

**DESIGN AND FABRICATION OF METAMATERIAL  
LOADED MICROSTRIP PATCH ANTENNA FOR RADAR  
CROSS SECTION REDUCTION**

*A Thesis submitted in partial fulfillment of the requirement for the Award of the Degree of*

**MASTER OF ENGINEERING**

in

**Electronics and Communication**

Submitted By

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## DECLARATION

I, Manbir Kaur, hereby declare that the work presented in this thesis entitled "Design and Fabrication of Metamaterial Loaded Microstrip Patch Antenna for Radar Cross Section Reduction" in partial fulfillment of the requirement for the award of degree of Master of Engineering (ECE) submitted at Electronics and Communication Engineering Department, Thapar Institute of Engineering and Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of Dr. Rajesh Khanna (Professor, Electronics and Communication Engineering Department), Thapar Institute of Engineering and Technology (Deemed to be 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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## ABSTRACT

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Radar cross section reduction (RCSR) has been prompted due to evolution of military technology. This thesis reviews the basic concepts and characteristics of metamaterials, as these are the most favourable development that impact defence industry products and stealth technology. It emphasizes the role of airpower and the ever-increasing demand of stealth. Initially, the blending of the fundamental aspects of stealth technology through radar signatures and methods of signature reduction are discussed. It also explores the recent research activities on metamaterials in various areas. Some existing research techniques used for RCSR are examined. The metamaterials are engineered media whose electromagnetic responses depend on their composition as well as on their structure. The general benefits of metamaterials are pointed in the thesis. Metamaterials are mostly used in antenna configuration for enhancing antenna performance such as realizing miniaturization, expanding operating band, enhancing gain as well as reducing RCS. The characteristics of the metamaterials like negative permeability and negative permittivity are basically the reason why MMs should be used in stealth technology. The various categories of metamaterials used for RCSR are studied in thesis. In this thesis we have also proposed a unit cell of metamaterial. Metamaterial unit cell consist of square loop and intersecting strips at the edges of add shaped structure.

In this thesis, primary antenna used is microstrip patch antenna. The microstrip patch antenna is having dimension  $66 \times 66 \text{ mm}^2$  and substrate height of 2mm, fabricated on FR-4. Another microstrip antenna is proposed for attainment of enhanced RCSR. A metamaterial loaded antenna is proposed for this application, which operates over frequency range of 2-18 GHz. The metamaterial unit cell is replicated eight times to form ground of proposed microstrip patch antenna. Coaxial feed technique is used which gives freedom to optimize impedance matching easily. Parametric analysis and simulation results validate that the metamaterial used on microstrip patch antenna enhances the RCSR. Along with the RCS, different properties of antenna i.e. return loss and surface current are studied. The simulated and measured results of fabricated prototype unveil that the suggested work is suitable for RCSR application.

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## LIST OF GLOSSARY

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RCS	Radar Cross Section
RCSR	Radar Cross Section Reduction
FSS	Frequency Selective Surface
EBG	Electromagnetic Band Gap
AMC	Artificial Magnetic Conductor
VHF	Very High Frequency
UHF	Ultra High Frequency
RAM	Radar Absorbing Material
NIM	Negative Index Metamaterial
DNG	Double Negative Metamaterial
SNG	Single Negative Metamaterial
PCM	Polarization Conversion Metamaterial
PRS	Partially Reflecting Surface
AFSR	Absorbent Frequency Selective Radome
RAS	Radar Absorbing Structure
MA	Metamaterial Absorber
PRMS	Phase Random Metasurface



# CHAPTER 1

## INTRODUCTION AND STATEMENT ANALYSIS

Significant research attentiveness in radar cross section reduction (RCSR) has been prompted due to evolution of military electronic technology. In order to avoid detection by radars, radar cross section (RCS) of key military targets should be reduced [1]. Antenna makes significant offering to overall RCS due to its key function which is to receive and radiate electromagnetic energy. Nuclear weapons are possessed by large number of countries, but the number of countries that have the ability of making stealth military vehicles is quite low. The possibility of any country using a nuclear weapon is very less because of the extreme international pressure. Therefore in tactical warfare owning nuclear weapons is not of much significance.

Stealth technology is a part of military tactics [2]. The main concept of stealth is to work/operate without giving enemy forces any indications of its presence. This technique was first explored by blending into the background visual clutter. It covers active and passive electronic counter measures which includes a range of techniques used with ships, aircrafts, submarines, satellites to make them invisible to various detection devices like radar, infrared, sonar[4,5]. For these parts of the electromagnetic spectrum it corresponds to military camouflage. The degree of stealth embedded in a particular design is selected according to the predicted extent of threats [6].

In most of the cases, especially in case of war devices, the key requirement is low RCS so that the device can be hidden from the rival's radar [7]. RCS of any device be it airborne or naval ships depend on its shape and material. RCSR has been a matter of interest from past numerous years. Microstrip antennas are quite favoured in microwave dominion especially in aircraft systems. So, it is an essential researching part of a stealth object to reduce the RCS of microstrip antennas [8].

### 1.1 MICROSTRIP PATCH ANTENNA

Microstrip patch antennas are preferably used for military applications due to their properties such as light weight, low profile and ease of fabrication [3]. These antennas are most

commonly used in array configurations. The basic design of microstrip antenna comprises of dielectric substrate with ground plane below it and radiating patch above the it as depicted in Figure1.1.

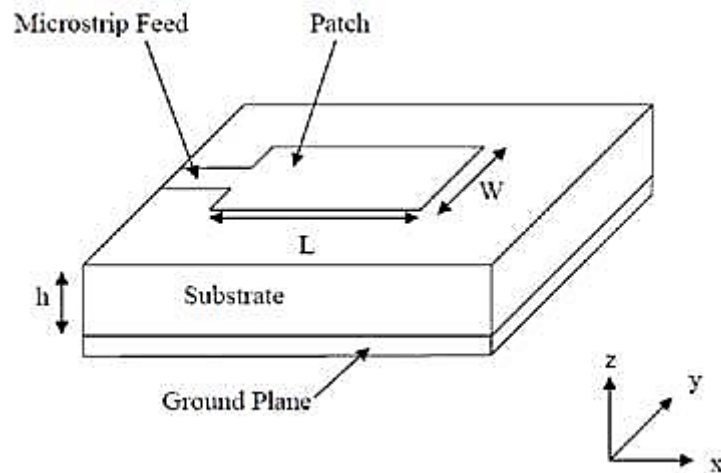


Figure1.1 Microstrip patch antenna [12]

The patch is usually formed of any conducting material such as copper or gold and it could have any possible shape. The feed lines and radiating patch are mostly photo etched on the dielectric substrate.

Some commonly used shapes of patch used for designing a microstrip patch antenna are rectangular, square, triangular, circular and elliptical. In case of rectangular patch, the length  $L$  of the patch is mostly in range  $0.3333\lambda_0 < L < 0.5 \lambda_0$ , in this case  $\lambda_0$  is the free-space wavelength. The patch should have quite less thickness so as to  $t \ll \lambda_0$ , where  $t$  is the patch thickness. The dielectric substrate has a height in range  $0.003\lambda_0$  to  $0.05\lambda_0$ . The value of dielectric constant ( $\epsilon_r$ ) is usually in the range  $2.2 \leq \epsilon_r \leq 12$ .

Microstrip patch antennas basically radiate due to the fringing fields between the patch edge and the ground plane. For efficient performance of antenna it is preferred to use a thick dielectric substrate with a low dielectric constant as it provides larger bandwidth, better radiation and hence better efficiency. These conventional arrangements lead to quite large antenna size. In an attempt to minimize size of the microstrip antenna, it is preferred to use substrates that have higher dielectric constant, but these provide results over narrow

bandwidth and are less efficient than conventional ones. So trade-off needs to be achieved between the antenna performance and antenna dimensions.

The microstrip patch antenna ground plane has higher radar cross section and upto now many methods have been devised for reduction of RCS of microstrip patch antenna [8]. High efficiency and composite absorbing structures allow a large portion of incidental energy to be scattered or attenuated in insignificant direction in order to minimize monostatic scattering, but antenna due to its characteristics could not be coated with any broadband absorbing material while continuing to operate. Due to these reasons RCS reduction while maintaining electrical visibility is difficult.

## 1.2 FEEDING TECHNIQUES

Feeding techniques are categorised in two sections. First one is contacting and the second one is non-contacting. The four most popular feeding techniques used are

**A. Microstrip line:** In this feeding technique, the conducting strip is to be attached directly to the edge of the microstrip patch. The width of conducting strip is smaller in comparison to the dimensions of microstrip patch [9]. This feeding configuration has a benefit that it can be engraved on the same substrate, so it provides a planar structure. In order to achieve good impedance matching, an inset cut can be incorporated. This technique provides simplicity in modelling, ease of fabrication as well as impedance matching.

**B. Coaxial probe (both contacting schemes):** The probe feed is one of the most commonly used feeding technique for microstrip patch antennas. This feeding technique can be stationed at any required location inside the patch so as to achieve impedance matching [9]. This feed method has advantages like ease of fabrication and low spurious radiation effects. The major shortcoming of this feeding technique is that it is quite hard to model because a hole needs to be drilled into the substrate and due to this it provides narrow bandwidth.

**C. Aperture coupling:** In aperture coupling, in order to obtain aperture coupling, the microstrip feed line is engraved at the bottom of the feed substrate and the radiating microstrip patch element is placed on the top of the antenna substrate [9]. The extent of coupling achieved from the feed line to the patch is dependent on the size, shape as well as

location of the aperture. As the patch and the feed line are separated by the ground plane, spurious radiations are minimized.

**D. Proximity coupling (both non-contacting schemes):** This feeding technique is also called as the electromagnetic coupling scheme. In this technique, two dielectric substrates are used and the feed line is present in between these two substrates. The radiating patch lie above the upper substrate [9]. The main benefit of this technique is its ability to eradicate fallacious feed radiation as well as to provide very high bandwidth of about 13%. The major disadvantage of this technique is difficulty in fabrication because the two dielectric layers need proper alignment. Table1.1 compares these four feeding techniques.

Table1.1 Comparison of Various Feeding Techniques [9]

Characteristics	Microstrip Line Feed	Coxial Feed	Aperture Coupled Feed	Proximity Coupled Feed
Ease of Fabrication	Easy	Drilling and Soldering Required	Alignment Needed	Alignment Needed
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	21%	13%
Reliability	Better	Poor	Good	Good
Fallacious Feed Radiation	High	High	Low	Minimum

### 1.3 RADAR CONCEPTS

The principle on which radar works is identical to the principle of sound-wave reflection. Radar uses electromagnetic energy pulses as depicted in figure. According to the principle, the radio-frequency energy is transmitted and is reflected back from the reflecting object. A small part of the energy is reflected and it returns back to the radar set. This reflected energy is called an ECHO. Radar uses the echo to decide the direction as well as the distance of

reflecting object. Radar signatures are used to distinguish or identify among objects, *i.e.*, targets, such as aircraft, decoys, missiles with warheads, and chaff. This section discusses radar basics and RCSR techniques [10].

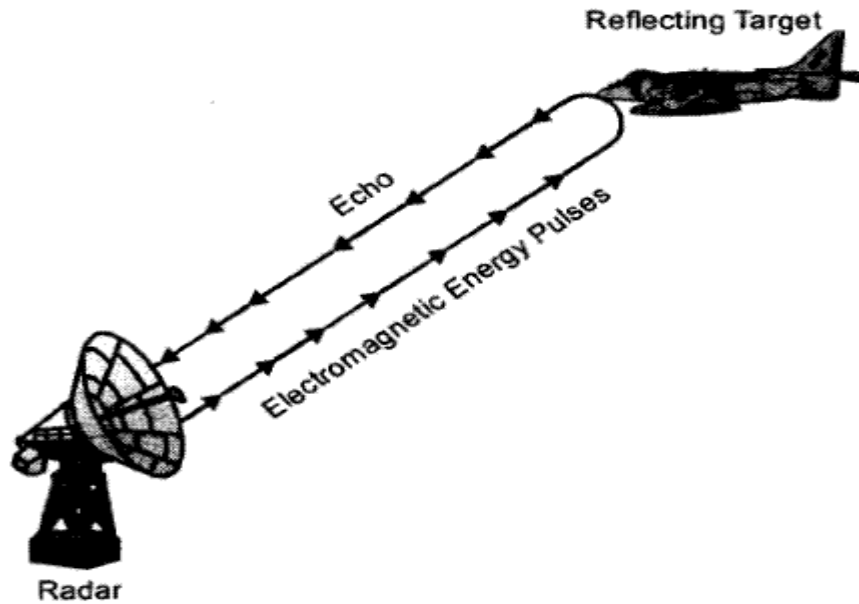


Figure1.2 Radar Operation [10]

### 1.3.1 Radar Signatures

Radio Detecting and Ranging is a device used to detect, locate, track, and identify objects at considerable distances. It operates by transmitting radio waves towards the objects, and observing the echoes returned from them.

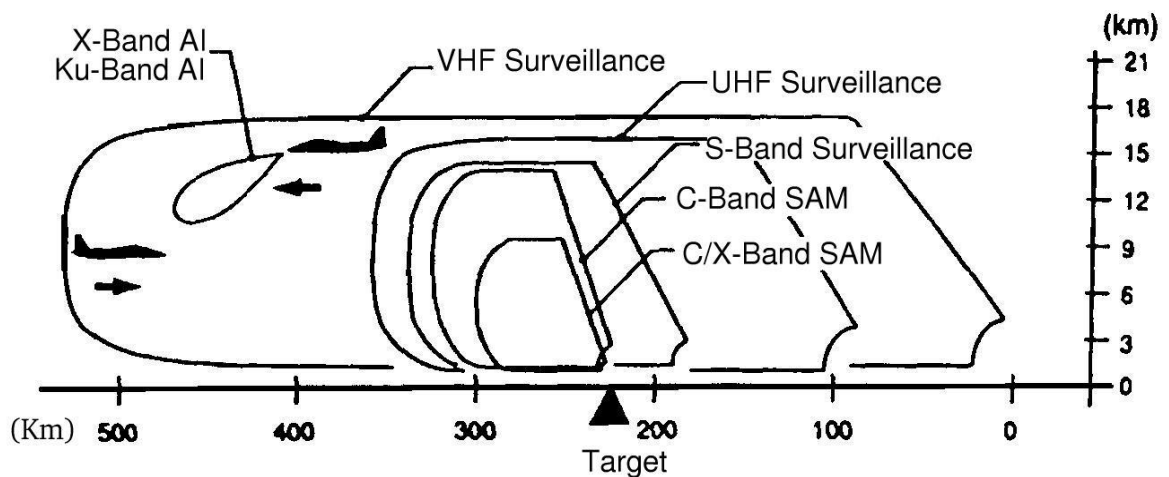


Figure1.3 Types of radar and their range of operation [11].

The various categories of radars used and their operating range as met by an aircraft as it enters a hostile region [12] is depicted as:

- Lower frequency range (0.1-1.0 GHz) is used for surveillance and detection (VHF, UHF, S-Band)
- Medium frequency range is used for tracking the target, used mostly by SAM launchers (C, X)
- Higher frequency range is used by radar onboard aircraft (Ku, K, Ka).

Table1.2 IEEE Radar letter-band nomenclature [13]

Band Designation	Nominal Frequency(MHz)	Band Designation	Nominal Frequency(GHz)
HF	3 – 30	X	8 – 12
VHF	30 – 300	Ku	12 – 18
UHF	300 – 1000	K	18 – 27
L	1000 – 2000	KA	27 – 40
S	2000 – 4000	V	40 – 75
C	4000 – 8000	Mm	100 – 300

### 1.3.2 Radar Cross Section (RCS) of an Aircraft

RCS is defined as the area of an imaginary perfect reflector that would reflect the same amount of energy back to the receiving radar antenna, as reflected by the actual target. According to the IEEE dictionary, RCS is represented as estimate of the reflective strength of a target. It is represented as  $4\pi$  times the ratio of the power per unit solid angle scattered in a specific direction, to the power per unit area of a plane wave incident on the scatterer from a specific direction, and is given as[14],

$$\text{RCS} = \frac{4 \cdot \pi \cdot r^2 \cdot S_r}{S_t} \quad (1)$$

r = radar range

$S_r$  = scattered power density ( $\text{w/m}^2$ )

$S_t$  = power density intercepted by target ( $w/m^2$ ).

