بسم الله الرحمن الرحيم

MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Design and Analysis of Microstrip Patch Antenna Loaded with Innovative Metamaterial Structure

By

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CERTIFICATE OF APPROVAL

The thesis titled "Design and Analysis of Microstrip Patch Antenna Loaded with Innovative Metamaterial Structure" submitted by Razin Ahmed bearing Student No. 112601 of Academic Year 2011-2012 has been found as satisfactory and accepted as partial fulfillment of the requirement for the degree of Master of Science in Electrical and Electronic Engineering on 10th October 2013.

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DEDICATION

This thesis is dedicated to my beloved parents, brother and sister for their endless love, support and encouragement.

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LIST OF SYMBOLS AND ABBREVIATIONS

MPA	Microstrip Patch Antenna
RMPA	Rectangular Microstrip Patch antenna
LHM	Left Hand Material
RHM	Right Hand Material
SNG	Single Negative Material
ENG	Epsilon Negative Material
MNG	Mu-Negative Material
DNG	Double Negative Material
SRR	Split Ring Resonator
CSRR	Complementary Split Ring Resonator
ε_r	Dielectric Constant
RF	Radio Frequency
VSWR	Voltage Standing Wave Ratio
RL	Return Loss
ε	Permittivity
μ	Permeability
TM_{10}	Traverse Magnetic
Q	Quality Factor
PCB	Printed Circuit Board
NIM	Negative Index Materials
FSS	Frequency Selective Surface
MMIC	Microwave Monolithic Integrated Circuit
OEIC	Optoelectronic Integrated Circuit
NRW	Nicolson-Ross-Weir

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ABSTRACT

Technology has evolved constantly over the years where the demand of Microstrip Patch Antenna (MPA) has been growing tremendously. This is mostly due to their versatility in terms of possible geometries that makes them applicable for many different situations. The lightweight construction and the suitability for integration with microwave integrated circuits are basic advantages. Additionally the simplicity of the structures makes this type of antennas suitable for low cost manufacturing. Besides all benefit, these antennas have major drawbacks such as narrow bandwidth, low efficiency, and low gain. Recently Ku band frequency range of (12-18) GHz has been studied vigorously for allocation of satellite communication, which became the most demanding subject around the world in last few decades. But researchers are facing difficulty to improve both bandwidth and gain in same MPA under this band which leads to examine and investigate for further enhancement. In last decade a new man made material has been discovered known as metamaterial and it has already drawn attention to antenna researchers. This advance material depicts unusual electromagnetic properties which are not available in nature, such as negative permittivity (ε_r) and permeability (μ_r). Due to its amazing feature, it has the capacity to enhance antenna characteristic rapidly. The primary objectives of this thesis is to exploit these exceptional properties of metamaterial in designing suitable MPA for better bandwidth and gain antenna characteristic that can operate under Ku band. In this thesis a series of MPAs have been designed in chronological order to achieve desirable objectives. Among them E slotted E shaped patch loaded with metamaterial antenna (proposed antenna) shows better improved characteristics. The intended design and feeding technique provides the antenna to operate at Ku band range with approximately total 4.40 GHz bandwidth which covers 73.33% of this domain. The proposed antenna resonates at 14.97 GHz with total field directivity 9.4 dBi. This thesis also contains four particular Microstrip patch antenna design including proposed antenna with a brief comparative study between them where effect of different antenna parameters are studied.

CHAPTER 1
OVERVIEW

1.1 Introduction

Wireless communication is the fastest growing segment of the communication industry. It has become so ubiquitous in our society and indispensable for our daily lives. It gives ease, unprecedented sense of mobility to us and revolutionized way to do almost everything. Many new applications, including wireless sensor networks, automated highways and factories, smart homes and appliance, and remote telemedicine are emerging for research where antenna is an essential and vivid component in wireless communication system. An antenna is an electrical component that is needed to transmit and receive electromagnetic energy from the space surrounding it, in order to establish a wireless connection between minimum two or more devices. The antenna's performance is generally characterized by some basic terms as antenna efficiency, gain and radiation pattern. Worldwide electromagnetic spectrum has been allocated for all types of electromagnetic (EM) radiation based on EM wave wavelengths and frequencies where antennas can operate according to the applications of wireless communication system such as mobile phones, base stations wireless local area network connections (WLAN), and satellite etc. The operating frequency selection for certain antennas in part determines the material that can be used to produce the antenna. Materials include flex, ceramic, steel plate, FR-4, or some wire material. In recent years, new artificial material known as metamaterial has been introduced which exhibits unusual properties that are not available in the nature. It is a composite structure of metallic pattern which affect the microscopic properties of the host medium and generates negative effective permittivity and permeability. Antenna performance can be improved by designing antenna with metamaterial. But antenna is one of the most complicated aspects of radio frequency (RF) design; it is also probably the most overlooked part of a RF design. The range and performance of an RF link are critically dependent upon the antenna. However, it is often neglected until the end of the design and expected to fit into whatever space is left, no matter how unfavorable to performance that location may be. Last few years antenna designing gains much priority to telecommunication researchers. Especially antenna miniaturization and multifunctional system became the most significant and interesting topics in related fields. The desire for small and versatile antennas is increasing everyday, based on antenna design it can operate at different radio frequencies. Microstrip Patch Antenna (MPA) has become most popular to antenna designer due to its diminutive structures. Compared with the conventional antenna, it has more multilateral advantages for planer profile, ability to operate in microwave frequency range, conformability with shaped surface, inexpensive to manufacture and especially easy to assemble in integrated circuit technology. Designing MPA with metamaterial properties opens the possibility in enhancement of antenna characteristic such as antenna size, high directivity, and tunable operational frequency.

1.2 Background

In 1950s the abstract idea of microstrip antenna was first introduced by G. A. Deschamps [1]. After the evolution of the printed circuit board (PCB) technology in the 1970s, Howell and Munson developed the first practical microstrip antenna, which opens extensive area of research all over the world [2]. The basic structure consists of a conducting patch of any non-planar or planar geometry on one side of a dielectric substrate and a ground plane on other side. The fundamental radiating structures for microstrip antennas are mainly rectangular and circular in geometry; nonetheless, comprehensive list of the geometries along with their outstanding features are available in chapter 2. The low profile planar configuration of microstrip antennas can be easily made conformal to host plane. Their light weight, low volume and low fabrication cost, allows them to be manufactured in large quantities. Microstrip antennas are robust in nature and also compatible with microwave monolithic integrated circuit (MMIC) and optoelectronic integrated circuit (OEICs) technologies [3]. Microstrip antennas can easily be designed to have horizontal polarization, vertical polarization, left hand circular polarization (LHCP) or right hand circular polarization (RHCP) by using single feed point or multiple feed points [4]. Microstrip antennas are widely used in civilian and military applications such as satellite communications, television, mobile systems, broadcast radio, vehicle collision avoidance system, global positioning system (GPS), radio-frequency identification (RFID), direction founding, radar systems, remote sensing, missile guidance, surveillance systems, and multiple-input multiple-output (MIMO) systems.

The design and implementation of such microstrip antennas is an ongoing area of research. Modified configurations and various shapes of MPA such as rectangular or triangular with different dimension of length (L) can help to get desirable resonant frequencies [5, 6]. The bandwidth of microstrip antennas is strongly influenced by the gap between the conducting patch and the ground plane. A smaller gap stores more energy in the patch capacitance and inductance and radiates less. Hence, the quality factor (Q) of the antenna increases, indicating a narrow radiation bandwidth. This Q can be reduced by increasing the thickness of the dielectric substrate but it affects the antenna size which tends to enlarge antenna plane or height. As the thickness increases, an augment fraction of the total power delivered by the source goes into surface waves and it is counted as an undesirable power loss, degrading antenna characteristics. It also exhibits low power gain, extra radiation from its feeds and junction points [7]. The substrate permittivity (ε_r) of the microstrip antenna also affects the resonant bandwidth and gain [8]. It is difficult to achieve standard antenna gain and bandwidth characteristic in same MPA under Ku band region [33-38].

1.3 Scope of Research

Metamaterials are manmade one of the new, advance and pioneer discoveries of the last decade. It shows unusual electromagnetic properties that are not found in naturally occurring substances. They are artificial compound structures of periodic metallic patterns printed on dielectric substrate which affects the macroscopic properties of the bulk compound and generates a negative effective permittivity and permeability for a certain frequency band [9]. With proper arrangements metamaterials can also exhibit negative index of refraction. There are different types of metamaterial bases with negative parameters, e.g. the negative index materials (NIM), the double negative (DNG) media, the left handed materials (LHMs) or the backward wave (BW) media. Among them LHMs are popular in microwave propagation studies because it exhibits negative permittivity and permeability resulting in an effective negative refractive index. Hence metamaterial have the power to grab electromagnetic radiation and deflect it smoothly which leads to invisibility [10]. It gives the ability to build high resolution and magnified flat converging lenses that surpass the diffraction limitation of conventional optical lenses. There are many other application with extra ordinary features in terahertz metamaterials, photonic metamaterials, tunable metamaterials, plasmonic metamaterials frequency selective surface (FSS) based metamaterials, metamaterial absorber, and elastic metamaterials. It is also possible to create new kinds of miniaturized antennas and microwave devices for the wireless communication systems with these advance material properties. Split ring resonator (SRR) is pair of loops which are made of nonmagnetic metal like copper and have a small gap between them that provides incredible LHM (negative permittivity and permeability) properties. In antenna designing it has been used in many places. In [11-13] it is noted that designing MPA with metamaterial superstrates or metamaterial structures better improvements have been made in directivity, bandwidth, gain compare to conventional microstrip antenna. Currently E shaped MPA has gain its popularity in antenna simulation and designing scheme because it can shows wideband application compared to basic MPA. For further antenna characteristic improvement loading metamaterial as SRR into the designed E shaped MPA opens a doorway for research.

1.4 Motivation

In recent years, the need to miniaturize electronic circuitry has shown a sharp and rapid increase. To meet this goal, smaller microstrip antennas have become an inevitable choice. Use of conventional microstrip antennas is limited mainly because of their poor gain and bandwidth. There has been a lot of research in the past decade in this area. These techniques include use of cross slots and, increasing the thickness of the patch, use of circular and triangular patches with proper slits and antenna arrays. Various feeding techniques are also extensively studied to overcome these limitations. Another way to enhance the gain and bandwidth is by integrating a selected metamaterial above the antenna; this metamaterial is an engineered material, does not exist in nature, and has simultaneous negative permittivity and permeability. Furthermore, this material has physical capabilities that can be used to focus the radiated field for the sake of antenna gain and bandwidth enhancement.

1.5 Aim and Objectives

In antenna technology, the patch antenna size is larger when there is a lower operating frequency, so MPA has been subjected in this thesis. Because of the specific properties of SRR, it has been selected and integrated on the top of MPA. The aim of this research is to exploit the exclusive features of metamaterial via SRRs to achieve better performance of the MPA characteristics. The objectives are highlighted below.

- To improve antenna gain.
- To increase antenna bandwidth.
- To reduce antenna return loss.

All the enhancements in performance of MPA have been done under Ku band frequency domain. Merging metamaterial and MPA together lead us to get adequate improved result. Fundamental procedures have been stated step by step to achieve our desirable objectives.

Step 1 To design a simple RMA with basic structure by defining its length (L) and width (W) for Ku band operations.

Step 2 To design an E shaped MPA using same length and width of basic RMPA structure by cutting of two parallel slots.

Step 3 To design a basic structure of rectangular shaped SRR as metamaterial.

Step 4 To integrate SRRs on the top of designed E shaped MPA.

Step 5 To design a modified E shaped MPA loaded with same SRR structure for optimization.

Step 6 To analysis the performance of all designed antennas individually in term of antenna characteristics especially antenna gain, antenna return loss and antenna bandwidth.

Step 7 To compare antenna characteristics in between all designed antennas.

1.6 Contribution

As mentioned, this thesis presents design and simulation of four identical MPA and basic realization of metamaterial. All antennas are unique with distinctive features and all have the ability to operate in Ku band region. Among them proposed antenna has shown promising outcomes and fulfill basic objectives of this research. The antenna has improved bandwidth of 4.40 GHz in Ku band which covers almost 73.33% of this domain with maximum gain of 8.6 dB. Comparative study has been made in between all the antennas to study effect of metamaterial on MPA as well as various parameters of designed antennas.

1.7 Thesis Organization

The dissertation is organized into five chapters. The first chapter provides a general introduction to MPA and metamaterial with main objectives and research methodology of this work.

Chapter 2 presents an overview of basic antenna characteristics with extensive detail about MPA and metamaterial properties. It also contains literature review and motivation of the research.

A series of antenna designed configuration with optimization has been discussed in chapter 3. The average and vector current distribution, 2D and 3D radiation patterns for all individual antennas have been illustrated in chapter 4. A brief comparative study also has been made between proposed antenna and other designed antennas in terms of various antenna parameters.

Finally, chapter 5 gives a conclusion of the work and scope for future work considerations.

CHAPTER 2
BACKGROUND

2.1 Antenna Characteristics

An antenna is the component of a radio system that is used to send or receive a radio signal. A radio frequency (RF) signal that has been generated in a radio transmitter travels through a transmission line (coaxial cable) to an antenna. An antenna connected to a transmitter is the device that releases RF energy to be sent to a distant receiver. The receiving antenna picks up the RF energy. As the electromagnetic field strikes the receiving antenna, a voltage is induced into the antenna, which serves as a conductor. The induced RF voltages are then used to recover the transmitted RF information. [14]. Antenna design has become one of the most active fields in the communication studies. In the early years when radio frequency was found, simple antenna design was used as an apparatus to transmit electrical energy or radio wave through the air in all direction. Wireless technology has expanded rapidly not only for commercial but also for military purposes. Wireless technology provides less expensive alternative and a flexible way for communication. [15]. There are many various types of antenna. The isotropic point source radiator, one of the basic theoretical radiators, is useful because it can be considered a reference to other antennas. The isotropic point source radiator radiates equally in all directions in free space. Physically, such an isotropic point source cannot exist. Most antenna gains are measured with reference to an isotropic point source radiator and rated in decibels with respect to an isotropic point source (dBi) [16]. Before selecting an antenna for any particular application there are several different significant antenna characteristics that must be justified.

- Polarization
- Radiation Pattern
- Antenna Gain
- Directivity
- Bandwidth
- VSWR
- Return loss

The effective polarization of an antenna is an important characteristic. Polarization refers to the orientation of the lines of flux in an electromagnetic field. When an antenna is oriented horizontally with respect to ground, it is said to be horizontally polarized. Likewise, when it is perpendicular to ground, it is said to be vertically polarized. The polarization of an antenna normally parallels the active antenna element; thus, a horizontal antenna radiates and best receives fields having horizontal polarization while a vertical antenna is best with vertically polarized fields. If the transmitter and receiver's antennas are not oriented in the same polarization, a certain amount of power will be lost. In many applications, there is little control over the antenna orientation; however, to achieve maximum range, the antennas should be oriented with like polarization whenever possible. In the VHF and UHF spectrums, horizontal polarization will generally provide better noise immunity and less fading than a vertical polarization [17]

In the field of antenna design, radiation pattern refers to the directional dependence of the strength of the radio waves from the antenna or other source. These patterns are graphical representations of the electromagnetic power distribution in free space. They also depict the relative field strengths of the field radiated by antenna. Isotopic antenna is commonly used to describe an antenna with a theoretically perfect radiation pattern. That is one which radiates electromagnetic energy equally well in all directions. It serves to a conceptual standard against which real world antennas can be compared. The radiation patterns are three-dimensional, but usually the measured radiation patterns are a two dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format [17].

The gain in any direction is power density radiated in direction divided by power density this would have been radiated at by a loss less isotropic radiator having the same total accepted input power. If the direction is not specified, the value for gain is taken to mean the maximum value in they provide useful and simple theoretical antenna patterns with which to compare real antennas. An antenna gain of 2 (3 dB) compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires an adjustable dipole or a number of dipoles of different lengths. An antenna gain of 1 (0 dB) compared to a dipole antenna would be written as 0 dBd. A high antenna will preferentially radiate in a particular direction.

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However, in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an omni-directional antenna.

Another important parameter of any antenna is the bandwidth. Only impedance bandwidth is specified most of the time. For an efficient transfer of energy, the impedance of the antenna and the transmission cable connecting them must be the same. Transceivers and their transmission lines are typically designed for particular impedance. If the antenna has impedance different from that, then there is a mismatch and an impedance matching circuit is required. The bandwidth of an antenna refers to the range of frequencies over which its performance does not suffer due to a poor impedance match.

The voltage standing wave ratio (VSWR) is defined as the ratio of the maximum voltage to the minimum voltage in a standing wave pattern. The VSWR is a measure of how much power is delivered to a device as opposed to the amount of power that is reflected from the device. If the source and load impedance are the same, the VSWR is 1:1; there is no reflected power. Thus, the VSWR is also a measure of how closely the source and load impedance are matched.

The Return Loss (RL) is a parameter which indicates the amount of power that is lost to the load and does not return as a reflection. When there is VSWR greater than 1, there is some level of power loss due to backward reflection of the RF signal within the system. This energy that is reflected back toward the RF generator or transmitter results in return loss. Return loss is a measurement, usually expressed in decibels, of the ratio between the forward current (incident wave) and the reflected current (reflected wave). To minimize VSWR and return loss, impedance mismatches need to avoid. Another representation of return loss is S_{11}, the most commonly quoted parameter. If S_{11}=0 dB, then all the power is reflected from the antenna and nothing is radiated. If S_{11}=-10 dB, this implies that if 3 dB of power is delivered to the antenna.

2.2 Microstrip Patch Antenna

The concept of microstrip radiators was first proposed by Georges A. Deschamps in 1953. However, 20 years passed before practical antennas were actually fabricated. The development of these antennas during the 1970s was accelerated by the availability of good substrate with low loss tangent and attractive thermal and mechanical properties.

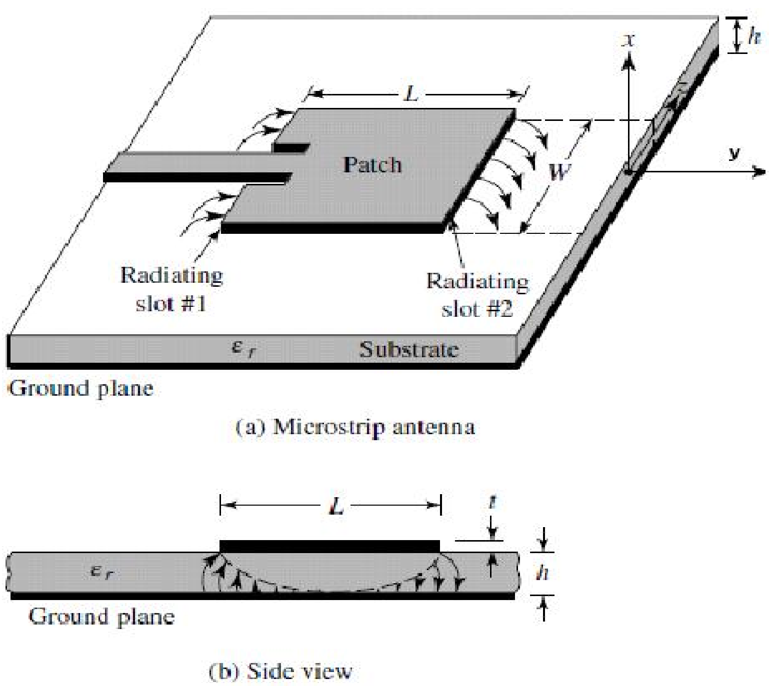


Figure 2.1: Basic Microstrip Patch Antenna configuration

Also, the improvement in photolithographic techniques and the availability of suitable theoretical models helped the fast development of these antennas. The first practical antennas were developed by Howell and Munson in the early 1970's. Microstrip antennas have considerably matured in the last 25 years, and many of their limitations have been overcome. Microstrip antennas are low profile, light weight, inexpensive and easy to integrate with accompanying electronics antennas. They are most suitable for aerospace and mobile applications. Many of the antenna applications for satellite links, mobile communications, and wireless local-area networks, impose constraints on compactness, dual frequency operation, frequency agility, polarization control, and radiation control. These functions can be achieved by properly loading a simple microstrip antenna. For that reason, they are becoming more and more popular. The characteristics of microstrip antennas can be significantly improved by using multilayered structures with thick substrate and low permittivity materials. Because of their low power handling capabilities, these antennas can also be used in low power transmitting and receiving applications. As shown in Figure 2.1, a microstrip antenna in its simplest configuration consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side and h is height of the antenna. The patch conductors normally made of copper or gold, can assume virtually any shape, but regular shapes, such as rectangles and circles, are generally used to simplify performance prediction. Ideally, the dielectric constant ε_r, of the substrate should be low ($\varepsilon_r < 2.5$), to enhance the fringing fields that account for radiation [18].

Advantages of MPA

Since 1950s, microstrip antennas have been widely used, as compared as the conventional microwave antennas. Below the extraordinary feature of microstrip antennas over the conventional microwave antennas given

- Light weight, low volume and thin profile configurations
- Low fabrication cost (readily amenable to mass production)
- Compatible with printed-circuit technology

- In case of very thin substrate, they may also be conformable such as bending that leads to unobtrusive antenna
- Linear and circular polarizations can be applied with simple feed
- Dual frequency and dual polarization antennas can be easily made
- No cavity backing is required
- Easily integrated with microwave integrated circuits
- Feed lines and matching networks can be fabricated simultaneously with the antenna structure

Disadvantages of MPA

However there are several drawbacks as well, which makes researcher to examine and investigate further enhancement of MPA.

- Narrow bandwidth and associated tolerance problems
- Some, lower gain (-6dB)
- Larger ohmic loss in the feed structure of arrays
- Most radiate into half-space
- Complex feed structures required for high-performance arrays
- Polarization purity is difficult to achieve
- Poor end-fire radiator, except tapered slot antennas
- Extraneous radiation from feeds and junctions
- Lower power handing capability
- Reduced gain and efficiency as well as unacceptably high levels of cross-polarization and mutual coupling within an array environment at high frequencies
- Excitation of surface waves
- Most fabricated on a high dielectric constant of substrate, leads to poor efficiency and narrow bandwidth
- Lower radiation efficiency

Although microstrip antennas have these limitations, most can be minimized. Several techniques have been proposed to overcome these limitations such as array configuration techniques with power handling or increasing substrate height, detail study is given in literature review [19].

2.2.1 Types of Microstrip Patch Antenna

There are a large number of shapes of MPAs; they have been designed to match specific characteristics. Some of the common types are shown in Figure 2.2, for millimeter wave frequencies, the most common types are rectangular, square, and circular patches.

