the reflective metasurface inspired MSPA's utilization and discussing the concept of metamaterial and various perceptions and gaps during its implementation

## **2.5 MOTIVATION**

It included the design requirement of a simple antenna's fabrication which can provide high gain and enhanced bandwidth at dual band. Concept of bandwidth enhancement methods ie Parasitic patch and air gap has been used in different sense and combination provide Reflective metasurface providing improved results. Earlier, while implementing the metamaterial certain parameters need to be chosen properly. So, the enhanced properties can be seen. Keeping the design simple allowed the enhancement of parameter resulting high gain in dual band.

# **CHAPTER 3**

## **DESIGN OF ACS FED PRINTED MEANDERED SINGLE BAND ANTENNA FOR 2.5GHz**

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### **3.1 INTRODUCTION**

In today's era LTE band is the band of high demand, as it provides the high speed data transfer for mobile phones and other data terminals, holding on to UMTS/HSPA and GSM/EDGE. It benefits in increasing speed and capacity of data using a different radio interface along with core network improvement. LTE marketed as 4G LTE working on 2.5 GHz frequency is now ready to become a significant part for 5G application. But due to size miniaturization of devices and high traffic in LTE 2.5 GHz band the implication is lagging behind. In order to serve the LTE technique in an electronic device various antenna design have been studied for single dual, tri and broadband applications. This chapter deals with design and fabrication procedure of miniaturized planar antennas using ACS feed. Firstly the chapter discusses different kind of feeding techniques used in MSAs. After that it validates that ACS is the most likely used feed for compact antennas comparing the characteristics of simple coplanar and ACS feed. And finally this chapter provides measured and simulated results of designed antenna using concept of Asymmetric coplanar feed (ACS) for LTE application.

### **3.2 MICROSTRIP PATCH ANTENNAS**

As per the concept of miniaturization without effecting bandwidth and gain of the antennas the designers are forced to use different alternatives in designing of MSAs. The main property of antenna is to radiate power which is given to it through an input feed. So design of matched feed is really important for transmitting power from source to radiator. In order to make antenna compact designer usually gives attention to the size of patch only thus the feed region remain intact. Keeping in the mind that overall area of antenna includes radiating element as well as feed region the compact antenna design using ACS is proposed.

### **3.3 FEEDING TECHNIQUES IN MSPA**

In this section various types of feeding techniques of antenna has been discussed briefly. The widely used feeding transmission lines are microstrip line feed (non-planar dual layered), inset feed and coplanar feed.

### 3.3.1 Microstripline Feed

The strip line feed contains strip on a ground plane separated by a layer of dielectric substrate. The Fig. 3.1 below shows a microstrip line fed antenna. The characteristic impedance of strip line depends on height and width of the strip and also on substrate's dielectric constant. It can be termed as Dual planar feed as substrate is sandwiched in between the strip line and ground plane.

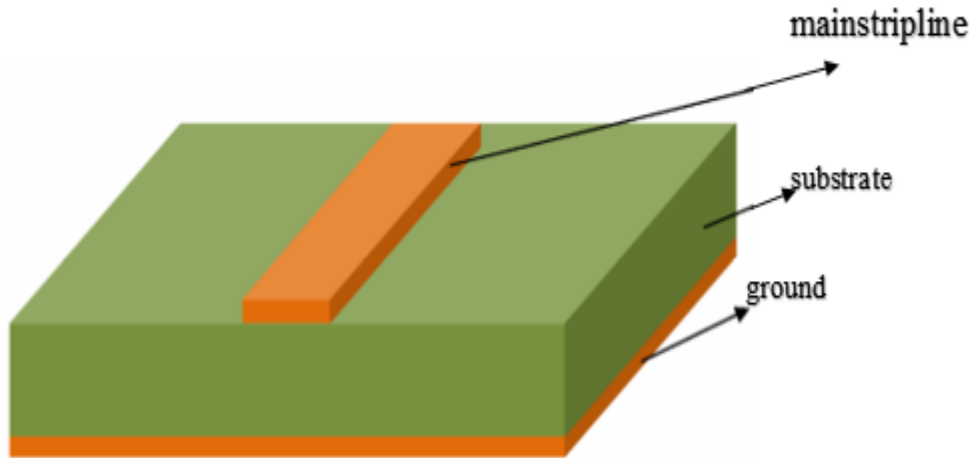


Figure 3.1 Microstripline feed

### 3.3.2 Coplanar Waveguide Feed

Coplanar feed has twin lateral ground strips on both sides adjacent to the main feed. Here the characteristic impedance depends upon width of main strip feed as well as gap between the lateral and main stripline determined height of substrate and Substrate's dielectric constant. This can be shown by the figure below.

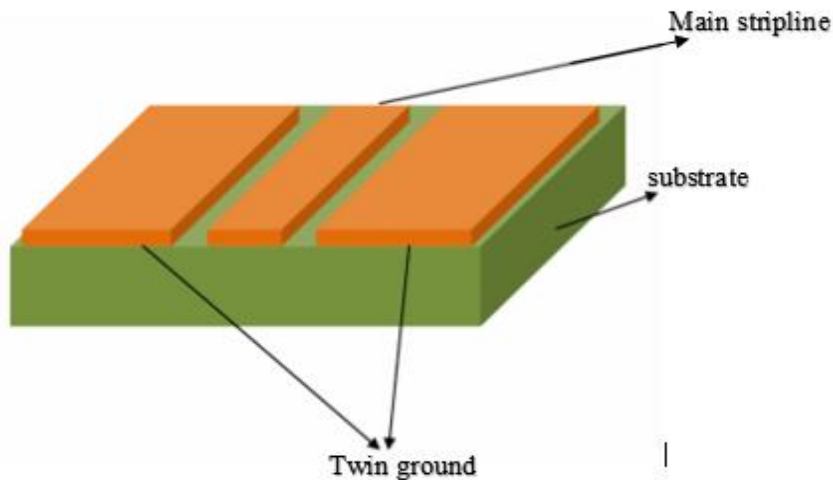


Figure 3.2 CPW feed

### 3.3.3 Slotted Feed

Complementary to coplanar feed the slotted feed has its advantage of mounting passive as well as active circuits onto the stripline. Height of the substrate and slot's width are the deciding parameters for characteristic impedance.

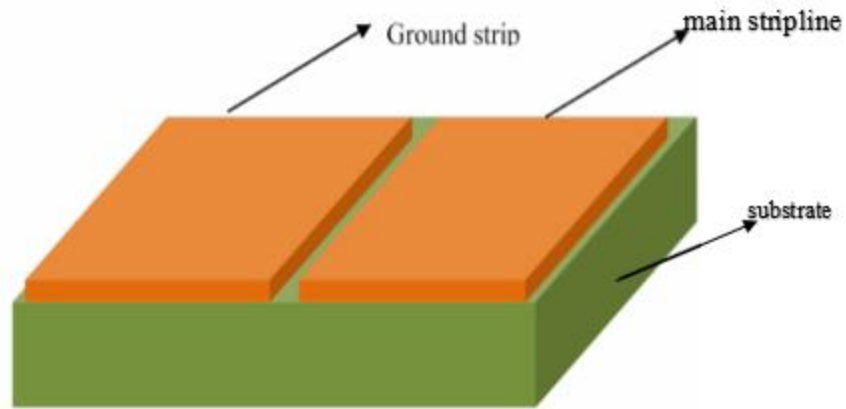


Figure 3.3 Slot line Feed

### 3.3.4 ACS Feed

Asymmetric coplanar feed is combined concept of slot as well as coplanar feed. Here lateral strip has narrow width there. Associated many advantages as Ease of fabrication, simple designing validating the use of ACS feed efficient. Fig shows schematic diagram of ACS feed having  $W_1$  as mainstripline and  $W_2$  as lateral ground  $g_i$  is the gap between mainline and lateral ground  $h$  is height of substrate. When the width of  $W_2$  is much greater than  $W_1$ , its effect on the characteristic impedance is found to be less and hence  $W_2$  can be removed from characteristic impedance calculations, without any erroneous result. In other words the width of  $W_1$  and  $W_2$  can be altered in order to optimize the result of antenna.

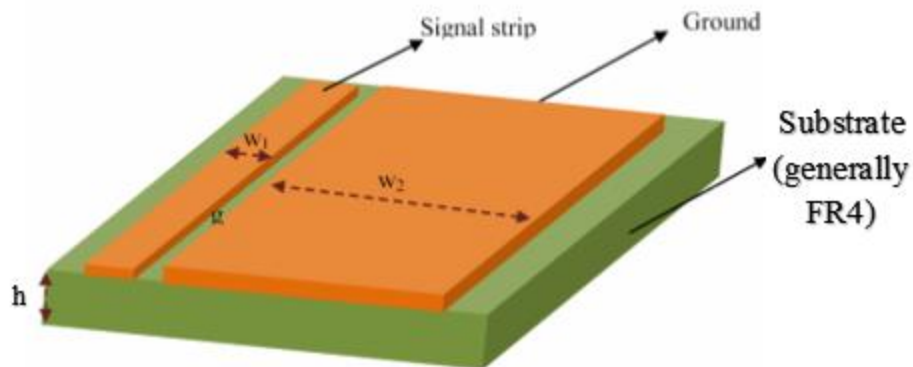


Figure 3.4 ACS feed

### 3.4 ADVANTAGES OF ACS OVER CPW FEED

ACS is advantageous over CPW due to:

- **Size:** ACS allows reduction of effective area of antenna as it reduces area occupied by feed unlike CPW.
- **Effect on Characteristic Impedance:** As described above if width of lateral strip is larger than mainstripline it causes less effect on impedance. Thus designer has freedom for selection of dimensions as per antenna's resonance on desired frequency.

#### 3.4.1 Design Comparison of CPW and ACS

In this section geometry of CPW as well as ACS is studied and compared using Monopole antenna. Here the length of main microstrip feed is given by  $L_s$ , length above ground plane is  $L_m$  for the feeds. The antenna generally designed on 1.6mm height FR4 having dielectric constant 4.4. The Width of main strip line is  $W$ .

The lateral feed has dimension of  $L_g \times W_g$ ,  $g_i$  is the gap between main stripline and lateral ground  $S$  and  $S_1$  are feeding points for ACS. Similarly in CPW, twin lateral ground plane has dimension  $2 * L_{g1} * W_{g1}$ . Gap on both side is  $g_i$  respectively. The gap and ground plane dimensions should be optimized accordingly for impedance matching.

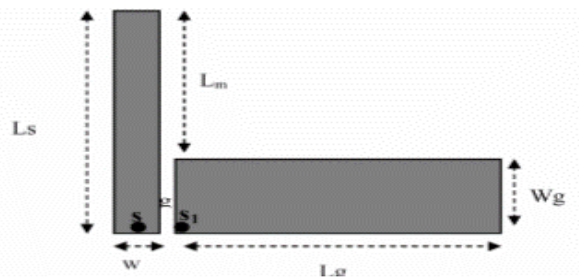


Figure 3.4(a) ACS

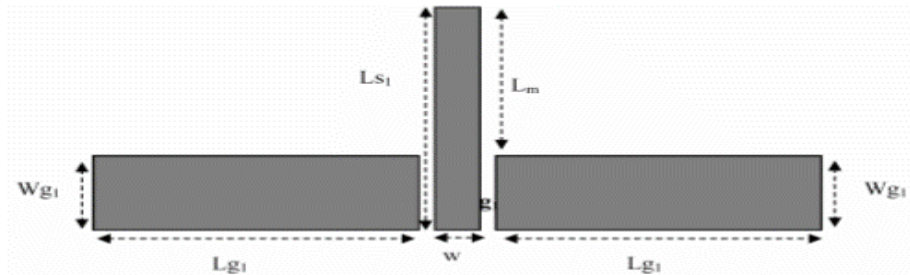


Figure 3.4(b) CPW

Figure 3.5 (a) ACS feed line (b) CPW feed

### 3.5 ANTENNA DESIGN

The design process includes design of ACS inspired antenna using CST design suite. Studying different parameters of antenna and then fabricating the antenna on FR4 substrate using methods of photolithography and etching.

- Effect of increase in strip width: When the strip width is increased the mismatching of impedance take place. The width of the signal strip also affects Asymmetric coplanar strip's impedance. For larger values of W bandwidth is slightly affected.
- Effect of varying substrate
- The resonant frequency decreases with an increase of dielectric constant.

#### 3.5.1 Parameters

The parameters involved in design are tabulated below and labelling is done in the diagram. All the radiating elements and ground plane is on one side. The monopole rectangular strip having meandered structure allows antenna to radiate at 2.5 Ghz.

Sr. No.	Parameters	Value(mm)
1	L	20
2	L1	4
3	L2	5
4	L3	5.34
5	L6	2.7
6	LS	15
7	S	1
8	W	31.75
9	W1	4.3
11	W3	4
12	T	1.64

Table 3.1 Design parameters of ACS fed Meandered antenna

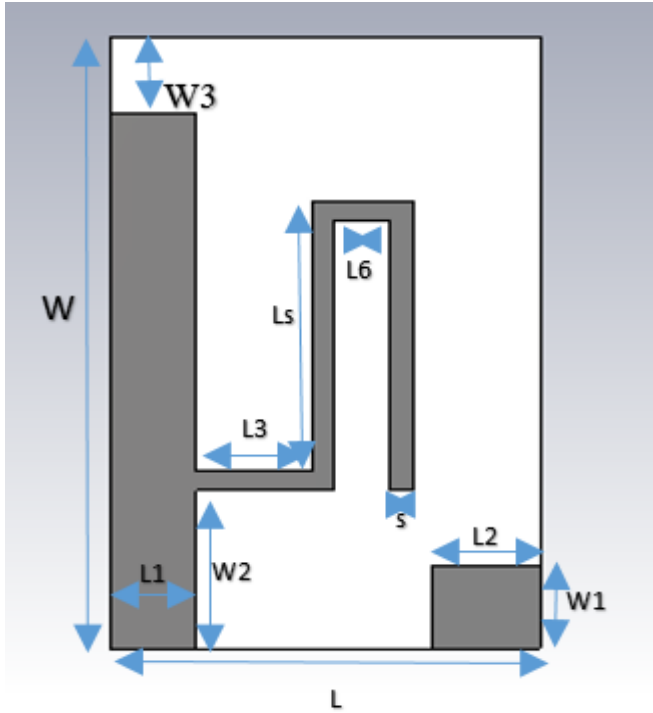


Figure 3.6 Designed antenna labelled diagram

The designed antenna is having size of  $31.75 \times 20 \text{ mm}^2$  and fed by ACS feed which is been etched on FR4 substrate having thickness of 1.64 and dielectric constant of 4.3. The meandered part has width  $s$  equals to 1. According to design configuration here ACS feed is used which allows etching to be done on single side of the substrate. This helps in removal of misalignment between the radiating patch and ground. Thus, the antenna becomes compatible with different microwave devices.

### 3.6 MATHEMATICS OF ACS FED ANTENNA DESIGN

To get the optimum output antenna's input impedance should be matched.

