DESIGN AND DEVELOPMENT OF WIDEBAND MICROSTRIP PATCH ANTENNA/ANTENNA ARRAY FOR BIOMEDICAL APPLICATION

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CERTIFICATE OF THE GUIDE

Certified that the work incorporated in the thesis **"Design and Development of Wideband Microstrip Patch Antenna/Antenna Array for Biomedical Application", s**ubmitted by **Mr. Dnyaneshwar Dadaji Ahire** was carried out by the candidate under my supervision and guidance. Such material as has been obtained from other sources has been duly acknowledged in the thesis.

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DECLARATION BY THE CANDIDATE

I declare that the thesis entitled **"Design and Development of Wideband Microstrip Patch Antenna/Antenna Array for Biomedical Application"**, submitted by me for the degree of **Doctor of Philosophy** is the record of work carried out by me during the period from **24/8/2015** to **1/8/2018** under the guidance of **Dr. Gajanan Kashiram Kharate** and has not formed the basis for the award of any degree, diploma, associate ship, fellowship, titles in this or any other University or other institution of higher learning.

I further declare that the material obtained from other sources has been duly acknowledged and credited in the thesis.

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ABSTRACT

With the advent of a tremendous update and upgrade in communication technology, it becomes challenging to supply the demand of an unprecedented rise in the bandwidth of the services. One of the major applications in the medical field, where wideband microstrip patch antenna is a suitable candidate on which the specialist can rely for the diagnosis of malignant tissues in at an early stage. Federal Communications Commission (FCC) recommends Ultra-Wide Band (UWB) which is approximate for early detection of malignant tissues in the human body. Federal Communications Commission (FCC) has defined the standard of a 7.5GHz (from 3.1GHz to 10.6GHz) bandwidth for ultra-wideband (UWB) wireless communications.

Microwave signals have shown a great usefulness in a wide variety of applications. Owing to their penetrative nature in the human body, one of the useful applications of all is the use of microwave signals to see through dielectric structures. Microwave imaging is a competent investigative modality for non-invasive imagining dielectric properties of human bodies. Growing attention towards this field has been paid during this era. Many application areas in the biomedical field have been cited. Medical imaging is considered as the most effective way of diagnosis of malignant tissues, where X-ray, mammography and Magnetic Resonance Imaging (MRI) are the leading methodologies, however, those are not appropriate for the bulky scale screening program. False-negative rate and false-positive rate to detect malignancies using mammography is up to 15 %. Many a times there is a need to go for the incisive biopsy to verify a diagnosis. Microwave imaging possibly would be quite inexpensive and has big potential to overcome limitations of existing methodologies. Microstrip patch antenna used in biomedical devices help the specialist medical professionals to diagnose the fatal disease.

With this objective to contribute in the designing miniaturized microstrip patch antenna for biomedical applications research work is carried out. We have designed and developed a wideband candidate suitable for the biomedical application, which is significantly appropriate due wide bandwidth and desired radiation pattern. The research is directed towards the design and implementation of wideband microstrip patch antennas followed by testing, analysis, and validation.

In this research work, the designing of various wideband microstrip patch antennas are presented. Varieties of Probe feed and microstrip line feed wideband

microstrip patch antenna designs have been presented. Probe feed design achieves bandwidth up to 2.43GHz. Further to enhance bandwidth, microstrip feed line technique is applied which helps to overcome the problem of inductive effect of probe. Further, Monopole wide band antennas have been proposed. Slotting and defective ground structure techniques are used to improve bandwidth. Length of current flow has been modified and increased by incorporating rounded corner shape cuts to lower side of radiating patch. Rounded corner shape cuts to upper corner of partial ground plane has been introduced which helps to match impedance. Samples of design have been presented, results of simulated and fabricated designs are observed and analyzed. The novel key shaped oval slotted antenna with rounded corner and a groove-shaped notch in the partial ground is implemented. Implemented design resonates from 3.20GHz to 20.46GHz which covers FCC defined UWB, suitable for biomedical applications. Measurement has been carried out for simulated and fabricated designs. Parametric analysis has been carried out to observe effect of slot length and slot width and slot position. Theoretical analysis for few designs has been carried out and the work validates simulated and measured results.

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LIST OF ABBREVIATIONS

BW	Bandwidth
DGS	Defective Ground Structure
dB	Decibel
dBi	Decibels relative to isotropic
FCC	Federal Communication Commission
FR4	Flame Retardant
IEEE	Institute of electrical and electronics engineers
MI	Microwave Imaging
MPA	Microstrip Patch Antenna
MRI	Magnetic Resonance Imaging
MoM	Method of Moments
RMPA	Rectangular Microstrip Patch Antenna
SMA	Sub Miniature A
UWB	Ultra-Wide Band
VSWR	Voltage standing Wave Ratio
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
WILSI	Widex Infant Listening Skill Inventory

CHAPTER 1
INTRODUCTION

1.1 Preamble:

Accurate diagnosis of the diseases of human beings is major issues in today's leading biomedical field. Timely diagnosis of critical diseases like cancer, Tuberculosis, brain tumors still a challenging task and great need of society. Last decades show major cause of death is cancer. After heart diseases, various types of cancers are the major reason for early death. In India, out of 1,44,937 registered cases of cancer, 27% cases are related to breast cancer in the year 2017. Globally, this accounts 23% only for breast cancer. The incidence rates in India begin to rise in the early thirties and peak at ages 50-64 years. Out of 28, 1 woman is likely to develop breast cancer during her lifetime [1]. It is a group of diseases characterized by the uninhibited growth and spread of abnormal cells. If spread of abnormal cells is not controlled, it can result in death. Breast cancer is most serious type of cancer and second leading cancer that affects many women which occur in the prime of their lives. Breast cancer is a proliferation of malignant cells that arises in the breast tissue, specifically in the terminal ductal-lobular unit. It can be possible to prevent the undesired growth of malignant tissues in human body if they are being detected early and accurately [2-4]. Various methods exist to detect malignant tissues inside human body. However, these methods are limited due to their false positive and false negative diagnosis. Likewise, these techniques are trustworthy and individual isn't feel ease while experiencing it. Microwave Imaging is one of the upcoming innovations to beat every one of these limitations and give an answer to detect malignancy at the very early stage to keep the life of person [5-9]. Antenna is one of the key functionality to capture the reflected waves which can further be synthesized in the prognostics of the malignancy. This chapter covers brief Literature survey, Current research status, Motivation, Problem statement, Objectives and Organization of the Thesis.

1.2 Research Status:

From statistical study [10], obviously it is of quick and verifiable significance to discover new strategies for the early recognition of malignant growth so as to give treatment to patients as right on time as would be prudent. This won't just decrease mortality and frequency rates, yet in addition fundamentally facilitate the necessities on treatment and medical procedure, and the included expense to the medicinal services framework. Until ongoing years, there were not very many and less exact breast tumor discovery is fundamental in relieving the breast malignancy, nonetheless, because of the ongoing headways in innovation, breast tumor can be precisely distinguished and treated in a most of the subjects to spare the valuable human lives. The reason of this breast cancer is still remaining unidentified but it is found that early detection and treatment can considerably increase the survival rate [11-12]. In today's medical field, the most well-known and prevalent screening method for breast cancer detection, and malignant growth location finding is the mammography, Ultrasound and Magnetic Resonance Imaging. Numerous researches have been carried out around the world to detect and treat this kind of cancer.

Cancer detection techniques:

There are various cancer detection techniques available these are: X-ray Mammography, Ultrasound Method, Magnetic Resonance Imaging and Microwave Imaging Technique.

The researchers have proposed Microwave Imaging Technique which overcomes the limitations of existing cancer detection techniques and help to timely detect and diagnose cancer.

Microwave Imaging Technique

In Microwave Imaging Technique, antenna as a transmitter transmits the microwave signal into human body. When these signals hit a malignant structure, get scattered and reflect back, based on the dielectric properties of structure. The dielectric properties of the body get change due to malignancy. These scattered signals have enough information which helps to diagnose the malignancy. These signals have very wide bandwidth, would then be able to be received by using a sensor as an antenna.

However, the Wide Band Microstrip Patch Antenna is most appropriate contender for the Microwave Imaging in biomedical application. As the reflected signal from malignant tissue is supposed to be scattered, may have a very wide bandwidth. Therefore, it is a challenging task to design and develop wideband Microstrip Patch Antenna.

After the thorough literature review it is found that the existing research has been carried out on implementing multi band and wideband Microstrip antennas for various biomedical applications. Further the requirement of bandwidth of Microstrip patch antennas for biomedical applications has been increasing day by day. The demand of enhanced bandwidth from wideband to ultra- wideband results in complex designs of UWB Microstrip patch antennas. Therefore, for designing a simple, low profile UWB Microstrip patch antennas for biomedical applications is a challenging task for the antenna researchers. A very few designs have been proposed for biomedical application, having limited bandwidth, complex geometry and poor radiation characteristics. There is need of super wideband beyond 10 GHz antennas with improved radiation characteristics covering UWB band for biomedical applications.

Microwave imaging technique shows a high-level capability for sensing malignant tumors in the breast because of the differentiation in the dielectric properties of normal and malignant tissues of breast [13]-[15]. The fundamental standard is that tumor is a lossy dielectric medium that is encompassed by different sorts of lossy mediums that reason reflections and scatterings because of the boundary conditions. A normal breast comprises of fatty, fibro glandular and skin tissues with various dielectric properties and have diverse boundary conditions. Utilizing this data with properly designed structured antenna for biomedical devices, malignancy can be precisely identified. This is the fundamental research theme of this research work. Microwave Imaging (MI) gives various points of interest. A few of the advantages that can be accomplished by utilizing MI systems are high ease to the individual experiencing during the screening, high exactness, minimal effort, high penetration capacity with less risk to the breast tissues, high resist from the obstruction, and the utilization of low power non-ionizing electromagnetic waves contrasted with X-Ray and mammography procedures.

Deschamps first proposed the idea of the MPA in 1953, However, useful antennas were produced by Munson [16, 17] and Howell [18] over 20 years after the first recommendation was made in the1970s. With expanding prerequisites for individual and medical field, the interest for smaller, low-profile and high bandwidth antennas which effectively incorporate to biomedical apparatuses has conveyed the MPA to the cutting edge. An MPA in its most straightforward shape comprise of radiating patch on one side and a ground plane on opposite side. For wireless devices the antenna is a standout amongst the most basic segments. A decent structure of the antenna can relax prerequisites of system and enhance complete framework execution. Moreover, notwithstanding, the sorts of uses of MPAs are confined by the antennas intrinsically narrow bandwidth (BW).

The thorough literature survey about WB antenna literature has been carried out. The papers presented by the researchers in 1958, 1972 to 2018, total 104 papers related to the research work have been studied. The researchers have claimed to achieve the bandwidth up to 11GHz. The detail literature survey is presented in Chapter 2.

1.3 Motivation:

The fatal disease Cancer is the major cause of death all over the world. Among the different categories breast cancer shares the major percentage in females. The timely and precise diagnosis save the lives of the sufferers and reduce the expenses of treatment. The microwave imaging technique is one of the latest techniques proposed by the researchers for the detection of breast cancer. In microwave imaging technique the wideband antenna plays the key role.

From the literature survey it is observed that the Microstrip Patch Antenna with different feeding techniques have been proposed in microwave imaging. The bandwidth of the antenna has improved by using the notches, slots on radiating patch with partial ground or defective ground. Even though different techniques have been proposed for the improvement of bandwidth it is limited up to 11GHz. There is a further scope to improve the bandwidth. It is a great challenge and need to design and develop the wideband Microstrip Patch Antenna/Antenna Array for biomedical applications to operate within ultra- wide band range in giga hertz with bandwidth more than 11GHz.

1.4 Problem Statement and Objectives:

Considering the need of wideband Microstrip antenna in microwave imaging technique for the detection of abnormalities in human body, the research work is aimed at designing and developing the suitable bandwidth antenna.

Problem Statement:

The title of this research work is “Design and Development of Microstrip Patch Antennas/Antennas Array for Biomedical Application.”

Objectives of the Research work

The objectives of the research work are,

- To conduct extensive literature survey of microstrip patch antenna and understand the response of human body for the microwave signal.

- To study the performance parameters of single and multiband microstrip patch antenna for bio-medical applications.
- To identify the scope for research.
- To design and develop single and multiband microstrip patch antennas for bio-medical application.
- Simulate single and multiband microstrip patch antenna and fabricate the samples of designed antenna.
- To Test and measure the results of fabricated antenna, and validate the results.

This work is limited to fabricate the samples of antenna and the testing of multiband microstrip patch antennas/antenna array for the detection of abnormalities of human body is limited to simulations only.

1.5 Contributions:

This research work includes the designs of wide band microstrip patch antenna. The research contribution has been categorized into Probe Feed Rectangular Antenna and Probe Feed Modified Rectangular Antennas, Microstrip Line Feed Rectangular Antenna, Microstrip Line Feed Modified Rectangular Antennas, Microstrip Line Monopole Antenna, Microstrip Line Feed Modified Monopole Antennas and array antenna. These antennas are simulated using CADFEKO electromagnetic simulation tool and some of the antennas are fabricated. The performance of simulated and fabricated antennas is measured in terms of bandwidth, reflection coefficient, radiation pattern, surface current distribution and impedance.

The list of designed and simulated antennas is,

1. Rectangular Microstrip Patch Antenna.
2. U-Slot Loaded Rectangular Microstrip Patch Antenna.
3. U-Slot Rectangular Microstrip Patch Antenna with Defective Ground.
4. T-Slot Loaded Rectangular Microstrip Patch Antenna.
5. T-Slot Rectangular Microstrip Patch Antenna with Defective Ground.
6. Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground.
7. Notch Cut I-Slotted Rectangular Microstrip Patch Antenna.
8. Microstrip Line Feed Rectangular Microstrip Patch Antenna.

9. Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground.
10. Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.
11. Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.
12. Monopole Microstrip Patch antenna with Partial Ground.
13. Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna.
14. Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground.
15. Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground.
16. Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.
17. Slotted Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.
18. Oval shape Slotted Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground.
19. Oval shape Slotted Key Shape Monopole RMPA with Rounded Corner and Groove Shape Notch in Partial Ground.
20. Oval shape Slotted Key Shaped Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shaped Notch in Partial Ground.
21. 1×2 Simple Square Patch Array Antenna.

The list of fabricated antennas is,

1. Rectangular Microstrip Patch Antenna.
2. U-Slot Loaded Rectangular Microstrip Patch Antenna.
3. U-Slot Rectangular Microstrip Patch Antenna with Defective Ground.
4. T-Slot Loaded Rectangular Microstrip Patch Antenna.
5. T-Slot Rectangular Microstrip Patch Antenna with Defective Ground.
6. Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground.
7. Monopole Microstrip Patch antenna with Partial Ground.
8. Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna.

9. Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground.
10. Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground.
11. Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.
12. Slotted Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.
13. Oval shape Slotted Key Shape Monopole RMPA with Rounded Corner and Groove Shape Notch in Partial Ground.
14. Oval shape Slotted Key Shaped Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shaped Notch in Partial Ground.

Measuring Parameters:

To measure and compare the performance of UWB antenna the parameters used are:

Reflection Coefficient bandwidth, Voltage Standing Wave Ratio (VSWR) bandwidth, Radiation Pattern, Surface Current distribution and Impedance.

Reflection Coefficient bandwidth and (VSWR) bandwidth:

The VSWR is defined in terms of the input reflection coefficient Γas,

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{1}$$

Γ is a measure of reflected signal at the feed-point of the antenna. The reflection coefficient depends upon the input impedance of the antenna and output impedance of the feeding probe or microstrip line. In ideal case $Z_{in} = Z_0$ and reflected signal is zero. VSWR bandwidth has been measured between the frequencies at which the reflection coefficient is considered at below -10dB and referred as the reflection coefficient bandwidth and VSWR is below 2 referred as VSWR bandwidth.

Radiation Pattern:

It is a graphical representation of electric field distribution over the space. There are two types of principle radiation patterns: E-plane radiation pattern and H-plane radiation pattern.

Similarly, radiation pattern is observed in the elevation plane ($0 < \theta < 180^0$ or $-90^0 < \theta < 90^0$) and azimuth plane ($0 < \varphi < 360^0$) also. The radiation pattern exhibits the directivity of radiation. It helps to calculate the gain at resonance frequency/frequencies.

Surface current distribution:

It is a graphical representation of electric vector current on the surface of radiating patch and ground plane. The nature of surface current distribution helps to decide the possibility of resonance frequencies and scope for the improvement.

Input Impedance:

Input impedance of microstrip patch antenna can be represented in the form of real and imaginary part $R + jX$. This value is calculated at resonance frequency/frequencies. It helps to understand the problem of loading and its effect can be observed in radiation pattern.

1.6 Organization of Thesis:

The thesis is organized in five chapters viz Introduction, Literature Review, Design and Development of Wideband Antenna, Results and Inferences, and Conclusion and Future Scope.

Literature Review discusses the detailed study and extensive literature review on existing microwave wideband antenna and its applications confined to medical applications.

Design and Development of Wideband Antenna covers various designs of microstrip patch antennas. The design includes probe fed types of rectangular microstrip patch antennas and various microstrip line fed monopole antennas covering ultra-wideband frequencies.

Results and Inferences present the results of simulated and/or fabricated microstrip wideband antennas and the inferences based on the results.

Conclusion and Future Scope covers the conclusion and future scope of the research.

Chapter 2
Literature Survey

2.1 Overview:

The extensive literature review has been carried out regarding applications of Microstrip Patch Antennas (MPA) used in various biomedical applications. It has been studied that, for biomedical application wideband microstrip patch antennas are required. Various bandwidth enhancement techniques are also studied and reviewed. It is observed that, bandwidth is directly proportional to the thickness of substrate used, however, it may increase the overall volume of microstrip patch antenna. For biomedical applications compact, light-weight and low profile microstrip patch antennas are desired. Therefore, low thickness substrates are studied. It has been observed that using slotting, stacking techniques bandwidth can be enhanced. But, as the bandwidth is limited due to probe inductance, microstrip feed line technique is one of the techniques used to cope up with the problem of bandwidth limitation to some extent. The papers from various researchers of high repute journals are reviewed [1-104].

Microwave imaging is a science which has been evolved from older detecting/locating techniques in order to evaluate hidden or embedded objects in a structure (or media) using electromagnetic (EM) waves in microwave regime (i.e., ~300 MHz-300 GHz). The use of microwave imaging in biomedical applications were first demonstrated by Larsen and Jacobi *et.al.* in the late 70s and they designed a basic water-immersed antenna for biomedical applications [7]. This was the first time someone was starting the use of a biological object with microwaves, to create images of the internal structures of the body.

Recently researchers suggested the use of microwave imaging for breast tumor detection, in particular the biomedical application, offering a promising trade-off between imaging resolution and tissue penetration. Microwave imaging for biomedical is currently a very capable technology for wireless communications having characteristics of very high speed, high precision radars and imaging systems [8].

Microwave imaging of biomedical application have developed a massive amount of attention because of its one of the abilities to access the breast for imaging. The microwave breast imaging technique develops the signal scattering by an object when the object is illuminated by an electromagnetic signal. Microwave breast imaging (MBI) uses low power and longer wavelength signals as compared to X-ray mammography, to obtain information about breast tissues, and promises a safer and more accurate method for regular breast scanning. The signal scattering by an object depends on various factors, including the environment, signal strength, and the material dielectric properties of the object. This principle is utilized to detect the tumor in the breast using microwave signals. To reduce the effect of signal reflection from the breast skin, a new methodology of placing the antenna in-contact with the breast skin has been attempted. In this method, the skin is considered as a layer of the antenna substrate, and the effect of having the antenna in contact with the skin is included in the antenna design itself [9].

Over the past several years significant progress has been made in using microwaves for breast cancer detection. Microwave imaging can be defined as seeing the internal structure of an object by illuminating the object with low power electromagnetic wave at microwave frequencies. In the microwave frequency range, passive, hybrid and active approaches to breast cancer detection are being researched. Such methods would be beneficial to patients because both ionizing radiation and breast compression are avoided.

By considering the requirements of scattered microwave signal reflected from malignant tissue; Federal Communication Commission (FCC) has allotted unlicensed ultra -wideband range of frequencies from 3.1 GHz to 10.6 GHz for various biomedical applications. Antennas are an integral part of the wireless communication system; it attracts the minds of researches to have some modification in the present design technology to achieve better performance characteristics. The basic goal of antenna design with higher performance include wide bandwidth which covers basically UWB range along with size reduction which was obtained by various techniques such as slotting, metamaterial, defective ground structure and various feeding techniques. The antenna which is used as transmitter and receiver to transmit UWB signals must permit a high level of resolution. This requirement thus limits the class of antenna that can be utilized. The existing antennas used for breast cancer detection have been nothing but a compact microstrip antenna [11].

2.2 Microstrip Patch Antenna:

A new class of omnidirectional antenna has been discussed and they are: Wraparound microstrip antennas, Flat thin microstrip antennas and A phased array that consists of flat, (or curved) thin microstrip antennas. These antennas have capability of producing expectable and nearly perfect omnidirectional coverage (R.E. Munson, 1974) [12]., Microstrip antennas ideally suit to applications which require low-profile antenna elements or conformal arrays at frequencies from UHF up to *S* band have been discussed by the researcher [13].

A new method to analyze a microstrip antenna which involves representing the antenna by a fine wire grid immersed in a dielectric medium and then using Richmond's reaction formulation to evaluate the piecewise sinusoidal currents on the wire grid segments has been proved by Pradeep K. Agrawal And M. C. Bailey in 1977. This technique will help as an excellent tool to design microstrip antennas [14].

In 2011 Custodio Peixerio have presented historic perspective of development of microstrip patch antenna. Basically, a survey on microstrip patch antenna carried out initially along the evolution since last 40 years. It has been observed that since last 30 years the research development in microstrip patch antenna increased rapidly [15].

The comparison of three widely popular designs of microstrip patch antennas i.e. rectangular, square and hexagonal has been done by experimentation conducted by Vinita Mathur and Dr. Manisha Gupta in year 2014. Designing begins with the design of patches and then its analysis. All microstrip patch antennas have been analyzed using High Frequency Structure Simulator (HFSS) and dealt advantages such as low-profile structures, lightweight, high gain and compact size. [16]. The researchers concluded that,

- Rectangular and square patches have almost same radiation pattern.
- Feed line impedance value provides a good input output matching of the antennas and ideally its value is taken as 50 Ω.
- The performance of optimized hexagonal patch antenna is much improved in comparison to that of a conventional rectangular and square patch antenna.
- The simulated parameters are achieved with a substrate having high loss tangent value.

2.3 Probe feed technique of Microstrip Patch Antenna:

The coaxial feed or probe feed technique have been universally used for feeding microstrip patch antennas. In this technique, the inner conductor of the coaxial connector extends through the dielectric and it is soldered to the radiating patch, and the outer conductor is connected to ground plane. The main benefit of this type of feeding scheme is that the feed can be placed at any desired location on radiating patch in order to match with its input impedance.

In the presented work, the microstrip patch is short-circuited using a shorting pin and fed by a single probe feed. By varying the shorting-pin position in the microstrip patch, it can provide a large tunable frequency ratio of about 2.5–4.9 for the two different operating frequencies i.e. 464MHz and 2275MHz [17].

Jongkuk Park, Hyung-gi Na, and Seung-hun Baik (2004) have demonstrated that by replacing the bent part of an L-probe with a printed strip on a suspended substrate and by placing a radiating patch beneath the substrate, the antenna can be more easily fabricated as a planar antenna. An antenna has been fabricated for operation near 2.2 GHz and was found to have a broad impedance bandwidth with average gain of 7.8dB [18].

Because of various wireless interoperability microwave access (WiMAX) applications, U-shape slotted patch antennas have been drawing attention since last two decades. U shape slotted microstrip antenna have been proposed which work at four bands i.e. S-band, C-band and X band communication systems with appreciable gains. The substrate Teflon based material of permittivity 2.08 is selected. [19].

In 2017, T. Shanmuganatham, Deepanshu Kaushal have verified the structure and the result characterization of a multi band microstrip patch antenna which closely resemble Microsoft Calculator Accessory logo. The substrate used is FR4 epoxy substrate with a relative permittivity of 4.4. Multiple bands with considerable gain and significant bandwidth have registered. The design used a probe feeding mechanism owing to numerous advantages offered by it. The simulation software used is HFSS. The structure resonated at 6 different frequencies including 1.2 GHz offering a reflection coefficient of -24.9 dB and a bandwidth of 47 MHz for aeronautical radio navigation, 1.53 GHz with a reflection coefficient of - 16.9 dB and a bandwidth of 74.2 MHz for satellite communication, 2.56 GHz with a reflection coefficient of -29.7 dB and bandwidth of 121.7 MHz for wireless communication, 1.962 dB at 3.27 GHz with a reflection coefficient of -12.3 dB and a bandwidth of 62.7 MHz for private land mobile devices, 3.89 GHz with a reflection coefficient of -13.4 dB and a bandwidth of 68.4 MHz for fixed microwave devices and 5.91 GHz with a reflection coefficient of -17.3 dB and a bandwidth of 340 MHz for ISM equipment, personal land mobile, personal radio and amateur radio. [20].

2.4 Use of slotting and stacking methods on Microstrip Patch Antenna:

In 1984, H. Pues, Mem. I.E.E.E., and A. Van de Capelle Presented an accurate and numerically efficient model for the rectangular microstrip antenna which mainly concerns a transmission-line model featuring the following three major improvements with respect to earlier such models:

- The mutual radiative coupling (both real and imaginary parts) between the equivalent slots have been fully considered.
- The influence of the side slots on the radiation conductance considered implicitly.
- Simple analytic expressions are introduced for all relevant model parameters [21].

With the loading of a pair of right-angle slots and a modified U-shaped slot in a rectangular microstrip patch, novel bandwidth enhancement of microstrip antennas is demonstrated. The operating bandwidth obtained is 2.4 times more as compared with conventional microstrip patch antenna. The peak antenna gain 5.3dB is obtained with IE3D simulator software [22].

In 2003, Steven Weigand, Greg H. Huff, Kankan H. Pan, and Jennifer T. Bernhard have studied that a wide operating bandwidth for a single-layer coaxially fed rectangular microstrip patch antenna can be obtained by cutting a U-shaped slot on the patch. The substrate thickness and the feed point position remain important factors for broad-band frequency operation. The approximate design rules are derived by analysis of method of moments (MoM) simulations [23].

By loading properly arranged slots in a single-layer circular microstrip antenna, the novel bandwidth enhancement design have been proposed and experimentally studied by using a single probe feed. For the proposed broadband design, a pair of narrow arc-shaped slots placed close to the side edges of the circular patch and connected with a narrow rectangular slot oriented along the excited surface current direction of the fundamental resonant mode of the unslotted circular patch. By properly adjusting the narrow rectangular slot's length, broadband operation of the proposed circular microstrip antenna near its fundamental resonant mode can be achieved. And, it is found that the obtained impedance bandwidth in the proposed design can be greater than 2.3 times that of a conventional unslotted circular microstrip antenna [24].

To extend the surface-current path of dual operating bands, a novel compact dual-band equilateral-triangular slot antenna (ETSA) for 2.45GHz wireless local area networks (WLANs) have been designed with a pair of F-shaped strips centrally inset at the side edge of the ETSA. The obtained impedance bandwidths cover IEEE 802.11b/g and IEEE 802.11a. Peak antenna gains for the operating frequencies are measured to be, respectively, 2.8 and 5 dB [25].

A compact variation of the rectangular microstrip antenna (RMSA) with a half U-slot, which reduces the antenna area by half, have been proposed. Initially a U-slot RMSA etched on a glass epoxy substrate having relative permittivity of 4.3, thickness 0.16 cm, and loss tangent of 0.02 suspended over the ground plane with an air gap of 1.7cm have been discussed and its even-mode equivalent, a compact half U-slot (L shaped slot) RMSA, whose size reduced by half are presented. A variation of the U-slot, the stepped U-slot RMSA, is proposed and the BW of a compact shorted square MSA (SMSA) have been increased by cutting a half-stepped U-slot. All the MSAs have been initially optimized using the IE3D software [26].

A novel form of the familiar E-shaped patch antenna has been studied and implemented. In the presented approach, by using the genetic algorithm (GA) based on fuzzy decision-making, some modifications have been implemented to the incorporated slots which lead to even more enhancement in the antenna bandwidth. The Method of Moment (MOM) have been employed for analysis at the frequency band of 1.8GHz–2.6GHz by the optimization parameters of supply locations and slot dimensions. The obtained antenna bandwidth has been 36.7per cent which is observed larger than that of a corresponding unslotted rectangular microstrip antenna [27].

In 2008, Shing-Lung Steven Yang, Ahmed A. Kishk,and Kai-Fong Leehave studied and proved a frequency reconfigurable microstrip patch antenna in which incorporation of a U-slot in the patch can provide a flat input resistance and a linear input reactance across a wider bandwidth when compared with the conventional patch antenna. By placing a variable capacitor and an inductor at the antenna input, the impedance matching frequency of the antenna can be varied. The fabricated prototype antenna attains a tunable frequency range from 2.6 to 3.35 GHz [28].

J A Ansari, Satya Kesh Dubey and Prabhakar Singh, 2008 have found that a dual band antenna with specific frequency ratio can be designed by cutting a U-slot with suitable dimensions. Along with this researcher carried out the analysis of U- slot loaded patch using equivalent circuit concept. Parametric studies have been done which shows effect on dual resonance by varying slot dimension. The theoretical results are compared with the simulated data using IE3D software [29].

For WLAN application a very small size microstrip antenna have been presented. The main patch antenna consists of an M-shaped slot with shorting wall. The shorted triangular parasitic patch and a folded patch results in the overall antenna size is reduction. The simulated and measured results show that by selecting a proper shorting wall width, the proposed antenna can provide an impedance bandwidth of 21.17 per cent covering the 4.93–6.09 GHz band. The proposed antenna has 75 per cent surface size reduction compared to a conventional patch antenna operating at the same center frequency [30].

In 2009, Amit A. Deshmukh and K. P. Ray have proved that by cutting a half-U-slot and rectangular slot on the edges of the patch antenna gives more bandwidth as compared to only a single rectangular-slot-cut or a single half-U-slot-cut on rectangular microstrip antenna. The proposed antenna has broadside radiation pattern over the entire bandwidth. The proposed RMSA provides more than twice the bandwidth compared to the bandwidth given by single half-U-slot-cut RMSA or RMSA. The MSA has gain of more than 7dBi over the entire BW with the broadside radiation pattern [31].

With the use of L-probe feed and E-H microstrip patch, the antenna has achieved 30 per cent impedance bandwidth ranging from 1.76 GHz to 2.38 GHz and a maximum gain of 9.37 dBi. Furthermore, the parametric studies have been carried out to observe the effect which will be useful for antenna engineers to develop a better antenna. The proposed patch with dimension of 80mm×50mm have integrated both the E and H-shaped slots on the same radiating element. For the E-shaped patch, the slots have been embedded in parallel to the radiating edge of the patch symmetrically with respect to the centerline (*x*-axis) of the patch, and for the H-shaped patch, the slots have been embedded in series on the non-radiating edge of the patch. A dielectric substrate with dielectric permittivity of 2.2 and thickness of 1.5748mm has been used in proposed work. The thickness of the air-filled substrate is 16.0 mm. An aluminum plate with dimensions of 200mm×180mm and thickness of 1mm is used as the ground plane [32].

To provide a wideband matching in feeding system, a microstrip patch with a U-shaped slot that have been fed by a broadband electromagnetic coupling probe, known as L-probe which has been developed with RF-35 substrate having relative permittivity of 3.5, loss tangent of 0.0018 and thickness of 1.524 mm. Dimensions of the ground plane have been 100mm×100 mm to provide a wideband matching in feeding system, a broadband electromagnetic coupling probe have been used. Radiation characteristics of the antenna have been investigated experimentally and by numerical simulations. It has been observed that the antenna radiation pattern is broadside and cross-polarization level have been low at both resonant frequencies [33].

In 2010, J. A. Ansari, *et al* have discussed analysis of double U-shape slot merged in fed (Coaxial fed) rectangular patch. Microstrip patch has been considered as a parallel combination of capacitance, inductance and resistance. Slot in microstrip patch can be analyzed by using duality relationship between the dipole and the slot. From the analysis it has been observed that the bandwidth of the antenna mainly depends on slot thickness (d) and the value of Vertical slot length (Ws) [34].

Analysis of two parallel slots embedded in circular disk patch antenna have been studied and presented by J. A. Ansari, *et al*. in 2010. The proposed antenna exhibits dual band behavior working at 2.93 GHz and 3.52 GHz suitable for WLAN application. Research group proposed that the resonance frequency has been highly dependent on the slot dimension as well as substrate thickness. It has been found that upper resonance frequency remains constant while lower resonance frequency shifts towards lower side as the slot length increases. Also, as the value of h increases, lower resonance shifts towards higher side and upper resonance frequency shifts toward lower side and matching condition degrades as h increases. [35].

To achieve a dual frequency resonance, a half U-shaped slot in semicircular disk has been introduced in patch. It has been examined by using circuit theory concept. It has been observed that the slot length, feed point along with slot width have major effect on resonance which mean frequency depends inversely on the slot length and feed point, while it increases with increasing the slot width and coaxial probe feed radius. [36]

Dual-Band antennas have relative interest since they can support multiple communication systems. A new design of a novel compact small size microstrip antenna suitable for dual-band operations has been presented. By loading properly arranged slots on a rectangular microstrip patch, dual frequency and broadband operations of a single feed rectangular patch is achieved. Dual frequency operation has been achieved by loading two pair of narrow slots in rectangular patch, parallel to the non-radiating edge and better impedance bandwidth has been achieved by using two dielectric materials Rohacell RO3003 in combination with foam. The slotted antenna has been resonated at the two frequencies at 3.51 GHz (S-band) and 9.65 GHz (X-band). The return loss obtained -28.76db at 3.51 GHz and -24.8db at 9.65 GHz. The impedance bandwidth of 130MHz and 1.45GHz band have been obtained in the proposed design [26].

In order to achieve reduction in patch size up to 71 per cent, a dual frequency, compact single probe-feed rectangular microstrip patch antenna by cutting rectangular slits at two sides of the patch is considered in standard IE3DTM simulation tool instead of the single layered antenna which is designed to resonate in dual frequency mode [37].

In 2013, Radha Sharma has covered two aspects of microstrip antenna designs. The First aspect was nothing but the analysis and design of trapezoidal patch with V-shaped slot microstrip antenna which produce dual band operation. Resonance for the first band is at 3.26 GHz - 3.38 GHz and second band is 5.13 GHz - 5.96 GHz, operating in the WLAN Band. The gain of proposed antenna has showed the maximum achievable gain at first resonant frequency and it is about 5 .95 dBi over the entire frequency band of 3.26 GHz -3.38 GHz and 3.98 dBi maximum gains have been achieved at second resonant frequency over the entire band of 5.13 GHz - 5 .96 GHz and the gain showed stable performance. The Second aspect was an analysis and design of trapezoidal patch with H-shaped slot microstrip antenna which provides single band operation and operates at the central frequency of 4.48 GHz. Resonance occurred between 4.07 GHz -4.94 GHz which operated in INSAT/Super extended C-band for receiving purpose. The gain of proposed antenna has showed the maximum achievable gain of 4.58 dBi over the entire frequency band of 4 .07 GHz -4.94 GHz. The simulated and measured reflection characteristics of the antenna along with gain are presented and discussed and the proposed antenna is implemented on RT-Duroid with εr=2.2 and h=6 mm. [38].

A compact dual-polarized double E -shaped patch antenna with high isolation for pico base station applications have been presented in proposed communication. The proposed antenna has employed a stacked configuration composed of two layers of substrate. Two modified -shaped patches have been printed orthogonally on both sides of the upper substrate. Two probes have been used to excite the E-shaped patches, and each probe has been connected to one patch separately. A circular patch has been printed on the lower substrate to broaden the impedance bandwidth. Both simulated and measured results showed that the proposed antenna has a port isolation higher than 30 dB over the frequency band of 2.5 GHz – 2.7 GHz, while the return loss has been less than -15dB within the band. Moreover, stable radiation pattern with a peak gain of 6.8 dBi – 7.4 dBi have been obtained within the band [39].

A compact dual-band rectangular microstrip antenna (RMSA) has been realized by two different single-slotted single-band rectangular microstrip antennas with defective ground plane. A wide impedance band has been achieved by each open-ended slot in the single-slotted antenna. Also, by varying the length and position of each open-ended slot antenna, observed to operate in a suitable resonant band (5.15 GHz –5.35 GHz and 5.725 GHz –5.825 GHz**)** with compactness upto53.73per cent [40]**.**

A small and compact triple-band microstrip-fed printed monopole antenna for Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) has been designed by inserting L- and U-shaped slots on a rectangular radiating patch with a ground plane. Also a parametric study on the lengths of the U- and L-shaped slots of the proposed antenna have been carried out to obtain the required operational frequency bands i.e. WLAN (2.4 GHz /5.2 GHz /5.8 GHz) and WiMAX (2.5 GHz /3.5 GHz /5.5 GHz) [41].

It has been realized that by using an L-slot loaded ground and V-slotted patch antenna resonates at three bands. L-slot defected ground structure (DGS) and V-slotted patch antenna shows multiband operation at Wi-MAX/WLAN applications at 3.5 GHz (WiMAX) and 5.8 GHz and 7.5 GHz (WLAN) [42].

For overcoming the limitation on Bandwidth of a general Microstrip antenna, work on U-shaped patch antenna with two equal arms on FR4 epoxy substrate has been presented. A U-shaped slot has been introduced on the square shaped ground plane just under the U-shaped patch. In this communication the effect of size and shape of the ground plane on impedance bandwidth has been studied. Maximum impedance bandwidth of 13 per cent (5.1 GHz –5.8 GHz) has been obtained with introduction of U-shaped slot on the square shaped ground plane. The Voltage Standing Wave Ratio of the antenna at desired frequency has been observed as 1.2. The results of simulations have matched with measured results. The proposed antenna has simple structure & smaller in size as compared to the regular stacked or coplanar parasitic patch antennas.

The proposed antenna has given high gain & wideband, with simple & compact structure. Proposed design was highly suitable for wireless communications. [43]

Various stacked broadband microstrip antennas using compact variations of the rectangular microstrip antenna, such as C shaped, H-shaped, square-ring and S-shaped antennas, are proposed. The effects of using combinations of these compact antennas as a fed or stacked element on the bandwidth, gain, and radiation pattern of the antenna have been discussed. The square ring and C-shaped MSAs have the largest BW, whereas the H shaped MSA with a square ring gives lower cross-polarization levels. The stacked S-shaped MSA has larger gain and BW, but with a higher cross-polar levels, as compared to the stacked C- and H-shaped MSAs [44].

A wideband stacked microstrip patch antenna was presented by Mohammad Tariqul Islam, Norbahiah Misran, Mohammed Nazmus Shakib, and Baharudin Yatim in year 2008 . The proposed structure combines the merits of the stacked patch antennas and L-shaped feed for broadband operation. This paper has presented extended E and H shaped patch stacked with rectangular patch (53mm × 35mm). The composite effect of integrating inverting techniques and by introducing the proposed patch, offer a low profile, high gain, and compact antenna element. The simulated impedance bandwidth of the proposed antenna is 680 MHz (33per cent). It has been found that the wide bandwidth is caused by two-frequency resonances. The study showed maximum achievable gain of about 9.58 dBi and gain variation of 0.76 dBi between the frequency ranges of 1.72GHz to 2.4GHz [45].

2.5 Microstrip Line Feed techniques:

In 1993, Masoud Kahrizi, Tapan K. Sarkar, and Zoran A. Maricevic have studied and described analysis of a wide rectangular radiating slot excited by a microstrip line. Coupled integral equations have been formulated to find the electric current distribution on the feed line and the electric field in the aperture. The solution basically based on the method of moments and it has used the space domain Somerfield type Green’s function. The information about the input impedance or reflection coefficient have been extracted from the electric current distribution on the microstrip line by utilizing the matrix pencil technique [46].

In 2000, Wen-Shyang Chen, Kin-Lu Wong, and Chun-Kun Wu proposed Circular polarization (CP) designs of inset microstrip-fed microstrip antennas and three designs with a single slit, two pairs of slits, and three pairs of slits have been experimentally studied. The excited patch surface currents have meandered in the proposed designs, and the obtained center CP frequency would greatly be lowered. In addition to good CP radiation obtained, a large antenna size reduction for operating at a fixed frequency was obtained by using the proposed antennas in place of the conventional CP antennas with simple patches [47].

In 2005, D. Chen and C. H. Cheng presented a novel ultra-wideband wide-slot antenna fed with a microstrip- line which composed of a circular microstrip patch and a semicircular arc cut on the ground of the microstrip line with substrate having relative permittivity of 2.65 and thickness of 1.0 mm. with length and width of 82.5 mm and 54.5 mm, respectively. The diameter of the circular patch was 20.3 mm. The length and width of the wide-slot was 47mm and38.5mm respectively. The gap size between the circular patch and the side of the slot has been set to 1.2mm. The microstrip feed-line has been designed at 75 Ohm. However, the microstrip line at the input of the antenna designed at 50 Ohm for connection to a cable with a characteristic impedance of 50 Ohm. The length of the tapered microstrip line for the impedance conversion from 75 Ohm to 50 Ohm has been 15.75 mm. The measured results show that the proposed antenna has an impedance bandwidth of more than 150 per cent with center frequency of 6.1GHz [48].

In 2007 Lin-Yu Tseng and Tuan-Yung Han have presented a printed slot broadband circular polarization (CP) antenna. The proposed antenna has been excited by an L-shaped strip with a taper end, connected in series to a microstrip-line-fed located along the diagonal line of the circular-slot. A circular slot of radius 18.8 mm was etched on the ground plane of a FR4 substrate with thickness 1.6 mm and relative dielectric permittivity of 4.4. The L-shaped strip with a taper end is fabricated directly opposite the circular slot. The measured results demonstrated a circular polarization and impedance bandwidth of around 44 per cent and 38 per cent, respectively [49].

In 2011 Wen-Chung Liu, Chao-Ming Wu, and Yang Dai have proposed multiband operation, a novel triple-frequency microstrip-fed planar monopole antenna which mainly consist of Defected ground structure (DGS), having a rectangular patch with dual inverted L-shaped strips and which has been fed by a cross-shaped strip line to achieve additional resonances and wide bandwidth. The designed antenna has a small size of 20 × 30 mm and operates over the frequency ranges, 2.14 GHz –2.52 GHz, 2.82 GHz –3.74 GHz, and 5.15 GHz –6.02 GHz suitable for WLAN 2.4 GHz /5.2 GHz /5.8

GHz and WiMAX 3.5 GHz /5.5 GHz applications. Measured and simulated results demonstrated good agreement. Experimental results show that the antenna gives monopole-like radiation patterns and large antenna gains over the operating bands [50].

In 2011, Yazhou Wang, Aly E. Fathy have presented a novel compact tapered microstrip slot antenna for microwave breast imaging assuming that it will be embedded in breast tissues rather than air. By using a microstrip tapered slot with a fork shaped feeding structure, the designed antenna has achieved a good matching performance at 2 GHz to 8 GHz with compact size. By considering that the antenna radiates into the breast tissue rather than into air in the design stage, the antenna has demonstrated a very good performance when facing the breast tissue. The designed antenna also shows good near-field radiation characteristics [51].

In 2012, Y. Sung has studied and experimentally investigated a printed wide-slot antenna with a parasitic patch for bandwidth enhancement. A simple 50- microstrip line is used to excite the slot. A rotated square slot resonator has been considered as reference geometry. The rotated square slot antenna exhibits two resonances. By embedding a parasitic patch into the center of the rotated square slot, the lower resonant frequency shifted towards lower side and the higher resonant frequency shifted towards higher side alternately. The results demonstrated that, antenna structure exhibits a wide impedance bandwidth, which has over 80 per cent frequencies ranging from 2.23 GHz to 5.35 GHz. A stable and omnidirectional radiation pattern has been observed within the operating bandwidth [52].

In 2013, Wenwen Yang, Jianyi Zhou have proposed a technique to design a wideband low profile microstrip patch antenna along with low fabrication cost, easy integration with planar circuits. It has the advantages of high gain and wideband consisting of single dielectric layer, a tooth-like-slot patch on the top of the dielectric layer and ground plane on the bottom with an inset feeding microstrip line. The projected antenna has been designed with the center frequency chosen at 10 GHz. Full wave simulations of the antenna have been carried out by using Ansoft HFSS. The prototypes with single element achieved a bandwidth of 10.5 per cent for -10dB return loss and a gain of 9.4dBi [53].

Roy C. Park, in 2013, has proposed novel methods for integrating and constructing broadband microstrip antennas, particularly at high microwave and millimeter wave frequencies where dimensions get very small and fabrication tolerances have been critical. Researcher suggested reliable methods of creating high frequency integrable microstrip patch antennas that maintains a broad bandwidth and reduced substrate mode generation. Along line-fed patch antenna created on a high permittivity substrate with an air-filled cavity machined into the carrier/package exhibited enhanced gain and bandwidth performance. The return loss bandwidth for the edge-fed cavity backed antenna was 1.7 per cent, compared to 0.5per cent for the conventional long line-fed patch. Also, the cavity backed gain observed to be 1.5 dB greater than the conventional long edge-fed patch antenna [54].

In 2014, Richa Chandel, A. K. Gautam, and Binod Kr. Kanaujia have proposed a novel microstrip-line fed beak-shaped monopole-like slot UWB antenna to achieve ultra-wideband for Bluetooth, GPS, and GSM applications. Designed geometry has a beak-shaped radiating patch fed by a microstrip-line and a square ground plane has been defected by etching a hexagonal slot. Two triangular slots in the beak-shaped radiator and hexagon-shaped defect in the ground plane have been used to obtain GPS (1520 MHz –1590 MHz), GSM (1770 MHz –1840 MHz), and Bluetooth (2385 MHz –2490 MHz). Furthermore, the bandwidth of an antenna was increased by etching a triangular slot at the junction of patch and feeding line which has been fabricated on 1.6 mm thick commercially available FR4 material [55].