RCS is an approximation of observability of a target, which in turn is dependent on its EM properties and external features. The RCS emphasizes on the electromagnetic energy of the receiver that is reflected from the target to the incident electromagnetic energy. When electromagnetic waves are incident on a body, some part of the energy is absorbed and the remaining energy is reckoned by the phenomena of reflection and diffraction. The RCS of an object is an approximate dimension of target as seen by the radar which in turn is used for detection of objects. RCS can be represented as coherent summation of contributions from numerous scattering centers of the target which were once illuminated by the radar.

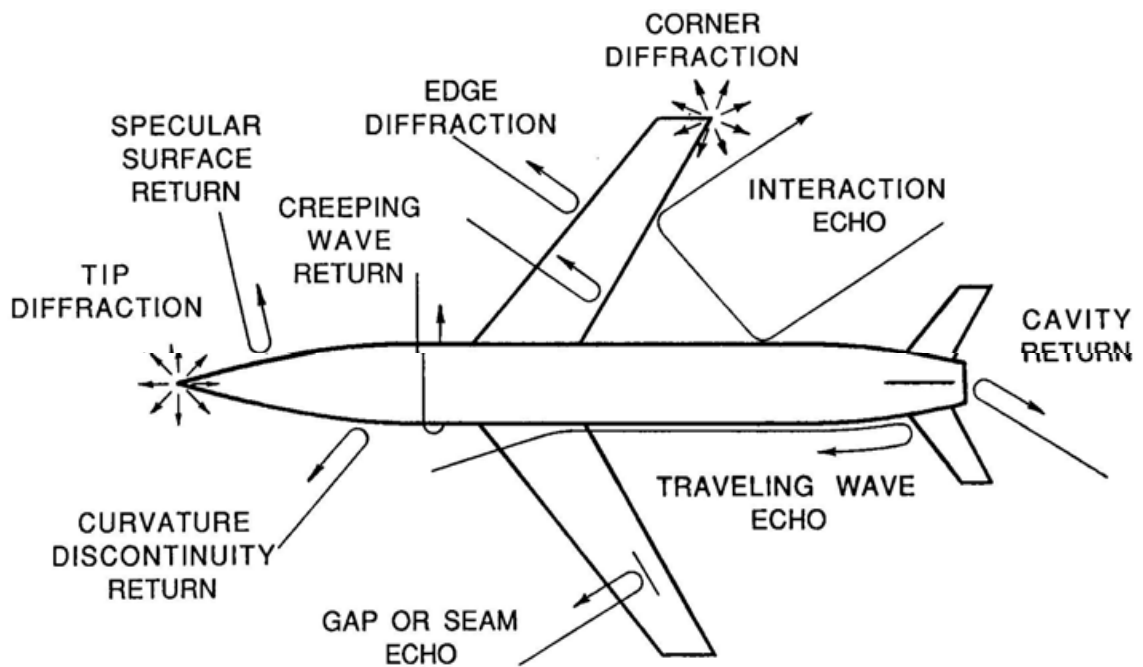


Figure1.4 Sources and Types of radar reflections in an aircraft [14].

Multiple or sequential reflections may be caused by some part of the reflected signal that may be in the direction of other conducting surfaces, the resultant RCS is computed as vectorial sum of all these returns. The superposition of individual echoes in addition to the highly specular return from the various flat surfaces and retro-reflectors cause widely varying

echo amplitude with small change in the view angle (termed as scintillation). The RCS of an object is dependent on [15]

- Shape of target
- Size of target
- Ratio of the target dimension, to the wavelength of the impinging radar wave.

Based on the ratio between impinging wavelength ( $\lambda$ ) and the characteristic target dimension ( $\alpha$ ), RCS may lie in one of the three regions [15]:

- Rayleigh Region ( $\lambda \geq \alpha$ ) - In Rayleigh region,  $\sigma$  varies smoothly with  $\lambda$ , and is proportional to the reciprocal of fourth power of the wavelength and square of the body volume.
- Resonant Region ( $\lambda \approx \alpha$ ) - Due to interactions between various scattering mechanisms rapid changes in  $\sigma$  are likely to occur in this region.
- Optical Region ( $\lambda \leq \alpha$ ) - In this region  $\sigma$  varies smoothly with the wavelength and approaches to some definite value. Most of the radars operate in this region. RCS is highly affected by the size, shape and material properties of the target in this region. For targets in the optical region few of the scattering analysis techniques applicable are [20, 26]: - Physical Optics (PO), Source Distribution Technique (SDT), Geometrical Optics (GO), and Geometrical Theory of Diffraction (GTD).

### 1.3.3 Radar Detection Range

The maximum range of the radar depends upon its operating frequency. Radar waves with lower frequency are less attenuated in propagation. The antenna size required can be impractical if frequency is too low. For precisely tracking the targets, tracking radars require good accuracy and necessary. Because of this anti aircraft gun systems and guided missiles operate at a high frequency. The range of monostatic radar is given as [16],

$$R_{max} = \sqrt[4]{\frac{P_S \cdot G^2 \cdot \lambda^2 \cdot \sigma}{P_{Emin} \cdot (4\pi)^3}} \quad (2)$$

For radar the maximum detection range alters as a function of fourth root of the target's RCS. So attaining reduction in the detection range of threat radar, leads to significant

reduction in the aircraft RCS. For example, to reduce the detection range by half, RCS has to be decreased 16 times.

#### 1.3.4 RCS Reduction Techniques

An aircraft has to use several RCSR techniques simultaneously in order to reduce RCS by significant amount. The number and type of RCSR techniques used depend on several factors like cost, mission effectiveness, mission profile, etc. The key difference between the active and passive techniques of RCSR is that active techniques works by destructive interference of the incoming wave with the scattered field within the array while in passive techniques, difference of amplitude and phase of the scattered wave from one part of the target cancels the same from the other part. The platform is made 'invisible' to the probing radar sources by the active cancellation of the impinging waves.

Nowadays, the tremendous knowledge of passive RCSR techniques can be used for controlling the EM scattering. These passive reduction techniques mostly use either shaping [18] or applying radar absorbing material (RAM) [17]. The efficiency of such methods is dependent on the angle of incidence, frequency as well as polarisation of the incident wave. For an aerial vehicle (missile or aircraft), stealth may be achieved by considering angular region. The profile of the vehicle is designed so that only a small angular range is available to the radar. In addition to above-mentioned passive techniques, some other methods such as frequency selective surfaces (FSS)[35], artificial magnetic conductors (AMC) [51]and active RCSR [23,24] have also been used for RCSR. The technique of RCSR using shaping is defined as follows

##### *1.3.4.1 RCSR by Shaping*

The overall size of ships, military vehicles or airplanes cannot be varied much, because of confines of operational capabilities [18]. The geometric cross section of military vehicles cannot be easily reduced. The concept of shaping works by orienting the target edges and surfaces to achieve deflection of scattered energy in the direction away from the radar [25].

Two approaches can be taken in the technique of shaping.

- First approach is to replace flat surfaces with curved surfaces and this leads to elimination of narrow but intense specular lobes. This increases the general echo levels at nearby aspect angles, although this reduces the magnitudes of specular echoes.
- The second approach is to extend flat and singly curved surfaces, even if this increases its intensity but it narrows the specular lobe. To confine specular flash to a narrow angular region it is preferred to keep larger surfaces as flat and smooth as possible. Larger is the area, higher will be maximum RCS, and faster it drops off.

A spherical surface independent of its orientation will reflect from any point. When the specular reflections are suppressed or eliminated then reflections from other directions become significant. The structures are shaped so as to reduce the corners, edges and surface discontinuities. The key motive is redirection of the reflected waves in nonspecular directions, thereby reducing the backscattering. The shaping technique must satisfy the aerodynamic requirements of the military vehicle (e.g. aircraft, missiles, ships, etc.). Another technique of RCSR is radar absorbing material.

#### *1.3.4.2 RCSR by Radar Absorbing Material (RAM)*

The second technique of RCSR is the usage of RAM. As the name suggests, the function of the radar absorber is to soak up incident energy, hence reducing the scattered energy or energy reflected back to the radar. At radar frequencies, two primary approaches exist to reduce reflections from a structure: absorption and cancellation. Absorption is the process in which energy from the wave is transferred to the material as it passes through it [20]. Radar energy can be enwrapped through one or more of the loss mechanisms, which might be involving magnetic or dielectric properties of the material. The loss of radar energy is due the transformation of radio energy into heat energy. Majority of the absorbers do not dissipate sufficient amount of energy so as to become detectably warm when they are irradiated by incident wave. The wave should be able to travel many wavelengths before being significantly attenuated.

RAM operates by enwrapping the incident EM energy and transforming it into heat energy, hence reducing the scattered energy in the direction of radar [21]. RAMs are quite efficient in

controlling the back scattering than forward scattering. They have comparatively high values of imaginary part of permeability and permittivity. Salisbury screen and Dallenbach layer are narrowband RAM coatings and have been used since 1950s [20]. Modern radar systems span over a wide range of frequencies. Hence a wideband RAM is needed. A typical RAM used in aircraft could be a composite or ferrite based paint [22].

However, there are significant disadvantages of using RAM. Firstly, most of RAMs are toxic. Secondly, precise application techniques are required for RAM coatings, as it is necessary that the coating thickness and smoothness must be uniform across the platform. Both the passive approaches i.e. shaping and RAM are mostly considered simultaneously to obtain the acceptable low visibility over the operational frequency band. Two more RCSR techniques are active and passive cancellation.

#### *1.3.4.3 Active RCSR*

Active cancellation also known as active loading, is more ambitious than passive loading. In this technique, the target emits the radiance in time coincidence with approaching pulse so that the amplitude and phase of emitted wave cancel those of the reflected wave. In active cancellation, the target emits a signal which copies the echo received by the radar provided that it is out of phase by one half wavelength, so that as a result the radar receives no signal at all. The key benefit of this approach is that it uses quite a small amount of power and it provides no indication about the target's presence.

The shortcoming of this approach is that it requires fast processing. A poorly executed process of active cancellation could make the target more visible to the radar. Active cancellation technique is most suitable for low-frequency RCSR. In this frequency range scattering patterns exhibit broader lobes and use of absorber and shaping become quite difficult. This technique has been reported to be applied by the Rafale [23, 24] and has been implicitly confirmed by Dassault [26], without revealing any details [25].

#### *1.3.4.4 Passive Cancellation*

In passive cancellation, the basic approach is to bring out an echo source whose phase and amplitude is adjusted so that it can cancel wave from another echo source. The target which consist of the scattering element is called the loaded body, as opposed to this the bare target,

is called the unloaded body. This technique is termed as impedance loading. This method is usually limited to a small spatial sector and is efficient over only a narrow frequency band [27].

#### **1.4 METAMATERIALS**

In present years, metamaterials have drawn tremendous interest due to their unique electromagnetic properties. Metamaterials are mostly used in antenna configuration for enhancing antenna performance such as realizing miniaturization, expanding operating band, enhancing gain as well as reducing RCS of antennas.

Metamaterials are the artificial materials with characteristics which may not be generally available in nature [28]. These metamaterials do not attain their characteristics from composition but they are dependent on structure. These operate by using the involvement of small inhomogeneities to implement macroscopic behaviour [33, 34].

The metamaterials have become part of main stream of electromagnetics. The main characteristic of metamaterials is their desired and unusual qualities that exist due to their unique structure & design. In a composite media, the interaction of electromagnetic waves with the inclusions lead to production of electric & magnetic moments. This will affect the macroscopic effective permeability and permittivity of the bulk composite medium. Metamaterials classification is as follows.

A. **NEGATIVE INDEX:** Negative-index metamaterials (NIM) have negative index of refraction due to negative values of both permeability and permittivity [31]. These material can be termed as DNG(double negative materials). Some other keywords used for these metamaterials are "media with a negative refractive index" as well as "backward-wave media"[43].

B. **SINGLE NEGATIVE :** Single negative metamaterials(SNG) have either negative relative permeability ( $\mu_r$ ) or negative relative permittivity ( $\epsilon_r$ ) but both conditions should not exist simultaneously[31]. These work as metamaterials when used together with a complementary and different single negative metamaterials, hence behave as a double negative material. For eg:- a material named epsilon negative media has a negative  $\epsilon_r$  whereas a positive  $\mu_r$  [29,31].

C. BANDGAP: Electromagnetic band gap (EBG) metamaterial have the property of controlling light propagation. This property is implemented done with **photonic crystals** and left-handed materials. Photonic crystal have a property of prohibiting light propagation completely. Both categories can be designed with band gaps at desired frequencies and amount of light allowed to propagate in desired and specific directions [32].

D. CHIRAL: Metamaterials with chirality property are made of chiral materials which have non zero effective parameter  $k$ . The term left handed refers to circularly polarized waves that constitute the propagating modes in case of chiral media. The term right handed refers to the trio of magnetic field, electric field and Poynting vector which exist in negative refractive index(NIM) media, which generally is not chiral [33].

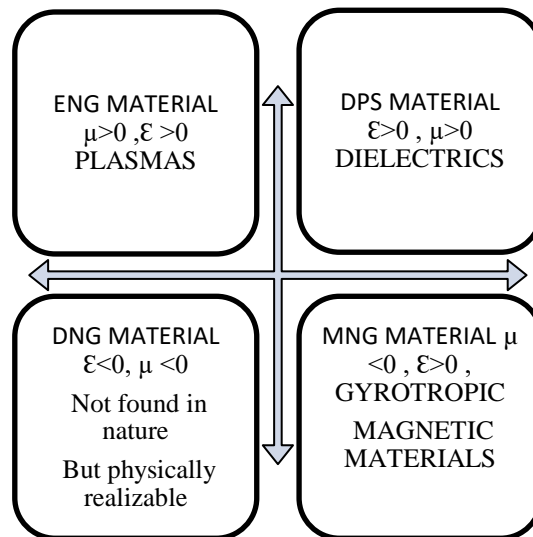


Figure1.5 Metamaterial Classification [34]

## 1.5 PROBLEM STATEMENTS

Antenna makes significant offering to overall RCS due to its key function which is to receive and radiate electromagnetic energy. In order to avoid detection by radars, RCS of targets should be reduced [1]. Out-of-band RCS reduction using FSS and radar absorbing material (RAM) has been achieved, challenge is to work on In-band RCS. Some of the methods

working on out-of-band RCS reduce antenna performance. Usage of RAM has an adverse influence on antenna performance. More attention is to focus on RCS reduction without degrading radiation performance. The optimization of metamaterial structures is also a challenging task. Metamaterials have property of structure dependence rather than composition dependence, so any slight change in its structure changes its functionality which in turn affects the performance of antenna. There is a need to explore some new metamaterials structures to enhance the absorbing properties of existing structures. The fabrication and measurement complexities are another important issue in the development of metamaterial based antenna structures. In microstrip patch antenna 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.

## **1.6 OBJECTIVE OF THESIS**

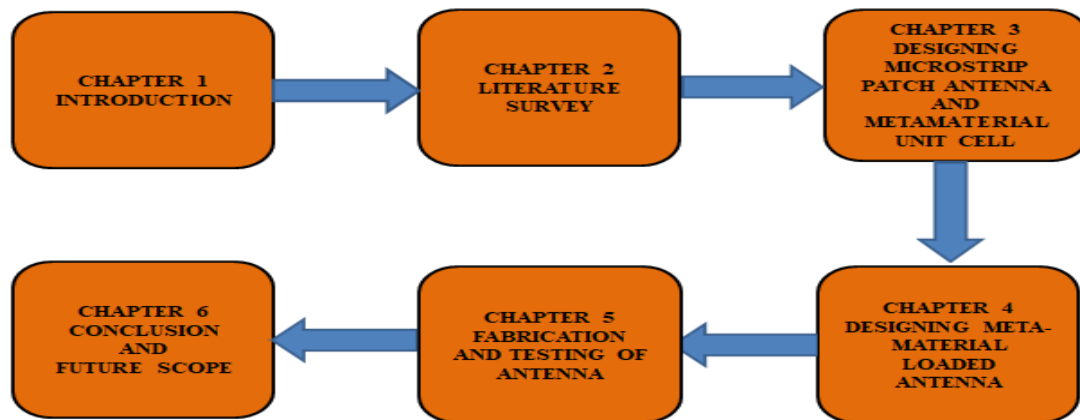
- Design and simulation of a microstrip patch antenna and a novel shaped metamaterial unit cell.
- Analysis of designed antenna along with metamaterial cells for various parameters of RCS.
- Parametric study of proposed metamaterial loaded antenna to optimize dimensions of metamaterial cell to reduce RCS.
- Fabrication and testing of primary microstrip patch antenna and proposed metamaterial loaded antenna.
- Comparison of simulated and measured results.