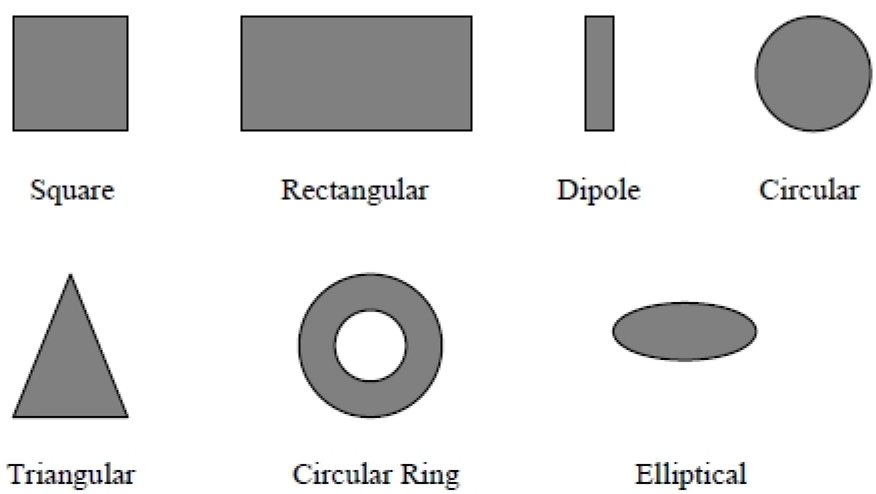


Figure 2.2: The most common shapes of patch antennas

Choosing of substrate is very important especially the temperature, humanity, and other environmental ranges of operating. Thickness of the substrate *h* has a big effect on the resonant frequency and bandwidth of the antenna. Bandwidth of the microstrip antenna will increase with increasing of substrate thickness *h* but with limits, otherwise the antenna will stop resonating.

2.2.2 Microstrip Antenna Design Considerations

2.2.2.1 Substrate Selection

It is critical for the design of these antennas to select a suitable dielectric substrate of appropriate thickness *h*, and loss tangent. A thicker substrate, besides being mechanically strong, will increase the radiated power, reduce conductor loss and improve impedance bandwidth. However, it will also increase the weight, dielectric loss, surface wave loss and extraneous radiation from the probe feed. A rectangular patch antenna stops resonating for a substrate thickness greater than $0.11\lambda o$ due to inductive reactance of the feed [18]. The substrate dielectric constant (ε_r) plays a role similar to that of substrate thickness.

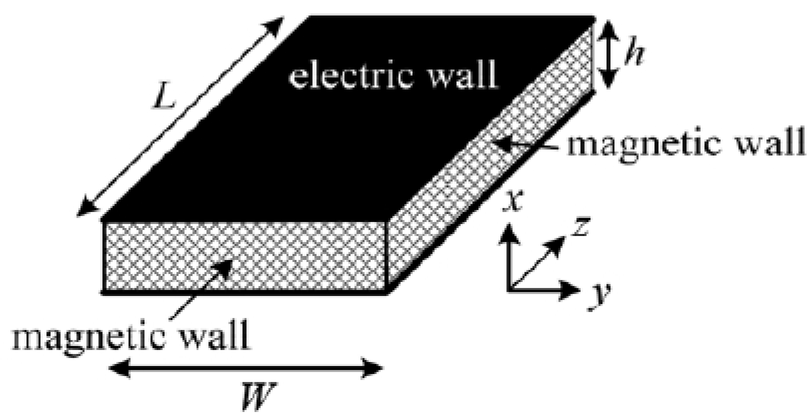


Figure 2.3: Magnetic and electric wall model of MPA

A low dielectric constant for the substrate will increase the fringing field at the patch periphery. As a result, the radiated power of the antenna will be also increased. Therefore, a dielectric constant of less than 2.55 (ε_r <2.55) is preferred unless a smaller patch size is desired. An increase in the substrate thickness has similar effects on the antenna characteristics as decreasing the value of the dielectric constant. A high substrate loss tangent increases the dielectric loss of the antenna and reduces the antenna efficiency.

2.2.2.2 Element Width and Length

Patch width has a minor effect on the resonant frequency and radiation pattern of the antenna. However, it affects the input resistance and bandwidth to a larger extent. A bigger patch width increases the power radiated and thus provides a decreased resonant resistance, increased bandwidth, and increased radiation efficiency. A constraint against a larger patch width is the generation of grating lobes in antenna arrays. It has been suggested that the length to width ratio of the path has to lie in the range of one and two ($1 < L/W < 2$) to obtain a good radiation efficiency. The patch length determines the resonant frequency, and is a critical parameter in the design, because of the inherent narrow bandwidth of the patch. The microstrip patch length (L), for TM_{10} (Traverse Magnetic) mode of operation can be approximated as,

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_r}} \qquad (2.1)$$

where c, f_r and ε_r represents speed of light in free space , resonant frequency and dielectric constant of the substrate respectively.

In practice, the fields are not confined to the patch. A fraction of the fields lie outside the physical dimensions of the patch (LxW) as shown in figure 2.4. This is called the fringing field.

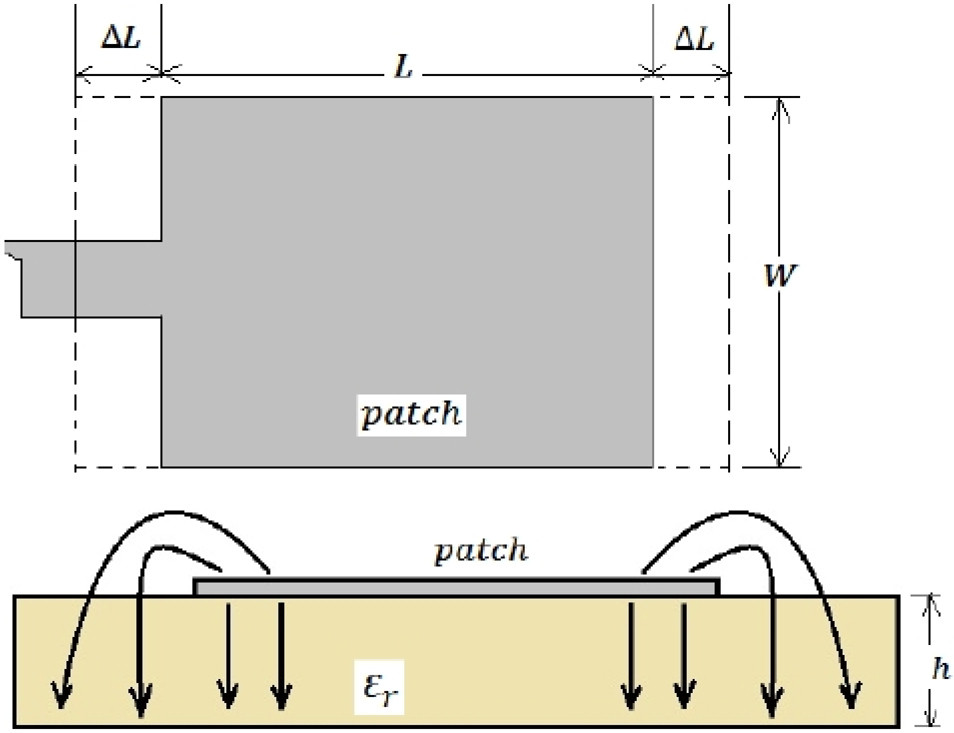


Figure 2.4: physical, effective length and electric field lines of a microstrip patch

The effect of the fringing field along the patch width, W can be included through the effective dielectric constant ε_{eff} for a microstrip line of width W on the given substrate.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}} \qquad (2.2)$$

where ε_{eff}, ε_r, h and W is effective dielectric constant, dielectric constant of substrate, height of dielectric substrate and width of the patch respectively.

Whereas the effect of the fringing field along the patch length L can be described in terms of an additional line length on either ends of the patch length [18] as

$$\frac{\Delta L_{eff}}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \qquad (2.3)$$

The effective length is given by:

$$L_{eff} = \left(L + 2\Delta L_{eff}\right) \qquad (2.4)$$

The resonant frequency is expressed as

$$f_r = \frac{c}{2L_{eff}\sqrt{\varepsilon_{eff}}}$$

For efficient radiation the width W is given by:

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad (2.5)$$

For practical considerations, it is essential to have a finite ground plane. Similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for this design, the ground plane dimensions given as

$$L_g = 6h + L \qquad (2.6)$$

$$W_g = 6h + W \qquad (2.7)$$

2.2.2.3 Feed Point Location

After selecting the patch dimensions *L* and *W* for the given substrate, the feed point has to be determined to achieve a good impedance match between the generator impedance and input impedance of the patch element. The change in feed location gives rise to a change in the input impedance and hence provides a simple method for impedance matching. The feed point is selected such that the input resistance R_{in} is equal to the feed line impedance, usually taken to be 50 ohm.

2.2.2.4 Polarization

The polarization of a rectangular patch antenna is linear and directed along the resonating dimension, when operated in the dominant mode. Large bandwidth patch antennas may operate in the higher order mode also. The radiation pattern and polarization for these modes can be different from the dominant mode. Another source for cross-polarization is the fringing field along the no radiating edges. These fields are oriented 90 degrees with respect to the field at the radiating edges. Their contribution to the radiation fields in the E and H planes is zero. However, in the intercardinal planes, even the ideal, single mode patch will radiate cross-polarized fields. The cross-polarization level increases with substrate thickness. Polarization of the antenna can be changed mechanically or electronically. For the electronic tuning, PIN diodes or varactor diodes can be used. Polarization diversity used in mobile communications to account for the reduction in signal strength due to fading [18].

2.2.3 Feeding Technique

MPA has various methods of feeding techniques. As these antennas having dielectric substrate on one side and the radiating element on the other. These feed techniques are being put as two different categories contacting and non-contacting. Contacting feed technique is the one where the power is being fed directly to radiating patch through the connecting element i.e. through the microstrip line. Non contacting technique is the one where an electromagnetic magnetic coupling is done to transfer the power between the microstrip line and the radiating patch. Even though there are many new methods of feed techniques the most popular or commonly used techniques are the microstrip line, coaxial probe, aperture coupling and proximity coupling.

2.2.3.1 Microstrip Line

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 2.5. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

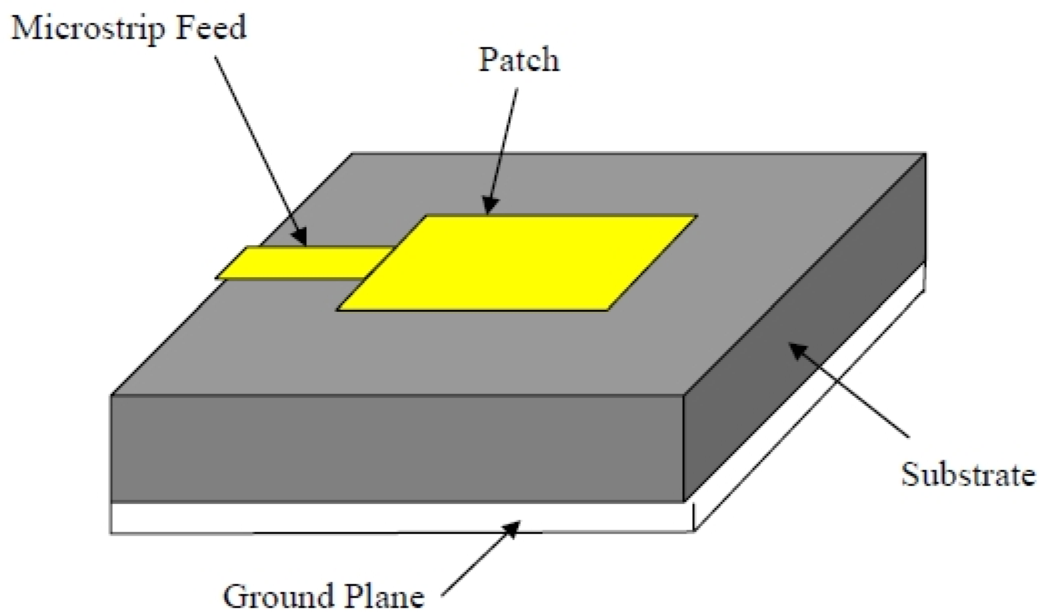


Figure 2.5: Microstrip Line Feed

2.2.3.2 Coaxial feed

The Coaxial feed or probe feed is a very common technique used for feeding MPAs. As seen from Figure 2.6, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

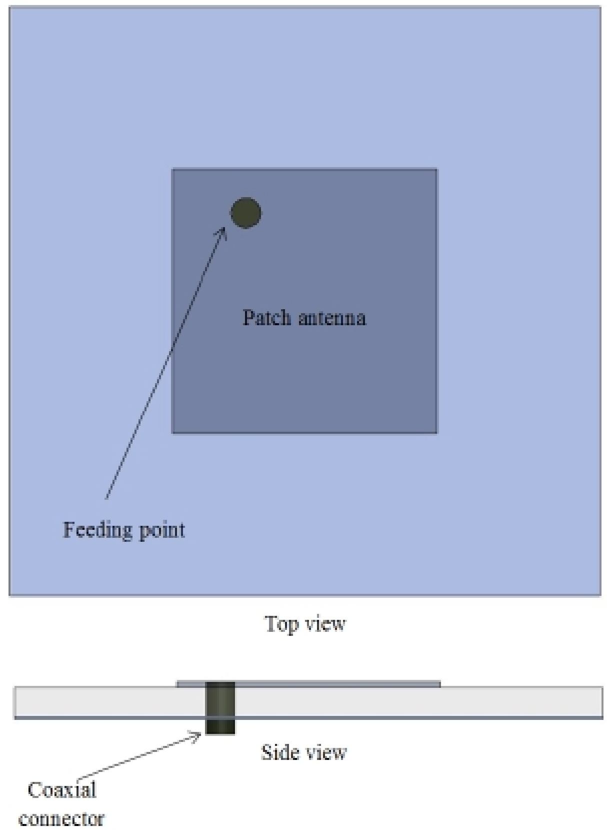


Figure2.6: Probe-fed patch antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feeding point can be determine by varying the position of feed point where minimum return loss is obtained or using smith chart. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these problems.

2.2.3.3 Aperture-Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.7. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

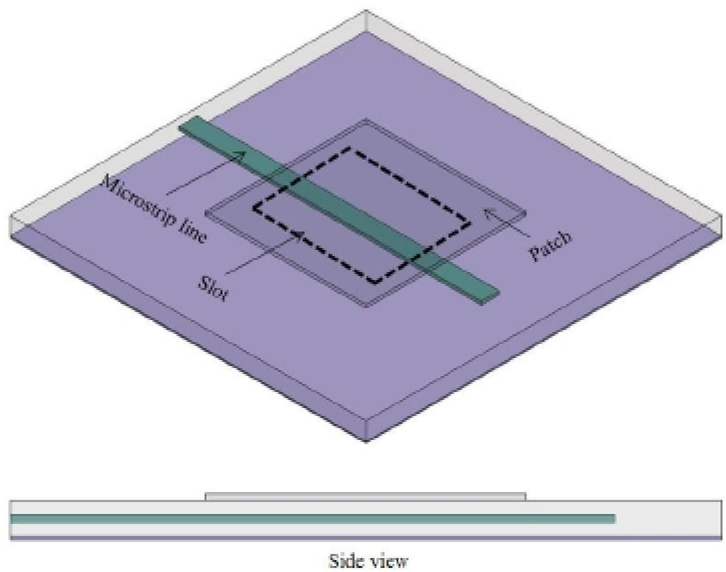


Figure 2.7: Aperture-coupled feed

The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

2.2.3.4 Proximity Coupled Feed

This type of feed technique is also called the electromagnetic coupling scheme. As shown in Figure 2.8, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the MPA.

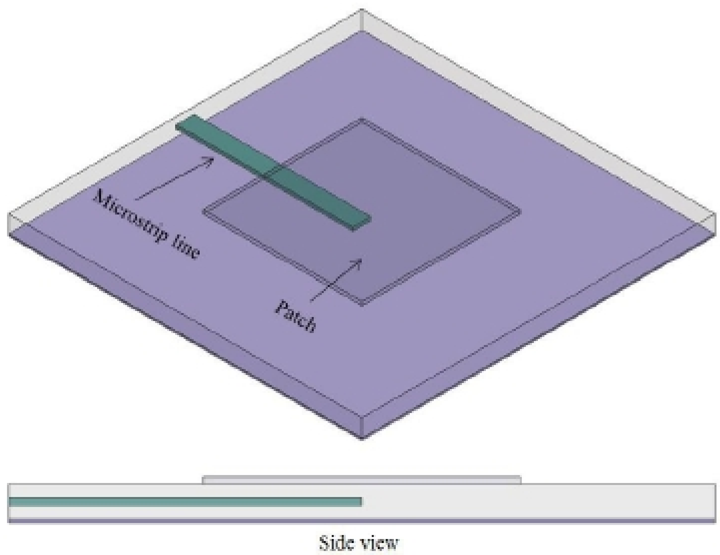
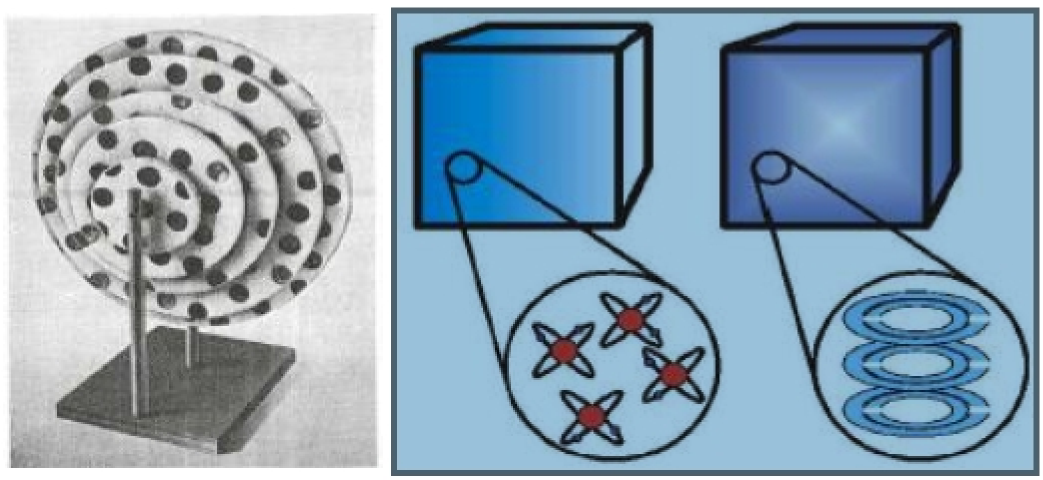


Figure 2.8: Proximity-coupled feed

This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna [22].

2.3 Metamaterial

In 1968, the theoretical verification of negative index material and left handed (LH) phenomenon in a medium with negative permittivity (ε) and negative permeability (μ) was postulated and pointed out by Veselago. His research showed the exhibition of the phase velocity direction opposite to the Poynting vector of the wave propagation in such a medium; the occurrence of backward wave propagation. Therefore, his study is to support the theory of negative index of refraction.



(a) (b)

Figure 2.9: (a) The first artificial dielectrics lenses: Lattice of conducting disks arranged to form lens by Kock and Cohn in 1948 [19], and (b) J.B. Pendry designed periodic structure of negative ε and μ.

The first structure that showed negative permittivity in certain frequency bands was proposed by Pendry et al.[19] Owing to the ideas of Pendry, Smith designed a composite medium which have both negative permittivity and permeability. Next, Shelby et al, designed the periodical structures by using split-ring resonators and wire strips, and investigated metamaterials, their properties, and their applications. The Left-Handed Materials (LHMs), Double Negative (DNG) Materials, and Single Negative (SNG) Materials, are the example of metamaterial. However, metamaterials can be referred to many materials that provide the permittivity or permeability less than 1.

Metamaterials are artificial materials, consisting of sub-wavelength periodic (or quasi-periodic) inclusions (atoms) of metals and/or dielectrics, whose electromagnetic, or optical, properties can be controlled through structuring, rather than through composition. Since the period is smaller than a wavelength, effective (continuous) media properties are achieved, and it is possible to obtain properties beyond those available in nature. For these reasons, it is necessary to study and control these unnatural material characteristics for the specific purpose in wireless communication systems [19].

2.3.1 Left Handed Materials (LHMs)

The idea of LHMs dates back to 1967, when Veselago considered theoretically electromagnetic plane wave propagation in a lossless medium with simultaneously negative real permittivity and permeability at a given frequency. In order to describe a LHM, we need to start with a description of a Right Handed Material (RHM) first. In general, materials have two unique parameters, permeability and permittivity that determine how the material will interact with electromagnetic radiation, which includes light, microwaves, radio waves, even X-rays. A Right handed material is a material whose permeability and permittivity are simultaneously positive. Right handed materials are also called Double Positive Material (DPS) in the literatures. If the direction of the electric field (E) and the magmatic field (H) are represented by the thumb and the index finger of the right hand respectively, then the middle finger gives the direction of propagation of the wave, if it is placed normal to both fingers. Additionally, in RHMs wave propagation or the energy flow represented by Poynting vector (P_{av}= 0.5 Re [E x H*]) and the phase changes represented by phase constant $k = \omega\sqrt{\varepsilon}\sqrt{\mu}$ are in the same direction, as shown in Figure 2.10. Electromagnetic Waves propagation in all known natural materials follows the Right Hand Rule, with positive refractive indices.

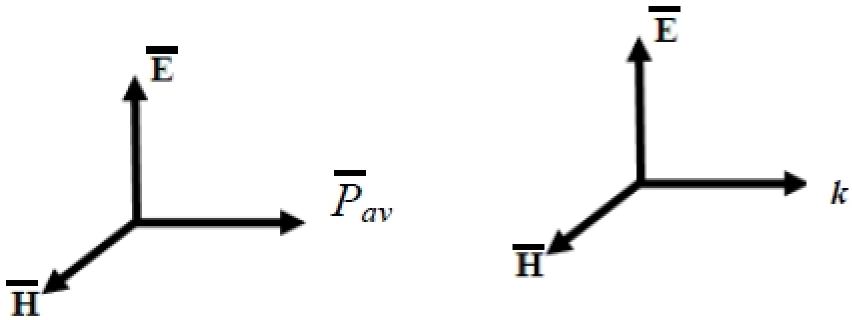


Figure 2.10: Wave Propagation in Right Handed Medium

On the other hand, a LHM is a material whose permeability and permittivity are simultaneously negative. Left handed materials also called double negative materials (DNGs). LHM as defined by Sihvola, is an engineered material that does not exist in nature which gains its material properties from its structure rather than inheriting them directly from the material that it is composed of. In such a medium, (LHM), if the direction of the electric field (E) and the magmatic field (H) are represented by the thumb and the index finger of the left hand respectively, then the middle finger gives the direction of phase changes of the wave $k = \omega\sqrt{\varepsilon}\sqrt{\mu}$ if it is placed normal to both fingers. In LHM medium, the energy flow (P_{av}= 0.5 Re [E x H*]) and the phase changes represented by phase constant (k) are in opposite directions (anti-parallel) as shown in Figure 2.10 and 2.11. This type of propagation is called backward propagation [23].