The impedance  $Z'$  of ACS can be equated to

$$Z' = \frac{60\pi K_0(t)}{\sqrt{\epsilon_{req}} K(t_0)} \quad (3.1)$$

where,

$$t = \sqrt{\frac{W1}{W1 + g_i}} \quad (3.2)$$

$W1$  is width of mainstripline feed

$g_i$  is gap in between  $W1$  and  $W2$

$$\epsilon_{req} = 1 + n * (\epsilon_r + 1) \quad (3.3)$$

where,  $n = \frac{K(t)t'(t)}{K'(t)t(t)}$

$$t' = \sqrt{1-t^2} \quad (3.4)$$

Now,

$$t1 = \frac{\sinh\left(\frac{\pi W1}{zh}\right)}{\sinh\left(\frac{\pi(W1+g_i)}{zh}\right)} e^{-\pi g_i/2h} \quad (3.5)$$

$h$  is height of substrate

$$\frac{K(t)}{K'(t)} = \frac{\pi}{\ln\left[2(1+\sqrt{t'})\right]} \text{ for } 0 \leq t \leq 1/\sqrt{2} \quad (3.6)$$

Where,  $K(t)$  and  $t'(t)$  are elliptical function

$$\frac{K(t)}{K'(t)} = \frac{1}{\pi} \ln\left[2(1+\sqrt{k})/(1-\sqrt{k})\right] \text{ for } 1/\sqrt{2} \leq t \leq 1 \quad (3.7)$$

Mathematical analysis provides the ease of designing for ACS.

### 3.7 SIMULATED RESULTS

The antenna has been designed for LTE band operation having centre frequency of 2.5GHz. The bandwidth attained the designed antenna is 400 MHz. It covers the band of frequency from 2.35 GHz to 2.755 GHz as shown in Figure 3.6.

#### 3.7.1 Return Loss

As discussed earlier, return loss is measure of the power loss in the signal. Signal's power gets reflected back due to some discontinuity lies in transmission line causing mismatch of impedance.

Good or high return loss tells how perfectly the devices are matched. For an ideal antenna it should be high in negation. As per this design is concerned the designed antenna gives -26dB return loss at 2.5GHz frequency (Fig. 3.6).

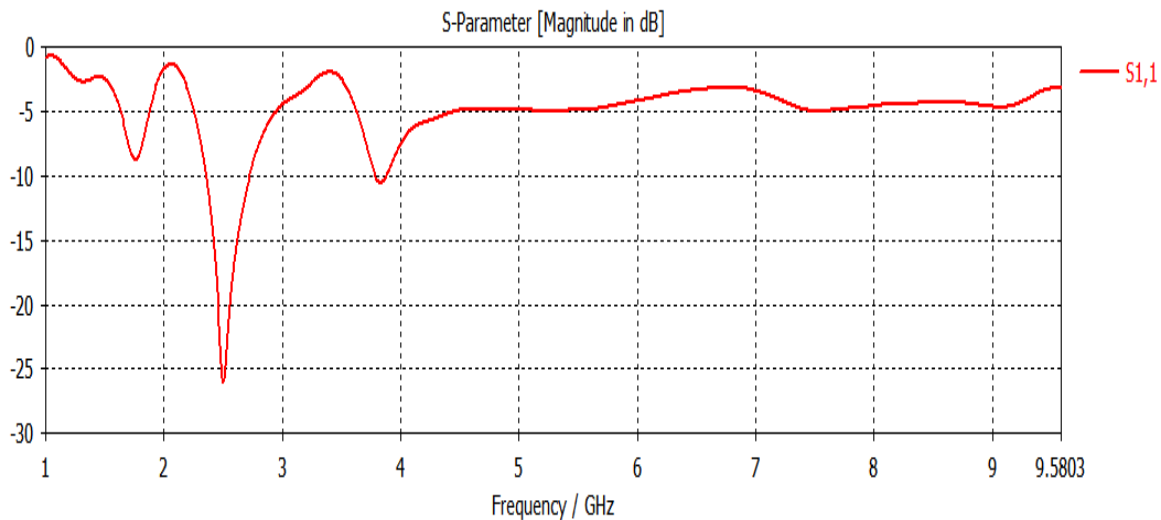


Figure 3.7 S-Parameter

### 3.7.2 Smith Chart

This is a complex reflection coefficient's plane plot whose scaling is in the terms of normalized impedance and admittance. Usually 50ohm is used as factor for normalizing the impedance. Points on the smith chart covering the locus of the ranges of frequency can be interpreted for visual representation of:

- Difficulty of matching at some frequencies.
- How much can a component be matched.
- Limit of inductive or capacitive load present across the frequency range.

Impedance matching of this antenna is 51.9 ohm.at 2.5 Ghz can be depicted through smith chart as:

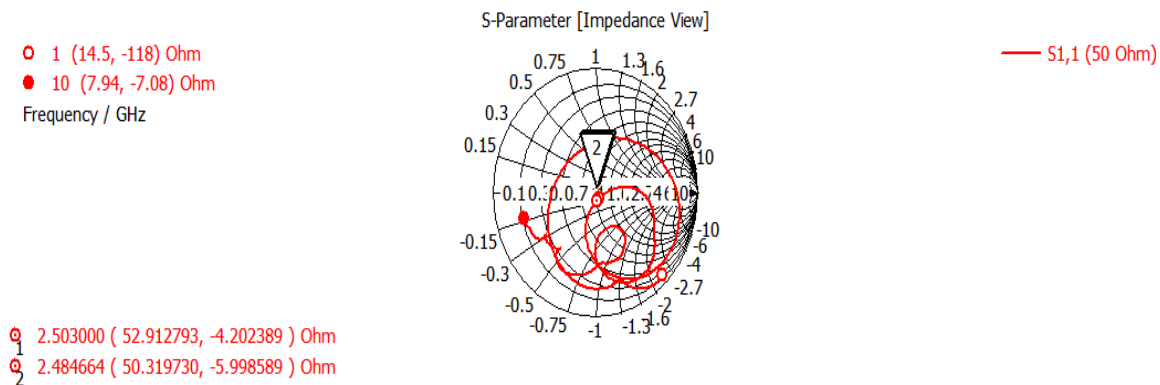


Figure 3.8 Smith Chart

### 3.7.3 VSWR

It is numerical ratio for measuring amount of impedance mismatching of antenna with transmission line to which it is connected. Physically it is ratio of maximum to minimum standing wave. It ranges from 0 to  $\infty$ . But practically not greater than 2. For this antenna VSWR is 1.106.

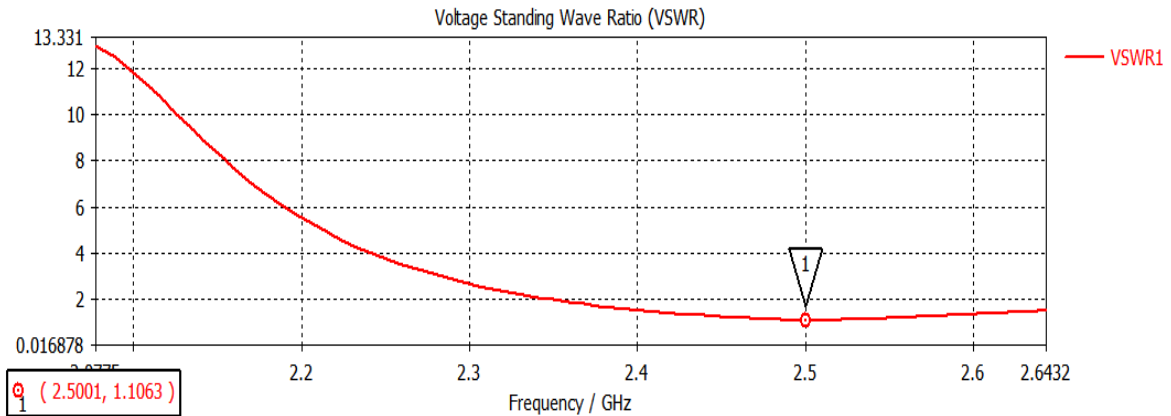


Figure 3.9 VSWR vs frequency

### 3.7.4 Gain and Directivity

Gain is also one of the major parameter studied in the designing of an appropriate antenna. It is basically the ratio of power produced by the antenna to power produced by reference antenna. The unit is dBi.

Directivity is given by ratio of gain to efficiency of antenna. For this particular antenna limit was less gain up to 0.38 dBi.

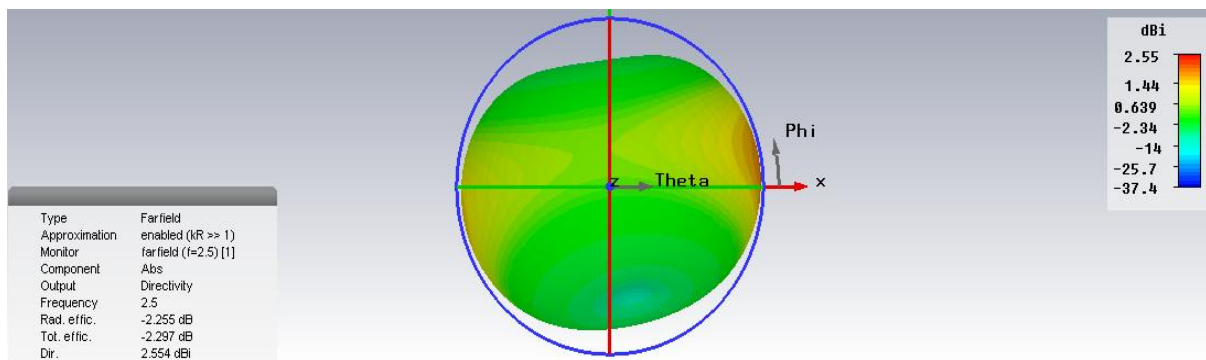


Figure 3.10 Farfield patterns (Directivity)

### 3.7.5 Radiation pattern

It is variation of antenna's radiating power in direction away from antenna. The polar plot shows the radiation pattern of the designed antenna.

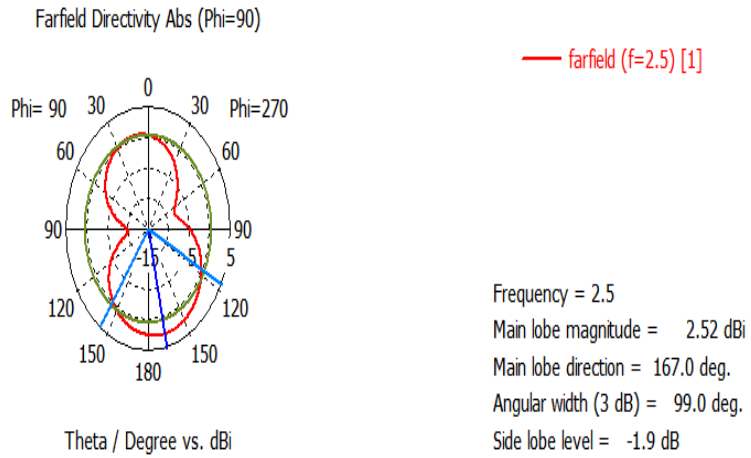


Figure 3.11 Radiation pattern at abs (phi=90)

### 3.7.6 Axial ratio

Axial ratio is the ratio of orthogonal measures of E field. It varies with type of polarization. It defines the polarization nature of circularly or linearly polarized antennas. Axial ratio is given as the ratio between the major and minor axis of the polarization. If ellipse has same major and minor axis it is circularly polarized. Axial ratio becomes linearly polarized antenna axial ratio is infinitely large as one of the ellipse axis is approx to zero. For a circularly polarized antenna, the closer the axial ratio is to 0 dB, the better. For this antenna the axial ratio at 2.5 GHz is 25 which state that antenna is linearly polarized.

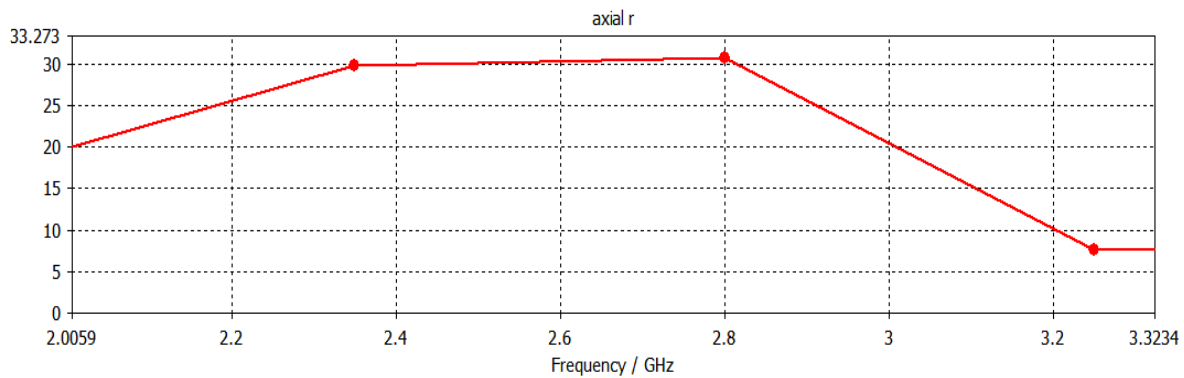


Figure 3.12 Axial ratio

### 3.7.7 Current density

The current distribution over patch tells behaviour of an antenna. The surface distribution of the above designed antenna has been shown in Figure 3.12. It is shown that current is at its peak at the edges of feed main strip line, minimum on the ground plane.

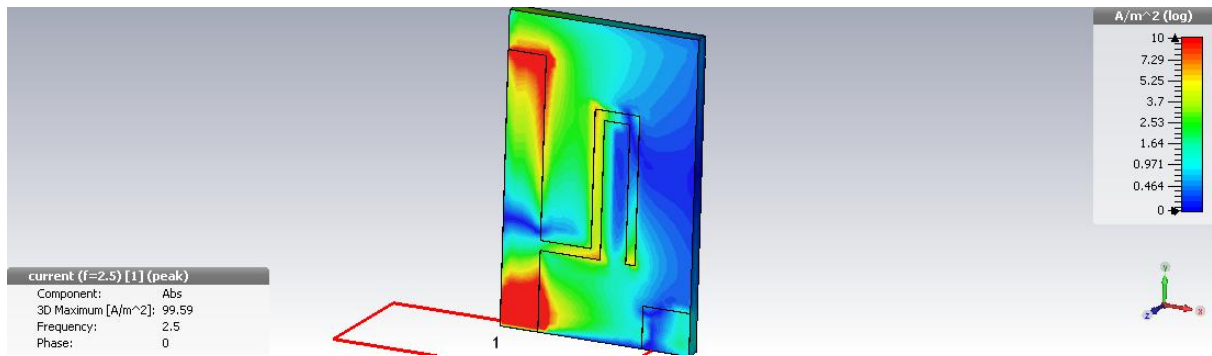


Figure 3.13 Current distribution

### 3.8 PARAMETRIC STUDY OF ANTENNA

By varying different parameter simultaneously as well as typically we get parametric sweep results varying  $L_2$ ,  $L_s$ ,  $L$  and some other parameter.

Case 1 When  $L_2$  (length of ground plane) was changed. It was observed that on increasing the length of ground plane or increasing the gap between main strip line and ground plane resonant frequency shifted towards 3.2GHz. Remaining parameters were made constant.