## **1.7 SCOPE OF WORK**

This thesis comprises of two concepts and accordingly designing and manufacturing two different antennas. First antenna includes microstrip patch antenna using coaxial feed resonating at 4 GHz frequency i.e. suitable for military application.

Other part comprises of designing and manufacturing of metamaterial loaded microstrip patch antenna resonating at operational frequency 3.9 GHz. This metamaterial enhances the RCS property of the antenna.

## 1.8 ARRANGEMENT OF THESIS



## CHAPTER 2

### PERFORMANCE ANALYSIS – A REVIEW

#### 2.1 INTRODUCTION

The chapter contains brief introduction of work done in field of microstrip patch antenna to vary its parameters as per required application and also it gives detailed study by various researchers on the concept of metamaterial and metasurfaces. Some of the research works related to RCSR using metamaterials are presented in this section. This chapter is divided into several parts, which constitutes the different techniques to reduce the RCS.

#### 2.2 FREQUENCY SELECTIVE SURFACES (FSS)

FSS are periodic surfaces with similar two-dimensional arrays of elements organised on a dielectric substrate [35]. Based on the characteristics of 2-D array, incident plane wave will be either transmitted (passband) or it will be reflected back (stopband) and this will be either completely or partially. This conditions occur when resonant frequency of FSS elements and frequency of electromagnetic (EM) wave are same. So, an FSS has capability of blocking or passing the electromagnetic waves of particular frequency ranges in the free space.

FSS are best known as spatial filter. The properties of FSS elements like their shape, size as well as their periodicity result in the resonance. FSS have been widely studied over past five - six decades and a variety of optical and microwave FSS have been invented. Earlier these were mostly used in reflector antennas [36], involving antenna radomes as well as resonant beam splitters [37].

In present times, the most prominent application of FSS is for reducing or controlling RCS or as antennas radomes. The design complications of FSS limit their performance, including unresponsiveness to the angle of incidence, polarization of electromagnetic wave and requirement of compact size. Traditional FSS did not provide sufficient spatial filtering results and they were narrow band.

Comprehensive research is going on to improve the FSS, efforts are made to miniaturize the frequency selective structure and enhance the frequency response along with broader

bandwidth (BW) at higher angles of incidence. Single layered FSS experience unstable performance due to variation of electromagnetic wave angle of incidence, hence they have been proved inefficient. To overcome this limitation multi-layered FSS have come into existence. These provide flexibility of changing parameters to attain required performance.

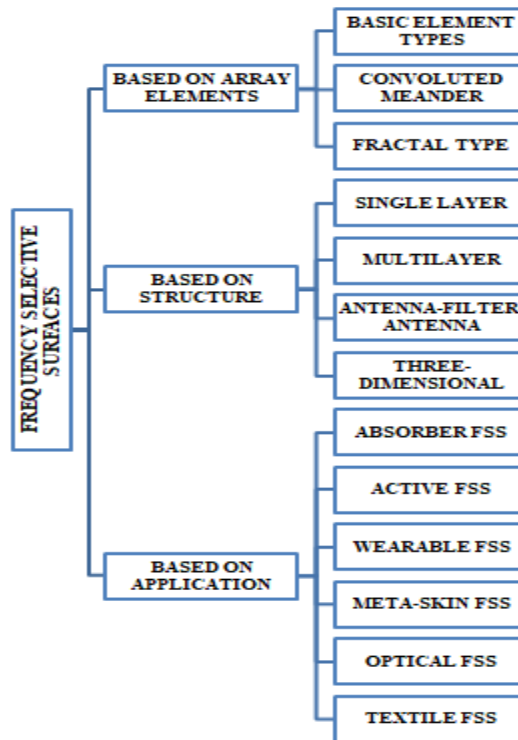


Figure2.1 A taxonomy of FSS [38]

Various types of FSS exist such as

- FSS on basis of Fractal elements
- Active and Three-dimensional structure for microwave technology
- Embedded structures consisting of inserted plates and metallic rods on basis of stepped-impedance resonator
- Integrated structures
- Electromagnetic band gap structures
- Metamaterial structures

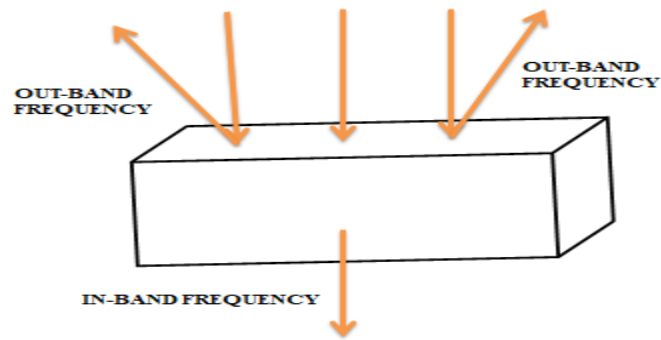


Figure2.2 The functionality of an FSS [38]

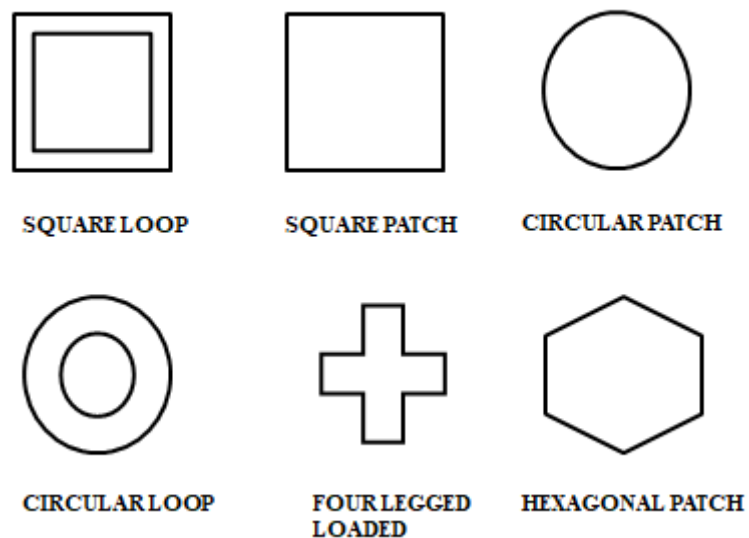


Figure2.3 Various shapes of FSS elements [35].

Ying Liu et.al [39] proposed a novel method to minimize RCS along with preserving radiation characteristics of antenna. This is achieved by using principle of passive cancellation along with Polarization conversion metamaterial (PCM). Results show in-band RCS is reduced 16 dB in comparison to reference antenna. In addition to this out -band RCS has been reduced by 14 dB.

Yuping Shang et.al [40] proposed a microstrip patch antenna with reduced value of RCS. This reduction is achieved by switching the reference antenna ground plane with a complex ground plane consisting of band stop FSS unit cells.

Mohsen Zahir Joozdani et.al [41] investigated RCSR of 2x2 patch antenna array using miniaturized square loop, which were part of bandstop FSS. Stopband of FSS was identical with the resonant frequency band of antenna from 3.3-3.4 GHz. The ground plane of reference antenna is replaced by miniaturized FSS excluding the region below patch. FSS behaves as ground plane for stop band other than this region it is transparent. The wideband RCSR is achieved in 4-9.5 GHz range.

Jeremiah P. Turpin et.al [42] proposed a technique of replacing ground plane of reference antenna with absorbing FSS with intention of reducing RCS at higher frequencies. This approach is advantageous than many other techniques used for RCSR as these techniques degrade the antenna performance.

Ying Liu et.al [43] investigated a low RCS microstrip antenna. The basis of design is microstrip resonator and implementation of FSS out of RCSR can be achieved by replacing metal ground with FSS ground. In band RCSR can be achieved by loading of microstrip resonator. Majority of the RCSR is achieved in the frequency range of 3-10 GHz. In and out of band RCSR achieved is around 13 and 17 dB respectively.

Hao Jiang et.al [44] proposed an antenna with partially reflecting surface (PRS) and high gain for out of band and in band RCSR. In band RCS is achieved by using metamaterial ground plane. PRS is situated about one half wavelength higher than metamaterial ground plane (MGP) in order to increase antenna directivity out of band reduction is attained by using absorbing material. A significant RCSR has been achieved in frequency range 8-17 GHz.

Qi Zheng et.al [45] proposed an antenna with low RCS on PCM for C-band. It is low profile as well as circularly polarized slot antenna. In order to convert linearly polarized wave to circularly polarized wave corner truncated square metasurface is used. According to simulated results, impedance bandwidth is 33.6% and 3 dB axial ratio bandwidth value is 18.2% in frequency range of 5.05-6.05 GHz is attained. Gain of antenna ranges from 7.25 to 7.95 dBic. Simulated results depict that RCS of proposed antenna is reduced below -10 dB from 4.40 to 6.00 GHz in comparison to conventional slot antenna.

Mao Long et.al [46] investigated low RCSR property with PRS and PCM. To form Fabry-Perot resonant cavity, PRS and PCM are printed above the microstrip patch antenna and on

two sides of a substrate. Due to existence of symmetrical arrangement significant RCSR can be attained in x- and y- polarization. Wideband RCSR is attained in the range 9 to 20 GHz. Maximum in-band value is 20dB at 9.4 GHz and 33db out of band verified its effectiveness in RCS control.

HIS are the high impedance surfaces [47]. These are two-dimensional arrays which are designed to reject bounded surface waves and to completely reflect in phase incident plane wave. They are used to nullify propagation of surface modes. PBG and EBG (photonic band gap structures) possess such characteristics and they explain forbidden and impulsive emission.

### **2.3 ELECTROMAGNETIC BAND GAP STRUCTURE (EBG)**

The EBG operates by inhibiting propagation of electromagnetic wave in particular band of frequencies termed as bandgap, which in turn depend upon its material parameters as well as its geometrical parameters, in contrary to this metamaterial show left handed behavior opposing well known phenomena of optics such as Doppler effects etc.

The reflection phase characteristics are used to estimate electromagnetic nature of any surface. The  $0^\circ$  reflection phase refers to a PMC and a  $180^\circ$  reflection phase suggests a PEC surface. When a plane wave is incident normally on a PEC surface, the total tangential E field should be zero to satisfy boundary conditions. The incident electric field and the reflected electric field must have the opposite sign, which lead to value of reflection coefficient to be  $-1$ . The reflection phase in case of perfect electric conductor is  $180^\circ$ . Similarly, for a perfect magnetic conductor, the reflected electric field and the incident electric field should have the same sign but the reflected magnetic field and the incident magnetic field should have the opposite sign. For this case the reflection phase is  $0^\circ$  and corresponding reflection coefficient value is equal to  $+1$  [48].

In reality, the PMC surfaces do not actually exist in nature. EBG reflection phase range from  $+180^\circ$  to  $-180^\circ$  with increase in frequency. The frequency range of  $+90^\circ$  and  $-90^\circ$  mostly coexist with bandgap of the EBG structures. In band RCS reduction is achieved by using EBG structure loaded with lumped resistances [49] and for out of band RCS reduction mushroom like EBG structures are used [50,51].

Yongtao Jia et.al [52] presented broad band mushroom antenna with high gain to attain wideband RCSR. In band RCS can be largely reduced as the mushroom structure resonates at antennas operating frequency. For out of band RCSR metal ground is being replaced by bandstop FSS. In order to add zero degree reflection phase square metallic patches are printed periodically below the cells of FSS. This aids the RCSR.

Qi Zheng et.al [53] presented a low RCS metasurface based planar and wideband circularly polarized slot antenna. The array consists of 2x2 metasurface based antennas. Due to polarization conversion of metasurface, circular polarized radiation is attained. Total metasurface patches could be observed as checkerboard comprising of mirror array and metasurface array. A phase difference of  $180^\circ$  existing between metasurface unit and mirror unit lead to attainment of RCSR. Simulated results show that operating bandwidth of 34.6% in the range of 4.3-6.1 GHz. The simulated RCS value of less than -30.9 dBsm is achieved at 5.0 GHz.

Wengang Chen et.al [54] proposed RCSR using EBG structures. To attain wide frequency bandwidth for -10 dB RCSR, checkerboard configuration comprising of two different EBG structures has been used. The paper proposed dual band RCSR with -10dB bandwidth of 61% and 24% by using two dual band EBG structures, while still retaining scattering in four quadrants. Good agreement has been attained between experimental and measured results.

J. Ling et.al [55] proposed a microstrip printed dipole antenna which consist of distorted uniplanar compact-EBG (DUC-EBG) ground plane and which operates in S-band. According to simulated and measured results the proposed structure has lower RCS in comparsion to conventional one at frequencies which lie out of the operating band within 1–8GHz. The proposed ground design hardly effect the radiation pattern in comparison to conventional metal ground. The proposed DUC-EBG allow much more incident waves to pass through in pass band. Hence, it can efficently achieve out of band RCSR of microstrip printed dipole antenna.

Cheng Huang et.al [56] proposed a method to attain high-efficiency transmission as well as wideband scattering reduction by combination of FSS and EBG at two sepearte frequency bands. Design constitute two-layer metallic patterns. The bottom layer made of FSS operate

as a filter by letting signals which are in-band to pass through while out-of-band signal are reflected. The upper layer is EBG layer which makes use of 0 and  $\pi$  reflection phase cells. These are arranged in chessboard configuration to avoid the backward scattering wave. In order to check the effectiveness of the concept, the planar and cylindrical surfaces are designed respectively in order to verify their functionalities. The FSS-EBG surface makes antenna to transmit in S-band with minor insertion loss. It is suitable for usage as stealth antenna radome due to its ability of wideband low-scattering property over X–Ku band.

Zi-Jian Han et.al [57] proposed a novel antenna design so as to enhance the gain and achieve RCSR of patch antenna by employing metamaterial surface. Blocks of slotted EBG structures forming a polarization-dependent metamaterial were presented. To improve the gain of the antenna, layout pattern of the slotted EBG elements is designed. Chessboard configuration is prepared for scattering cancellation. The phenomena of the gain enhancement by the EBG is explained by studying the induced currents on EBG. This provides the strategy of designing a high gain and low RCS antenna by using EBGs.

#### **2.4 ARTIFICIAL MAGNETIC CONDUCTORS (AMC)**

Among all the metamaterial, AMC structures [58] are specifically used in designing of low-profile as well as highly efficient antennas [59]. AMC have inherited the in phase reflection properties which in turn reduce the radiations meted out to body in wearable applications [60]. PMC does not actually exist in nature. AMC are synthesized PMC. From view point of electromagnetics, AMC is dual to a PEC. AMC exhibit a phase value of  $0^\circ$  and reflection coefficient value of 1 in the ideal lossless case. AMC show characteristics of PMC over a particular frequency band. AMC operation bandwidth varies from  $+90^\circ$  to  $-90^\circ$ . For this range the destructive interference between reflected and direct waves will not be caused by phase values.

The main drawback in unilayer case is the restricted AMC operational bandwidth. Due to usage of low relative dielectric permittivity substrate and optimizing the design of unit cell, additional reduction in cost is attained

In AMC structure every unit cell is represented as a distributed parallel *LC* network having one or more resonant frequencies. The resonant frequency is the frequency where AMC conditions exist and at this frequency impedance is high. For the parallel *LC* circuit in phase

reflection bandwidth value is  $\sqrt{L/C}$  and resonant frequency has value  $1/(2\pi\sqrt{LC})$ . In order to design an AMC structure with the required bandwidth and at certain frequency, we have to change the unit cell's geometry along with other changes like changing relative dielectric permittivity of substrate as well as its thickness.