In 2014, Mohammad Aneesh*, Jamshed A. Ansari, Ashish Singh, Kamakshi, and Saiyed S. Sayeed have proposed artificial neural network-based design to model the parametric analysis of the slot-loaded microstrip line feed patch antenna. The bandwidths of the proposed antenna obtained at TM01, TM02, and TM03 frequency modes are 10.2 GHz, 13.6 GHz, and 17.2 GHz, respectively. The proposed antenna consists of microstrip line feeding, notches, and it has been loaded with two parallel slots. [56].

In 2015, Jamshed A. Ansari, Sapna Verma, Mahesh K. Verma, and Neelesh Agrawal have been proposed novel wide band microstrip line-fed antenna with defected ground structure for C-band and partially X-band operation which has a circularly polarized characteristic. Initially antenna consists of microstrip-line-feed, and the square-shaped slot and a defect has been incorporated in the ground plane. Furthermore, rectangular and circular patches are embedded in the square-shaped slot that improves the performance of the radiating because of which the antenna show advantages like compactness in size and a good quality of polarization at resonant frequency band with impedance bandwidth of 40.72 per cent in the frequency range 6.45 GHz – 9.75 GHz [57].

In 2016, Kendrick Q. Henderson, Saeed I. Latif, , and Georgios Y. Lazarou have proposed a Microstrip line-fed slot antenna to operate in the entire 4G/LTE band. The slot antenna has the a ‘L’ shape, and when excited with a transmission line generates multiple modes. Two L-shaped slots introduced on each side of the top corners of the ground plane. The overall length of each slot is 41.8 mm and this size has one quarter of a wavelength at 1800 MHz frequency. The vertical slot length: $L1 = 27.8\,mm$ and the horizontal slot length: $L2 = 14\,mm$ on each side. Initially only the slot in the top right corner has been fed by a 50-Ω microstrip transmission line that has been excited by a 50-Ω SMA probe. These modes have combined to obtain the large bandwidth for covering most of the 4G/LTE band. Several feed lines have been studied to enhance the bandwidth. The slot width also varied to achieve large impedance bandwidth. The radiation patterns show the behavior of the antenna. This antenna can be further optimized to provide polarization diversity in the 4G/LTE systems [58].

2.6 Early detection of breast cancer and microstrip patch antenna for Biomedical Application:

Breast cancer is a cancer that develops from breast tissues. Signs of breast cancer may include a lump in the breast, a change in breast shape, dimpling of the skin, fluid coming from the nipple, a newly inverted nipple, or a red or scaly patch of skin. Now a days X-ray mammography technique is used to detect the breast cancer. But the major drawback in this technique is the ionizing radiation level from X-rays which leads to cell death, cell mutation and fatal damage within the body. So, the Microwave Imaging (MI) technique is proposed to get the information about breast tissues using antenna structure.

In 1999, Susan C. Hagness, Allen Taflove, and Jack E. Bridges have investigated a new ultra-wide-band (UWB) microwave radar technology to detect and image early-stage malignant breast tumors that are often invisible to X rays. In the proposed work basically, the methodology and initial results of three-dimensional (3-D) finite-difference time-domain (FDTD) simulations have been implemented. The discussion mainly focuses on the design of a single resistively loaded bowtie antenna element of a proposed confocal sensor array. The dynamic range of a sensor array comprised of such elements integrating with existing microwave equipment to detect small cancerous tumors usually missed by X-ray mammography [59].

To radiate directly into a dielectric medium that has similar dielectric properties to breast tissues, a patch antenna has been presented which consists of two stacked patches printed on a dielectric substrate of ε_r= 2.2 and separated from the ground plane by a second substrate of ε_r = 10.2. A higher dielectric permittivity was chosen as the antenna radiates into a high permittivity medium and which minimizes the size of the patches. The antenna geometry presented by means of simulation and practical measurement to possess a wide input bandwidth, stable radiation patterns and a good front-to-back ratio. These results show the antenna has a -10dB antenna-feed match from 4 GHz to 9 GHz, with the exception of a small mid-band mismatch at 6.5GHz [60].

An optimal antenna array design is likely to improve a microwave imaging system's ability to detect and resolve tumors by maximizing the system's signal to- noise ratio (SNR) and spatial sampling density while minimizing the effect of mutual coupling. A novel antenna array of tapered microstrip patch antennas operating at 2.7 GHz has been investigated [61].

In 2009, J. Yu, M. Yuan, and Q. H. Liu have proposed a simple half oval patch antenna for the active breast cancer imaging over a wide bandwidth. The antenna consists of a half oval and a trapezium, with a total length 15.1mm and is fed by a coaxial cable. Both simulation and measurement results show that the return loss of the proposed antenna observed to be less than 10 dB from 2.7 GHz to 5 GHz [62].

In 2010, Mudar A. Al-Joumayly, Suzette M. Aguilar, Nader Behdad, and Susan C. Hagness have studied and implemented a three-dimensional (3-D) microwave tomography system for breast imaging, a dual-band slot-loaded patch antenna comprising two slots parallel to and near the radiating edges of the patch and a third slot located at the center of the patch. By manipulating the fundamental resonant mode of the patch antenna and one of its higher order modes, dual band operation has been achieved. Miniaturization and tuning of the resonant frequencies are achieved by loading the antenna with non-radiating slots at strategic locations along the patch. Two samples of given antenna were fabricated and verified experimentally in a biocompatible immersion medium. The results of these fabricated samples indicate that given structure proposed to be suitable candidate in array for multi frequency microwave breast imaging where high signal-to-noise ratio have been expected [63].

In 2010, David Gibbins, Maciej Klemm, Ian J. Craddock, Jack A. Leendertz, Alan Preece, and Ralph Benjamin have proposed a system based on the principle of synthetically focused UWB radar using a fully populated static array, a wide-slot UWB antenna which mainly consists of an approximately square slot set in a ground plane on one side of a substrate having relative permittivity of 10.2 while On the other side of the substrate forked microstrip feed have been incorporated, that splits just below the slot, from a 50 Ohm feed into two 100 Ohm sections which has excited the slot used in the detection scheme. The fork feed has been chosen as a means of increasing the operational bandwidth. The antenna's measured and simulated, input and radiation characteristics are open and equated to an existing, stacked patch antenna that has been designed for the same purpose. The results of this study show that the wide-slot antenna has excellent performance across the required frequency range [64].

In 2013, Matteo Bassi, Michele Caruso, Muhammad Saeed Khan, Andrea Bevilacqua, Antonio-Daniele Capobianco, and Andrea Neviani have proposed and implemented a basic module of the imaging antenna array mainly consisting of a custom integrated circuit implemented in a 65-nm CMOS technology and a pair of patch antennas in which the semicircular part acts as a tapering section for better impedance matching all over the bandwidth to the 50 Ohm microstrip feeding line. In order to obtain a compact design, the two monopoles are placed very close to each other on the same face of the substrate. To minimize the unavoidable mutual coupling between the antennas, a T-shaped decoupling structure has been introduced on the back of the laminate. The radar operates on the broad frequency range from 2 GHz to 16 GHz [65].

In 2013, S.Banu, A.Vishwapriya, R.Yogamathi have proposed a design of a circular patch antenna using flexible FR4 substrate with the radius of 14.5 mm having a rectangular shaped slot in the ground. The given antenna geometry used on the skin model to get the cancer level within the body. Both the models get designed in Ansoft HFSS software over an operating frequency range of 2.5GHz. The results of the proposed antenna get evaluated such as return loss, VSWR, gain, directivity which have been achieved of about -21dB, 1.2 dB, 4.404dB, 4.48dB [66].

In 2015, Rabia Çaliskana, S. Sinan Gültekin, Dilek Uzer, Ozgur Dundar have proposed a 3D breast structure having different permittivity and conductivity has been modeled in HFSS by using Finite Element Method (FEM) to solve electromagnetic field values and a rectangular microstrip patch antenna operating at 2.45 GHz has been designed and it has used substrate material FR4 having relative permittivity of 4.4 F/m.

Researcher also found that slotting on microstrip patch and modifying ground plane have improved imaging quality of system [67].

Antenna which operate in the Industrial, Scientific, and Medical (ISM) band (2.4 GHz –2.4835 GHz) for biomedical applications have been implanted using a flexible folded slot dipole. To make the designed antenna appropriate for implantation, it is embedded in biocompatible Polydimethylsiloxane (PDMS).

In 2013, Wanlan Yang, Kaixue Ma, Kiat Seng Yeo, Wei Meng Lim, and Zhi Hui Kong have presented the design of a low-profile dual-band planar antenna using 50 Ω input port and on LTCC substrate with $\varepsilon_r = 7.1$ and $\tan\delta = 0.005$ in meandered shape with microstrip line feed for biomedical applications. The presented structure operates in the ZigBee dual band 868 MHz -928 MHz and 2.4 GHz -2.5 GHz respectively. [69]

Now a day there is a very high demand on miniaturized antennas for implantable medical devices (IMDs). So, a novel design of a Planar Inverted–F Antenna (PIFA) for biomedical applications in the medical implant and communication service band (MICS) 402 MHz -405MHz has been studied and implemented. The planned antenna has a multi-layered structure consisting of a ground plane and two circular patches (radiators), lower patch and upper patch. The upper patch has the mirror image of the lower patch etched on the second layer substrate [70].

For industrial-scientific-medical (2.4GHz –2.48 GHz) biomedical applications, a single-fed miniaturized circularly polarized microstrip patch antenna have been considered and experimentally verified. The projected antenna structure was designed by utilizing the capacitive loading on the radiator [71].

In 2017, N. Mahalakshmi, A. Thenmozhi have presented a novel hexagon shape bow-tie antenna for implantable bio-medical application at a frequency ranging from 2.4 GHz to 2.48 GHz of ISM band. In order to achieve high frequency response, the proposed antenna has been designed with CPW feed. Alumina ceramic $A_{l2}O_3$ is used as the substrate material with 1 mm thickness and the dielectric constant is 9.8. The main advantage of the proposed system is that it has reduced the size with increased accuracy. The proposed antenna possesses the return loss of -29 dB at 2.43 GHz [72].

The proposed antenna of a rectangular structure composed of a ground plane, a slotted radiating patch, a substrate and a superstrate. The radiating patch has been Sandwiched between the ground plane and a rectangular patch. Rogers 3210 substrate with $\varepsilon_r = 10.2$ and $\tan\delta = 0.003$ has been used with thickness equal to 0.635mm. At the top of the radiating element, superstrate with the same material of the substrate has been used. The use of the superstrate (Rogers RO3210) is to ensure the biocompatibility and to prevent contact between antenna and human tissue. The superstrate also assists the antenna to well match to 50 Ω through decreasing the effects of the high conductive biological tissues [73].

Dinesh. S Vivek Priyan. R Mrs. R. Lothichitra (2015) have proposed an implantable antenna for short-range biomedical applications. The design of implantable antennas mainly emphasizes miniaturization and biocompatibility, also conserving energy to extend the life span of the implantable medical device. The implantable antenna is operating in Industrial, Scientific and Medical (ISM) (2.4 GHz-2.48 GHz) bands. The simulated return losses have -14 dB at the resonant frequency of 2.45 GHz. The return loss achieved from -14dB to - 19dB and the VSWR values have been achieved from 1.4to 1.28 [74].

2.7 UWB Antennas history:

Ultra-Wideband, a new class of antenna is a carrier-less short-range communications technology which transmits the information in the form of very short pulses. This earlier military technology has gained a lot of popularity among researchers and the wireless industry. UWB has also offered high data rates at short distances with low power, primarily because of wide resolution bandwidth. A rectangular monopole on one side of an FR4 substrate of thickness 1.6 mm and relative permittivity 4.4 with the partial ground plane located on the other side has been practically studied and experimented. The antenna gave excellent performance for UWB system, ranging from 3.7 GHz to 13.8 GHz. Width of the partial ground, the width of the feed line and position of the feed line played an important role for appropriate frequency band [75].

In 2008, J. Rashed-Mohassel, N. Ghassemi have presented an aperture coupled microstrip antenna with a rectangular patch located on top of two slots on the ground plane with U shaped feed line for UWB application. The patch and slots have been separated by an air gap and a material with low dielectric constant and relative permittivity of 2.2. There was a 50Ω feed line which was divided into two 100Ω feed lines by a two-way microstrip power divider under the ground plane. Simulation results show that the antenna has VSWR less than 2 for 5.3 GHz –13.2 GHz [76].

In 2012, Wen Jiang and Wenquan Che have investigated a novel planar ultra-wideband (UWB) antenna with dual notched bands consisting of a square patch and a modified grounded plane. To understand dual notched bands characteristics, a T-shaped stub embedded in the square slot of the radiation patch and a pair of U-shaped parasitic strips beside the feed line has been used. The antenna structure has been fabricated on Rogers4003 substrate with dielectric constant of 3.38 and thickness of 0.8 mm. The radiating element and feeding line printed on the top side of the substrate and the ground plane on the bottom side. The width of the microstrip feed line is chosen as 2 mm to achieve the characteristic impedance of 50 Ohm. The antenna showed a wide bandwidth from 2.8 GHz to 11.0 GHz defined by voltage standing wave ratio, with two notched bands of 3.3 GHz -4.0 GHz (WiMAX band) and 5.05 GHz –5.90 GHz (WLAN band), respectively. Both the experimental and simulated results of the proposed antenna were presented, indicating that the antenna is good candidate for various UWB applications [77].

2.7.1 UWB for Microwave Imaging:

For the proposed antenna two type of rectangular patches are used, one patch is a rectangular ring and other is a small rectangular patch. Rectangular ring patch is used for radiation and small rectangular patch is used for coaxial probe feed. Hole on radiating patch will increase the bandwidth of antenna. But it doesn't mean that increasing more and more area of hole, increases the bandwidth of an antenna. Proposed antenna has a return loss less than -9.5 dB loss from frequency range 4.4 GHz to 8.42 GHz and bandwidth of antenna is 4.02 GHz. This wide bandwidth is useful for taking image with high resolution and it also help in fast signal processing. This antenna has 66.44per cent impedance bandwidth so it is UWB antenna because we all know that UWB devices have at least 20per cent impedance bandwidth [78].

In 2014, M. Aziz ul Haqand M. Arif Khan have proposed an antenna with the ring slots on FR-4 substrate and it has fed through a microstrip line by optimizing the width and the position of the feed along with the width of the partial ground structure. The main antenna consists of four circular rings. Circular patch antennas have wide use in wireless transceiver applications because of their consistent radiation patterns [79].

In 2014, Lee Chia Ping and Chandan Kumar Chakrabarty have studied the bending effect of Ultra-Wideband (UWB) antenna, Comparisons have been made between antenna without bending and antenna with bending. From detail study and simulated result, it has been observed that the bending antenna exhibits poorer performance than the antenna without bending, but still complying with UWB characteristics. The bending of antenna did not drastically affect the antenna performances. The bending of antenna causes a shift in resonant frequencies while displaying impedance bandwidth from 3.5 GHz to 5.47 GHz and 6.25 GHz to 10.4 GHz, compared to the antenna without bending ,3.45 GHz to 11.14 GHz. This indicates the impedance bandwidth has minimally affected. Besides, there are no significant changes in terms of other antenna performances such as radiation patterns, VSWR, phase angle and input impedance [80].

For Ultra-Wide Band applications, the design of new compact printed broadband antennas has been presented which mainly based on the CPW-fed combined with a slot and a stub line to increase the bandwidth. The proposed antennas have been successfully designed, optimized and simulated by using Momentum software integrated into Advanced Design System (ADS) and CST Microwave Studio. The measured input impedance bandwidth of the final broadband antennas ranging from 2.1 GHz -7.3 and 2.1-11 GHz [81].

2.7.2 UWB as Monopole Patch Antenna:

In 2005, Kyungho Chung, Jaemoung Kim, *Senior Member, IEEE*, and Jaehoon Choi have proposed an antenna to increase the impedance bandwidth. They have used a narrow slit in rectangular patch. By inserting a modified inverted U-slot on the proposed antenna, the frequency band notch characteristic has satisfied the voltage standing wave ratio requirement of less than 2.0 in the frequency band between 3 GHz and 11 GHz [82].

In 2008, Marco A. Antoniades, and George V. Eleftheriades have proposed a compact multiband antenna that consists of a printed circular disc monopole antenna with an L-shaped slot cut out of the ground, forming a defected ground plane. It has been studied and proved by doing analysis of current distribution of antenna that at low frequencies the addition of the slot creates two orthogonal current paths, which are responsible for two additional resonances in the response of the antenna [83].

In 2008, X.-C. Yin, C.-L. Ruan, C.-Y. Ding, and J.-H. Chu have studied and developed an ultra-wideband (UWB) U type monopole antenna fed by a coplanar waveguide (CPW) antenna which resonates from3.08GHz to 12. 75GHz.Parametric study shows that the small changes in the spacing between edge of ground plane and U type-loaded has an effect on the impedance matching of the proposed antenna [84].

By cutting two modified E-shaped slots with variable dimensions on the ground plane corners and also by inserting two T-shaped strips inside the rectangular slot located in the ground plane center, additional resonances are excited, and hence much wider impedance bandwidth (2.97 GHz -12.83GHz) can be produced, especially at the higher band. Square shape patch has been designed, it shows a good omnidirectional radiation pattern [85].

In 2015, Ugur Alkasi, Tughan Caglayan, Habibullah Ahmadzay and Mehmet Cayoren have proposed two methods in terms of bandwidth broadening for monopole slot ultra-wideband (UWB) antennas supporting mobile terminal applications. The original antenna has a bandwidth of 9.27 GHz (1.73 GHz –11 GHz) that covers PCS1900, UMTS2000, TD-SCDMA, WLAN 802.11b/g or Bluetooth, LTE, WiMAX, and UWB frequency ranges. Later, by cutting two new slots on the ground plane, the antenna can expand its bandwidth to 9.33 GHz (1.67 GHz –11 GHz) which supports extra DVB-H, DCS1800 services. Two different methods have been investigated to broaden the bandwidth of the monopole antennas. By cutting slots on the system ground plane additional resonances generated which can be coupled to original resonances of the antenna, which can contribute to bandwidth enhancement. In this method two slots have been used in the monopole slot UWB antenna as the new slots placing on the ground plane. The bandwidth can be expanded from 9.27 GHz to 9.33 GHz by changing the two methods [86].

The researchers have discussed the antenna, which has a rectangular shape having substrate with FR-4 material with relative permittivity of 4.3, a rectangular PEC ground, a discrete port which is designed for a coaxial cable feed, and two radiation elements printed on the substrate which has also made using PEC material. The antenna has a triple band operating region in free-space at frequencies 1.1 GHz, 2.75 GHz and 3.92 GHz [87].

In 2016, Chandu D.S., and S. S. Karthikeyan have presented a broadband dual circularly polarized (CP) planar monopole antenna which has fed by dual orthogonal microstrip lines for polarization diversity. Circular polarization has been achieved with a modified ground-plane structure and the isolation between the ports and improved by extending a protruded strip between the feed lines. L-shaped strips (LSSs) and inverted L-shaped strips (ILSSs) are designed along the radiating edges of the monopole to improve bandwidth up to80.7 per cent (3.74 GHz -8.8 GHz) [88].

A novel cactus-shaped Ultra-Wideband (UWB) monopole antenna fabricated on Liquid Crystal Polymer (LCP) have been studied and proposed which have a very compact design since it can be fabricated on a board with dimensions only 20mm×28 mm, while the three linear segments that comprise the cactus-shaped monopole provide a direct control on antenna matching. The proposed antenna has been operated from 2.85 GHz to 11.85 GHz and it gave very consistent omni-directional patterns throughout the UWB frequency range [89].

2.8 Metamaterial and Array Techniques:

In the proposed work, a rectangular slotted microstrip patch antenna with partially loaded metamaterial multiple-split ring resonator (MSRR)ground plane have been presented. In unloaded condition, the rectangular slotted patch antenna resonates at *9.38* GHz. When the same antenna is loaded with MSRR in the ground plane, it resonates at lower resonant frequencies 4.60 GHz and 7.70 GHz respectively. The mutual coupling between the slots leading to mismatch at lower resonant frequencies have been analysed. The MSRR loading reduces the mutual coupling in order to obtain better matching at these resonant frequencies [90].

In 2012, J.G. Joshi, Shyam S. Pattnaik have presented a planar metamaterial-based magneto-inductive (MI) waveguide loaded rectangular microstrip patch antenna. The MI waveguide consists of transverse array of three metamaterial split ring resonators (SRRs) placed in between the two microstrip lines.

The rectangular microstrip patch antenna has been magnetically coupled with the MI waveguide. The unloaded rectangular microstrip patch antenna resonates at 23 GHz. Under loading condition, the resonant frequency of rectangular microstrip antenna is reduced to 6.05 GHz with an impedance bandwidth and gain of 253 MHz and 6.25 dBi respectively. The pass band frequency of MI waveguide is calculated by using the theoretical model of dispersion equation [91].

In 2016, Vasujadevi Midasala, Dr. P. Siddaiah have proposed a 3×3 antenna array of rectangular topology to operate at Ku Band. The antenna has been designed as arrays of patches. Antenna array has achieved a gain of 17.29db, which has much more as compared to normal patch antenna [92].

In 2014, Ricardo Meneses González Hayat Errifi and Shivani Singh have presented an antenna which has a 2×1, 4×1 and 4×4 array antennas, based on E-type microstrip slot antenna which shows greater directivity and gain performance.

These arrays have been designed to operate at a frequency of 10 GHz. Using antenna array the gain obtained is more as compared to normal patch antenna [93-95].

2.9 Research Gap and challenge:

After the thorough literature review it is found that the existing research has been carried out on implementing multi band and wideband microstrip antennas for various biomedical applications. Further the requirement of bandwidth of microstrip patch antennas for biomedical applications has been increasing day by day. The demand of enhanced bandwidth from wideband to ultra- wideband results in complex designs of UWB microstrip patch antennas. Therefore, to designing of a simple, low profile UWB microstrip patch antennas for biomedical applications is a challenging task for antenna researchers. A very few designs have been proposed for biomedical application, having limited bandwidth, complex geometry and poor radiation characteristics. There is need of super wideband beyond 10 GHz antennas with improved radiation characteristics covering UWB band for biomedical applications.

Chapter 3

DESIGN AND DEVELOPMENT OF WIDEBAND ANTENNA

3.1 Overview:

Microstrip patch antenna is a low profile, narrowband, wide pillar radio antenna created by scratching receiving antenna component design in metal follow attached to a protecting dielectric substrate, for example, PCB with a metal layer clung to an opposite side of substrate which shape a ground plane. Microstrip patch antenna is also called as printed reception apparatus as it is specifically imprinted onto circuit board. Essentially, a miniaturized scale microstrip antenna is only a metallic fix suspended over a ground plane. It is built on dielectric substrate utilizing a procedure like lithography.

A microstrip patch antenna in its easiest arrangement comprising of transmitting patch on one side of a dielectric substrate which has ground plane on opposite side. Major operational drawbacks of microstrip patch antenna are low productivity, low power, high Q and false feed radiations from feed point and limited transfer speed.

The general objective of configuration is to accomplish particular execution attributes at planned operating frequency. In the event that microstrip patch antenna can accomplish these general objectives then the principal choice is to choose reasonable antenna geometry. Rectangular patch antenna can be planned utilizing the accompanying methodology.

Substrate Selection:

First design step is to pick reasonable dielectric substrate of proper thickness and loss tangent. Thicker substrate other than being mechanically strong, will build the radiated power, diminish conductor loss, and enhance impedance bandwidth.

Transmission Line Model:

Transmission line model is simplest model to understand the execution of a microstrip patch antenna. The operation of this model is mainly based on equivalent magnetic current distribution around the patch edges [24]. The patch is represented by two conductors that are isolated by dielectric having thickness in terms of wavelength.

This model was proposed for rectangular patches but has been extended for other patch shapes also. Patch width has minor effect on the resonant frequency and radiation pattern on microstrip antenna. It affects the input resistance and bandwidth. The patch width should be selected to obtain good radiation efficiency. Suggested value is that $1 < W/L < 2$ [24]. Patch length determines the resonant frequency. The effective patch length L_{eff} is given by,

$$L_{\text{eff}} = \frac{c}{2f_{\text{r}}\sqrt{\epsilon_{r_{eff}}}} \tag{3.1}$$

Additional line length ΔL is given by,

$$\frac{\Delta \text{L}}{\text{h}} = 0.412\frac{\left(\epsilon_{r_{eff}} + 0.3\right)\left(\frac{w}{h} + 0.2264\right)}{\left(\epsilon_{r_{eff}} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{3.2}$$

where w is width of patch and h is thickness of substrate.

Effective dielectric constant is given by,

$$\epsilon_{r_{eff}} = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2\sqrt{1 + 12\left(\frac{h}{w}\right)}} \tag{3.3}$$

Patch length value is given by,

$$\text{L} = \text{L}_{\text{eff}} - 2\Delta\text{L} \tag{3.4}$$

Patch width is given by,

$$W = \frac{c\sqrt{\frac{2}{1 + \epsilon_r}}}{2f_{\text{r}}} \tag{3.5}$$

The resonating frequency is given by,

$$f_r = \frac{c}{2(L + 2\Delta\text{L})\sqrt{\epsilon_{r_{eff}}}} \tag{3.6}$$

Feeding Techniques:

Microstrip patch antenna can be fed by contacting and non-contacting feeding techniques. The RF control is fed straight forwardly to the transmitting patch utilizing an associating component, for example, a microstrip line in the contacting plane. In the non-contacting plane, electromagnetic field coupling is done to exchange control between the microstrip line and the radiating patch. Feeding strategy impacts the input impedance and qualities of the antenna, and it is a vital structure parameter. There are two types of feeding techniques used named as coaxial feed and microstrip feed [26-28].

Coaxial Feed:

The coaxial feed or probe feed is an exceptionally widespread procedure utilized for sustaining Microstrip patch antenna. In this the inner conductor of the coaxial connector reaches out through the dielectric and is bound to the radiating patch, while the external conductor is associated with ground plane. The primary advantage of this kind of feeding technique is that the feed can be set at any desired area inside the patch with the end goal to match with impedance. However, its significant detriment is that it gives narrow bandwidth and is hard to display since a gap must be bored in the substrate and the connector ends outside the ground plane, along these lines not making it totally planar for thick substrates [29-31].

Microstrip Feed:

In this sort of feed system, a conducting strip is associated specifically to the edge of the microstrip patch. The conducting strip is smaller in width when contrasted with the patch and this sort of feed course of action has the preferred standpoint that the feed can be carved on a similar substrate to give a planar structure [47-48].

3.2 Design of Rectangular Microstrip Patch Antenna:

The geometry of a rectangular microstrip fabricated patch antenna is shown in Figure 3.1. The antenna has been designed for length $L_p = 29.21\,mm$ and $W_p = 37.26\,mm$ and substrate length $L_{sub} = 37.82mm$ and width $W_{sub} = 46.36mm$. The antenna has been planned utilizing a substrate FR4 having dielectric constant of 4.4 and loss tangent of 0.02 and having thickness $1.59mm$. The transmitting patch is sustained by a 50Ω microstrip probe feed. The radiating patch and probe feed are set on top side of the substrate and the ground plane set on the base side of the substrate. The antenna structure is simulated and improved by the full wave electromagnetic recreation programming CADFEKO suite, utilizing the method of moment. Feed purpose of coaxial feed strategy is $6.7mm$ on X-axis.

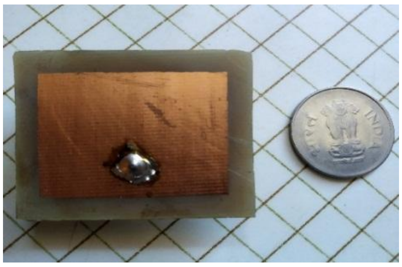

Figure. 3.1**: Fabricated Rectangular Microstrip Patch Antenna Radiating Patch**.

Figure. 3.2**: Fabricated Rectangular Microstrip Patch Antenna Ground Plane.**

For the design of rectangular microstrip patch antenna, the width and the length of the microstrip patch, and length and width of the substrate are calculated using the following equations. These parameters are the functions of resonance frequency, dielectric constant of the substrate, height of the substrate and velocity of light.

$$W = \frac{c \sqrt{\frac{2}{1+\epsilon_r}}}{2f_r} \tag{3.7}$$

$$L_{eff} = \frac{c}{2fr\sqrt{\epsilon_{r_{eff}}}} \tag{3.8}$$

$$\epsilon_{r_{eff}} = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2\sqrt{1 + 12\left(\frac{h}{w}\right)}} \tag{3.9}$$

$$\frac{\Delta \mathrm{L}}{\mathrm{h}} = 0.412\frac{\left(\epsilon_{r_{eff}} + 0.3\right)\left(\frac{w}{h} + 0.2264\right)}{\left(\epsilon_{r_{eff}} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{3.10}$$

For the resonance frequency $f_r = 2.45$ GHz , dielectric constant of the substrate $\epsilon_r = 4.4$ and thickness of the substrate $h = 1.59mm$. The antenna has been designed, parameters are calculated as $W_p = 37.26\ mm, L_p = 29.21\ mm,\ W_{sub} = 46.36\ mm,$ $L_{sub} = 37.82mm.$

Analysis of Rectangular Microstrip Patch Antenna:

The electrical equivalent circuit of the antenna consists of the parallel combination of resistance, inductance and capacitance. The equivalent circuit model of Rectangular microstrip patch antenna is shown Figure 3.3.

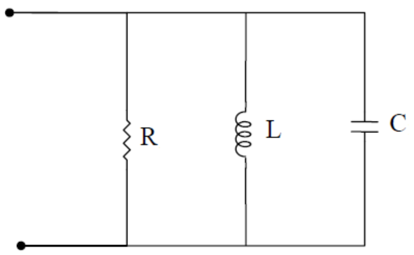

Figure. 3.3: **Equivalent Circuit of Rectangular Patch Antenna.**

The capacitance of microstrip patch antenna is a function of the length l, width w of rectangular patch, thickness of the substrate material h and the x coordinate of the feed point x_0. It is given by the equation,

$$C = \frac{\epsilon_{r_{eff}} \epsilon_0 l\, w}{2h} cos^{-2}\left(\frac{\pi . x_0}{l}\right) \tag{3.11}$$

The inductance of microstrip patch antenna is,

$$L = \frac{1}{\omega^2 C} \tag{3.12}$$

Resistance of the microstrip patch antenna is,

$$R = \frac{Q}{\omega C} \tag{3.13}$$

where Q is a quality factor which is given by the equation,

$$Q = \frac{c\sqrt{\varepsilon_{reff}}}{4fh} \tag{3.14}$$

The calculated values for the design of a rectangular microstrip patch antenna are as $C = 22.66pF$, $L = 0.186nH$ and $R = 52.04ohm$.

Frequency domain performance of Rectangular Microstrip patch antenna is observed and detail discussion of the results is presented in chapter 4. The graph of reflection coefficient vs frequency, VSWR Bandwidth vs frequency, far field radiation pattern at 2.45GHz, E and H plane Co and cross radiation pattern at 2.45GHz, Surface Current distribution on radiating patch at 2.45GHz, and Impedance vs frequency plot of designed antenna are observed and conclusions are drawn in chapter 4.

3.3 Design of U-Slot Loaded Rectangular Microstrip Patch Antenna:

To improve execution of microstrip patch antenna slotting method is being utilized. Slotting means cutting a specific piece of specific shape on radiating patch. For the proposed antenna, the geometrical U shape slot is chosen to enhance bandwidth and directivity. U-shape fundamentally comprises of one horizontal arm and two vertical arms. The antenna patch has a length $L_p = 26mm$, width $W_p = 36mm$, length of the substrate $L_{sub} = 37.82mm$ and width of the substrate $W_{sub} = 46.36mm$. In addition to this there are horizontal arm length $L_h = 19.5mm$, vertical arm length $L_v = 2.5mm$, horizontal arm width $W_h = 2.5mm$ and vertical arm length $W_v = 20mm$, parameters those are calculated by using the fundamental equations of the antenna at desired resonance frequency. The antenna has been designed utilizing a substrate FR4 having dielectric constant of 4.4 and loss tangent of 0.02 having thickness $h = 1.59mm$, radiating patch and ground plane as shown in Figure 3.4 and Figure 3.5 respectively. The radiating patch is nourished by a 50Ω microstrip probe feed. Here in the proposed structure initially slot is set on radiating patch. The antenna is simulated and enhanced by the full wave electromagnetic reproduction programming CADFEKO suite, utilizing the method of moment. Feed purpose of coaxial feed technique is $4mm$ on X-axis. Just by contrasting basic fix radio wire and U-space stacked fix reception apparatus slight size decrease has been observed.

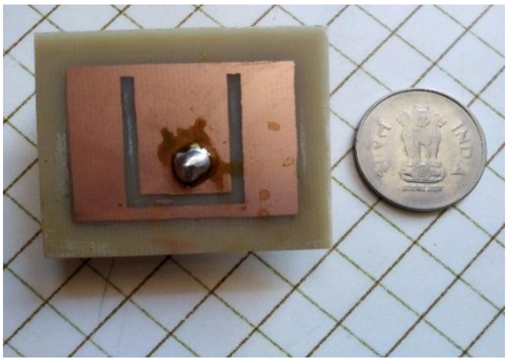

Figure.3.4: **Fabricated U-Slot Loaded Rectangular Microstrip Patch Antenna Radiating Patch.**

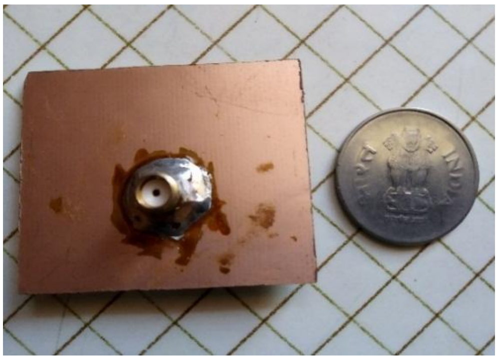

Figure.3.5: **Fabricated U-Slot Loaded Rectangular Microstrip Patch Antenna Ground Plane.**

Mathematical Analysis of U-Slot Loaded Rectangular Microstrip Patch Antenna:

U slot loaded patch is analyzed by considering two sections in the patch. First section only the parallel vertical arms of U slot are considered for the analysis and then second as a microstrip horizontal line of U section. This perturbation in the patch changes the current length which is accounted for by an additional series inductance ΔL and a series capacitance ΔC.

Case 1: Mathematical analysis of parallel vertical arms of U slot

These changes of inductance and capacitance have been calculated using the values of Inductance, Capacitance and Resistance of the basic rectangular microstrip patch as discussed in section 3.2 and using the following equations,

$$\Delta L = \frac{Z_1 + Z_2}{16\pi \cos^{-2} \frac{\pi . Z_0}{L}} \tan\left(\frac{\pi . f_r . L_s}{C}\right) \tag{3.15}$$

$$\Delta C = 2L_s \frac{\varepsilon_0}{\pi}\left[\ln\left(\frac{2\left(1+\sqrt{k'}\right)}{1+\sqrt{k'}+}\right) + ln\,(\coth\frac{\pi . d}{4h}) + 0.013C\frac{h}{d}\right] . \cos^{-2}\frac{\pi . Z_0}{L_e} \tag{3.16}$$

where Z_0 is characteristic impedance of basic patch of value $50\,ohm$, Z_1 is the impedance of vertical arms and Z_2 is impedance of horizontal arm of U slot which is given by the equations,

$$Z_1 = \frac{120\pi}{\frac{W_S}{h} + 1.393 + 0.6667\ln\left(\frac{W_S}{h} + 1.444\right)} \tag{3.17}$$

$$Z_2 = \frac{120\pi}{\frac{W_S - 2d}{h} + 1.393 + 0.6667\ln\left(\frac{W_S - 2d}{h} + 1.444\right)} \tag{3.18}$$

where d is the distance between the parallel vertical arms of U slot and k' is propagation constant, and it is calculated using the following equations as,

$$k' = \sqrt{1 + K^2} \tag{3.19}$$

$$K^2 = \frac{\frac{2W_S}{d} - 1}{\left(1 + \frac{W_S}{d}\right)\left(\frac{W_S - d}{d}\right)} \tag{3.20}$$

The values of ΔL and ΔC have been calculated by substituting the values of the R, L, C, W_S, L_s of a basic patch and distance between two vertical arms at resonance frequency. These values are calculated $\Delta L = 15.58pH$ and $\Delta C = 18.25pF.$

The change in the inductance and capacitance modify the inductance and the capacitance as $L_1 = L + \Delta L = 0.20158nH$, $C_1 = C + \Delta C = 10.11pF.$

Case 2: Mathematical analysis of horizontal arm of U slot

The second section is considered as microstrip bend line and the equivalent impedance of the shape is given as,

$$Z_b = j\omega L_b + \frac{1}{\frac{1}{j\omega L_b} + j\omega C_b} \tag{3.21}$$

where L_b= Inductance of horizontal slot, C_b = Capacitance of horizontal slot.

$$\frac{C_b}{W_b} = (9.5\varepsilon_r + 1.25)\frac{W_s}{h} + 5.2\varepsilon_r + 7.0\frac{pF}{m} \tag{3.22}$$

$$C_b = 0.3145pF$$

$$\frac{2L_b}{h} = 100\left(4\sqrt{\frac{W_b}{h}} - 4.21\right)nH \tag{3.23}$$

$$L_b = 0.3145nH$$

Now total impedance of U-slot loaded rectangular microstrip patch antenna is calculated by using given equation.

$$Z_P = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1} + j\omega C_1} \tag{3.24}$$

where Z_p is base patch impedance.

$$Z_P = 204ohm$$

$$Z_T = \frac{Z_b Z_p + Z_b Z_p + Z_b Z_b}{Z_b + Z_p + Z_b} \tag{3.25}$$

where Z_T total impedance of antenna

$$Z_T = 58ohm$$

Frequency domain performance of U-Slot loaded Rectangular microstrip patch antenna is observed and detail discussion of the results is presented in chapter 4. This antenna is resonating at three different frequencies. It has low gain and low bandwidth.

3.4 Design U-Slot Rectangular Microstrip Patch Antenna with Defective Ground:

The difference between U slot loaded rectangular microstrip patch antenna and U-Slot Rectangular Microstrip Patch Antenna with Defective Ground microstrip patch antenna is that there is no patch loaded at the ground plane in U-slot loaded rectangular microstrip patch antenna, but in case of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground, the patch is loaded above the ground plane and it is U shaped to enhance the bandwidth. The fabricated U-slot with defective ground structure microstrip patch antenna is shown in the Figure 3.6 and Figure 3.7.

As the gain and bandwidth of microstrip patch antenna with U space isn't up to the mark, and hence to improve gain and bandwidth defective ground structure has been utilized.

Figure 3.6 and 3.7 demonstrates the geometry of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground. The antenna is made out of radiating patch having length $L_p = 26mm$, width $W_p = 36mm$, length of substrate $L_{sub} = 37.82mm$ and width of substrate $W_{sub} = 46.36mm$. In addition to this there

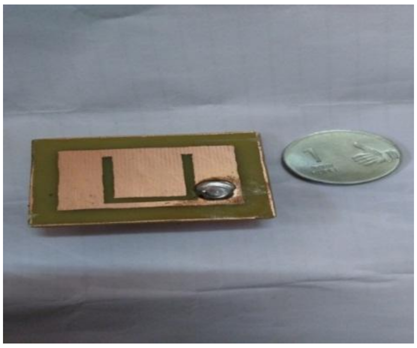

Figure. 3.6 **Fabricated U-Slot with Defective Ground Structure (DGS)Radiating Patch.**

Figure. 3.7 **Fabricated U-Slot with Defective Ground Structure (DGS) Ground Plane.**

are horizontal arm length $L_h = 19.5mm$, vertical arm length $L_v = 2.5mm$, horizontal arm width $W_h = 2.5mm$ and vertical arm length $W_v = 20m$. Same dimensions of U-slot have been used for slot at defective ground plane. The low cost FR4 having dielectric constant of 4.4 and loss tangent of 0.02 used as a substrate. The similar U-shaped structure of same dimensions has been fabricated on ground plane as shown in the Figure 3.6 and Figure 3.7. The emanating patch is sustained by a 50Ω microstrip test feed. Utilizing CADFEKO reenactment device, the antenna is designed and upgraded. Feed point of coaxial feed technique is made diagonally with $10.7mm$ on X-axis and $8.2mm$ on Y-axis.

Frequency domain performance of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground is observed and detail discussion of the results is presented in chapter 4. Due to the defective ground structure the length of surface current increases, two frequency bands of U-slot rectangular path antenna are fused which increases the bandwidth of the antenna and it resonates at two frequencies only.

3.5 Design of T-Slot Loaded Rectangular Microstrip Patch Antenna:

The geometry of a T-Slot loaded rectangular microstrip fabricated patch antenna is shown in Figure 3.8 and Figure 3.9. The antenna is made out of radiating patch having length $L_p = 25.80mm$, width $W_p = 36.10mm$, length of substrate $L_{sub} = 37.82mm$ and width of substrate $W_{sub} = 46.36mm$. In addition to this there are horizontal arm length $Lh = 19mm$, vertical arm length $L_v = 2.5mm$, horizontal arm width $W_h = 2.5mm$ and vertical arm length $W_v = 18.5mm$. The low cost FR4 having dielectric constant of 4.4 and loss tangent of 0.02 is used. The transmitting patch is sustained by a 50Ω microstrip probe feed. Utilizing CADFEKO recreation apparatus, the antenna is structured and enhanced. Feed purpose of coaxial feed strategy is made slantingly with $10.7mm$ on X-axis and $8.2mm$ on Y-axis.

Figure.3.8: **Fabricated T-Slot Loaded Rectangular Microstrip Patch Radiating Patch.**

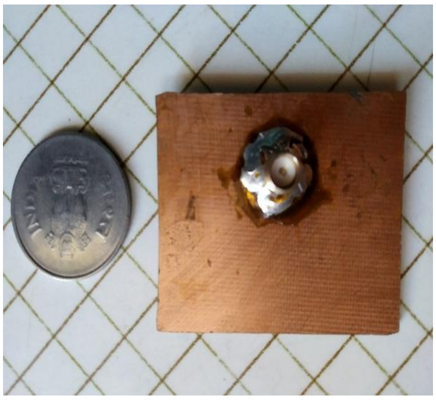

Figure.3.9: **Fabricated T-Slot Loaded Rectangular Microstrip Patch Ground Plane.**

Analysis of T-Slot loaded patch is considered separately as vertical slot and horizontal slot of T shaped slot.

Vertical Slot:

The real part of the impedance of vertical slot can be determined using the following equations:

$$R_{vs} = 60 \begin{bmatrix} c + \ln(k.L_v) - C_i\,(k.L_v) + \frac{1}{2}\sin(k.L_v).\left(S_i(2k.L_v) + 2S_i(k.L_v)\right) + \\ \frac{1}{2}\cos(k.L_v)\left[c - \ln\left(\frac{k.L_v}{2}\right) + C_i(k.L_v) - 2C_i(k.L_v)\right] \end{bmatrix} \quad (3.26)$$

where c is the velocity of light, k is a propagation constant which is equal to ${}^{2\Pi}/_{\lambda}$, L_v is the Length of vertical slot, $S_i(x)$ and $C_i(x)$ are calculated as,

$$S_i(x) = \int_0^x \frac{\sin x}{x}.dx \tag{3.27}$$

$$C_i(x) = -\int_x^\infty \frac{\cos x}{x}.dx \tag{3.28}$$

The imaginary part of the impedance of vertical slot can be determined using the following equations:

$$X_{vs} = 30\begin{bmatrix} 2S_i(k.L_V) + \cos(k.L_V).\left(2S_i(k.L_V) - S_i(k.L_V)\right) \\ -\sin(k.L_V)\left[2C_i(k.L_V) - c_i(2k.L_V) - c_i\frac{(k.a^2)}{2L}\right]\end{bmatrix} \tag{3.29}$$

The real part and imaginary part of the impedance of the given design is obtained as $R_{vs} = 81.89\ ohm, X_{vs} = 30.81\ and\ Z_{vs} = 81.89 + j30.81.ohm$

Horizontal Slot:

The real part of the impedance of horizontal slot can be determined using the following equations:

$$R_{hs} = 60\begin{bmatrix} c + \ln(k.L_h) - C_i\,(k.L_h) + \frac{1}{2}\sin(k.L_h).\left(s_i(2k.L_h) + 2s_i(k.L_h)\right) \\ +\frac{1}{2}\cos(k.L_h)\left[c - \ln\left(\frac{k.L_h}{2}\right) + C_i(k.L_h) - 2C_i(k.L_h)\right]\end{bmatrix} \tag{3.30}$$

$$R_{hS} = 80.26\ ohm$$

where c is the velocity of light, k is a propagation constant which is equal to ${}^{2\Pi}/_{\lambda}$, L_h is the Length of horizontal slot, $S_i(x)$ and $C_i(x)$ are as calculated.

The imaginary part of the impedance of horizontal slot can be determined using the following equations:

$$X_{hs} = 30\begin{bmatrix} 2s_i(k.L_h) + \cos(k.L_h).\left(2s_i(k.L_h) - s_i(k.L_h)\right) \\ -\sin(k.L_h)\left[2C_i(k.L_h) - c_i(2k.L_h) - c_i\frac{(k.a^2)}{2L}\right]\end{bmatrix} \tag{3.31}$$

The real part and imaginary part of the impedance of the given design is obtained as $R_{hS} = 80.26,\ X_{hs} = 28.17\ ohm\ and\ Z_{hs} = 80.26 + j28.17\ ohm.$

The overall impedance of the proposed design of T- slot microstrip patch antenna is,

$$\mathrm{Z_{TS}} = \frac{\mathrm{Z_{vs}.Z_{hs}}}{\mathrm{Z_{vs}.+Z_{hs}}} \tag{3.32}$$

$$\mathrm{Z_{TS}} = 40.53 + j14.73\ ohm$$

Frequency domain performance of T-Slot loaded rectangular microstrip patch antenna is observed and detail discussion of the results is presented in chapter 4. T-slot microstrip patch antenna provides the multiband resonance but low bandwidth as compared to U slot with defective ground. The impedance of the probe and input impedance of the antenna are not tuned perfectly.