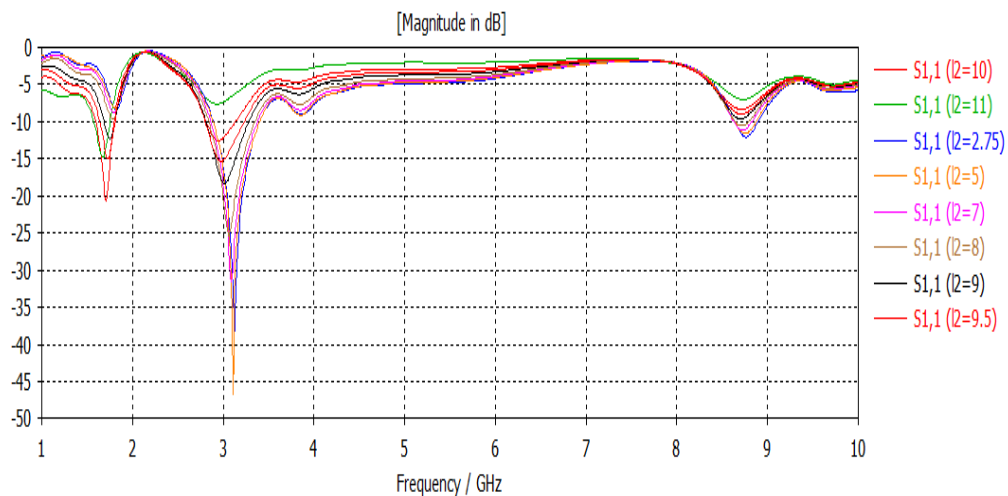


Figure 3.14 Sweep results varying  $L_2$  only

Case 2 The optimal result was obtained when the parameters in table 3.1 were applied.

Here from parametric sweep results were deduced as:

When  $L=18$ ,  $L_1=4$ ,  $L_2=0$ ,  $L_s=15$ ,  $W_3=4$  other parameters remained the same as in table 3.1 then we get maximum return loss of -60dB which is impossible to attain as ground can never be zero for ACS fed antenna. It is denoted by marker 1.

When  $L=20, l_1=4, L_2=5, L_s=15, W_3=4$  we get the optimal result.

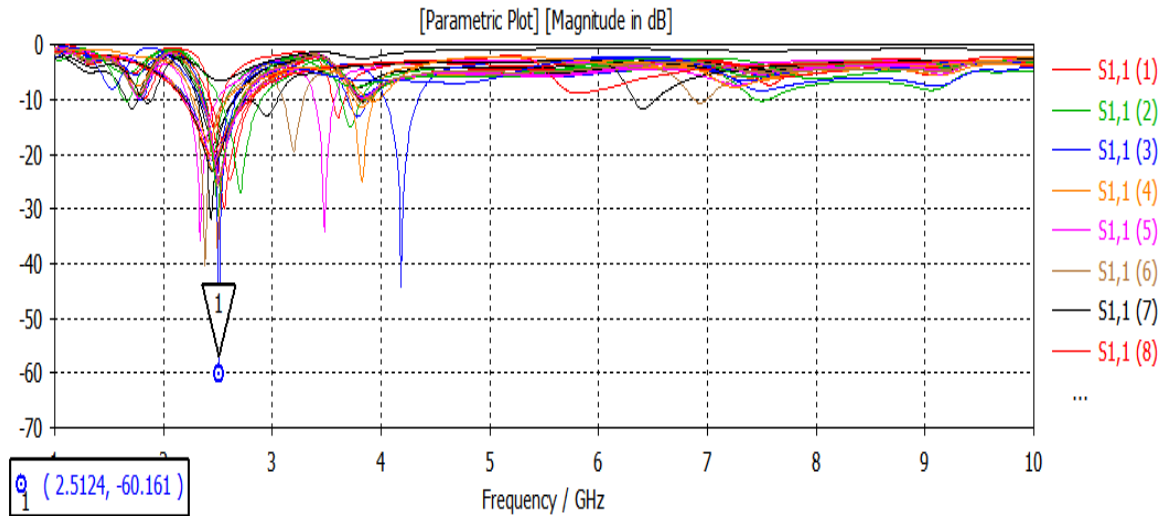


Figure 3.15 Parametric sweep applied to find optimal result

### 3.9 FABRICATION AND RESULTS MEASURED

After the final optimization of antenna with the help of suitable geometrical specifications, the simulated ACS fed meandered antenna is been fabricated onto the FR4 substrate having thickness 1.64mm with dielectric constant 0.0024 and dielectric permittivity 4.4. The antenna was fabricated through Photolithography technique which uses UV rays of appropriate wavelength comprising photo resist which is sensitive to this operating frequency. This Photo resist material is of two types-positive and negative photo resist. The developers accordingly select photo resist and dip the substrate in it. And etch out through  $FeCl_3$  undesired copper making the desired structure. The snapshot of fabricated antenna has been presented in Figure 3.15.

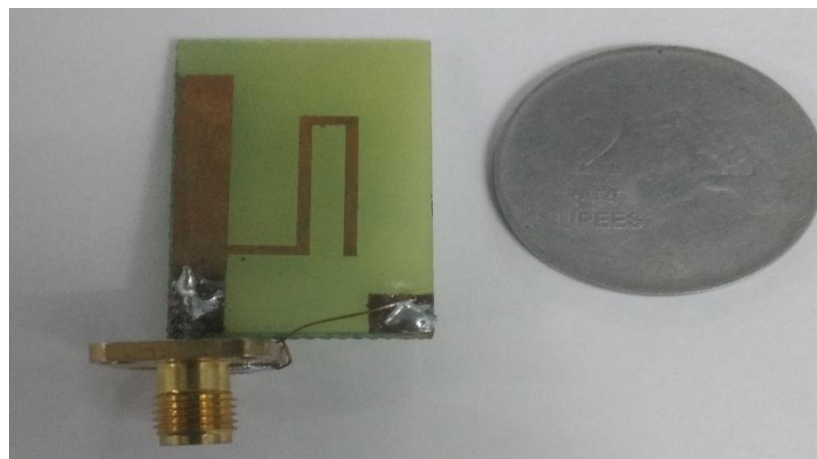


Figure 3.16 Picture of ACS fed fabricated antenna at 2.5 GHz.

The return loss of the final fabricated was tested using AGILENT E5071C vector network analyzer employed at Antenna Research Lab, Thapar University, Patiala. The following measured return loss had value -22dB at 2.66 GHz and also we got some frequency dips at farther frequency i.e. at 3.5 GHz. The shifting of resonating frequency is due to the impedance of stub applied in order to join ground plane with the feed. Figure 3.17 shows both simulated and measured results.

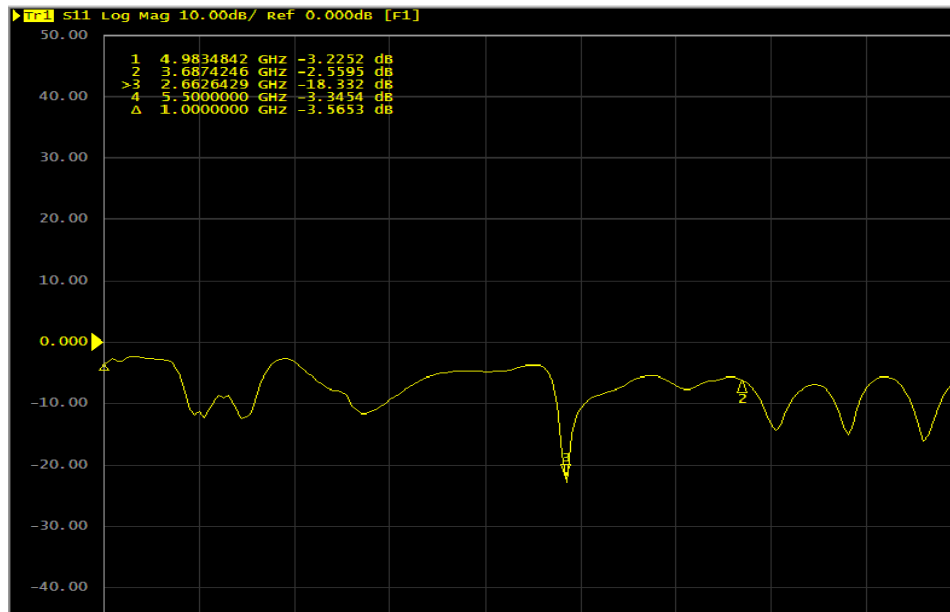


Figure 3.17 Measured result

Return Loss Plot

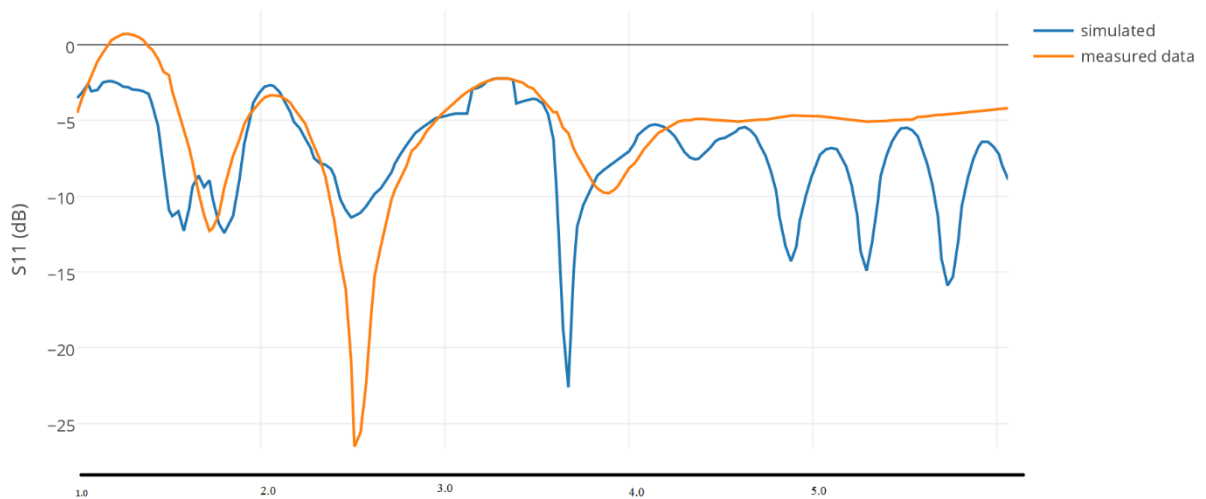


Figure 3.18 Comparison of simulated and measured return loss

### **3.10 CONCLUSION**

It can be concluded that the ACS Fed antenna has all the merits of a conventional monopole having nearly 46 % area reduction. Owing this uniplanar nature many integrated devices can be embedded into these antennas. The reflection and radiation characteristics of the Asymmetric Coplanar Strip fed antenna are same as of antennas using conventional feeding mechanisms. The antenna is conformal and easily fabricated. Thus, the above fabricated antenna working in range from 2.5 to 2.65 GHz at -10 dB having linear polarization. It has effective area less than CPW fed antenna.

# CHAPTER 4

## DESIGN OF DUAL SLOT MSPA FOR WIMAX AND WLAN APPLICATION

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### 4.1 INTRODUCTION

Due to rapid updating in design and performance of the small communication devices is increasing. Use of smaller and cost effective antenna should be taken into account. The Chapter includes designing of dual slot patch antenna and discussing its result.

### 4.2 MICROSTRIP PATCH ANTENNA (MSPA)

#### 4.2.1 Overview of MSPA

A micro strip rectangular antenna having rectangular shaped radiating patch and ground plane which is separated by a substrate of thickness 'h' having some dielectric constant is the most simple configuration among antennas. In which the length of RMSPA which is critically equal to  $\lambda/2$ , determines the resonating frequency. And width is directly proportional to the gain and bandwidth of antenna. Presently, the importance is given to suppress the disadvantages of MSPA in order to make it more likely an ideal antenna. The alterations and advancement in designs results in overcoming the disadvantages of this antenna. Also, the shape of patch, height of substrate, dielectric constant are important factors to be altered preferably to enhance the performance of MSPA.

#### 4.2.2 Effect of surface wave on MSPA

Surface waves radiating in broadside direction perpendicular to patch causes decrement in amplitude of the source provided input signal before it propagate via air. It also causes queer and abrupt coupling between transmission line and antenna element which degrades the effective performance of antenna. The surface waves reaches the external boundaries of the mSPA are deflected back by edges which cause additional radiation degrading the pattern and hence increasing the side lobes and cross polarization levels of antenna radiation pattern.

#### 4.2.3 Effect of Substrate

Substrate thickness and dielectric constant also plays a great role in improvement of gain bandwidth and return loss of antenna. As per thickness of substrate is concerned, if thickness of substrate increases it decreases effective permittivity of material and hence cause increase in

fringing field and also increase in permittivity causes decrease in fringing field causes decrease in radiation as it starts propagating and thus degrades the antenna performance. The table shows different dielectric material and their effective cost.

Sr. .No.	Name	Dielectric constant	Loss tangent ( $\tan \delta$ )	Cost
1	Alumina(compact antenna)	9.8 (9.6-10.2)	0.001 (low loss tangent)	Very high
2	Glass epoxy(FR4)	4.4	0.02	Low
3	Duroid (Arlon)	2.2 (2.1-2.5)	0.0009	High
4	Foam	1.05	0.0001	Low/medium cost
5	Air	1	0	NA

Table 4.1 Types of substrate material

In the present work Duroid (RT5880) is used. Lowest dielectric constant leads to highest bandwidth as well as gain. But it can be clearly seen that we cannot use air as substrate. Foam is another option but it is a way too flexible to implement in circuit modelling. Another option is FR4 which has low cost but dielectric constant is high compared to Duroid and lastly the alumina with high dielectric constant as well as cost. Thus, Duroid is most suited among all but compromise would to done in cost.

#### 4.2.4 Advantages of MSPA

Due to the several advantages of MSPA it is in trend now a day's to provide effective wireless communication. Major advantages are:

- Light weight, low profile, volume is less too and planer configuration which could be made conformal.
- Fabrication cost of antenna is less and manufacturing is easy.
- Different type of polarization such as linear circular as well as elliptical polarizations are possible.
- Single, dual, Multi and broadband can be realized.

- Another advantage is ease of integration of feed lines and matching network in the circuit.
- Easily fabricated.

#### 4.2.5 Disadvantages of MSPA

Along with number of advantages there are several disadvantages or gaps in MSPA are to be improved yet.

- Narrow bandwidth
- Power handling capacity is low.
- Practical limitation of gain (even array provides a maximum of 30dB).
- Isolation is poor between feed and patch.
- Surface waves's excitation
- Tolerance problem requires good quality expensive sub-state which is not economic.
- Large size at lower frequencies.
- Purity of polarization is less.

#### 4.2.6 Microstrip Feed

Stripline used in this antenna design is microstrip feed line with width  $W$ . This is the simplest applied strip line.