Higher is the value of relative permittivity of dielectric substrate, lower will be the value of AMC bandwidth [59]. The change of unit cell geometry leads to modifications in the equivalent LC resonant circuit. In order to attain broader AMC operational bandwidth, value of L is to be increased and that of C is to be reduced. To increase value of L thick dielectric substrate can be used. Other means to increase L are by including long and narrow strips in geometry. Value of C can be increased by enhancing gap between the unit cell metallization edges. Another method is by reduction in relative dielectric permittivity of substrate. A trade-off solution involving  $\epsilon_r$  and substrate thickness has to be chosen, so as to attain both compact size as well as broad AMC operation bandwidth.

The shaping technique used for RCSR is based on changing the surface or shape of the device under test (DUT) so as to redirect all the scattered energy away from the source. One technique of obtaining this scattering is by usage of planar configuration.

The planar structure that has shown the possibility of narrow band RCSR is based on using combination of AMC and PEC in a chessboard like configuration [61]. The principle of operation of the chessboard configuration consisting of AMC and PEC is based on the destructive interference between the waves reflected by these two cells. At its working frequency AMC cells lead to  $0^\circ$  phase change of reflected wave whereas in case of PEC cells phase change of  $180^\circ$  exist.

Summing these two effects a net phase difference of  $180^\circ$  is achieved between the radiations of the PEC and AMC cells which lead to destructive interference and hence attaining a null in the specific direction [61].

The major drawback of AMC and PEC chessboard configuration is narrowband operation bandwidth structure. Outside the range of operation bandwidth, AMC act as PEC and destructive interference property does not hold. This shortcoming can be removed by replacing PEC cells in chessboard configuration by another AMC cell which operate at different resonant frequency. This replacement allows the condition of destructive

interference to hold at atleast the resonant frequency of both AMC. As a result, a dual band design may be constructed to overcome this gap.

Ali Azarbar et.al [62] proposed a technique using composite artificial magnetic conductor (AMC) surface with magneto dielectric substrate for broadband reduction of RCS. The advantage of using magneto-dielectric is that it increases in phase reflection bandwidth of AMC structure. The composite surface constitutes two types of AMC cell where each AMC cell operate at different frequency. The phase differences are tuned to be close such that reflections from cells cancel out each other. The results show that RCSR more than 13 dB was achieved with a 93% bandwidth.

M. Mighani et.al [63] proposed a novel wideband chess board surface along with double layer in order to reduce RCS. By using a novel structure of two AMC cells we can achieve -10 dB RCSR over 73% of frequency bandwidth. Boards with higher thickness are required to increase bandwidth in case of chessboard structure.

Yunqi Fu et.al [64] proposed usage of composite AMC surface for wideband RCSR. The composite surface constitutes two AMC cells, with AMC cells having different resonant frequency. The phase difference between AMC cells is required to be in range close to  $6\pi$ , due to this reflection from AMC cells cancel out each other.

You Li et.al [65] proposed a wideband RCSR metasurface. The unit cell of metasurface consists of hexagonal non central symmetry patch having two semi circular slots existing at the symmetric corners. For x- and y- polarized wave this unit has anisotropic response. The reflection phase varies with radius of slots. For RCSR chessboard configuration is used. Results show that 10 dB RCSR has been attained in wideband from 8.5 to 13 GHz.

Tao hong et.al [66] presented a triangle type AMC structure for RCSR. The conventional chessboard design has been replaced by four triangle type AMC parts. According to simulated results peak value has been reduced by more than 5db in comparison to conventional design. The bistatic RCS below -10 dB has been attained in a wide angular range of theta from  $-25^\circ$  to  $+25^\circ$ .

Fuwei Wang et.al [67] proposed that for RCSR of Yagi Uda antenna consisting of chessboard configuration formed by reconfigurable polarization rotation surface (PRS). This reflector could be switched between metal reflector and low RCS PRS reflector. When the PRS reflector is used with on state diode, it is observed that antenna has identical radiation characteristics in comparison to Yagi Uda using metal reflector. Depending on the working state of the diodes, it is possible to vary status of RCS. Using PRS reflector, the RCSR of antenna with off state diode could be more than 25 dB.

Edris Ameri et.al [68] designed and fabricated wideband RCSR metasurface. Chessboard configuration was achieved by combination of two different types of AMC unit cells. One of the unit cells used are Jerusalem unit cells and the others are saltire arrow unit cells. This configuration attains RCSR below 10 dB in frequency range of 15.75GHz to 41.3GHz (90% bandwidth). This proposed configuration works efficiently at both TM and TE modes. It has stable 10 dB RCSR bandwidth which in case of TM propagation mode is upto 50° oblique incident angle while for TE it is 30°.

Jingjing Xue et.al [69] proposed a quasi-fractal structure based chessboard configuration AMC surface for attainment of broad band RCSR. The chessboard structure is designed by using two different cells with  $180^\circ \pm 37^\circ$  phase difference over more than 90% frequency bandwidth. Monostatic RCS and bistatic RCS of the chessboard configuration are evaluated and results are compared with results of same sized PEC ground plane. RCSR of more than 10 dB can be achieved from 5.4 to 14.2 GHz. Measured results validate the simulated ones.

Edris Amer et.al [70] presented a PCM design, in order to achieve ultra wideband RCSR. The proposed PCM is made of dual headed arrow unit cell which is rotated by 90°, 180° and 270° to achieve cancellation through the destructive interference and consequently attain RCSR. The proposed metasurface provides ultra wideband 10 dB RCSR in frequency range of 9 to 40 GHz for TE and TM polarized incident waves. A good agreement of measured and simulated results at 0°, 20° and 40° incident angles support the choice of metasurface. The ultra wideband RCSR of the designed metasurface along with its light weight, low cost and low profile validates its high capability in comparison with references.

## 2.5 RADAR ABSORBING MATERIAL (RAM)

The function of the radar absorber is to soak up incident energy, hence reducing the scattered energy or energy reflected back to the radar. RAM operate by enwrapping the incident EM energy and transforming it into heat energy, hence reducing the scattered energy in the direction of radar [21].

Zhilong Miao et.al [71] proposed a method for RCSR in two different frequency bands in case of patch antenna. The technique consists of absorbing metamaterial , which is to be loaded around patch. The design is made of double squared loop structure with resistors inserted in it. This leads to absorption of incident wave at two different frequency bands. Simulated results show that RCSR has been attained by 8dBsm at 5.8 GHz and at 9 GHz relative to conventional patch antenna. Loaded metamaterial has no negative effect on antenna performance.

Peng Mei et.al [72] investigated absorbent frequency selective radome (AFSR) codesigned with low profile antenna. A pair of circular slot resonators are engraved on surface of ASFR. A patch antenna has been etched within ASFR and it is optimized to operate at frequency of 8.9 GHz. The measured results depict that designed antenna has ability to attain substantial RCSR and good radiation pattern.

F.-W. Wang et.al [73] introduced a radar absorbing structures (RAS) which is to be used to achieve in-band RCSR of the array antennas. The design consists of square patch structure. Design constitutes an array which has four patch elements and RAS was loaded between two adjacent patch elements. Radiation performance is retained even with usage of RAS. At operating frequency, due to RAS, the RCS of array antenna is reduced.

Ankit Sharma et.al [74] presented the design and analysis of a MM absorber (MMA) for achieving in band RCSR of antenna. The designed MMA design constitute periodic array made of double square loop engraved on a FR4 substrate, which has a thickness of about  $0.022\lambda_0$ . The simulated and measured results validate that MMA aid RCSR of the designed antenna within its impedance bandwidth. Maximum RCSR of 15dB is attained at frequency of 6.75GHz. The RCS of the proposed antenna is substantially reduced after loading of MA on the patch antenna and there is no deterioration of its radiation properties

## 2.6 METASURFACES

Yaqiang Zhuang et.al [75] proposed a technique to design a tri-band and low-scattering metasurface. The RCSR in these three frequency bands is dependent on diffusion, absorption, and scattering cancellation respectively. Four units operating at different frequencies were combined to attain a wide band absorption. The scattering cancellation was achieved by using chessboard configuration consisting of two out of phase elements. The tri-band metasurface was designed by using three different metasurfaces in a single assembly. A good agreement is observed between simulated and measured results. The tri-band RCSR is retained up to  $45^\circ$  with polarization-independent performance.

Yang Shen et.al [76] presented a phase random metasurface (PRMS) for RCSR over broad range of incident angles and frequencies. By increasing the distribution interval of metal patch sizes, the bandwidth of RCSR can be widened. Acceptable agreement has been attained between experimental and measured results.

## 2.7 CODING METAMATERIAL

The coding metamaterial operates by introducing two types of unit cells with 0 and  $\pi$  phase responses to imitate the '0' and '1' elements for 1-bit digital. These '0' and '1' elements are not required to be defined by macroscopic medium parameters. In coding metamaterials, by designing coding sequences of '0' and '1' elements, EM waves can be manipulated to attain different functionalities. This concept could be implemented to 2-bit or more.

Jianxun Su et.al [77] proposed coding metamaterial tile with uneven layering to achieve ultra wideband RCSR. The designed metamaterial tile constitutes two types of square ring unit cells and each has separate layer thickness. Existence of phase difference of  $180^\circ (\pm 37^\circ)$  among square unit cells, leads to coverage over an ultra wide band. To attain reduction of the monostatic as well as bi-static RCS simultaneously, the metamaterial tile is encoded as '0' and its 90-degree rotation can be encoded as '1'. The metamaterial tile was able to attain  $-10$  dB RCSR in frequency range of 6.2 GHz to 25.7 GHz. A good agreement between simulated and measured result confirm that the designed metamaterial tile can substantially expand the bandwidth for diffuse scattering and RCSR.

Xiao Liu et.al [78] designed a coding diffuse metasurface for RCSR. First, two types of AMC unit cells are studied and then  $5 \times 5$  AMC unit cells are combined to form metamaterial block. A linear array factor is optimized and the sequence is expanded from one-dimension to two-dimension. The diffuse metasurface is designed using metamaterial block arrangement. Simulated results validate that the bandwidth of RCSR increased in comparison to the conventional chessboard configuration. Experiment results validate the theoretical design and simulation.

## **2.8 SUMMARY**

The literature review of various methods used for achieving RCSR are studied in detail. Survey provides ease of understanding what can be required specifically to reduce the RCS of antenna. The literature survey was divided into six parts. Firstly method of RCSR using FSS has been studied. Further sections discuss the RCSR techniques using RAM and other metamaterials such as EBG, AMC. Last two sections discuss latest RCSR techniques, which are using multi-layer metasurfaces and coding metamaterials.

## **2.9 MOTIVATION**

It included the design requirement of a simple antenna's fabrication which can provide RCSR at wider band. Concept of RCSR using metamaterials has been used in different sense and combination. Multi-layer metasurface and coding metamaterials provides improved results. Earlier, while implementing the metamaterial certain parameters need to be chosen properly. So, the reduction property can be seen. Keeping the design simple allowed the enhancement of parameter resulting in reduction over wider band.

## CHAPTER 3

### DESIGN OF MICROSTRIP PATCH ANTENNA AND METAMATERIAL UNIT CELL

#### 3.1 INTRODUCTION

Microstrip antennas are preferably used for military application due to their features like light weight, low profile and ease of fabrication [3]. These antennas are most commonly used in array configurations. For efficient performance of antenna it is preferred to use a thick dielectric substrate with low dielectric constant with an aim to provide wide bandwidth along with better radiation and better efficiency. The microstrip patch antenna ground plane has higher radar cross section and upto now many methods have been devised for reduction of RCS of microstrip patch antenna [8].

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 coaxial feed is proposed.

In this section we have presented the design and simulated results of primary microstrip patch antenna and proposed metamaterial unit cell for application of RCSR.

#### 3.2 ANTENNA DESIGN

A simple linearly polarized rectangular coaxial cable fed microstrip patch antenna on a planar  $L \times W \text{ mm}^2$ , 'h' mm thick FR-4 substrate was designed. The substrate used has relative permittivity,  $\epsilon_r = 4.3$ , and dielectric loss tangent,  $\tan \delta = 0.025$ . The designed patch dimensions are  $L_P \times W_P \text{ mm}^2$ . The thickness of patch is 'c' mm. The copper employed for patch structure has an electrical conductivity of  $5.7 \times 10^7 \text{ S/m}$ . The antenna was designed in presence of conventional, continuous ground plane and it was not adjusted in order to upgrade the performance. Dimension of ground plane is  $L \times W \text{ mm}^2$ . Ground is made of

copper metal and has thickness of ‘c’ mm. Table3.1 exhibits the detailed parameters of reference antenna.

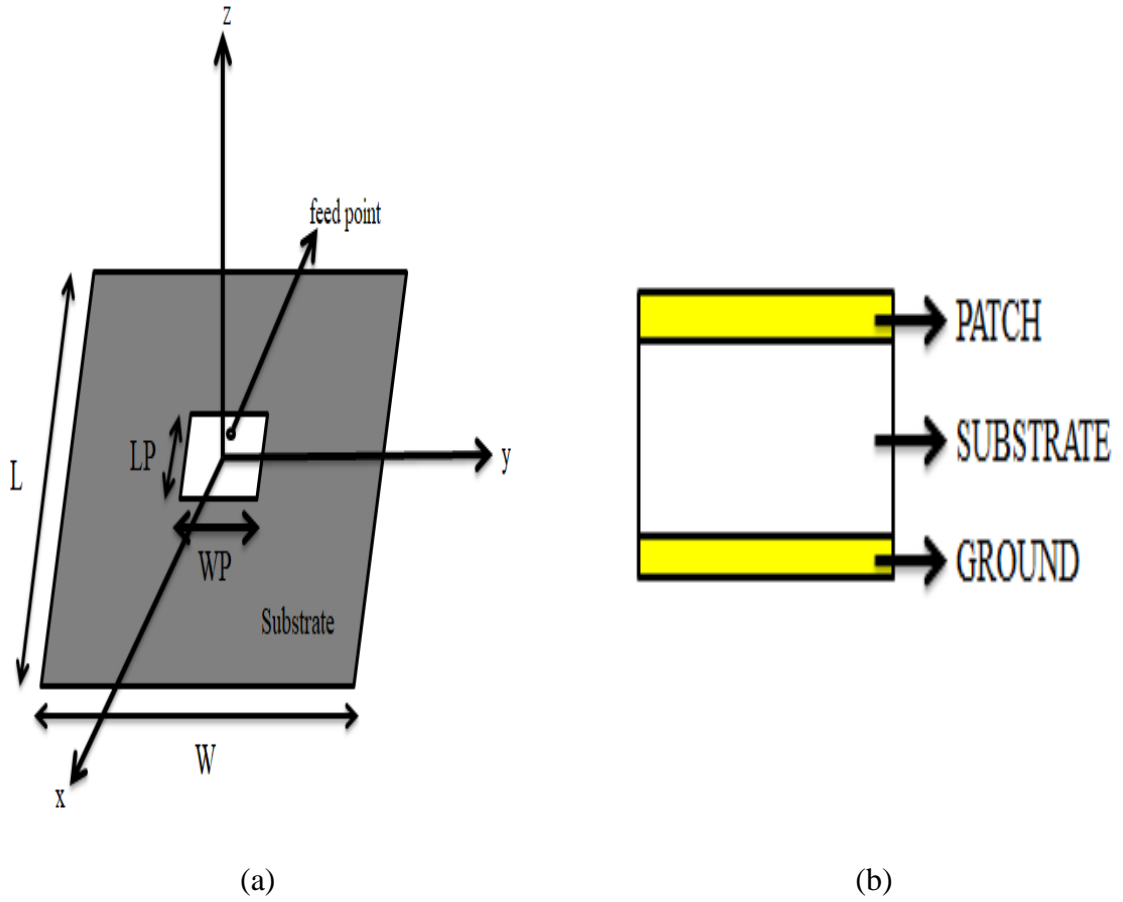


Figure3.1 Primary antenna (a) front view (b) side view

Table3.1 Parameters of Primary Antenna

Parameter	Value (mm)
L	66
W	66
LP	16.3
WP	21
C	0.035
H	2

The origin of the coordinate system is at the centre of the patch. The probe feed used is located at  $(X_f, Y_f) = (-3.5\text{mm}, 0\text{mm})$ . The coaxial feed used for excitation of the patch consists of three layers. First one is pin, which is formed of copper material and has radius 'r0' mm and height of 'h1' mm. Second layer is dielectric coat, which is formed of teflon and has height of 'h2' mm. It has outer radius of 'r1' mm and inner radius value of 'r0' mm. Third layer is protective coating of copper metal and has thickness of 't' mm.