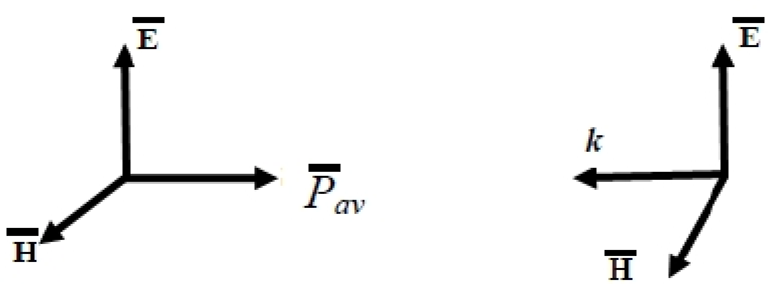


Figure 2.11: Wave Propagation in Left Handed Medium

Considering the effect that the LHM has on the refractive index (n) defined by equations (2.8) to (2.11):

$$n = \sqrt{\varepsilon_r} \times \sqrt{\mu_r} \qquad (2.8)$$

Where

μ_r is relative permeability of material and ε_r is relative permittivity of material

When both permittivity and permeability are negative, thus equation (2.8) takes the following from.

$$n = \sqrt{(-\varepsilon_r)} \times \sqrt{(-\mu_r)} \qquad (2.9)$$

Which reduces to

$$n = j\sqrt{\varepsilon_r} \times j\sqrt{\mu_r} \qquad (2.10)$$

Hence the refractive index becomes negative and is given by the following

$$n = -\sqrt{\varepsilon_r \mu_r} \qquad (2.11)$$

Figure 2.12 represents the electromagnetic applications based on the signs of the material permittivity, permeability, and refraction index at the interface between air and each medium. There are four regions in the diagram. Plasma belongs to the region with negative permittivity and positive permeability. It can be obviously seen that when the two signs opposite, there is no wave transmission in medium. This is because the wave vector becomes imaginary. When both parameters are positive, refraction occurs positively and vice versa. A material with negative permeability or permittivity is called Single Negative material (SNG). When the permittivity (Epsilon) of a material is the only negative parameter then the material is named Epsilon Negative material (ENG). While, if the permeability (Mu) is the only negative parameter then it is called Mu-Negative material (MNG).

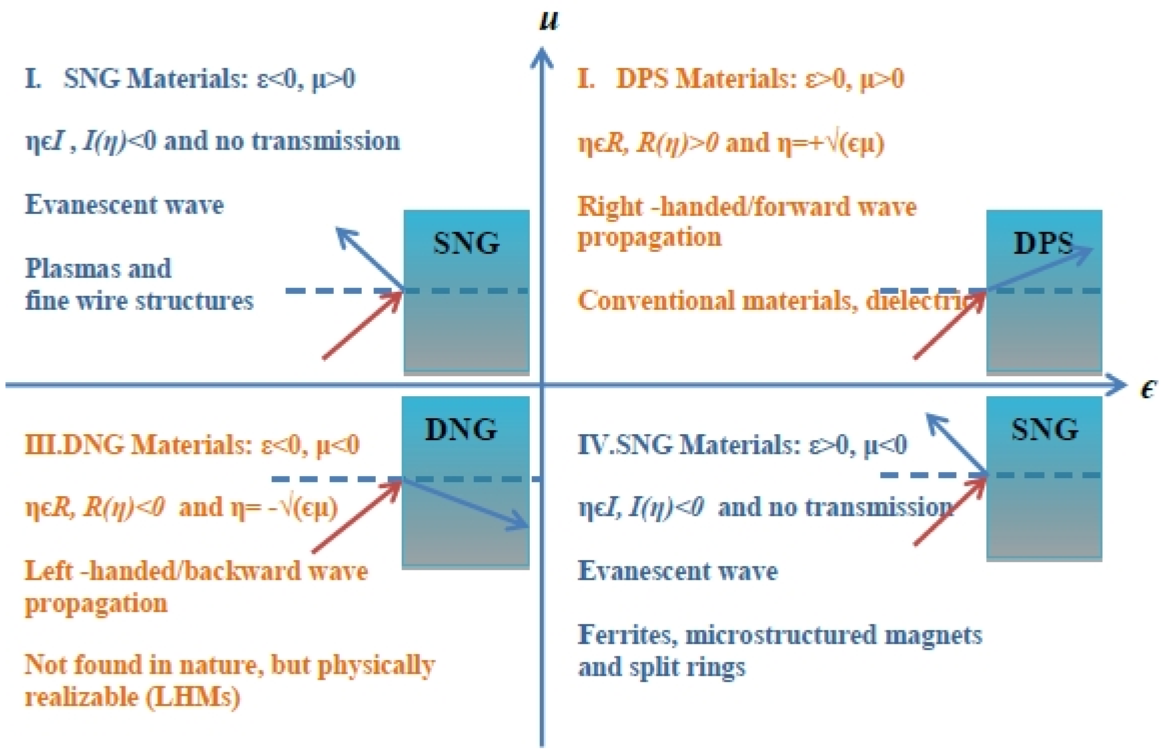


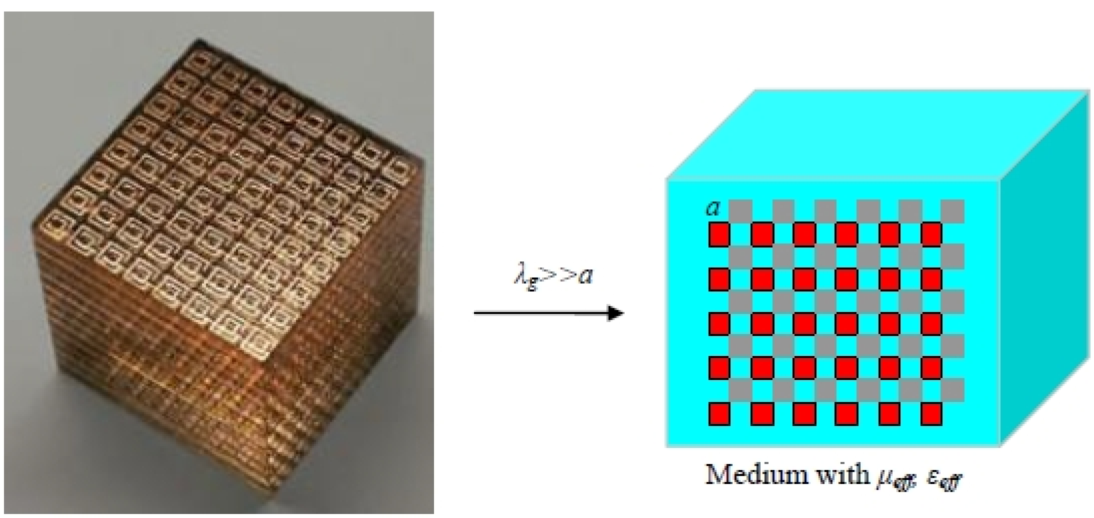
Figure 2.12: Material classifications according to ϵ, μ pairs and η, type of waves in the medium, and example of structures [19].

2.3.2 Realization of Left-Handed Materials

In 1999, Pendry et al [19] proved that the negative effective permeability ($\mu_{eff}(\omega)$) can modify the permeability of the host substrate from an array of conducting non-magnetic rings. The cause of bulk $\mu_{eff}(\omega)$ variation for a very large positive value of $\mu_{eff}(\omega)$ at the lower resonance frequency and a significantly large negative $\mu_{eff}(\omega)$ at the higher resonance frequency is from the considerable enhancement of magnitude of $\mu_{eff}(\omega)$ when the constituent unit cells are resonantly made. Schultz et al [19] are the scientists who first realized the LH materials by creating a periodical array of interspaced conducting non-magnetic split-ring resonators and continuous wires. Before their success of realizing the LHMs, the attempts to produce the negative permittivity materials were made earlier by Pendry. In order to create the negative permittivity, a three dimensional mesh of conducting wires was used as a structure to alter the permittivity with supporting substrate. The exhibition at the frequency region in his experiment can show the simultaneously negative values of both effective permeability $\mu_{eff}(\omega)$ and effective permittivity $\varepsilon_{eff}(\omega)$. Then Schultz et al used these two concepts to create a LH structure. The wire strips and a mesh of interspaced split-ring resonators are introduced for this achievement. The wire strips generate ε while the split-ring resonators (SRRs) alter μ. Therefore, the frequency dependent negative material with both negative parameters was realized. It should be noticed that this would only happen under the condition that the size of unit cell is considerably smaller than the smallest operation wavelength. As a result, these periodic structures can give a uniform isotropic alteration of the base material properties. In order to consider the actually effective parameters of a homogeneous medium, the constraint of the wave on a unit cell dimension is analyzed. For a typical electromagnetic wave of frequency (ω), the characteristic dimension of the structure (a) must satisfy the condition below [19],

$$a << \lambda = 2\pi c_0 \omega^{-1} \qquad (2.12)$$

where λ, c_0 and ω is wavelength, speed of light and radian frequency of electromagnetic wave



(a) (b)

Figure 2.13: (a) Photograph of the metamaterial cube, and (b) generic view of a host medium with periodically placed structures constituting a metamaterial.

2.3.3 Split-Ring Resonator Geometry (SRR)

Because the specific property of SRRs embedded in a host medium can give the bulk composite permeability and become negative in a certain frequency band, the study of the region above the SRR resonant frequency has been widely observed.

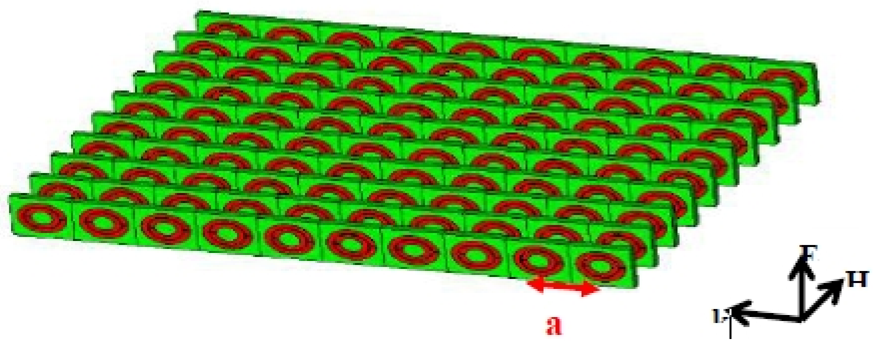


Figure 2.14 Metamaterial structures: Split ring resonators lattice exhibiting negative μ_{eff} if magnetic field *H* is perpendicular to the plane of the ring.

While applying the magnetic field *H* perpendicular to the plane of the ring, the induced currents then are generated around the ring equivalent to the appearance of the magnetic dipole moments. The permeability frequency function is formed as

$$\mu_{eff}(\omega) = 1 - \frac{F\omega^2}{\omega^2 - \omega_{0m}^2 + j\omega\varsigma} \qquad (2.13)$$

where ω_{0m} is the resonant frequency in GHz range given by

$$\omega_{0m}^2 = c\sqrt{\frac{3a}{\pi \ln\left(\frac{2wr^3}{d}\right)}} \qquad (2.14)$$

F is the filling fraction of the SRR, while ς is the damping factor due to metal loss, these parameters are expressed as

$$F = \pi\left(\frac{r}{a}\right)^2 \text{ and } \varsigma = \frac{2aR'}{r\mu_0} \qquad (2.15)$$

where *r*, *w*, *d* and *R'* is inner radius of the smaller ring, the width of the ring, the radial spacing between the inner and outer rings and the metal resistance per unit length respectively.

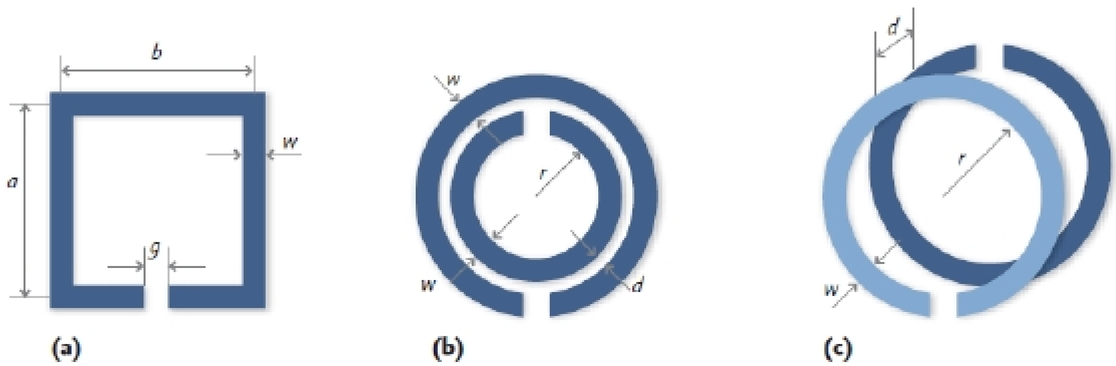
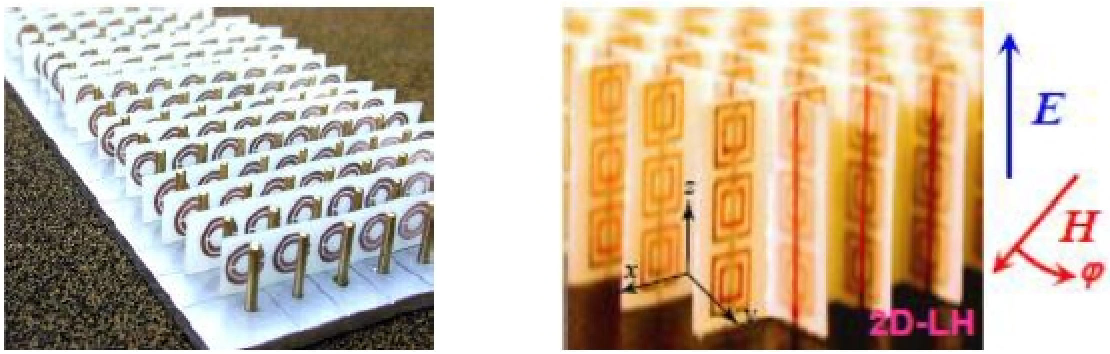


Figure 2.15: some geometries of SRR used to realize artificial magnetic materials

The SRR structure has a magnetic response due to the presence of artificial magnetic dipole moments by the ring resonator. At a resonant frequency range, these artificial magnetic dipole moments are larger than the applied field which leads to the presence of the real part of negative effective permeability, Re (μ_{eff}). In lossless case (ς=0), the range around the resonant frequency providing negative permeability is under the condition as $\omega_{0m} < \omega < \omega_p = \frac{\omega_{0m}}{\sqrt{1-F}}$, where ω_p is the plasma frequency of the SRR particle. In other words, in the medium the discontinuity of the dispersion relation of the permeability is occurs between ω_{0m} and ω_p because of the negative μ_{eff} at that frequency range.

The introduction of capacitive elements that enhances the magnetic effect is produced by the splits of rings. The strong capacitance between the two concentric rings helps the flow of current along the SRR configuration. Since in the SRR the capacitive and inductive effects nullify, the μ_{eff} has a resonant form. At resonant frequency, owing to the capacitive effects due to the gap interacts with the inherent inductance of the structure; the electromagnetic energy is shared between the external magnetic field and the electrostatic fields within the capacitive structure. Therefore, normally the experiments are focused on a certain frequency band which is around and above the resonance frequency in order to get the negative effective permeability.

Figure 2.16 shows, is the first LHM prototype designed by Smith et. al. In this work, the combined particles of the thin wire structure and SRR structure appeared an overlapping frequency range that have both negative permittivity and permeability. After applying an electromagnetic wave through this composite structure, the pass band is presented at the frequency range of interest that the constitutive parameters are simultaneously negative



(a) (b)

Figure 2.16: The first DNG metamaterial structures Smith et al., (a) Mono-dimensionally DNG structure and (b) Bi-dimensionally DNG structure (the rings and wires are on opposite sides of the boards)

2.3.4 Complementary Split-Ring Resonator

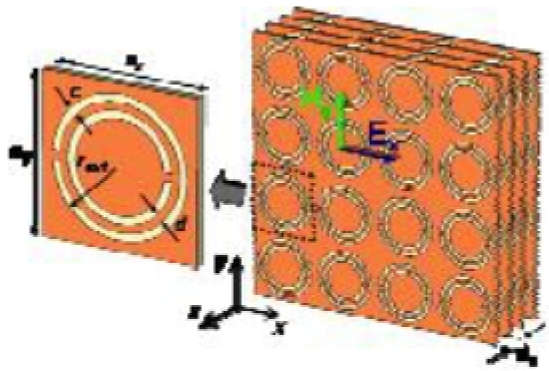


Figure2.17: Topology of CSRRs and the stack CSRRs, *E* is parallel to the CSRRs plane

In 2004, CSRRs are firstly introduced by Falcone et al. The CSRRs, a dual counterpart of SRRs or sometimes called slotted split-ring resonator, are comprised of slots which is the same dimensions as the corresponding SRR. By the principle of duality, the CSRRs properties are in dual relation of the SRRs properties. The SRRs behave as a magnetic point dipole, whereas the CSRRs present an electric point dipole with negative polarization. In CSRRs, the *E* field is applied parallel to the CSRRs plane in order to generate a strong electric dipole which affects the CSRRs resonant frequency. The CSRRs, as shown in Figure 2.17, *r* can be used to obtain the effective permittivity of a bulk medium. Both SRRs and CSRRs present approximately the same resonant frequency due to their shared dimensions. The CSRRs can be formed in planar transmission media by etching these resonators in the ground plane of the microstrip

2.3.5 Application of Metamaterial

2.3.5.1 Biosensors

Metamaterial can be used to provide more sensitive guiding modes (based on plasmon-mediated interaction between the inclusions which shows resonant excitation conditions). Surface plasmons occur at a metal dielectric interface and are extremely sensitive to the refractive index of the dielectric medium within the penetration depth of the evanescent field. The metamaterial inclusions can be functionalised with receptors on their surface. If the matrix consists of nanoporous material it allows analytes to reach the receptor and the refractive index will be changed upon binding. The reflection spectrum depends on this refractive index.

2.3.5.2 Superlens

A superlens (or perfect lens) is a lens, which uses metamaterials to go beyond the diffraction limit. The diffraction limit is an inherent limitation in conventional optical devices or lenses. A lens consisting of a negative index metamaterial could compensate for wave decay and could reconstruct images in the near field. In addition, both propagating and evanescent waves contribute to the resolution of the image and resolution underneath the diffraction limit will be possible.

2.3.5.3 Cloaking

A cloaking device is an advanced stealth technology that causes an object to be partially or wholly invisible to parts of the electromagnetic (EM) spectrum (at least one wavelength of EM emissions) Scientists are using metamaterials to bend light around an object.

2.3.5.4 Tags to store and process information

A remote detection via high-frequency electromagnetic fields will be possible due to the collective response of magnonic crystals at elevated frequencies [10].

To summarize the picture, all experimental and theoretical demonstrations of metamaterials to date have been operated in rather strict and controlled conditions. We are thus far from the magical world promised by the most fervent metamaterial disciples [24]. But that does not mean nothing good will comes out at the end of the long winding road. Within the next decade, metamaterial research at microwave and radio frequencies is expected to enable incremental improvements in antenna design resulting in smaller size and better performance for satellites' antennas and personal mobile devices. Significant theoretical progress is required before we see (or not see) actual invisible cloaking devices and superlenses made from metamaterials based on NIM or chiral materials at visible frequencies.

2.4 Literature Review

From previous discussion it has been noted that MPA has a lot of outstanding advantages as well as major drawbacks especially narrow bandwidth and low power gain of antenna characteristics. Many researchers and RF engineers around the world have been examining and investigating for further enhancement of MPA. Recently many progresses have been already made to over come some of prime drawbacks. The substrate permittivity (ε_r) and thickness of the MPA affects the resonant bandwidth and gain, varying them in proper magnitudes may lead to achieve desirable antenna characteristics [8]. Also it has been noticed that the bandwidth of MPA can be improved by using air as substrate [25], increasing the substrate height, adding up parasitic patches element in co-planer or stack configuration. In [26], an aperture-coupled MPA has been shown with parasitic patches stacked on the top of the main patch. Trimming slots off from the metallic patches have become a very popular way to increase bandwidth of single patch antennas. The slots can be any different shape on the patches. Various types of alphabetic slotted antennas have been observed in [27-29] such as U-slot patch antenna, V-slot patch antenna, C-slot patch antenna. In [30] it was shown that modifying the U-slot to a curtailed V-slot can improve antenna bandwidth. Altering the main shape and size of radiating patch into different geometrical or alphabetical shape also became another attractive way for antenna characteristic enhancement because it has the ability to maintain a single layer structure and provide thin profile.

Among them E shaped patch is popular and much acceptable for the simpler construction. The E shaped patch is formed by cutting off the two parallel slots from the boundary edge of RMPA. Figure 2.18 represents the equivalent circuit of basic RMPA where resonant frequency is determined by L_1 and C_1. The impedance of series LC circuit is zero and maximum power will be transfer at operating frequency. The value of input resistance of antenna can be varied by changing the location of feed point such that it matches the characteristic impedance of the coaxial cable; generally input impedance is match at 50 ohms.

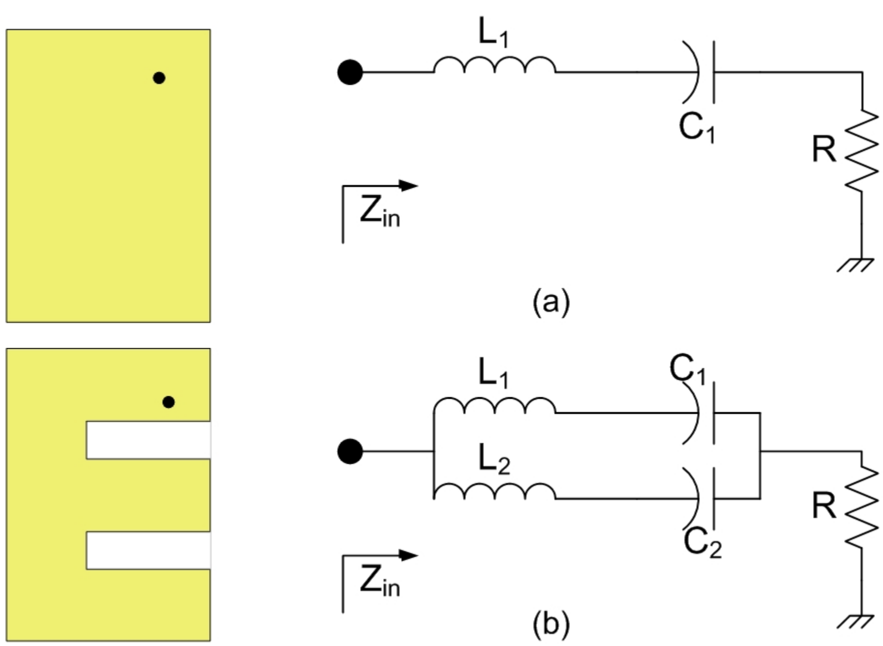


Figure 2.18: Equivalent circuits of (a) Rectangular Patch and (b) E shaped MPA

When the pair of the slots is trimmed off from RMPA, a modified equivalent circuit has been shown in Figure (b) where second resonant frequency is determined by L_2 and C_2. Two parallel slots perturb the surface current path on the patch and introduce local inductive effect which excites the second resonant frequency. The input impedance of the antenna can be represents by given equation after analysis the circuit network. At two series resonant frequencies the imaginary part of the input impedance is zero. When the two series resonant frequencies are too far apart, the reactance of the antenna at the midband frequency may be too high and the reflection coefficient at the antenna input may be unsatisfactory and the two series-resonant frequencies are set too near to each other, the parallel-resonant mode may affect the overall frequency response and the reflection coefficient near each of the series-resonant frequencies may be degraded. The amplitudes of currents around the slots in the E shaped MPA are different at low resonant frequencies and high resonant which helps to extent the bandwidth and affects the main operating frequency. At the high frequency, the amplitudes of the currents around the slots are almost the same as ordinary patch which means the effect of the slots are not significant. However the patch width is less affected by the slots in determining the high resonant frequency. At the low frequency, the amplitudes of the currents around the slots are greater than those at high frequency. The slots congregate the currents and this effect produces an inductance. Due to this additional inductance effect, it resonates at a low frequency. For this feature E shaped MPA can achieve mutiband as well as wide bandwidth antenna characteristic [31&32].