3.6 Design of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground:

The problem of impedance matching of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground can be overcome using a defective ground structure at a certain level. The difference between T-slot microstrip patch antenna and T-Slot Rectangular Microstrip Patch Antenna with Defective Ground rectangular microstrip patch antenna is that there is no slot loaded at the ground plane in T-slot microstrip patch antenna, but in case of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground, the patch is loaded above the ground plane also and it is in T shape to enhance the bandwidth and improve the impedance matching. The fabricated T-Slot Rectangular Microstrip Patch Antenna with Defective Ground is shown in the Figure 3.10 and Figure 3.11 respectively.

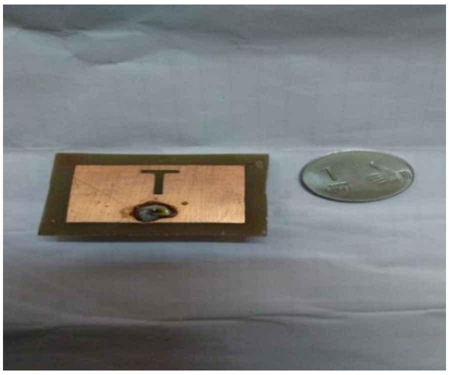

Figure. 3.10: **Fabricated T-Slot Rectangular Microstrip Patch Antenna with Defective Ground Radiating Patch.**

Figure. 3.11: **Fabricated T-Slot Rectangular Microstrip Patch Antenna with Defective Ground, Ground Plane.**

By embedding a single T-slot on the patch, antenna radiates at three distinctive resonating frequencies with suitable return loss. So, for data transmission execution enhancement defective ground structure antenna has been proposed.

The antenna is composed of radiating patch having length $L_p = 25.80mm$, width $W_p = 36.10mm$, length of substrate $L_{sub} = 37.82mm$ and width of substrate $W_{sub} = 46.36mm$. In addition to this there are horizontal arm length $L_h = 19mm$, vertical arm length $L_v = 2.5mm$, horizontal arm width $W_h = 2.5mm$ and vertical arm length $W_v = 18.5mm$. Same dimensions of T-slot have been used for slot at defective ground plane. The low-cost FR4 having dielectric constant of 4.4 and loss tangent of 0.02 is used. The radiating patch is fed by a 50Ω microstrip probe feed. Using CADFEKO simulation tool, the antenna is designed and optimized. Feed point of coaxial feed method is made diagonally i.e. $x = y = 8.2mm$. Utilizing T-Slot Rectangular Microstrip Patch Antenna with Defective Ground bandwidth capacity enhancement is observed when contrasted with U-slot stacked rectangular microstrip patch antenna.

Frequency domain performance of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground is observed and detail discussion of the results is presented in chapter 4. It is found that the bandwidth is improved and the gain is negative at the second resonance frequency. The bandwidth obtained is not sufficient to be used in the proposed biomedical application.

3.7 Design of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground:

The inductance of probe which is used for the feeding, dominates the capacitance of the load (microstrip patch) and hence the gain is negative at certain resonance frequency. This problem can be overcome by designing the Capacitive Loaded T-Slotted Rectangular microstrip patch antenna with Defective ground.

The capacitor is loaded in a rectangular microstrip patch antenna by providing the additional vertical strip as shown in the Figure 3.12. The Fabricated capacitive loaded T-slotted RMPA with T-DGS is shown in the Figure 3.12 and Figure 3.13 respectively.

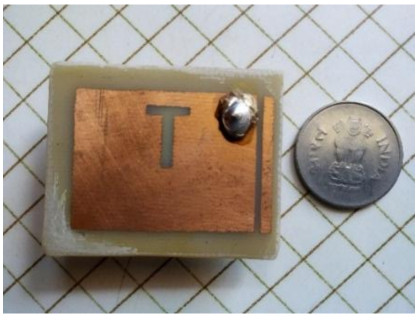

Figure. 3.12: **Fabricated Capacitive T-Slot Rectangular Microstrip Patch Antenna with Defective Ground Radiating Patch**

Figure. 3.13: **Fabricated T-Slot Rectangular Microstrip Patch Antenna with Defective Ground, Ground Plane**

Antenna is basically made of radiating patch, ground plane, T-Slot on patch as well as on ground plane and capacitive loaded strip. The antenna is composed of radiating patch having length $L_p = 25.80mm$, width $W_p = 36.10mm$, length of substrate $L_{sub} = 37.82mm$ and width of substrate $W_{sub} = 46.36mm$. In addition to this there are horizontal arm length $L_h = 19mm$, vertical arm length $L_v = 2.5mm$, horizontal arm width $W_h = 2.5mm$ and vertical arm length $W_v = 18.5mm$, length of capacitive strip $L_{cs} = 26.50mm$ and width $W_{cs} = 2mm$.The low-cost FR4 substrate having dielectric constant of 4.4 and loss tangent of 0.02 is used. Using CADFEKO simulation tool, the antenna is designed and optimized. Feed point of coaxial feed method is made at coordinate $x = 8.25mm \; and \; y = 13.02 \; mm$. Using capacitive loaded T-slot with defective ground structure bandwidth improvement is observed as compared to other shape of slot.

Frequency domain performance Capacitive Loaded T-Slotted Rectangular microstrip patch antenna with Defective ground is observed and detail discussion of the results is presented in chapter 4. This antenna resonates at two frequencies. The bandwidth is slightly increased but gain is low.

3.8 Design of Notch Cut I-Slotted rectangular microstrip patch antenna:

It is observed that the bandwidth of a microstrip patch antenna can be improved by increasing the length of current flow. The length of the current flow can be increased by certain amount, if the I slot microstrip patch antenna is used, further increase in the current flow length can be achieved by introducing the notch cut to radiating edge. The geometrical structure of the notch cut radiating edge I slotted microstrip patch antenna is shown in figure 3.14 and 3.15 respectively.

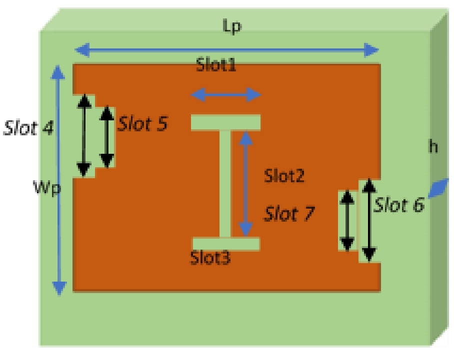

Figure. 3.14: **Notch Cut I-Slotted Rectangular Microstrip Patch Antenna Radiating Patch**

Figure. 3.15: **Notch Cut I-Slotted Rectangular Microstrip Patch Antenna Ground Plane**

Notch cut incorporates cutting slots along the edges as shown in Figure 3.14. The proposed geometry of slotted notch cut rectangular microstrip patch antenna is essentially comprising of I-Slot alongside notch cut along the edges. The antenna is composed of radiating patch having length $L_p = 26.30mm$, width $W_p = 36.40mm$, length of substrate $L_{sub} = 37.82mm$ and width of substrate $W_{sub} = 46.36mm$. In addition to this there are horizontal arm length $L_h = 11mm$, vertical arm length $L_v = 2.5mm$, horizontal arm width $W_h = 1.8mm$, vertical arm length $W_v = 14.2mm$, length of inner notch $L_{in} = 10mm$, width of inner notch $W_{in} = 2mm$, length of outer notch $L_{on} = 8mm$ and width of outer notch $W_{in} = 3mm$. Feed point of coaxial feed method is made with $8.2mm$ on x-axis. Using his technique bandwidth improvement has been observed drastically i.e.$2.43GHz$. This antenna is not fabricated but the results of the simulated structure have been observed.

Frequency domain performance of Notch Cut I-Slotted rectangular microstrip patch antenna is observed and detail discussion of the results is presented in chapter 4. It resonates at the single frequency and bandwidth is in a few GHz(2.43GHz) and gain is sufficient.

3.9 Design of Microstrip Line Feed Rectangular Microstrip Patch Antenna:

In the probe feed technique, the inductance of the probe dominates the capacitance of the patch which limits the bandwidth of the antenna. This problem can be overcome up to certain extent by providing the capacitive strip. This problem can be solved by using line feed technique.

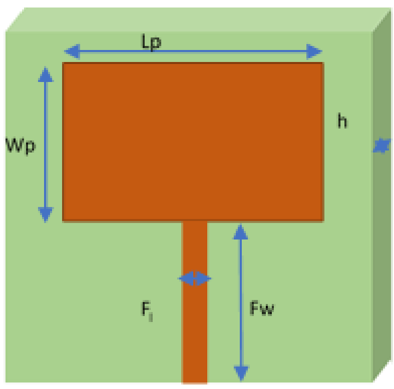

Figure. 3.16 **Microstrip Line Feed Rectangular Microstrip Patch Antenna Radiating Patch**

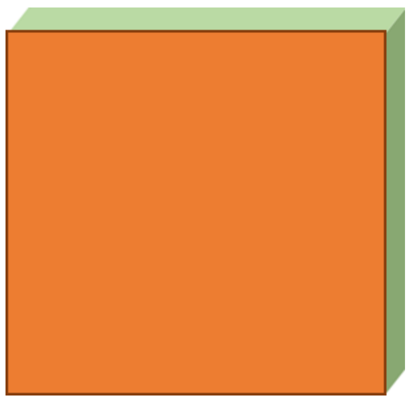

Figure. 3.17 **Microstrip Line Feed Rectangular Microstrip Patch Antenna Ground Plane**

The simple line feed rectangular microstrip patch antenna radiating patch and ground plane is as shown in figure 3.16, 3.17 respectively. Here for the rectangular microstrip patch the input is provided by a thin line. It is comprised of radiating patch of length $L_p = 28mm$, width $W_p = 37mm$, length of substrate $L_{sub} = 70mm$, width of substrate $W_{sub} = 70mm$, $h = 1.59mm$ is the thickness of the substrate used. Microstrip feed line has length $F_l = 30mm$ and width $F_w = 3mm$.The radiating patch is fed by $50\ ohm$ Microstrip line. CADFEKO, the full wave electromagnetic simulation software is utilized to simulate and optimize the antenna.

Characteristic impedance Z_0 can be calculated as,

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{re}}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right)\ for \frac{W}{h} \leq 1 \tag{3.33}$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{re}\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.444\right)\right]}} for \frac{W}{h} \geq 1 \tag{3.34}$$

For given Z_0 and ϵ_{re} , the W/h ratio can be found as,

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} = 2.7 \tag{3.35}$$

For $z_0\sqrt{\varepsilon_{re}}$=$50\sqrt{2.7} = 82.15 < 89.91\ i.e. A < 1.52$

$$\frac{W}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \tag{3.36}$$

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \tag{3.37}$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \tag{3.38}$$

$$B\ =\ 5.64$$

After putting the value of B

$$\frac{W}{h} = 1.94$$

$$h = 1.59mm$$

So,

$$W = 3.01\ mm$$

These are the calculated values of length and width of microstrip line feed.

Frequency domain performance of Microstrip Line Feed Rectangular Microstrip Patch Antenna is observed and detail discussion of the results is presented in chapter 4. It resonates at four frequencies and it has a bandwidth in the range of 100MHz to 240 MHz but the gain is low.

3.10 Design of Microstrip Line Feed Rectangular Microstrip Patch Antenna with partial ground:

To improve the radiation pattern of microstrip patch antenna and to avoid the radiation due to microstrip line which is used for the feeding, the concept of partial ground has been introduced. The geometrical structure the microstrip line feed rectangular microstrip patch antenna with partial ground radiating patch and ground plane is as shown in Figure 3.18 and Figure 3.19 respectively.

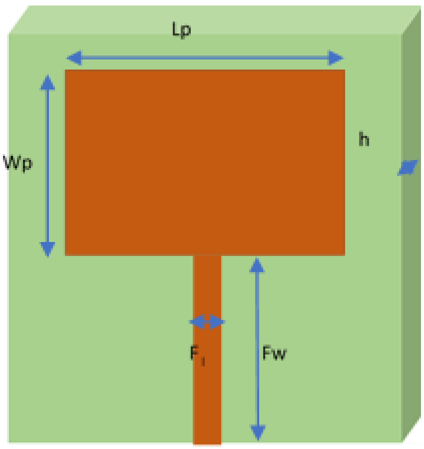

Figure. 3.18: **Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground Radiating Patch**

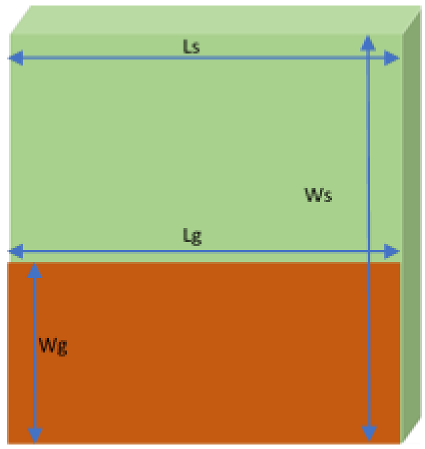

Figure. 3.19 **Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground, Ground Plane**

The structure has length of the patch $L_p = 28mm$, width $W_p = 37mm$, length of substrate $L_{sub} = 70mm$, width of substrate $W_{sub} = 70mm$, length of partial ground $L_g = 28mm$, Width of partial ground $W_g = 70mm$, $h = 1.59mm$ is the thickness of the substrate used. Microstrip feed line has length $F_l = 30mm$ and width $F_w = 3mm$.The radiating patch is fed by a $50ohm$ microstrip line. With proposed geometry bandwidth obtained is $1.23GHz$ with positive gain of $2.34dB$.

3.11 Design of Single Corner Cut Rectangular Microstrip Patch with Partial Ground:

In the previous design the simple rectangular patch with 50ohm microstrip feed line with partial ground has been considered. To enhance bandwidth and gain of the rectangular microstrip patch antenna with partial ground has been modified by providing the lower corner cuts to the patch which increases the length of current flow. The geometrical structure of Single Corner Cut RMPA with Partial Ground is shown in the Figure 3.20 and Figure 3.21 respectively.

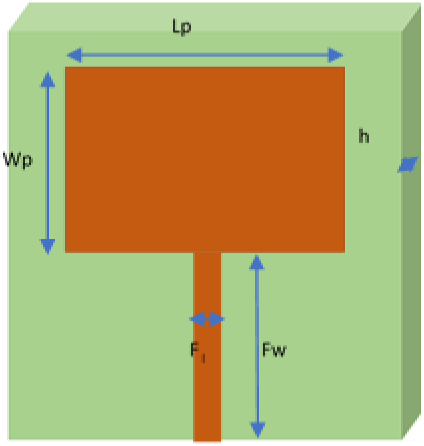

Figure. 3.20: **Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground Radiating Patch**

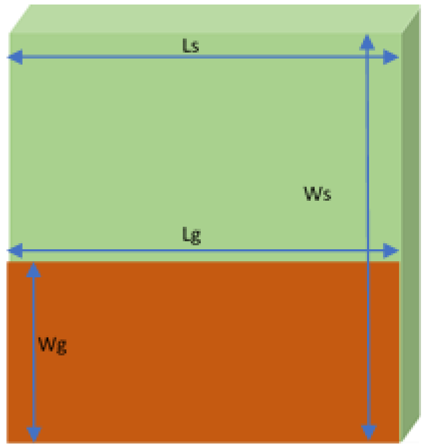

Figure. 3.21: **Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground, Ground Plane**

The corner cut radiating patch has a length $L_p = 28mm$, width $W_p = 37mm$, length of substrate $L_{sub} = 70mm$, width of substrate $W_{sub} = 70mm$, length of partial ground $L_g = 28mm$, Width of partial ground $W_g = 70mm$, $h = 1.59mm$ is the thickness of the substrate used. Microstrip feed line has length $F_l = 30mm$ and width $F_w = 3mm$. In addition to that there is a slot to lower corners of the radiating patch has length $Ls = 5mm$ and $Ws = 5mm$. The antenna design is simulated in CADFEKO simulation software. This proposed antenna is not fabricated, its results have been observed using simulation tool which is presented in chapter 4. Using this technique slight enhancement in bandwidth is observed which is $2.89GHz$.

3.12 Design of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground:

In the previous design a single corner cut helps to enhance the bandwidth and gain. For further improvement in bandwidth and the gain multiple cuts at the radiating edge of patch at the bottom have been proposed. The designed Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground antenna is as shown in figure. 3.22 and 3.23 respectively.

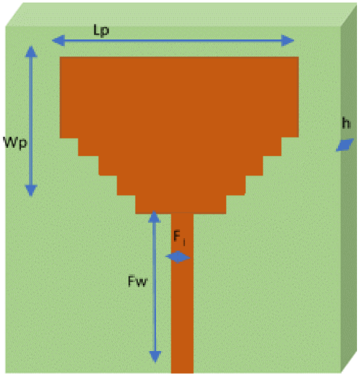

Figure. 3.22: **Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground Radiating Patch**

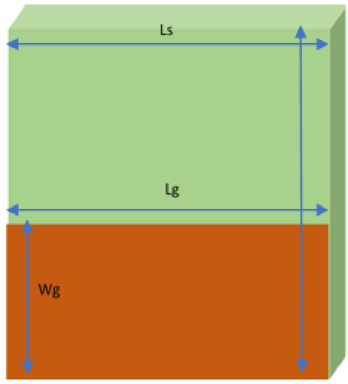

Figure. 3.23: **Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground, Partial Ground Plane**

The design comprises of four corner cuts on radiating patch, length of substrate $L_{sub} = 70mm$, width of substrate $W_{sub} = 70mm$, length of partial ground $L_g = 28mm$, Width of partial ground $W_g = 70mm, h = 1.59mm$ is the thickness of the substrate used. Microstrip feed line has length $F_l = 30mm$ and width $F_w = 3mm$. In addition to that there are four slots to lower corners of the radiating patch has length $L_s = 3mm$ and $W_s = 3mm$, $h = 1.59mm$ is the thickness of the substrate used. The radiating patch is fed by a $50ohm$ microstrip line. Defective ground structure has been utilized in order to achieve good impedance matching and proper radiation. The antenna design is simulated in CADFEKO simulation software. This proposed antenna is not fabricated, its results have been observed using simulation tool which is presented in chapter 4. Utilizing this technique improvement in bandwidth is observed radically which is $4.2GHz$ but the gain is poor.

3.13 Monopole Antennas:

Two-dimensional planar monopole receiving wires known as printed monopole radio antenna comprise of a transmitting patch, ground plane and feeding mechanism, appropriate for biomedical applications. A UWB radio antenna is of extraordinary consideration because of its extensive variety of points of interest, such as, miniaturization, wide bandwidth for data transmission, omnidirectional radiation and low cost. UWB is an innovation used in biomedical applications, that transmits low power over an extensive wide range of band. It transmits a short pulse into body and gets scattered signal which needs wide bandwidth that is given by UWB reception patch antenna geometry. It can be integrated in remote and biomedical gadgets. After allotment of Federal Communications Commission (FCC)band of $3.1GHz$ to $10.6GHz$ in 2002, it opens extraordinary opportunities to the researchers to design wide band transmitting and receiving antennas and to undergo implantation inside the human body. In this section the set of various type of monopole antenna are presented.

3.13.1 Design of Monopole Rectangular Patch Antenna with Partial Ground:

The structure of the Monopole Rectangular Patch Antenna with Partial Ground is as shown in Figure 3.24 and Figure 3.25 respectively. Antenna has a patch length $Lp = 12.7mm$, patch width $Wp = 15.21mm$, length of the substrate $Lsub = 39mm$, width of substrate $Wsub = 30mm$, Length of halfway ground $Lg = 15.21mm$,width of halfway ground $Wg = 30mm$,$h = 1.59mm$ is the thickness of the substrate used and $gap\ 'g' = 0.8mm$, between the patch and the DGS. The transmitting patch is fed by a 50Ω microstrip line of length $Fl = 16.01mm$ and width $Fw = 3mm$. The fix and microstrip feed line are on top side of the substrate and the DGS set on the base side of the substrate. Simulation of structured geometry has been done by CADFEKO, electromagnetic simulator. Design is carried out using a substrate, FR4 with dielectric constant of $\varepsilon r = 4.4$, with the thickness of the substrate h = 1.59 mm.

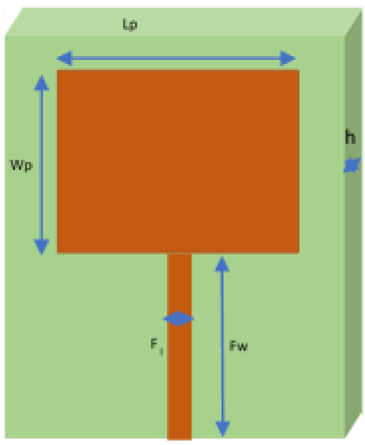

Figure. 3.24: **Monopole Rectangular Patch Antenna with Partial Ground Radiating Patch**

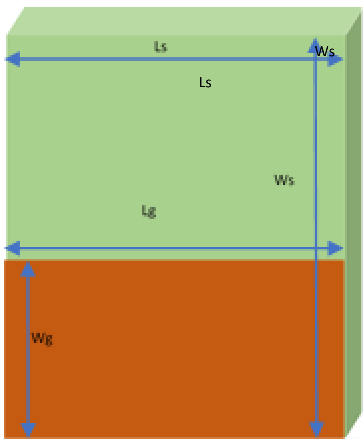

Figure. 3.25: **Monopole Rectangular Patch Antenna with Partial Ground, Ground Plane**

Design Equation of Monopole Patch Antenna:

The equivalent Inductance and Capacitance of monopole patch antenna is a function of length and width of the patch, thickness of the substrate, dielectric constant and position of a feed point. It is given by the equations

$$C_1 = \frac{\varepsilon_{reff}\,\varepsilon_0 L_p W_p}{2h}\cos^{-2}\left(\frac{\pi.\,x_0}{L_p}\right) \tag{3.39}$$

$$L1 = \frac{1}{\omega_r{}^2.\,C1} \tag{3.40}$$

The results of the simulation have been observed, which are presented in chapter 4. This antenna resonates at two frequencies; it has a stable radiation with bandwidth in Gigahertz (5.03 GHz).

3.13.2 Design of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna:

To increase the bandwidth of the antenna, the simple monopole microstrip patch antenna has been modified, lower corners of the radiating patch are rounded and it has been made smoother which enhances reflection bandwidth. The structure of the Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna with Partial Ground is as shown in Figure 3.26 and Figure 3.27 respectively.

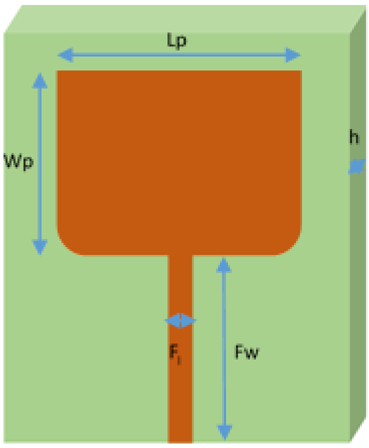

Figure. 3.26: **Lower Corner Rounded Monopole Microstrip Patch Antenna Radiating Patch**

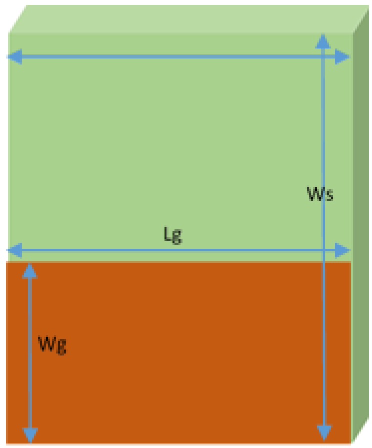

Figure. 3.27: **Lower Corner Rounded Monopole Microstrip Patch Antenna Ground Plane**

Gap between transmitting patch and DGS kept same as simple monopole antenna. Length of the patch is $L_p = 12.7mm$, patch width $W_p = 15.21mm$, length of the substrate $L_{sub} = 39mm$, width of substrate $Wsub = 30mm$, Length of halfway ground $L_g = 15.21mm$, width of halfway ground $W_g = 30mm$, $h = 1.59mm$ is the thickness of the substrate used. The radius of circular curve which is used to smooth the lower corners of the radiating patch is $r = 3mm$, gap $'g' = 0.8mm$, between the patch and the DGS. The fabricated antenna radiating patch and ground plane is as shown in the Figure 3.28 and Figure 3.29 respectively.

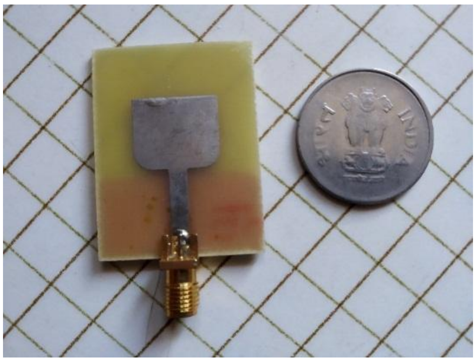

Figure.3.28: **Fabricated Lower Corner Rounded Monopole Microstrip Patch Antenna Radiating Patch.**

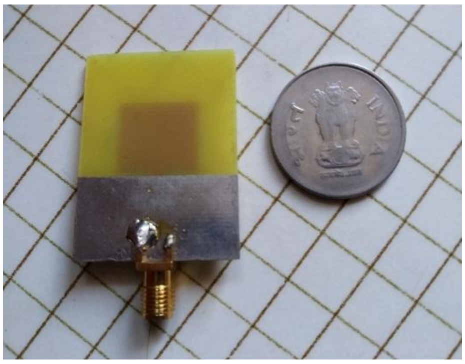

Figure.3.29: **Fabricated Lower Corner Rounded Monopole Microstrip Patch Antenna Ground Plane.**

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. Due to the smoothness at the lower corner of the patch the bandwidth is increased from $5.03\ GHz\ to\ 9.06GHz$. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance is not up to the expected value for resonating frequencies.

3.13.3 Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground

To increase the bandwidth, and to improve the impedance values for the resonating frequencies the lower corner rounded patch monopole rectangular antenna with partial ground has been modified, the upper corners of the partial ground are rounded and it has been made smoother which enhances reflection bandwidth and it also improves the impedance. The geometrical structure of the antenna radiating patch and ground plane is as shown in the figure 3.30 and 3.31 respectively.

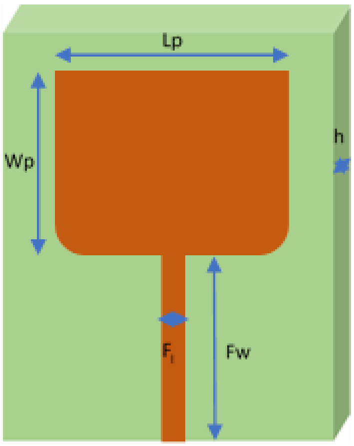

Figure. 3.30: **Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground Radiating Patch.**

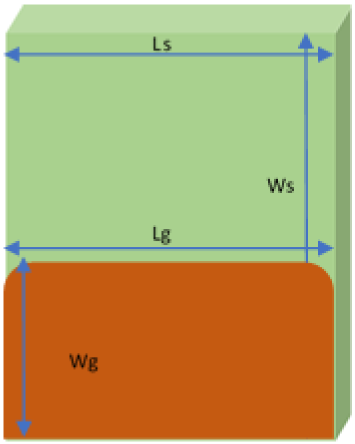

Figure. 3.31: **Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground, Ground Plane.**

In this geometry upper corners of DGS are made smoother than the previous geometry to watch the conduct of surface current which enhances bandwidth. Antenna structure is fed through microstrip feed line utilizing Sub-miniaturized A type connector, negative side of connector is associated with base side of DGS. Length of the patch is $L_p = 15.2mm$, width of the patch is $W_p = 12.7mm$, length of substrate $L_{sub} = 39mm$, width of substrate $W_{sub} = 30mm$, Length of halfway ground $L_g = 15.21mm$, thickness of the substrate is $h = 1.6mm$, length of partial ground $L_g = 15.21mm$ and width of halfway ground $W_g = 30mm$.The radius of circular curve which is used to smooth the lower corners of the radiating patch is $3mm$,The radius of circular curve which is used to smooth the upper corners of the partial ground is $3mm$. Relative Dielectric constant of the substrate used is $\varepsilon_r = 4.4$.

The Fabricated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground is shown in the figure 3.32 and 3.33 respectively.

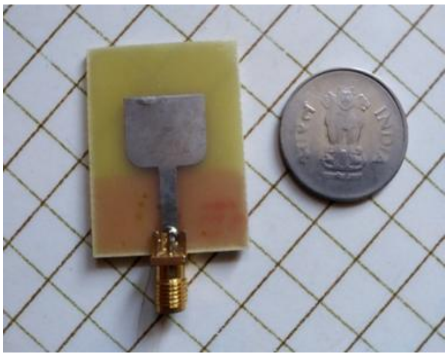

Figure.3.32: **Fabricated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground Radiating Patch**

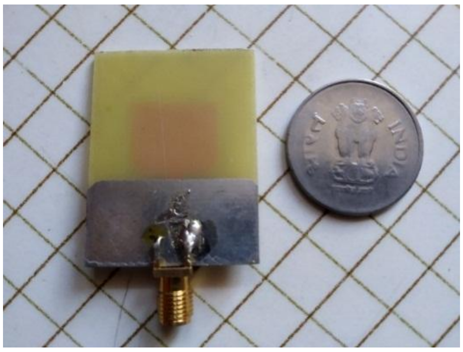

Figure.3.33: **Fabricated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground, Ground Plane**

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. Due to the smoothness at the lower corner of the patch and upper corner of the partial ground, the bandwidth is increased from $5.03GHz\ to\ 9.31GHz$. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance is near to the expected value for the resonating frequencies.

3.13.4 Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground:

By creating the smoothness at the lower corners of the radiating patch and upper corners of the partial ground the bandwidth has been improved. For the further improvement in bandwidth the Lower corner rounded patch monopole RMPA with rounded corner at partial ground has been modified. In the modified antenna the length of the smoothened part of the lower corner of the patch has been increased which increases the length of the surface current resulting in increase in the bandwidth. The Geometry of Modified Lower corner rounded patch monopole RMPA with rounded corner at partial ground is shown in the Figure 3.34 and Figure 3.35 respectively.

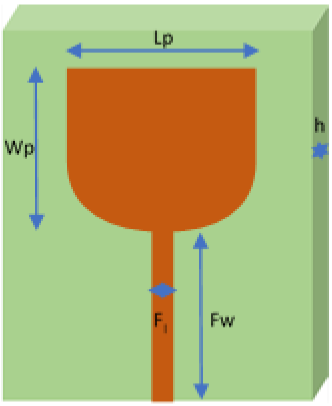

Figure.3.34**: Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground Radiating Patch**

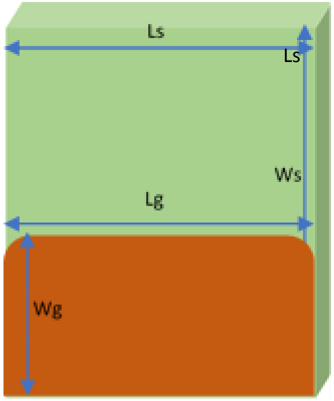

Figure.3.35**: Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground, Ground Plane**

Length of the patch is $L_p = 15.2mm$, width of the patch is $W_p = 12.7mm$, thickness of the substrate is $h = 1.6mm$, length of partial ground $L_g = 15.21mm$ and width of halfway ground $W_g = 30mm$.The radius of circular curve which is used to smooth the lower corners of the radiating patch is increased to $5mm$, the radius of circular curve which is used to smooth the upper corners of the partial ground is $3mm$. Relative Dielectric constant of the substrate used is $\varepsilon_r = 4.4$.The Fabricated Modified lower corner rounded patch monopole RMPA with rounded corner at partial ground is shown in the Figure 3.36 and Figure 3.37 respectively

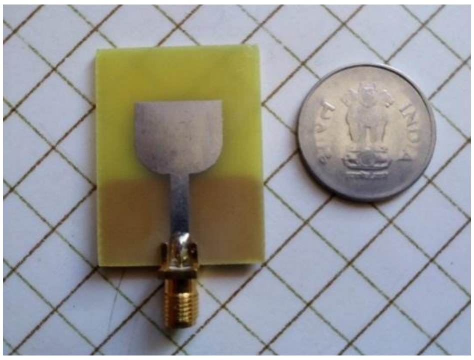

Figure.3.36: **Fabricated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground Radiating Patch**

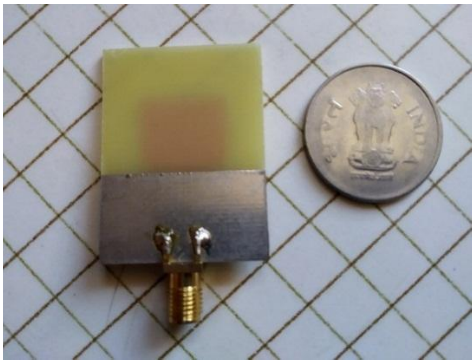

Figure.3.37: **Fabricated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch with Rounded Corner at Partial Ground, Ground Plane**

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. Due to the increased smoothness at the lower corner of the patch the bandwidth is increased from 9.31GHz to 9.61GHz. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance is near to the expected value for the resonating frequencies.

3.13.5 Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground:

By increasing the radius of the curves, the length of the smoothened curve is increased which results in increase in the bandwidth. If the length of the smoothened curve increased beyond certain limit the effective length of the current decreases which deteriorates the radiation pattern. This problem has been resolved by creating the notches over the radiation patch. In the Key Shape Monopole Rectangular Microstrip Patch Antenna (RMPA) with Rounded Corner in Partial Ground one notch is created on the top of the patch and two notches are created on lateral sides as shown in the Figure 3.38 and Figure 3.39 respectively.

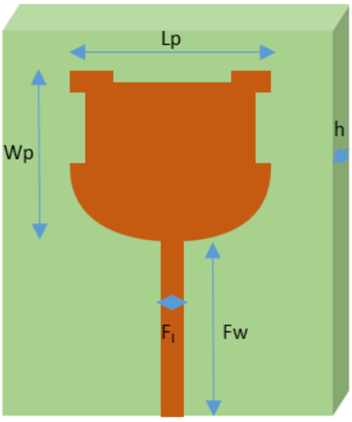

Figure.3.38: **Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground Radiating Patch**

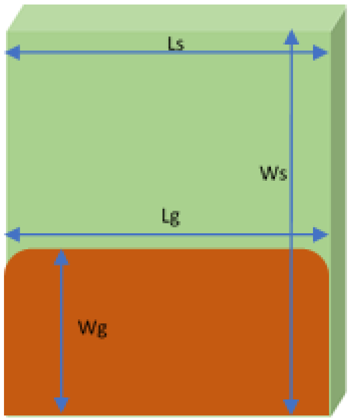

Figure.3.39: **Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground, Ground Plane**

The key shape monopole is fed through a microstrip line, which is appended to a coaxial link through a standard 50Ω, SMA connector for input signal transmission. The width of the microstrip feed line is settled at 3 mm and length is of $16.01mm$. On the base side of the substrate, a leading halfway ground plane with upper corners are fit as a fiddle is $15.01mm$ length and $30mm$ width. Partial ground structure corners are made roundabout fit as a fiddle with a sweep of $3mm$ and lower corners of radiating patch are made smoother with a radius of $5mm$. Addition to this there are notches on radiating has length of vertical notch $L_v = 5mm$, width of vertical notch $W_v = 1mm$, length of horizontal notch $L_h = 1mm$,and width of horizontal notch $W_h = 10mm$.

Figure.3.40: **Fabricated Key Shape Rectangular Microstrip Patch with Rounded Corner in Partial Ground Radiating Patch.**

Figure.3.41: **Fabricated Key Shape Rectangular Microstrip Patch with Rounded Corner in Partial Ground, Ground Plane.**

The Fabricated Key Shape Monopole Rectangular Microstrip Patch with Rounded Corner in Partial Ground is shown in the Figure 3.40 and Figure 3.41 respectively. The input impedance of the antenna has been calculated, it is a function of dimensions of top notch, lateral notches, the dimensions of the base rectangular patch and the relative dielectric constant of the substrate used. For this calculation the effect of smoothness of the curve on impedance has been assumed as insignificant. The following equations are used for the calculations.

$$Z_{in} = \frac{Z_{TL}.Z_P}{Z_{TL} + Z_P} \tag{3.41}$$

where, Z_p is the impedance of base rectangular patch and Z_{TL} is the total impedance of the notches.

$$Z_p = \frac{1}{\frac{1}{R1} + j\omega C1 + \frac{1}{j\omega L1}} \tag{3.42}$$

where, R_1, C_1 and $L_1$are the resistance, capacitance and inductance of the base rectangular patch.

$$R_1 = \frac{Q}{\omega_r.C_1} \tag{3.43}$$

$$C_1 = \frac{\varepsilon_e \varepsilon_0 L_p W_p}{2h}\left(\cos\frac{\pi * x_0}{L}\right)^{-2} \tag{3.44}$$

$$L_1 = \frac{1}{{\omega_r}^2.C_1} \tag{3.45}$$

$$Q = \frac{C\sqrt{\epsilon_e}}{4.f_r.h} \tag{3.46}$$

$$f_r = \frac{1}{2\pi\sqrt{L_1 * C_1}} \tag{3.47}$$

where, h=Thickness of substrate, ϵ_e=Effective Dielectric Constant, x_0=Feed point location along x axis, ε_0=Permittivity of free space

$$Z_{TS} = \frac{Z_{vl}.Z_{hl}}{Z_{vl}.+Z_{hl}} \tag{3.48}$$

where, Z_{vL} is an impedance of the side notches, Z_{hL} is an impedance of the top notch.

$$Z_{vL} = R_{vL} + jX_{vl} \tag{3.49}$$

$$Z_{hl} = R_{hL}.+jX_{hl} \tag{3.50}$$

$$R_{Vl} = 60\begin{bmatrix} C + ln(k.L_V) - C_i(k.L_V) + \frac{1}{2}sin(k.L_V).\left(s_i(2k.L_V) + 2s_i(k.L_V)\right) \\ +\frac{1}{2}cos(k.L_V)\left[c - ln\frac{(k.L_V)}{2} + C_i(2k.L_V) - 2C_i(k.L_V)\right] \end{bmatrix} \tag{3.51}$$

where L_v=Length of vertical slot, k is propagation constant

$$X_{Vl} = 30\begin{bmatrix} 2s_i(k.L_V) + COS(k.L_V).\left(2s_i(k.L_V) - s_i2(k.L_V)\right) \\ -\sin k.L_V\left[2C_i(k.L_V) - C_i2(k.L_V) - C_I\frac{Ka^2}{2L}\right] \end{bmatrix} \tag{3.52}$$

$$R_{hl} = 60\begin{bmatrix} C + \ln(k.L_h) - C_i(k.L_h) + \frac{1}{2}\sin(k.L_h).\left(s_i(2k.L_h) + 2s_i(k.L_h)\right) \\ +\frac{1}{2}\cos(k.L_h)\left[c - ln\frac{(k.L_h)}{2} + C_i(2k.L_h) - 2C_i(k.L_h)\right] \end{bmatrix} \tag{3.53}$$

$$X_{hl} = 30\begin{bmatrix} 2s_i + COS(k.L_h).\left(2s_i(k.L_h) - s_i2(k.L_h)\right) \\ -\sin k.L_h\left[2C_i(k.L_h) - C_i2(k.L_h) - C_I\frac{Ka^2}{2L}\right] \end{bmatrix} \tag{3.54}$$

where L_v=Length of vertical slot, L_h =Length of horizontal slot, k is propagation constant

$$S_i(x) = \int_0^x \frac{\sin x}{x}.dx$$

$$C_i(x) = -\int_x^\infty \frac{\cos x}{x}.dx$$

For the designed dimensions the input impedance has been calculated.

$$\mathrm{Z_{in}} = 60.10 + 12.56\mathrm{i\ ohm}$$

Magnitude of $\mathrm{Z_{in}} = 61.39 ohm$

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. Due to the increase in length of the current by creating the notches and smoothness at the corner's bandwidth has increased up to 10.05GHz. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance is near to the expected value for the resonating frequencies. But it is observed just above the higher resonance frequency the reflection coefficient is slightly more than -10dB.

3.13.6 Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground:

In Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground, it is found that just above the higher resonance frequency the reflection coefficient is slightly more than -10dB. The bandwidth of the antenna has a chance for further improvement if the reflection coefficient is reduced below -10dB and increase the higher resonance frequency. This can be achieved by reducing the density of a current near the center part of the patch by creating the slot.

The Geometry of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground is shown in the Figure 3.42 and Figure 3.43 respectively.

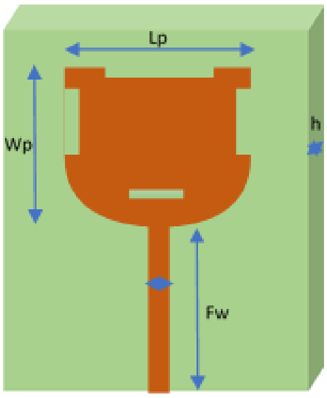

Figure.3.42: **Slotted Key Shape Slotted Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground Radiating Patch**

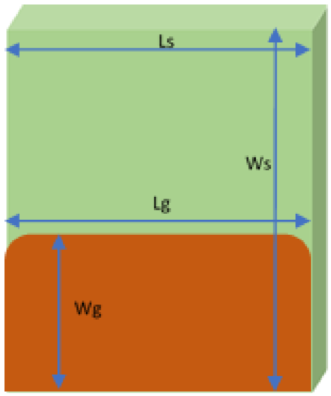

Figure.3.43: **Slotted Key Shape Slotted Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground, Ground Plane**

The rectangular slot has been created as shown in the Figure 3.44 and Figure 3.45. The length of the rectangular slot $L_s = 2mm$ and width of the rectangular slot

$W_s = 1mm$. The Fabricated Slotted Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground is shown in the Figure 3.44 and Figure 3.45 respectively.

Figure.3.44: **Fabricated Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground Radiating Patch**

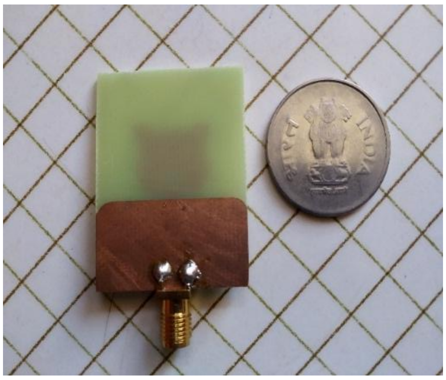

Figure.3.45: **Fabricated Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground, Ground Plane**

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. Due to the increase in length of the current by creating slot, notches and smoothness at the corner's bandwidth has increased up to 10.29GHz. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance is near to the expected value for the resonating frequencies.

3.13.7 Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground:

In Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground, the bandwidth has increased up to 10.29 GHz but it is found that due to the rectangular shape of the slot, the path of some of the current components have been terminated. There is a further chance of improving the bandwidth if the problem of termination of current components is resolved. To resolve this problem, the rectangular shape of the slot has been changed to oval shape.

Geometry of Oval Shape Slotted Key Shaped Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground is shown in Figure 3.46 and Figure 3.47 respectively.

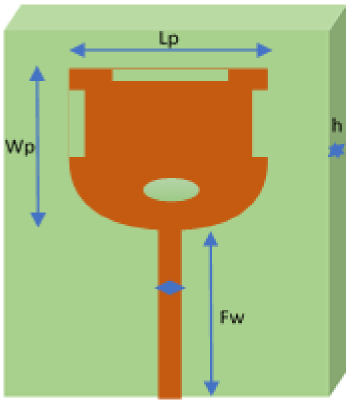

Figure. 3.46: **Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground Radiating Patch**

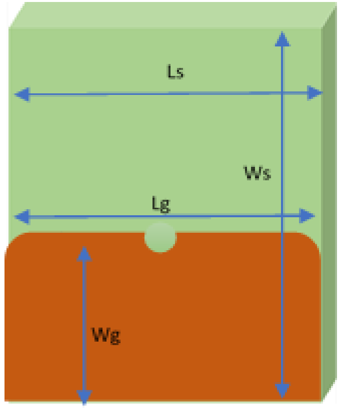

Figure. 3.47: **Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground, Ground plane**

The length of the horizontal axis of the oval slot $L_x = 2mm$, and length of the vertical axis of the oval slot $L_y = 1mm$.

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. By minimizing the current flow termination problem by replacing rectangular slot with oval slot the bandwidth has increased up to $11.34GHz$. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance at higher frequency is slightly deviating from the expected impedance.

3.13.8 Oval Shape Slotted Key Shape Monopole RMPA with Rounded Corner and Groove Shape Notch in Partial Ground:

In Oval Shape Slotted Key Shape Monopole RMPA with Rounded Corner and Groove Shape Notch in Partial Ground**,** the bandwidth has increased up to 11.34 GHz but it is found that impedance at higher frequency is slightly deviating from the expected impedance. It is because of the oval shape slot crated on the radiating patch, which reduces the electrical size of the patch. This problem can be compensated by creating groove shaped notch in partial ground. Geometry of Oval Shape Slotted Key Shape Monopole RMPA with Rounded Corner and Groove Shape Notch in Partial Ground is shown in Figure 3.48 and Figure 3.49 respectively.

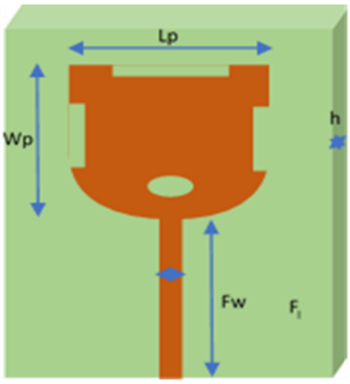

Figure.3.48: **Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground radiating patch.**

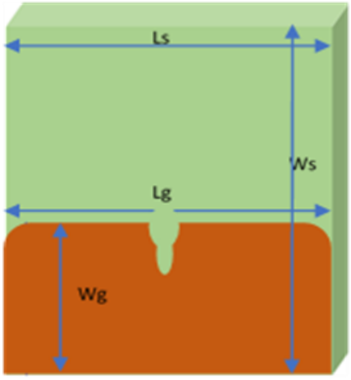

Figure.3.49: **Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground, ground plane.**

The dimensions of the proposed antenna are maintained sane as previous design, only the additional groove shape slot has been created at top of the partial ground. The groove shape is created with the help of two different dimension ellipses as shown in the Figure 3.51. The dimensions of ellipses are $3mm \times 2mm$ and $1mm\ x\ 2mm$. The Fabricated Oval Shape Slotted Key Shape Monopole RMPA with Rounded Corner and Groove Shape Notch in Partial Ground is shown in the Figure 3.50 and Figure 3.51 respectively.