Table3.2 Parameters of Coaxial Feed

Dimension	Value (mm)
r0	0.5
r1	2.5
h1	8.035
h2	6
T	0.02

### 3.3 SIMULATED RESULTS

The antenna has been designed for operation in 2-18 GHz band. The simulations are performed by usage of commercial full wave simulation software, CST Microwave Studio. Some of the key features discussed in this section are return loss, current density and radar cross section.

#### 3.3.1 Return Loss

Return loss is measure of the power loss in the signal. Signal's power gets reflected back due to some discontinuity in transmission line causes 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 this design is concerned, the designed antenna gives – 10.37dB return loss at 4 GHz frequency as depicted in Figure3.2.

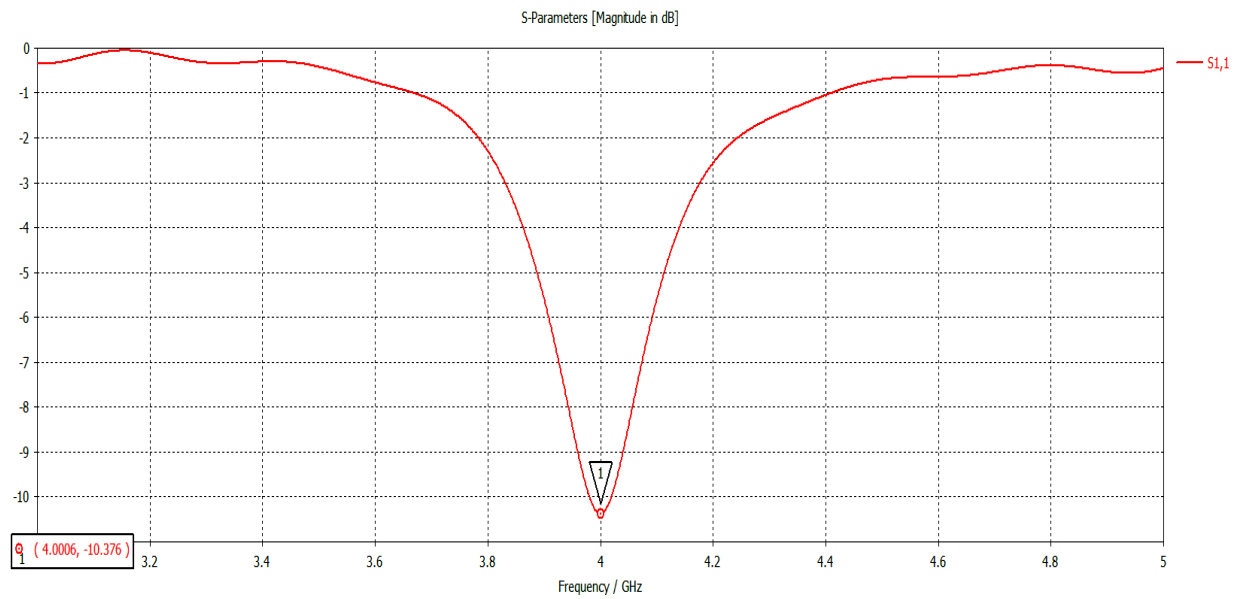


Figure3.2 Simulated results of  $S_{11}$  of microstrip patch antenna

### 3.3.2 Current density

The current distribution over patch tells behaviour of an antenna. Surface current is the actual electric current that is induced on application of electromagnetic field. The surface current maximum intensity is observed at centre of the patch, while less intensity is obtained at the left and right vertical arms of the patch. The surface distribution of the above designed antenna has been shown in Figure3.3.

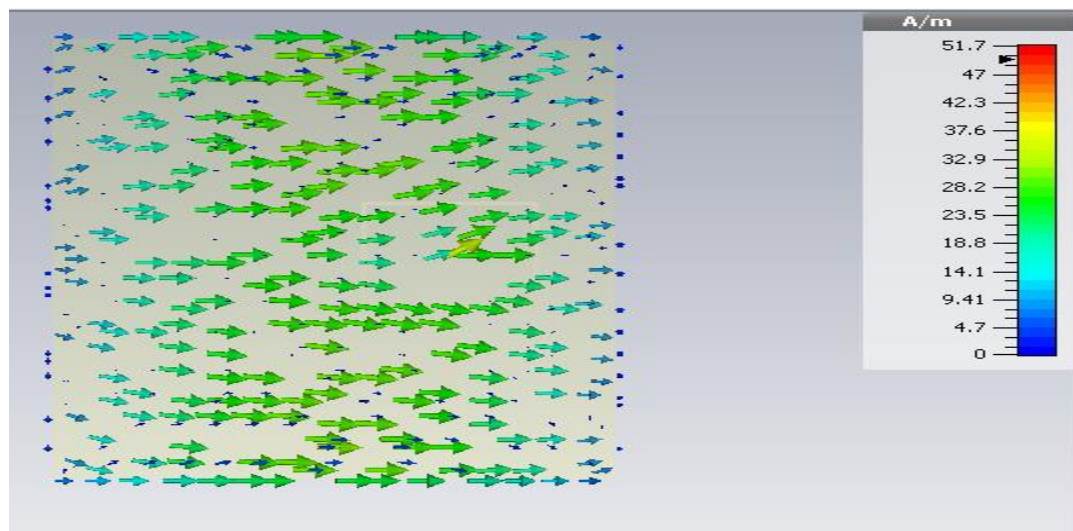


Figure3.3 Surface current of microstrip patch antenna.

### 3.3.3 Radar cross section

The monostatic RCS results of the metamaterial loaded antenna under incident plane wave of magnitude of 1V/m are shown in Figure3.4. The maximum RCS achieved is 20.87 dB at 5.4012 GHz. This graph results depict that the bandwidth corresponding to -10 dB RCS for the primary microstrip patch antenna is 2.894 GHz from 3 GHz to 5.894 GHz.

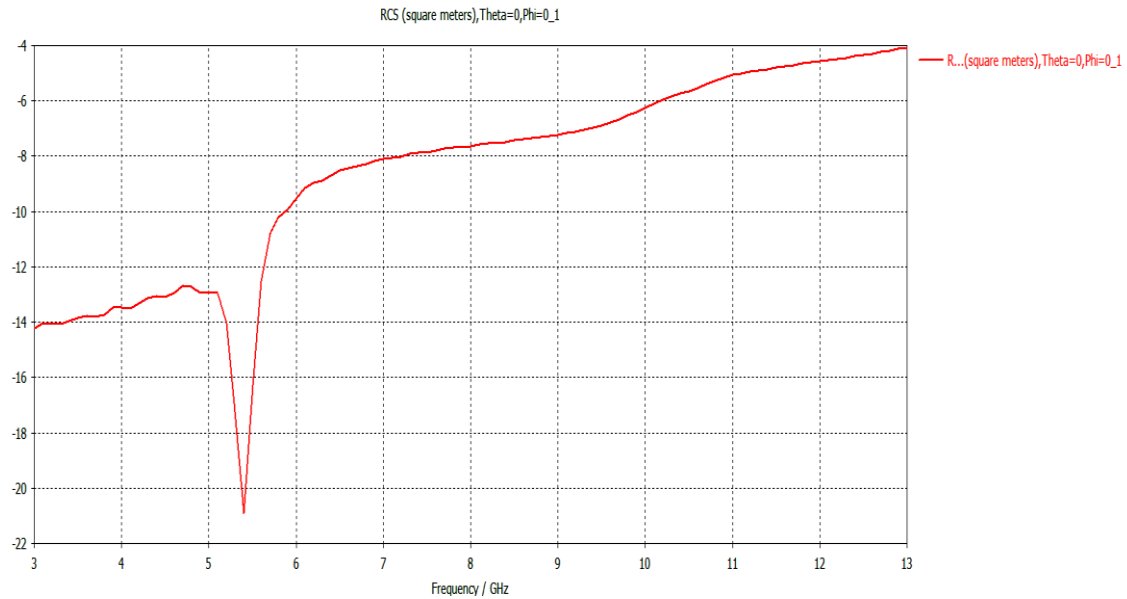
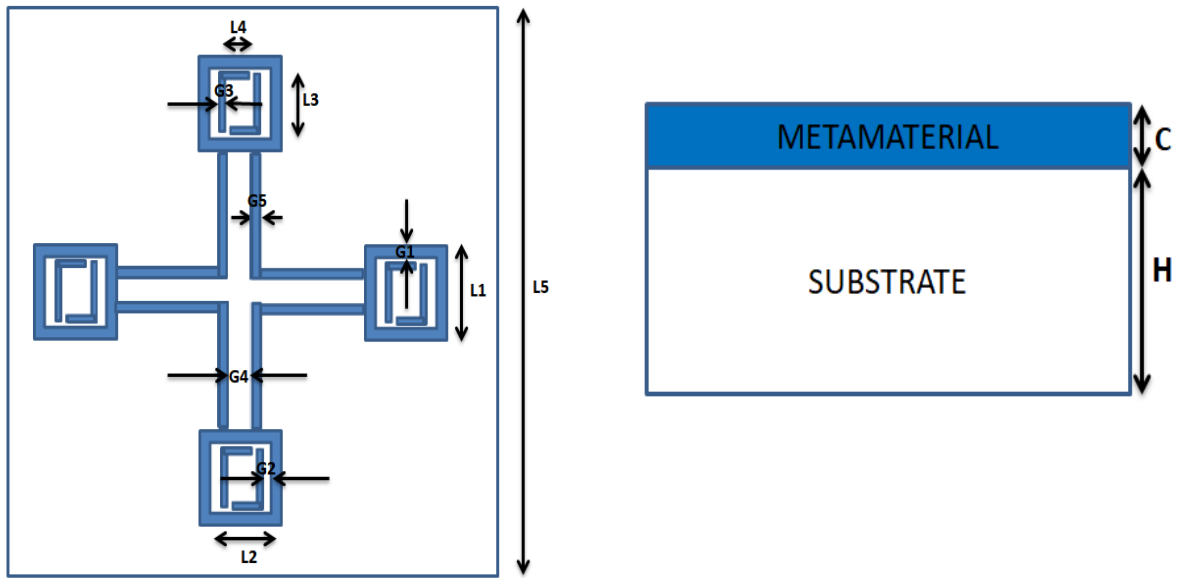


Figure3.4 Monostatic RCS of microstrip patch antenna

### 3.4 DESIGN OF METAMATERIAL UNIT CELL

The design of metamaterial unit cell is depicted in Figure3.5. Square loop and intersecting strips at the edges of add shaped structure is selected as the basic shape of the unit cell. It is etched on the FR4 substrate with thickness of 'h', relative permittivity,  $\epsilon_r = 4.3$ , and dielectric loss tangent,  $\tan \delta = 0.025$ . Each unit cell is formed by etching metamaterial shape metal patch on a dielectric layer and there is no backing by metallic plate.

The copper employed for metamaterial structure has an electrical conductivity of  $5.7 \times 10^7$  S/m and thickness of copper is 0.035mm. The geometry parameters of cell have the periodicity  $L_5 = 22$  mm. Table 3.3 exhibits the detailed parameters of unit cell.



(a)

(b)

Figure 3.5 Metamaterial Unit cell (a) front view (b) side view

Table 3.3 Parameters of Metamaterial Unit Cell

Parameter	Value(mm)
L1	4.5
L2	3.5
L3	3
L4	1.75
H	2
G1	0.55
G2	0.3
G3	0.25
G4	1
G5	0.4

### 3.5 SIMULATED RESULTS

The antenna has been designed for operation in 2-8 GHz band. The periodic boundary conditions are considered for both x and y directions and the unit cell is excited by Floquet port to evaluate its frequency dependent response in infinite periodic structure.

#### 3.5.1 Return Loss

The simulated reflection and transmission characteristics of the metamaterial unit cell under the normal incidence in the frequency range from 2-8 GHz are shown in Figure3.6. It is seen that the designed unit cell exhibits a bandstop performance at the center frequency of 5 GHz. The peak reflection characteristic value of the unit cell is -20.24dB at 5.0 GHz. The bandwidth corresponding to -10 dB reflection characteristics for the unit cell is 2.2 GHz from 3.9 GHz to 6.1 GHz.

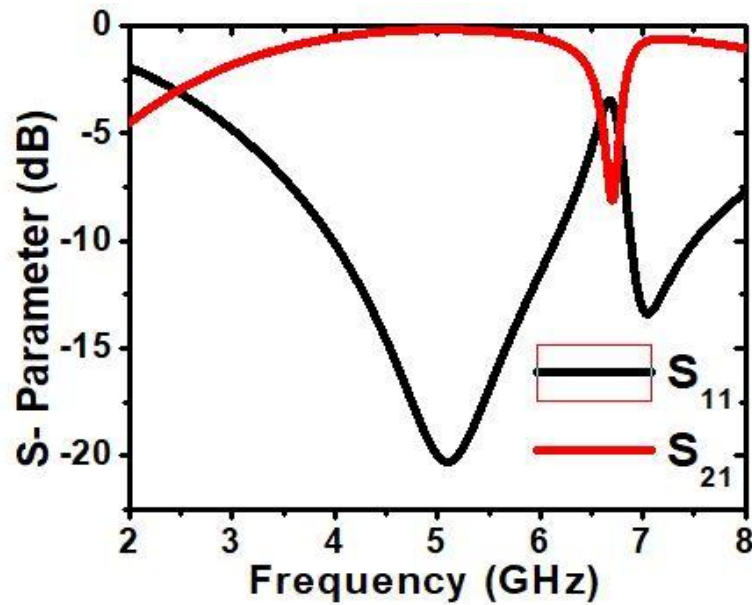


Figure3.6 Simulated Results of Unit cell

#### 3.5.2 Surface current

Surface current is the actual electric current that is induced on application of electromagnetic field. The surface current distribution for the metamaterial unit cell is shown in Figure3.7. The current distribution is maximum along vertical arm of add shape of metamaterial design and it is sparse along outer square loop and maximum observed at inner square loop.

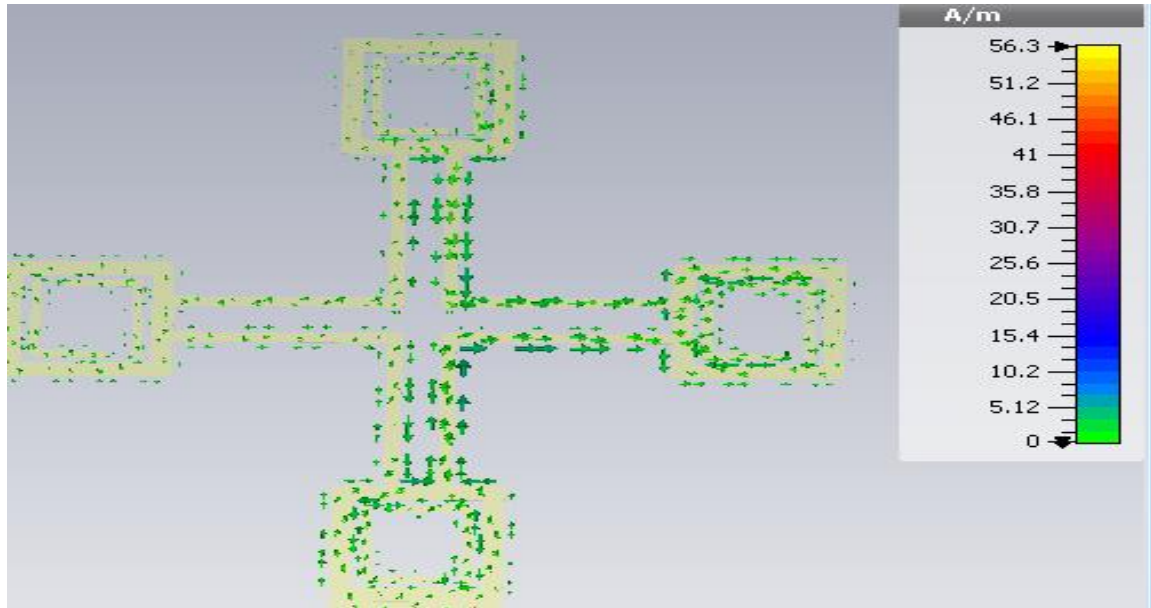


Figure3.7 Surface current of metamaterial unit cell

### 3.6 CONCLUSION

In this chapter the primary microstrip patch antenna and proposed metamaterial unit cell is designed and simulated for RCSR application. Substrate used was FR-4 for primary antenna and MM unit cell. Simulated primary antenna resonates at 4.0 GHz while MM unit cell resonates at 5.0 GHz.