Recently extensive research works on E shaped MPA have been going on around the world at different frequency band range especially in L band, S band and C band. However for E shaped MPA there are not much of study have been made under Ku band frequency domain. The Ku band is a portion of the electromagnetic spectrum in the microwave range of frequencies which is used for satellite communications, particularly for satellite backhauls from remote locations back to a television network's studio for editing and broadcasting.

In [33], an X shaped MPA with five triangular slots is designed, which produces multiband operation for Ku and K band applications. The structure of the patch allows antenna to operate at 15.33 GHz, 17.61 GHz and 18.90 GHz with about 528 MHz, 576 MHz and 804 MHz bandwidth respectively. The current distribution and radiation pattern of antenna are also shown with peak gain of 4.80 dBi, 6.42 dBi and 3.91dBi, respectively. From [34] it is seen that authors have developed a compact MPA with three pairs of thin slits at the sides of the rectangular patch. This modified configuration help antenna to resonate at 12.545 GHz and 14.151 GHz with bandwidth of 90 MHz and 60 MHz respectively. The antenna has return loss of -23.83 dB and -14.04 dB with gain of over 4 dBi. In [35] slotted technique has been applied on octagonal patch for multiband operation. The simulation results of its performance are investigated where antenna resonates at 7.49GHz, 10.89GHz, 15.70GHz and 20.10GHz under bandwidth range of 0.303GHz, 0.652GHz, 0.801GHz and 1.92GHz with gain of 5.654dBi, 5.0dBi, 5.35dBi and 3.47dBi respectively. An E shaped MPA has been designed for Ku band frequency range in [36]. The antenna is a modified form of conventional E shaped antenna. The antenna has high return loss of -42 dB and -43 dB at resonant frequencies of 11.95 GHz and 14.24 GHz with 510 MHz and 500 MHz bandwidth respectively. The radiation pattern is also present with maximum gain of 7.2 dBi. Other patch antennas with slots have been studied in [37] where they operates at mutiband frequency range with less than 1.5 GHz bandwidth and have gain of less than 3.5 dBi. It is seen that in [38], the antenna has 4.97 GHz bandwidth in Ku band range with -40.85 dB return loss at centre frequency of 14.3 GHz but the power gain is less than -2.5 dBi. From above study and research papers it has clearly remark that bandwidth and gain constantly poor except few cases. As mentioned earlier, metamaterials are artificially man made metallic patterns with unusual electromagnetic properties. Applying these materials to increase performance of antennas has garnered much interest. One of the recent solutions for patch antennas performance enhancement is based on the use of ENG or DNG in the near environment of the antennas. In [39] authors have designed wearable RMPA for IEEE 802.11a WLAN application. The antenna resonates at 5.10 GHz with improved bandwidth and gain of 97 MHz and 4.9 dBi compare with conventional RMPA. Here slot is trimmed off from the rectangular patch and SRR is been loaded. The simulation design is fabricated and SRR properties have been investigated. In [40] wearable T shaped MPA is designed and fabricated on the geo-textile polypropylene substrate with four SRRs by the same authors. The properties of SRR have been justified by NRW method. The antenna resonates at 4.97 GHz with bandwidth and gain of 50 MHz and 6.4dBi respectively. Comparative study has been shown between basic RMPA and RMPA loaded with metamaterial structure in [41]. It has also been reported that the impedance bandwidth of the RMPA is improved by 487%, return loss is reduced by 117%, and directivity is improved by 96%. In [12], the paper depicts the improvement of the MPA performance by using metamaterial superstrate where two layers are introduced as metamaterial superstrate, first layer is designed with S shaped metamaterials and other one designed with SRRs. The antenna operates in Ku band with satisfactory bandwidth and gain.

From above literature it has been observed that metamaterial can be used to enhance gain and bandwidth characteristic of antenna which has encouraged and motivated us to design a modified E shaped MPA loaded with metamaterial structure for Ku band operation.

CHPATER 3

DESIGN OF MPAs

In last few decades demand of satellite communication has been increased intensively due to rapid growth in high resolution mapping, satellite altimetry, radio astronomy service, space research service, mobile satellite service, radiolocation service (radar), and radio navigation. These applications and devices mainly operate in Ku band which is allocated in the microwave radio region of the electromagnetic spectrum. It is defined by an IEEE standard for radio waves and radar engineering under the frequencies ranges from 12.0 to 18.0 GHz. Ku Band is mainly used for tracking the satellite within the ranges roughly from 12.87 GHz to 14.43 GHz and it is also used in specific applications for NASA's Tracking Data Relay Satellite including both space shuttle and International Space Station (ISS) communications.

Due to versatile and significant application the antennas are designed under Ku band domain. During literature review it has been observed that the antennas operating in Ku band region power gain and impedance bandwidth characteristics are consistently poor in same antenna. The primary focus of this thesis is to design antenna having standard gain, bandwidth and return loss for this band. In this chapter four antennas design are shown in chronological order where gradual antenna performance enhancements are observed from rectangular microstrip patch antenna to proposed antenna. To design the desired antenna initially conventional rectangular MPA has been designed and IE3D simulator has been used for designing. All the antennas are unique and have the ability to operate for Ku band application.

3.1 Basic Parameters

Three general parameters are given below for designing all the antennas accordingly.

- The frequency of operation: Ku band frequency domain has been selected for MPAs operation.
- Dielectric constant: Rogers's FR4 substrate with dielectric constant of 4.2 has been selected as dielectric material for MPAs and superstrate of metamaterial to design the antennas. It is a very common and by far the most used substrate in consumer electronics market as it has a good quality-to-price ratio.
- Height of substrate: Generally MPAs are very compact devices so for basic configuration of MPA standard thickness and height of metamaterial superstrate have been selected as 1.6mm and 3.2 mm respectively.

3.2 Design of RMPA

Figure 3.1 shows basic construction of RMPA. The initial dimension of the RMPA obtained from the equations () and () of chapter 2, where reference frequency is taken as 4GHz and dielectric constant is 4.2. After calculation the length and width of the patch considered as L = 17mm and W = 24mm respectively with standard thickness of h = 1.6mm from the ground plane. The feeding technique and location of the feeding point provides antenna to operate in Ku band region. As mention FR4 substrate with dielectric constant of 4.2 has been used as dielectric material. The dimension of the ground plane of length and width also extracted from equation (2.8) and (2.9) respectively from pervious chapter. The RMPA is excited by probe feeding technique at position of X axis at15.6 and Y axis at 15.6 where minimum return loss have been found. Detail parameters given in Table 3.1.

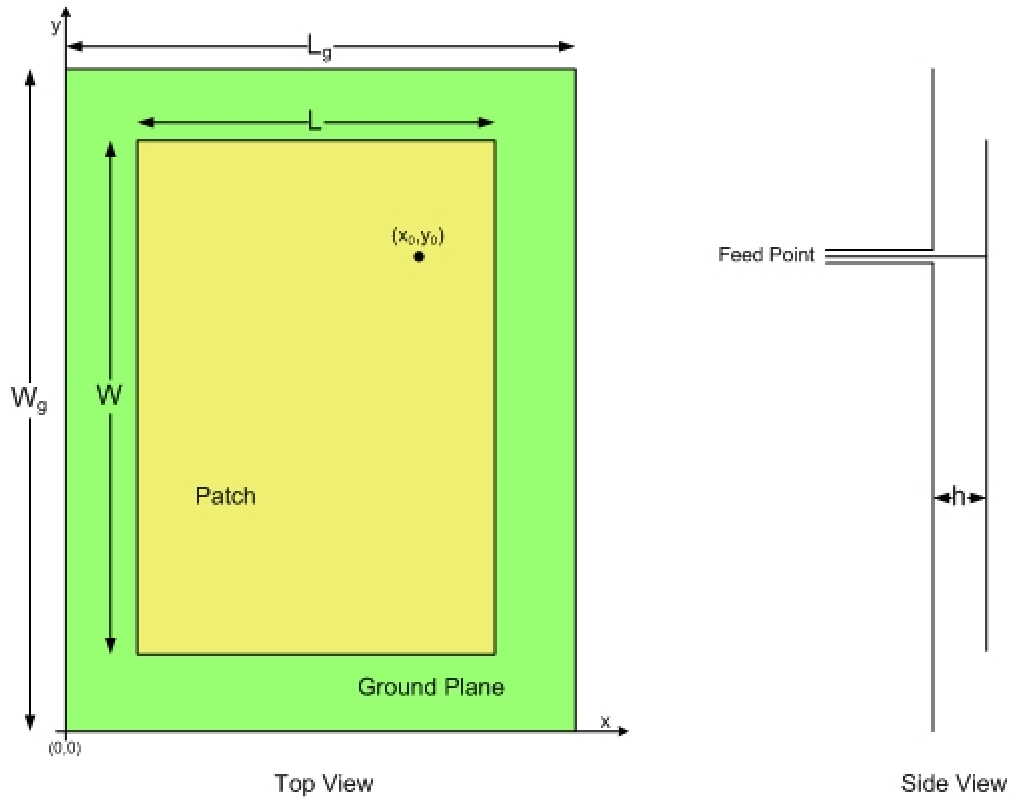


Figure3.1: Design structure of RMPA

Table 3.1 Design dimensions of RMPA

Parameters	Dimension (mm)
L_g	26.6
W_g	33.6
L	17
W	24
h	1.6
(x_0,y_0)	(15.6,19.6)

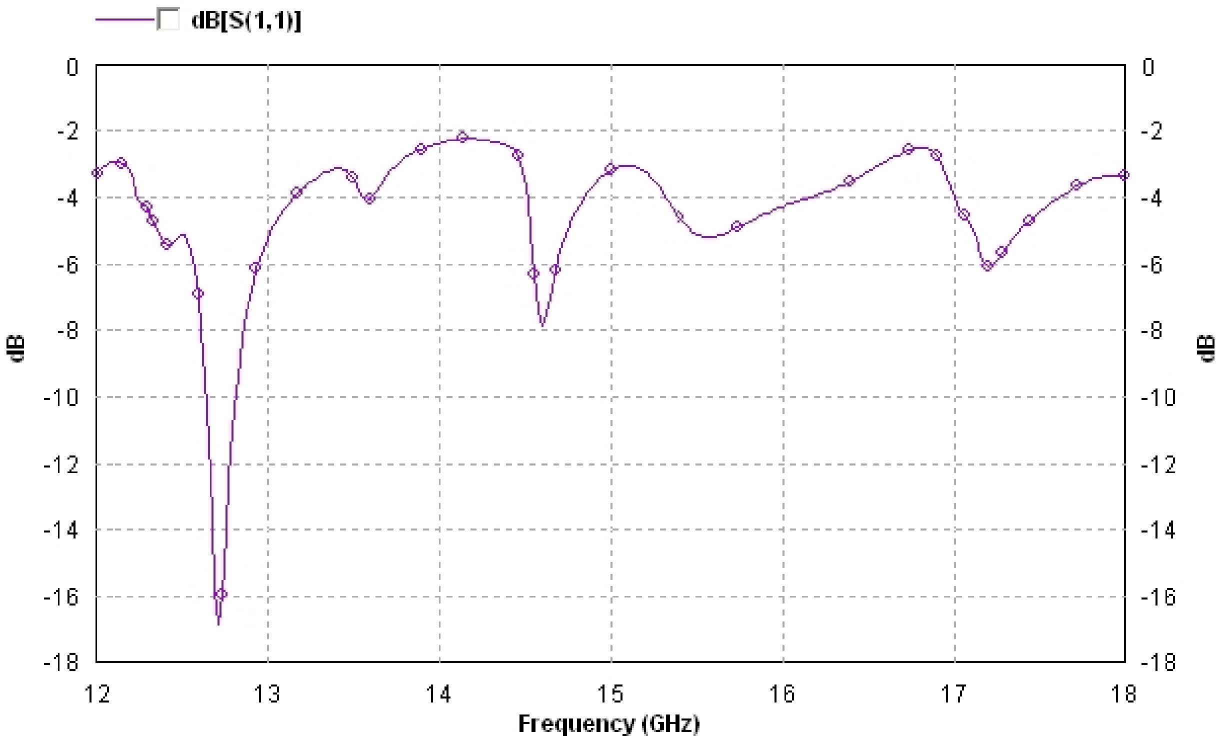


Figure 3.2: Simulated return loss (S_{11}) characteristic of RMPA

All the parameters are transferred to the IE3D simulator software for simulation. It is an efficient and integrated full wave electromagnetic simulation tool with optimization package. From the simulation, it is observed that RMPA operates at resonant frequencies of 12.73 GHz and 14.66 GHz with return loss of -16.5 dB and 7.7 dB respectively. The bandwidth of first operating frequency is 170 MHz but bandwidth of other operating frequency is 0 because it does not have minimum return loss of -10dB. RMPA seems to operate in Ku band but it only covers 2.83% of whole band which is inadequate. Figure 3.2 illustrates return loss versus frequency of RMPA where it has been observed narrow bandwidth which is basic disadvantage of MPA.

3.3 Design of E shaped MPA

E shaped MPA became one of the popular in antenna simulation and designing scheme because it can exhibits wideband and multiband application compare to basic RMPA. Many eminent enhancements of MPA characteristic have been observed with this configuration in last few years at frequency range of L band, S band and C band especially under wireless local area network (WLAN) and global position system (GPS).

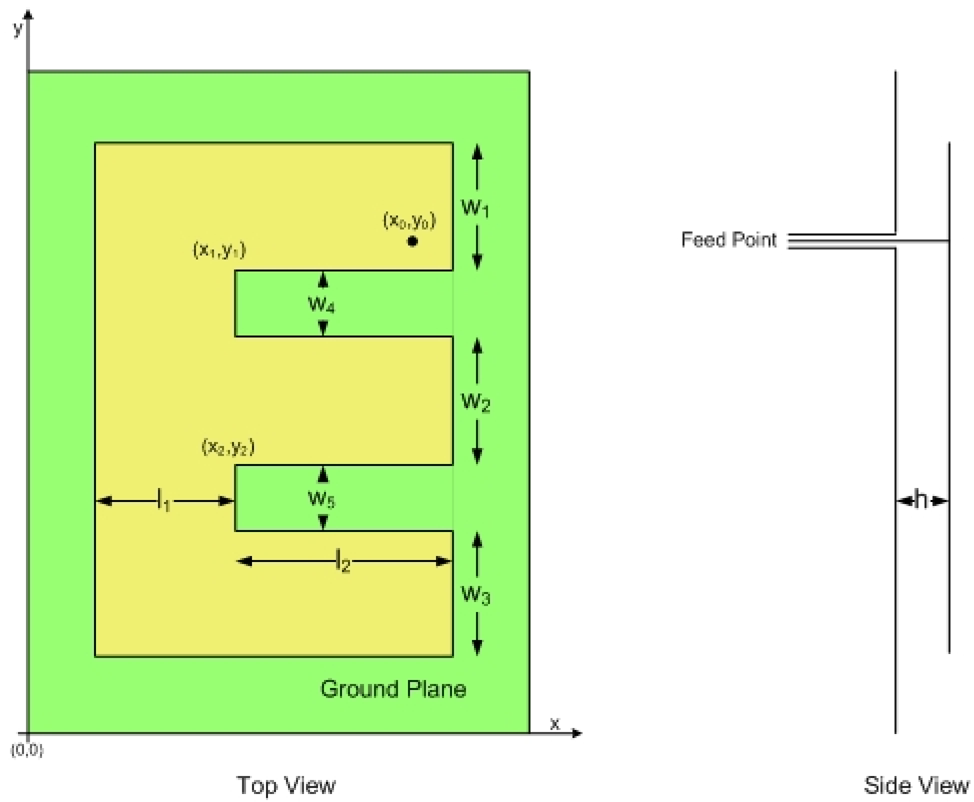


Figure 3.3: Design structure of E shaped MPA

In this thesis E shaped MPA has been design on the foundation of RMPA. Means E shaped MPA has same patch and ground plane dimensions of predefined RMPA with same feeding position and technique. Two mini rectangular parallel slots have been trimmed off from right side of RMPA to achieve conventional E shaped MPA. Figure 3.3 shows main configuration of E shaped MPA where slots positions are at (x_1, y_1) and (x_2, y_2) respectively. The lengths and widths slots are defined as l_1, l_2, and w_4, w_5 and E shaped MPA widths are defined as w_1, w_2, and w_3 respectively.

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Table 3.2: Design dimensions of E shaped MPA

Parameters	Dimension (mm)
l_1	7
l_2	10
w_1	6
w_2	6
w_3	6
w_4	3
w_5	3
(x_1,y_1)	(7,18)
(x_2,y_2)	(7,9)

The simulation Figure 3.4 shows return loss versus frequency curve of designed E shaped MPA. The dimension parameters are rechecked and simulated. The simulation is done for same feed point with same thickness of RMPA. From the graph improvement in bandwidth and two more bands has been noticed respect to RMPA. For the parallel slots, E shaped MPA gained the ability to operate at multiband application where the resonant frequencies are 12.4 GHz, 13.28 GHz and 14.45 GHz with return loss of -16 dB, -27.7 dB and -11.6 dB respectively. The bandwidths of the operating frequencies are 235 MHz, 357 MHz and 200 MHz respectively which covers total 13.25% of Ku band, but still insufficient.

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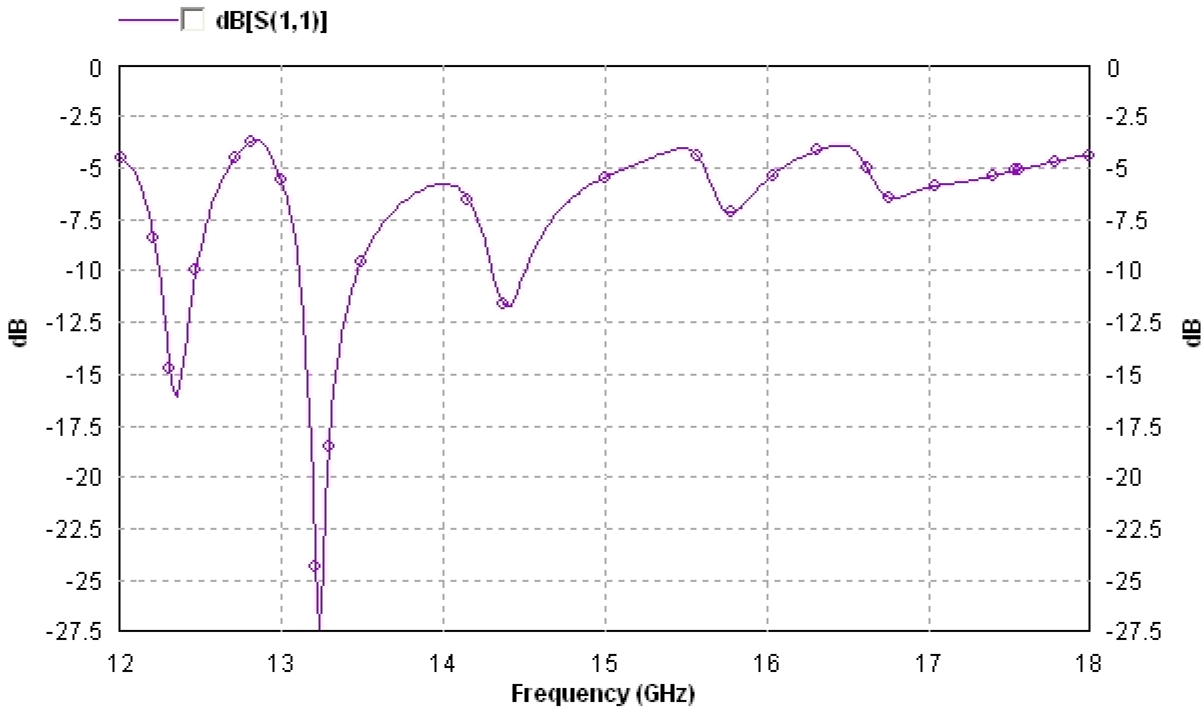

Figure 3.4: Simulated return loss (S_{11}) characteristic of E shaped MPA

3.4 Design of Metamaterial Structure via SRRs

Metamaterial is one of the advance materials in recent years. It exhibits extraordinary properties of negative permittivity and permeability that no other materials can provide. They are compound structures of periodic metallic patterns printed on dielectric substrates which interrupt the macroscopic properties of the medium which generates a negative effective permittivity and permeability for a certain frequency band. They have opened the vast area of research and levitated the technology in new other level.

In this thesis most commonly used SRRs have been constructed as metamaterial. It is a pair of concentric metal rings. The loops are made of nonmagnetic metal like copper and have a small gap between them. External magnetic field penetrates through the rings and induces rotating current in the loops which produce their own flux to oppose the incident field. Here SRR has been designed on FR4 substrate with dielectric constant of 4.2 which is same as RMPA and E shaped MPA. Figure 3.5

represents basic structure of SRR. Here the dimensions of SRR are inherited from [43] and converted to millimeters. For better performance dimensions are slightly modified and reduced in some multiple to [43]. Table 3.3 shows optimum dimension for antennas.