Figure. 3.50: **Fabricated Key Shape oval slotted monopole Rectangular Microstrip Patch with rounded corner and groove shaped notch in partial ground radiating patch**

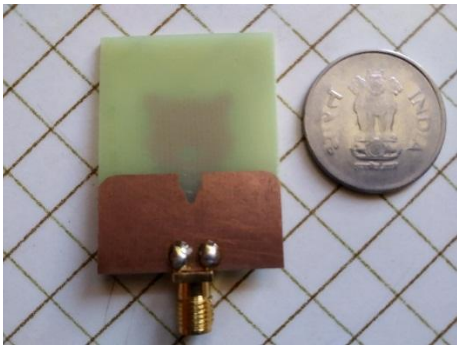

Figure. 3.51: **Fabricated Key Shape oval slotted monopole Rectangular Microstrip Patch with rounded corner and groove shaped notch in partial ground, ground plane**

The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. By minimizing the current flow termination problem by replacing rectangular slot with oval slot the bandwidth has increased up to

11.37GHz. It also resonates at two frequencies; it has a stable radiation with moderate gain. It is also found that impedance matching has been improved.

3.13.9 Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground:

In Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground the bandwidth has been observed up to 11.36 GHz and the problem of impedance matching is resolved to certain extent. This antenna has been modified by changing the position of side notches on radiating patch. The side notches are shifted down by an amount of 2 mm. Since the side notches have shifted down the length of the current path is slightly increased which results in increase in bandwidth. Geometry of Oval Shape Slotted Key Shaped Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shaped Notch in Partial Ground is shown in the Figure 3.52 and fabricated key shaped oval slotted modified monopole RMPA with rounded corner and groove shaped notch in partial ground is shown in Figure 3.53.

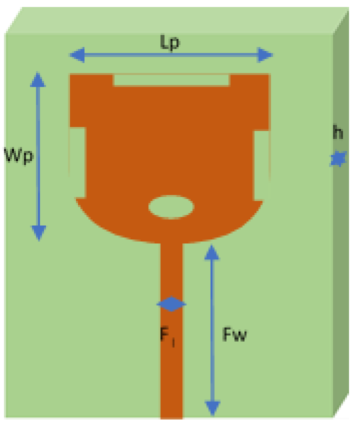

Figure 3.52: **Oval shape Slotted Key Shaped Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground radiating patch**

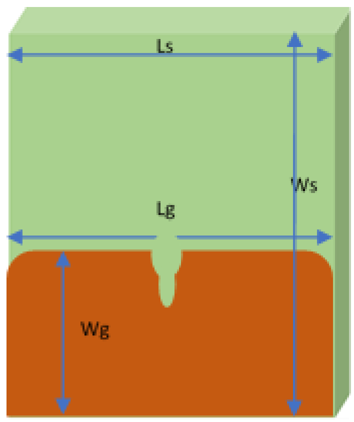

Figure 3.53: **Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground, ground plane**

Figure.3.54 **Fabricated Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground radiating patch**

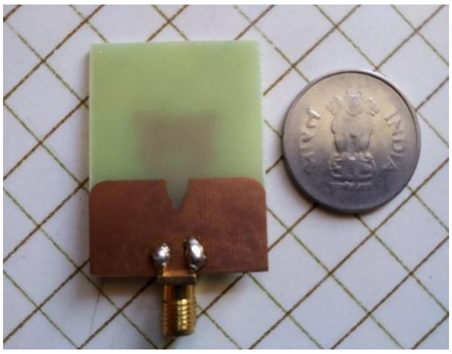

Figure.3.55 **Fabricated Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground, ground plane**

From Figure 3.54 and Figure 3.55, The results of the simulated antenna and fabricated antenna have been observed, which are presented in chapter 4. By shifting the position of the side notches the bandwidth has increased up to 17.41GHz. It has a stable radiation with moderate gain. This band is suitable to be used for receiving almost all the frequency components those are scattered from the human malignancies which have significant information needed in the diagnosis.

3.14 Array Design

In the previous discussion the set of antennas have been designed, simulated and fabricated and their results have been observed and finally the high bandwidth UWB antenna has been proposed. In addition to this work the concept of array antenna has been studied, designed and simulated, and results are observed. In the concept of array design more than one antenna is used to radiate the signals those are supplied from a single source simultaneously. The concept of array has been implemented here for a simple rectangular patch antenna only.

3.14.1 Design of 1 × 2 Simple Square Patch Array:

The geometrical structure of 1x2 simple rectangular patch antenna with a partial ground is as shown in the Figure 3.26.1. In this antenna the two simple rectangular patch antennas are created on a single copper plate. These antennas are separated by a distance d = 0.15λ. The microstrip technique is used to feed the signal to the array. This antenna has a partial ground structure.

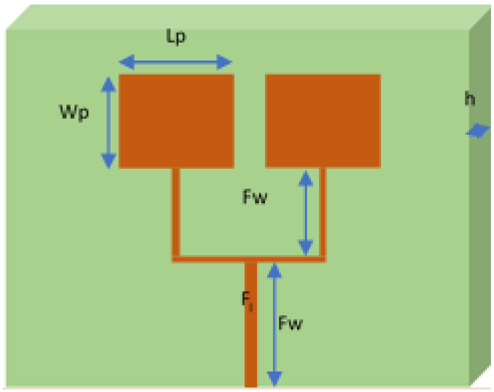

Figure.3.56: **1 × 2 square patch array radiating patch**

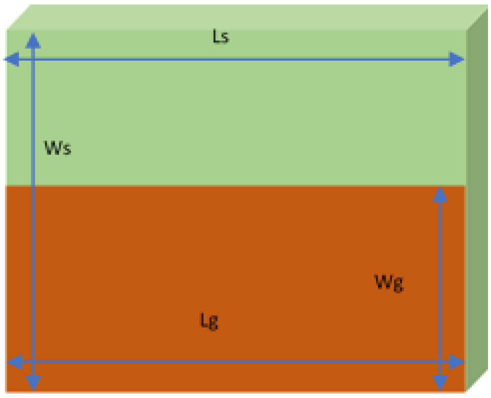

Figure.3.57: **1 × 2 square patch array ground planes**

The antenna array is designed for the resonance frequency $f_r = 6GHz$. The dimensions of the designed antenna is length of the rectangular patch $L_p = 15mm$, Width of the rectangular patch $W_p = 15mm$, Length of microstrip feed1 $f_{l1} = 15mm$, Width of the microstrip feed1 $f_{w1} = 2mm$, Length of microstrip feed2 $f_{l2} = 15mm$, Width of the microstrip feed2 $f_{w2} = 3mm$, the length of the partial ground $L_g = 27mm$, and width of the partial ground $W_g = 70mm$,

The results of the simulated antenna have been observed, which are presented in chapter 4. These results have been compared with a simple rectangular microstrip patch antenna with partial ground. It is found that bandwidth of the antenna array is increased by an amount of 430MHz and the radiation pattern is more directed as compared to simple rectangular microstrip patch antenna with partial ground.

Chapter 4

RESULTS AND INFERENCES

4.1. Overview

Planar and printed probe feed antennas are most widely used in applications like Wi-Fi, Wi-Max, WLAN. Techniques like slotting and stacking adopt to enhance the performance and convert design into wideband antenna suitable for Biomedical application. The designs of antenna are discussed in chapter 3 and the performance of the designed antennas have been presented and discussed in this chapter. The parameters used to define the performance of the microstrip patch antenna are: Reflection and VSWR Bandwidth, Far Field Radiation Pattern, E and H Plane Co and Cross Polarization, Surface Current Distribution, and Impedance of the patch. These parameters are also observed by varying the dimensions and position of the slot and discussed under the heading of Parametric Analysis.

4.2. Rectangular Microstrip Patch Antenna:

The Rectangular Microstrip patch antenna is designed at $L_P = 29.21mm$, $W_P = 37.26mm$, $L_{sub} = 37.82mm$, $W_{sub} = 46.36mm$, $h = 1.59mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

Simple rectangular patch antenna is designed and simulated at resonance frequency 2.45GHz. The plot of reflection coefficient vs frequency and VSWR vs frequency are obtained as shown in Figure 4.1 and Figure 4.2 respectively.

From Figure 4.1 it is found that the designed antenna has a resonance frequency f_r= 2.4563GHz and reflection coefficient of -71.2643 dB, the reflection bandwidth of 66MHz in the frequency band 2.424 GHz-2.492 GHz. From figure 4.2 it is observed that VSWR is below 2 which is measured at -10dB value of reflection coefficient and VSWR bandwidth is 71MHz in the frequency band 2.422GHz-2.493GHz.

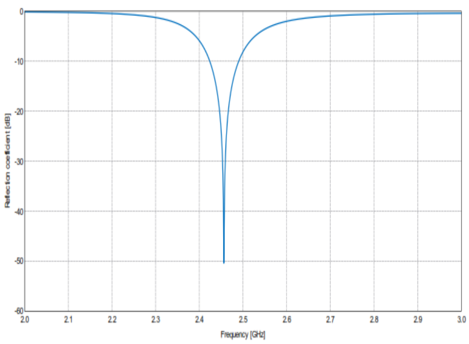

Figure. 4.1: **Reflection Coefficient Vs Frequency of Rectangular Microstrip Patch Antenna.**

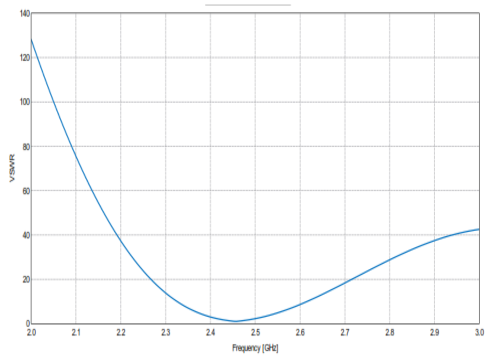

Figure. 4.2: **VSWR Vs Frequency of Rectangular Microstrip Patch Antenna.**

The reflection coefficient of the fabricated antenna is observed to be -35dB which is not matching with the simulated results, resonance frequency is tuned at 2.45GHz which is matching with the simulated results.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated simple rectangular microstrip patch antenna at the resonance frequency 2.45GHz is shown in Figure 4.3. It helps to measure the gain of antenna.

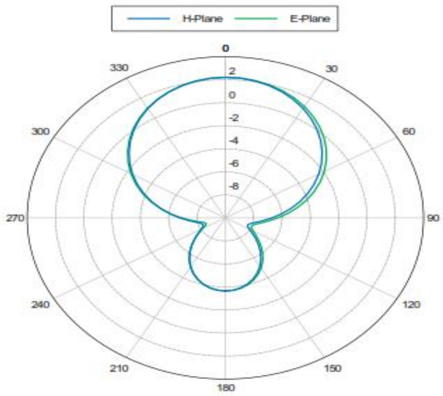

Figure.4.3: **Far Field Radiation Pattern at 2.45GHz of Rectangular Microstrip Patch Antenna.**

It is observed that the gain of the rectangular microstrip patch antenna is of 2.21dBi at 2.45 GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 2.45GHz.

E and H Plane Co Polarization and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated rectangular microstrip patch antenna at the resonance frequency 2.45 GHz are shown in Figure 4.4. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated rectangular microstrip patch antenna at the resonance frequency 2.45 GHz are shown in Figure 4.5. It helps to measure the gain at the resonance frequency for co polarization and cross polarization separately. Further it is used to view and analyse the pattern of radiation.

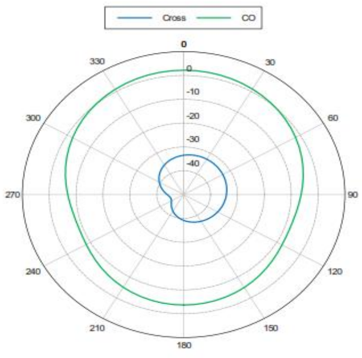

Figure 4.4: **E Plane Co and Cross Radiation Pattern of Rectangular Microstrip Patch Antenna at 2.45 GHz.**

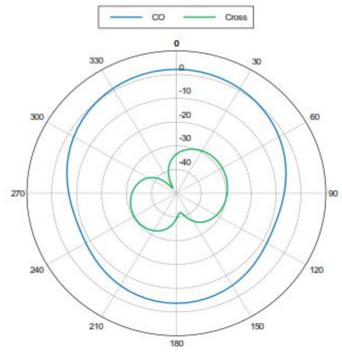

Figure 4.5: **H Plane Co and Cross Radiation Pattern of Rectangular Microstrip Patch Antenna at 2.45 GHz.**

The cross-polarization variations in E-Plane are slightly less than -40dB while for H-Plane it is slightly greater than -40dB and the co polarizations are observed to be nearly same and stable at the resonating frequency 2.45GHz with a gain of 2.21dBi.

Surface Current Distribution:

The Surface Current Distribution pattern of the simulated rectangular microstrip patch antenna at the resonance frequency 2.45GHz is shown in figure 4.6.

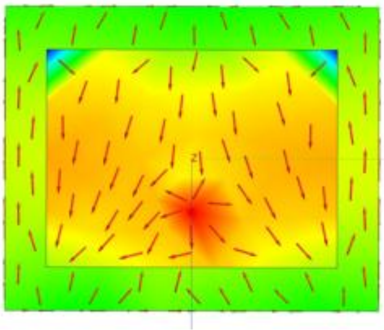

Figure .4.6: **Surface Current Distribution on Radiating Patch at 2.45GHz of Rectangular Microstrip Patch Antenna**

It is observed that, Surface current is linearly distributed at 2.45GHz and the radiating patch current distributed linearly over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated rectangular microstrip patch antenna at the resonance frequency 2.45GHz is shown in figure 4.7. It helps to find the real and imaginary part of the impedance of the antenna at resonance frequency 2.45GHz.

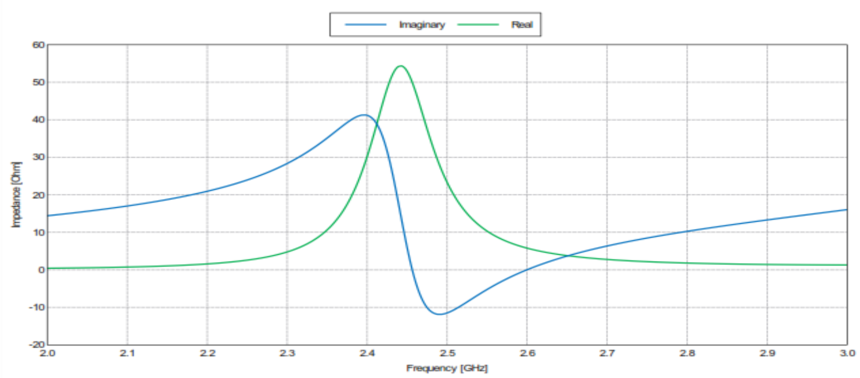

Figure 4.7: **Impedance of Proposed Antenna at 2.45GHz of Rectangular Microstrip Patch Antenna.**

From the Figure 4.7 it is found that the impedance of the simulated antenna is 50.9+1.54j ohm and |z| = 50.92 ohm.

Parametric Analysis:

Parametric analysis is carried out to see the effect of change of length and width of the radiating patch. Figure 4.1 shows reflection coefficient of reference antenna which is having appropriate dimension resonates at 2.45GHz. Design structure resonates for the band of 66MHz from 2.424 GHz-2.492 GHz. For parametric analysis the length of the patch and width of the patch are increased and decreased by 0.5mm alternately and the plot of reflection coefficient vs frequency is plotted. Figure 4.8 and figure 4.9 show the results due to variation in length and variation in width respectively.

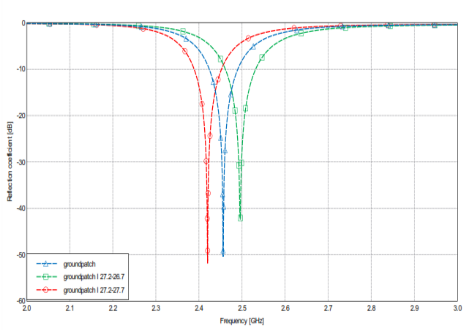

Figure 4.8: **Parametric Analysis When Length Changed of Rectangular Microstrip Patch Antenna.**

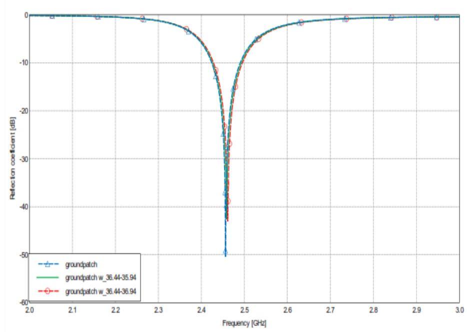

Figure 4.9: **Parametric Analysis When Width Changed of Rectangular Microstrip Patch Antenna.**

When length of the patch is decreased by an amount of 0.5mm, the antenna resonates at 2.49GHz, with reflection coefficient of -43.96 dB with slight increase in bandwidth i.e. 70MHz from 2.461GHz-2.532GHz. When the length of the patch is increased by the amount of 0.5mm, the antenna resonates at 2.41GHz with reflection coefficient of -52.60 dB with slight abatement in bandwidth i.e. 63MHz from 2.389GHz-2.455GHz. When the width of the Patch is decreased by an amount of 0.5mm, the antenna resonates at 2.45GHz with reflection coefficient of -43.04 dB with bandwidth i.e. 67MHz from 2.425GHz-2.491GHz. When the width of the Patch is increased by the amount of 0.5mm, the antenna resonates at 2.46GHz with reflection coefficient of -43.03 dB with bandwidth 67MHz from 2.429GHz-2.495GHz.

Inference:

It is resonating at single frequency with very less bandwidth of 80MHz. It suffers from the problem of impedance matching despite it has a moderate gain for short distance applications.

4.3 U-Slot Loaded Rectangular Microstrip Patch Antenna:

The U-slot loaded rectangular microstrip patch antenna is designed at $L_P = 26mm$, $W_P = 36mm$, $L_{sub} = 37.82mm$, $W_{sub} = 46.36mm$, $h = 1.59mm$, $L_h = 19.5mm$, $W_h = 2.5mm$, $L_v = 2.5mm$, $W_v = 20mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

U-slot loaded rectangular microstrip patch antenna is designed and simulated at resonance frequency 2.45GHz. The plot of reflection coefficient vs frequency and VSWR vs frequency are obtained as shown in figure 4.10 and 4.11

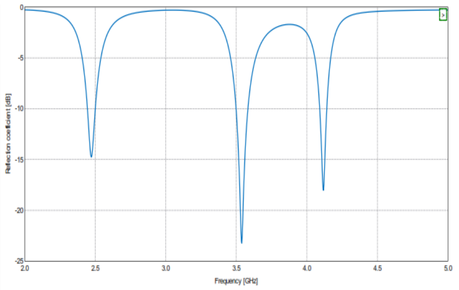

Figure 4.10: **Reflection Coefficient Vs Frequency of U-Slot Loaded Rectangular Microstrip Patch Antenna.**

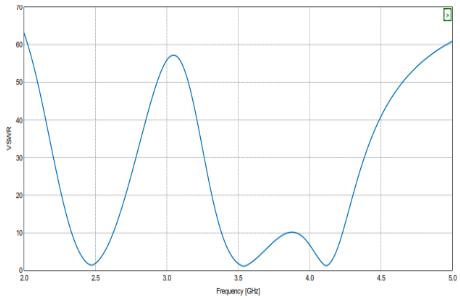

Figure 4.11: **VSWR Vs Frequency For U-Slot Loaded Rectangular Microstrip Patch Antenna.**

From Figure 4.10 it is found that the designed antenna is resonating at three different frequencies. The resonance frequencies are f_{r1}= 2.474GHz, f_{r2}=3.538GHz and f_{r3}=4.11GHz, and the corresponding reflection coefficients are -14.7 dB, -23.26

dB and -18.06dB. The reflection bandwidths are 36MHz, 83MHz, 53MHz seen from 2.446GHz-2.502GHz, 3.497GHz-3.593GHz and 4.089GHz-4.142GHz respectively. From Figure 4.11 VSWR is observed below 2 from 2.44GHz -2.503GHz, 3.493GHz - 3.586GHz, 4.09GHz -4.176GHz and VSWR bandwidths are of 63MHz, 93MHz and 86MHz.

The reflection coefficient of the fabricated antenna are observed to be -18dB, -18dB, -17dB is match at third resonancesame as simulated results and slightly deviated for first and second resoanance. The reflection bandwidths of the fabricated antenna are 20MHz, 38MHz, 40MHz respectively, resonance frequency is tuned at 2.8GHz, 3.7GHz and 4.5GHz which is not matching with the simulated results.

Far Field Radiation Pattern:

The field radiation pattern of the simulated U-slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.474GHz, 3.53GHz and 4.11GHz are shown in Figure 4.12, Figure 4.13 and Figure 4.14. It helps to measure the gain of antenna.

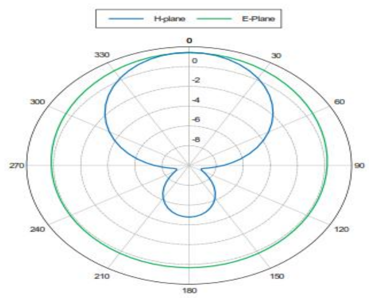

Figure 4.12: **Far Field Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna At 2.474GHz.**

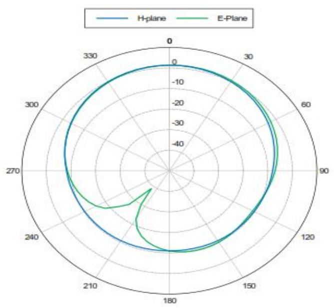

Figure 4.13: **Far Field Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna At 3.53GHz.**

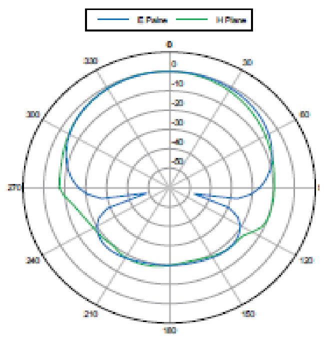

Figure 4.14: **Far Field Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 4.11GHz.**

It is observed that the gains of the U-slot loaded rectangular microstrip patch antenna are 1.44dBi at frequency 2.47 GHz, 1.36dBi at frequency 3.5383GHz and 0.015dBi at frequency 4.11GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 2.47GHz while the pattern is deviating from the ideal pattern for resonance frequency 3.5383GHz and 4.11GHz.

E and H Plane Co and Cross Polarization:

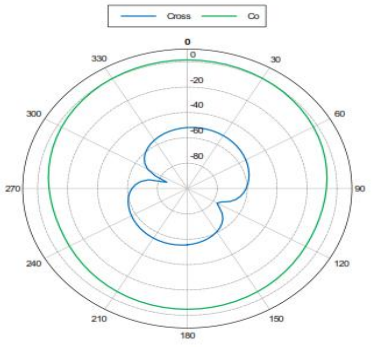

Figure 4.15 : **E Plane Co and Cross Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 2.47GHz.**

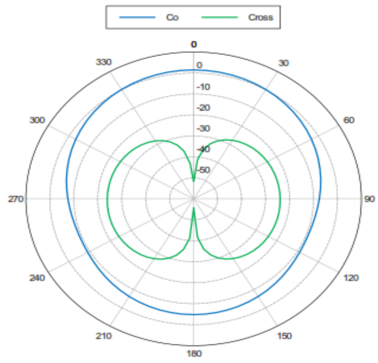

Figure 4.16: **H Plane Co and Cross Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 2.47GHz.**

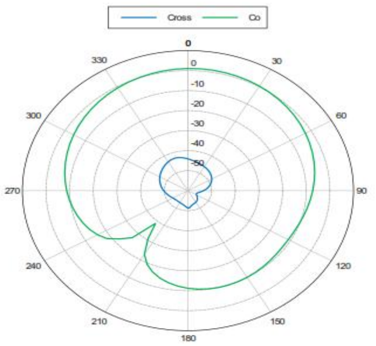

Figure 4.17 : **E Plane Co and Cross Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 3.53GHz.**

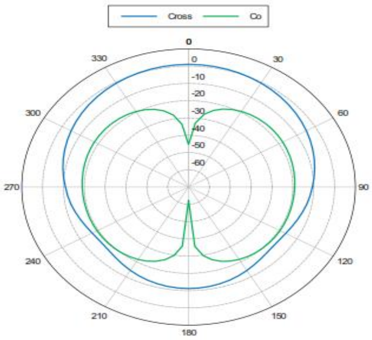

Figure 4.18: **H Plane Co and Cross Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 3.53GHz.**

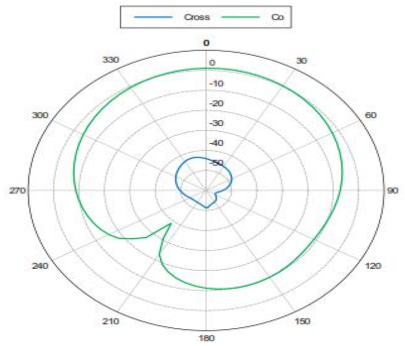

Figure .4.19 : **E Plane Co and Cross Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 4.11GHz.**

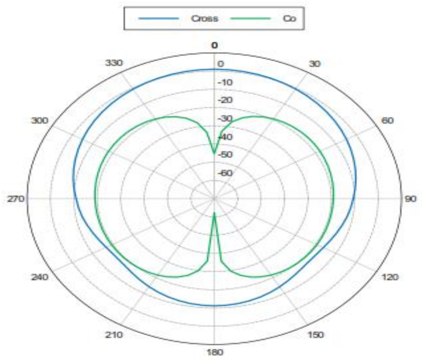

Figure 4.20: **H Plane Co and Cross Radiation Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 4.11GHz.**

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated U-slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.474GHz, 3.538GHz and 4.11GHz are shown in Figure 4.15, Figure 4.17, Figure 4.19 and H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated U-slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.474GHz, 3.538GHz and 4.11GHz are shown in Figure 4.16, Figure 4.18 and Figure 4.20. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately.

For the resonance frequency 2.47 GHz the cross-polarization variations in E-Plane are slightly less than -60dB, while for H-Plane it is -40dB. For the resonance frequency 3.53 GHz the cross-polarization variations in E-Plane are slightly less than -40dB, while for H-Plane it is -10dB.

For the resonance frequency 4.11 GHz the cross-polarization variations in E-Plane are slightly less than -50dB, while for H-Plane it is -40dB. The gain of the antenna is 1.44 dBi at 2.47 GHz**,** 1.36 dBi at 3.5383GHz and 0.015dBi at 4.11GHz**.** The co polarizations are observed to be nearly same and stable at the resonating frequencies 2.47 GHz and 3.53 GHz while it is more deviating from the ideal at resonating frequency 4.11 GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated U-slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.47GHz, 3.53 GHz ad 4.11GHz are as shown in Figure 4.21, Figure 4.22 and Figure 4.23 respectively.

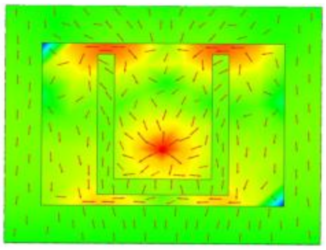

Figure 4.21: **Surface Current Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 2.47GHz.**

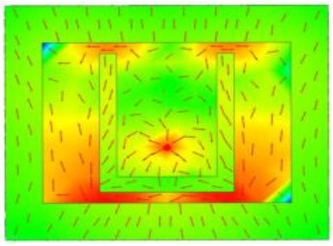

Figure 4.22: **Surface Current Pattern of U-Slot Loaded Rectangular Microstrip Patch Antenna at 3.53GHz.**

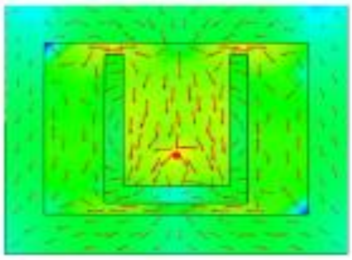

Figure 4.23: **Surface Current Pattern Of U-Slot Loaded Rectangular Microstrip Patch Antenna at 4.11GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 2.47GHz while for resonance frequency 3.53 GHz and 4.11GHz, the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated U-slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.4GHz, 3.53 GHz and 4.11 GHz are shown in Figure 4.24.

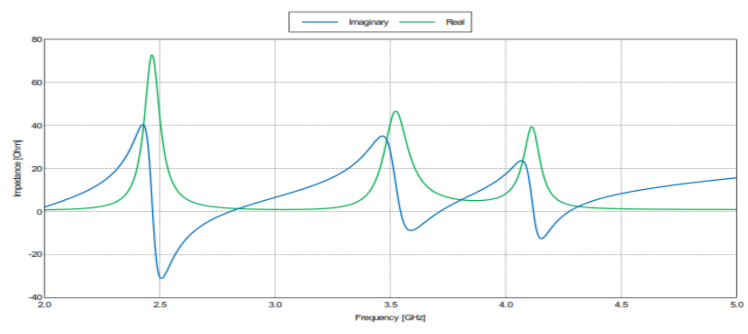

Figure 4.24: **Impedance Vs Frequency of U-Slot Loaded Rectangular Microstrip Patch Antenna.**

From the Figure 4.24 it is found that the impedance of the simulated antenna is 68.5- j12.6 ohm at resonance frequency 2.47GHz, 46+ j7.56 ohm at resonance frequency 3.53GHz ohm and 37.6-2.28j ohm at resonance frequency 4.11GHz. The corresponding magnitudes of the impedance are |z| = 69.65 ohm, |z| = 46.62 ohm and

|z| = 37.67 ohm for the resonating frequencies 2.47 GHz, 3.53 GHz and 4.11 GHz respectively.

It is observed that the impedance goes on reducing with the increase in resonance frequency and the impedance is closer to the ideal value for resonance frequency 3.53 GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the length and width of the slots are changed and the effect has been observed. For parametric analysis the length and width of the horizontal and vertical slots of the U-shaped antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.25, Figure 4.26, Figure 4.27 and Figure 4.28 show the results due to variation in lengths and widths.

Effect of change in horizontal slot length and width:

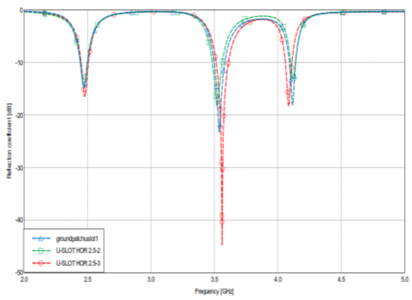

Figure 4.25: **Reflection Coefficient Vs Frequency of U-Slot Loaded Rectangular Microstrip Patch Antenna for Horizontal Slot Length Changed.**

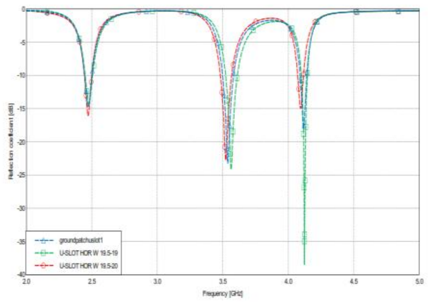

Figure 4.26: **Reflection Coefficient Vs Frequency of U-Slot Loaded Rectangular Microstrip Patch Antenna Horizontal Slot Width Changed.**

When length of the horizontal slot is decreased by an amount of 0.5mm and width is maintained constant, the antenna resonates at frequencies f_{r1}= 2.47GHz, f_{r2}=3.52GHz, f_{r3}=4.12GHz, and the corresponding reflection coefficients are -14.52 dB, -18.26dB and -13.1dB. The reflection bandwidths are observed as 53MHz,77MHz and 38MHz in the frequency bands 2.44 GHz-2.493GHz, 3.485 GHz-3.563GHz, 4.103 GHz-4.1414GHz respectively.

When the length of the horizontal slot is increased by an amount of 0.5mm width is maintained constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}=3.56GHz, f_{r3} =4.08GHz, and the corresponding reflection coefficients are -16.3 dB, -47.88dB and -18.32dB. The reflection bandwidths are observed as 59MHz, 95MHz and 53MHz in the frequency bands 2.452 GHz-2.511GHz, 3.515 GHz-3.61GHz, 4.061 GHz-4.114GHz respectively.

When the width of the horizontal slot is decreased by an amount of 0.5mm length is maintained constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}=3.56GHz, f_{r3}=4.12GHz, and the corresponding reflection coefficients are -14.08 dB, -24.22dB and -38.87dB. The reflection bandwidths are observed as 56MHz, 90MHz and 47MHz in the frequency bands 2.449 GHz-2.505 GHz, 3.52 GHz-3.61GHz, 4.101 GHz-4.148GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mmand length is maintained constant, the antenna resonates at frequencies f_{r1}= 2.47GHz, f_{r2}=3.52GHz, f_{r3}=4.09GHz, and the corresponding reflection coefficients are -16.08 dB, -22.79dB and -14.94dB. The reflection bandwidths are observed as 59MHz, 85MHz and 44MHz in the frequency bands 2.446 GHz -2.505 GHz, 3.485 GHz -3.576 GHz, 4.073GHz-4.117GHz respectively.

Effect of change in Vertical slot length and width:

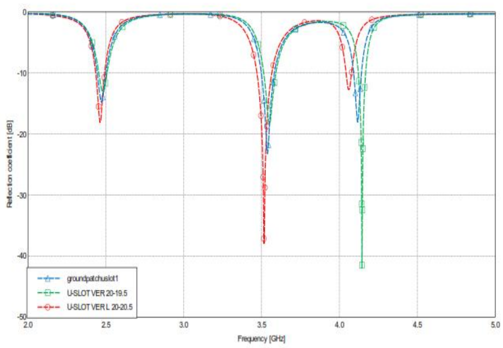

Figure 4.27: **Reflection Coefficient Vs Frequency of U-Slot Loaded Rectangular Microstrip Patch Antenna for Vertical Slot Length Changed.**

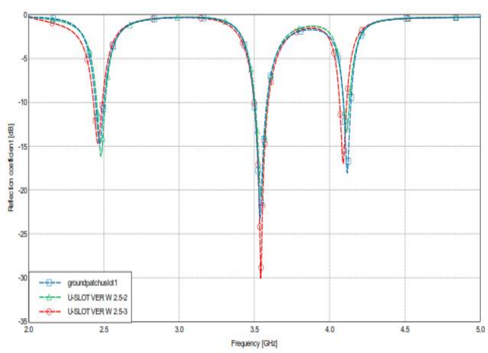

Figure 4.28: **Reflection Coefficient Vs Frequency Of U-Slot Loaded Rectangular Microstrip Patch Antenna for Vertical Slot Width Changed.**

When length of the vertical slot is decreased by an amount of 0.5mm and width is maintained constant, the antenna resonates at frequencies f_{r1} = 2.48GHz, f_{r2} =3.55GHz, f_{r3}= 4.14GHz, and the corresponding reflection coefficients are -13.2 dB, -18.38dB and -46.51dB. The reflection bandwidths are observed as 49MHz, 81MHz and 47MHz in the frequency bands 2.456 GHz-2.505GHz, 3.512 GHz-3.593GHz, 4.12 GHz-4.167GHz respectively.

When the length of the vertical slot is increased by an amount of 0.5mm and width is maintained constant, the antenna resonates at frequencies f_{r1}= 2.46GHz,

f_{r2}=3.51GHz, f_{r3} =4.06GHz, and the corresponding reflection coefficients are -18.23 dB, -42.46dB and -12.69dB. The reflection bandwidths are observed as 59MHz, 96MHz and 40MHz in the frequency bands 2.434GHz-2.493GHz, 3.472GHz-3.568GHz, 4.042 GHz-4.082GHz respectively.

When the width of the vertical slot is decreased by an amount of 0.5mm and length is maintained constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}= 3.54GHz, f_{r3}= 4.11GHz, and the corresponding reflection coefficients are -16.16 dB, -20.63dB and -13.13dB. The reflection bandwidths are observed as 56MHz, 81MHz and 47MHz in the frequency bands 2.452GHz-2.508GHz, 3.506 GHz-3.587GHz, 4.095 GHz-4.142GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm and length is maintained constant, the antenna resonates at frequencies f_{r1}= 2.46GHz, f_{r2}= 3.54GHz and f_{r3}= 4.08GHz, and the corresponding reflection coefficients are -14.55 dB, -30.60dB and -16.99dB. The reflection bandwidths are observed as 59MHz, 94MHz and 47MHz in the frequency bands 2.431GHz-2.49GHz, 3.496 GHz-3.59GHz, 4.067 GHz-4.114GHz respectively.

Inferences:

It is resonating at multiple frequencies with very less bandwidth (63MHz, 93MHz and 54MHz). It suffers from the problem of impedance matching and it has poor gain.

4.4 U-Slot Rectangular Microstrip Patch Antenna with Defective Ground:

The U-Slot Rectangular Microstrip Patch Antenna with Defective Ground structure is designed $L_P = 26mm$, $W_P = 36mm$, $L_{sub} = 37.82mm$, $W_{sub} = 46.36mm$, $h = 1.59mm$, $L_h = 19.5mm$, $W_h = 2.5mm$, $L_v = 2.5mm$, $W_v = 20mm$, $L_{gh} = 19.5mm$, $W_{gh} = 2.5mm$, $L_{gv} = 2.5mm$, $W_{gv} = 20mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

U-Slot Rectangular Microstrip Patch Antenna with Defective Ground is designed and simulated. The plot of reflection coefficient vs frequency and VSWR vs frequency are obtained as shown in Figure 4.29 and 4.30 respectively.

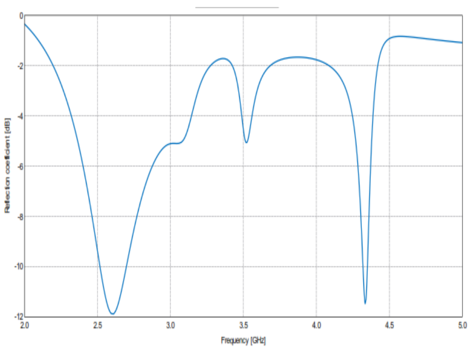

Figure 4.29: **Reflection Coefficient Vs Frequency of U-Slot for Rectangular Microstrip Antenna with Defective Ground.**

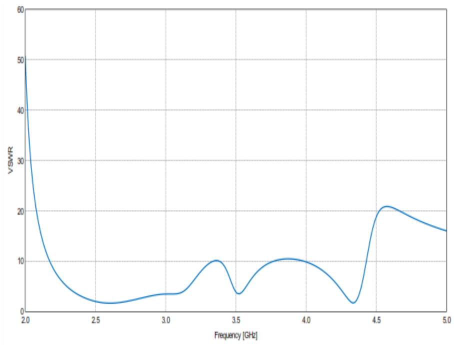

Figure 4.30: **VSWR Vs Frequency for Rectangular Microstrip Antenna with Defective Ground.**

From Figure 4.29 it is found that the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground is resonating at two frequencies. The first resonance occurs at frequency 2.59GHz, second resonance occurs at frequency 4.33GHz, and the corresponding reflection coefficients are -11.89dB and -11.49dB. The reflection bandwidths are observed at 180MHz, 31MHz in the frequency bands 2.518GHz-2.698GHz and 4.318GHz-4.349GHz respectively.

From Figure 4.30 VSWR is observed below 2 in the frequency bands 2.497GHz-2.716GHz, 4.309GHz-4.352GHz and VSWR bandwidths are of 219MHz and 43MHz.

The reflection coefficient of the fabricated antenna are observed to be -8.9 dB, -10.9 dB, is not matching with simulated results. The reflection bandwidth is observed at second resonance only and it is 12MHz, resonance frequency is tuned at 3.02GHz and 5.14GHz which is shifted towards higher side of the simulated results.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at the resonance frequencies 2.59 GHz and 4.33GHz are shown in Figure 4.31 and Figure 4.32 respectively.

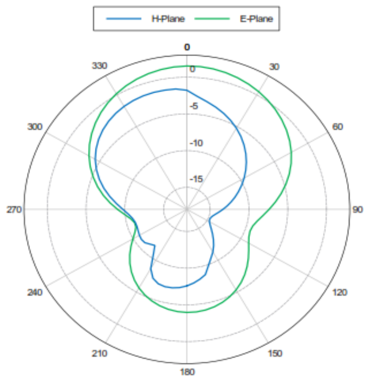

Figure 4.31: **Far Field Radiation Pattern of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 2.59GHz**.

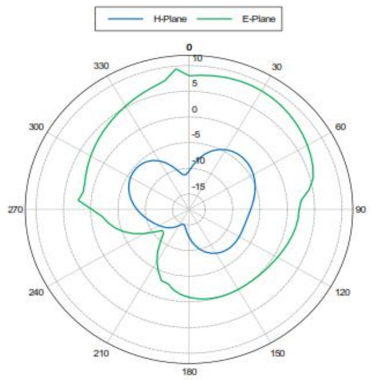

Figure 4.32: **Far Field Radiation Pattern of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 4.33GHz.**

It is observed that the gains of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground are 1.22 dBi at 2.59GHz and 8.02 dBi at 4.33GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 2.59GHz while the pattern is more deviating from the ideal pattern for resonance frequency 4.33GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at the resonance frequencies 2.59GHz and 4.33GHz are shown in Figure 4.33and 4.35 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at the resonance frequencies 2.59GHz and 4.33GHz are shown in Figure 4.34 and 4.36 respectively. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately. Further it is used to view and analyse the pattern of radiation.

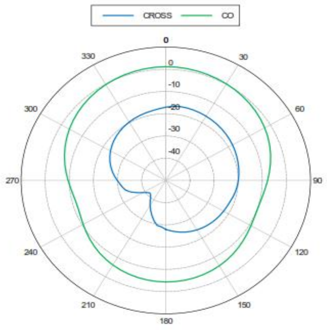

Figure .4.33: **E Plane Co and Cross Radiation Pattern of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 2.59GHz.**

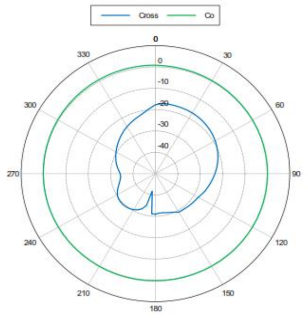

Figure .4.34: **H Plane Co and Cross Radiation Pattern of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 2.59GHz.**

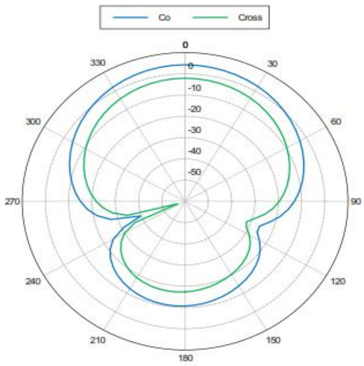

Figure 4.35: **E Plane Co and Cross Radiation Pattern of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 4.33GHz.**

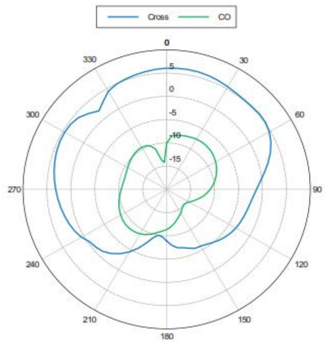

Figure 4.36: **H Plane Co and Cross Radiation Pattern of the U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 4.33GHz.**

For the resonance frequency 2.59 GHz the cross-polarization variations in E-Plane are slightly less than -20dB, while for H-Plane it is -20dB. For the resonance frequency 4.33 GHz the cross-polarization variations in E-Plane are slightly less than -10dB, while for H-Plane it is -10dB. The gain of the antenna is 1.22 dBi at frequency 2.60 GHz and 8.02 dBi at frequency 4.33GHz. The co polarizations are observed to be nearly same and stable at the resonating frequency 2.59 GHz while it is more deviating from the ideal at resonating frequency 4.33 GHz.

Surface Current Distribution:

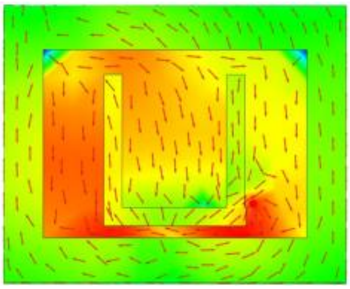

Figure 4.37: **Surface Current Pattern of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 2.47GHz.**

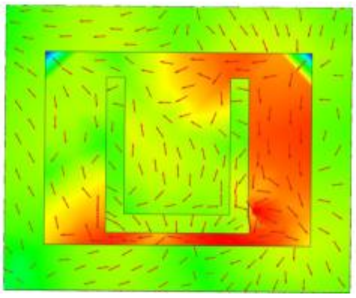

Figure 4.38: **Surface Current Pattern of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at 4.33GHz.**

From Figure 4.37, 4.38, it is observed that, Surface current is linearly distributed at resonance frequency 2.59GHz while for resonance frequency 4.33 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated U-Slot Rectangular Microstrip Patch Antenna with Defective Ground at the resonance frequencies 2.59GHz and 4.33GHz is shown in Figure 4.39.

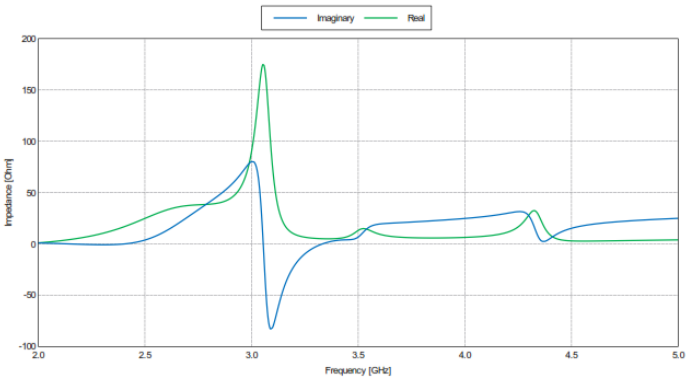

Figure 4.39: **Impedance Vs Frequency of U-Slot Rectangular Microstrip Antenna with Defective Ground.**

From the Figure 4.39, it is found that the impedance of the simulated antenna is 32.8+ j 12.7 ohm at resonance frequency 2.59GHz and 31.3+ j 11.3 ohm at resonance frequency 4.33GHz ohm. The corresponding magnitudes of the impedance are |z| = 35.17 ohm and |z| = 33.27 ohm for the resonating frequencies 2.59 GHz and 4.33 GHz respectively. It is observed that the impedance goes on reducing with the increase in resonance frequency and the impedance is not matching with the ideal value for both resonance frequencies.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the length and width of the slots are changed alternately and the effect has been observed. For parametric analysis the length and width of the horizontal and vertical slots on radiating patch and ground plane of the U-shaped antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.40, 4.41, 4.42 and 4.43 show the results due to variation in lengths and variation in widths.