## CHAPTER 4

### DESIGN OF METAMATERIAL LOADED ANTENNA FOR RCSR

#### 4.1 INTRODUCTION

In this section we have presented the proposed metamaterial loaded microstrip patch antenna. This chapter deals with design and simulation procedure of proposed metamaterial loaded microstrip patch antennas using coaxial feed. And finally the last chapter provides the simulated results of designed antenna as well as the parametric analysis of various design parameters for RCSR application.

#### 4.2 ANTENNA DESIGN

This section presents the design of the complete metamaterial loaded antenna for RCSR. All the dimensional specifications are discussed in this part.

##### 4.2.1 Metamaterial Loaded Microstrip Patch Antenna

In metamaterial loaded microstrip patch antenna FR-4 substrate with thickness of 2mm, relative permittivity,  $\epsilon_r = 4.3$ , and dielectric loss tangent,  $\tan \delta = 0.025$  is used. In order to reduce the monostatic RCS of primary microstrip patch antenna designed in last chapter, the solid metal ground plane of the primary microstrip patch antenna is replaced by a complex ground plane formed with the proposed metamaterial unit cells. Total of eight unit cells and a metallic patch at the centre of antenna constitute ground plane of proposed antenna. The radiation patch is fed by coaxial cable and has dimensions similar to primary antenna.

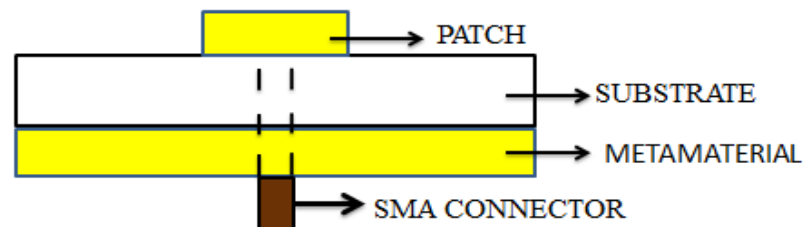


Figure4.1 Side view of metamaterial loaded antenna

Connectors used in metamaterial loaded antenna are SubMiniature version A (SMA) connectors. These are coaxial RF connectors which were designed in 1960s for usage as a minimal connector interface for coaxial cable. These connectors have a  $50\Omega$  impedance. SMA is designed for use from DC (0 Hz) to 18 GHz, and these are mostly used in microwave systems.

### 4.3 SIMULATED RESULTS

The simulations of the metamaterial loaded antenna are performed by usage well known commercial full wave simulation software, CST Microwave Studio. The antenna has been designed for RCS reduction operating over frequency range of 2 to 8 GHz.

#### 4.3.1 Return Loss

The simulated reflection characteristics of the metamaterial loaded microstrip patch under the normal incidence in the frequency range from 3 to 5 GHz are shown in Figure 4.2. Good or high return loss tells how perfectly the devices are matched. For an ideal antenna it should be high in negation. As this design is concerned, the designed antenna gives  $-20.74\text{dB}$  return loss at  $3.913\text{GHz}$  frequency.

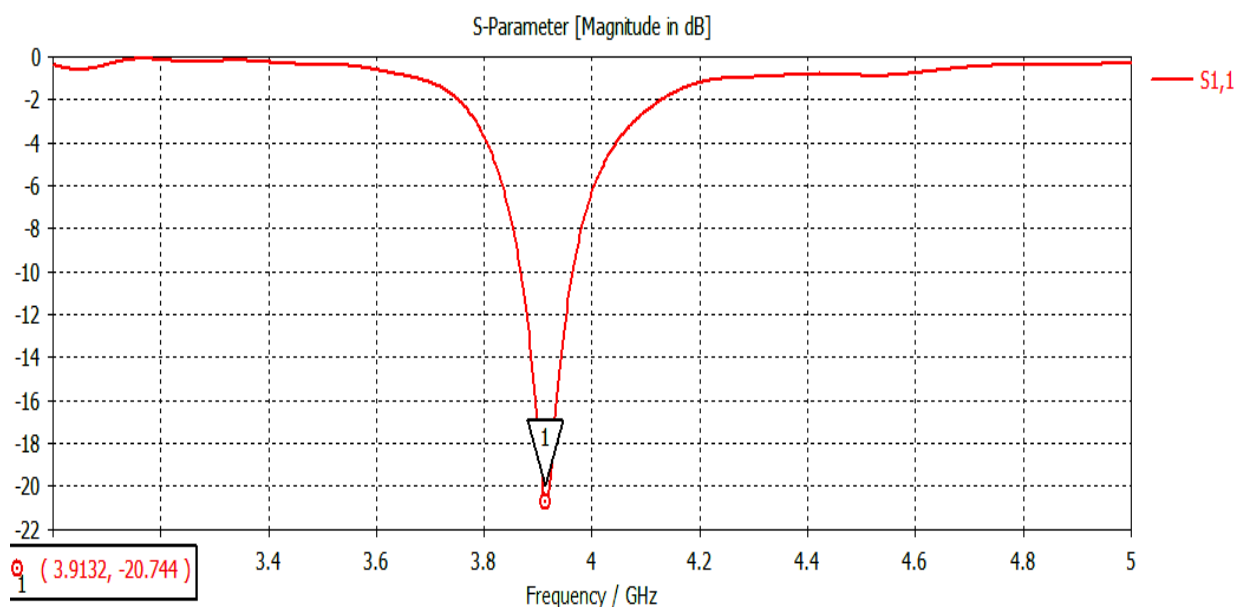


Figure 4.2 Simulated results of  $S_{11}$  of metamaterial loaded antenna

### 4.3.2 Current Density

The current distribution over patch tells behaviour of an antenna with metamaterial. The current distribution is maximum along vertical arm of add shape of metamaterial design and it is sparse along outer square loop and maximum observed at inner square loop. Similarly, The surface current maximum intensity is observed at centre of the patch, while less intensity is obtained at the left and right vertical arms of the patch.

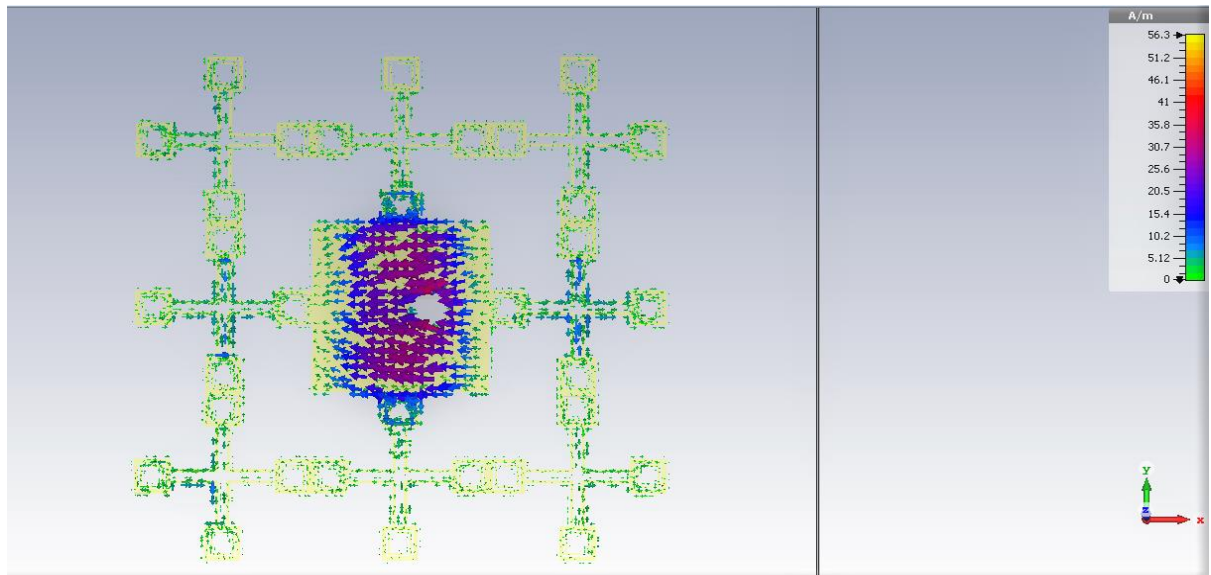


Figure4.3 Surface current of metamaterial loaded antenna

### 4.3.3 Radar Cross Section

The monostatic RCS results of the metamaterial loaded antenna under incident plane wave of magnitude of 1V/m are shown in Figure4.4. The maximum RCSR achieved is 54.889 dB at 3.499 GHz. It is seen that monostatic RCS has been reduced in comparison to that of primary microstrip patch antenna. This graph results depict that the bandwidth corresponding to -10 dB RCS for the proposed metamaterial loaded antenna is 9.522 GHz from 2 GHz to 11.522 GHz and 2.902 GHz from 12.817 GHz to 15.719 GHz. Due to loading of antenna by metamaterial, RCSR has been achieved both in band and out of band.

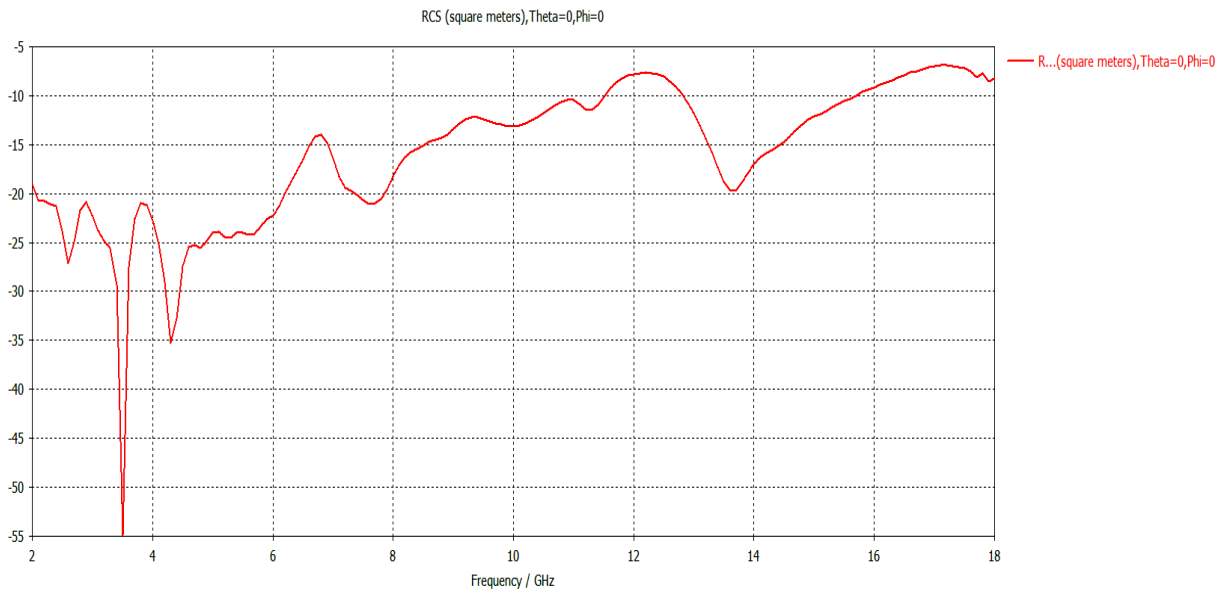


Figure 4.4 Monostatic RCS of metamaterial loaded antenna

#### 4.4 PARAMETRIC STUDIES OF PROPOSED ANTENNA

There is a need to obtain an optimum value of all parameters so that proposed metamaterial loaded antenna can work efficiently. The Parametric studies are shown below with corresponding graphs.

##### 4.4.1 Varying thickness of substrate h

During this analysis thickness of substrate of metamaterial loaded antenna is varied. By varying thickness of substrate the optimum value of thickness is obtained where desired results are obtained. The plot of RCSR is shown in Figure 4.5. The thickness of substrate is varied from 1 mm to 3mm with step width of 0.5mm. As observed from monostatic RCS v/s frequency graph, the optimum value of thickness of substrate at which maximum RCSR is attained is 2mm.

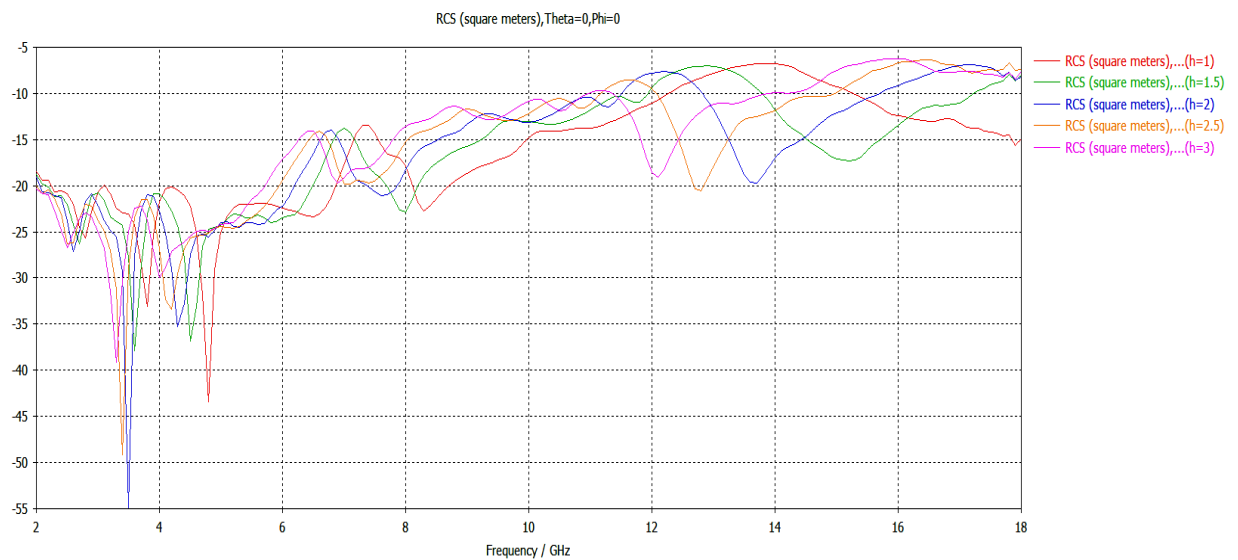


Figure4.5 Graph of monostatic RCS by varying thickness of substrate ‘h’

#### 4.4.2 Varying gap G1

During this analysis gap ‘g1’ in metamaterial design of proposed antenna is varied. By varying ‘g1’, the optimum value of gap is obtained where desired results are obtained. The plot of RCSR is shown in Figure4.6. The value of g1 is varied from 0.25 mm to 0.65mm with step width of 0.1mm. As observed from monostatic RCS v/s frequency graph, the optimum value of ‘g1’ is 0.55mm.