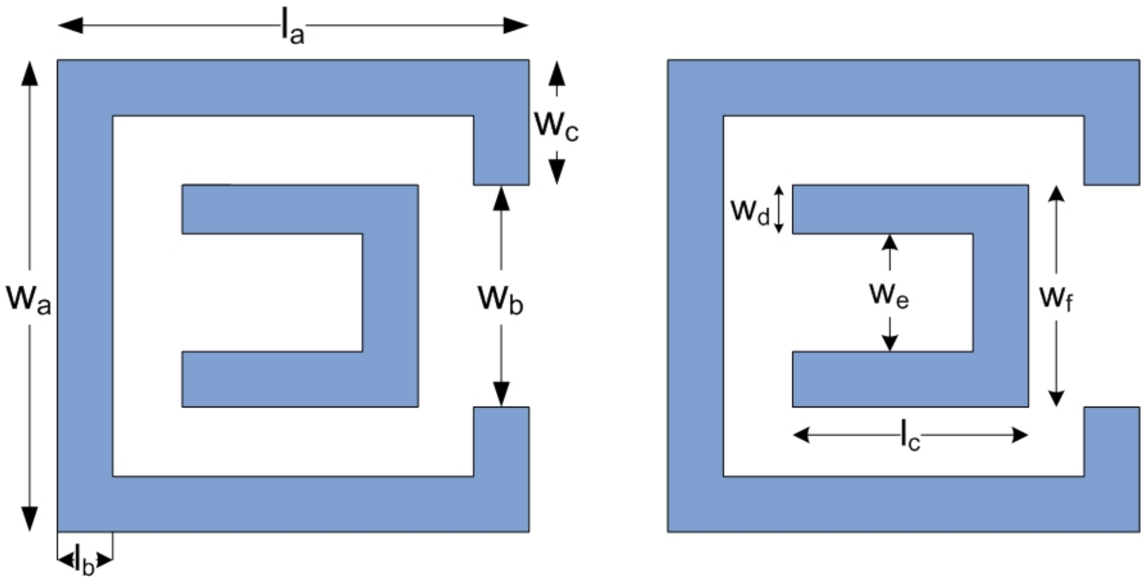

Figure 3.5: Design structure of SRR

Table 3.3 Design dimensions of SRR

Parameters	Dimension (mm)
l_a	1.6
l_b	0.2
w_a	1.6
w_b	0.8
w_c	0.4
l_c	0.8
w_d	0.2
w_e	0.4
w_f	0.8

3.5 Design of E shaped MPA loaded with SRRs

This metamaterial superstrate has been used on the top of the E shaped MPA. Total 15 numbers of SRRs are designed for this antenna design. Horizontally distance between SRRs is 0.4 mm and vertically apart by 7.4 mm. These SRRs are set at the height of 3.2 mm from ground plane. After configuration with SRRs the antenna is excited at same feeding point and technique as discussed before. Figure 3.6 shows E-shaped MPA loaded with metallic array of SRRs.

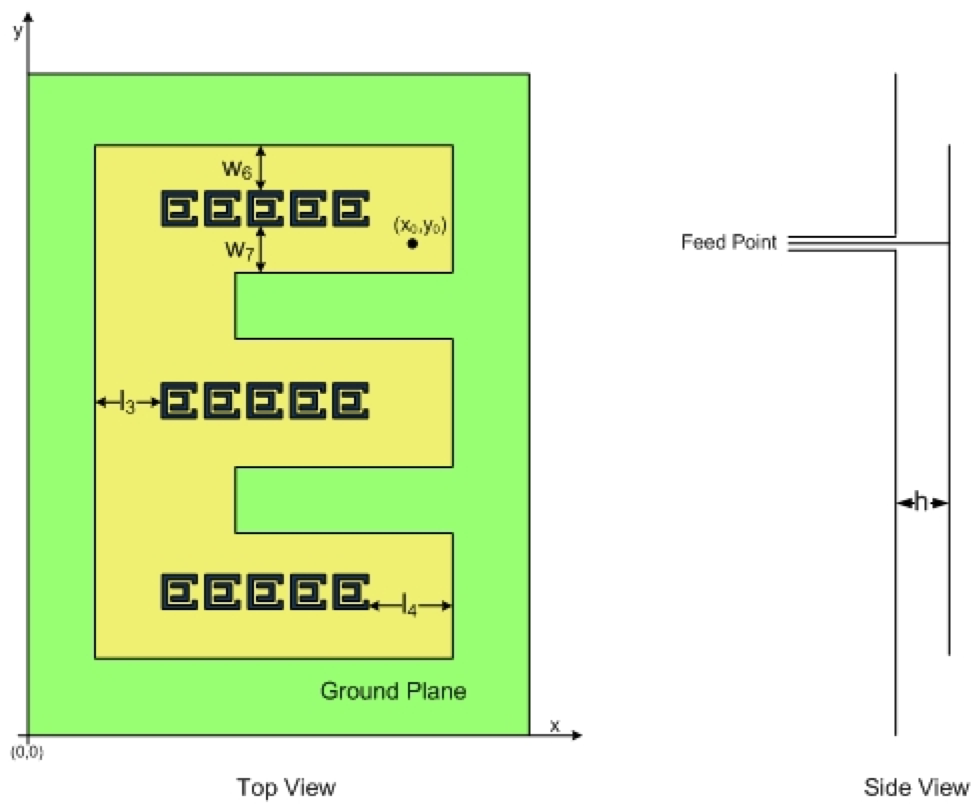

Figure 3.6: Design structure of E shaped MPA loaded with SRRs

Table 3.4: Design dimensions of E shaped MPA loaded with SRRs

Parameters	Dimension (mm)
w_6	2.2
l_3	3.2
w_7	2.2
l_4	4.2

Figure 3.7 shows the simulation result where the bandwidth improvement has been observed. Compared with E shaped MPA, bandwidth of this antenna rapidly enhanced. It has bandwidth of almost 2.50 GHz but it operates at both X band and Ku band. This thesis mainly focuses on Ku band only. Here SRR properties have been noticed where resonant frequency shifted to 11.97 GHz with total enhancement in bandwidth. But under Ku band this antenna has total bandwidth of 1.25 GHz which covers only 20% of this band. So to operate under Ku band with more bandwidth new modified E shaped MPA loaded with metamaterial has been introduced in next section.

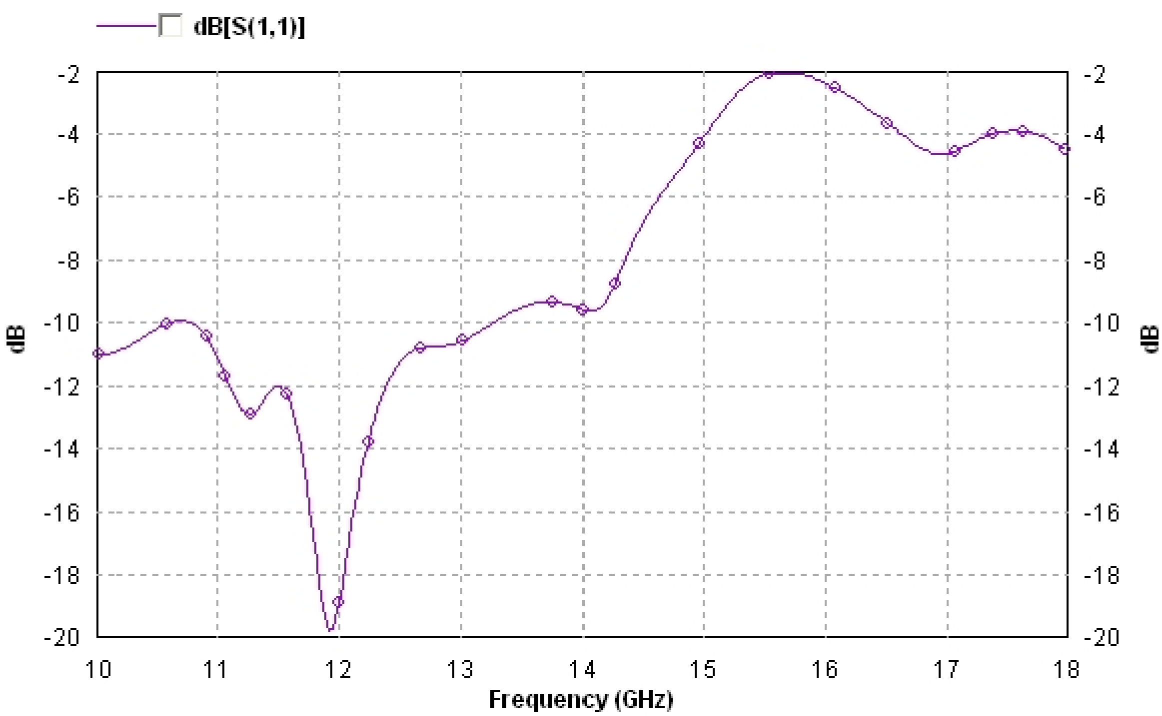

Figure 3.7: Simulated return loss (S_{11}) characteristic of E shaped MPA loaded with SRRs

3.6 Design of E shape E slotted MPA loaded with SRRs (Proposed Antenna)

From the literature review it has observed that cutting slots from the patches help to enhance bandwidth. Cutting off the slot changes the surface current path as well as changes the patch dimension (length and width) which helps to vary the resonant frequency. Considering literature review and for further improvement in antenna characteristics an innovative E shape slot has been cut off from E shaped patch of E shaped MPA and loaded with same structures of metamaterials which has been used before. The new shaped antenna has been excited again at same feeding point with same technique. The shape of slot is same as E shaped patch in reduced dimensions. The slot area is 1.5 time of E shaped MPA which has previously discussed. The dimensions of E slot with E shaped MPA loaded with metamaterial has been illustrate in Figure 3.8 where (x_3, y_3) and (x_4, y_4) points are slot position on E shaped patch. Dimension of the slot given in Table 3.5.

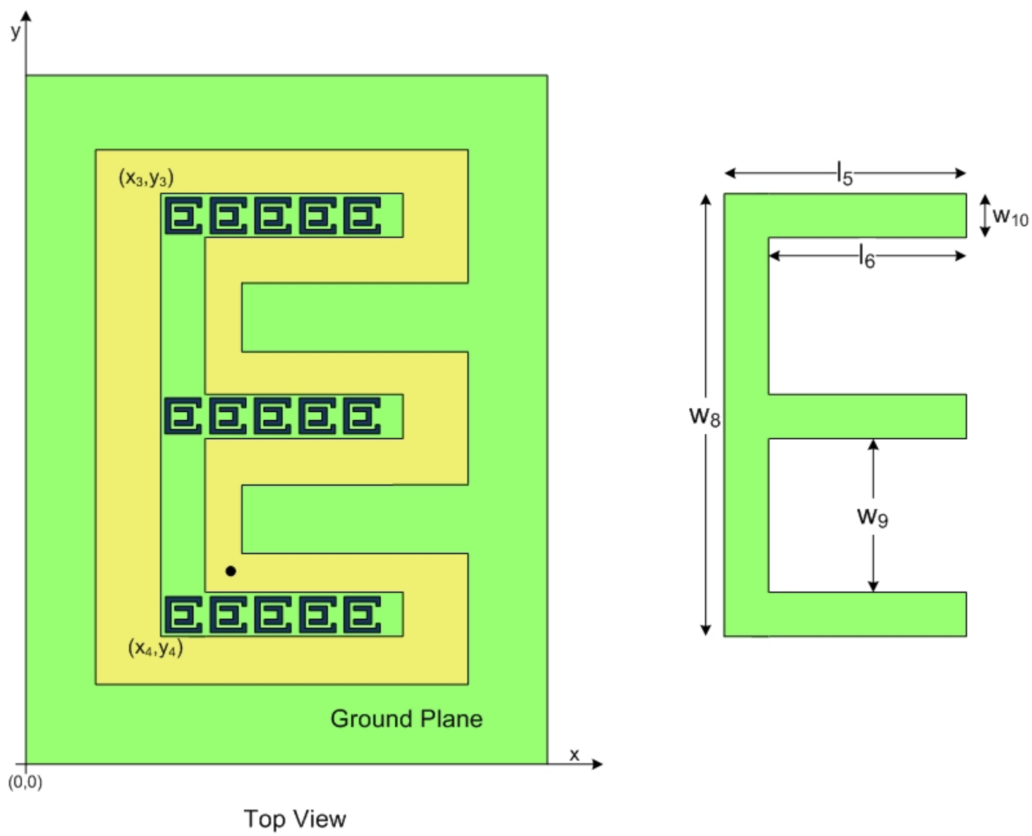

Figure 3.8: Design structure of E shape E slotted MPA loaded with SRRs

Table 3.5 Design dimensions of E shape E slotted MPA loaded with SRRs

Parameters	Dimension (mm)
l_5	14
l_6	9
w_8	20
w_9	7
w_{10}	2
(x_3, y_3)	(3, 22)
(x_4, y_4)	(3, 2)

After simulation dissatisfactory result has been observed (Figure 3.9). It has bandwidth of 1.76 GHz in Ku band range and resonant at 13.72 GHz with return loss of only -12.01 dB. It covers approximately 29% of total Ku band range. To find optimized result the probe feeding point has is changed in different place of the patch, among them some sample point are shown in Figure 3.10

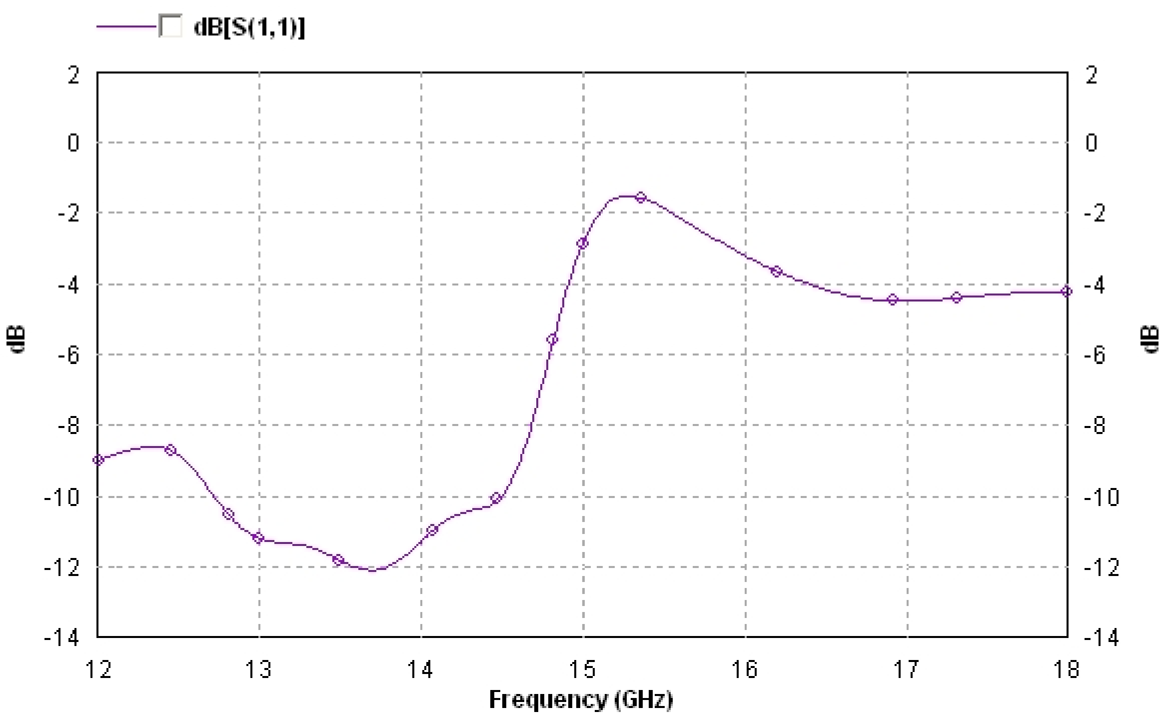

Figure 3.9: Simulated return loss (S_{11}) characteristic of E shape E slotted MPA loaded with SRRs

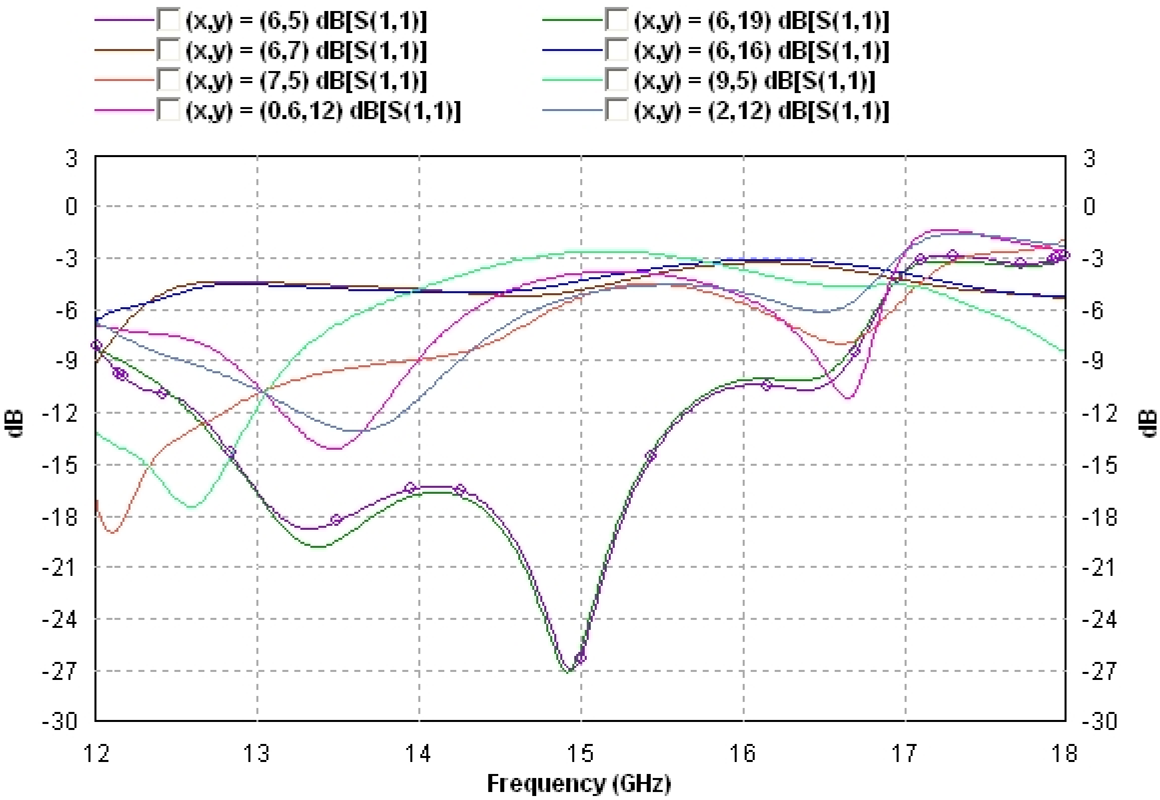

Figure 3.10: Simulated return loss (S_{11}) characteristic of E shape E slotted MPA loaded with SRRs at different feeding point.

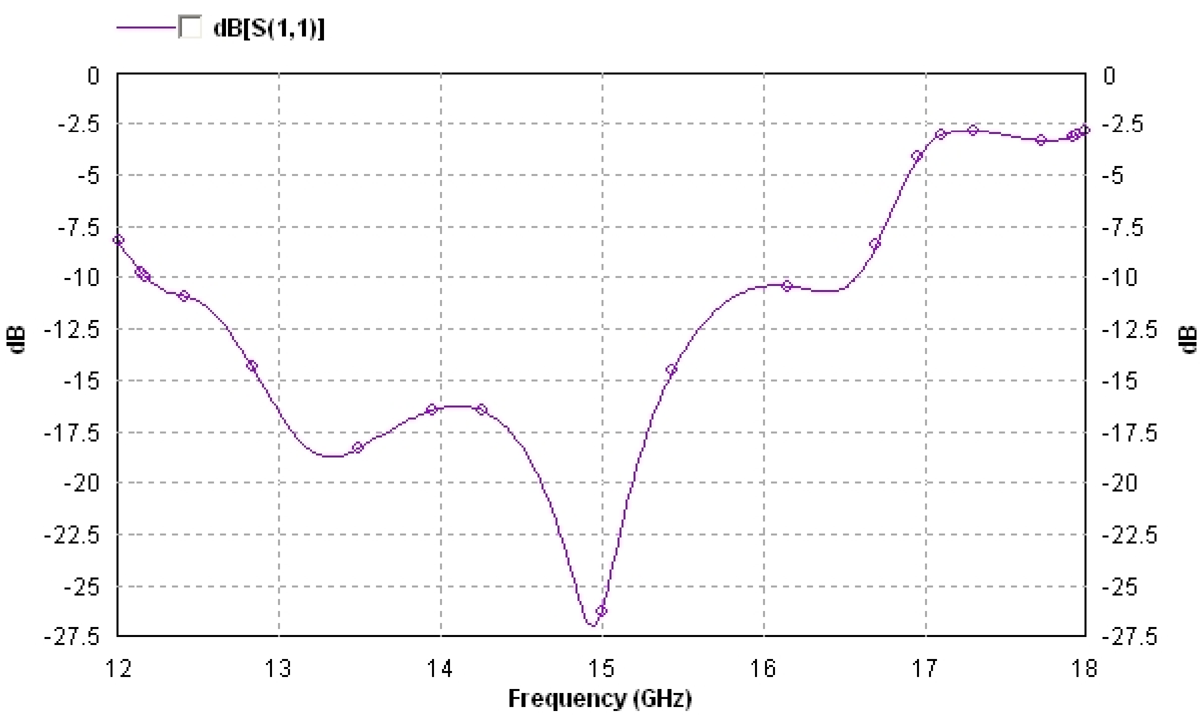

Figure 3.11: Simulated return loss (S_{11}) characteristic of proposed antenna

Finally, at (6, 5) point profound result has been found for antenna characteristic. The antenna operates at 14.97 GHz frequency with return loss -26.97 dB respectively. The proposed antenna has total bandwidth of approximately 4.40 GHz with upper and lower limit of frequency is 12.18 GHz and 16.56 GHz respectively shown in Figure 3.11. The antenna can support 73.33% of total bandwidth of Ku band. Overall this new innovative E shape E slotted MPA loaded with SRRs as metamaterial shows most robust performance compared with other antennas which have been discussed earlier. This antenna is proposed antenna for this research work. Further more detail, comparative study has been discussed in next chapter.

3.7 Metamaterial Verification

To verify the metamaterial structure via SRR properties complex dielectric properties need to be measured at given frequency domain. Measurement of dielectric properties involves measurements of the complex relative permittivity (ε_r) and complex relative permeability μ_r of the materials. A complex dielectric permittivity consists of a real part and an imaginary part. The real part of the complex permittivity, also known as dielectric constant is a measure of the amount of energy from an external electrical field stored in the material. The imaginary part is zero for lossless materials and is also known as loss factor. It is a measure of the amount of energy loss from the material due to an external electric field. The term tangent loss represents the ratio of the imaginary part to the real part of the complex permittivity. The loss tangent is also called by terms such as tangent loss, dissipation factor or loss factor. The complex permeability also consists of a real part which represents the amount of energy from an external magnetic field stored in the material whereas the imaginary part represents the amount of energy dissipated due to the magnetic field. Measurement of the complex permeability is only applicable to magnetic materials. Most materials are non-magnetic and thus, the permeability is very near to the permeability of free space. Many methods have been developed to measure these complex properties such as methods in time domain or frequency domain with one port or two ports, etc. Every method is limited to specific frequencies, materials and applications by its own constraint. With the advance of new technologies, the methods can be employed with a software program (IE3D) that measures the complex reflection and transmission coefficients with a vector network analyzer and converts the data into the complex dielectric property parameter. In this thesis Nicolson-Ross-Weir method is used for calculation [42].