Effect of change in horizontal slot length and width:

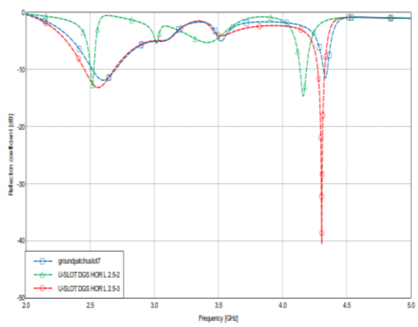

Figure 4.40: **Reflection Coefficient Vs Frequency of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground for Horizontal Slot Length Changed.**

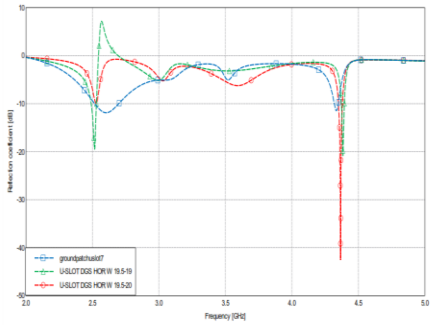

Figure 4.41: **Reflection Coefficient Vs Frequency of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground for Horizontal Slot Width Changed.**

When length of the horizontal slot is decreased by an amount of 0.5mm maintaining the width of the horizontal slot constant for both the planes, the antenna resonates at frequency, f_{r1}= 2.51GHz, f_{r2}= 4.16GHz, and the corresponding reflection coefficients are -12.86dB and -14.74dB. The reflection bandwidths are 28MHz and 47MHz in the frequency bands 2.502 GHz-2.53GHz, 4.138 GHz-4.185GHz respectively.

When the length of the horizontal slot is increased by an amount of 0.5mm maintaining the width of the horizontal slot constant for both the planes, the antenna resonates at frequency f_{r1} =2.56GHz, f_{r2} =4.30GHz, and the corresponding reflection coefficients are -13.18 dB and -55.66dB. The reflection bandwidths are 223MHz and 52MHz in the frequency bands 2.456 GHz-2.679GHz, 4.275GHz-4.327GHz respectively.

When the width of the horizontal slot is decreased by an amount of 0.5mm maintaining the length of the horizontal slot constant for both the planes, the antenna resonates at frequency f_{r1}= 2.51GHz, f_{r2}= 4.38GHz, and the corresponding reflection coefficients are -19.63 dB and -21.06dB. The reflection bandwidths are 37MHz and 22MHz in the frequency bands 2.493GHz-2.53GHz, 4.374GHz-4.396GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm maintaining the length of the horizontal slot constant for both the planes, the antenna resonates at frequency f_{r1}= 2.52GHz, f_{r2}= 4.36GHz, and the corresponding reflection coefficients are -10dB and -58.49dB. The reflection bandwidths are 30MHz and 29MHz in the frequency bands 2.524 GHz-2.557GHz, 4.349 GHz-4.38GHz respectively.

Effect of change in Vertical slot length and width:

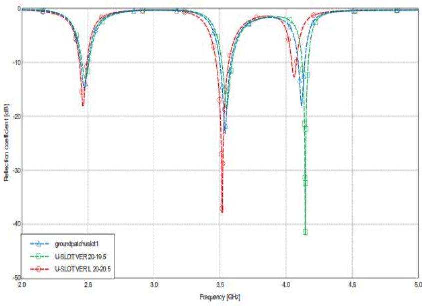

Figure 4.42: **Reflection Coefficient Vs Frequency of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground for Vertical Slot Length Changed.**

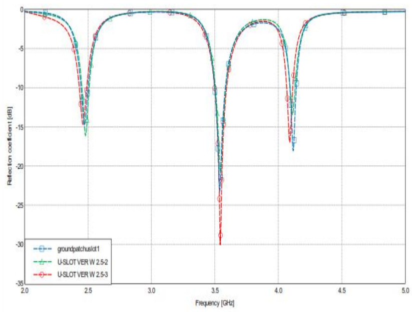

Figure .4.43: **Reflection Coefficient Vs Frequency of U-Slot Rectangular Microstrip Patch Antenna with Defective Ground for Vertical Slot Length Changed.**

When the length of the vertical slot is decreased by an amount of 0.5mm maintaining the width of the horizontal slot constant for both the planes, the antenna resonates at frequency, f_{r1}= 2.93GHz, f_{r2}= 4.17GHz, and the corresponding reflection coefficients are -25.26 dB and -14.13dB. The reflection bandwidths are 172MHz and 52MHz seen from 2.806 GHz-2.985GHz, 4.148GHz-4.2GHz respectively.

When the length of the vertical slot is increased by an amount of 0.5mm maintaining the width of the horizontal slot constant for both the planes, the antenna resonates at unique frequency 2.49GHz and the corresponding reflection coefficient is -11 dB. The reflection bandwidth is 10.79MHz in the frequency band 2.489 GHz-2.499GHz.

When the width of the vertical slot is decreased by an amount of 0.5mm maintaining the length of the horizontal slot constant for both the planes, the antenna resonates at frequencies, f_{r1}= 2.51GHz, f_{r2}= 4.129 GHz, and the corresponding reflection coefficients are -30.65dB and -19.81 dB. The reflection bandwidths are

328MHz and 59MHz in the frequency bands 2.521-2.849GHz, 4.107-4.166GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm maintaining the length of the horizontal slot constant for both the planes, the antenna resonates at frequencies f_{r1}= 2.68GHz, f_{r2}= 4.13 GHz, and the corresponding reflection coefficients are -31.96dB and -13.74dB. The reflection bandwidths are 328MHz and 59MHz in the frequency bands 2.521GHz-2.849GHz, 4.107GHz-4.166GHz respectively.

Inferences:

It is resonating at two frequencies and the bandwidth is improved up to 219 MHz by increasing the length of surface current. It resolves the impedance matching problem to certain extent. It has a moderate gain but it deteriorates the radiation pattern.

4.5 T-Slot Loaded Rectangular Microstrip Patch Antenna:

The T-Slot Loaded Rectangular Microstrip Patch Antenna is designed at $L_P = 25.80mm$, $W_P = 36.10mm$, $L_{sub} = 37.82mm$, $W_{sub} = 46.36mm$, $h = 1.59mm$, $L_h = 19mm$, $W_h = 2.5mm$, $L_v = 2.5mm$, $W_v = 18.5mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

T-Slot Loaded Rectangular Microstrip Patch Antenna is designed and simulated. The plot of reflection coefficient vs frequency and VSWR vs frequency are obtained as shown in Figure 4.44 and 4.45 respectively.

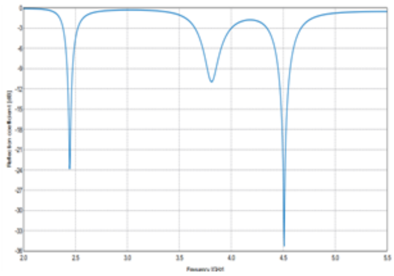

Figure 4.44: **Reflection Coefficient Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna.**

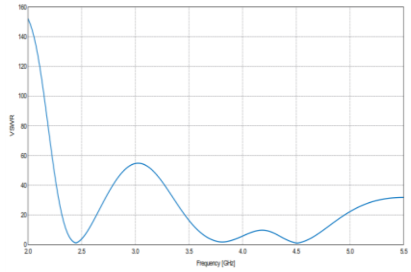

Figure .4.45: **VSWR Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna.**

From Figure 4.44 it is found that the T-Slot loaded rectangular microstrip patch antenna is resonating at two frequencies. The first resonance occurs at frequency

2.44GHz, second resonance occurs at frequency 4.50GHz, and the corresponding reflection coefficients are -24.13 dB and -36.05dB. The reflection bandwidths are 43MHz, 101MHz in the frequency bands 2.427 GHz-2.47 GHz, 4.463GHz-4.564GHz respectively. From Figure 4.45 VSWR is observed below 2 in the frequency bands 2.421GHz-2.472GHz, 4.452GHz-4.564GHz and VSWR bandwidths are 51MHz and 112MHz.

The reflection coefficient of the fabricated antenna are observed to be -22 dB, -26 dB, which is not matching with simulated results. The reflection bandwidths of the fabricated antenna is 25MHz and 55MHz respectively, resonance frequency is tuned at 2.55GHz and 4.9 GHz which is slightly shifted towards higher side of the simulated results.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated T-Slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.44 GHz and 4.50GHz are shown in Figure 4.46 and Figure 4.47 respectively.

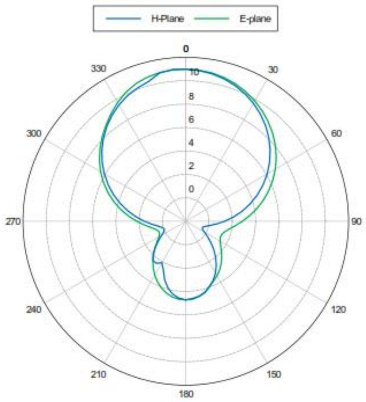

Figure .4.46: **Far Field Radiation Pattern of T-Slot Loaded Rectangular Microstrip Patch Antenna at 2.44GHz.**

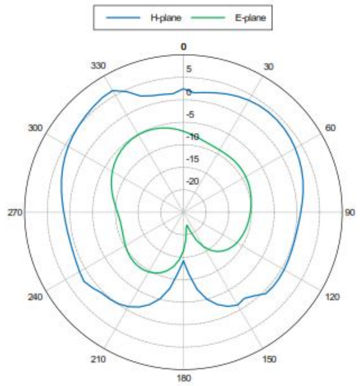

Figure 4.47: **Far Field Radiation Pattern of T-Slot Loaded Rectangular Microstrip Patch Antenna at 4.50GHz.**

It is observed that the gains of the T-Slot loaded rectangular microstrip patch antenna are 10.99 dBi at frequency 2.44 GHz and 1.42 dBi at frequency 4.50GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 2.44GHz while the pattern is slightly deviating from the ideal pattern for resonance frequency 4.50GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated T-Slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.44GHz and 4.50GHz are shown in Figure 4.48 and Figure 4.50 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated T-Slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.44GHz and 4.50GHz are shown in Figure 4.49 and Figure 4.51 respectively. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately. Further it is used to view and analyse the pattern of radiation.

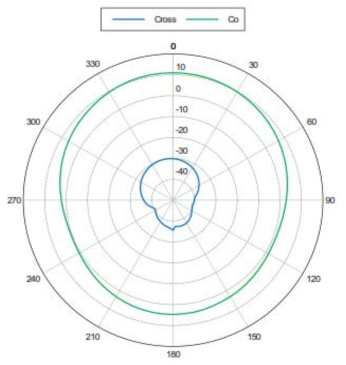

Figure .4.48: **E Plane Co and Cross Radiation Pattern of T-Slot Loaded Rectangular Microstrip Patch Antenna at 2.44GHz.**

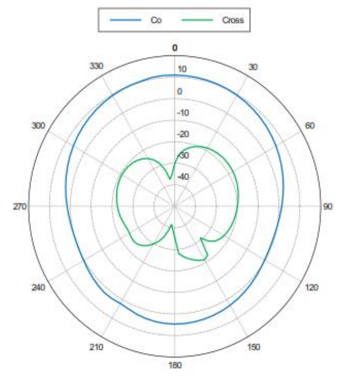

Figure 4.49: **H Plane Co and Cross Radiation Pattern of T-Slot Loaded Rectangular Microstrip Patch Antenna at 2.44GHz.**

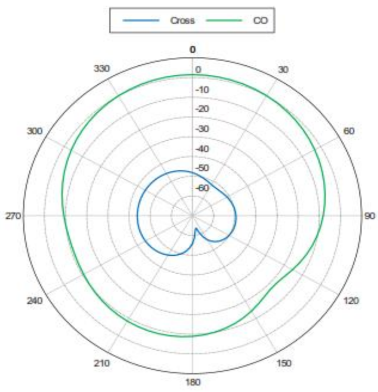

Figure 4.50: **E Plane Co and Cross Radiation Pattern of T-Slot Loaded Rectangular Microstrip Patch Antenna at 4.50GHz.**

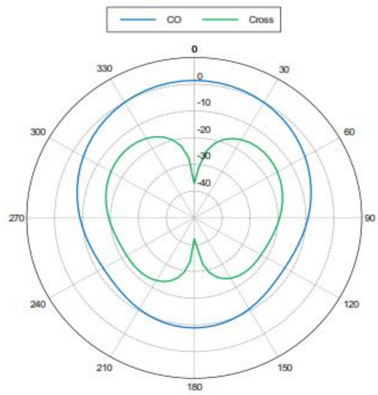

Figure 4.51: **H Plane Co and Cross Radiation Pattern of T-Slot Loaded Rectangular Microstrip Patch Antenna at 4.50GHz.**

For the resonance frequency 2.44 GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is -15dB. For the resonance frequency 4.33 GHz the cross-polarization variations in E-Plane are slightly less than -40dB, while for H-Plane it is -10dB. The gain of the antenna is 10.99dBi at frequency 2.44GHz and 1.42dBi at frequency 4.50GHz. The co polarizations are observed to be nearly same and stable at the resonating frequency 2.44GHz while it is slightly deviating from the ideal at resonating frequency 4.50GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated T-Slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.44GHz and 4.50 GHz are as shown in Figure 4.52 and 4.53 respectively.

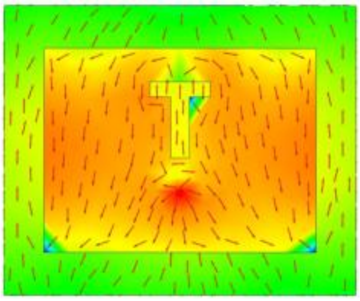

Figure 4.52: **Surface Current Distribution on Radiating Patch of T-Slot Loaded Rectangular Microstrip Patch Antenna at 2.44GHz.**

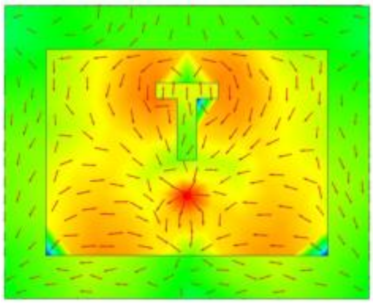

Figure 4.53: **Surface Current Distribution on Radiating Patch of T-Slot Loaded Rectangular Microstrip Patch Antenna at 4.50GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 2.44GHz while for resonance frequency 4.50 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated T-Slot loaded rectangular microstrip patch antenna at the resonance frequencies 2.44GHz and 4.50 GHz is shown in Figure 4.54.

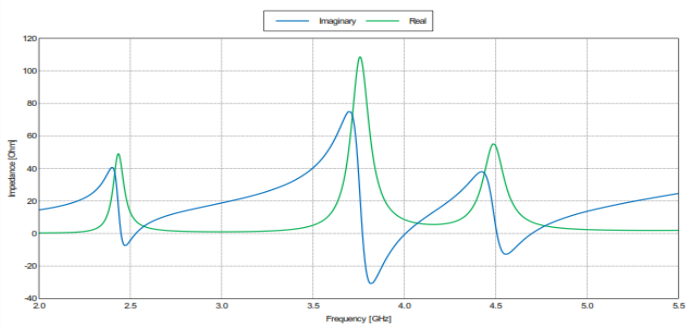

Figure 4.54: **Impedance Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna.**

From the Figure 4.54 it is found that the impedance of the simulated antenna is 44.8+j3.01 ohm at resonance frequency 2.44GHz and 52.1+j0.497 ohm at resonance frequency 4.50GHz ohm. The corresponding magnitudes of the impedance are |z| = 44.9

ohm and |z| = 52.1 ohm for the resonating frequencies 2.44 GHz and 4.50 GHz respectively. It is observed that the impedance goes on increasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequencies at 4.50GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the length and width of the slots are changed and the effect has been observed. For parametric analysis the length and width of the horizontal and vertical slots of the T shaped antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.55, 4.56, 4.57 and 4.58 show the results due to variation in lengths and variation in widths.

Effect of change in horizontal slot length and width:

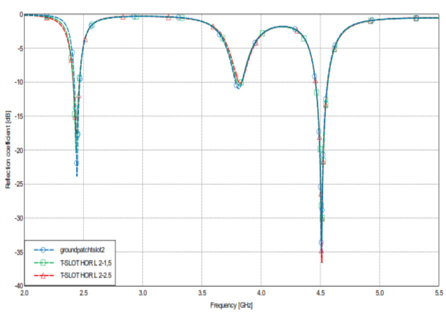

Figure 4.55: **Reflection Coefficient Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna for Horizontal Slot Length Changed.**

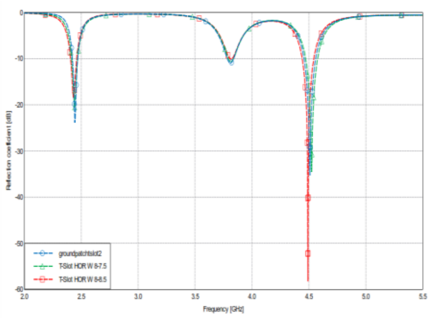

Figure 4.56: **Reflection Coefficient Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna for Horizontal Slot Width Changed.**

When length of the horizontal slot is decreased by an amount of 0.5mm maintaining the width of the horizontal slot constant, the antenna resonates at frequencies f_{r1}=2.43GHz and f_{r2}= =4.51GHz, and the corresponding reflection coefficients are -20.48dB, -33.46dB. The reflection bandwidths are 54MHz,104MHz in the frequency bands 2.412GHz-2.466GHz, 4.46GHz -4.564GHz respectively. When the length of the horizontal slot is increased by an amount of 0.5mm maintaining the width of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= =2.43GHz, f_{r2}=4.51GHz, and the corresponding reflection coefficients are -17.70dB and -39.01dB. The reflection bandwidths are 45MHz,103MHz in the frequency bands 2.421GHz-2.466GHz, 4.461GHz-4.564GHz respectively.

When the width of the horizontal slot is decreased by an amount of 0.5mm maintaining the length of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.44GHz, f_{r2}= 4.52GHz, and the corresponding reflection coefficients are -20.75 dB, -34.98dB. The reflection bandwidths are 54 MHz, 105 MHz in the frequency bands 2.416GHz -2.47 GHz, 4.461 GHz-4.578GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm maintaining the length of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.433GHz, f_{r2}= 4.49GHz, and the corresponding reflection coefficients are -18.70 dB, -77.41dB. The reflection bandwidths are 50MHz, 102 MHz in the frequency bands 2.409GHz -2.459GHz, 4.441GHz -4.543 GHz respectively.

Effect of change in vertical slot length and width:

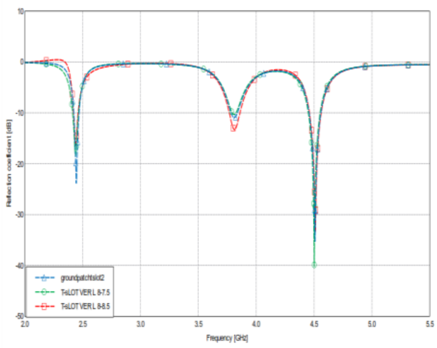

Figure 4.57: **Reflection Coefficient Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna for Vertical Slot Length Changed.**

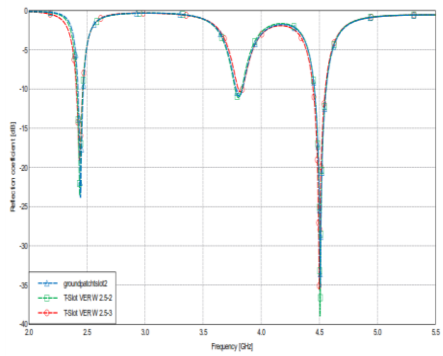

Figure 4.58: **Reflection Coefficient Vs Frequency of T-Slot Loaded Rectangular Microstrip Patch Antenna for Vertical Slot Width Changed.**

When the length of the vertical slot is decreased by an amount of 0.5mm maintaining the width of the vertical slot constant, the antenna resonates at frequency, f_{r1}= 2.43GHz, f_{r2}= 4.50GHz, and the corresponding reflection coefficients are -18.50dB, -40.98dB. The reflection bandwidths are 50MHz and 101MHz in the frequency bands 2.416GHz-2.466GHz, 4.451GHz-4.543 GHz respectively.

When the length of the vertical slot is increased by an amount of 0.5mm maintaining the width of the vertical slot constant, the antenna resonates at frequency f_{r1}= 2.43GHz, f_{r2}= 4.51GHz, and the corresponding reflection coefficients are -16.48dB, -34.67dB. The reflection bandwidths are 50MHz and 101MHz in the frequency bands2.416 GHz -2.466GHz, 4.451 GHz -4.543 GHz respectively.

When the width of the vertical slot is decreased by an amount of 0.5mm maintaining the length of the vertical slot constant, the antenna resonates at frequency,

f_{r1}= 2.43GHz, f_{r2}= 4.50GHz, and the corresponding reflection coefficients are -23.72 dB and -43.56dB. The reflection bandwidths are 51 MHz and 100 MHz in the frequency bands 2.412 GHz -2.463 GHz, 4.456 GHz -4.556GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm maintaining the length of the vertical slot constant, the antenna resonates at frequency, f_{r1}= 2.43GHz, f_{r2}= 4.49GHz, and the corresponding reflection coefficients are -19.20 dB and-35.58dB. The reflection bandwidths are 57MHz and104 MHz in the frequency bands 2.409 GHz -2.466GHz, 4.452 GHz -4.556 GHz.

From above observation it is found that with increase in vertical slot width and decrease in vertical slot width don't have any major effect on performance. There are slight changes observed on performance.

Inferences:

It is resonating at two frequencies with bandwidths 51MHz and 112MHz. It resolves the impedance matching problem to certain extent. It has a moderate gain at low frequency and less gain for high frequency.

4.6 T-Slot Rectangular Microstrip Patch Antenna with Defective Ground:

The T-Slot Rectangular Microstrip Patch Antenna with Defective Ground is designed at $L_P = 25.80mm$, $W_P = 36.10mm, L_{sub} = 37.82mm, W_{sub} = 46.36mm,$ $h = 1.59mm$, $L_h = 19mm, W_h = 2.5mm$, $L_v = 2.5mm$ $, W_v = 18.5mm$, $L_{gv} = 2.5mm, W_{gv} = 18.5mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

T-Slot Rectangular Microstrip Patch Antenna with Defective Ground is designed and simulated. The plot of reflection coefficient vs frequency and VSWR vs frequency are shown in Figure 4.59 and Figure 4.60 respectively.

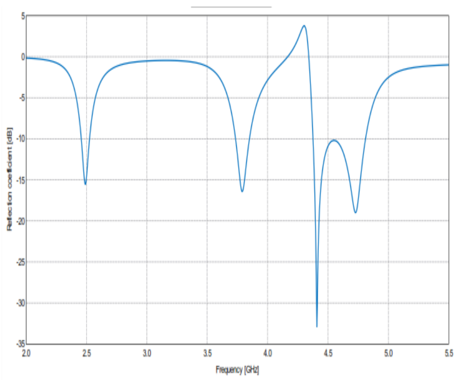

Figure 4.59: **Reflection Coefficient Vs Frequency of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground.**

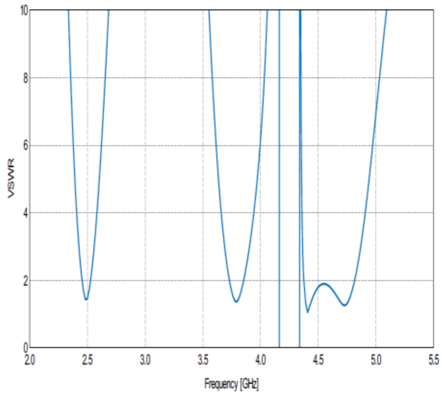

Figure 4.60: **VSWR Vs Frequency of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground.**

From Figure 4.59, it is found that the T-Slot Rectangular Microstrip Patch Antenna with Defective Ground is resonating at three frequencies. The resonance frequencies are f_{r1} = 2.492GHz, f_{r2}= 3.793GHz, and f_{r3}=4.40GHz, and the corresponding reflection coefficients are -15.5 dB, -16.3 dB and -32.99dB. The reflection bandwidths are 65MHz, 109MHz and 435 MHz in the frequency bands 2.459 GHz -2.524GHz, 3.739GHz-3.848GHz, 4.371 GHz -4.806 respectively. From Figure 4.60 VSWR is observed below 2 in the frequency bands 2.455GHz -2.529GHz, 3.73GHz -3.859GHz, 4.376 GHz -4.82GHz and VSWR bandwidths are 74MHz, 129MHz and 444MHz.

The reflection coefficients of the fabricated antenna are observed to be -11.5 dB, -12 dB and -18dB is not perfectly matching with simulated results. The reflection bandwidths of the fabricated antenna are 32MHz, 65MHz and 189MHz respectively, resonance frequency is tuned at 3.09GHz, 3.93GHz and 4.76GHz which is slightly shifted towards higher side of the simulated results.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated T-Slot loaded defective ground structure rectangular microstrip patch antenna at the resonance frequencies 2.492GHz, 3.793GHz and 4.40GHz are shown in Figure 4.61, 4.62 and 4.63 respectively.

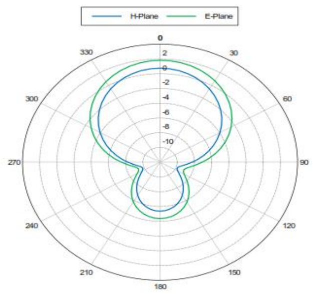

Figure 4.61: **Far Field Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground structure at 2.492GHz.**

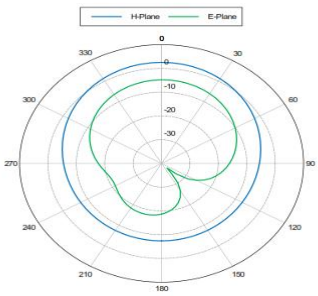

Figure 4.62: **Far Field Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground structure at 3.73GHz.**

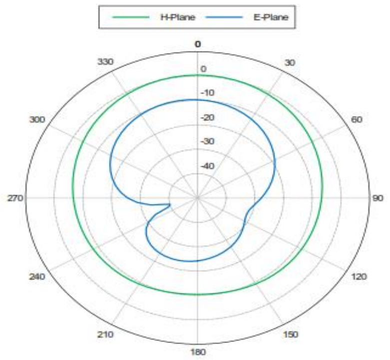

Figure 4.63: **Far Field Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with Defective Ground structure at 4.40GHz.**

It is observed that the gains of the T-Slot rectangular microstrip patch antenna with defective ground are 1.81 dBi at 2.49 GHz and 2.55 dBi at 3.73GHz and -0.422 dBi at 4.40GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 2.49GHz while the pattern is more deviating from the ideal pattern for resonance frequencies 3.73GHz and 4.40GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated T-Slot rectangular microstrip patch antenna with defective ground at the resonance frequencies 2.49GHz, 3.73GHz and 4.40GHz are shown in Figure 4.64, Figure 4.66 and Figure 4.68 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated T-Slot structure rectangular microstrip patch antenna with defective ground at the resonance frequencies 2.49GHz, 3.73GHz and 4.40GHz are shown in Figure 4.65, Figure 4.67 and Figure 4.69 respectively. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately.

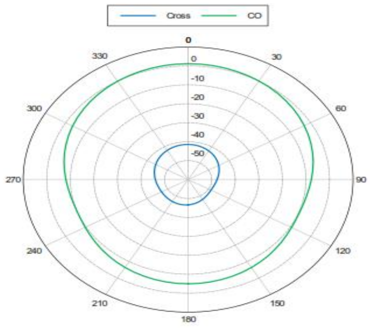

Figure 4.64: **E Plane Co and Cross Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with defective ground at 2.49GHz.**

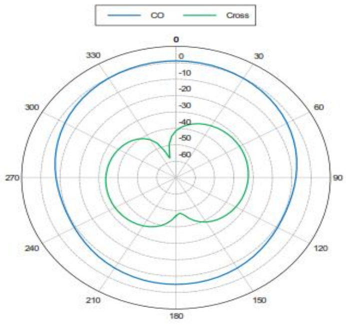

Figure 4.65: **H Plane Co and Cross Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with defective ground at 2.49GHz.**

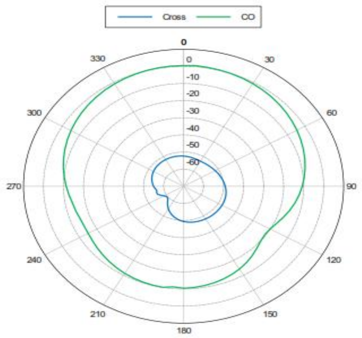

Figure 4.66: **E Plane Co and Cross Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with defective ground at 3.73GHz.**

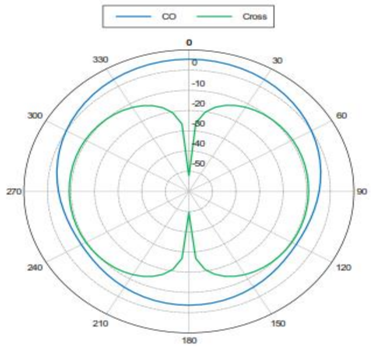

Figure 4.67: **H Plane Co and Cross Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with defective ground at 3.73GHz.**

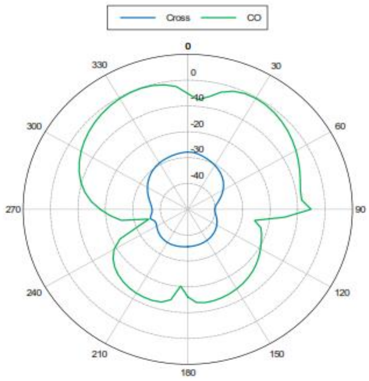

Figure 4.68: **E Plane Co and Cross Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with defective ground at 4.40GHz.**

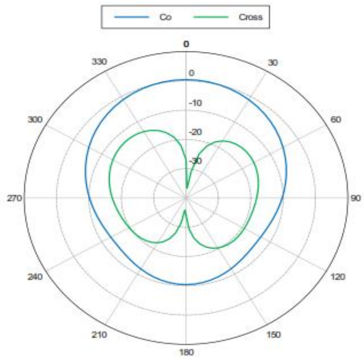

Figure 4.69: **H Plane Co and Cross Radiation Pattern of T-Slot Rectangular Microstrip Patch Antenna with defective ground at 4.40GHz.**

For the resonance frequency 2.49 GHz the cross-polarization variations in E-Plane are less than -40dB, while for H-Plane it is -30dB. For the resonance frequency

3.73 GHz the cross-polarization variations in E-Plane are slightly less than -45dB, while for H-Plane it is -10dB. For the resonance frequency 4.40 GHz the cross-polarization variations in E-Plane are slightly less than -20dB, while for H-Plane it is -10dB. The gain of the antenna is 1.81 dBi at 2.49 GHz, 2.55 dBi at 3.73GHz and -0.422 dBi at 4.40GHz respectively. The co polarizations are observed to be nearly same and stable at the resonating frequencies 2.49 GHz and 3.73GHz while it is more deviating from the ideal at resonating frequency 4.40 GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated T-Slot rectangular microstrip patch antenna with defective ground at the resonance frequencies 2.49GHz, 3.73GHz and 4.40 GHz are as shown in Figure 4.70, 4.71 and 4.72 respectively.

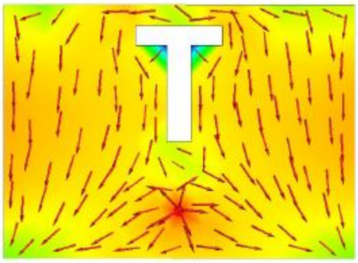

Figure 4.70: **Surface Current Distribution on Radiating Patch of T-Slot rectangular microstrip patch antenna with defective ground at 2.49GHz.**

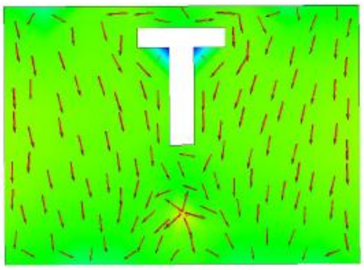

Figure 4.71: **Surface Current Distribution on Radiating Patch of T-Slot rectangular microstrip patch antenna with defective ground at 3.73GHz.**

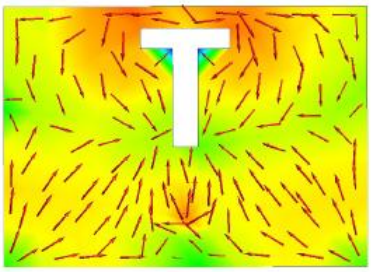

Figure 4.72: **Surface Current Distribution on Radiating Patch of T-Slot rectangular microstrip patch antenna with defective ground at 4.4GHz.**

It is observed that, Surface current is linearly distributed at resonance frequencies 2.49GHz and 3.73GHz while for resonance frequency 4.40 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated T-Slot rectangular microstrip patch antenna with defective ground at the resonance frequencies 2.49GHz, 3.73GHz and 4.40 GHz is shown in Figure 4.73.

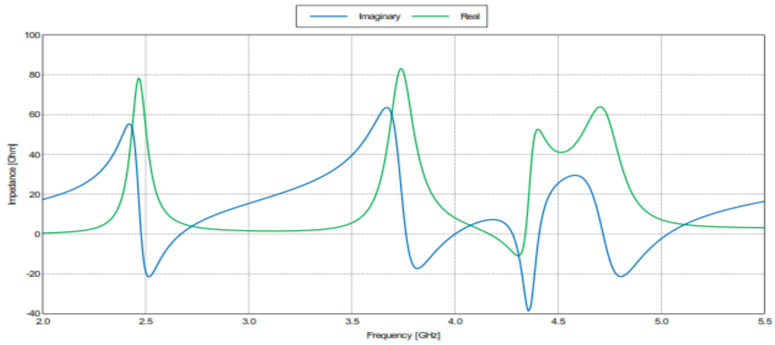

Figure 4.73: **Impedance Vs Frequency of T-Slot rectangular Microstrip patch antenna with defective ground.**

From the Figure 4.73 it is found that the impedance of the simulated antenna is 60.5-j15.6ohm at resonance frequency 2.49GHz, 57.1-j14.6ohm at resonance frequency 3.73GHz and 52.6-j5.37 ohm at resonance frequency 4.40GHz. The corresponding magnitudes of the impedance are |z| = 62.47ohm, |z| = 58.93 ohm and |z| = 52.86 ohm for the resonating frequencies 2.49GHz, 3.73GHz and 4.40 GHz respectively. It is observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequencies at 4.40GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the length and width of the slots are changed and the effect has been observed. For parametric analysis the length and width of the horizontal and vertical slots of the T shaped antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.74, Figure 4.75, Figure 4.76 and Figure 4.77 show the results due to variation in lengths and variation in widths.

Effect of change in horizontal slot length and width:

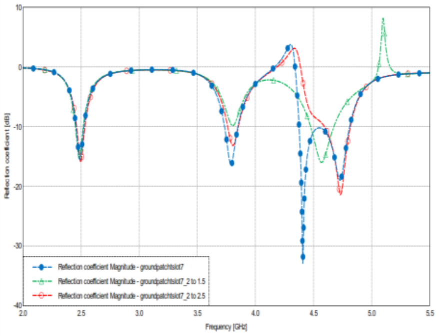

Figure 4.74: **Reflection Coefficient Vs Frequency of T-Slot rectangular microstrip patch antenna with defective ground for Horizontal Slot Length Changed.**

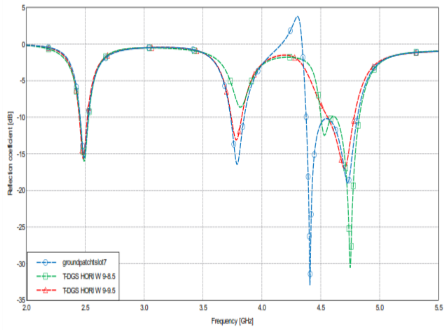

Figure 4.75: **Reflection Coefficient Vs Frequency of T-Slot rectangular microstrip patch antenna with defective ground for Horizontal Slot Width Changed.**

When length of the horizontal slot is decreased by an amount of 0.5mm maintaining the width of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}= 4.56GHz, and the corresponding reflection coefficients are -15.41dB and -16.027dB. The reflection bandwidths are 69MHz, 200MHz in the frequency bands 2.448GHz-2.517GHz, 4.479GHz-4.679GHz respectively.

When the length of the horizontal slot is increased by an amount of 0.5mm maintaining the width of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.49GHz, f_{r2}= 3.804GHz, f_{r3}= 4.73GHz and the corresponding reflection coefficients are -15.96 dB, -13.15dB and -21.48dB. The reflection bandwidths are 72MHz, 94MHz and 223MHz in the frequency bands 2.463GHz-2.535GHz,3.761GHz-3.855GHz, 4.6GHz-4.823GHz respectively.

When the width of the horizontal slot is decreased by an amount of 0.5mm maintaining the length of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.49GHz, f_{r2}= 4.75GHz, and the corresponding reflection coefficients are -16.07dB and -30.57dB. The reflection bandwidths are 72MHz, 203MHz in the frequency bands 2.456GHz-2.528GHz, 4.625GHz-4.789GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm maintaining the length of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}= 4.70GHz, and the corresponding reflection coefficients are -15.70dB and -17.03dB. The reflection bandwidths are

65MHz,225MHz in the frequency bands2.452GHz-2.517GHz, 4.564GHz-4.789GHz respectively.

Effect of change in vertical slot length and width:

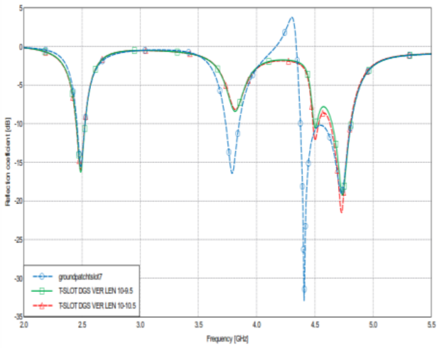

Figure 4.76: **Reflection Coefficient Vs Frequency of T-Slot rectangular microstrip patch antenna with defective ground for Vertical Slot Length Changed.**

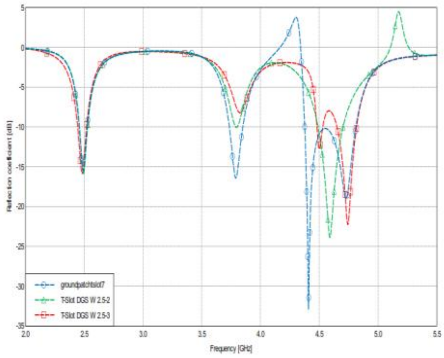

Figure 4.77: **Reflection Coefficient Vs Frequency of T-Slot rectangular microstrip patch antenna with defective ground for Vertical Slot Width Changed.**

When the length of the vertical slot is decreased by an amount of 0.5mm, maintaining the width of the vertical slot constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}= 4.73GHz, and the corresponding reflection coefficients are -16.28dB, -19.24dB. The reflection bandwidths are 80MHz, 162MHz in the frequency bands 2.448GHz-2.524GHz, 4.647GHz-4.809GHz respectively.

When the length of the vertical slot is increased by an amount of 0.5mm, maintaining the width of the vertical slot constant, the antenna resonates at frequencies f_{r1}= 2.48GHz, f_{r2}= 4.72GHz, and the corresponding reflection coefficients are -16.017 dB and -21.51dB. The reflection bandwidths are 76MHz,174MHz in the frequency bands 2.448GHz-2.524GHz and4.625GHz-4.799GHz respectively.

When the width of the vertical slot is decreased by an amount of 0.5mm, maintaining the length of the vertical slot constant, the antenna resonates at frequencies f_{r1}= 2.49GHz, f_{r2}= 4.59GHz, and the corresponding reflection coefficients are -15.95 dB and -23.90dB. The reflection bandwidths are 69MHz and 213MHz in the frequency bands 2.459GHz-2.528 GHz and 4.459GHz-4.708GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm, maintaining the length of the vertical slot constant, the antenna resonates at frequencies f_{r1}=2.48GHz, f_{r2}= 4.74GHz, and the corresponding reflection coefficients are -15.86 dB and -22.27dB. The reflection bandwidths are 72MHz and 166MHzin the frequency bands 2.445GHz-2.517GHz and 4.654GHz-4.82GHz respectively.

Inference:

It is resonating at three frequencies with improved bandwidth up to 44MHz at highest resonance frequency. It resolves the impedance matching problem to certain extent at lower frequencies. It has a moderate gain at low frequency and negative gain for high frequency.

4.7 Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground:

The Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground is designed at $L_P = 26.50mm$, $W_P = 36.40mm$, $L_{sub} = 37.82mm$, $W_{sub} = 46.36mm$, $h = 1.59mm$, $L_h = 9mm, W_h = 2mm$, $L_v = 2.5mmm$, $W_v = 10mm$, $L_{gv} = 2.5mm, W_{gv} = 10mm, L_{gh} = 9mm, W_{gh} = 2mm,$ $L_{cs} = 26.50mm,\ W_{cs} = 2mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground is designed and simulated. The plot of reflection coefficient vs frequency and VSWR vs frequency are shown in Figure 4.78 and Figure 4.79 respectively.

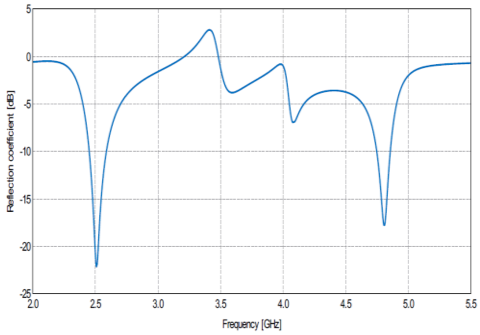

Figure 4.78: **Reflection Coefficient Vs Frequency of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground.**

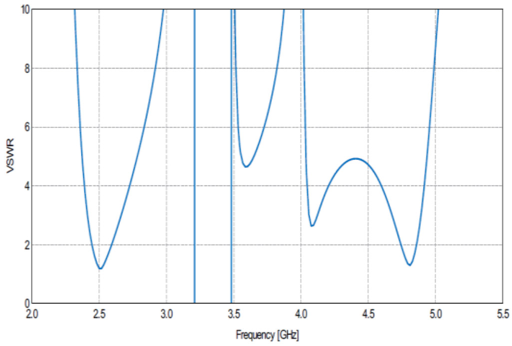

Figure 4.79: **VSWR Vs Frequency of Capacitive Loaded Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground.**

From Figure 4.78 it is found that the Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground is resonating at two frequencies. The resonance frequencies are f_{r1}= 2.50GHz, and f_{r2}=4.80GHz, and the corresponding reflection coefficients are -22.24 dB, and -17.86dB. The reflection bandwidths are 137MHzand 123MHz in the frequency bands 2.443-2.58GHz and 4.73-4.85GHz respectively.

From Figure 4.79 VSWR is observed below2 for the frequency bands 2.44GHz-2.59GHz, 4.73GHz-4.86GHz and VSWR bandwidths are of 150MHz and130MHz. The reflection coefficient of the fabricated antenna is observed to be -13dB and -11dB which is not matching with the simulated results, resonance frequency is tuned at 2.75GHz and 5.2GHz which is slightly shifted towards higher side compare to the simulated results.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground resonates at frequencies 2.50GHz, and 4.805 GHz as shown in Figure 4.80 and 4.81 respectively. It helps to measure the gain of antenna.

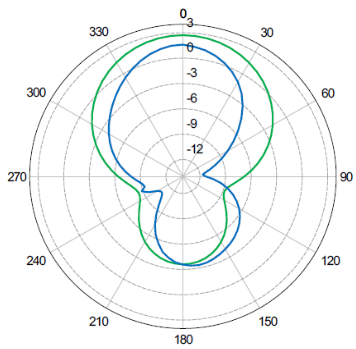

Figure 4.80**: Far Field Radiation Pattern of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 2.50GHz.**

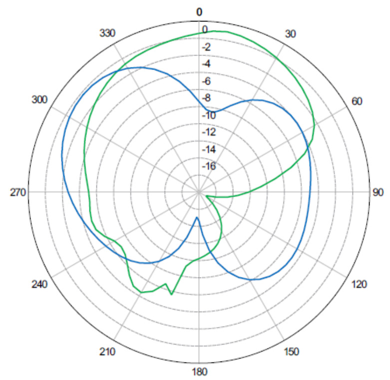

Figure 4.81**: Far Field Radiation Pattern of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 4.80GHz.**

It is observed that the gains of the Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground are 2.71 dBi at 2.50 GHz, 1.51dBi at 4.80GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 2.50GHz while the pattern is more deviating from the ideal pattern for resonance frequency 4.80GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground resonates at frequencies 2.50GHz and 4.80GHz as shown in Figure 4.82,4.84 and H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground resonates at frequencies 2.50GHzand 4.80GHz as shown in Figure 4.83 and 4.85 respectively. It helps to measure the gain at the resonance frequencies for Co polarization and Cross polarization separately. Further it is used to view and analyse the pattern of radiation.