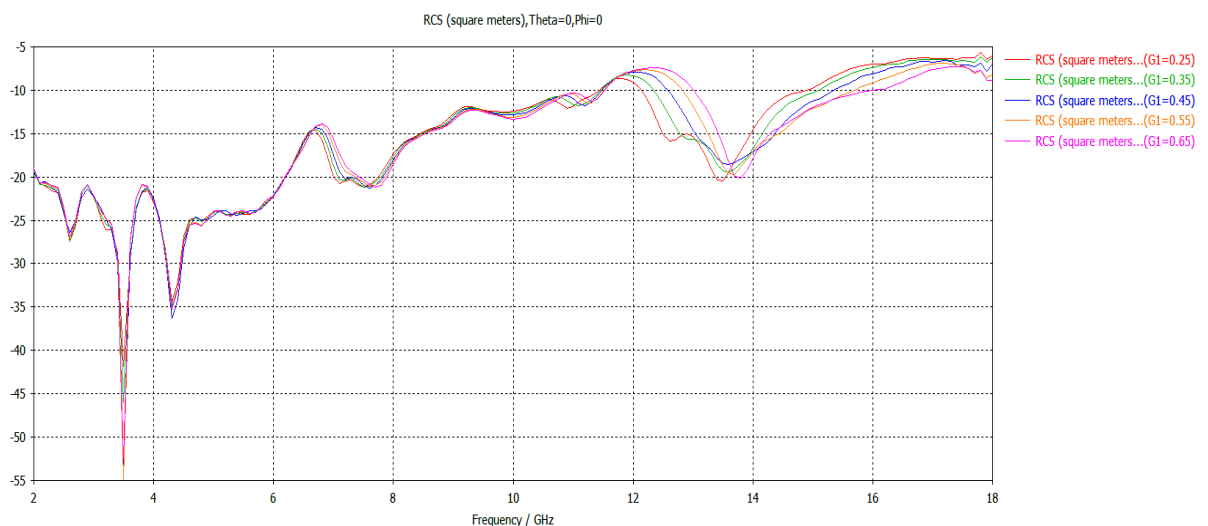


Figure4.6 Graph of monostatic RCS by varying gap G1

#### 4.4.3 Varying gap G2

During this parametric analysis gap 'g2' in metamaterial design of proposed antenna is varied. By varying 'g2', the optimum value of gap is obtained where desired results are obtained. The plot of RCSR is shown in Figure4.7. The value of g2 is varied from 0.15mm to 0.35mm with step width of 0.05mm. As observed from monostatic RCS v/s frequency graph, the maximum RCSR is attained at 0.3mm.

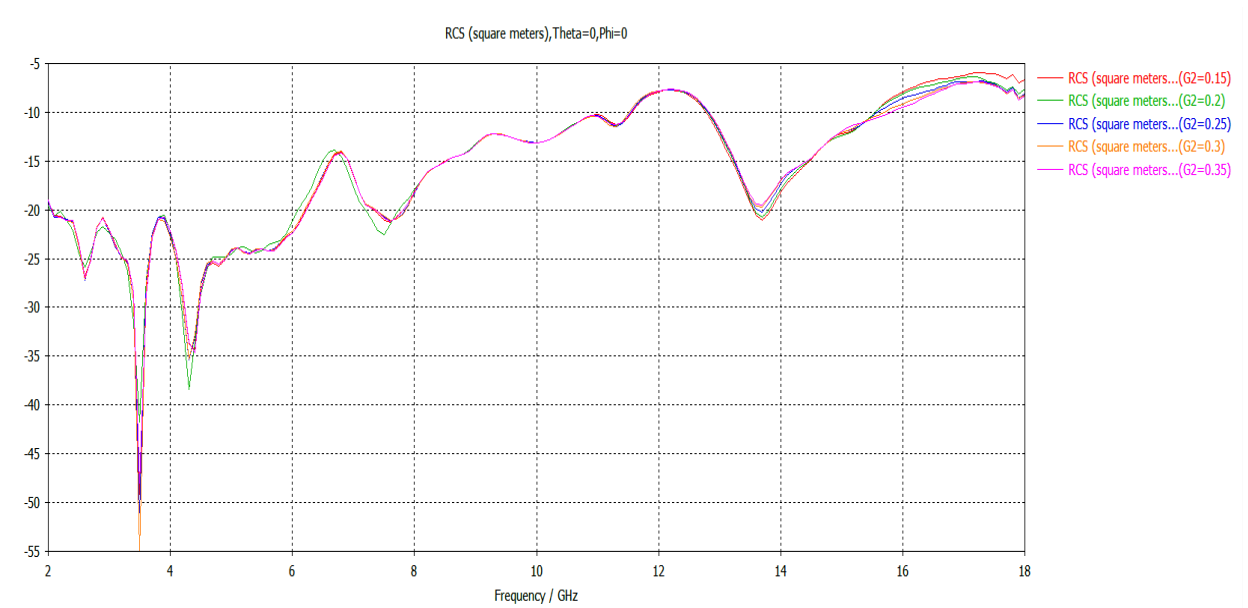


Figure4.7 Graph of monostatic RCS by varying gap G2

#### 4.4.4 Varying gap G3

During this analysis gap 'g3' in metamaterial design of proposed antenna is varied. By varying 'g3', the optimum value of gap is obtained where desired results are obtained. The plot of RCSR is shown in Figure4.8. The value of g3 is varied from 0.1mm to 0.3mm with step width of 0.05mm. The optimum value of 'g3' at which maximum RCSR is obtained is 0.25 mm as observed from monostatic RCS v/s frequency graph.

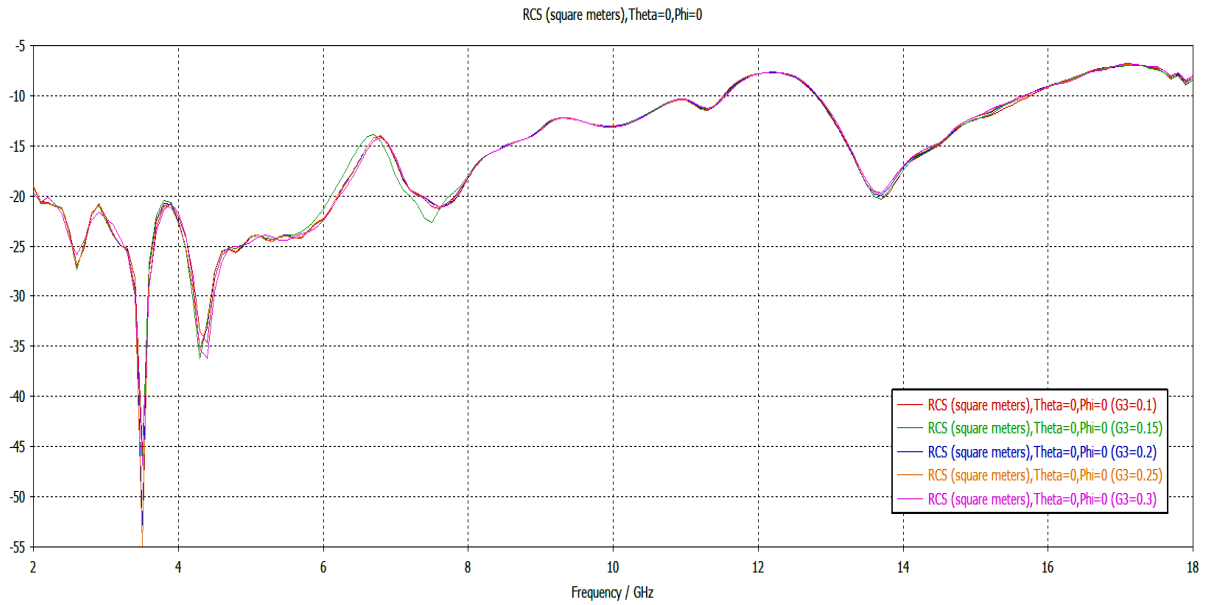


Figure4.8 Graph of monostatic RCS by varying gap G3

#### 4.4.5 Varying gap G4

During this parametric analysis gap ‘g4’ in metamaterial design of proposed antenna is varied. By varying ‘g4’, the optimum value of gap is obtained where desired results are obtained. The plot of RCSR is shown in Figure4.9. The value of g4 is varied from 0.6mm to 1.2mm with step width of 0.1mm. As observed from monostatic RCS v/s frequency graph, maximum RCSR is achieved at value of ‘g4’ equal to 1mm.

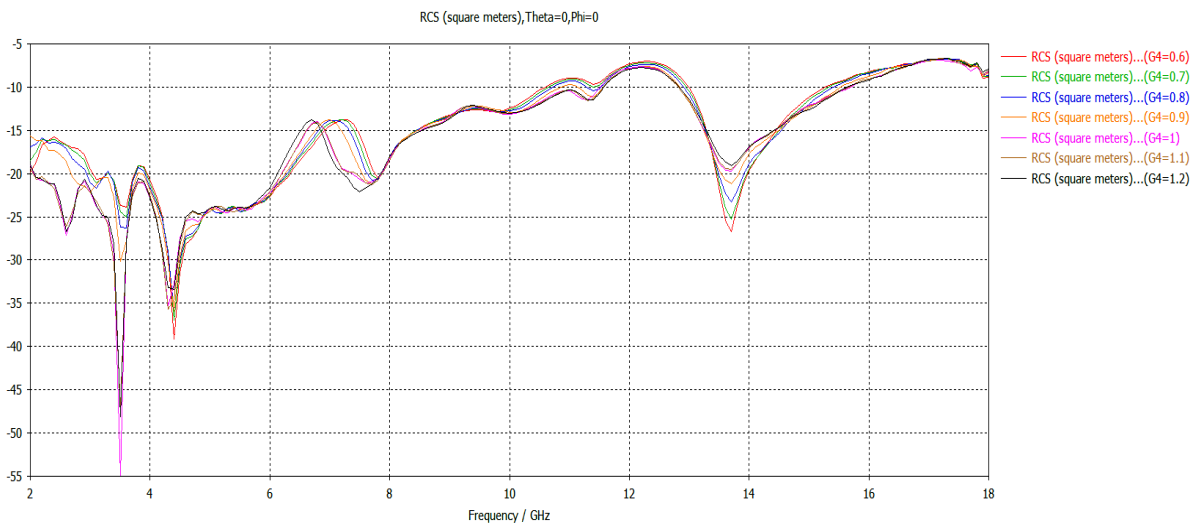


Figure4.9 Graph of monostatic RCS by varying gap G4

#### 4.4.6 Varying gap LP

In this parametric analysis length of patch ‘LP’ is varied. By varying length of patch, an optimum value is obtained at which maximum RCSR is attained. The graph of RCSR is shown in Figure4.10. The length of patch is varied from 13.3mm to 18.3mm with step width of 1mm. As observed from monostatic RCS v/s frequency graph, the optimum value is 16.3mm.

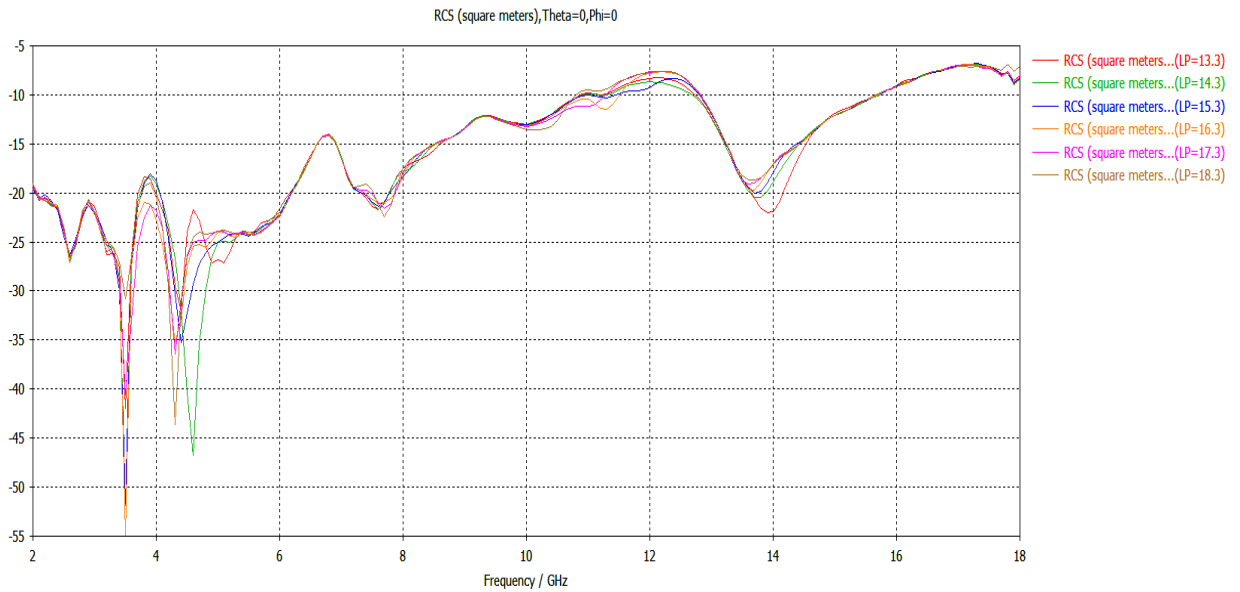


Figure4.10 Graph of monostatic RCS by varying length of patch

#### 4.4.7 Varying gap WP

In this parametric analysis width of patch ‘WP’ is varied. By varying width of patch, an optimum value is obtained at which maximum RCSR is attained. The graph of RCSR is shown in Figure4.11. The length of patch is varied from 19.5mm to 22mm with step width of 0.5mm. As observed from monostatic RCS v/s frequency graph, the optimum value is 21mm.

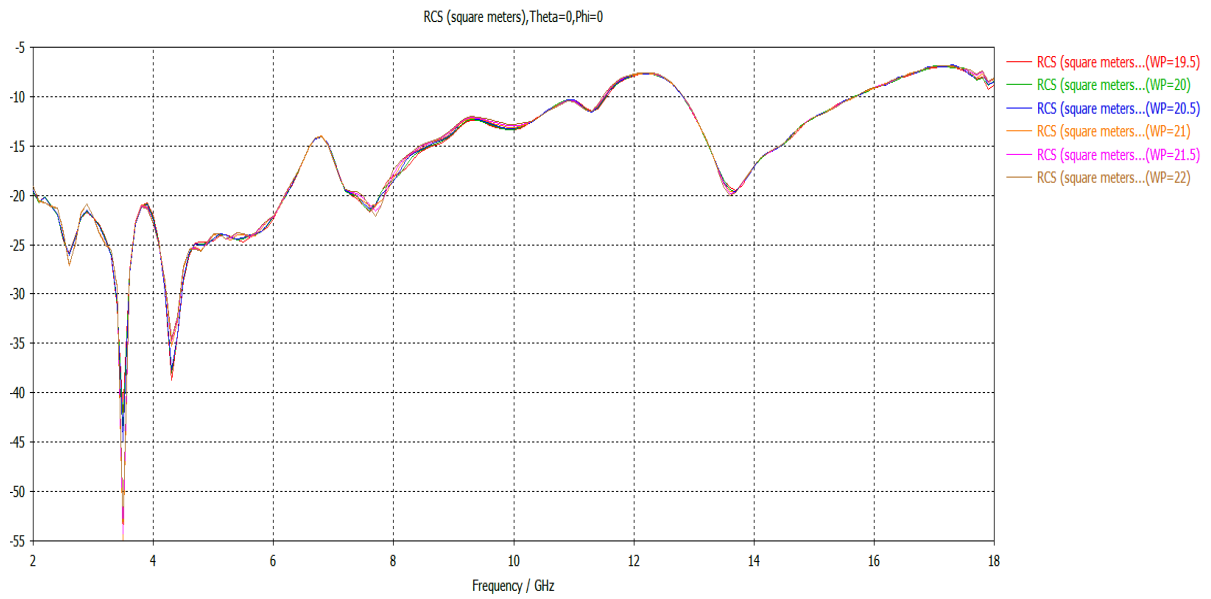


Figure4.11 Graph of monostatic RCS by varying width of patch

#### 4.5 CONCLUSION

In this chapter a design of metamaterial loaded antenna is designed and simulated for achieving maximum RCSR. Parametric studies by varying thickness of substrate and various gaps in the design have been done to get optimized dimensions of the structure. The results of all parametric studies are presented. This metamaterial loaded antenna enhances RCSR capability of antenna as observed in simulated results.

## CHAPTER 5

### FABRICATION AND TESTING OF ANTENNA

#### 5.1 FABRICATION AND TESTING OF PROPOSED MICROSTRIP PATCH ANTENNA

After the final optimization of antenna with the help of suitable geometrical specifications, the simulated coaxial fed antenna is been fabricated onto the FR4 substrate having thickness 2mm with dielectric constant 0.0024 and dielectric permittivity 4.4. The antenna was fabricated through Photolithography technique making the desired structure. The snapshot of fabricated antenna has been presented in Figure5.1. Figure5.2 presents the experimental setup used.