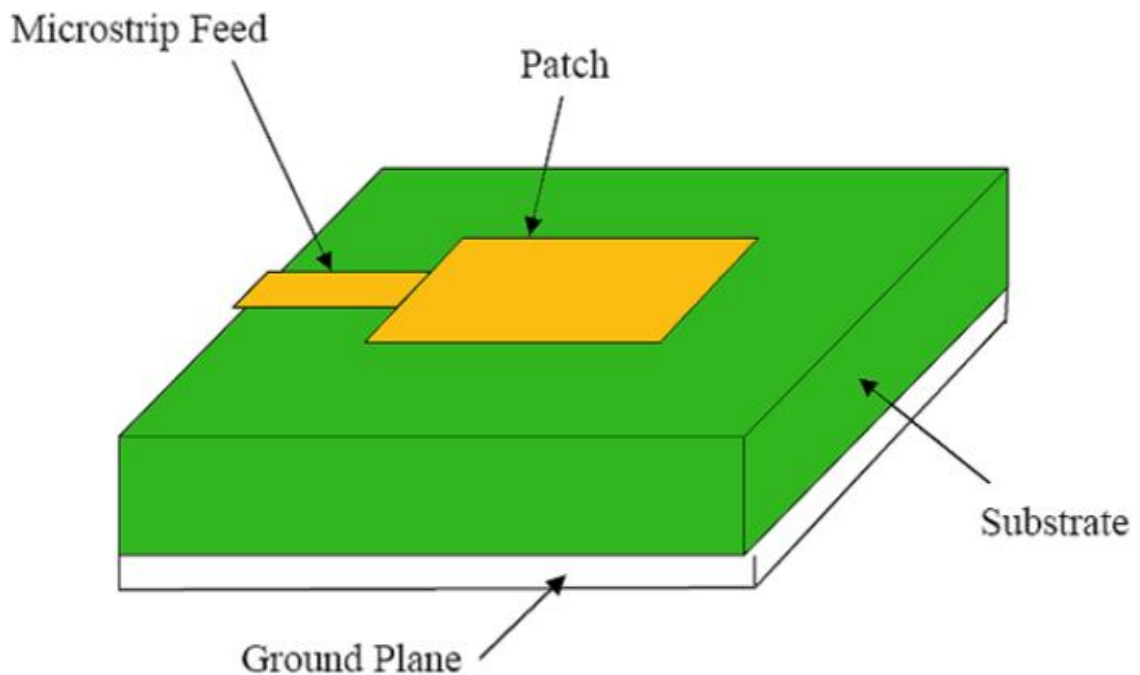


Figure 4.1 MSPA with microstrip feed

### 4.3 MATHEMATICS BEHIND DESIGNING MSPA

Designing of antenna is based on several equation which involves the extraction of length and width using the resonating frequency for which designing of antenna is required.

Length  $L_s$  is given by

$$L_s = L_p + 2\Delta L_p \quad (4.1)$$

Width  $W_s$  is given by

$$W_s = W_p + 2\Delta W_p \quad (4.2)$$

where,

$L_s$  is length of substrate

$L_p$  is length of patch

$W_s$  is width of substrate

$W_p$  is width of patch.

$$\text{Where, } \Delta L_p = \frac{h_s}{\sqrt{\epsilon_r}} \quad (4.3)$$

where,

$h_s$  is the height of substrate.

The resonance frequency is related to length and width as:

$$f_i = \frac{c}{2\sqrt{\epsilon_{\text{effective}}}} \left( \left( \frac{m}{L_p} \right)^2 + \left( \frac{n}{W_p} \right)^2 \right)^{1/2} \quad (4.4)$$

where,

$m=1, n=0$  for  $TE_{10}$  mode.

Now, most of field is confined within substrate. It is in air too thus the effective dielectric constant is slightly less than relative permittivity.

$$\epsilon_{\text{effective}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left( 1 + \frac{12h_s}{W_p} \right)^{-1/2} \quad (4.5)$$

where,  $h_s$  is height of substrate.

$$W_p = \frac{c}{2f_i \sqrt{\frac{\epsilon_r + 1}{2}}} = \frac{\lambda_i}{2\sqrt{\frac{\epsilon_r + 1}{2}}} \quad (4.6)$$

Thus the bandwidth and gain is directly proportional to the width of the radiating patch.

It is studied that larger value of  $W_p$  cause increase in aperture area and hence increase in gain of antenna. Moreover with increase in width fringing field increases which cause more radiation. Hence, bandwidth of antenna increases. But simultaneously it cause increase in size of radiating patch and hence the antenna. On increasing  $W_p$ ,  $\epsilon_{effective} = \epsilon_r'$ .

$$L_p = \frac{\lambda_i}{2\sqrt{\epsilon_{effective}}} \quad (4.7)$$

Characteristic impedance  $Z_c$  given by:

$$Z_c = 60 \frac{\ln \left[ \frac{8h_s}{W_p} + \frac{W_p}{4h_s} \right]}{\sqrt{\epsilon_{effective}}} \quad (4.8)$$

The substrate length and width can thus be calculated by

$$L_s = L_p + 6h_s \quad (4.9)$$

$$W_s = W_p + 6h_s \quad (4.10)$$

For finite ground plane the length and width can be:

$$L_{ground} = L_p + 12h_s \quad (4.11)$$

Width can be given as

$$W_{ground} = W_p + 12h_s \quad (4.12)$$

Inset Feeding is mathematically given as:

$$L_{fc} = 10^{-4} \frac{L_p}{2} \left( \frac{0.001699\epsilon_r'^7 + 0.13761\epsilon_r'^6 - 6.17\epsilon_r'^5 + 93.18\epsilon_r'^4}{-682.69\epsilon_r'^3 + 2561.9\epsilon_r'^2 - 4043\epsilon_r' + 6697} \right) \quad (4.13)$$

Where  $L_{fc}$  inset feed is cut length

#### 4.4 DESIGNED ANTENNA CONFIGURATION

This section includes the design parameter of antenna fabricated. Antenna is resonating in dual band having overall size  $60 \times 50 \text{ mm}^2$  and the size of radiating patch  $46 \times 40 \text{ mm}^2$ . Two slots of size  $3.4 \times 14 \text{ mm}^2$  adjacent to feed and  $4 \times 20 \text{ mm}^2$  along the width of patch is created. Antenna is

fed by microstrip feed which is considered to be simplest of all. The substrate used for sandwiching in between ground plane and radiating patch is Routersdroid (5880).

Plane is partially grounded which provides high front to back radiation ratio. Material used as substrate is expensive but provides high gain in comparison with FR4.

Sr. no.	Parameters	Value (mm)
1	$L_s$	60
2	$L_f$	11.8
3	$L_p$	46
4	$T$	1.6
5	$T_p$	0.035
6	$W_s$	50
7	$W_f$	5
8	$W_p$	40
9	$L_g$	33.5
10	$W_g$	50

Table 4.2 Parametric dimensions

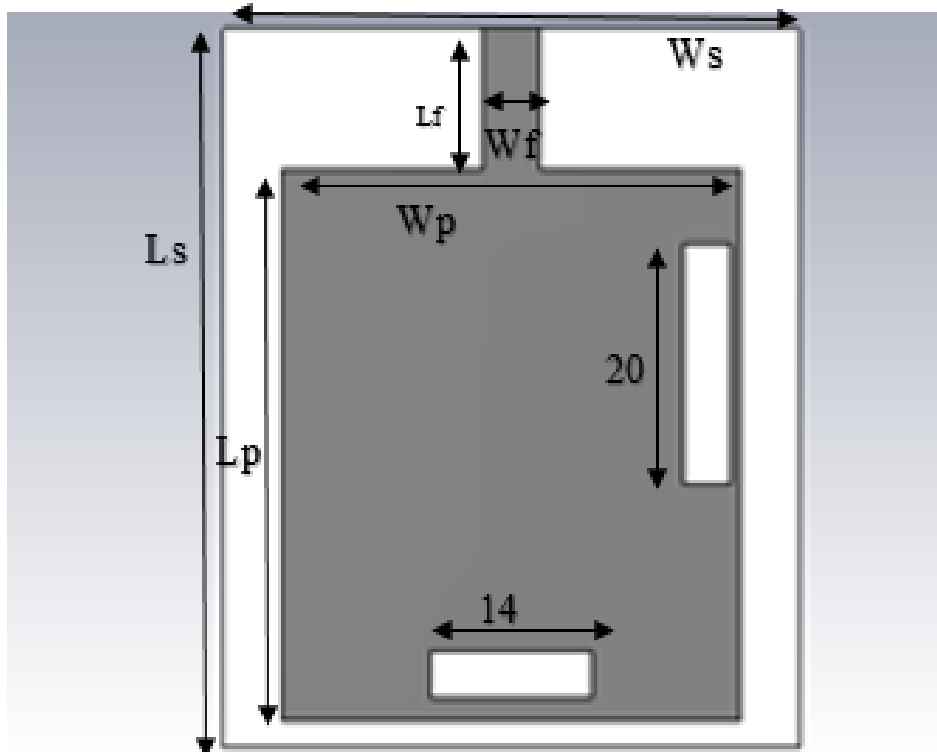


Figure 4.2 Designed antenna

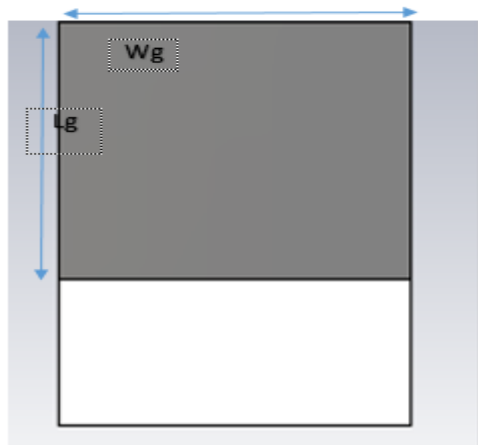


Figure 4.3 Back view ground plane

#### 4.5 DESIGN STEPS

Design step include the making of patch of  $46 \times 40 \text{ mm}^2$  on Fr4 substrate then cutting two slots of  $3 \times 14 \text{ mm}^2$  and  $4 \times 20 \text{ mm}^2$  on it providing two resonant frequencies.

#### 4.6 SIMULATED RESULTS

This designed antenna having dual band resonating frequency at 3.5 GHz and 5.8 GHz covering WLAN and WiMAX band.

##### 4.6.1 Return Loss

As discussed previously, return loss is representation of power loss. Here we get the value of return loss at two frequencies i.e.  $-36.6 \text{ dB}$  at 3.5 GHz and  $-26.7$  at 5.8 GHz.

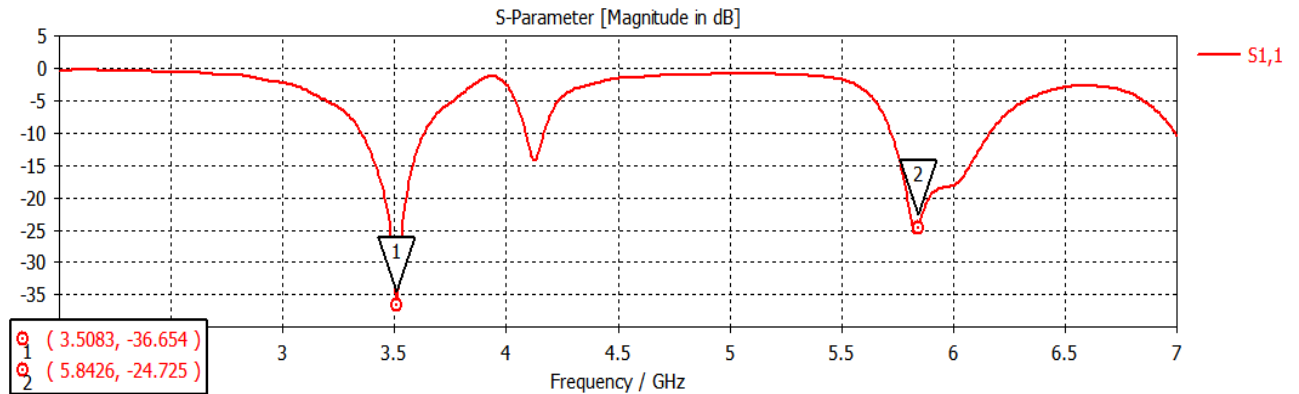


Figure. 4.4 Return loss vs frequency

##### 4.6.2 Smith Chart

Good Impedance matching is obtained at both frequencies lying between 40 to 55 ohm. Antenna is perfectly matched at  $50 \Omega$ . Practically matching is up to  $60 \Omega$ .

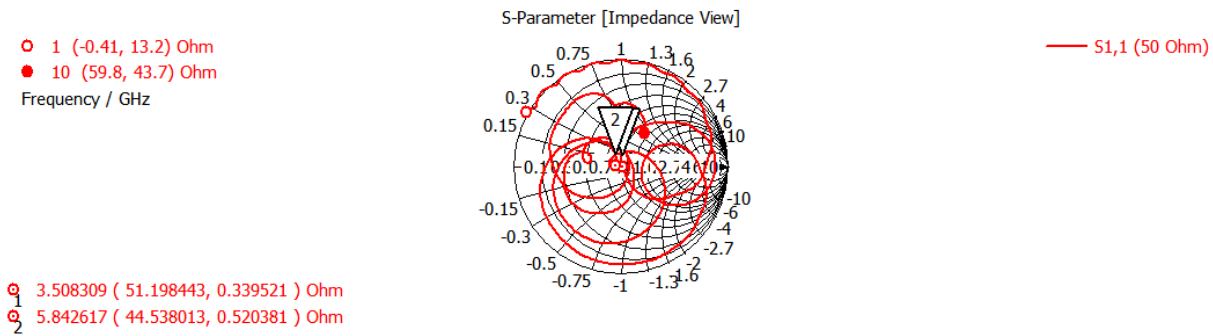


Figure 4.5 Smith chart

#### 4.6.3 VSWR

VSWR should not be greater than 2. Here for this antenna we get graph as below. At both resonating frequency it is less than 2 i.e. nearly equals to 1.

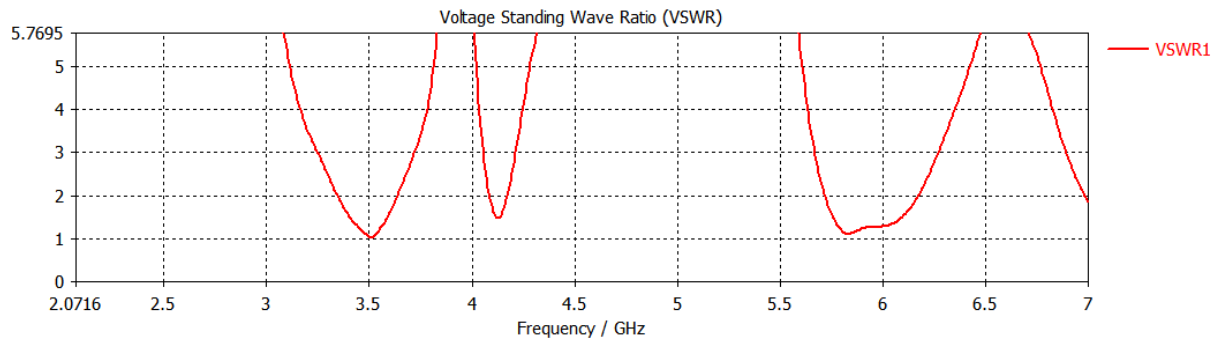


Figure 4.6 VSWR vs Frequency

#### 4.6.4 Gain and Directivity

This designed antenna is important due to its high gain vs frequency graph. Due to the use of Rougerduroid it provide an increased gain of 4.18 dBi at 3.5 GHz and 6.5 dBi at 5.8 GHz frequency.