NRW method provides a direct calculation of both the permittivity and permeability from the S-parameters. It is the most commonly used method for performing such conversion. Measurement of reflection coefficient and transmission coefficient requires all four (S_{11}, S_{21}, S_{12}, S_{22}) or a pair (S_{11}, S_{21}) of s parameters of the material under test to be measured. The equation provides the permittivity and permeability of the medium related to S-parameters [43&44].

$$\mu_r = \frac{2c(1-V_2)}{\omega d(1+V_2)j} \tag{3.1}$$

$$\varepsilon_r = \mu_r + \frac{2S_{11}cj}{\omega d} \tag{3.2}$$

$$V_2 = S_{21} - S_{11} \tag{3.3}$$

Here, ε_r, μ_r, V_2 ω is, *d*, and *c* are relative permittivity, relative permeability, voltage minima, frequency in radian, thickness of the substrate and speed of light.

The array structure of SRRs which have been used on proposed antenna are now placed between the two waveguide ports at X axis in order to calculate S_{11} and S_{21}. The Y-Plane is defined as Perfect Magnetic Boundary (PMB) and Z-Plane is defined as the Perfect Electric Boundary (PEB). The excitation of the signal is done from the left side to the right side of the structure assuming the surrounding was air. After the simulation in IE3D software the S_{11} and S_{21} parameters are evaluated using the equations (3.1-3.3). Total six sample frequencies are taken and calculated. Table 2 shown satisfactory results because, it shows negative value under all operating frequencies.

Table 3.6 Design dimensions of E shape E slotted MPA loaded with SRRs

Frequencies (GHz)	S_{11}	S_{21}	Permittivity	Permeability
12.2	0.8021-0.1545j	-0.1143-0.1076j	-24.531-40j	-24.908-41.959j
12.8	0.7699-0.1342j	0.1912-0.07683j	-55.331-33.605j	-55.644-35.399j
13.30	0.692-0.1373j	0.2347-0.05411j	-0.938-4.277j	-1.246-5.83j
14.92	1.04-0.07699j	0.03317+0.2247j	-13.035+4.356j	-13.189+2.287j
14.96	1.042-0.08994j	0.03514+0.2185j	-12.718+4.343j	-12.897+2.27j
15.5	1.035-0.2436j	0.04591+0.1881j	-8.44+3.689j	-8.912+1.697j
16.5	0.8071-0.4299j	0.2408+0.1652j	-3.176+0.373j	-3.95-1.079j

CHAPTER 4
RESULT AND DISCUSSION

To accomplish the basic objective of the thesis intensive simulations have been done in the previous chapter to find the desirable optimized antenna for Ku band operation. Four particular antennas have been designed where gradual improvement in bandwidth has been observed. In the proposed antenna SRRs have been imposed for better antenna characteristics. The bandwidth has been increased exponentially due to the unusual properties of metamaterial. The proposed antenna has bandwidth of 4.40GHz and it can cover 73.33% of Ku band frequency range, it means antenna has the ability to support uplink and broadcasting satellite service of all ITU Region (1-3) with downlink support for ITU Region 3 as well as broadcasting satellite, fixed microwave, cable TV relay, fixed-satellite (Earth-to-Space), earth exploration satellite, aeronautical radio-navigation and space research, standard frequency and time signal satellite (earth-to-space), mobile satellite (earth-to-space), and radio astronomy.

All the antennas are examined by the performance analysis under the IE3D simulator standards of average current distribution, vector current distribution, 2D, 3D radiation patterns of gain and directivity. The current distribution illustrates the antenna structure and helps to understand the density and direction of the current movement inside the patch at any frequencies. It also shows how different part of the antenna behaves for different operating frequencies. 2D and 3D radiation patterns are graphical representation of the power radiated by antenna as a function of the direction away from the antenna. 2D radiation option provides information mainly about antenna gain and directivity gain of E-H fields in terms of axial ratio, azimuth and elevation for both polar and cartesian form where as 3D radiation pattern provides 3D rotatable view of antenna directivity and gain with emission style. The simulations have been done for all designed antennas at operating frequencies which provides better understanding of antenna parameters.

4.1 Average Current Distribution

Average current distribution shows average intensity of the current in terms of color representation on the patch at each location. The color window shows a color bar for the scaling of the colors. Different colors at different locations of the patch indicate the current magnitudes are different. Below designed antennas are shown.

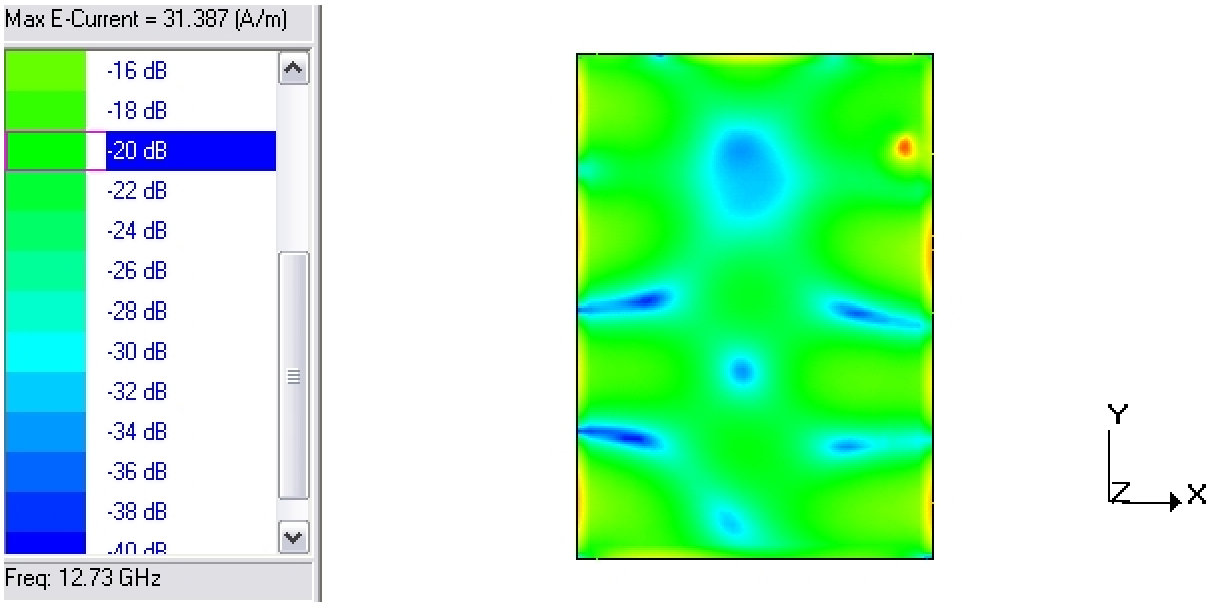

Figure 4.1: Average current distribution of RMPA at 12.73 GHz

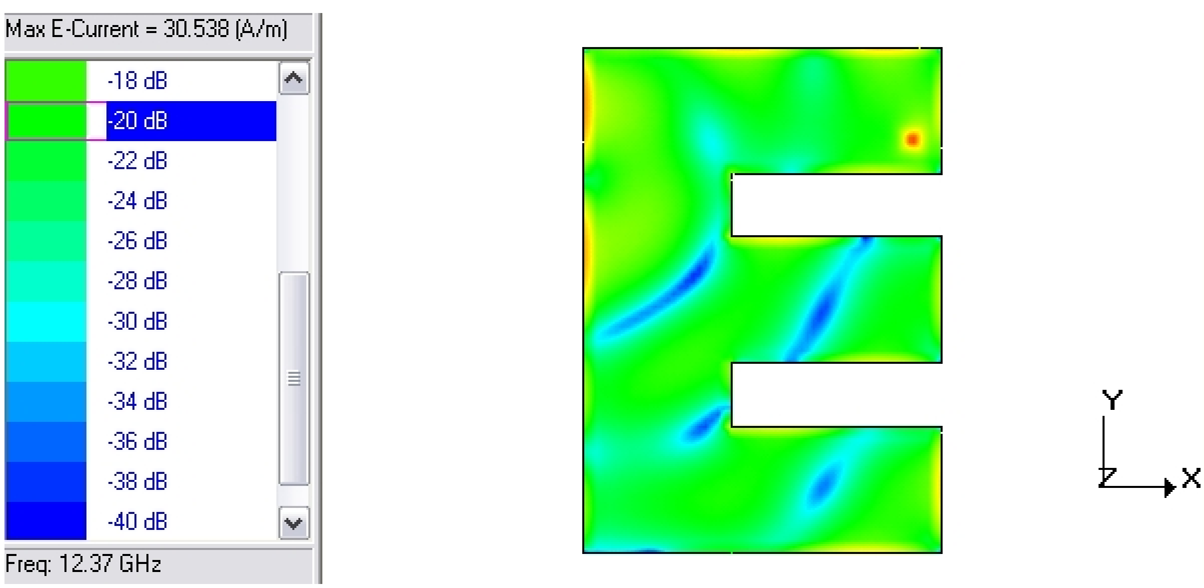

Figure 4.2: Average current distribution of E shaped MPA at 12.4 GHz

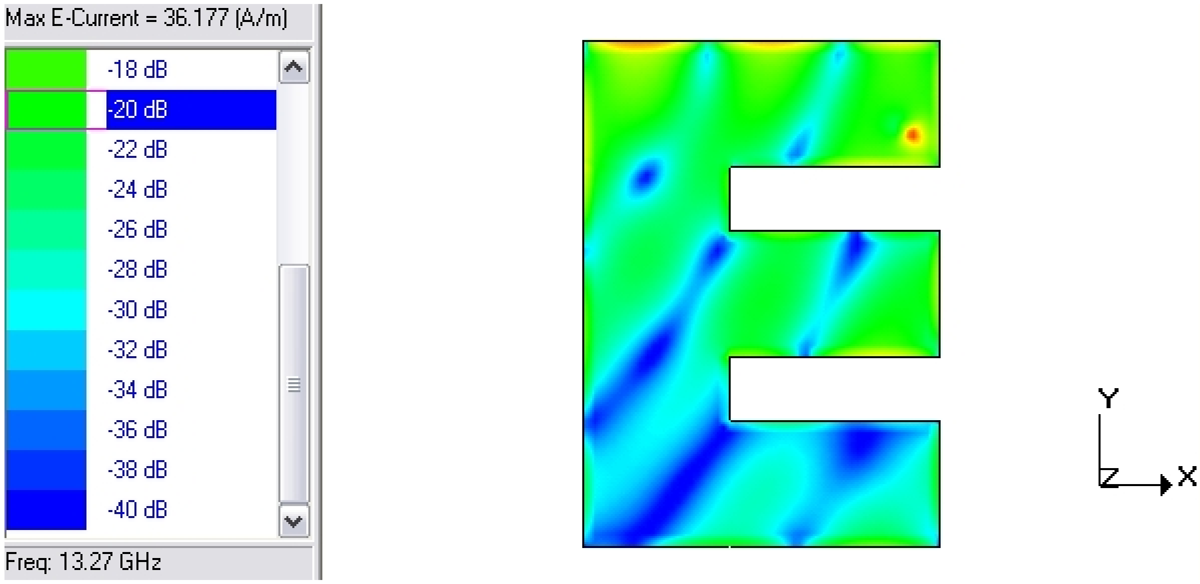

Figure 4.3: Average current distribution of E shaped MPA at 13.28 GHz

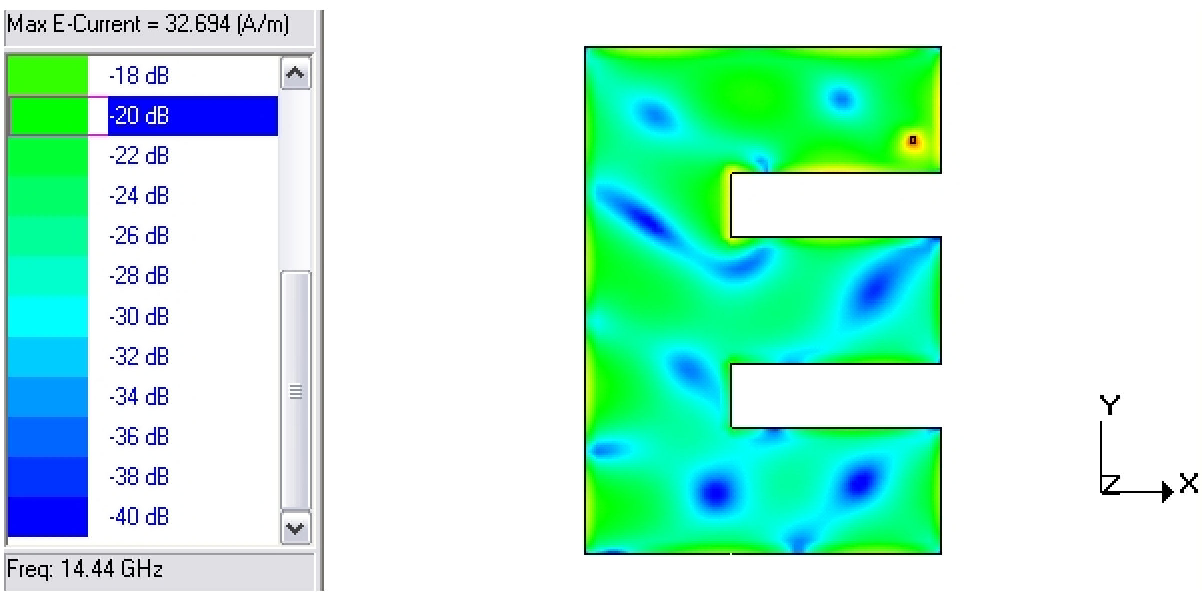

Figure 4.4: Average current distribution of E shaped MPA at 14.45GHz

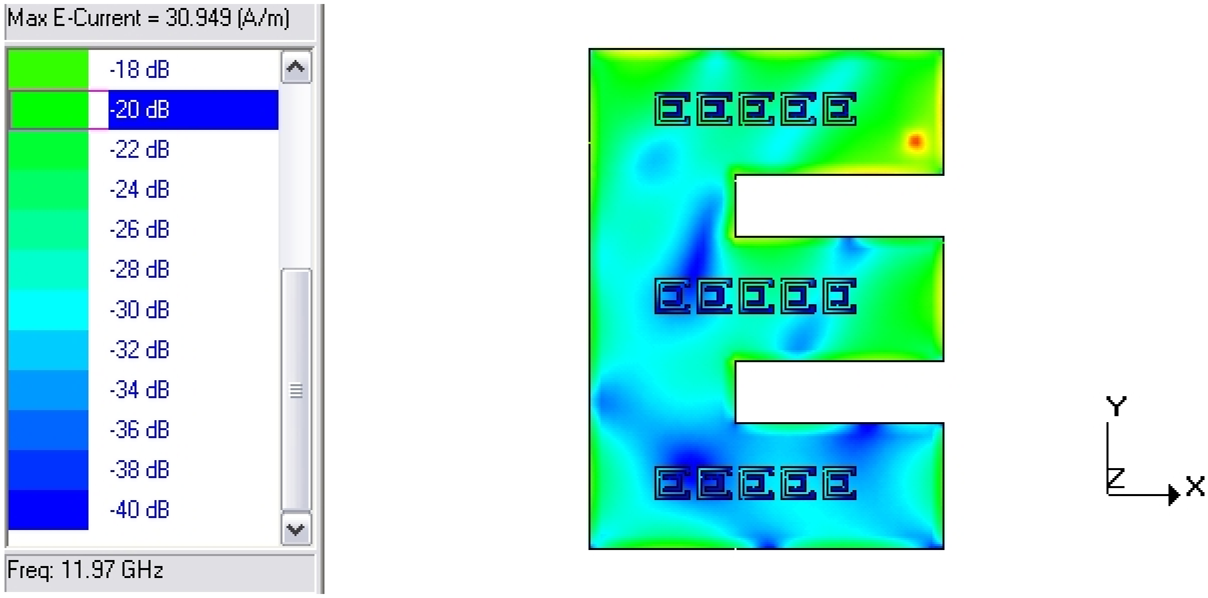

Figure 4.5: Average current distribution of E shaped MPA loaded with SRRs at 11.97 GHz

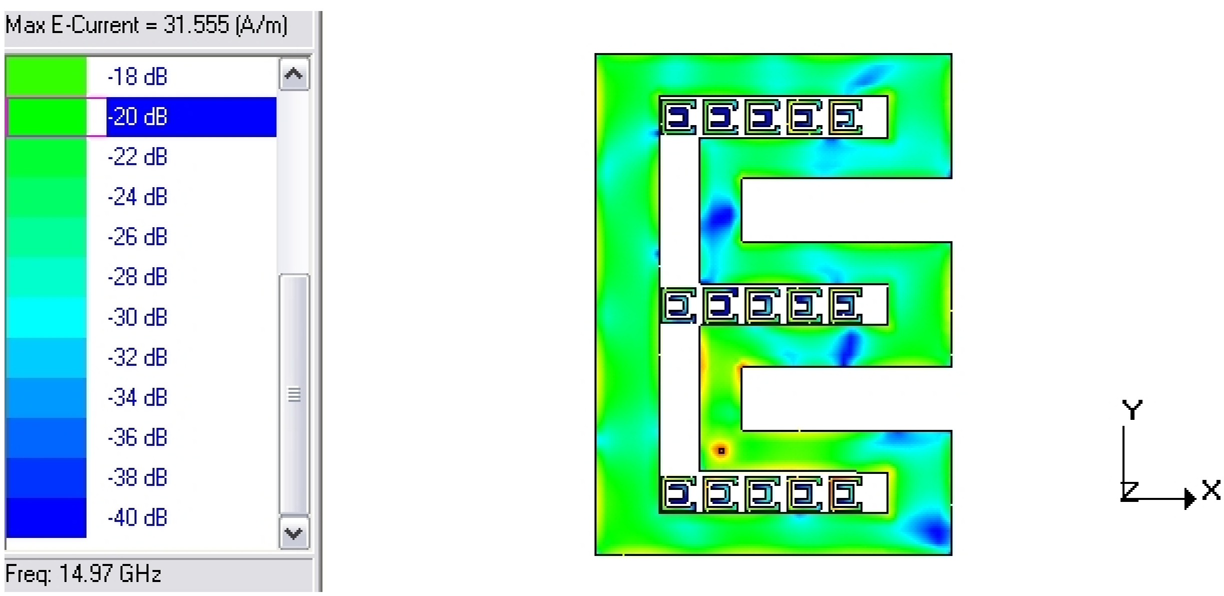

Figure 4.6: Average current distribution of proposed antenna at 14.97 GHz

The average current density on the surface of all the antennas is shown in Figure 4.1 to 4.6 at there operating frequencies. The maximum electric current is shown at the top left of the figures. Current distribution for all antennas is most likely blue and green which illustrate amplification from -20 dB to -40 dB. It is also observed from the figures that the current is maximum at the center and current is zero at the edges which indicates a resonance condition.

4.2 Vector Current Distribution

Vector current distribution shows the direction as well as intensity of the current inside the patch at specific location and time as vectors by arrows. It indicates where the current are strong or weak as a time average value. But the direction of the current at specific locations cannot be achieved because the direction of the vector is normally time varying. Therefore, it is meaningless to display the time average vector current but the vector current at specific locations at different times can be displayed. From the directions at specific times antennas performance are given below