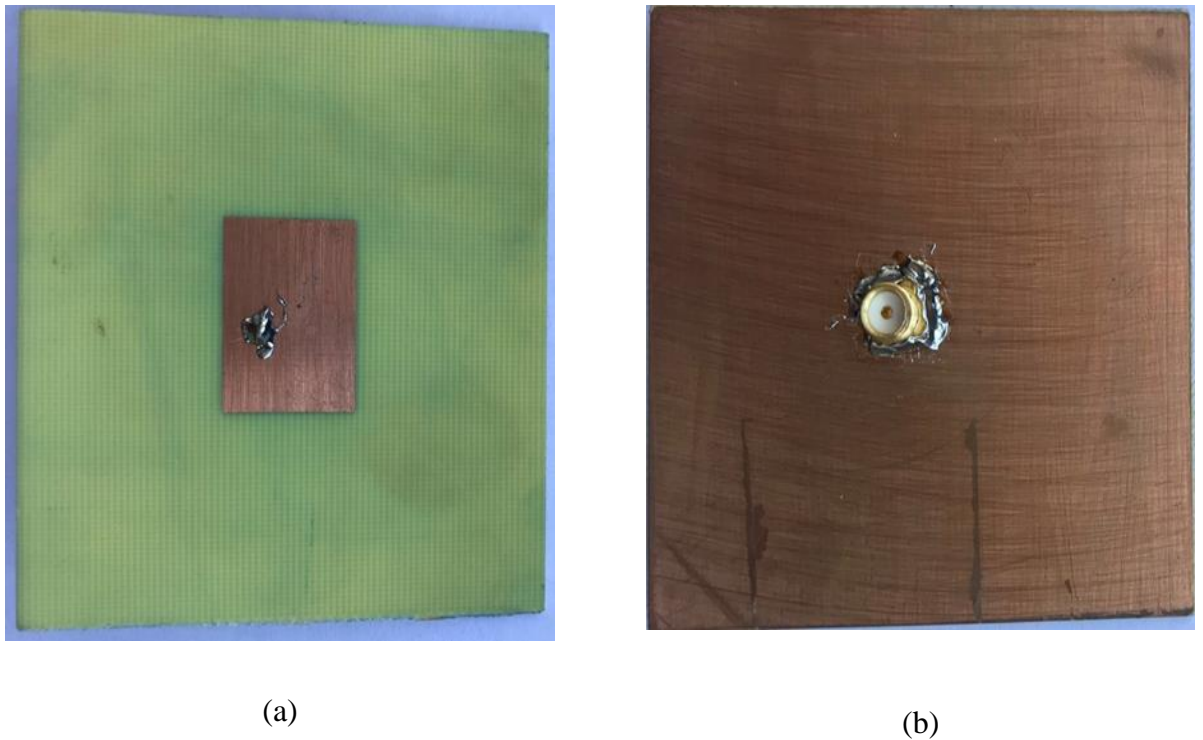


Figure5.1 Primary Microstrip Patch Antenna (a) Front View (b) Back View

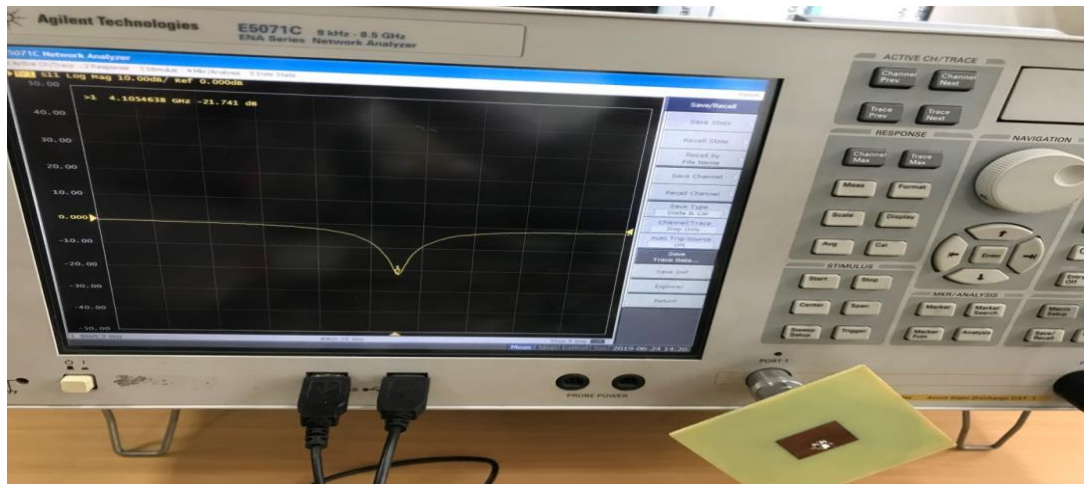


Figure 5.2 Experimental Setup of coaxial fed fabricated microstrip patch antenna

The return loss of the final fabricated was tested using AGILENT E5071C vector network analyzer employed at Antenna Research Lab, Thapar Institute of Engineering and Technology, Patiala. Figure 5.3 represents the measured primary antenna results. The measured return loss value is -21.86 dB at resonant frequency of 4.1 GHz.

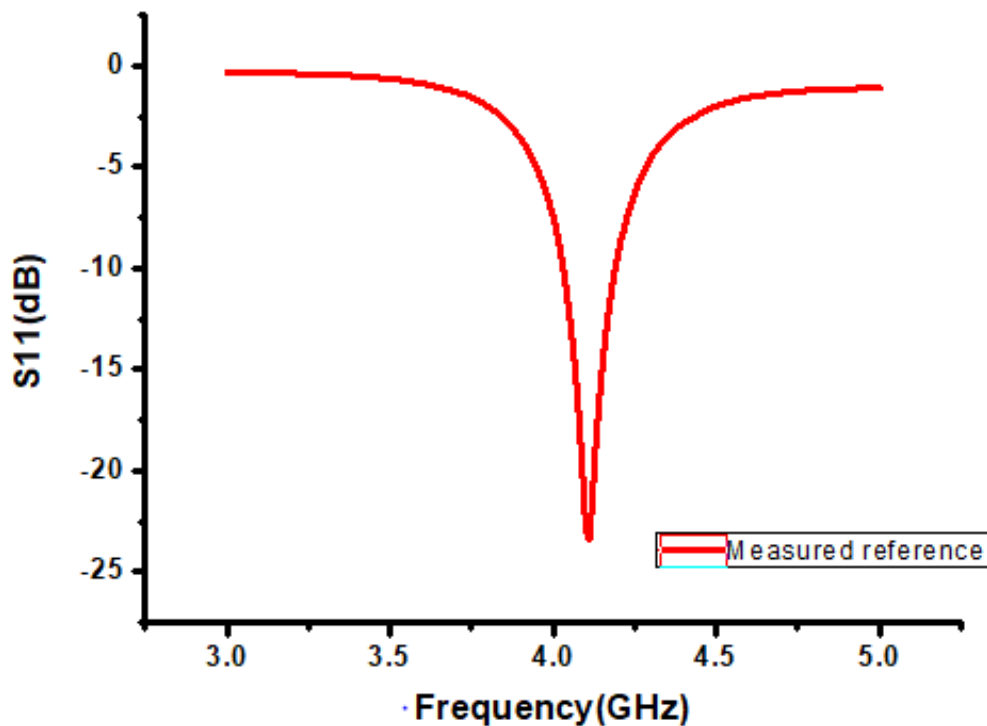


Figure 5.3 Measured results of S11 of primary antenna

The shifting of resonating frequency is due to the connector loss, mismatching of dielectric constant of the substrate as well due to fabrication process used while designing and manufacturing. Table 5.1 provides comparison of simulated and measured results of microstrip patch antenna.

Table 5.1 Comparison of simulated and measured results of microstrip patch antenna

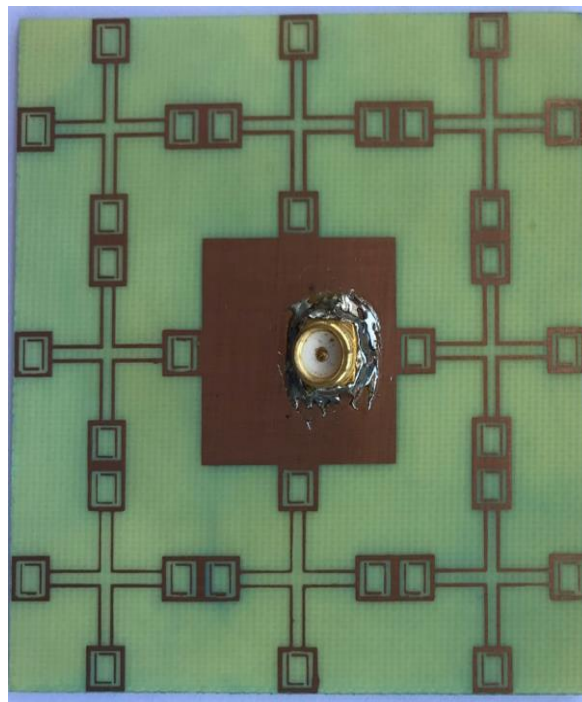
Parameter	Simulated	Measured
Resonant Frequency(GHz)	4	4.1
Return Loss(dB)	-10.37	-21.86

## **5.2 FABRICATION AND TESTING OF PROPOSED METAMATERIAL LOADED ANTENNA**

After the final optimization of antenna with the help of suitable geometrical specifications, the simulated coaxial fed antenna is been fabricated onto the FR4 substrate having thickness 2mm with dielectric constant 0.0024 and dielectric permittivity 4.4. The fabrication was done by Photolithography technique. The Figure 5.4 shows the fabricated antenna and Figure 5.5 depicts experimental setup used. Because of connector losses and fabrication process there is slight difference between simulated and measured results.



(a)



(b)

Figure5.4 Proposed Metamaterial Loaded Antenna (a) Front View (b) Back View

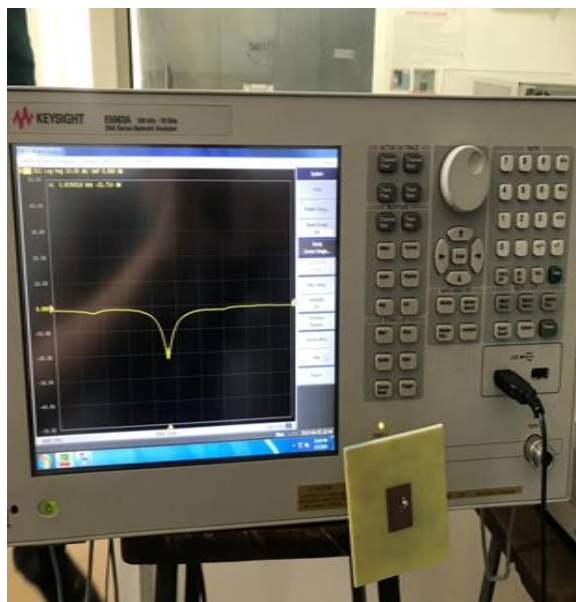


Figure5.5 Experimental Setup of coaxial fed fabricated metamaterial loaded antenna

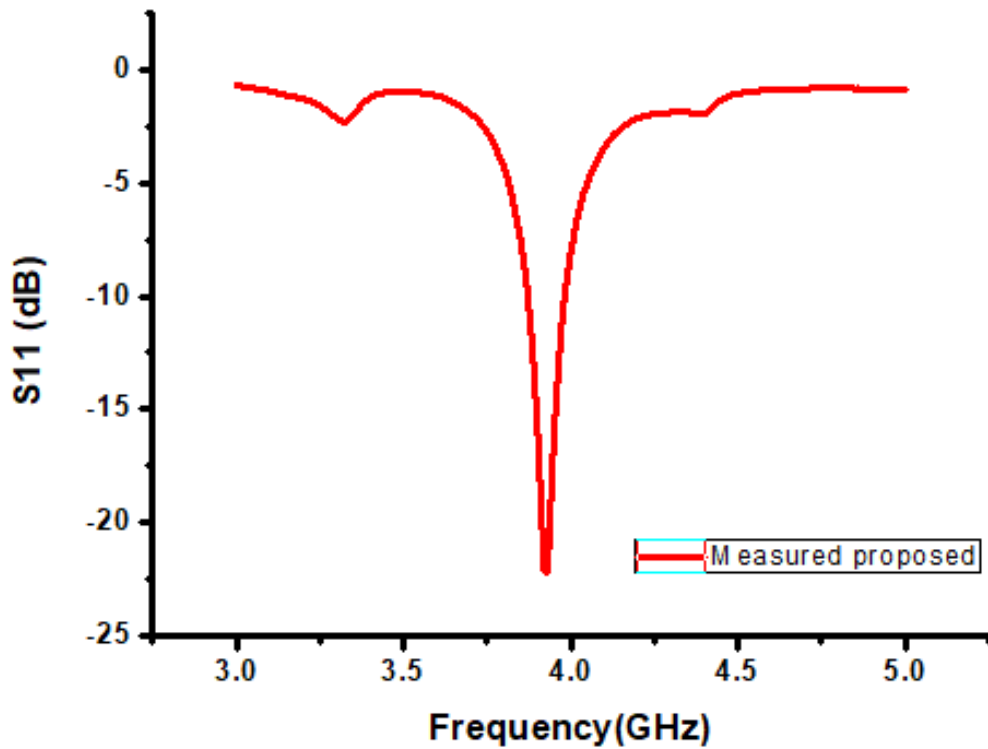


Figure 5.6 Measured results of S11 of metamaterial loaded antenna

To avoid the background environment noise, measurement of reflection phase are performed in anechoic chamber. The return loss of the final fabricated was tested using AGILENT E5071C vector network analyzer employed at Antenna Research Lab, Thapar Institute of Engineering and Technology, Patiala. The measured results of metamaterial loaded antenna are depicted in Figure 5.6. The measured return loss value is -21.714 dB at resonant frequency of 3.92 GHz. Table 5.2 provides comparison of simulated and measured results of metamaterial loaded antenna.

Table 5.2 Comparison of simulated and measured results of metamaterial loaded antenna

Parameter	Simulated	Measured
Resonant Frequency(GHz)	3.913	3.92
Return Loss (dB)	-20.74	-21.714

### **5.3 CONCLUSION**

In this chapter fabrication of primary microstrip patch antenna and metamaterial loaded antenna is presented. Measured results of microstrip patch antenna and metamaterial loaded antenna are shown. Fabricated microstrip patch antenna resonates at 4.1 GHz and fabricated metamaterial loaded antenna resonates at 3.92 GHz.

## CHAPTER 6

### CONCLUSION AND FUTURE SCOPE

#### 6.1 CONCLUSION

The main aim of this thesis work was to design antenna for RCSR application. This thesis has been divided into two parts. First one involves the use of coaxial fed microstrip patch antenna as a primary antenna. The structure thus obtained is conformal, uniplanar, easy to fabricate and requires low cost of operation. The primary microstrip patch antenna geometry is fabricated on a low cost FR4 substrate having an overall dimension of  $66 \times 66 \text{ mm}^2$ . The second part of the thesis includes designing of metamaterial loaded antenna. The new design is proposed and fabricated in order to enhance the RCSR of microstrip patch antenna using metamaterial. 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 designed, studied and implemented for the required frequency range and after that the unit cell is multiplied to make  $66 \times 66 \text{ mm}^2$  sized 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. A parametric analysis has also been conducted to adjudge the effects of the thickness of substrate, length and width of integrated patch as well as various gaps in between the metamaterial design.

In chapter 3 primary microstrip patch antenna and metamaterial unit cell is designed and simulated. Simulation results show that

- At resonant frequency of 4 GHz, - 10.37dB return loss is obtained.
- The maximum value of RCSR is 21.4dB at frequency of 5.4 GHz.

In chapter 4, we design metamaterial loaded antenna. The dimensions of antenna were similar to last one. The results of metamaterial loaded antenna depict that

- At resonant frequency of 3.91 GHz, -20.744dB return loss is obtained.
- The maximum value of RCSR is 55dB at resonant frequency 3.91 GHz.

In chapter 5 microstrip patch antenna and metamaterial loaded antenna is fabricated. Measured results show that

- In case of primary microstrip patch antenna, at resonant frequency of 4.1 GHz, -21.86dB return loss is obtained.
- In case of metamaterial loaded antenna, at resonant frequency of 3.9 GHz, -21.714dB return loss is obtained.

## **6.2 FUTURE SCOPE**

- The work can be carried further by introducing some new structures such as artificial magnetic conductors, multi layer metasurfaces and coding metamaterials.
- Future work includes changing the different feed lines from simple coaxial to complex proximity coupling.
- The optimization of metamaterial is a challenging task. There is a need to explore some new techniques for efficient optimization of metamaterial designs.

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