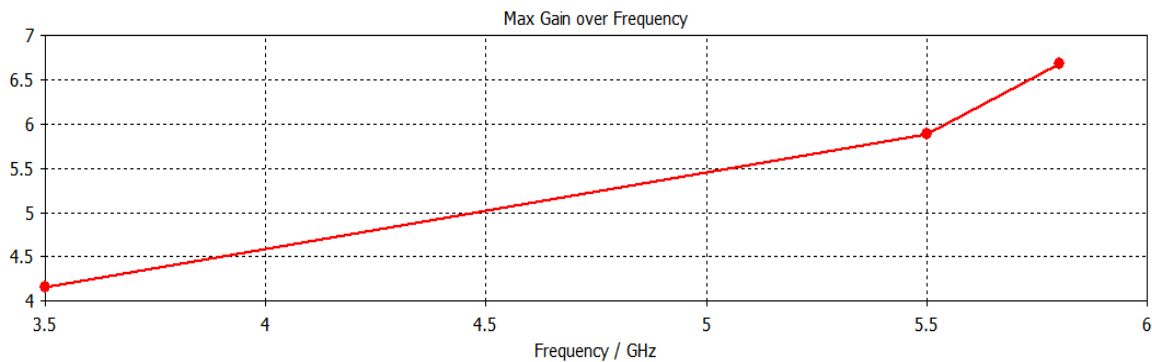


Figure 4.7 Gain vs frequency

Figure 4.9 and 4.10 gives the 3D plot of directivity of antenna having values 4.8dBi at3.5 GHz frequency and 6.9 dBi at5.8 GHz frequency.

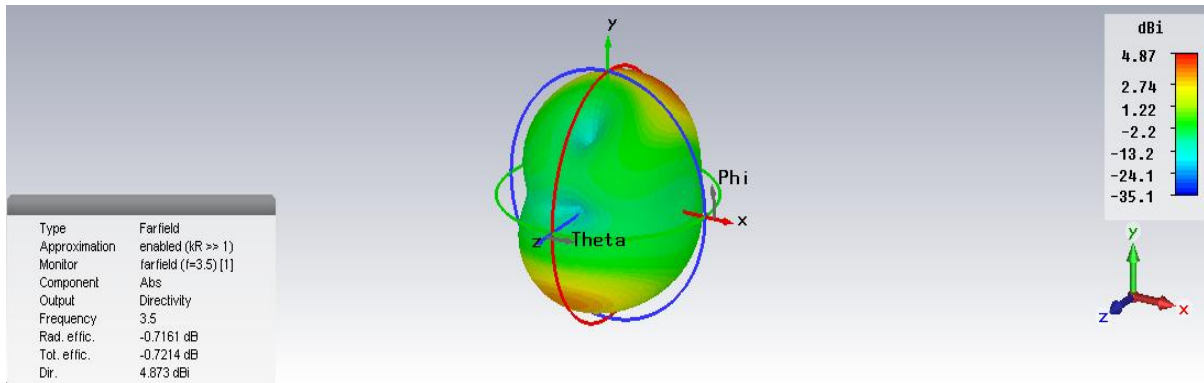


Figure 4.8 Far fields result (directivity) at 3.5 GHz

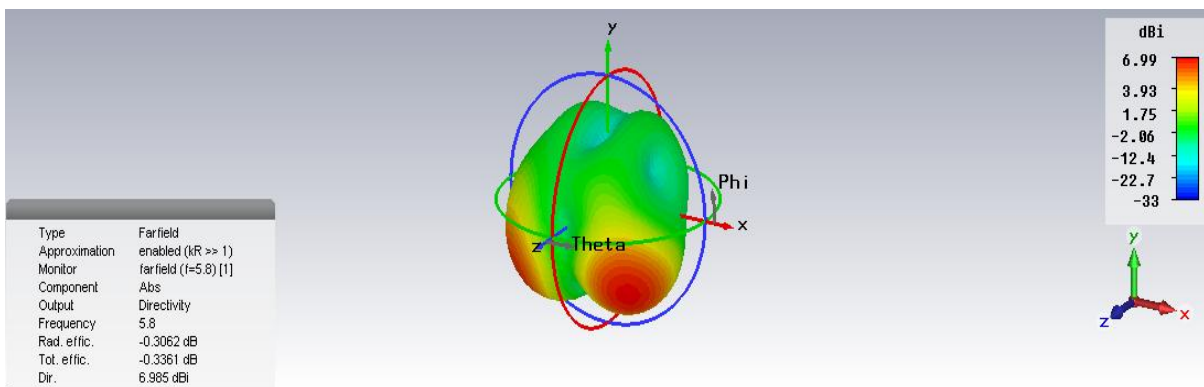


Figure 4.9 Far fields result (directivity) at 5.8 GHz

#### 4.6.5 Radiation pattern

In figure 4.11 radiation pattern is given in E and H plane for azimuth 90 for which  $\Phi = 0$  and  $\theta = 0$ . The designed antenna is omnidirectional in H field.

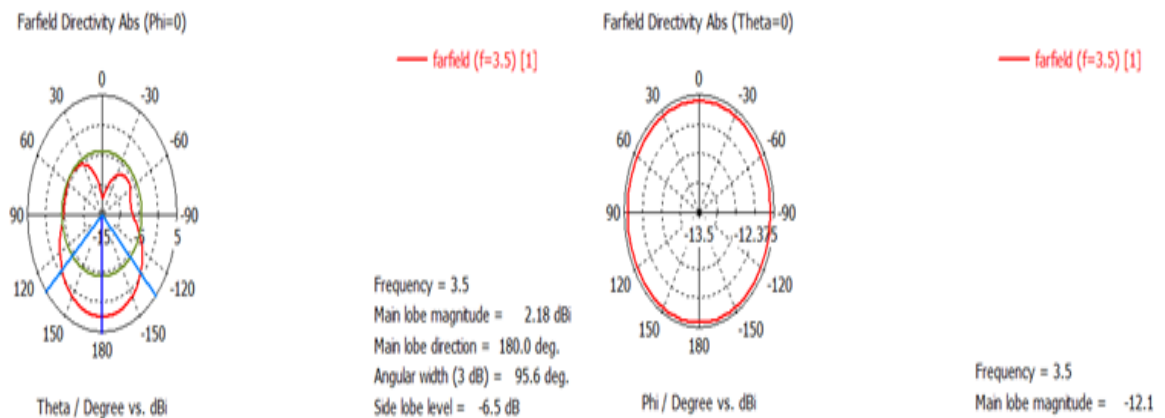


Figure 4.10 E-Plane (left) and H-Plane (right) results at 3.5 GHz

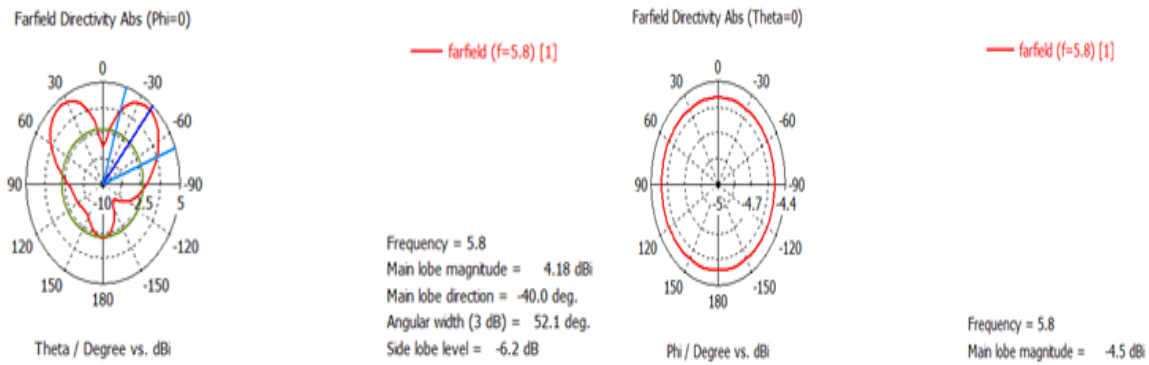


Figure 4.11 E-Plane (left) and H-Plane (right) results at 5.8 GHz

#### 4.6.6 Axial ratio

The antenna is circularly polarized having axial ratio below 3 at both frequencies. This is caused by slots entered into the structure.

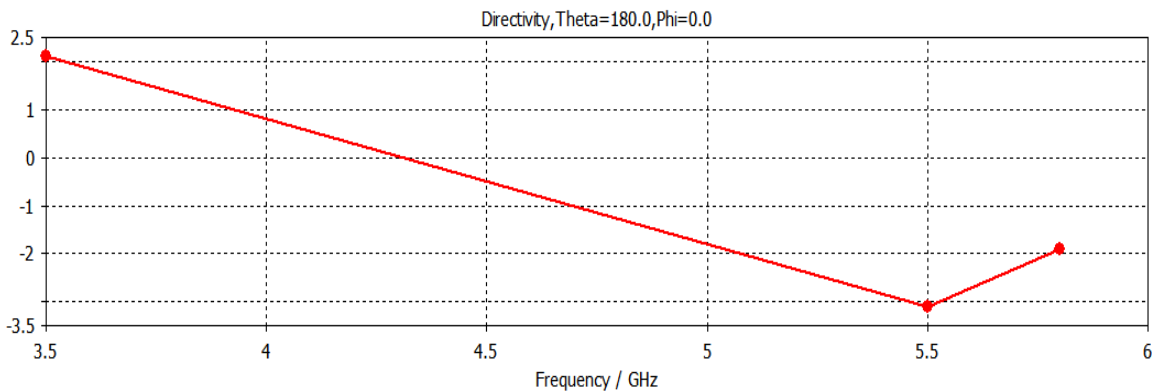


Figure 4.12 Axial ratio vs frequency

#### 4.6.7 Front to Back Ratio

It is the ratio of power transmitted in forward direction to reflected power. It should be large.

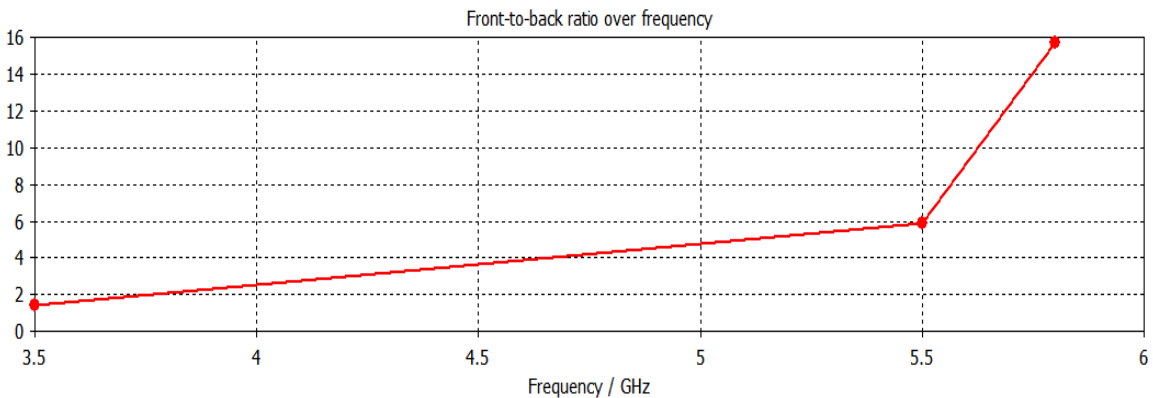


Figure 4.13 Front to back ratio

#### 4.7 FABRICATED AND MEASURED RESULTS

The optimized results were obtained with that geometrical structure was fabricated on Rougher duroid (RS5880) having thickness 1.64 mm and dielectric constant 2.2. The fabrication was done by Photolithography technique which includes requirement of photoresist, that can be of two type positive and negative, and also UV rays for exposure. Developer dissolves the exposed part of positive photo resist. The step by step fabrication is done. Negative of computer based geometrical design is printed on transparent sheet which acts as mask. Thus copper clad substrate obtained is cleaned by acetone and allow to dry. This ensures proper conductivity of copper and do not cause any kind of alteration in frequency, this is followed by lamination by photoresist onto the dried copper layer. Then the whole prototype is subjected to UV rays. After development of the copper clad, substrate is etched by  $\text{FeCl}_3$  solution. This etched substrate is further rinsed with water and dried. Further present photoresist is removed by sodium hydroxide. The Figure 4.16 shows the fabricated antenna. Also Figure 4.17 contains the measured results of the dual band resonating MSPA.

And Finally, Figure 4.18 shows the simulated as well as measured results.