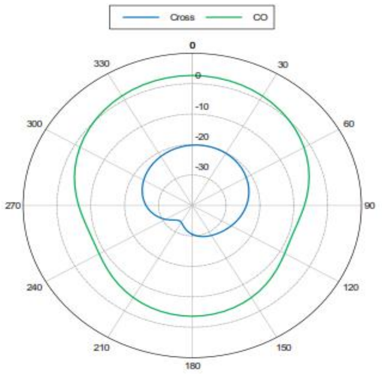

Figure 4.82: **E Plane Co and Cross Radiation Pattern of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 2.50GHz.**

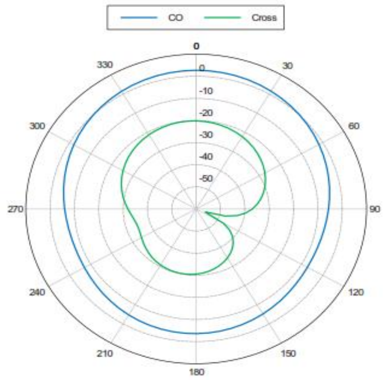

Figure 4.83**: H Plane Co and Cross Radiation Pattern of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 2.50GHz.**

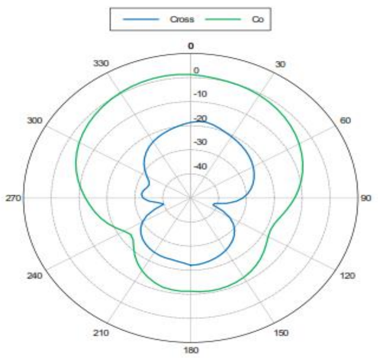

Figure 4.84: **E Plane Co and Cross Radiation Pattern of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 4.80GHz.**

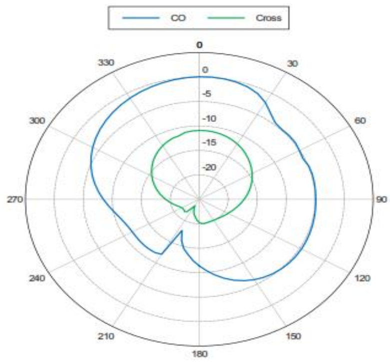

Figure 4.85: **H Plane Co and Cross Radiation Pattern of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 4.80GHz.**

For the resonance frequency 2.50 GHz the cross-polarization variations in E-Plane are less than -20dB, while for H-Plane it is -20dB. For the resonance frequency 4.80 GHz the cross-polarization variations in E-Plane are slightly less than -15dB, while for H-Plane it is -10dB. The gain of the antenna is 2.71 dBi at 2.50 GHz and 3.73dBi at 4.75GHz. The Co polarizations are observed to be nearly same and stable at the resonating frequency 2.50 GHz, while it is more deviating from the ideal at resonating frequencies 3.175 GHz and 3.73GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at the resonance frequencies 2.50GHz, and 4.80 GHz are as shown in Figure 4.86 and Figure 4.87 respectively.

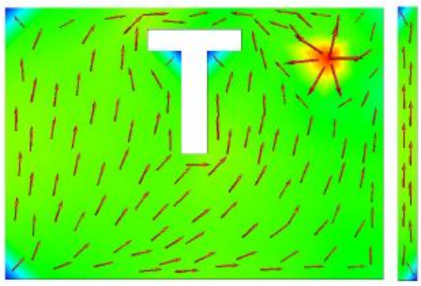

Figure 4.86: **Surface Current Distribution on Radiating Patch of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 2.50GHz.**

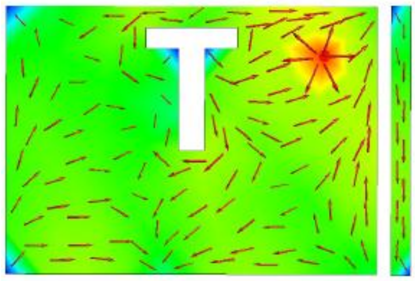

Figure 4.87: **Surface Current Distribution on Radiating Patch of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at 4.80GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 2.50GHz while for resonance frequency 4.80 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground at the resonance frequencies 2.50GHz and 4.80 GHz is shown in Figure 4.88.

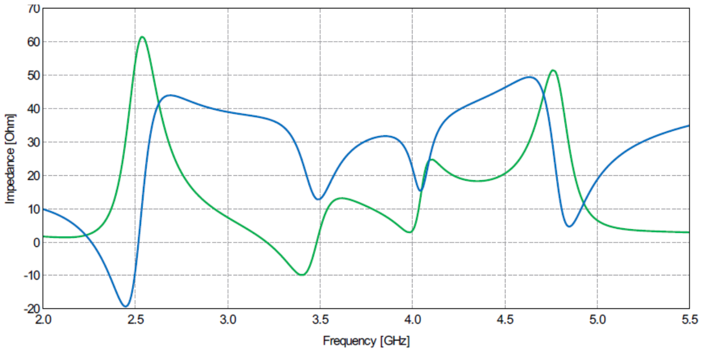

Figure 4.88: **Impedance Vs Frequency of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground.**

From the Figure 4.88 it is found that the impedance of the simulated antenna is 55.59-j6.03 at resonance frequency 2.50GHz and 45.6+j12.2 at resonance frequency

4.80 GHz. The corresponding magnitudes of the impedance are |z| = 55.91 ohm and |z| = 47.2 ohm for the resonating frequencies 2.50 GHz and 4.80 GHz respectively. It is observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequencies at 2.50GHz and 4.80GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the length, width of the slots are changed and the effect has been observed. For parametric analysis the length and width of the horizontal and vertical slots of the T shaped antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.89, Figure 4.90, Figure 4.91 and Figure 4.92 show the results due to variation in lengths and variation in widths.

Effect of change in horizontal slot length and width:

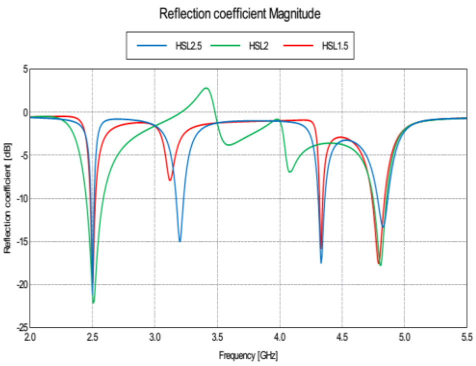

Figure 4.89: **Reflection Coefficient Vs Frequency of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground for Horizontal Slot Length Changed**.

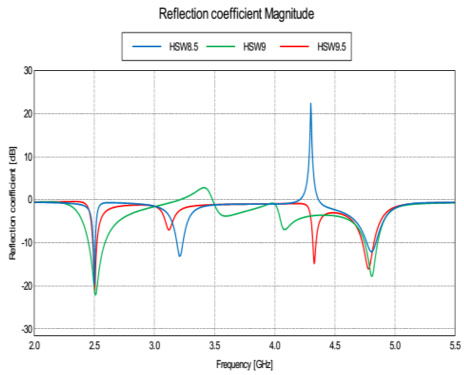

Figure 4.90: **Reflection Coefficient Vs Frequency of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground for Horizontal Slot Width Changed**.

When length of the horizontal slot is decreased by an amount of 0.5mm, maintaining the width of the horizontal slot constant, the antenna resonates at frequencies, f_{r1}= 2.5GHz, f_{r2}=4.35GHz, f_{r3}=4.78GHz and the corresponding reflection coefficients are -19.86dB, -16.5dB and -21dB. The reflection bandwidths are 30MHz, 40MHz and 121MHz in the frequency bands 2.49GHz-2.52GHz, 4.33GHz-4.37GHz, 4.72GHz-4.841GHzrespectively.

When the length of the horizontal slot is increased by an amount of 0.5mm, maintaining the width of the horizontal slot constant, the antenna resonates at frequencies f_{r1}=2.5GHz, f_{r2}=3.18GHz, f_{r3}= 4.35GHz, f_{r4}= 4.86GHz and the corresponding reflection coefficients are -21dB, -15dB, -16.1dB and -13dB The reflection bandwidths are 20 MHz, 110 MHz, 80MHz and 123MHz in the frequency bands 2.49GHz-2.51GHz, 3.14GHz-3.25GHz, 4.31GHz-4.39GHz and 4.79GHz-4.913GHz respectively.

When the width of the horizontal slot is decreased by an amount of 0.5mm, maintaining the length of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.49GHz, f_{r2}= 3.21GHz, f_{r3}= 4.80GHz and the corresponding reflection coefficients are –21.36 dB, -13.26dB and -12.1dB. The reflection bandwidths are 18 MHz, 50 MHz and 50MHz in the frequency bands 2.489GHz-2.507 GHz, 4.28GHz-4.33GHz, 4.78GHz-4.83GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm, maintaining the length of the horizontal slot constant, the antenna resonates at frequencies f_{r1}= 2.5GHz, f_{r2}= 4.3GHz, f_{r3}= 4.79GHz and the corresponding reflection coefficients are –23.17 dB, -15.29dB and -18.34dB. The reflection bandwidths are 17 MHz, 60 MHz and 100MHz in the frequency bands 2.494GHz-2.51 GHz, 4.26GHz-4.32GHz, 4.72GHz-4.82GHz respectively.

From above observations it is found that with decrease in horizontal slot length and increase in horizontal slot length slight improvement in bandwidth is observed.

Effect of change in vertical slot length and width:

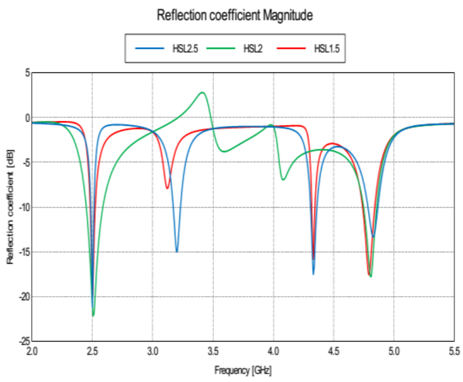

Figure 4.91: **Reflection Coefficient Vs Frequency of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground for Vertical Slot Length Changed.**

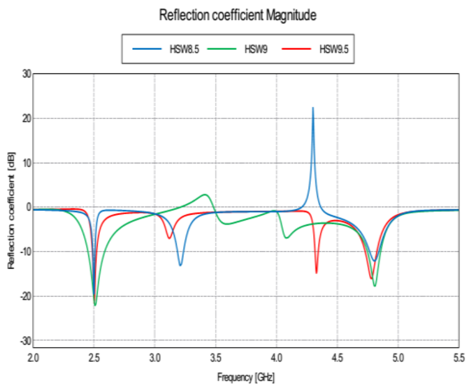

Figure 4.92: **Reflection Coefficient Vs Frequency of Capacitive Loaded T-Slotted Rectangular Microstrip Patch Antenna with Defective Ground for Vertical Slot Width Changed.**

When the length of the vertical slot is decreased by an amount of 0.5mm, maintaining the width of the vertical slot constant, the antenna resonates at frequencies,

f_{r1}= 2.49GHz, f_{r2}= 4.82GHz, and the corresponding reflection coefficients are -20.4dB and -13.2dB. The reflection bandwidths are 17MHz, 98 MHz in the frequency bands 2.48GHz-2.597GHz, 4.733GHz-4.871 GHz respectively.

When the length of the vertical slot is increased by an amount of 0.5mm, maintaining the width of the vertical slot constant the antenna resonates at frequencies, f_{r1}=2.5GHz, f_{r2}= 4.78GHz and the corresponding reflection coefficients are -20.16dB and -14.9dB. The reflection bandwidths are 18 MHz,117 MHz in the frequency bands 2.49GHz-2.508GHz, 4.75GHz-4.867respectively.

When the width of the vertical slot is decreased by an amount of 0.5mm, maintaining the length of the vertical slot constant the antenna resonates at frequencies, f_{r1}= 2.5GHz, f_{r2}=4.32GHz, f_{r3}= 4.77GHz and the corresponding reflection coefficients are -21.96 dB, -14.9dB and -16.09. The reflection bandwidths are 40 MHz, 30 MHz and 100MHz in the frequency bands 2.478GHz-2.518GHz, 4.298GHz-4.328GHz, 4.73GHz-4.83GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm, maintaining the length of the vertical slot constant, the antenna resonates at frequencies, f_{r1}= 2.49GHz, f_{r2}= 4.39GHz, f_{r3}= 4.81GHz and the corresponding reflection coefficients are -20.88 dB, -35.38dB and -13.1. The reflection bandwidths are 30 MHz, 34 MHz and 76MHz in the frequency bands 2.479GHz-2.509GHz, 4.384GHz-4.410GHz, 4.76GHz-4.836GHz respectively.

From above observation it is found that with decrease in vertical slot length no bandwidth improvement is observed and also antenna resonance is not up to the mark. With increase in vertical slot length slight improvement in bandwidth is observed.

Inference:

It is resonating at two frequencies with bandwidths 150MHz and 130MHz. It minimizes the effect of inductance of the probe by creating the capacitance at the radiating patch. It has a moderate gain.

4.8 Notch Cut I-Slotted Rectangular Microstrip Patch Antenna:

The Notch Cut I-Slotted Rectangular Microstrip Patch Antenna is designed at $L_P = 26.30mm$, $W_P = 36.40mm$, $L_{sub} = 37.82mm$, $W_{sub} = 46.36mm$, $h = 1.59mm$, $L_h = 11mm, W_h = 1.8mm$, $L_v = 2.5mm, W_v = 14.2mm, L_{is} = 10mm$,

$W_{is} = 4.4mm$, $L_{os} = 8mm$, $W_{os} = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Notch Cut I-Slotted Rectangular Microstrip Patch antenna are shown in Figure 4.93 and Figure 4.94 respectively.

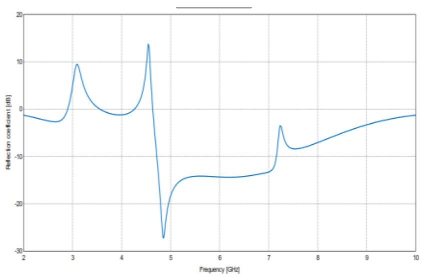

Figure 4.93: **Reflection Coefficient Vs Frequency and of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna.**

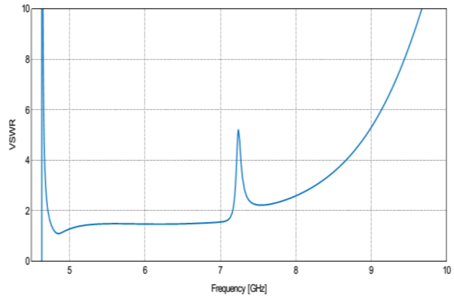

Fig.4.94: **VSWR Vs Frequency for Notch Cut I-Slotted Rectangular Microstrip Patch Antenna.**

From Figure 4.93, it is found that the Notch Cut I-Slotted Rectangular Microstrip Patch antenna is resonating at single frequency. The resonance frequency is f_{r1} =4.85GHz, and the corresponding reflection coefficients are -27.29dB. The reflection bandwidth is 2.43GHz in the frequency band 4.72 GHz to 7.15 GHz.

From Figure 4.94 VSWR is observed below 2 for 4.71GHz-7.17GHz and VSWR bandwidths is of 2.46GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Notch Cut I-Slotted Rectangular microstrip patch antenna at the resonance frequency 4.85GHz is shown in Figure 4.95.

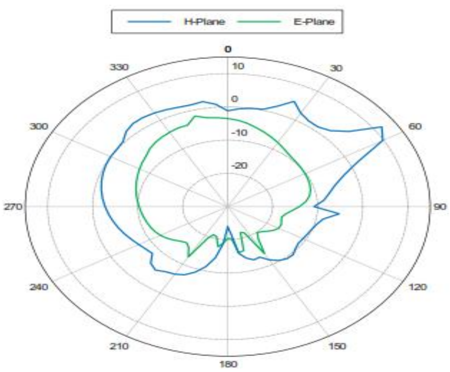

Figure 4.95: **Far Field Radiation Pattern of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna at 4.85GHz.**

It is observed that the gain of the Notch Cut I-Slotted Rectangular microstrip patch antenna is 11.84 dBi at 4.85 GHz. The radiation pattern is deviating from the ideal pattern for resonance frequency 4.85GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Notch Cut I-Slotted Rectangular microstrip patch antenna at the resonance frequency 4.85GHz is shown in Figure 4.96. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Notch Cut I-Slotted Rectangular microstrip patch antenna at the resonance frequency 4.85GHz is shown in Figure 4.97. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately. Further it is used to view and analyse the pattern of radiation. For the resonance frequency 4.85 GHz the cross-polarization variations in E-Plane are less than -5dB, while for H-Plane it is -5dB. The gain of the antenna is 1.84 dBi at resonance frequency 4.85GHz. The co polarization is observed to be slightly deviated in E plane radiation pattern and stable in H plane radiation pattern at resonating frequency 4.85GHz.

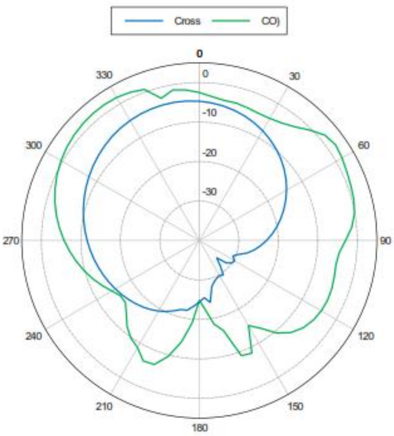

Figure 4.96: **E Plane Co and Cross Radiation Pattern of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna at 4.85GHz.**

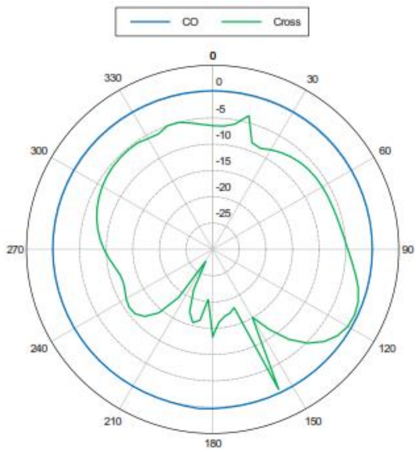

Figure 4.97: **H Plane Co and Cross Radiation Pattern of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna at 4.85GHz.**

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Notch Cut I-Slotted Rectangular microstrip patch antenna at the resonance frequency 4.85 GHz is as shown in Figure 4.98.

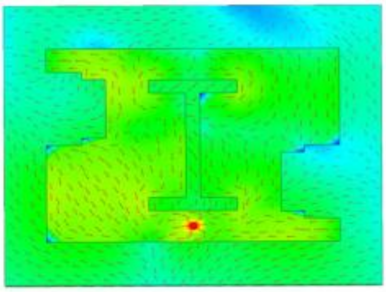

Fig. 4.98: **Surface Current Distribution on Radiating Patch Notch Cut I-Slotted Rectangular Microstrip Patch Antenna at 4.85GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 4.85 GHz.

Impedance:

The plot of impedance vs frequency of the simulated Notch Cut I-Slotted Rectangular microstrip patch antenna at the resonance frequency 4.85 GHz is shown in Figure 4.99.

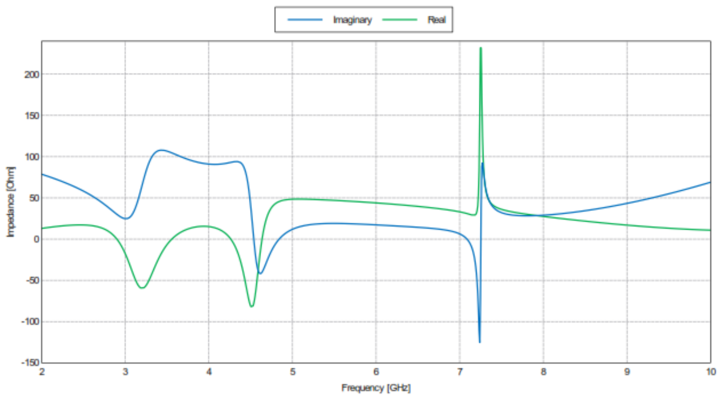

Fig.4.99: **Impedance Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna.**

From the Figure 4.99 it is found that the impedance of the simulated antenna is 45.82+j0.7493ohm at resonance frequency 4.85GHz. The corresponding magnitude of the impedance is |z| = 45.82 ohm for the resonating frequency 4.85 GHz. It is observed that the impedance at resonance frequency is approximately matched with the ideal value for resonance frequency at 4.85GHz.

Parametric Analysis:

In Parametric analysis of simulated Notch Cut I-Slotted Rectangular microstrip patch antenna the length, width of the radiating patch is maintained constant and the length, width of the slots and notches to radiating edge are changed and the effect has been observed. For parametric analysis the length and width of the horizontal and vertical slots and the notches of the Notch Cut I-Slotted Rectangular microstrip patch antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.100, Figure 4.101, Figure 4.102 and Figure 4.103 show the results due to variation in lengths and variation in widths of the slots of Notch Cut I-Slotted Rectangular microstrip patch antenna, Figure 4.104 and Figure 4.105 show the results due to variation in lengths and variation in widths of the inner notch of Notch Cut I-Slotted Rectangular microstrip patch antenna, and Figure 4.106 and Figure 4.107 show the results due to variation in lengths and variation in widths of the outer notch of Notch Cut I-Slotted Rectangular microstrip patch antenna.

Effect of change in horizontal slot length and width:

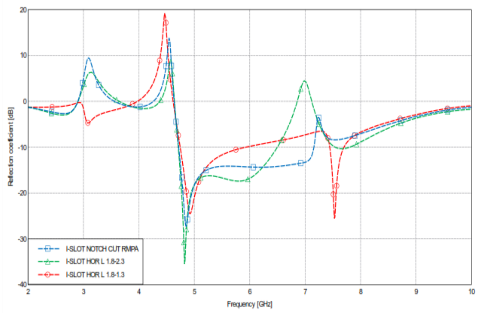

Figure 4.100: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Horizontal Slot Length Changed.**

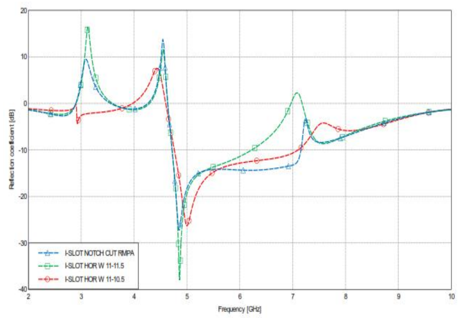

Figure 4.101: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Horizontal Slot Width Changed.**

When length of the horizontal slot is decreased by an amount of 0.5mm, maintaining the width of the horizontal slot constant, the antenna resonates at frequencies, f_{r1}= 4.92GHz, f_{r2}= 7.53GHz, and the corresponding reflection coefficients are-24.56dBand -25.69dB. The reflection bandwidths are 1.17GHz, 256 MHz in the frequency bands 4.75GHz-5.92GHz, 7.45GHz-7.706 GHz respectively. When the length of the horizontal slot is increased by an amount of 0.5mm, maintaining the width of the horizontal slot constant, the antenna resonates at frequency 4.82GHz and the corresponding reflection coefficient is-35.64dB. The reflection bandwidth is 1.78 GHz in the frequency band 4.71GHz-6.49GHz.

When the width of the horizontal slot is decreased by an amount of 0.5mm, maintaining the length of the horizontal slot constant, the antenna resonates at frequency 5 GHz, and the corresponding reflection coefficient is-26.32dB. The reflection bandwidth is 2.34GHz in the frequency band 4.77GHz-7.11 GHz.

When the width of the horizontal slot is increased by an amount of 0.5mm, maintaining the length of the horizontal slot constant, the antenna resonates at frequency 4.86GHz, and the corresponding reflection coefficient is-38.43dB. The reflection bandwidth is 1.50 GHz in the frequency band 4.73GHz-6.23 GHz.

From above discussion it is found that with decrease and increase in horizontal slot no bandwidth improvement is observed and also antenna resonance is not up to the mark.

Effect of change in vertical slot length and width:

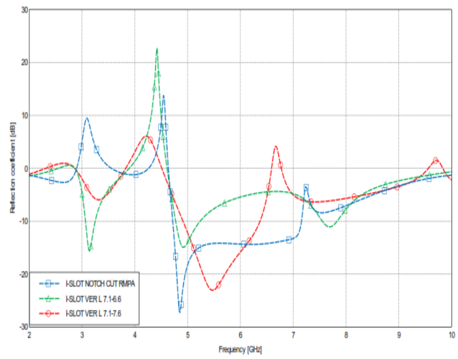

Figure 4.102: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Vertical Slot Length Changed.**

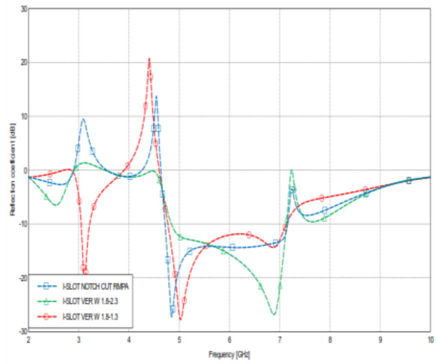

Figure 4.103: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Vertical Slot Width Changed.**

When the length of the vertical slot is decreased by an amount of 0.5mm, maintaining the width of the vertical slot constant, the antenna resonates at frequencies, f_{r1} = 3.14GHz, f_{r2}= 4.92GHz, and the corresponding reflection coefficients are -15.629dB, -14.95dB. The reflection bandwidths are 184MHz, 450 MHz in the frequency bands 3.056GHz-3.24GHz, 4.78GHz-5.23GHz respectively.

When the length of the vertical slot is increased by an amount of 0.5mmmaintaining the width of the vertical slot constant, the antenna resonates at frequency 5.47 GHz, and the corresponding reflection coefficient is-23.06dB. The reflection bandwidth is1.458 GHz in the frequency band 4.91GHz-6.368GHz.

When the width of the vertical slot is decreased by an amount of 0.5mm maintaining the length of the vertical slot constant, the antenna resonates at frequencies, f_{r1}= 3.11GHz, f_{r2}= 5.028GHz, and the corresponding reflection coefficients are -25.14 dB and -27.86dB. The reflection bandwidths are 160MHz, 2.35GHz in the frequency bands 3.06GHz-3.22GHz and 4.77GHz-7.12 GHz respectively.

When the width of the horizontal slot is increased by an amount of 0.5mm maintaining the length of the vertical slot constant, the antenna resonates at frequency 6.88GHz, and the corresponding reflection coefficient is -26.86dB. The reflection bandwidth is 2.29 GHz in the frequency band 4.86GHz-7.15 GHz.

Effect in change of inner notch length and width:

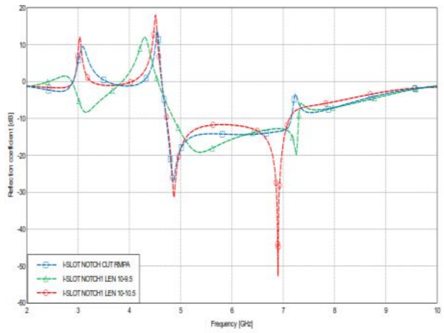

Figure 4.104: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Inner Notch Length Changed**.

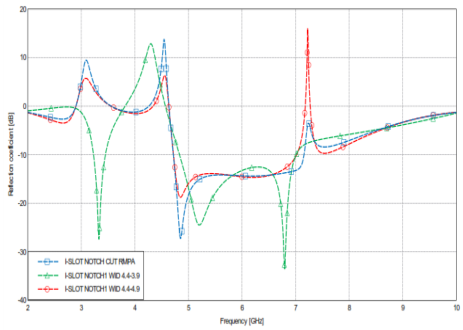

Figure 4.105: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Inner Notch Width Changed**.

When length of the inner notch is decreased by an amount of 0.5mm, maintaining the length and width of the outer notch constant and width of the inner notch constant, the antenna resonates at frequencies f_{r1}=5.37GHz, f_{r2}=7.25GHz, and the corresponding reflection coefficients are-19.18dB and -19.81dB. The reflection bandwidth is 2.44GHz in the frequency band 4.87GHz- 7.31GHz.

When length of the inner notch is increased by an amount of 0.5mm, maintaining the length and width of the outer notch constant and width of the inner notch constant, the antenna resonates at frequencies f_{r1}= 4.87GHz, f_{r2}= 6.89GHz, and the corresponding reflection coefficients are -31.36dB and -78.54dB. The reflection bandwidth is 2.39 GHz in the frequency band 4.74GHz-7.13GHz.

When width of the inner notch is decreased by an amount of 0.5mm, maintaining the length and width of the outer notch constant and length of the inner notch constant, the antenna resonates at frequencies f_{r1}= 3.32GHz, f_{r2}= 5.21GHz, f_{r3}= 6.79GHz and the corresponding reflection coefficients are-27.46dB, -24.4dB and -33.85dB. The reflection bandwidth is 230MHz, 2.17GHz in the frequency bands 3.23GHz-3.46GHz and 4.83GHz-7GHz respectively.

When width of the inner notch is increased by an amount of 0.5mm, maintaining the length and width of the outer notch constant and length of the inner notch constant, the antenna resonates at frequency 4.84GHz and the corresponding reflection coefficient is -18.80dB. The reflection bandwidth is 2.29GHz in the frequency band 4.72GHz-7.01GHz.

Effect in change of outer notch length and width:

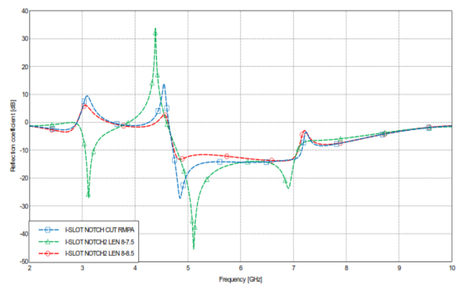

Figure 4.106: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Outer Notch Length Changed.**

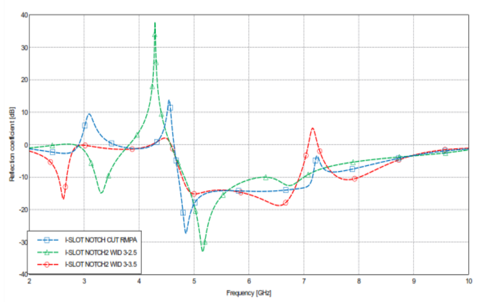

Figure 4.107: **Reflection Coefficient Vs Frequency of Notch Cut I-Slotted Rectangular Microstrip Patch Antenna for Outer Notch Width Changed**.

When length of the outer notch is decreased by an amount of 0.5mm, maintaining the length and width of the inner notch constant and width of the outer notch constant, the antenna resonates at frequencies f_{r1}= 3.11GHz, f_{r2}= 5.11GHz, and the corresponding reflection coefficients are -27.11dB, -45.52dB. The reflection bandwidth is 150MHz, 2.29GHz in the frequency bands 3.05GHz-3.2GHz, 4.79GHz-7.08 GHz respectively.

When length of the outer notch is increased by an amount of 0.5mm, maintaining the length and width of the inner notch constant and width of the outer notch constant, the antenna resonates at frequency4.85 GHz and the corresponding reflection coefficient is -13.30dB. The reflection bandwidth is 2.34 GHz in the frequency band 4.74GHz-7.08GHz.

When width of the outer notch is decreased by an amount of 0.5mm, maintaining the length and width of the inner notch constant and length of the outer notch constant, the antenna resonates at frequencies, f_{r1}= 3.31GHz, f_{r2}= 5.15GHz and the corresponding reflection coefficients are-14.98 dB and -32.95dB. The reflection bandwidth is230MHz, 2.17GHz in the frequency bands 3.21GHz-3.44GHz, 4.83GHz-7 GHz respectively.

When width of the outer notch is increased by an amount of 0.5mm, maintaining the length and width of the outer notch constant and length of the inner notch constant, the antenna resonates at frequencies f_{r1}= 2.62GHz, f_{r2}= 5GHz and the corresponding reflection coefficients are-16.77dB and -15.1dB. The reflection bandwidth is 150 MHz, 2.13 GHz in the frequency bands 2.53GHz-2.68GHz, 4.79GHz-6.92 GHz respectively. From observation it is found that antenna performance improves slightly with change in notch width and length.

Inference:

It is resonating at single frequency and the bandwidth is improved up to 2.46 GHz. It has a moderate gain for the overall frequency range and high gain at specific frequency but it deteriorates the radiation pattern.

4.9 Microstrip Line Feed Design:

The coaxial feed or probe feed is an exceptionally used for feeding Microstrip patch antennas. Co-axial feed has significant drawback i.e. it provides narrow bandwidth of 2% -5% and is hard to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, consequently not making it completely planar for thick substrates. Additionally, for thicker substrates the expanded probe length makes the input impedance more inductive leading to matching problems. Along these lines, to beat the weakness of probe feeding technique a new technique i.e. Microstrip line feed technique has been proposed. In the microstrip line feed technique, a conducting strip is connected associated specifically to the edge of the Microstrip patch. The conducting strip is smaller in width when compared with the patch. This sort of feed arrangement has the advantage that the feed can be etched on the similar substrate to provide a planar structure. This method is beneficial due to its simple planar structure.

4.10 Microstrip Line Feed Rectangular Microstrip Patch Antenna:

The Microstrip line feed Rectangular microstrip patch antenna is designed at $L_P = 28mm,\quad W_P = 37mm,\ L_{sub} = 70mm,\ W_{sub} = 70mm,\ h = 1.59mm,\ F_l = 30mm, F_w = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

Microstrip Line Feed Rectangular microstrip patch antenna is designed and simulated. The plot of reflection coefficient vs frequency and VSWR vs frequency are obtained as shown in Figure 4.108 and Figure 4.109 respectively.

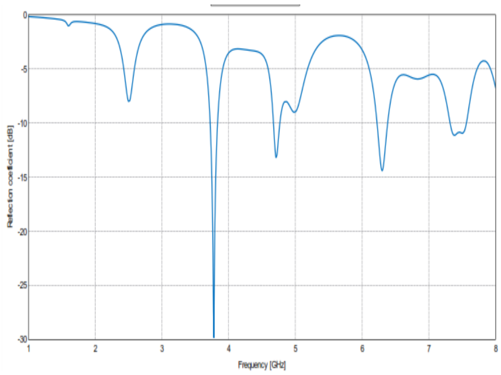

Figure 4.108: **Reflection Coefficient Vs Frequency of Microstrip Line Feed Rectangular Microstrip Patch Antenna.**

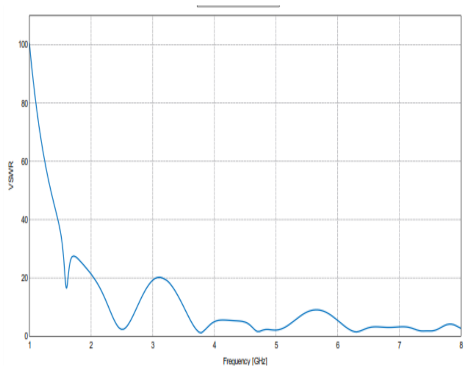

Figure 4.109: **VSWR Vs Frequency of Microstrip Line Feed Rectangular Microstrip Patch Antenna.**

From Figure 4.108 it is found that the Microstrip Line Feed Rectangular microstrip patch antenna is resonating at four frequencies. The resonance frequencies are f_{r1}= 3.77GHz, f_{r2}=4.72GHz, f_{r3}= 6.30GHz, f_{r4}= 7.4GHz and the corresponding reflection coefficients are -30.53dB, -13.1dB, -14.41dB and -11.1dB. The reflection bandwidths are 110 MHz, 100 MHz,170 MHz and 240 MHz in the frequency bands 3.73GHz-3.84GHz, 4.67GHz-4.77GHz, 6.22GHz-6.39 GHz and 7.33GHz-7.57 GHz respectively.

From Figure 4.109 VSWR is observed below 2 in the frequency bands 3.72GHz-3.84GHz, 4.66GHz-4.79GHz, 6.22GHz-6.4GHz and 7.3GHz-7.58GHz VSWR bandwidths are of 120 MHz,130 MHz,180 MHz and 280 MHz respectively.

Far Field Radiation Pattern:

The Far field radiation pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna at the resonance frequencies 3.77GHz, 4.72GHz, 6.30GHz and 7.4GHz are shown in Figure 4.110, Figure 4.111, Figure 4.112, and Figure 4.113. It helps to measure the gain of antenna.

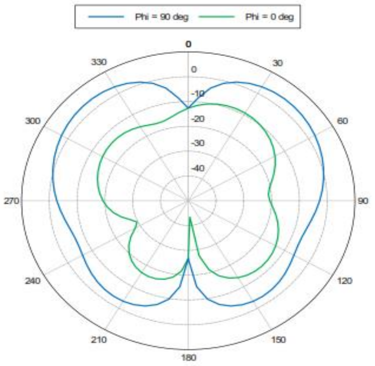

Figure 4.110: **Far Field Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Antenna at 3.77GHz.**

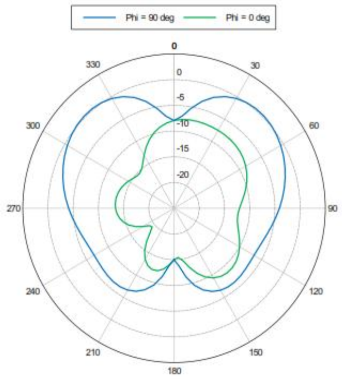

Figure 4.111: **Far Field Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Antenna at 4.72GHz.**

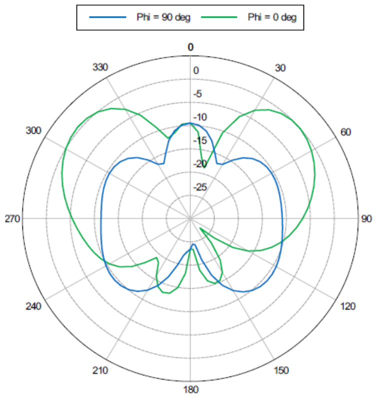

Figure 4.112: **Far Field Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Antenna at 6.30 GHz.**

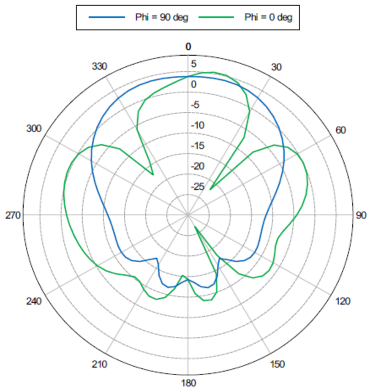

Figure 4.113: **Far Field Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Antenna at 7.4GHz.**

It is observed that the gains of the Microstrip Line Feed Rectangular microstrip patch antenna are 3.74dBi at 3.77GHz, 0.28dBi at 4.72 GHz, 0.9dBi at 6.30GHz, 1.1dBi at 7.4GHz.

The radiation pattern is slightly deviated with the ideal radiation pattern expected at resonance frequency 3.77GHz while the pattern is more deviating from the ideal pattern for resonance frequencies 4.72GHz,6.30GHz and 7.4GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna at the resonance frequencies 3.77GHz, 4.72 GHz,6.30GHz and 7.4GHz are shown in Figure 4.114, Figure 4.116, Figure 4.118 and Figure 4.120 and H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna at the resonance frequencies 3.77GHz,4.72 GHz,6.30GHz and 7.4GHz are shown in Figure 4.115, Figure 4.117, Figure 4.119 and Figure 4.121 respectively. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately. Further it is used to view and analyse the pattern of radiation.

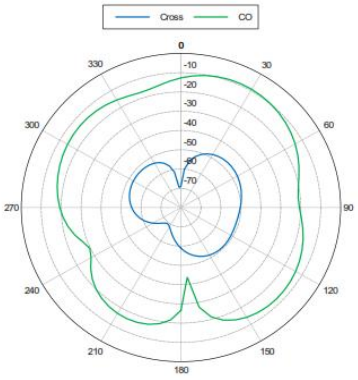

Figure 4.114: **E Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 3.77 GHz.**

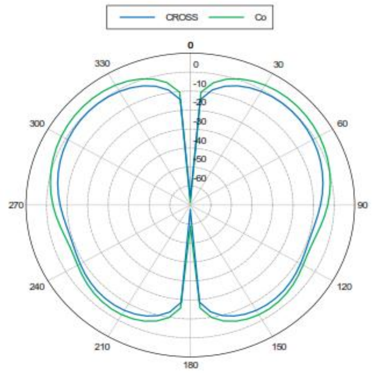

Figure 4.115: **H Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 3.77 GHz.**

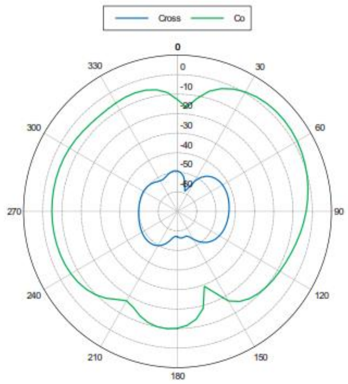

Figure 4.116: **E Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 4.72GHz.**

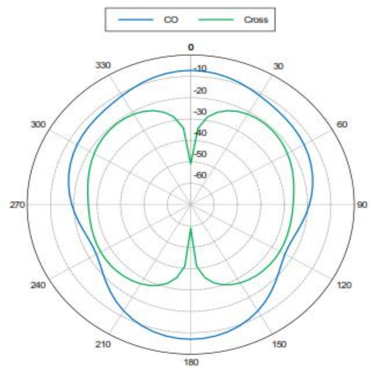

Figure 4.117: **H Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 4.72GHz.**

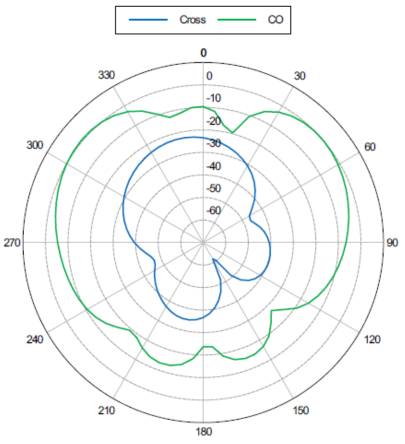

Figure 4.118: **E Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 6.30 GHz.**

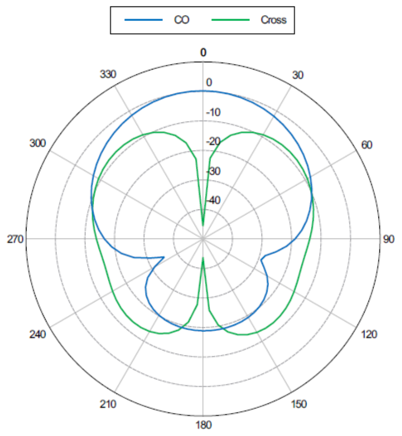

Figure 4.119: **H Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 6.30 GHz.**

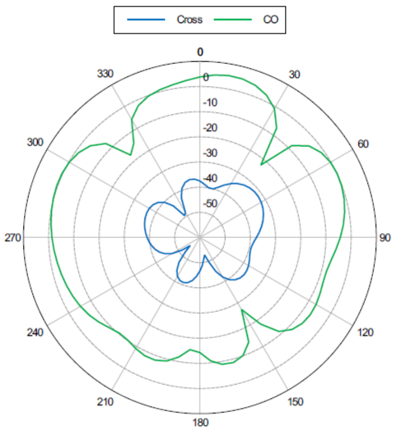

Figure 4.120: **E Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 7.4 GHz.**

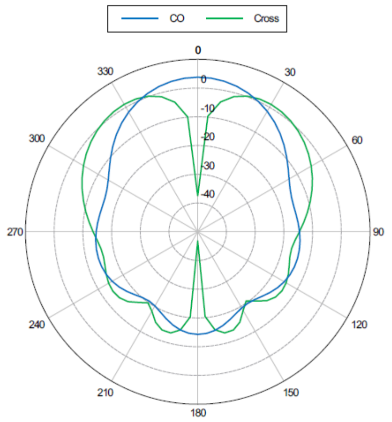

Figure 4.121: **H Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 7.4 GHz.**

For the resonance frequency 3.77 GHz the cross-polarization variations in E-Plane are less than -40dB, while for H-Plane it is just below 0dB. For the resonance frequency 4.72GHz the cross-polarization variations in E-Plane are slightly less than -40dB, while for H-Plane it is -20dB.

For the resonance frequency 6.30 GHz the cross-polarization variations in E-Plane are less than -30dB, while for H-Plane it is just below -5dB. For the resonance frequency 7.4GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is just below 0dB. The co polarizations in E Plane are observed to be slightly deviated from the ideal radiation pattern at the resonating frequencies 3.77 GHz and 4.72GHz, while it is more deviating at frequencies 6.30GHzand 7.4GHz while it is more deviating in H Plane from the ideal radiation pattern at resonating frequencies 3.77 GHz, 4.72GHz,6.30GHz and 7.4GHz.

Impedance:

The plot of impedance vs frequency of the simulated Microstrip Line Feed Rectangular microstrip patch antenna at the resonance frequencies 3.77GHz, 4.72 GHz, 6.30GHz, 7.4GHz is shown in Figure 4.122. It helps to find the real and imaginary part of the impedance of the antenna at these resonance frequencies.

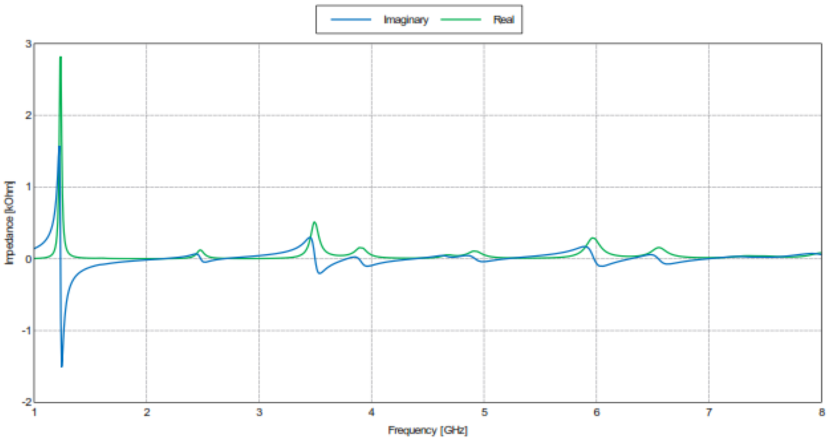

Figure 4.122: **Impedance Vs Frequency of Microstrip Line Feed Rectangular Microstrip Patch Antenna.**

From the Figure 4.122 it is found that the impedance of the simulated antenna is51.9+j4.51 ohm at resonance frequency 3.77GHz, 49.1+j2.37 ohm at resonance frequency 4.72 ohm, 34.8+j4.4 at resonance frequency 6.30GHz and 40.4+j2.4 at resonance frequency 7.4GHz. The corresponding magnitudes of the impedances are |z| = 52.09 ohm, |z| = 49.15 ohm, |z| = 35.07 and |z| = 40.47 ohm for the resonating frequencies 2.49 GHz, 3.73GHz and 4.40 GHz respectively.