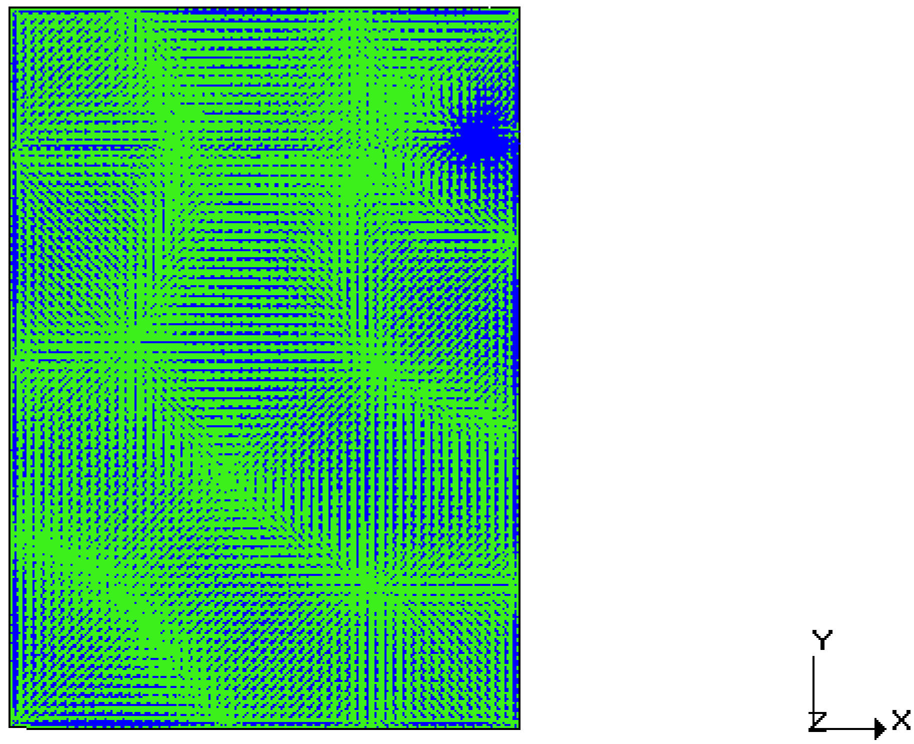

Figure 4.7: Vector current distribution of RMPA at 12.73 GHz

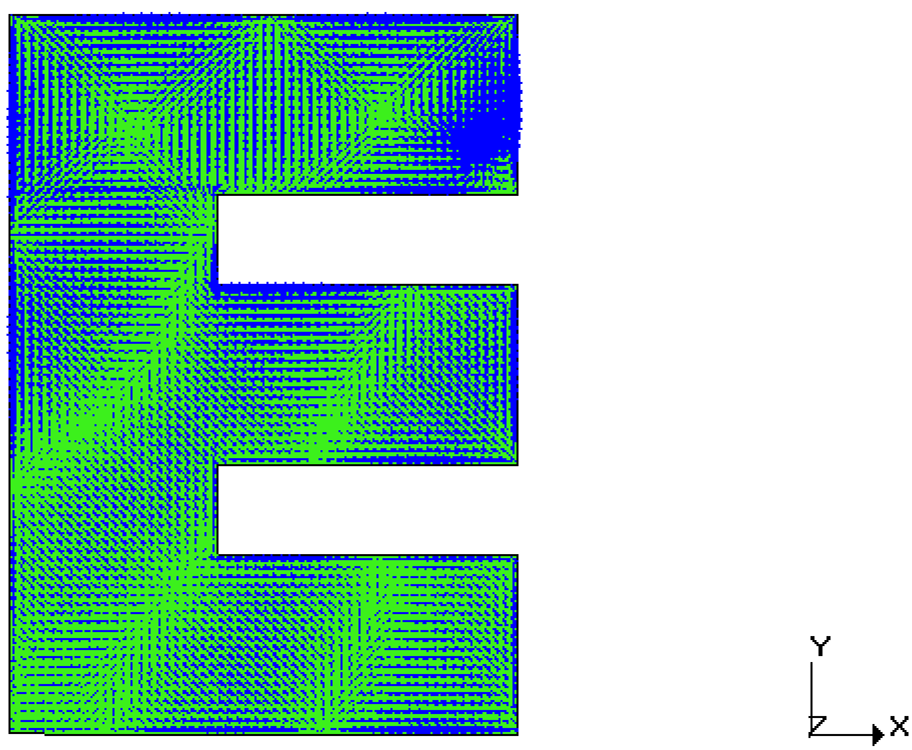

Figure 4.8: Vector current distribution of E shaped MPA at 12.4 GHz

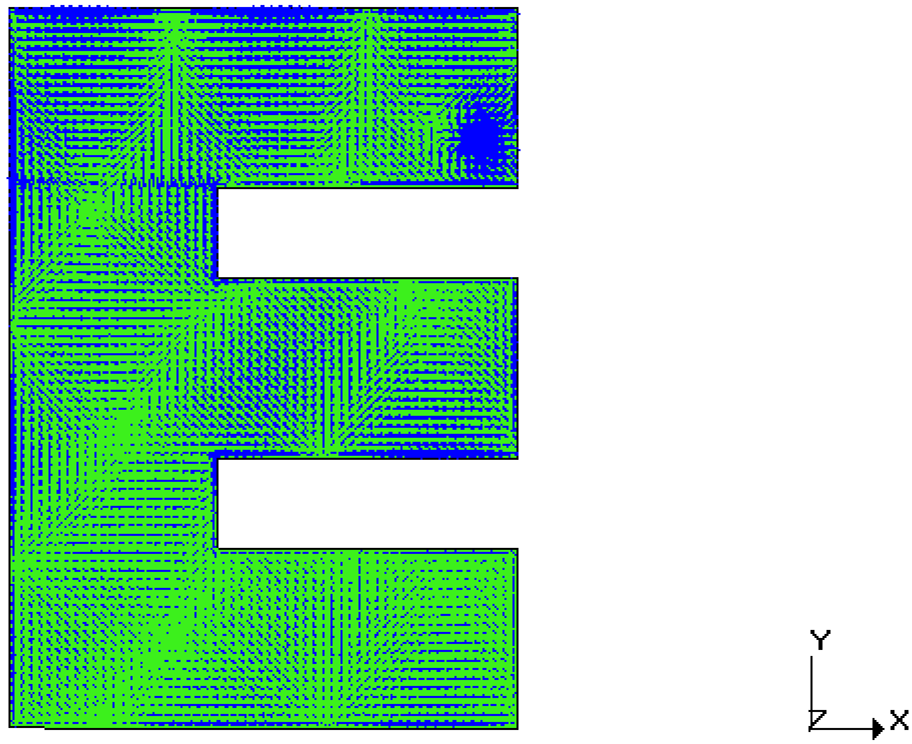

Figure 4.9: Vector current distribution of E shaped MPA at 13.28GHz

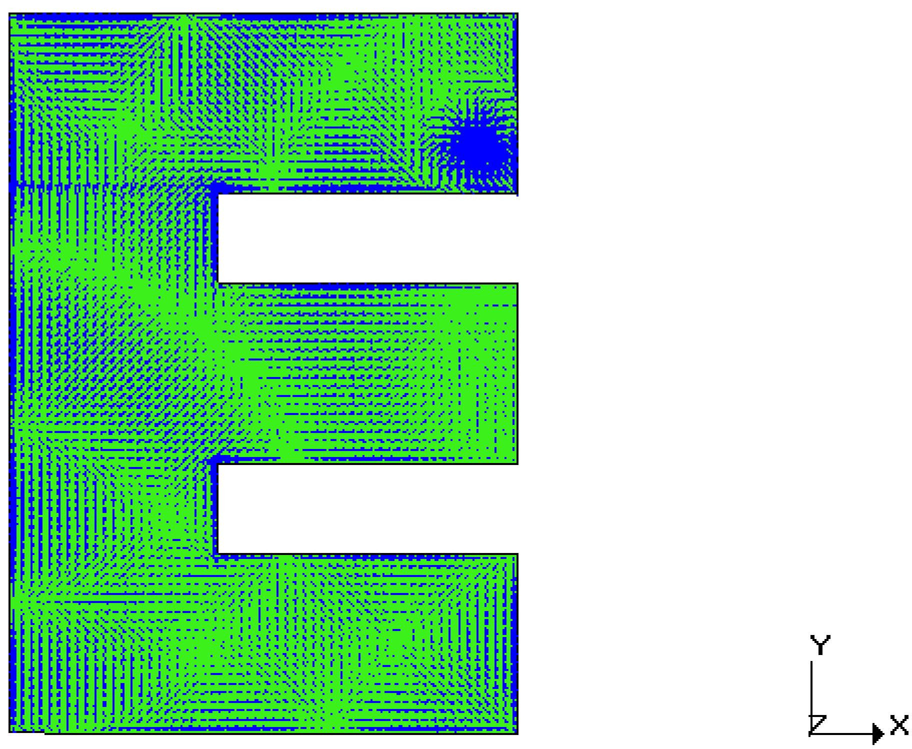

Figure 4.10: Vector current distribution of E shaped MPA at 14.45 GHz

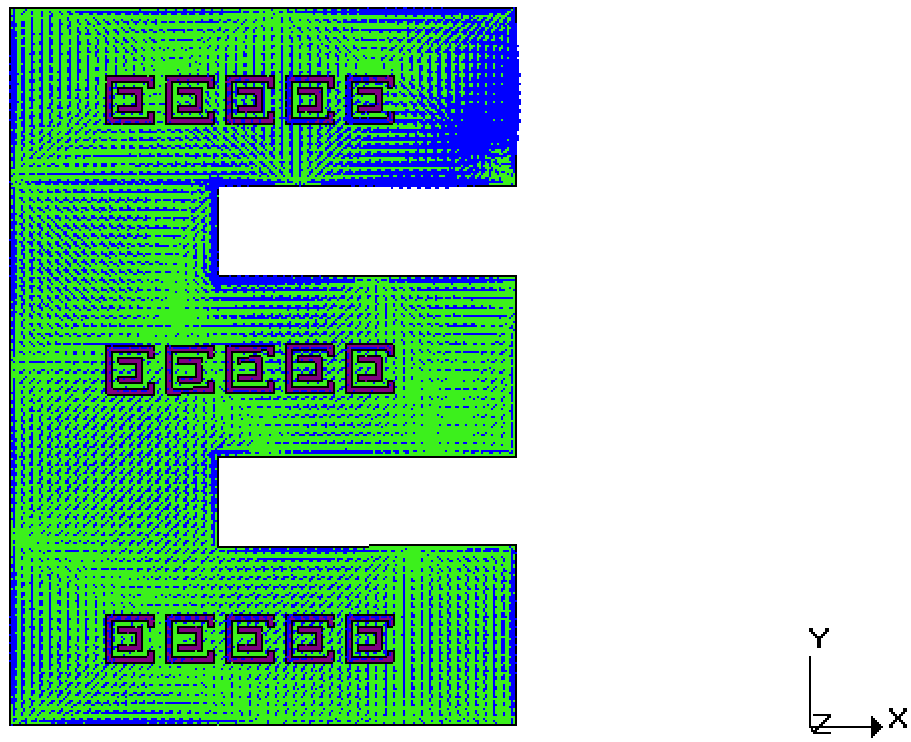

Figure 4.11: Vector current distribution of E shaped MPA loaded with SRRs at 11.97GHz

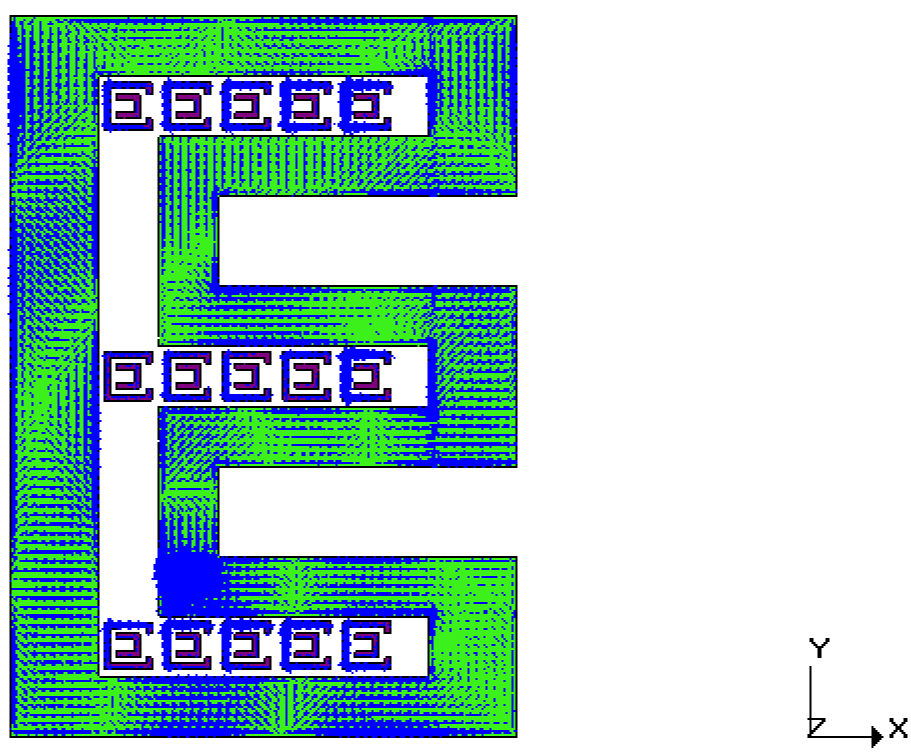

Figure 4.12: Vector current distribution of proposed antenna at 14.97 GHz

Vector distribution of the current over the surface of all the patch antennas are shown in Figure 4.7 to 4.12 at there operating frequencies. The size of the vectors indicates the magnitude of the current density at a specific location at a specific time. For all the designed antennas the current density is much higher closer to the edges of the structure compared to other places which indicates resonating condition

4.3 2D Radiation Pattern of Antenna Gain

In electromagnetics, an antenna's power gain or simply gain is a key performance diagram which combines the antenna's directivity and electrical efficiency. Antenna gain is usually defined as the ratio of the power produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions. Usually this ratio is expressed in decibels, and these units are referred to as decibels-isotropic (dBi). Since a MPA radiates normal to its patch surface, the elevation pattern for φ = 0 and φ = 90 degrees would be important.

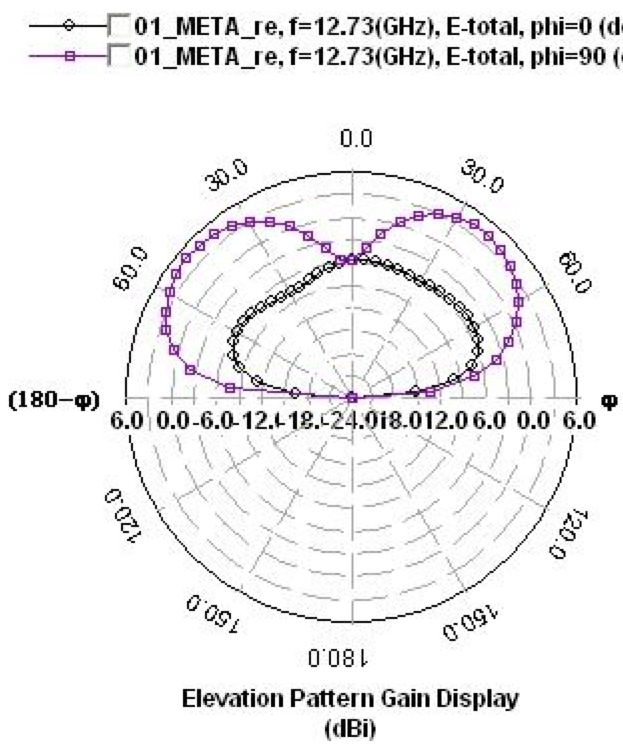

Figure 4.13: 2D radiation pattern of RMPA at 12.73 GHz

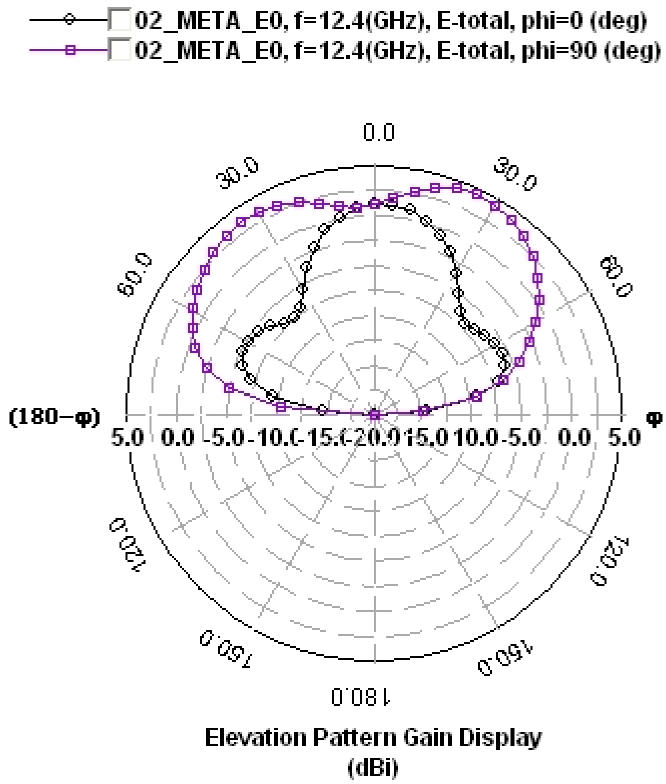

Figure 4.14: 2D radiation pattern of E shaped MPA at 12.4 GHz

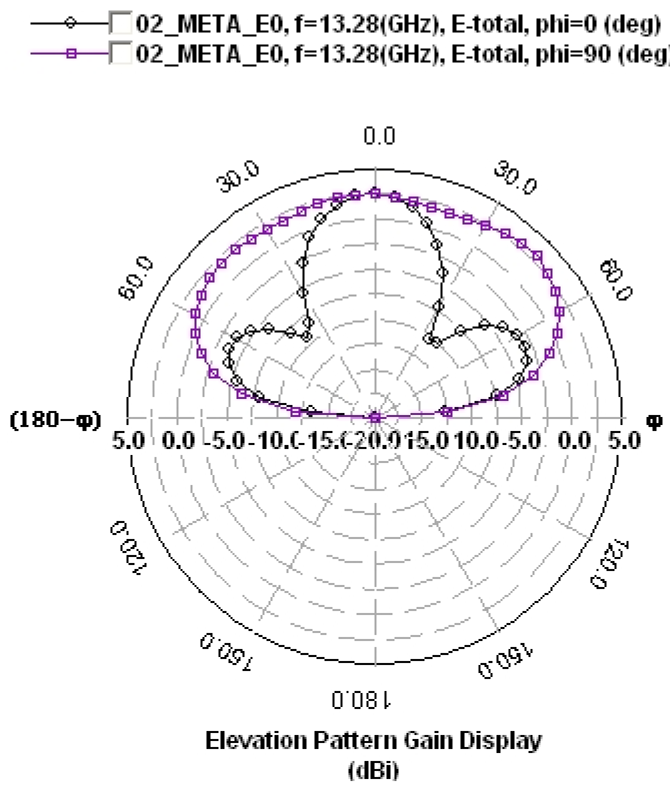

Figure 4.15: 2D radiation pattern of E shaped MPA at 13.28 GHz

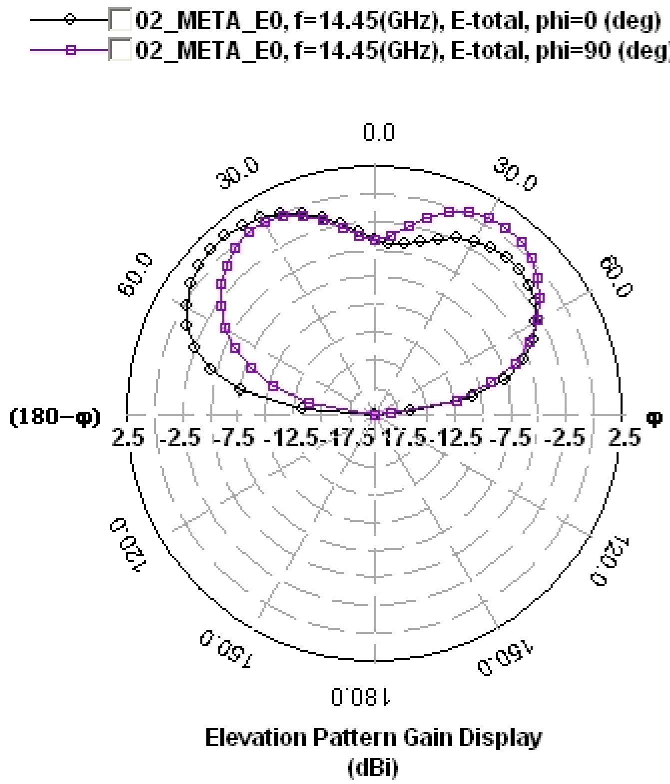

Figure 4.16: 2D radiation pattern of E shaped MPA at 14.45GHz

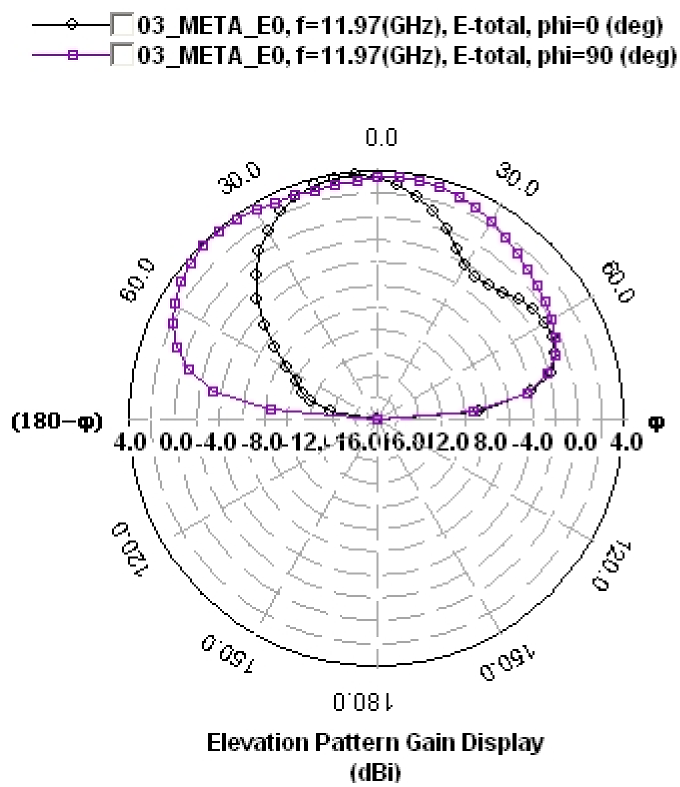

Figure: 4.17: 2D radiation pattern of E shaped MPA loaded with SRRs at 11.97 GHz

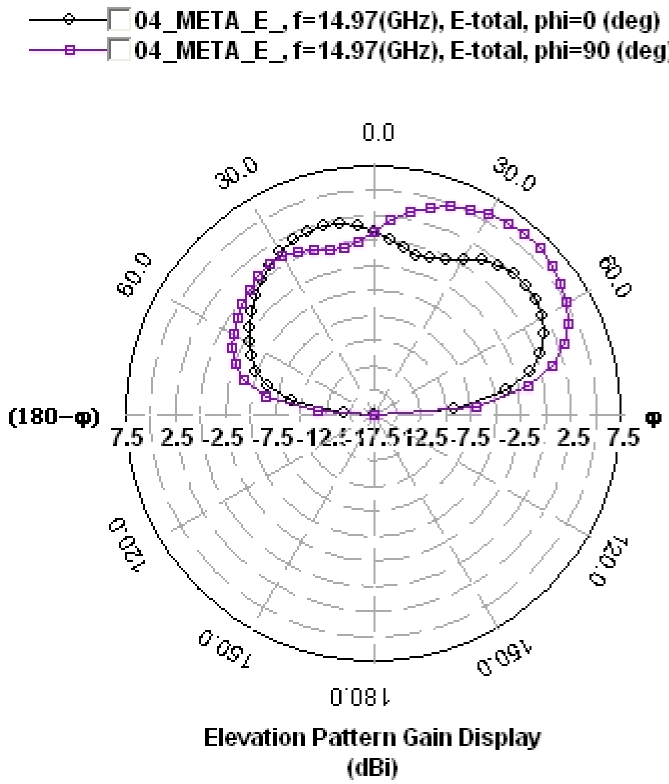

Figure 4.18: 2D radiation pattern of proposed antenna at 14.97 GHz

2D radiation pattern for all the antennas are shown in Figure 4.13 to 4.18 at there operating frequencies. Figure 4.13 indicates the RMPA has gain of 4.2 dBi at resonant frequency. E shaped MPA at operating frequencies has gain of 4.7 dBi, 3.04 dBi and 0.94 dBi respectively. E shaped MPA with SRR has gain of 3.96 dBi and finally the proposed has gain of 7.4 dBi at operating frequency. All the antennas provide a good radiation pattern.

4.4 3D Radiation Pattern of Directivity

3D radiation pattern depicts better understanding of antenna power radiation in all direction. Figure 4.19 to Figure 4.24 shows true 3D radiation pattern of directivity of all antennas respectively. They are the pattern in the actual 3D space. The size of the pattern from the origin represents how strong the field at a specific (theta, phi) angle.