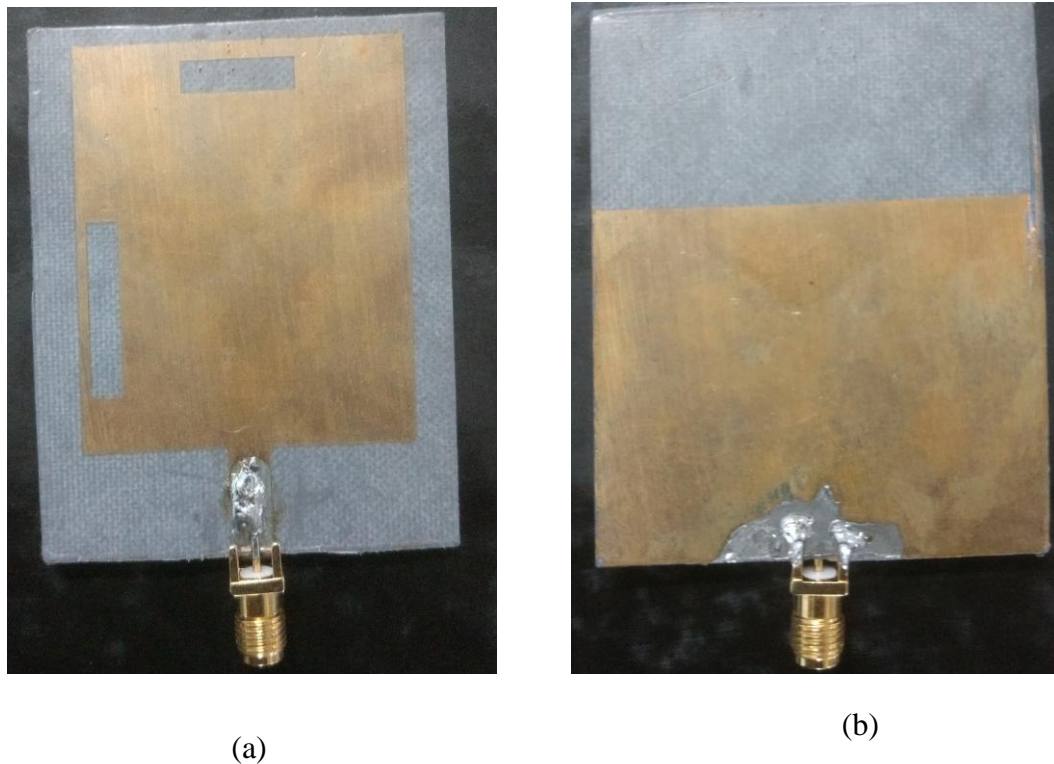


Figure 4.14 (a) Front view of antenna (b) Back view of antenna

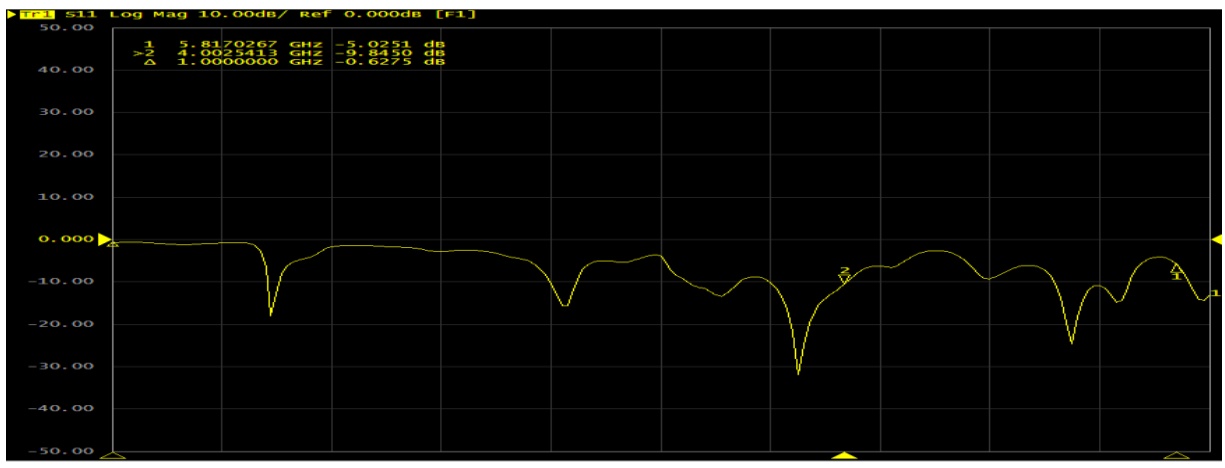


Figure 4.15 measured results for dual band MSPA

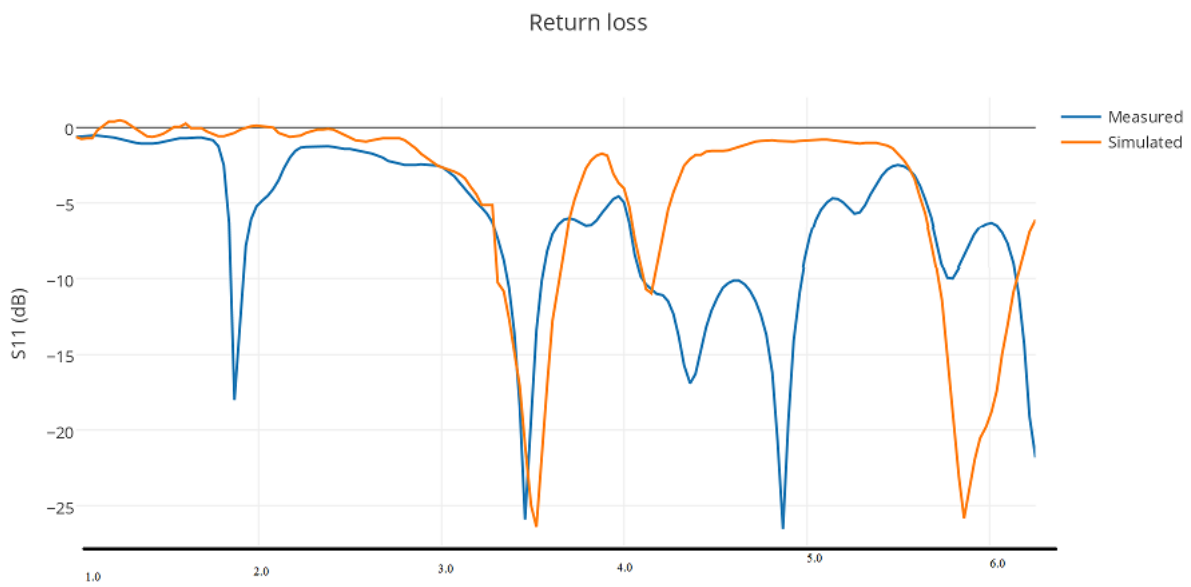


Figure 4.16 Simulated and measured results of dual band antenna

## 4.8 CONCLUSION

In this chapter the dual band microstrip patch antenna fed with inset feed is simulated and fabricated. For substrate we use Rougerduroid which can effectively enhance the gain of antenna. Thus gain achieved here was much greater than one can get using FR4.

# CHAPTER 5

## GAIN ENHANCEMENT OF DUAL BAND MSPA USING REFLECTIVE METASURFACE (RMS)

---

### 5.1 INTRODUCTION

Metamaterials are complex material whose electromagnetic properties depends upon material of composition as well as on the macroscopic structures that are particularly introduces to enhance and obtain a specific response. Thus the property of any material can be enhanced and altered by introducing various structure into it. The properties of meta has made them vulnerable and desirable for use in wide variety of frequency bands, from optics to microwave and so,. They are realized by gradually recurring basic unit in a particular pattern. The basic building unit is called as unit element, which defines the basic property of these materials. In CST studio suite, metamaterial are designed modelled and simulated by applying periodic boundaries of the unit element [55].

### 5.2 THEORY OF META MATERIAL

The metamaterial are the efficient artificial electromagnetic composite structures with rare properties which are not easily seen in nature. By usually rare properties one meant negative refractive index they possess. Metamaterial has both relative permeability as well as permittivity, negative which determines how certain material react to electromagnetic radiation Thus these materials having negative refractive index are termed as left handed composites(LHC).The relation is depicted mathematically as

$$N = \pm\sqrt{\epsilon\mu} \quad (5.1)$$

This is Maxwell equation for refractive index explains the behaviour of electromagnetic waves comprising both electric and magnetic field. It tells that the two fields are perpendicular to one another as well as perpendicular to the direction of wave propagation. Now the an EM wave enters into the material, fields of the wave comes in contact with the electrons as well as other atoms composing the material causing oscillations.

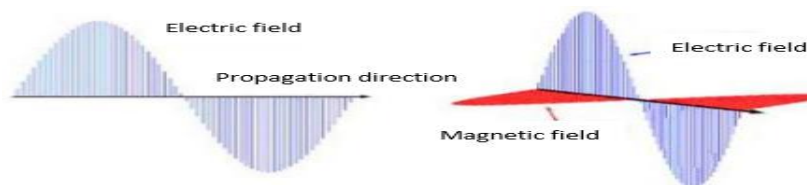


Figure 5.1 EM waves [56]

The concept allows to predict the permeability and permittivity are the only properties relevant to change of wave behaviour so after tuning this value it provides high degree of freedom to fabricate and design any antenna. And also the two properties can be either positive, negative or both .The graph below shows where the Meta material exist. The figure shows Single negative region i.e. region II and IV hamper the signal. Permeability and permittivity is positive in Region I. Region III is where lies the metamaterial. Materials present and behaves in this region are not easily available in nature.

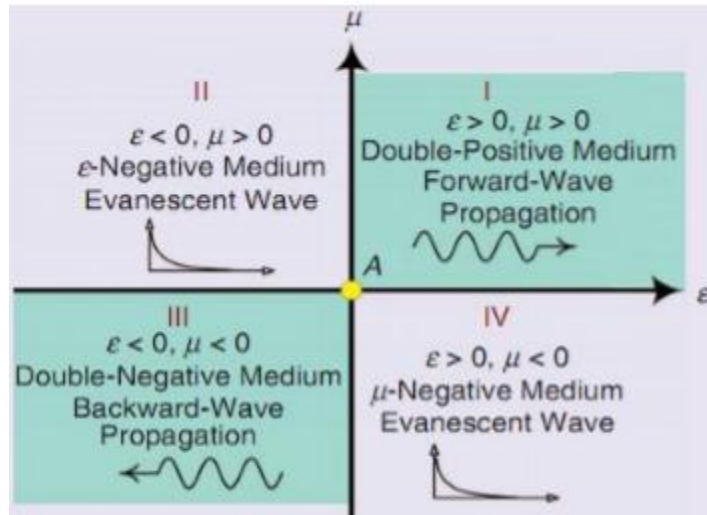


Figure 5.2  $\epsilon - \mu$  diagram (permittivity – permeability)[57]

### 5.2.1 Wave Behaviour

An EM wave is sinusoidal varying wave that travel to left or to the right being carried away by function of time. Wave travels from  $n_1$  to  $n_2$  as a material maintaining PRI (positive refractive index). On increment of refractive index speed of wave decreases as shown in Fig. 5.3.

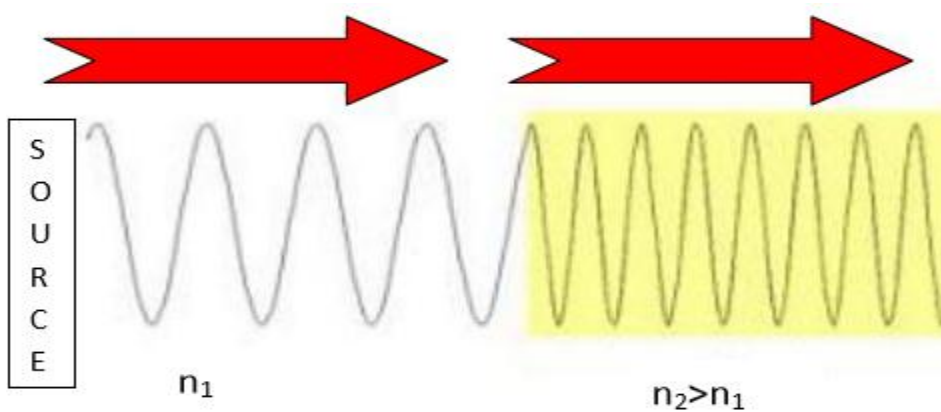


Figure 5.3 wave striking on PRI [56]

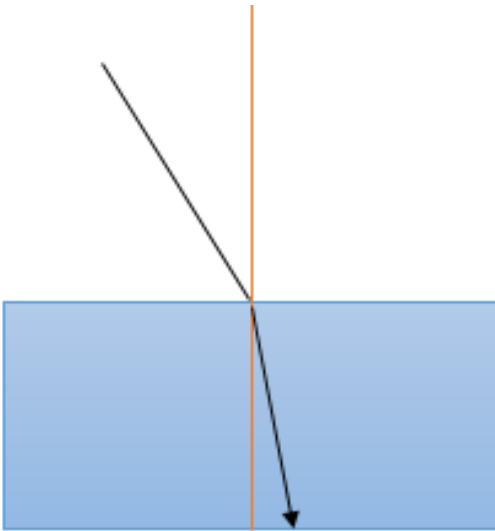


Figure 5.4 PRI behaviour

When wave travel backward towards the source the material possess negative refractive index and speed of wave is given by  $\frac{c}{n}$  which becomes negative. Thus as a result wave gets propagated in opposite direction of energy flow and therefore the material becomes left handed meta materials.

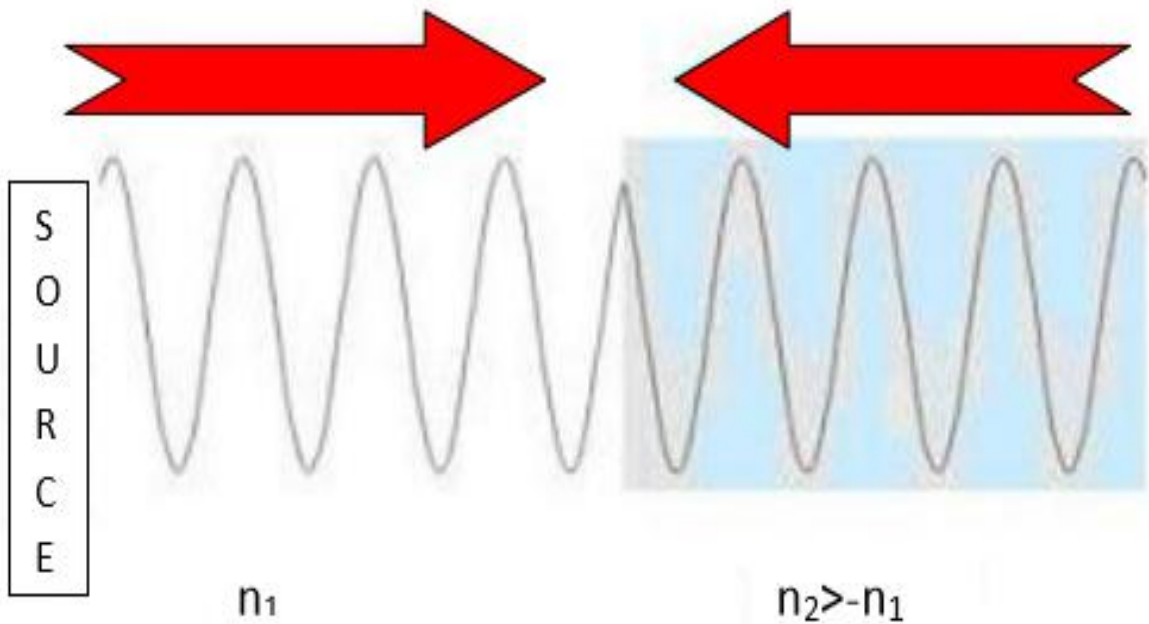


Figure 5.5 Wave striking on NRI [56]

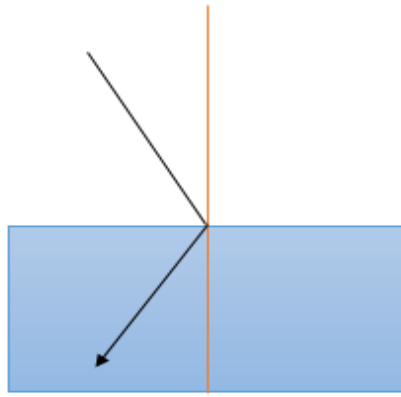


Figure 5.6 NRI behaviour

According to Snell's law, when an EM wave travels from one medium to another having refractive index of first is  $n_1$  and other is  $n_2$ . The change in trajectory can be given by

$$n_1 \sin \Theta_1 = n_2 \sin \Theta_2 \quad (5.2)$$

For left hand, material Snell's is applicable similarly. Figure 5.7 depicts that how Snell's Law get modified for these left handed material.