It is observed that the impedance goes on decreasing with the increase in resonance frequency for first two resonances and for higher resonance it is again increasing and the impedance is approximately matched with the ideal value for resonance frequencies at 3.77GHz and 4.72GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Microstrip Line Feed Rectangular microstrip patch antenna at the resonance frequencies 3.77GHz, 4.72 GHz,6.30GHz and 7.4GHz are as shown in Figure 4.123, Figure 4.124, Figure 4.125 and Figure 4.126 respectively.

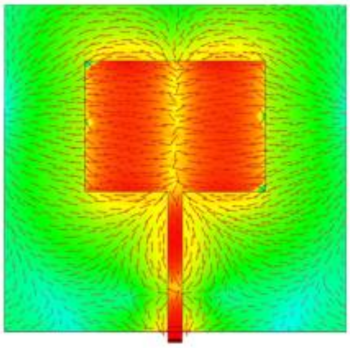

Figure 4.123: **Surface Current Distribution on Radiating Patch of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 3.77 GHz.**

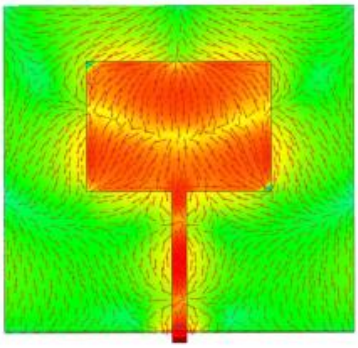

Figure 4.124: **Surface Current Distribution on Radiating Patch of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 4.72 GHz.**

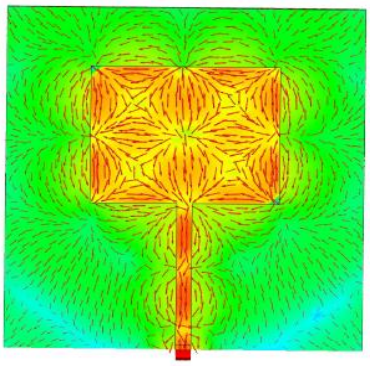

Figure 4.125: **Surface Current Distribution on Radiating Patch of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 6.30 GHz.**

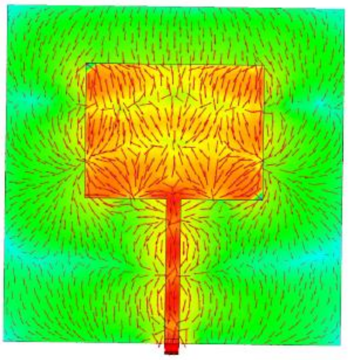

Figure 4.126: **Surface Current Distribution on Radiating Patch of Microstrip Line Feed Rectangular Microstrip Patch Antenna at 7.4 GHz.**

It is observed that, Surface current is distributed horizontally from centre towards radiating edge in linear form at resonance frequencies 3.77GHz, while for resonance frequency 4.72 GHz the flow of current is vertically distributed and in erratic over entire radiating patch at frequencies 6.30GHz and 7.4GHz.

Inference:

It is resonating at four frequencies and the bandwidth is in MHz up to 130MHz. It has a moderate gain.

4.11 Microstrip line feed Rectangular microstrip patch antenna with partial ground:

The Microstrip line feed Rectangular microstrip patch antenna with partial ground is designed at $L_p = 28mm$, $W_p = 37mm$, $L_g = 28mm$, $W_g =$

$70mm$, $L_{sub} = 70mm$, $W_{sub} = 70mm$, $h = 1.59mm$ $L_{sub} = 70mm$, $W_{sub} = 70mm$, $F_l = 30mm$, $F_w = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

Microstrip Line Feed Rectangular microstrip patch antenna with partial ground is designed and simulated. The plot of reflection coefficient vs frequency and VSWR vs frequency are obtained as shown in Figure 4.127 and Figure 4.128 respectively.

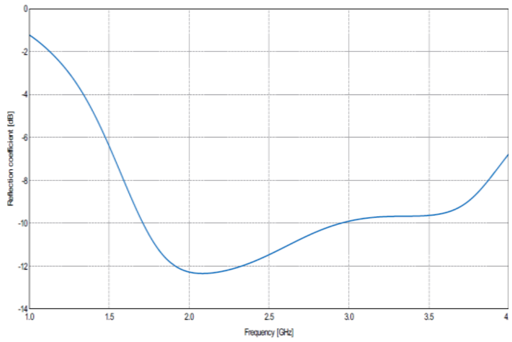

Figure 4.127: **Reflection Coefficient Vs Frequency of Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground.**

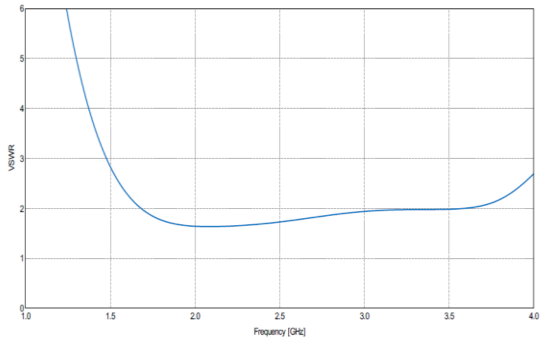

Figure 4.128: **VSWR Vs Frequency of Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground.**

From Figure 4.127 it is found that the Microstrip Line Feed Rectangular microstrip patch antenna with partial ground is resonating at single frequency. The resonance frequencies are f_{r1} = 2.08GHz, and the corresponding reflection coefficient is -12.34dB. The reflection bandwidth is 1.23 GHz, in the frequency bands 1.71GHz-2.94GHz.

From Figure 4.128 VSWR is observed below 2 in the frequency bands 1.68GHz-3.58GHz, bandwidth is 1.9GHz respectively.

Far Field Radiation Pattern:

The Far field radiation pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna with partial ground at the resonance frequencies 2.08GHz is shown in Figure 4.129.

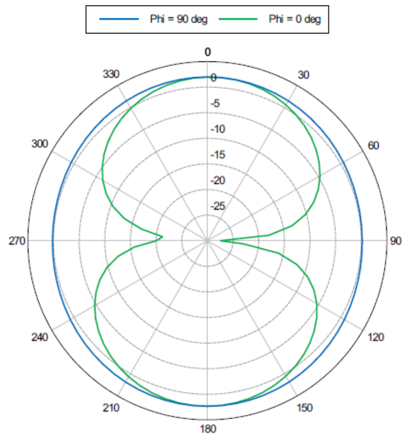

Figure 4.129: **Far Field Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Antenna with Partial Ground at 2.08GHz.**

It is observed that the gain of the Microstrip Line Feed Rectangular microstrip patch antenna with partial ground is 2.34 dBi at 2.08GHz. The radiation pattern is matched with the ideal radiation pattern at resonance frequency 2.08GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna with partial ground at the resonance frequencies 2.08GHzis shown in Figure 4.130. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna with partial ground at the resonance frequencies 2.08GHz is shown in Figure 4.131. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately.

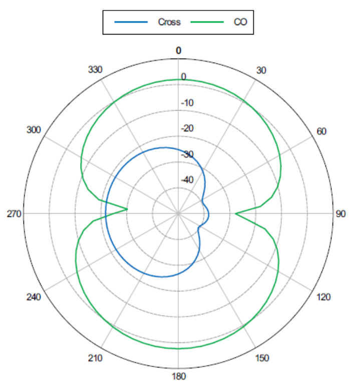

Figure 4.130: **E Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground at 2.08 GHz.**

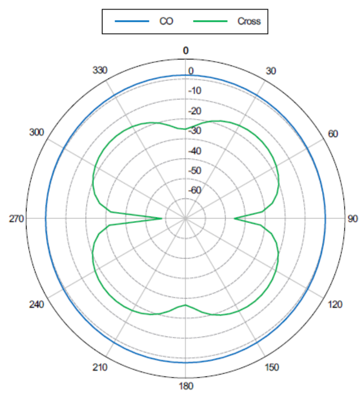

Figure 4.131: **H Plane Co and Cross Radiation Pattern of Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground at 2.08 GHz.**

For the resonance frequency 2.08 GHz the cross-polarization variations in E-Plane are less than -20dB, while for H-Plane it is just below -10dB.

The co polarizations in E Plane are observed to be nearly same and stable as ideal radiation pattern at the resonating frequencies 2.08 GHz.

Impedance:

The plot of impedance vs frequency of the simulated Microstrip Line Feed Rectangular microstrip patch antenna with partial ground at the resonance frequencies 2.08 GHz is shown in Figure 4.132.

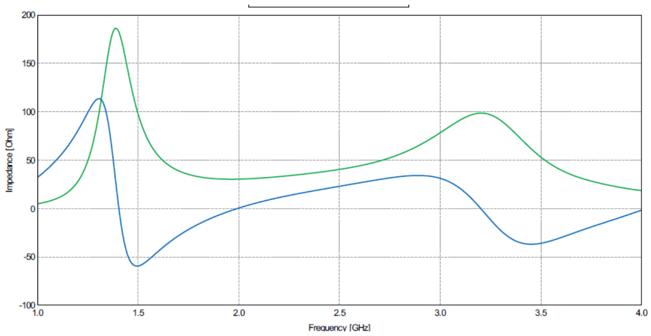

Figure 4.132: **Impedance Vs Frequency of Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground.**

From the Figure 4.132 it is found that the impedance of the simulated antenna is 31.13+j5.4 ohm at resonance frequency 2.08GHz. The corresponding magnitudes of the impedance are |z| = 31.59 ohm for the resonating frequencies 2.08 GHz. It is observed that the impedance is deviated from its ideal value at 2.08GHz.

Surface Current Distribution:

The Surface Current Distribution pattern of the simulated Microstrip Line Feed Rectangular microstrip patch antenna with partial ground, resonating at frequency 2.08GHz is shown in Figure 4.133.

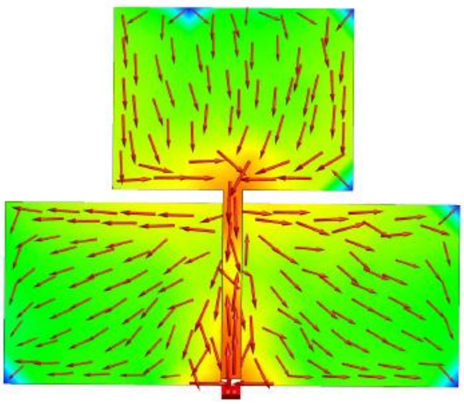

Figure 4.133: **Surface Current Distribution on Radiating Patch of Microstrip Line Feed Rectangular Microstrip Patch Antenna with Partial Ground at 2.08GHz.**

It is observed that, Surface current is linearly at resonance frequencies 3.77GHz, while for resonance frequency 2.08 GHz.

Inference:

It is resonating at single frequency and the bandwidth is in MHz up to 1.9MHz. It has a moderate gain.

4.12 Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground:

Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground is designed and simulated. The Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground is designed at $L_p = 28mm, W_p = 37mm, L_g = 28mm, W_g = 70mm$, $L_{sub} = 70mm$, $W_{sub} = 70mm$, $h = 1.59mm$, $L_s = 5mm$, $W_s = 5mm$ $F_l = 30mm$, $F_w = 3mm$ It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground are shown in Figure 4.134 and Figure 4.135.

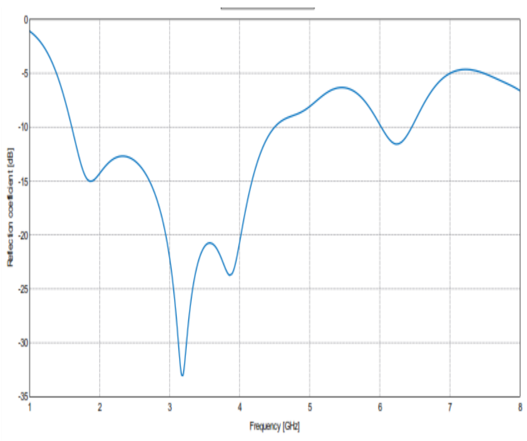

Figure 4.134: **Reflection Coefficient Vs Frequency and of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.**

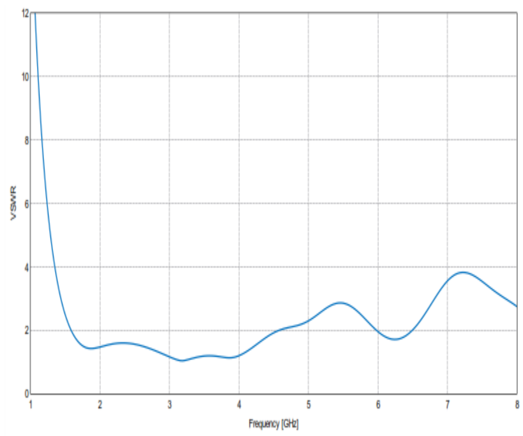

Figure 4.135: **VSWR Vs Frequency and of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.**

From Figure 4.134, it is found that the Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground is resonating at single frequency 3.18GHz, and the corresponding reflection coefficient is -33.17dB. The reflection bandwidth is 2.89GHz in the frequency band 1.61GHz-4.5GHz. From Figure 4.135 VSWR is observed below 2 in the frequency band 1.59 GHz to 4.59 GHz and VSWR bandwidth is of 3GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 3.18GHz is shown in Figure 4.136. It helps to measure the gain of antenna.

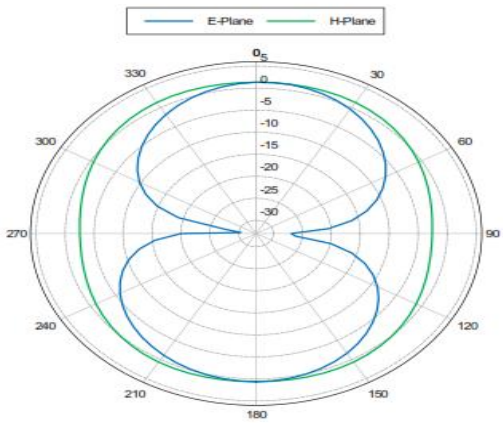

Figure 4.136: **Far Field Radiation Pattern of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 3.18GHz.**

It is observed that the gain of the Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground is 1.45 dBi at 3.18 GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.18GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 3.18GHz is shown in Figure 4.137, and H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 3.18GHz is shown in Figure 4.138. It helps to measure the gain at the resonance frequencies for co polarization and cross polarization separately. Further it is used to view and analyse the pattern of radiation.

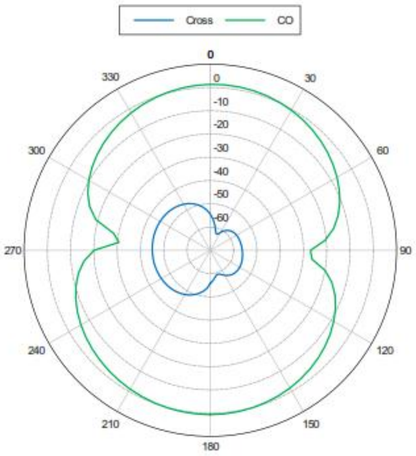

Figure 4.137: **E Plane Co and Cross Radiation Pattern of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 3.18G Hz.**

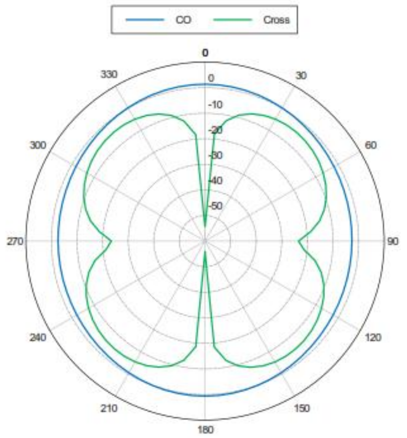

Figure 4.138: **H Plane Co and Cross Radiation Pattern of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 3.18GHz.**

Figure 4.137 and Figure 4.138 shows E & H plane co & cross radiation pattern of design antenna at 3.18GHz. For the resonance frequency 3.18 GHz the cross-polarization variations in E-Plane is less than -40dB, while for H-Plane it is just below 0dB. The gain of the antenna is 1.45 dBi at 3.18 GHz. The co polarization in E and H Plane is observed to be stable at the resonating frequency 3.18 GHz.

Surface Current Distribution:

The Surface Current Distribution pattern of the simulated Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground, resonating at frequency 3.18GHz is shown in Figure 4.139.

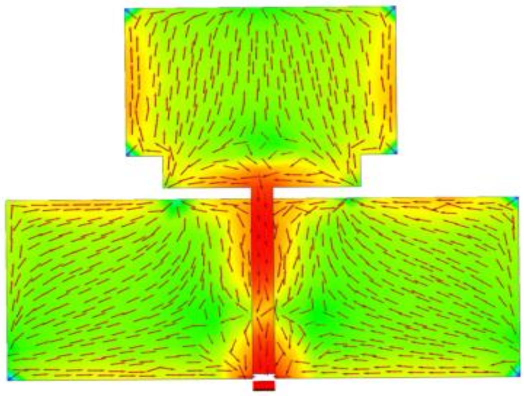

Fig. 4.139: **Surface Current Distribution on Radiating Patch Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 3.18GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 3.18GHz.

Impedance:

The plot of impedance vs frequency of the simulated Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 3.18GHz, is shown in Figure 4.140.

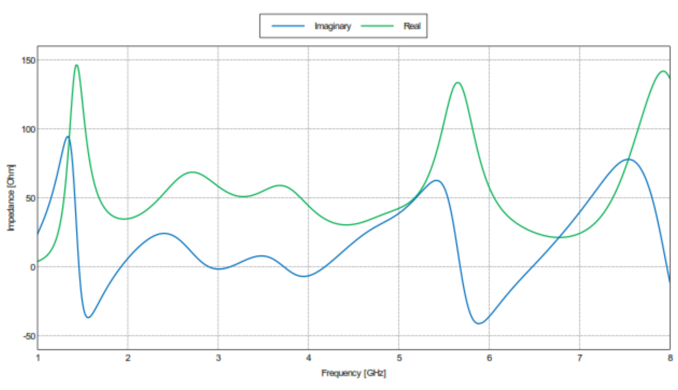

Fig.4.140: **Impedance Vs Frequency of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.**

From the Figure 4.140 it is found that the impedance of the simulated antenna is 52 +j1.12 ohm at resonance frequency 3.18GHz. The corresponding magnitudes of the impedance are |z| = 52.01 ohm, for the resonating frequency 3.18 GHz. It is observed that the impedance is approximately matched with the ideal value for resonance frequency at 3.18GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and ground gap between radiating patch and partial ground plane is changed and the effect has been observed. Also, the length and width of the slots are changed and the effect has been observed. For parametric analysis gap between radiating patch and partial ground plane is increased and decreased by an amount of 1mm independently and the plot of reflection coefficient vs frequency is plotted and length and width of the corner slots of the Single Corner Cut Antenna are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted.

Effect of change in ground gap:

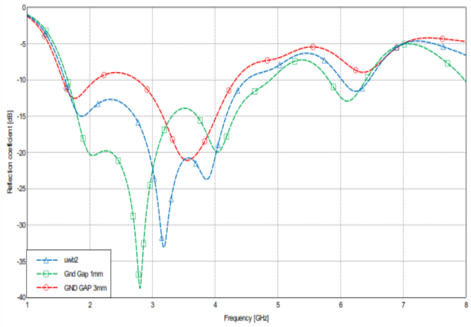

Figure 4.141: **Reflection Coefficient Vs Frequency of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground for Ground Gap Changed**.

Figure 4.141 shows the effect of change in gap between radiating patch and partial ground plane when increased and decreased by an amount of 1mm independently, maintaining the other dimensions constant.

When gap between radiating patch and partial ground is decreased by an amount of 1mm, maintaining the length, width of the radiating patch and ground plane constant, the antenna resonates at frequency 2.80GHz and the corresponding reflection coefficient is -38.74dB and the reflection bandwidth is 3.23 GHz in the frequency band 1.65 GHz - 4.88 GHz.

When gap between radiating patch and partial ground is increased by an amount of 1 mm, maintaining the length, width of the radiating patch and ground plane constant, the antenna resonates at frequency 3.55 GHz and the corresponding reflection coefficient is -21.10dB. The reflection bandwidth is 1.56GHz in the frequency band 2.75GHz - 4.31GHz.

Effect of change in corner cut slot length and width:

Figure 4.142 shows the effect of change in corner cut length and width, when increased and decreased by an amount of 0.5mm independently, maintaining the other dimensions constant.

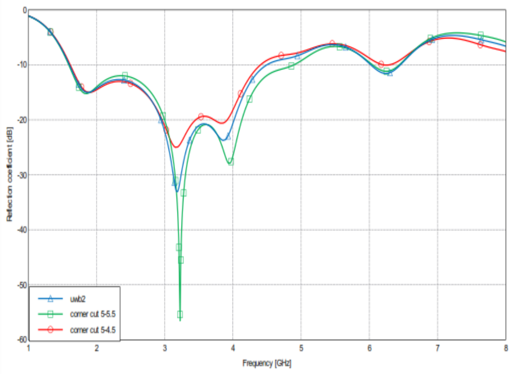

Figure 4.142: **Reflection Coefficient Vs Frequency of Single Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground for Length and Width Changed**.

When length and width of the corner cut slot is decreased by an amount of 0.5mm, maintaining the length and width of the patch constant, the antenna resonates at frequency, 3.16GHz, and the corresponding reflection coefficient is -25.02dB. The reflection bandwidth is 2.79 GHz in the frequency band 1.62 GHz - 4.41GHz.

When length and width of the corner cut slot is increased by an amount of 0.5mm, maintaining the length and width of the patch constant, the antenna resonates at frequency 3.22GHz and the corresponding reflection coefficient is -57.28dB. The reflection bandwidth is 3.30 GHz.in the frequency band1.6 GHz - 4.9GHz.

Inference:

It is resonating at single frequency at 3.1GHz and the bandwidth is improved up to 3 GHz. It has a moderate gain for the overall frequency range and stable radiation pattern.

4.13. Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground

Multiple corner cut Rectangular Microstrip Patch Antenna with Partial Ground is designed and simulated. The Multiple corner cut Rectangular microstrip patch antenna with Partial Ground is designed at $L_p = 28mm$,$W_p = 37mm$, $L_g = 28mm$, $W_g = 70mm$, $L_{sub} = 70mm$, $W_{sub} = 70mm$, $h = 1.59mm$, $L_s = 3mm$, $W_s = 3mm$, $F_l = 30mm$, $F_w = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Multiple corner cut Rectangular microstrip patch antenna with partial ground are shown in Figure 4.143 and Figure 4.144 respectively.

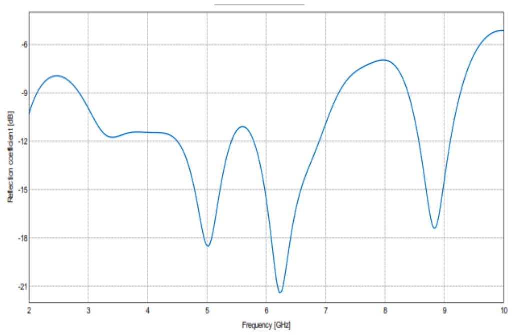

Figure 4.143: **Reflection Coefficient Vs Frequency and of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.**

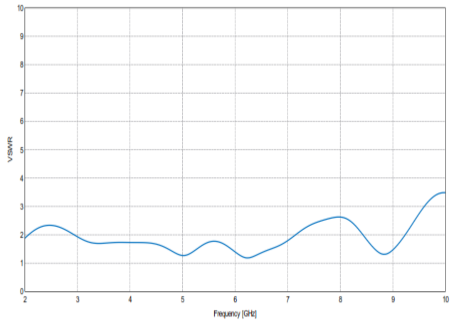

Figure 4.144: **VSWR Vs Frequency and of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.**

From Figure 4.143 it is found that the Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground is resonating at 6.23 GHz and 8.83GHz, and the corresponding reflection coefficients are -21.42dB and -17.38dB respectively. The reflection bandwidth is 4.08GHz and 740 MHz in the frequency bands 3.01GHz-7.09GHz, 8.46GHz-9.2GHz respectively.

From Figure 4.144 VSWR is observed below 2 in the frequency band 2.94 GHz-7.15GHz, 8.39GHz-9.25GHz and VSWR bandwidths are of 4.21 GHz and 860 MHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequencies 6.23GHz and 8.83GHz are shown in Figure 4.145, Figure 4.146 respectively.

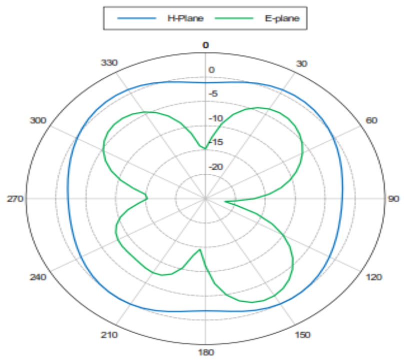

Figure 4.145: **Far Field Radiation Pattern of Multiple Corner Cut Rectangular Microstrip Antenna with Partial Ground at 6.23 GHz.**

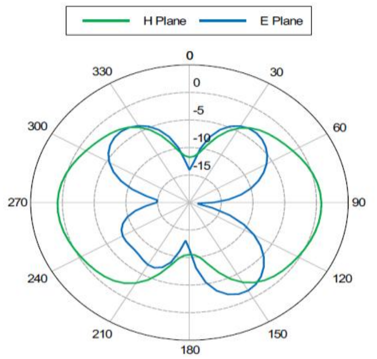

Figure 4.146: **Far Field Radiation Pattern of Multiple Corner Cut Rectangular Microstrip Antenna with Partial Ground at 8.83 GHz.**

It is observed that the gains of the Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground are 0.9 dBi at 6.23 GHz and 0.77dBi at 8.83GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 6.23GHz and it is more deviating at 8.83GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 6.23GHz and 8.83GHz is shown in Figure 4.147,4.149 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 6.23GHz and 8.83GHz is shown in Figure 4.148, Figured 4.150 respectively.

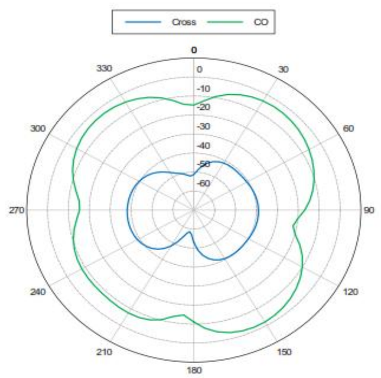

Figure 4.147: **E Plane Co and Cross Radiation Pattern of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 6.23GHz.**

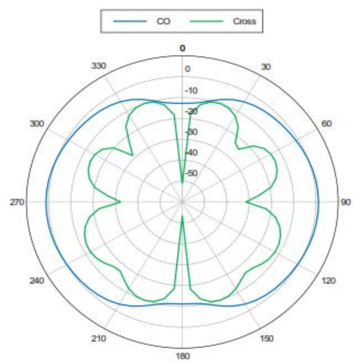

Figure 4.148: **H Plane Co and Cross Radiation Pattern of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 6.23GHz.**

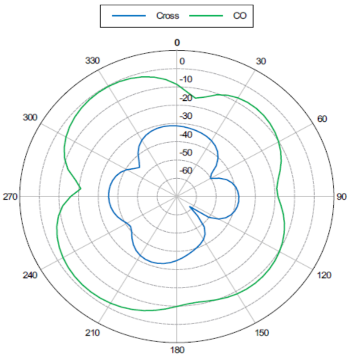

Figure 4.149: **E Plane Co and Cross Radiation Pattern of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 8.83 GHz.**

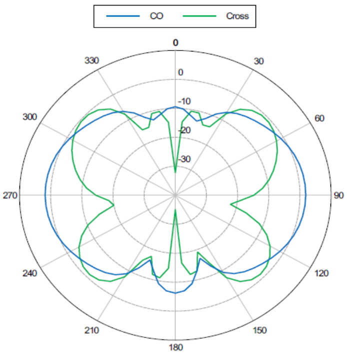

Figure 4.150: **H Plane Co and Cross Radiation Pattern of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 8.83 GHz.**

For the resonance frequency 6.23 GHz the cross-polarization variations in E-Plane is less than -35dB, while for H-Plane it is just below -10dB. For the resonance frequency 8.83 GHz the cross-polarization variations in E-Plane is less than -30dB, while for H-Plane it is just below 0dB.

The gain of the antenna is 0.9dBi at 6.23 GHz and 0.62dBi at 8.83GHz. The co polarization in E and H Plane is observed to be slightly deviated at the resonating frequency 6.23 GHz and 8.83GHz.

Surface Current Distribution:

The Surface Current Distribution pattern of the simulated Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequency 6.23GHz and 8.83GHz is shown in Figure 4.151 and Figure 4.152 respectively.

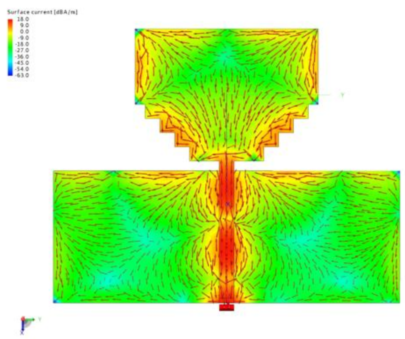

Fig. 4.151: **Surface Current Distribution on Radiating Patch Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 6.23GHz.**

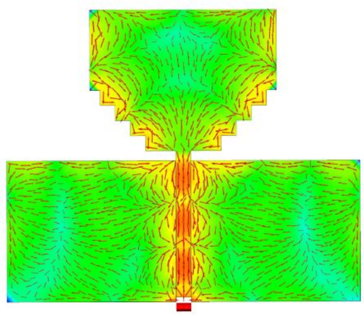

Fig. 4.152: **Surface Current Distribution on Radiating Patch Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at 8.83GHz.**

It is observed that, Surface current is erratic in nature on radiating patch at resonance frequency 6.23GHz and 8.83GHz.

Impedance:

The plot of impedance vs frequency of the simulated Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground at the resonance frequencies 6.23GHz and 8.83GHz is shown in Figure 4.153.

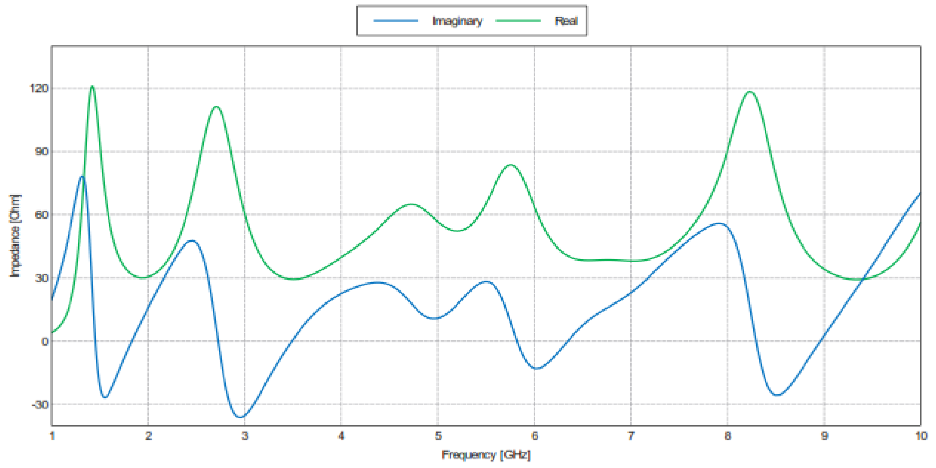

Figure 4.153: **Impedance Vs Frequency of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground.**

From the Figure 4.153 it is found that the impedance of the simulated antenna is 44.2 -j5.54 ohm at resonance frequency 6.23GHz and 41.9-j9.45 at resonance frequency 8.83 GHz. The corresponding magnitudes of the impedance are |z| = 44.54 and |z| = 42.95 ohm. It is observed that the impedance is deviated from the ideal value for resonance frequencies at 6.23GHz and 8.83GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and length, width of the corner cut slots are changed and the effect has been observed. For parametric analysis length and width of corner cut slots of the Multiple Corner Cut rectangular microstrip patch Antenna with Partial Ground are increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.154 show the results due to variation in lengths and variation in widths of corner slots.

Effect of change in corner cut slots length and width:

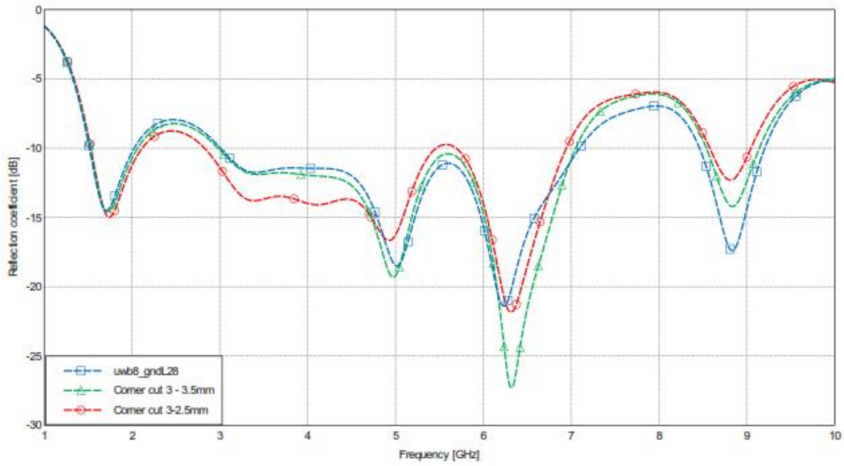

Figure 4.154: **Reflection Coefficient Vs Frequency of Multiple Corner Cut Rectangular Microstrip Patch Antenna with Partial Ground for Length and Width of Corner Cut Changed.**

When length and width of the corner cut slots are decreased by an amount of 0.5mm, maintaining the length and width of the patch constant, the antenna resonates at frequencies, 4.92GHz, 6.31GHz, and the corresponding reflection coefficients are-16.67dB and -21.86dB. The reflection bandwidths are 2.62 GHz and 1.25 GHz in the frequency bands 2.84GHz-5.46 GHz, 5.7GHz-6.95 GHz respectively.

When length and width of the corner cut slots are increased by an amount of 0.5mm, maintaining the length and width of the patch constant, the antenna resonates at frequency 6.32GHz and the corresponding reflection coefficient is -27.34dB. The reflection bandwidth is 4.07 GHz in the frequency band 2.99GHz-7.06GHz.

Inference:

It is resonating at two frequencies and the bandwidth is improved up to 4.21 GHz for lower resonance frequency and degraded up to 360MHz for higher resonance frequency. It has a low gain for the overall frequency range and deteriorated radiation pattern.

4.14. Monopole Antenna:

Planar and printed monopole antennas are most widely used for wideband and UWB antennas. The Sample performances of monopole antennas are presented.

4.14.1. Monopole Microstrip Patch antenna with Partial Ground:

In the above antenna designs the basic radiating patch has been selected as a square and then the antenna is created as per its geometry. But in monopole antenna the basic radiating patch selected as a rectangle and then antenna is created as per its geometry**.** The Monopole Rectangular Microstrip Patch Antenna with partial ground is designed at $L_p = 12.7mm, W_p = 15.2mm,\ L_{sub} = 39mm, W_{sub} = 30mm, W_s = 3mm, F_l = 16.01mm$, $F_w = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Monopole Rectangular Microstrip Patch Antenna with partial ground are shown in Figure 4.155 and Figure 4.156 respectively.

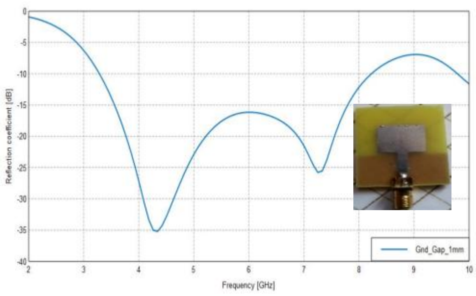

Figure 4.155: **Reflection coefficient Vs frequency and of Monopole Rectangular Microstrip Patch Antenna with partial ground.**

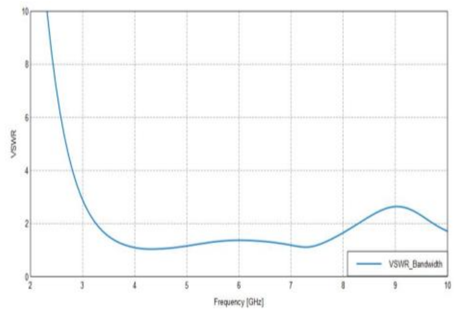

Figure 4.156: **VSWR Vs frequency and of Monopole Rectangular Microstrip Patch Antenna with partial ground.**

From Figure 4.155 it is found that the Monopole Rectangular Microstrip Patch Antenna with partial ground is resonating at two frequencies. The resonance frequencies are f_{r1}=4.30GHz, f_{r2}= 7.26GHz, and the corresponding reflection coefficients are -36 dB and -26 dB. The reflection bandwidth is 4.94GHz in the frequency band 3.29GHz-8.23GHz. From Figure 4.156 VSWR is observed below 2 in the frequency band 3.26GHz-8.29GHz and VSWR bandwidth is 5.03GHz.

Far Field Radiation Pattern:

The field radiation pattern of the simulated Monopole Rectangular Microstrip Patch Antenna with partial ground at the resonance frequencies 4.30GHz and 7.26GHz are shown in Figure 4.157,4.158 respectively.

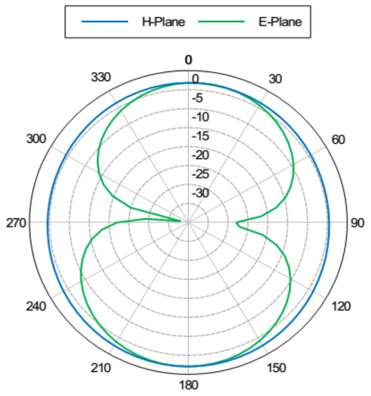

Figure 4.157: **Far Field Radiation Pattern of Monopole Rectangular Microstrip Patch Antenna with partial ground at 4.3GHz.**

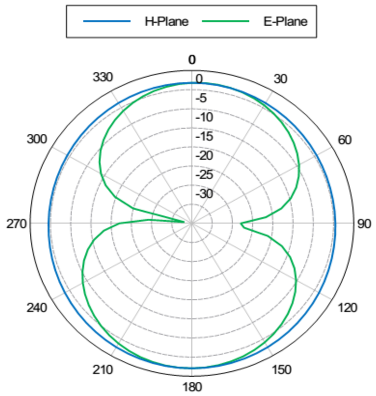

Figure 4.158: **Far Field Radiation Pattern of Monopole Rectangular Microstrip Patch Antenna with partial ground at 7.26GHz.**

It is observed that the gains of the Monopole Rectangular Microstrip Patch Antenna with partial ground are 2.97dBi at 4.3GHz and 2.89dBi at 7.26GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 4.3GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Monopole Rectangular Microstrip Patch Antenna with partial ground at the resonance frequencies 4.3GHz and 7.26GHz are shown in Figure 4.159 and Figure 4.161. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Monopole Rectangular Microstrip Patch Antenna with partial ground at the resonance frequencies 4.3GHz and 7.26GHz are shown in Figure 4.160 and Figure 4.162 respectively.

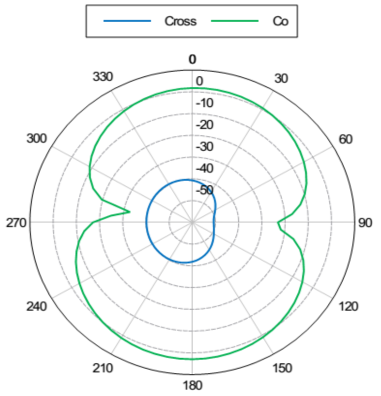

Figure 4.159: **E Plane Co and Cross Radiation Pattern of Monopole Rectangular Microstrip Patch Antenna with partial ground at 4.3GHz.**

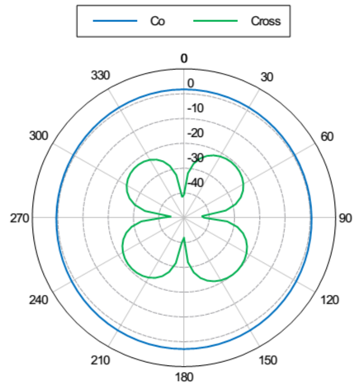

Figure 4.160: **H Plane Co and Cross Radiation Pattern of Monopole Rectangular Microstrip Patch Antenna with partial ground at 4.3GHz.**

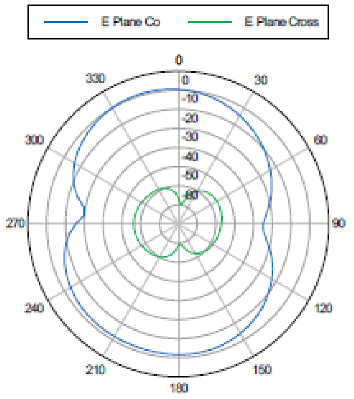

Figure 4.161: **E Plane Co and Cross Radiation Pattern of Monopole Rectangular Microstrip Patch Antenna with partial ground at 7.26GHz.**

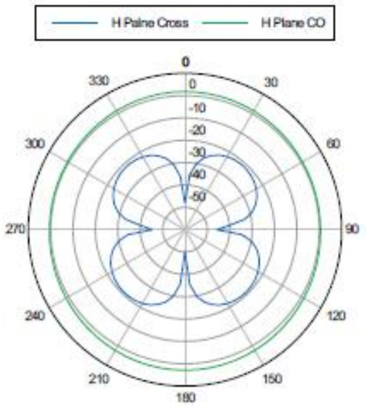

Figure 4.162: **H Plane Co and Cross Radiation Pattern of Monopole Rectangular Microstrip Patch Antenna with partial ground at 7.26GHz.**

For the resonance frequency 4.3 GHz the cross-polarization variations in E-Plane are less than -50dB, while for H-Plane it is -20dB. For the resonance frequency 7.26 GHz the cross-polarization variations in E-Plane are slightly less than -50dB, while for H-Plane it is -20dB. The gain of the antenna is 2.97dBi at 4.3 GHz and 2.89dBi at 7.26GHz. The co polarizations are observed to be nearly same and stable at the resonating frequencies 4.3 GHz and 7.26GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Monopole Rectangular Microstrip Patch Antenna with partial ground at the resonance frequencies 4.3GHz and 7.26 GHz are as shown in Figure 4.163 and Figure 4.164 respectively.

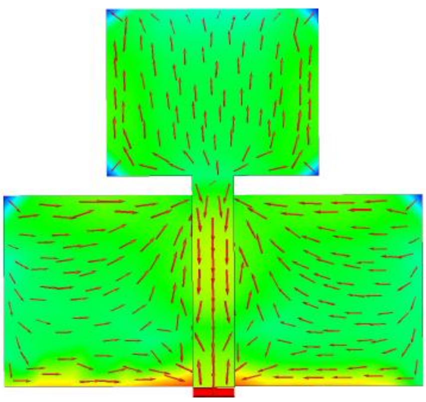

Figure 4.163: **Surface Current Distribution on Radiating Patch Monopole Rectangular Microstrip Patch Antenna with partial ground at 4.3GHz.**

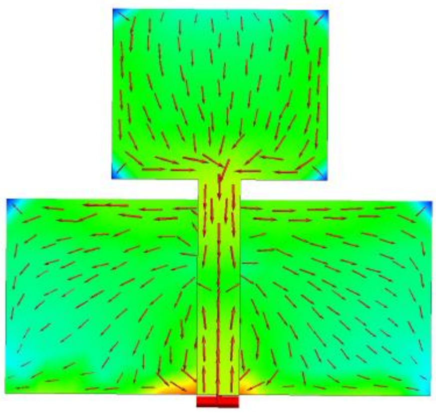

Figure 4.164: **Surface Current Distribution on Radiating Patch Monopole Rectangular Microstrip Patch Antenna with partial ground at 7.62GHz.**

It is observed that, Surface current is linearly distributed at resonance frequencies 4.3GHz and 7.26GHz.

Impedance:

The plot of impedance vs frequency of the simulated Monopole Rectangular Microstrip Patch Antenna with partial ground at the resonance frequencies 4.3GHz and 7.26 GHz is shown in Figure 4.165.

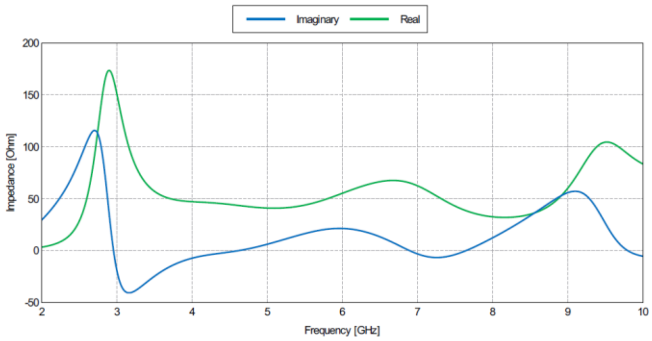

Figure 4.165: **Impedance Vs Frequency of Monopole Rectangular Microstrip Patch Antenna with partial ground.**

From the Figure 4.165 it is found that the impedance of the simulated antenna is 45.93-j3.22 ohm at resonance frequency 4.30GHz and 52.7-j6.53 ohm at resonance frequency 7.26GHz. The corresponding magnitudes of the impedances are |z| = 46.03 ohm and |z| = 53.09 ohm for the resonating frequencies 4.30 GHz and 7.26 GHz respectively.

It is observed that the impedance goes on increasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequency at 7.26GHz.

Results of fabricated antenna:

The reflection coefficient of the fabricated antenna is observed to be -30dB and -26dB which is not matching with the simulated results, resonance frequency is tuned at 4.3GHz and 6.8GHz, which is matching with the simulated results at 4.3GHz, and slightly shifted towards lower side at 6.8GHz. Reflection bandwidth of 4.21GHz is not matching with simulated results. The comparative results of fabricated antenna and simulated Simple Monopole Rectangular Microstrip Patch Antenna in terms of reflection coefficient Vs frequency is shown in Figure 4.166.