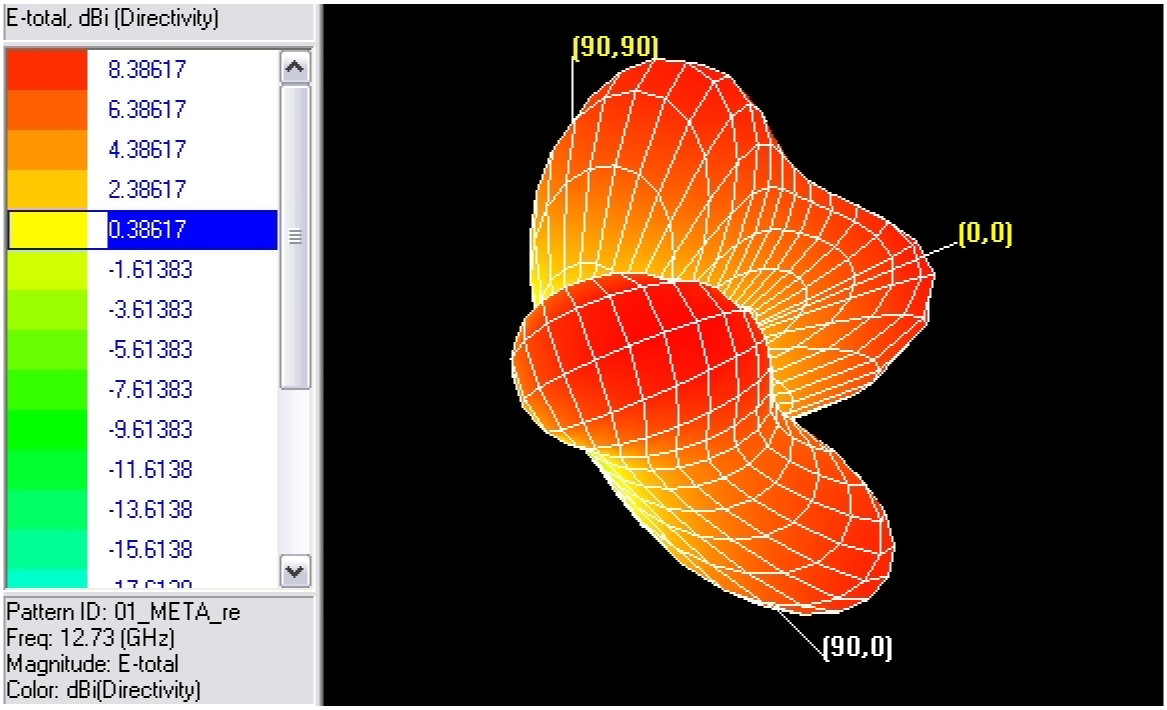

Figure 4.19: 3D radiation pattern of directivity for RMPA at 12.73 GHz

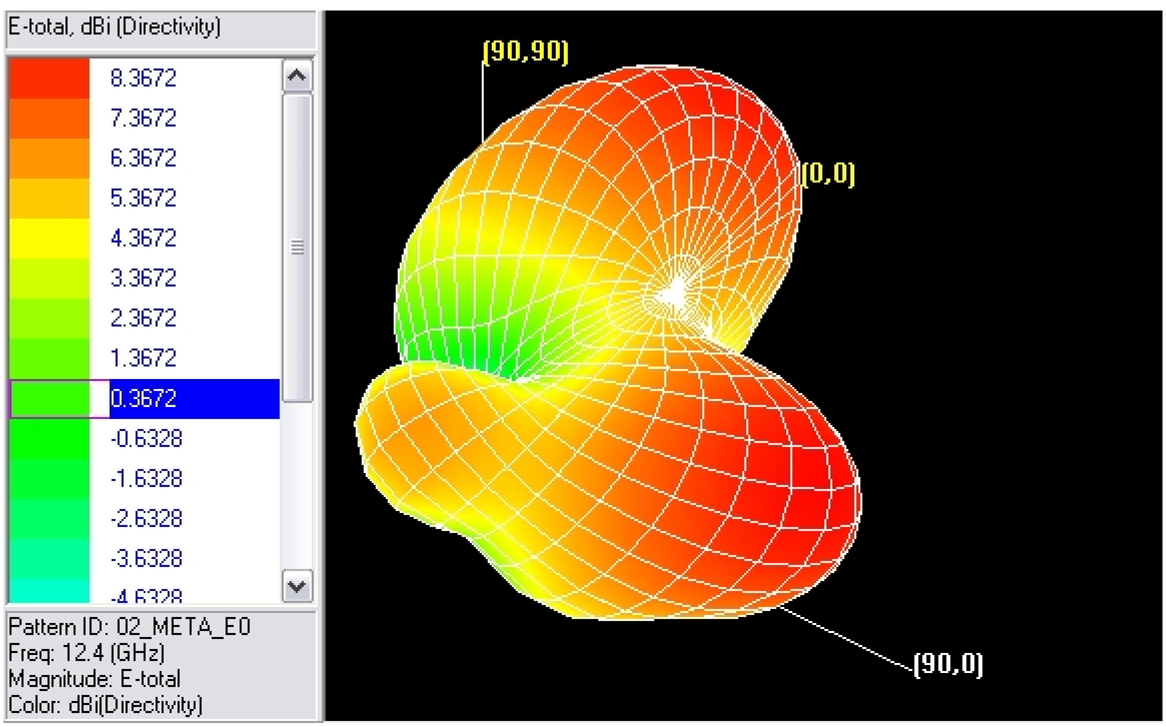

Figure 4.20: 3D radiation pattern of directivity for E shaped MPA at 12.4 GHz

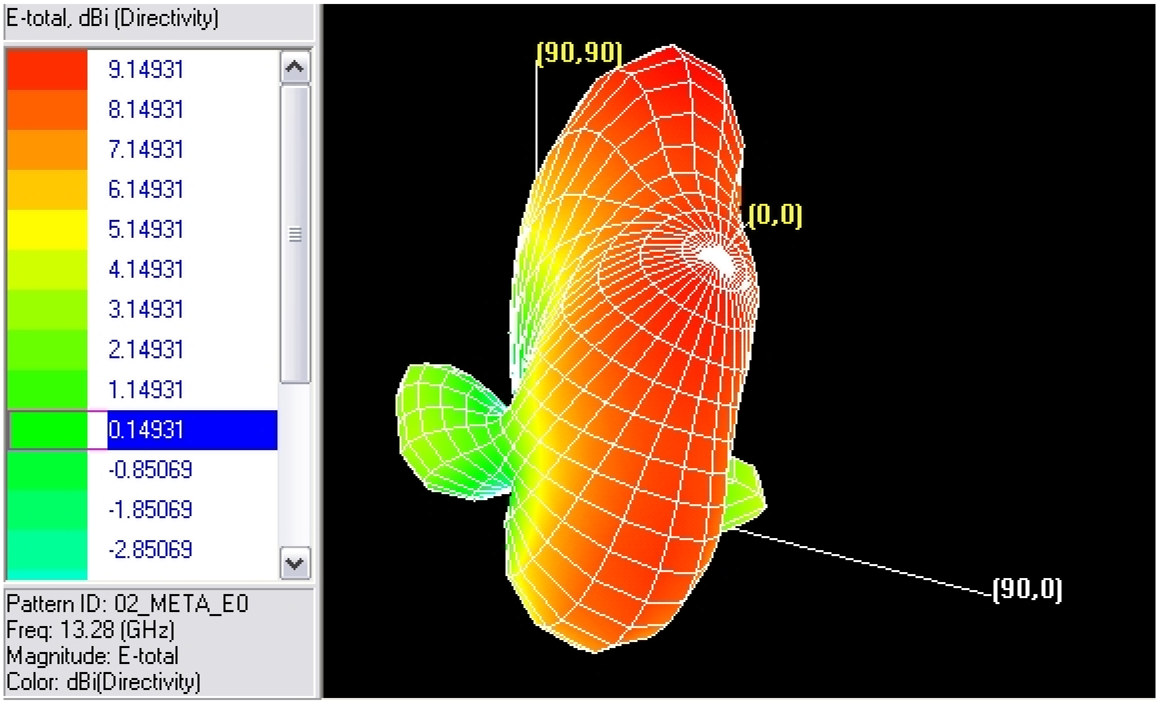

Figure 4.21: 3D radiation pattern of directivity for E shaped MPA at 13.28 GHz

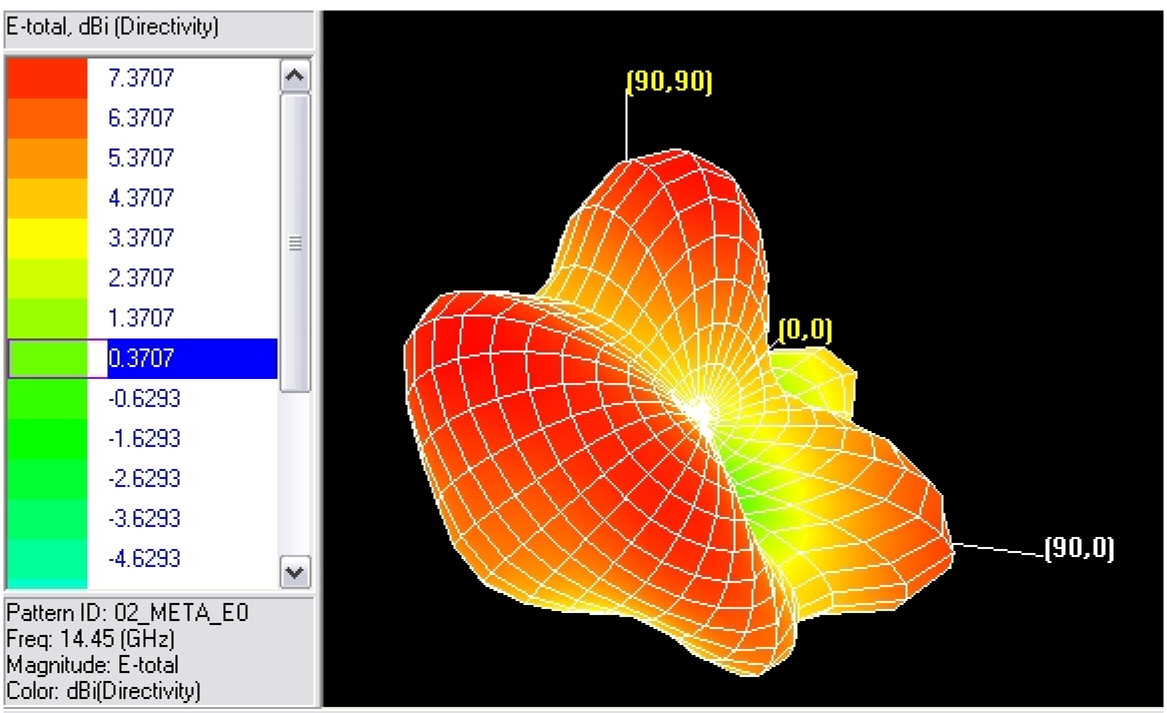

Figure 4.22: 3D radiation pattern of directivity for E shaped MPA at 14.45 GHz

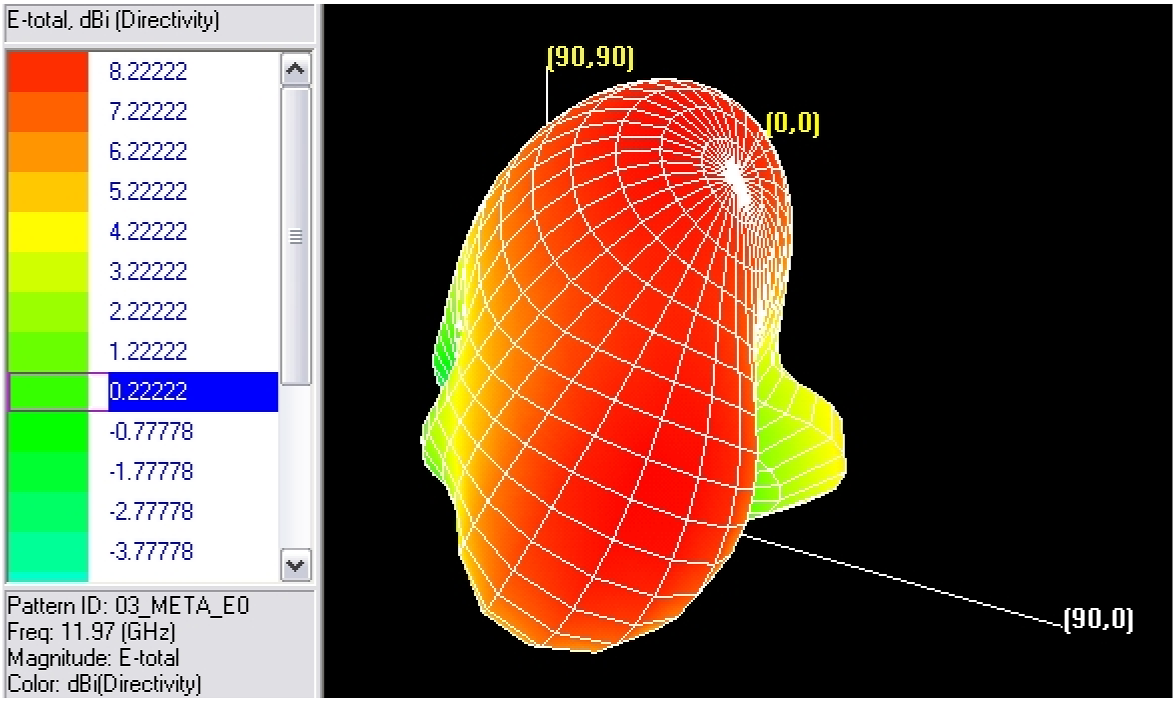

Figure 4.23: 3D radiation pattern of directivity for E shaped MPA with SRRs at 11.97GHz

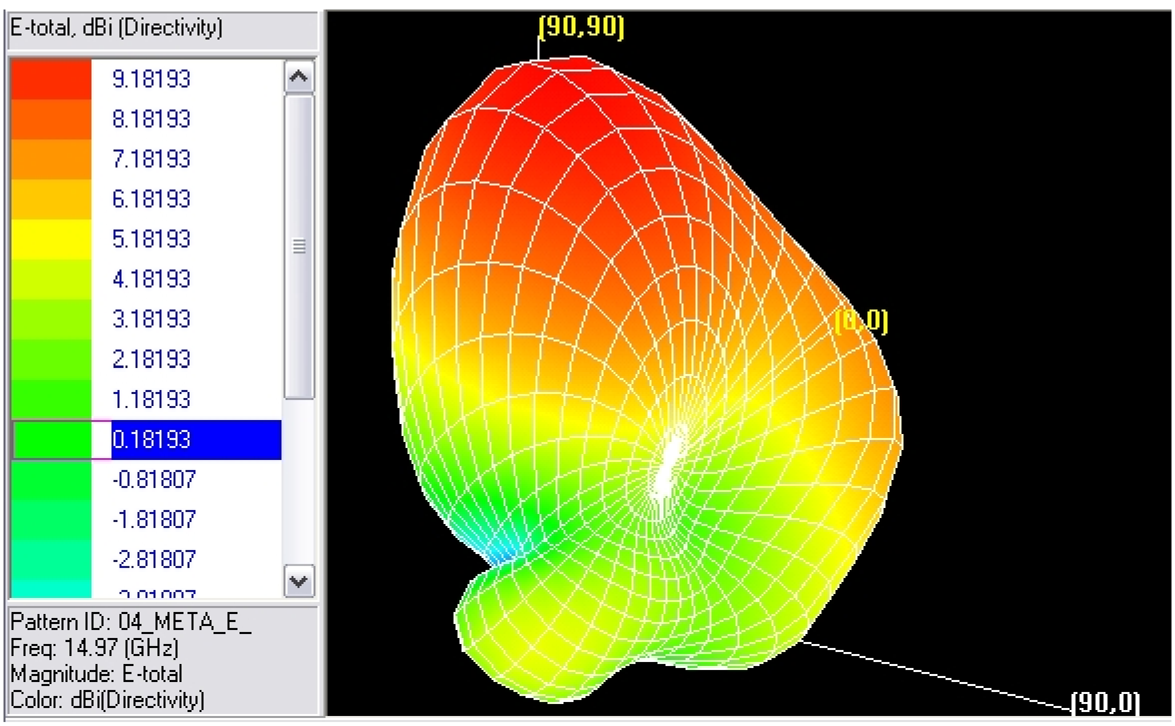

Figure 4.24: 3D radiation pattern of directivity for proposed antenna at 14.97 GHz

Directivity measures the power density that, the antenna radiates in the direction of its strongest emission, versus the power density radiated by an ideal isotropic radiator (which emits uniformly in all directions) radiating the same total power. Here it is observed that RMPA has directivity gain of 8.5 dBi, E shaped MPA has directivity gain of 8.6 dBi, 9.5 dBi and 7.4 dBi according to there operating frequencies, E shaped MPA loaded with SRRs has directivity gain of 8.24 dBi and proposed antenna has directivity gain of 9.4 dBi.

4.5 Comparative Study

4.5.1 RMPA vs E shaped MPA

All antennas operate in Ku band frequency region where RMPA resonates at 12.73 GHz and E shaped MPA operates in three different frequencies at 12.4 GHz, 13.28 GHz, and 14.45 GHz respectively. RMPA has narrow bandwidth of 170MHz which is a major disadvantage of MPA. E shaped MPA operates in multiband which is another feature of E shaped patch antenna over wideband. At operating frequencies it has 235 MHz, 357 MHz, and 200 MHz bandwidth respectively. Total of 792 MHz means E shaped MPA covers 13.25% of Ku band and RMPA covers only 2.83%. Return losses of E shaped MPA are -16 dB, -27.7 dB and -11.6 dB respectively also RMPA has -16.5 dB at resonant frequencies. From the simulation and result the power gain of RMPA is 4.2 dBi where as E shaped MPA have 4.7 dBi, 3.04 dBi and 0.94 dBi respectively. The RMPA has directivity of 8.5 dBi and E shaped MPA have directivity of 8.6 dBi, 9.5 dBi and 7.4 dBi. Hence, E shaped MPA has better performance than RMPA.

4.5.2 E shaped MPA vs E shaped MPA loaded with SRRs

As mentioned earlier E shaped MPA operates in three different frequencies in Ku band where as E shaped MPA loaded with SRRs operates partial both at X and Ku band. Here metamaterial via SRRs properties have been noticed where antenna resonant frequency shifted at 11.97 GHz. Including both bands antenna has total bandwidth of 2.50 GHz where under Ku band it has 1.25 GHz bandwidth which covers 20% of this frequency range. Compare to E shaped MPA bandwidth improved by 6.75%. E shaped MPA shows multiband operation where antenna loaded with SRRs provides wideband application with return loss of -18.7 dB. The antenna has gain and directivity of 3.96 dBi and 8.25 dBi respectively. Although E shaped MPA loaded with SRRs has significant improvement in bandwidth but it has similar gain and directivity pattern compare with E shaped MPA.

4.5.3 E shaped MPA loaded with SRRs vs Proposed Antenna

Both antennas have same shapes and dimensions but proposed antenna has E shape slot into the E shaped patch. The slot, feeding position and metamaterial structure provides the antenna to operate at 14.97 GHz frequency with 4.40 GHz bandwidth which covers almost 73.33% of the Ku band frequency domain where as E shaped MPA loaded with SRRs has 1.25 GHz bandwidth. Means proposed antenna shows 3.15 GHz development with more than 50% improvement in Ku band spectrum compare with other antennas. E shaped metamaterial antenna operates in both X and Ku band where proposed antenna operates only in Ku band region. The proposed antenna has power gain and return loss of 7.4 dBi and -26.97 dB respectively which are improved result compare to E shaped MPA loaded with SRRs. Hence the proposed antenna has far more better antenna performance than other antennas.

4.5.4 Proposed antenna vs RMPA

Conventional RMPA has operating frequency of 12.73 GHz with impedance bandwidth of 170 MHz which covers only 2.83% of Ku band frequency region. With same patch dimensions proposed antenna resonates at 14.97 GHz with bandwidth of 4.40 GHz which covers 73.73% of total Ku band domain. Compare to RMPA bandwidth enhance by 4.23 GHz or 70.47% improvement in overall Ku band spectrum. The RMPA has gain and directivity of 4.2 dBi and 8.5 dBi respectively where as the proposed antenna has gain of 7.4 dBi and directivity of 9.4 dBi at operating frequency respectively. Here significant improvement in antenna characteristics has been noticed.

4.5.5 Proposed antenna vs E shaped MPA

E shaped MPA has multiband frequency ranges which operates in Ku band and has total bandwidth of 792 MHz where proposed antenna with same patch configuration covers the entire multiband in a single bandwidth. Compare with E shaped MPA bandwidth improved by 3.60 GHz or 60% enhancement in total Ku band. The gains of E shaped MPA are 4.7 dBi, 3.04 dBi and 0.94 dBi at operating frequencies and directivities are 8.6 dBi, 9.5 dBi and 7.4 dBi respectively where as the proposed antenna has gain of 7.4 dBi and directivity of 9.4 dBi respectively. Again momentous enhancement in antenna characteristics is observed. Hence, it can be concluded that the proposed antenna has better antenna performance than all designed antennas.

Table 4.1: Antenna parameters of RMPA and E shaped MPA

Antenna Parameters	**RMPA**	**E shaped MPA**		
Resonant Frequencies (GHz)	12.73	12.4	13.28	14.45
Return loss (dB)	-16.5	-16	-27.7	-11.6
Bandwidth (MHz)	170	235	357	200
Gain (dBi)	4.2	4.7	3.04	.94
Directivity (dBi)	8.5	8.6	9.5	7.4

Table 4.2: Antenna parameters of E shaped MPA loaded with SRR and Proposed antenna

Antenna Parameters	E-MPA loaded (SRR)	Proposed Antenna
Resonant Frequencies (GHz)	11.97	14.97
Return loss (dB)	-18.7	-26.97
Bandwidth (GHz)	2.50	4.40
Gain (dBi)	3.96	7.4
Directivity (dBi)	8.24	9.4

4.6 Comparison of the proposed antenna with existing antenna

In [33] a MPA has been designed and operate as multiband operation at three different frequencies with total of 1.9 GHz bandwidth under both Ku and K band region. Among resonant frequencies maximum gain is 6.42 dBi where as the proposed antenna has much more better antenna performance shown in Table 4.2. In [34] authors have demonstrated a compact MPA for Ku band application which operates at 12.545 GHz and 14.151 GHz with only 90 MHz and 60 MHz of bandwidth respectively. The antenna has return loss of -23.8 dB and -14.04 dB with gain of over 4 dBi where proposed antenna can cover all the operating frequency in single band of 4.40 GHz bandwidth and has better performance in both gain and return loss. Another E shaped MPA is shown in [36] which resonates at dual frequency operation for Ku band domain where the bandwidth at operating frequencies are 510 MHz and 500 MHz respectively, total of 1.10 GHz with maximum gain of 7.2 dB. Proposed antenna has improved bandwidth performance and similar power gain pattern compare to [36].

During background and literature review it has been observed that almost all MPAs operating in Ku band region, standard power gain and bandwidth characteristic in same antenna is difficult to achieve where as proposed antenna has it all in one. It is more robust and efficient in antenna characteristics from all available antennas which have been reviewed.

CHAPTER 5
CONCLUSION

Metamaterials are the new concept of 20th century. Exploration, familiarization and understanding about the properties of the material just started. It affects electromagnetic properties of host medium so it has the capacity to improve bandwidth and gain in antenna designing process. This thesis represents a gradual improvement in antenna characteristic from RMPA to proposed antenna. All four designed antennas have briefly discussed where all of them operate in Ku band frequency range so they all have the capacity for advance satellite communication, broadcasting satellite and other exciting operations which are allocated in this domain. A comparative study has been to understand the effects of various parameters between each other in term of bandwidth, return loss, gain and directivity. The outcomes of the results are satisfactory and encouraging. The proposed antenna shows promising and improvement in bandwidth and gain characteristic compare to other antennas. The maximum gain has been noted as 8.6 dBi and VSWR is less than 2 in the bandwidth range. This proposed antenna can be used in wireless application under Ku band.

For future work fabrication of these antennas can be done to observe real time performance of the antennas. Further enhancement in antenna characteristic multi layers of metamaterial superstrate can be used for stacked configuration or innovative shape of metamaterial structure can be investigate on proposed antenna. The fabricated proposed antenna (E slotted E shaped MPA) can be manufacture commercially for Ku band applications around the world.

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List of Publications

Razin Ahmed and Md. Fokhrul Islam, "E-Shaped Microstrip Patch Antenna for Ku Band" *International Journal of Computer Applications*. (Published Volume 80, No.6)

Razin Ahmed and Md. Fokhrul Islam, "Modified E-Shaped Microstrip Patch Antenna Loaded with Metamaterial for Ku Band" *International Journal of Applied Electromagnetics and Mechanics*. (Submitted)