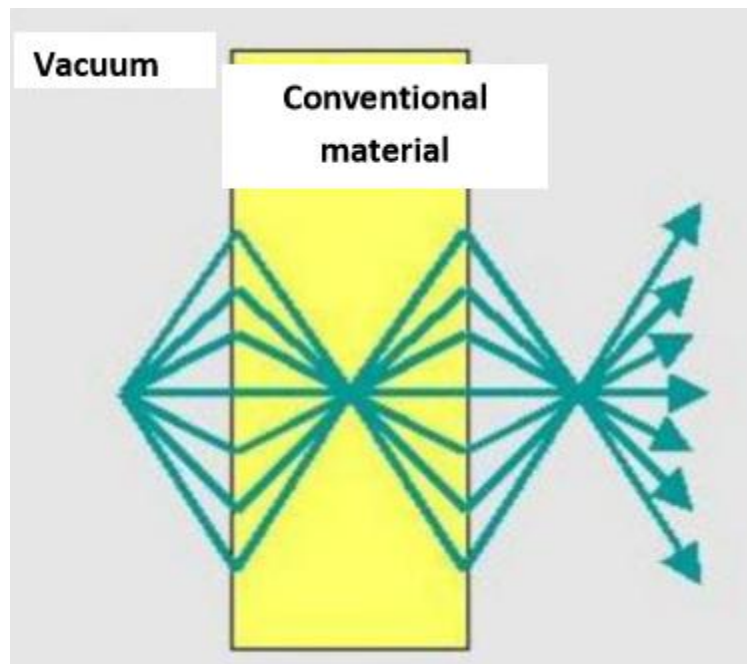


Figure 5.7 Refracted rays through NRI [57]

The Figure 5.7 gives idea about the basic principle of meta material. As for RHM the refracted waves are refracted away after leaving as well as entering the medium. But for the metamaterials, the waves are deflected in a manner as to provide a focus of wave itself inside the material and

another outside of the material. Thus in case of antenna radiation pattern is more a beamlike, which produces highly directional antennas and also may allow closed packing of antenna.

### 5.2.2 History of Metamaterial

The first discovery of LHM was occurred in year 1996 by Pendry et al. they invented the artificial electric plasma whose permittivity was negative using wire medium[53]. After that in 1999 he and his coworkers invented artificially magnetic plasma having negative permeability [53]. The work given by author [40] proposed SRR which further helps in achieving magnetic response [55]. Many researchers conducted a famous experiment verifying the negative refraction phenomenon which provides an attractive approach in using LHM with the inclusion of invention of super lens and perfect lens [53]. But by the time disadvantages were high Losses and narrow bandwidth. Meanwhile, an alternative approach of LHM was proposed using TL approach [49]. It is seen in their work that TL (transmission line) approach for meta material consists of distributed parameters while conventional uses materials having inductors as well as capacitor. Further in the dual model it has series of inductors as well as capacitors. This is described as CRLH structure and used in many proposed structures in detail as per requirement [46].

### 5.2.3 Resonant and Non Resonant structures

Meta materials are classified into two categories

- Resonant metamaterials
- Non resonant metamaterials

These are having different advantages and disadvantages of their own.

For resonant metamaterials permeability and permittivity have large dynamic range close to resonant frequency. Thus with a little variation in frequency, large variation in  $\mu$  and  $\epsilon$  can be observed. In other words, very small change in dimension of SRR structure causes small shifting in frequency and hence a very large change in values of  $\mu$  and  $\epsilon$ . This is advantage of using resonant structures. They have high loss and narrow bandwidth close to resonant frequency. In non resonant structure, resonating frequencies are at higher level. It can be seen that both  $\epsilon$  and  $\mu$  have high losses and changes slowly with respect to the frequency. Thus low loss and broad bandwidth are the major advantage of the non-resonant structures.

#### 5.2.4 Application of Metamaterial

Having such unusual and exciting features metamaterial found their advantages in lot of applications i. e. in super lenses which are used in very high-resolution medical imaging, on destructive detection and optical imaging. In 2004, first super lens used in microwave regime was developed and demonstrated [48]. The material help in three times enhancement in resolution than diffraction limit. The application includes the implementation of metamaterial in cloaking devices [54]. Complimentary structures such as CSRR are used in implementation of Filters, phase shifters and power dividers [44]. The broadband and narrowband polarizer's have been recently discovered using anisotropic three-dimensional metamaterials [47]. Also, gradient refractive index metamaterials are realized to produce beam-focusing lens and beam-bending lenses. As per these properties, high-gain and broadband gradient planar lens antennas [50] and Luneberg-like lens antennas [51] have been presented and realized.

#### 5.2.5 Disadvantage

Only disadvantage is narrow bandwidth and large loss.

### **5.3 REFLECTIVE METASURFACES (RMS)**

The main idea behind the designing of reflective metasurface is to spike resonating oscillations in area of reflector, which facilitate in widening of the radiation aperture. A Current introduced in radiating elements at particular frequency nullifies the wave incident from one to other to travel through out the set of given elements. In order to improve the gain and bandwidth the gaps in between the elements being optimized. Thus, two important characteristics are studied because of the capacitive effects and coupling of surface wave. Therefore, it results in either cancelling the element's current with each other or selecting the size of element perfectly so that both operating frequency bands can be combined together. Firstly, as RMS is volumetric, the meaning of cancellation of total current is note mission elimination. Thus, each element in the RMS will radiate individually in a alike manner, which deduce an unvarying aperture phase circulation. Mutual coupling effect among RMS should be taken care off. However, its being nullified by maintaining optimum dimensions of the element and gap between them.

### **5.4 METHODOLOGY**

This section includes the description of the design steps involve in the design of reflective metasurface (RMS) inspired dual band MSPA with the help of flow chart.

- It includes the designing of MSPA resonating at dual frequency.
- Simultaneously a metamaterial cell of  $9.25 \text{ mm}^2$  is realized and fed to obtain dual band resonance in the same resonating band as of designed MSPA.
- Both structures output were being optimized.
- Metamaterial cell was multiplied and transformed in order to make  $37 \times 47 \text{ mm}^2$  single reflective surface comprising 20 repeating SSRR's.
- The METASURFACE thus formed further mounted onto the radiating patch with some air gap D in between.
- Simulated Results thus obtained by analyzing the design of CST studio Suite were optimized and studied
- Next, this RMS inspired MSPA was fabricated.
- And finally, the measured results were realized with the help of network analyzer.

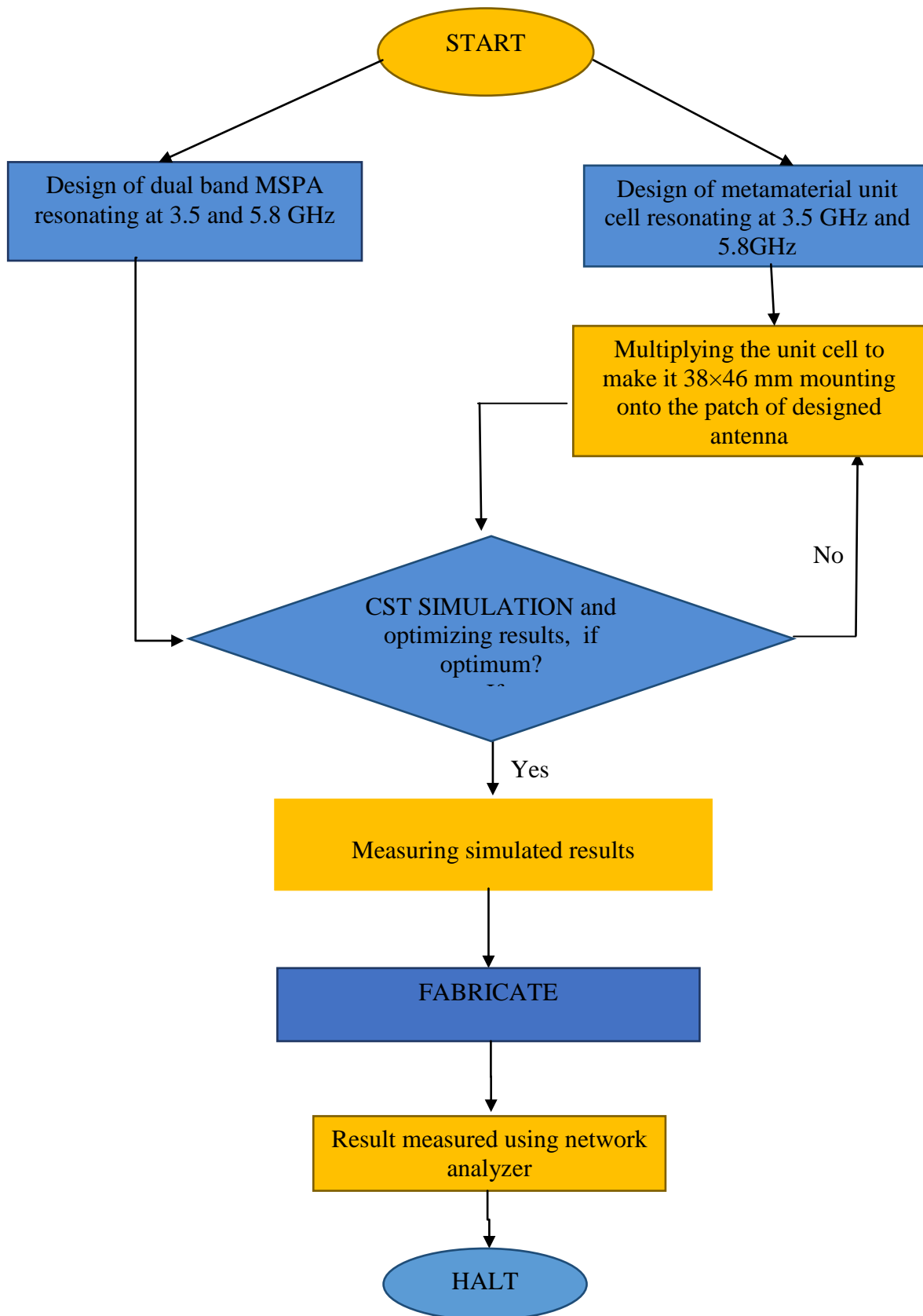


Figure 5.8 Flowchart of work done in designing RMS inspired MSPA

## 5.5 STEPS OF IMPLEMENTING METAMATERIAL

### Step 1: Unit Cell Configuration

Unit having dimensions given in table is designed to resonate at 3.5Ghz and 5.8 Ghz band. Dimensions of this SSRR is  $9.5 \times 9.5 \text{ mm}^2$ . It was back fed in order to make it optimize for this particular frequency band. The substrate used is FR4. Having thickness 0.25mm and dielectric constant 4.4.

Sr. No.	Parameters	Value(mm)
1	L	9.25
2	L1	9
3	L2	6
4	S	1.6
5	T	0.25
6	Tin	0.035
7	Wt	0.4
8	G	1

Table 5.1 Specification of unit cell

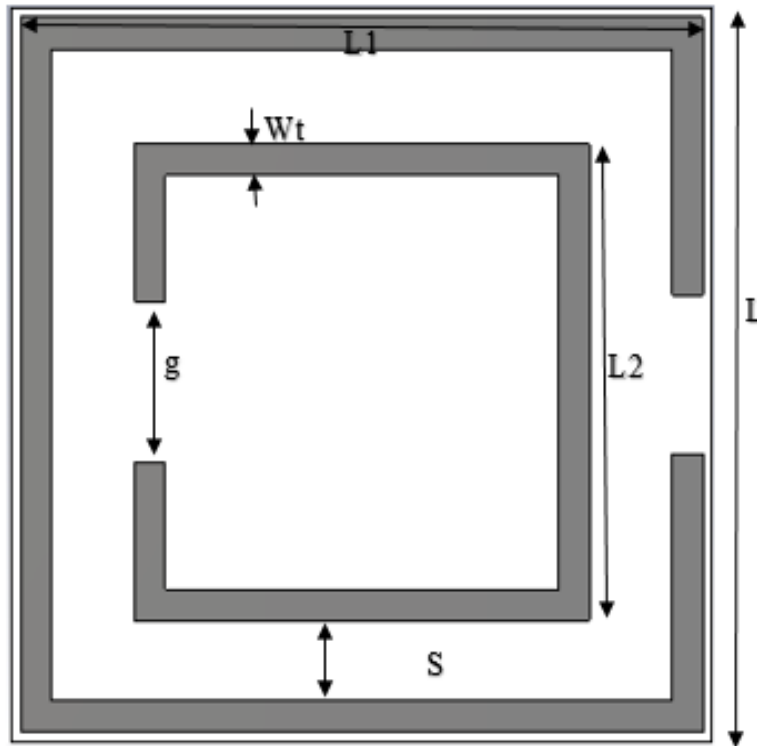


Figure 5.9 Unit cell metamaterial

Return Loss of single cell metamaterial provides resonance at 3.5 GHz and 5.8 GHz.

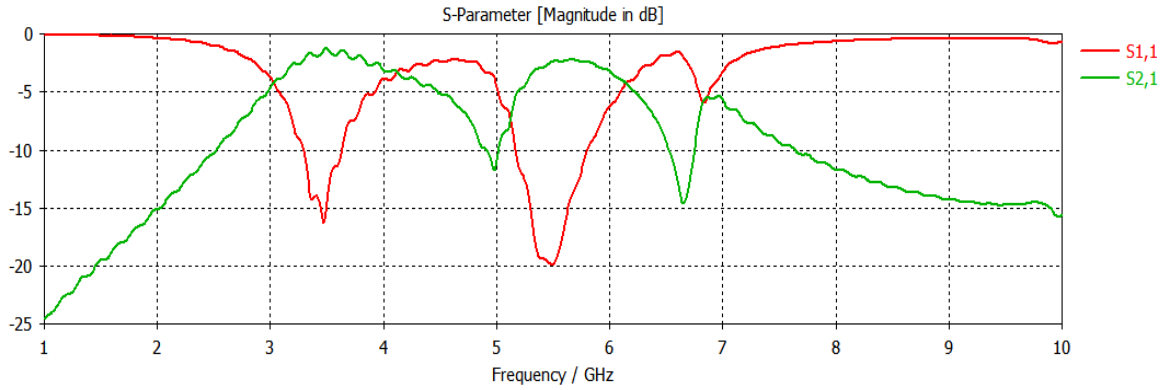


Figure 5.10 S-parameter

Step 2: Multiplying the single unit cell to cover the patch

As the antenna earlier fabricated has dimension's of radiating patch  $40 \times 46 \text{ mm}^2$ . So accordingly metamaterial unit cell is scaled by factor 4 in horizontal direction and factor 5 in vertical direction. It covers the patch with dimension of array  $38 \times 47 \text{ mm}^2$ .

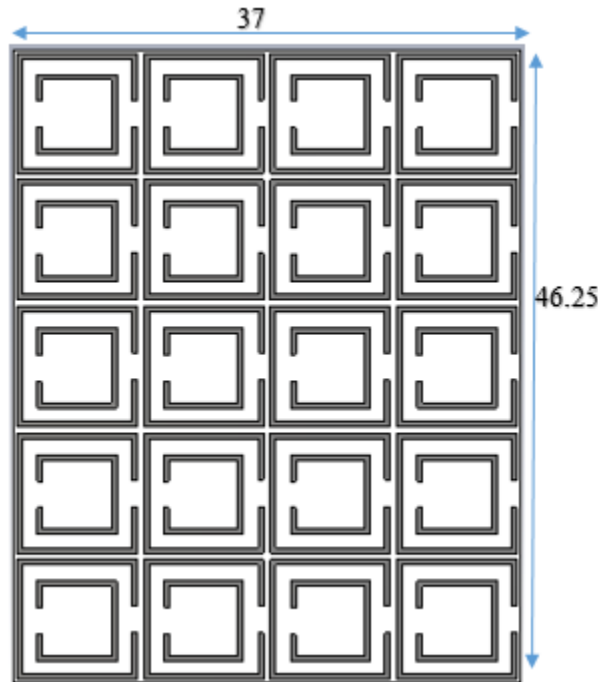


Figure 5.11 RMS

Step 3: Mounting RMS on Antenna

The above mounted surface covers the patch only having some air gap in between. Air gap helps to improve the results. The effect of gap between antenna and the RMS on the reflection coefficient is studied and depicted in results. The impact of the RMS position on the patch

depicts that for either band the reflection coefficient is lowest with highest gain and bandwidth has been acquired at  $D=15$ . The air gap in between RMS and the antenna has small impact on the lower band. Conversely, the upper band is strongly affected by this air gap.

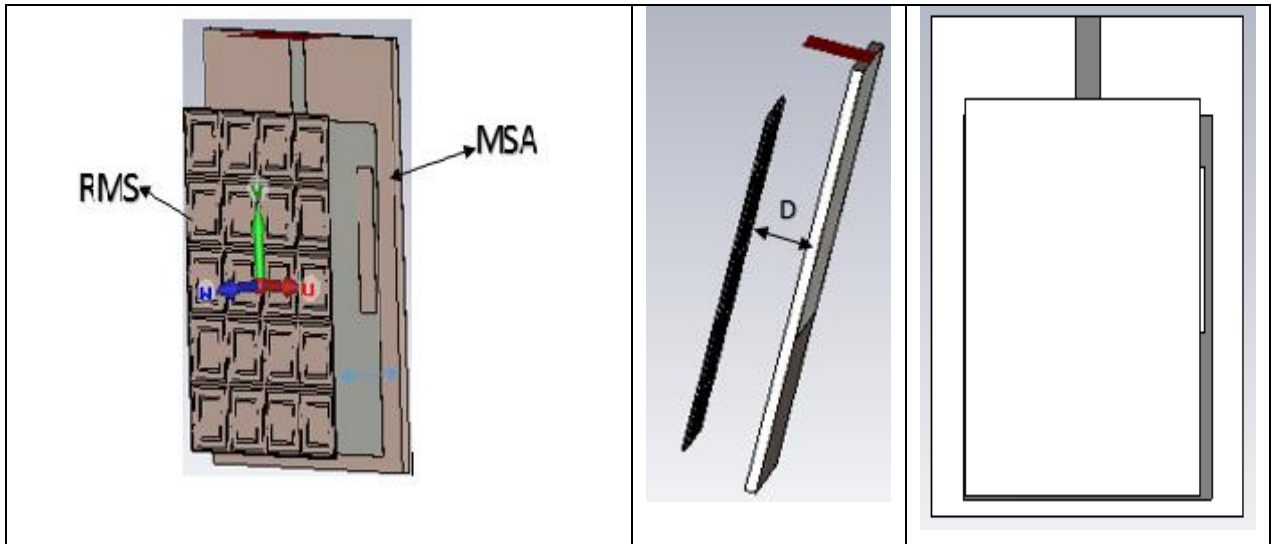


Figure 5.12 RMS mounted antenna (left) Side view (center) Front view (right)

## 5.6 SIMULATED RESULTS

RMS inspired dual band antenna has center frequency at 3.5 GHz and 5.8 GHz. RMS improved the gain at both frequencies.

### 5.6.1 Return Loss

After implementing RMS S parameter changes as shown in Figure 5.13. It tells that after implementing metamaterial the resonant peaks have been somewhat deflected from the resonating frequency 3.5 and 5.8 GHz. And also the return loss decreases on applying the metasurface over the dual band antenna.

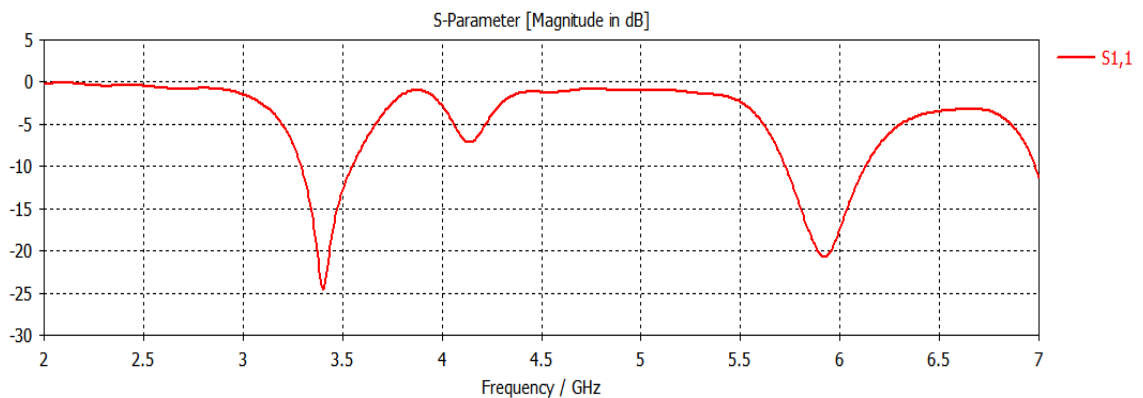


Figure 5.13 S parameter

### 5.6.2 Gain

Antenna gain is generally termed as the ratio of the power generated by the antenna from a Far field source on to the beam axis of antenna to the power produced by an isotropic antenna. Usually this ratio is depicted in ‘decibels isotropic (dBi)’. For a specific frequency, the effective area of antenna is directly proportional to the power gain. And also effective length of antenna is proportional to the square root of the antenna's gain for radiation resistance and specific frequency. As per reciprocity concept is taken into account, the gain of any antenna when acting as a receiver is equal to its gain when it is acting as a transmitter. Here after implying metamaterial gain of the antenna has been enhanced by approx. 1.5dB at both resonant frequencies.

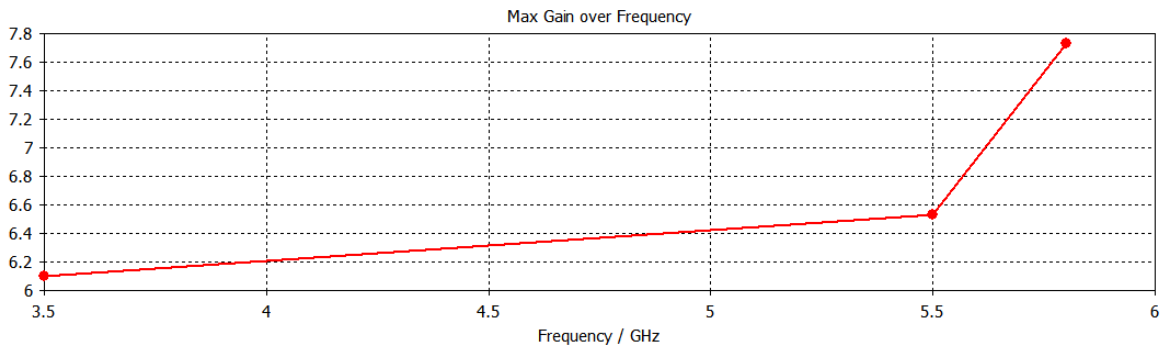


Figure 5.14 Gain vs Frequency

### 5.6.3 Directivity

The 3d graph of directivity for both 3.5 GHz and 5.8 GHz is presented here.

**At 3.5 GHz** resonating frequency its value is **6.49 dBi**.

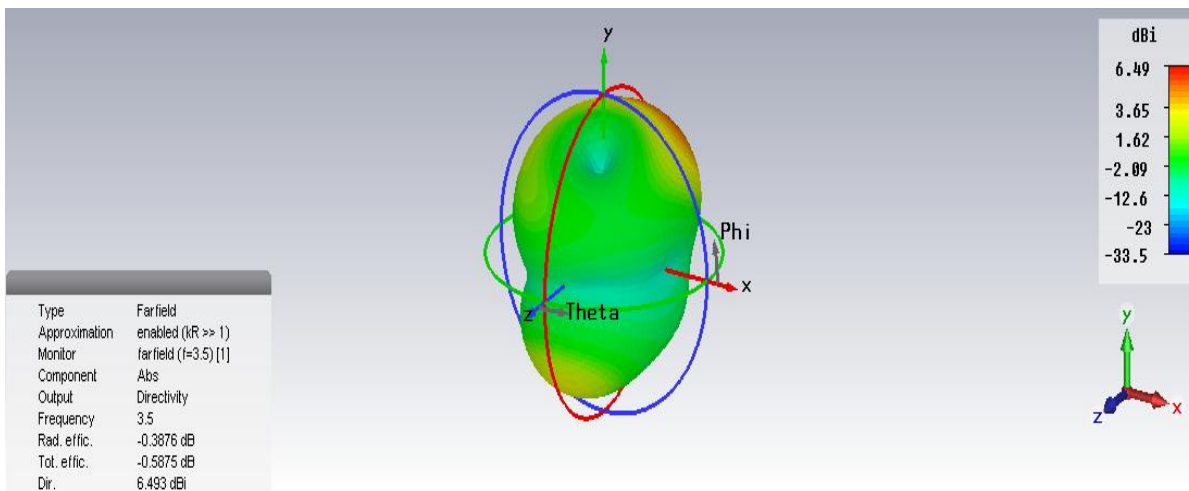


Figure 5.15 3D model of directivity at 3.5GHz

At 5.8 GHz its value is 8.064dBi.

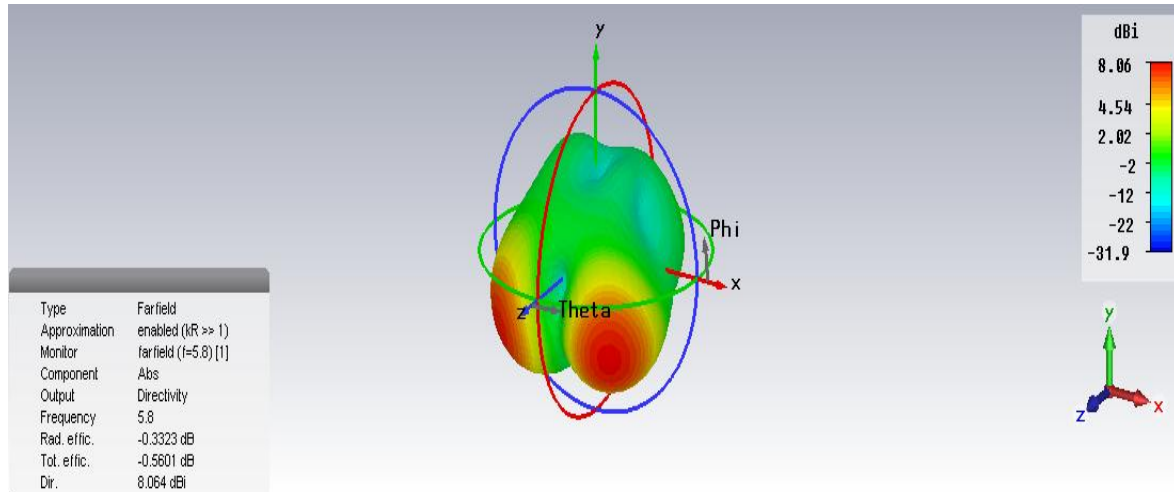


Figure 5.16 3D plot of far fields (directivity) at 5.8 GHz

#### 5.6.4 Effect of Gap on Gain

Effect of distance 'd' on gain is tabulated as:

Sr. No.	Air Gap 'd'	Gain at 3.5 GHz	Gain at 5.8 GHz
		(dB)	(dB)
1	5	5.830	7.000
2	10	6.090	7.400
3	12	6.055	7.572
4	15	6.100	7.732
5	17	6.109	7.713
6	20	6.120	7.635

Table 5.2 Gap vs Gain

Thus, one can observe that on decreasing the gap in between patch and metasurface layer we get lowest gain on both frequency. On further increasing it by 5 unit it gives hike in gain at 5.8 GHz frequency. Among all air gap of 15 mm is efficient to provide maximal of 6.109 dB gain at 3.5 GHz and 7.732 dB at 5.8 GHz.

#### 5.6.5 Comparing Gain with and without Metasurface

Gain at Resonating frequency (GHz)	Without RMS(dBi)	With RMS (dBi)
3.5	4.065	6.100

5.8	6.533	7.732
-----	-------	-------

Table 5.3 With RMS vs Without RMS

### 5.6.6 Effect of metasurface thickness on gain at d=15mm

Gain at Resonating frequency (GHz)	Thickness of RMS At T=0.25 Gain (dBi)	Thickness of RMS At T=1 Gain (dBi)
3.5	6.100	4.545
5.8	7.732	6.693

Table 5.4 Thickness vs Gain

## 5.7 CONCLUSION

This chapter describes how metasurfaces can be implemented to enhance the gain of the microstrip patch antenna without changing its surface geometry. Chapter started with introduction of these negative properties metamaterial proceeded further by designing of single metamaterial cell resonating on frequency similar to the tuned antenna frequency. By making repeating geometry of single metamaterial cell we made a reflective metasurface which was surmounted onto the radiating patch. Hence comparing and studying provides enhancement in antenna gain up to 1.5 dB.

## CHAPTER 6

### CONCLUSION AND FUTURE SCOPE

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#### 6.1 CONCLUSION

This thesis has been divided into two parts. One involves the use of ACS fed meandered MSPA. The above design gives concept of size miniaturization by the concept of decreasing the feed area to decrease the effective area of antenna. The structure thus obtain is conformal, uniplanar, easy to fabricate and require low cost of operation. Here asymmetric coplanar strip (ACS) fed dual-band printed monopole antenna is designed for 2.5 GHz LTE 4 G applications. The proposed geometry is fabricated on a low cost FR4 substrate having an overall dimensions of  $20 \times 31.75 \text{ mm}^2$ . By integrating a rectangular shaped strip with meandered structure to the basic AC monopole, desired single band frequency is obtained. Its being studied that the operating frequency can be changed by increasing and decreasing the electrical length of the structure. The simulated and experimental result shows that the proposed antenna is giving omnidirectional radiation patterns. The other part of the thesis includes designing of RMS inspired dual band antenna. The new design is proposed and fabricated in order to enhance the parameters of MSPA using Meta surface. It is observed that the metamaterial structure should be carefully handled in order to improve the various parameters of antenna. Firstly, a single unit cell is studied, optimised and implemented for the required frequency range and after that the unit cell is multiplied to make an array of size  $37 \times 46 \text{ mm}^2$  and further the array structure on mounted above the radiating patch with the air gap of 15 mm. Further the design structure is studied for different values of air gaps between the base antenna and the designed array. The measured and simulated results show good agreement providing a simple and a low-cost design, there is a bit difference between the curves for both measured and simulated antennas because of fabrication losses. The proposed antenna is suitable for WiMAX and WLAN applications A simultaneous enhancement of both the bandwidth and the gain of the base antenna is acquired by the introduction of the metamaterial array above the antenna. A parametric analysis has also been conducted to adjudge the effects of the patch structure, the ground plane and the air gap between the RMS and the radiating patch. In the work, a complete step-by-step procedure for obtaining the material parameters of a metamaterial structure is given based on the S parameters extracted from CST studio suite software based on FIT.

## **6.2 FUTURE SCOPE**

The work can be carried further by introducing some different structures for example DGS stacking and introducing parasitic patch and Air gap to the base antenna in order to provide bandwidth enhancement. Future work includes changing the different feed lines from simple micro strip to complex proximity coupling. Further the concept of size miniaturization can be implemented to subject all the designing gaps for any antenna to get best results.

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# Thesis

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