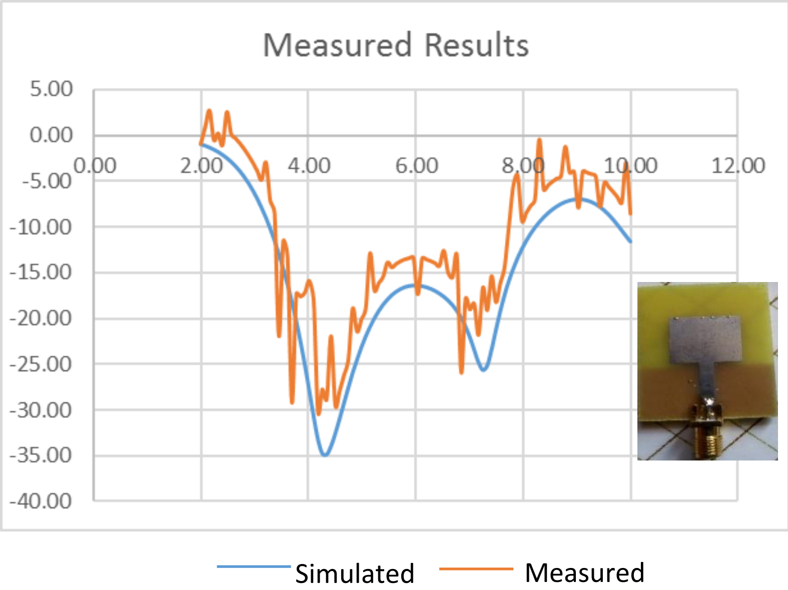

Figure 4.166 **Simulated and Measured Reflection Coefficient Vs Frequency of Monopole Rectangular Microstrip Patch Antenna with partial ground.**

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the gap between partial ground and radiating patch is changed and the effect has been observed. For parametric analysis the gap between partial ground and radiating patch of Monopole Rectangular Microstrip Patch Antenna with partial ground is increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.167 shows the results due to variation in lengths and variation in widths.

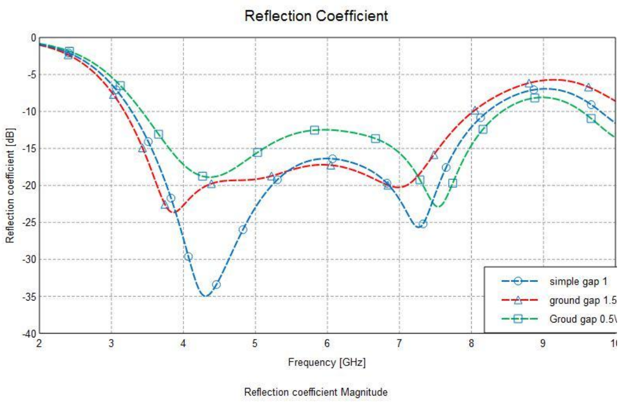

Figure 4.167: **Reflection Coefficient Vs Frequency of Monopole Rectangular Microstrip Patch Antenna with partial ground for Length and Width of Corner Cut Changed.**

Effect of change in ground gap:

When gap between radiating patch and partial ground is decreased by an amount of 0.5mm maintaining the length, width of the radiating patch and ground plane constant, the antenna resonates at frequencies, f_{r1}= 4.36GHz, f_{r2}= 7.53GHz and the corresponding reflection coefficients are -18.88dB and -22.90 GHz. The reflection bandwidth is 5GHz in the frequency band 3.43GHz-8.43GHz.

When gap between radiating patch and partial ground is increased by an amount of 0.5mm maintaining the length, width of the radiating patch and ground plane constant, the antenna resonates at frequencies, f_{r1}= 3.85GHz, f_{r2}= 6.98GHz and the corresponding reflection coefficients are -23.10dB and -20dB. The reflection bandwidth is 4.84GHz in the frequency band 3.85GHz -6.98GHz.

Inference:

It is resonating at two frequencies and the bandwidth is up to 5.03 GHz. It has a moderate gain for the overall frequency range and stable radiation pattern.

4.14.2. Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna:

The Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna is designed at $L_p = 12.7mm, W_p = 15.2mm,$ $L_{sub} = 39mm,$ $W_{sub} = 30mm, F_l = 16.01mm, F_w = 3mm,$ radius of curve $r = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna are shown in Figure 4.168 and Figure 4.169 respectively.

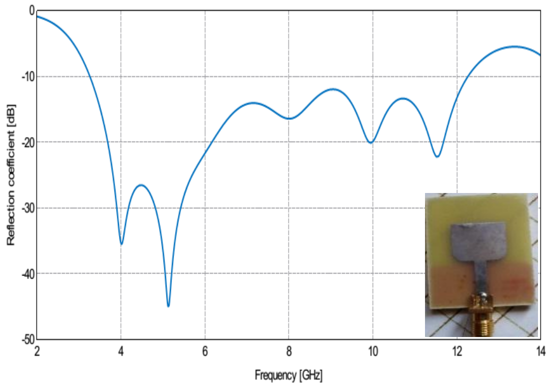

Figure 4.168: **Reflection Coefficient Vs Frequency and of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna.**

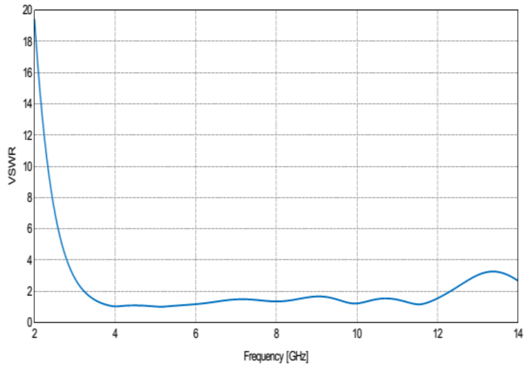

Figure 4.169: **VSWR Vs Frequency and of Lower Corner Rounded Rectangular Monopole Microstrip Patch Antenna.**

From Figure 4.168 it is observed that the Lower corner rounded monopole rectangular microstrip patch antenna is resonating at two frequencies. The resonance frequencies are f_{r1} =4.01GHz, f_{r2} =11.53GHz and the corresponding reflection coefficients are -35.49dB, and -22.2 dB. The reflection bandwidth is 9GHz in the frequency band 3.26GHz-12.26GHz.

From Figure 4.169 VSWR is observed below 2 in the frequency band 3.24GHz-12.3GHz and VSWR bandwidth is 9.06GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Lower corner rounded monopole rectangular microstrip patch antenna at the resonance frequencies 4.01GHz and 11.53GHz are shown in Figure 4.170 and Figure 4.171 respectively.

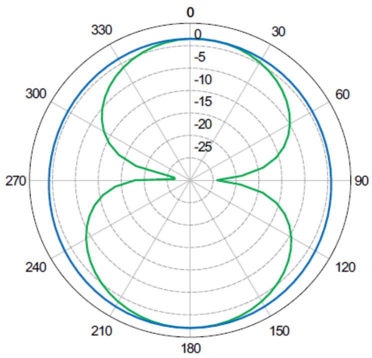

Figure 4.170: **Far Field Radiation Pattern of Lower Corner Rounded Monopole Rectangular Microstrip Antenna at 4.01GHz.**

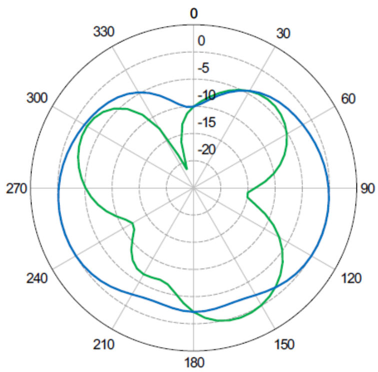

Figure 4.171: **Far Field Radiation Pattern of Lower Corner Rounded Monopole Rectangular Microstrip Antenna at 11.53GHz.**

It is observed that the gains of the Lower corner rounded monopole rectangular microstrip patch antenna are 2.95dBi at 4.01GHz and 1.02dBi at 11.53 GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 4.3GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Lower corner rounded monopole rectangular microstrip patch antenna at the resonance frequencies 4.01GHz and 11.53GHz are shown in Figure 4.172 and 4.174 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Lower corner rounded monopole rectangular microstrip patch antenna at the resonance frequencies 4.01GHz and 11.53GHz are shown in Figure 4.173 and 4.175 respectively.

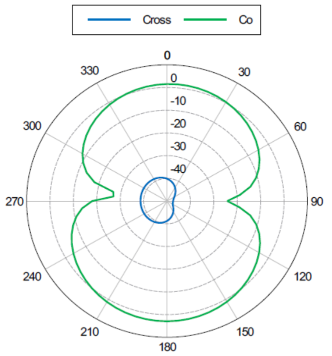

Figure 4.172: **E Plane Co and Cross Radiation Pattern of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna at 4.01GHz.**

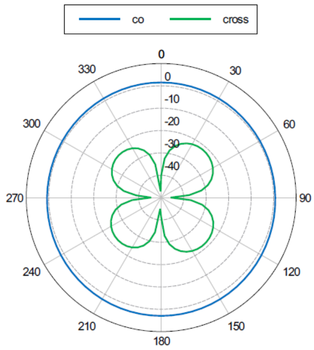

Figure 4.173: **H Plane Co and Cross Radiation Pattern of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna at 4.01GHz.**

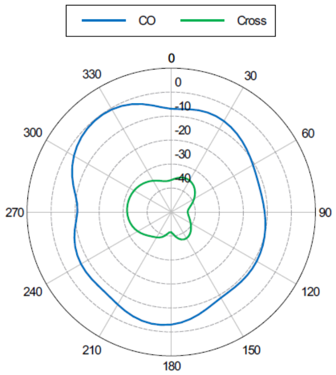

Figure 4.174: **E Plane Co and Cross Radiation Pattern of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna at 11.53GHz.**

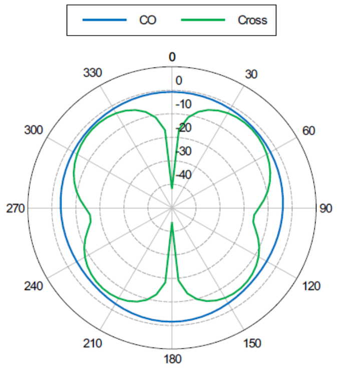

Figure 4.175: **H Plane Co and Cross Radiation Pattern of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna at 11.53GHz.**

For the resonance frequency 4.01 GHz the cross-polarization variations in E-Plane are less than -30dB, while for H-Plane it is -20dB. For the resonance frequency 11.53 GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is 0dB. The gain of the antenna is 2.95dBi at 4.01 GHz and 1.02dBi at 11.53GHz. The co polarizations is observed to be stable at the resonating frequencies 4.01 GHz, while it is slightly deviated at 11.53GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Lower corner rounded monopole rectangular microstrip patch antenna at the resonance frequencies 4.01GHz and 11.53 GHz are as shown in Figure 4.176 and Figure 4.177 respectively.

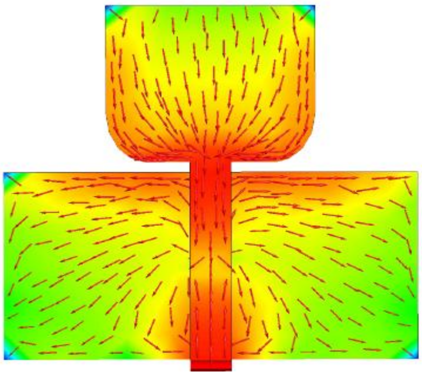

Figure 4.176: **Surface Current Distribution on Radiating Patch Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna at 4.01GHz.**

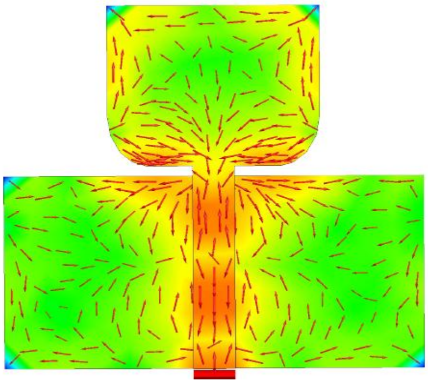

Figure 4.177: **Surface Current Distribution on Radiating Patch Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna at 11.53GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 4.01GHz, while for resonance frequency 11.53 GHz the flow of current is erratic over entire radiating patch. It is observed that at 11.53GHz current flow indicates, Transverse Electric (TE_{01}) mode is excited.

Impedance:

The plot of impedance vs frequency of the simulated Lower corner rounded monopole rectangular microstrip patch antenna at the resonance frequencies 4.01GHz and 11.53 GHz is shown in Figure 4.178.

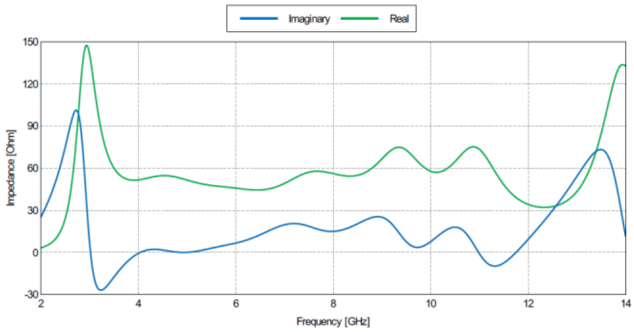

Figure 4.178: **Impedance Vs Frequency of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna.**

From the Figure 4.178 it is found that the impedance of the simulated antenna is 51.6-j0.478 ohm at resonance frequency 4.01GHz and 46.9-j6.83 ohm at resonance frequency 11.53GHz. The corresponding magnitudes of the impedances are |z| = 51.60 ohm and |z| = 47.39ohm for the resonating frequencies 4.01 GHz and 11.53 GHz respectively. It is observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequency at 4.01GHz.

Results of fabricated antenna:

The results of fabricated and simulated Lower corner rounded monopole rectangular microstrip patch antenna in terms of reflection coefficient Vs frequency is shown in Figure 4.179. The overall results of fabricated antenna and simulated antenna are nearly matching. The reflection coefficient of the fabricated antenna is found to be -33dB and -19dB which is not matching with the simulated results and resonance frequency is tuned at 4.35GHz and 7GHz which is also not matching with the simulated results. Reflection bandwidth is of 4.49GHz which is less than the simulated results. The comparative results of fabricated antenna and simulated Lower corner rounded monopole Rectangular Microstrip Patch Antenna in terms of reflection coefficient Vs frequency is shown in Figure 4.179.

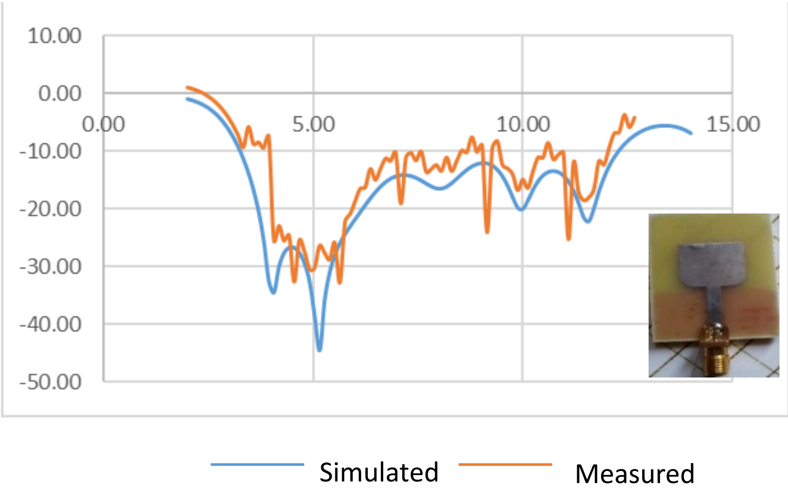

Fig.4.179: **Simulated and Measured Reflection Coefficient Vs Frequency of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna**

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the curve of the lower corners of the radiating patch is changed and the effect has been observed. For parametric analysis the curve of radiating patch of Lower corner rounded monopole rectangular microstrip patch antenna is increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.180 shows the results due to variation of curve radius.

Effect of change in radius of curve of lower corners of radiating patch:

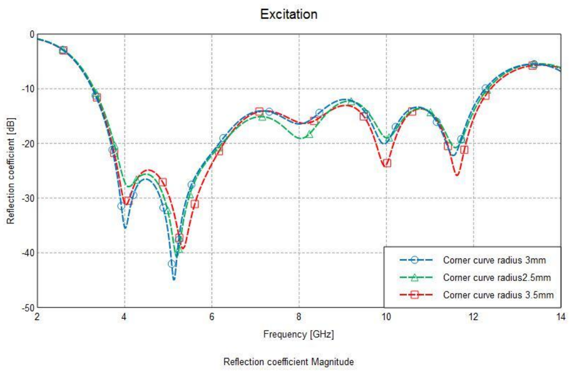

Figure 4.180: **Reflection Coefficient Vs Frequency of Lower Corner Rounded Monopole Rectangular Microstrip Patch Antenna for change in Curve radius.**

When radius of the curve of lower corners of radiating patch is decreased by an amount of 0.5 mm maintaining the length, width of the radiating patch and ground plane constant, the antenna resonates at frequencies, f_{r1} = 5.2GHz, f_{r2}= 11.69GHz and the corresponding reflection coefficients are -41dB and -21 GHz. The reflection bandwidth is 9.02GHz in the frequency band 3.31GHz-12.32GHz.

When radius of the curve of lower corners of radiating patch is increased by an amount of 0.5 mm maintaining the length, width of the radiating patch and ground plane constant, the antenna resonates at frequencies, f_{r1}= 5.33GHz, f_{r2}= 11.63GHz and the corresponding reflection coefficients are -39.28dB and -25.82dB. The reflection bandwidth is 9.11GHz in the frequency band 3.28GHz -12.38GHz.

This structure demonstrates appropriate matching for lower resonance, however at higher resonance it indicated poor matching.

Inference:

It is resonating at two frequencies and the bandwidth is improved from 5.03GHz to 9.06GHz. It has a moderate gain for the and stable radiation pattern.

4.14.3. Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground:

The Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground is designed at $L_p = 12.7mm, W_p = 15.2mm$, $L_{sub} = 39mm$, $W_{sub} = 30mm$, $F_l = 16.01mm$, $F_w = 3mm$, radius of ground curve $r_g = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground are shown in Figure 4.181 and 4.182 respectively.

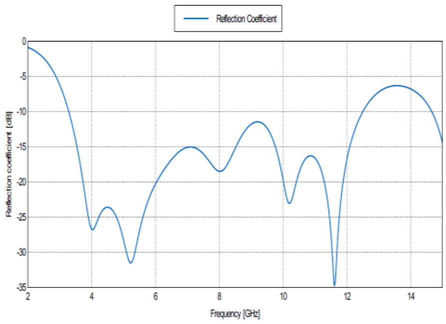

Figure 4.181: **Reflection Coefficient Vs Frequency and of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground.**

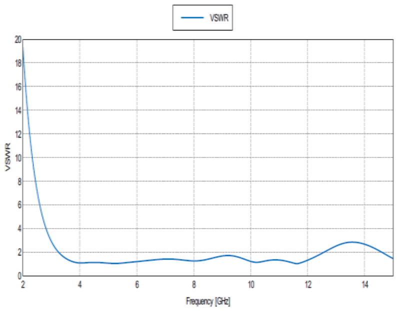

Figure 4.182: **VSWR Vs Frequency and of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground.**

From Figure 4.181 it is found that the Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1}= 5.22GHz, f_{r2}= 11.61GHz and the corresponding reflection coefficients are -31.53 dB, and -34.89 dB. The reflection bandwidth is 9.21GHz in the frequency band 3.28GHz-12.49GHz. From Figure 4.182 VSWR is observed below 2 in the frequency band 3.26GHz-12.57GHz and VSWR bandwidth is of 9.31GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 5.22GHz and 11.61GHz are shown in Figure 4.183 and 4.184 respectively.

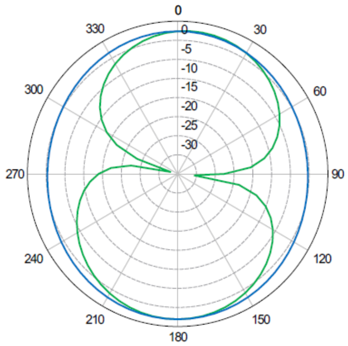

Figure 4.183: **Far Field Radiation Pattern of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 5.22GHz.**

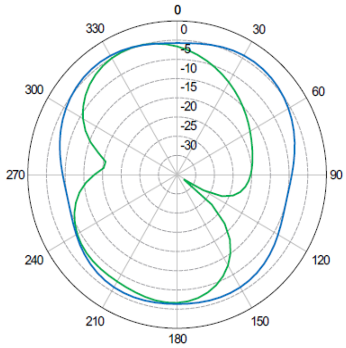

Figure 4.184: **Far Field Radiation Pattern of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 11.61GHz.**

It is observed that the gains of the Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground are 2.95dBi at frequency 5.22GHz and 1.01dBi at frequency 11.61GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 4.3GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 5.22GHz and 11.61GHz are shown in Figure 4.185 and Figure 4.187 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 5.22GHz and 11.61GHz are shown in Figure 4.186 and Figure 4.188 respectively.

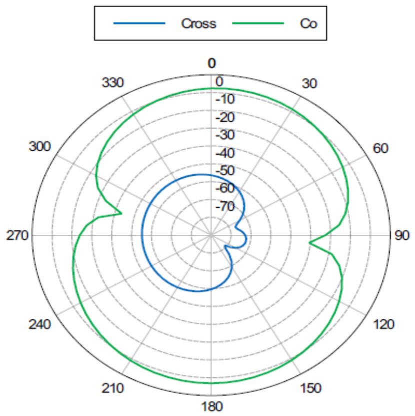

Figure 4.185: **E Plane Co and Cross Radiation Pattern of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 5.22GHz.**

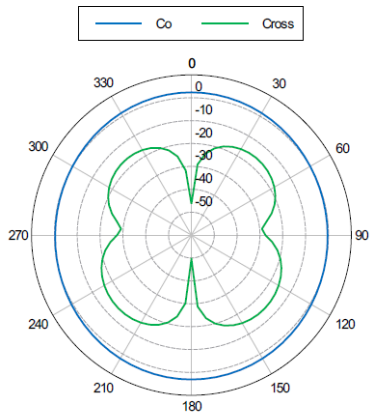

Figure 4.186: **H Plane Co and Cross Radiation Pattern of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 5.22GHz.**

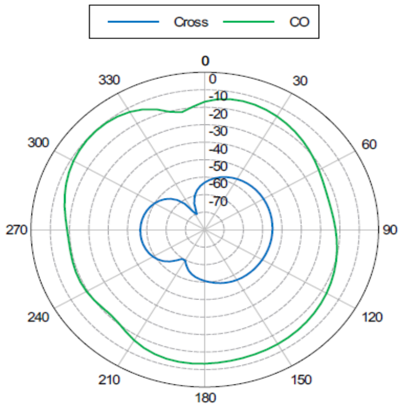

Figure 4.187: **E Plane Co and Cross Radiation Pattern of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 11.61GHz.**

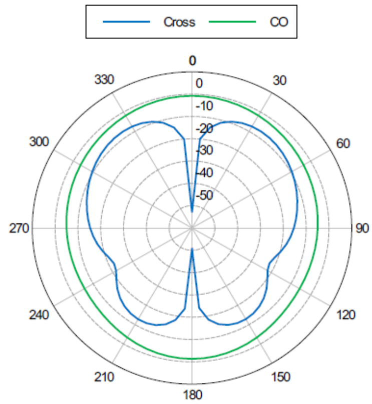

Figure 4.188: **H Plane Co and Cross Radiation Pattern of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 11.61GHz.**

For the resonance frequency 5.22 GHz the cross-polarization variations in E-Plane are less than -50dB, while for H-Plane it is -10dB. For the resonance frequency 11.61 GHz the cross-polarization variations in E-Plane are slightly less than -50dB, while for H-Plane it is -10dB. The gain of the antenna is 2.95dBi at 5.22 GHz and 1.01dBi at 11.61GHz. The co polarization is observed to be stable at the resonating frequency5.22GHz, while slightly deviated at 11.53GHzfrom ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 5.22GHz and 11.61GHz are as shown in Figure 4.189 and Figure 4.190 respectively.

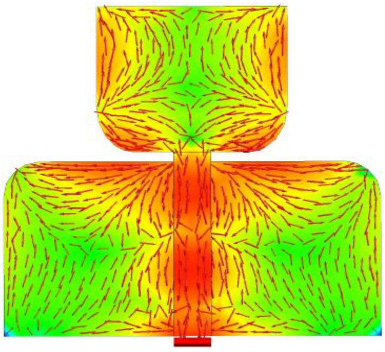

Figure 4.189: **Surface Current Distribution on Radiating Patch Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 5.22GHz.**

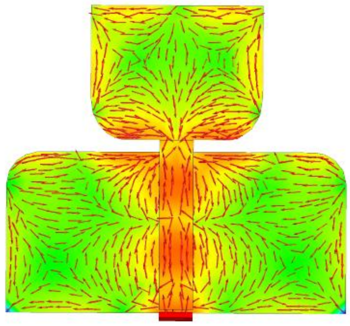

Figure 4.190: **Surface Current Distribution on Radiating Patch Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at 11.61GHz.**

It is observed that, Surface current is erratic in nature at resonance frequencies 5.22GHz and 11.61GHz, it is also observed that at frequency 5.22GHz TE_{01} mode is excited and at frequency 11.61GHz current flow indicates that TE_{11} mode is excited.

Impedance:

The plot of impedance vs frequency of the simulated Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 5.22GHz and 11.61 GHz is shown in Figure 4.191.

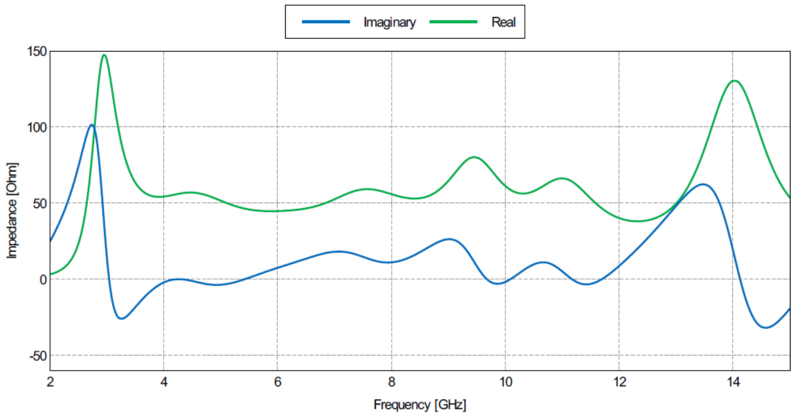

Figure 4.191: **Impedance Vs Frequency of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground.**

From the Figure 4.191 it is found that the impedance of the simulated antenna is 48.6- j2. 19ohm at resonance frequency 5.22GHz and 49.4-j1.71 ohm at resonance frequency 11.53GHz. The corresponding magnitudes of the impedances are |z| = 48.64 ohm and |z| = 49.42 ohm for the resonating frequencies 5.22 GHz and 11.61 GHz respectively.

It is observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value at resonance frequency 11.61GHz.

Parametric Analysis:

In Parametric analysis of this antenna, the length and width of the radiating patch is maintained constant and the radius of the curve of the lower corners of the radiating patch is changed and the effect has been observed. For parametric analysis the curve of radiating patch of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground is increased and decreased by an amount of 0.5mm independently and the plot of reflection coefficient vs frequency is plotted. Fig 4.192 shows the results due to variation in lengths and variation in widths.

Effect of change in curve's radius of lower corners of radiating patch:

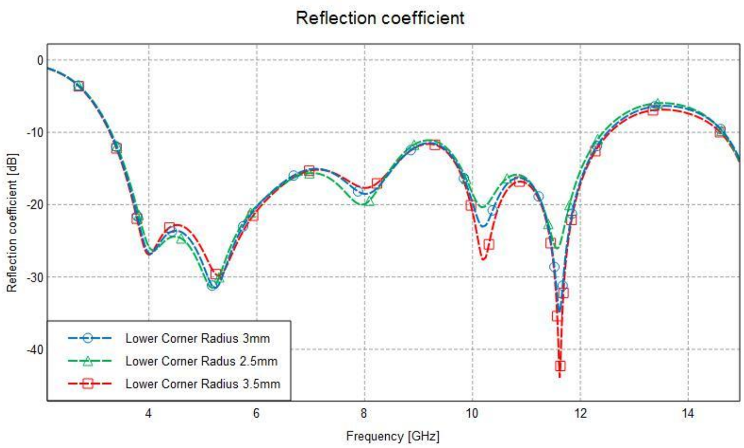

Figure 4.192: **Reflection Coefficient Vs Frequency of Lower Corner Rounded Patch Monopole Rectangular Microstrip Patch Antenna with Rounded Corner at Partial Ground for Width Change in Curve Radius of Corner.**

When radius of the curve of lower corners of radiating patch is decreased by an amount of 0.5 mm maintaining the other dimensions constant, the antenna resonates at frequencies, f_{r1}= 5.17GHz, f_{r2}= 11.56GHz and the corresponding reflection coefficients are -31.49dB and -26.02 GHz. The reflection bandwidth is 9.12GHz in the frequency band 3.29GHz-12.414GHz.

When radius of the curve of lower corners of radiating patch is increased by an amount of 0.5 mm maintaining the other dimensions constant, the antenna resonates at frequencies, f_{r1}= 5.25GHz, f_{r2}= 11.61GHz and the corresponding reflection coefficients are -29.81dB and -43.94dB. The reflection bandwidth is 9.27GHz in the frequency band 3.29GHz-12.5GHz.

Inference:

It is resonating at two frequencies and the bandwidth is improved from 9.06GHz to 9.31GHz. It has a moderate gain and stable radiation pattern.

4.14.4 Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground:

The Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground is designed at $L_p = 12.7mm$, $W_p = 15.2mm$, $L_{sub} = 39mm$, $W_{sub} = 30mm$, $F_l = 16.01mm$, $F_w = 3mm$, patch curve radius $r_p = 5mm$, ground curve radius $r_g = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna. The performance analysis of this antenna is not verified because from the earlier observations it is clear that the bandwidth of the antenna is improved by increasing the radius of the corner curves.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground are shown in Figure 4.193 and 4.194 respectively.

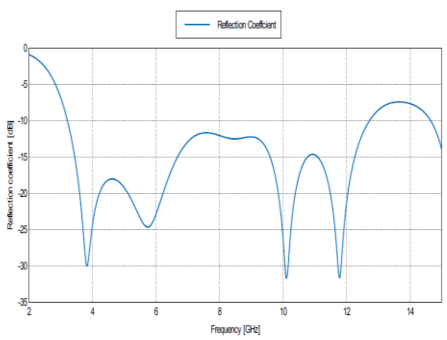

Figure 4.193: **Reflection Coefficient Vs Frequency and of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground.**

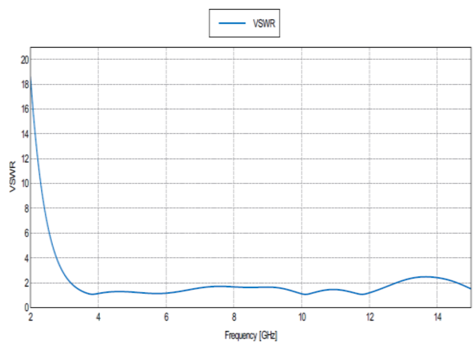

Figure 4.194: **VSWR Vs Frequency and of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground.**

From Figure 4.193 it is found that the Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1}= 3.82GHz, f_{r2}= 1 .77GHz and the corresponding reflection coefficients are -30 dB, and -31.67 dB. The reflection bandwidth is 9.51GHz in the frequency band 3.21GHz-12.72GHz. From Figure 4.194 VSWR is observed below 2 in the frequency band 3.19GHz-12.80GHz and VSWR bandwidth is of 9.61GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 3.82GHz and 11.77GHz are shown in Figure 4.195 and 4.196.

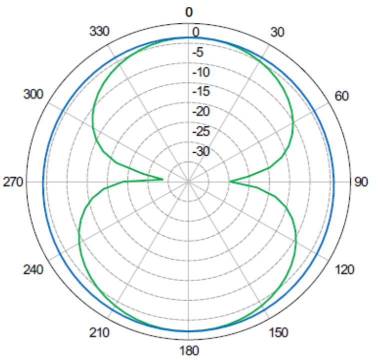

Figure 4.195: **Far Field Radiation Pattern of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 3.82GHz.**

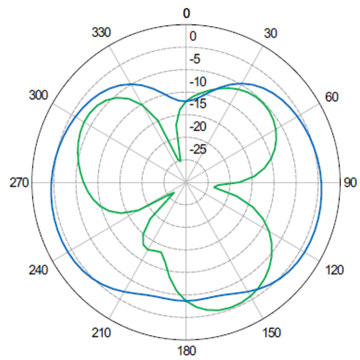

Figure 4.196: **Far Field Radiation Pattern of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 11.77GHz.**

It is observed that the gains of the Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground are 2.79dBi at frequency 3.82GHz and 1.03 dBi at frequency 11.77 GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.82 GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 3.82GHz and 11.77 GHz are shown in Figure 4.197 and 4.199. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 3.82GHz and 11.77GHz are shown in Figure 4.198 and Figure 4.200.

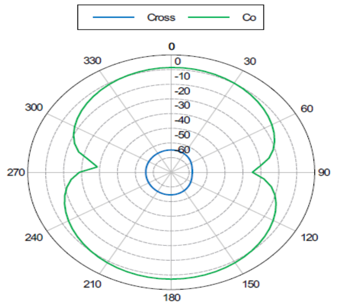

Figure 4.197**: E Plane Co and Cross Radiation Pattern of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 3.82GHz.**

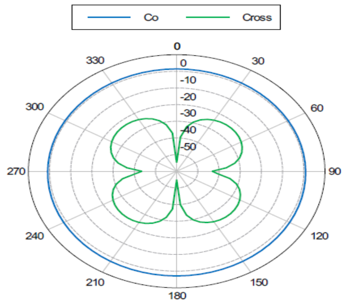

Figure 4.198: **H Plane Co and Cross Radiation Pattern of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 3.82GHz.**

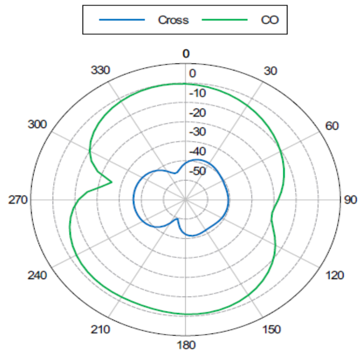

Figure 4.199: **E Plane Co and Cross Radiation Pattern of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 11.77GHz.**

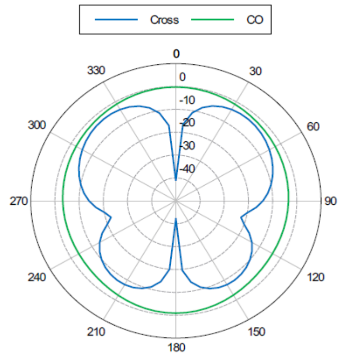

Figure 4.200: **H Plane Co and Cross Radiation Pattern of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 11.77GHz.**

For the resonance frequency 3.82 GHz the cross-polarization variations in E-Plane are less than -60dB, while for H-Plane it is -20dB.

For the resonance frequency 11.77 GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is 0dB. The gain of the antenna is 2.79dBi at 3.82 GHz and 1.03dBi at 11.77GHz. The co polarizations are observed to be stable at the resonating frequency 3.82 GHz, while it is slightly deviated at 11.77GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded

Corner at Partial Ground at the resonance frequencies 3.82GHz and 11.77 GHz are as shown in Figure 4.201 and 4.202.

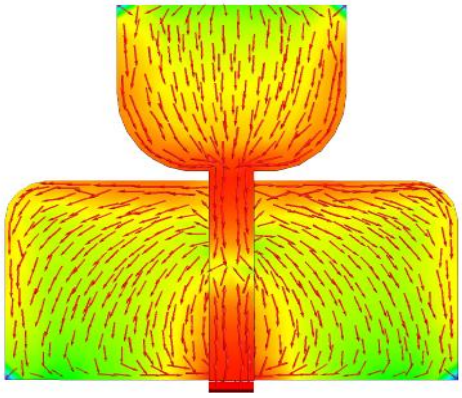

Figure 4.201: **Surface Current Distribution on Radiating Patch Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 3.82GHz.**

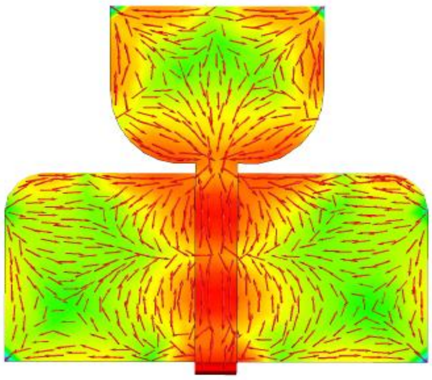

Figure 4.202: **Surface Current Distribution on Radiating Patch Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at 11.77GHz.**

It is observed that, Surface current is linear at resonance frequency3.82GHz, while for resonance frequency 11.77 GHz the flow of current is in erratic over entire radiating patch. It is observed that at frequency 11.77GHz current flow indicates TE_{11} mode is excited.

Impedance:

The plot of impedance vs frequency of the simulated Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground at the resonance frequencies 3.82GHz and 11.77 GHz is shown in Figure 4.203.

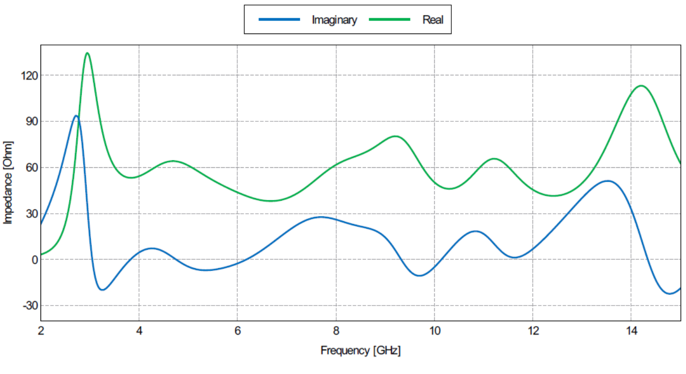

Figure 4.203: **Impedance Vs Frequency of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground.**

From the Figure 4.203 it is found that the impedance of the simulated antenna is 53.3-j0.1897ohm at resonance frequency 3.82GHz and 48.1-j1.7ohm at resonance frequency 11.77GHz. The corresponding magnitudes of the impedances are |z| = 53.3ohm and |z| = 48.13ohm for the resonating frequencies 3.82 GHz and 11.77 GHz respectively. It is also observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequency at 3.82GHz.

Results of fabricated antenna:

The reflection coefficient of the fabricated antenna is observed to be -30dB and -28dB which is not matching with the simulated results, resonance frequency is tuned at 3.78GHz and 11.48GHz, which is not matching with the simulated results. Reflection bandwidth of 8.14GHz which is matching with simulated results. The comparative results of fabricated antenna and simulated Simple Monopole Rectangular Microstrip Patch Antenna in terms of reflection coefficient Vs frequency is shown in Figure 4.204. Estimation is completed utilizing Rohde and Schwarz ZVL Network Analyser, Resonance band frame begins resonating from 3.58GHz and at higher side up to 11.72GHz, and total bandwidth is of 8.14GHz, and it demonstrates good agreement with simulated results.

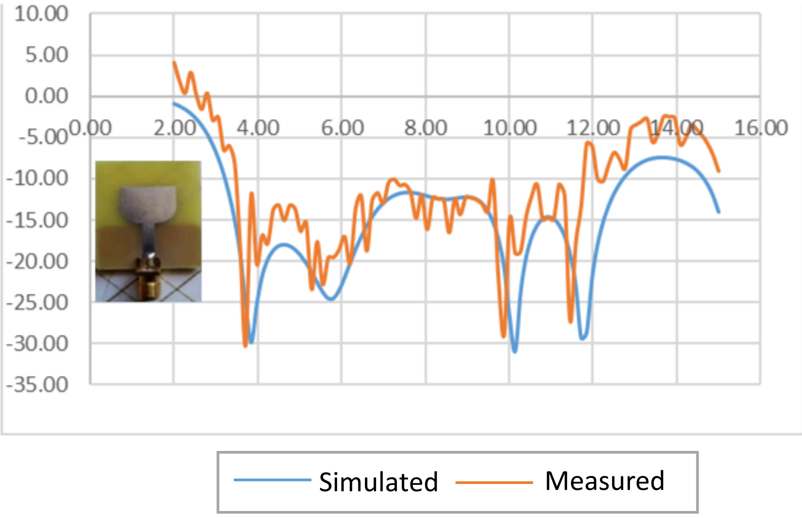

Fig. 4.204: **Simulated and Measured Reflection Coefficient Vs Frequency of Modified Lower Corner Rounded Patch Monopole Rectangular Microstrip patch Antenna with Rounded Corner at Partial Ground.**

Inference:

It is resonating at two frequencies and the bandwidth is improved from 9.31GHz to 9.61GHz. It has a moderate gain, stable radiation pattern and more smoothness of surface current.

4.14.5 Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground:

The Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground is designed at $L_p = 12.7mm$, $W_p = 15.2mm$, $L_{sub} = 39mm$, $W_{sub} = 30mm$, $F_l = 16.01mm$, $F_w = 3mm$. $r_p = 5mm$, $r_g = 3mm$, $r_p = 5mm$, $W_v = 1mm$, $L_v = 5mm$, $W_h = 10mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Modified Lower corner rounded monopole rectangular microstrip patch antenna with rounded corner in partial ground are shown in Figure 4.205 and Figure 4.206 respectively.

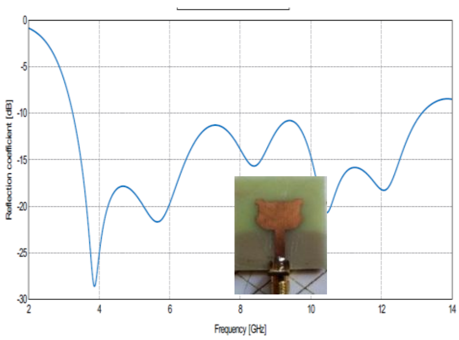

Figure 4.205: **Reflection Coefficient Vs Frequency and of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

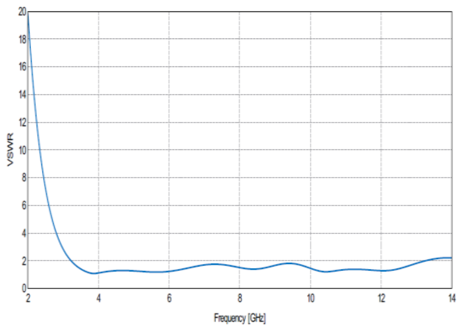

Figure 4.206: **VSWR Vs Frequency and of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

From Figure 4.205 it is found that the Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1} =3.86GHz, f_{r2}= 10.44GHz and the corresponding reflection coefficients are -28.62 dB, and -20.74 dB. The reflection bandwidth is 9.90GHz in the frequency band 3.25GHz -13.14GHz. From Figure 4.206 VSWR is observed below 2 in the frequency band 3.22GHz-13.25GHz and VSWR bandwidth is of 10.05GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.86GHzand 10.44GHz are shown in Figure 4.207 and 4.208 respectively.

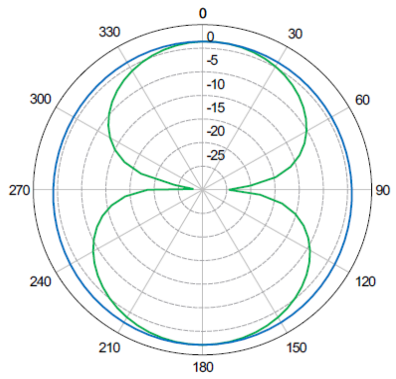

Figure 4.207**: Far field radiation pattern of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.86GHz.**

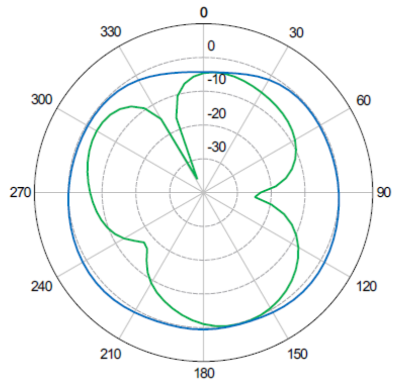

Figure 4.208: **Far field radiation pattern of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.at 10.44GHz.**

It is observed that the gains of the Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground are 2.87dBi at frequency 3.86GHz and 1.57dBi at frequency 10.44GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.86GHz and more deviating at frequency10.44GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.86GHz and 10.44GHz are shown in Figure 4.209 and Figure 4.211. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.86GHz and 10.44GHz are shown in Figure 4.210 and Figure 4.212.

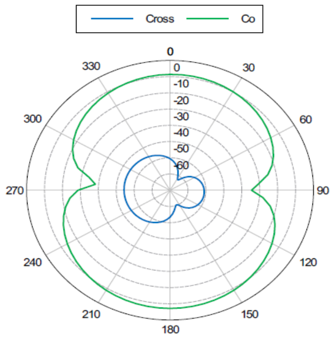

Figure 4.209: **E Plane Co and Cross Radiation Pattern of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.86GHz.**

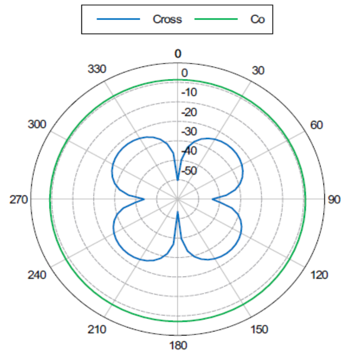

Figure 4.210: **H Plane Co and Cross Radiation Pattern of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.86GHz.**

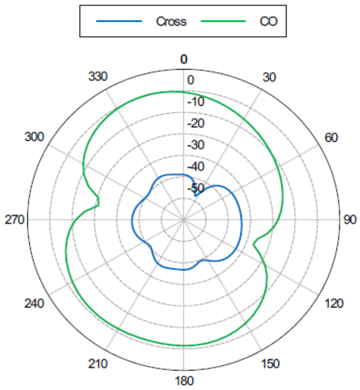

Figure 4.211: **E Plane Co and Cross Radiation Pattern of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.44GHz.**

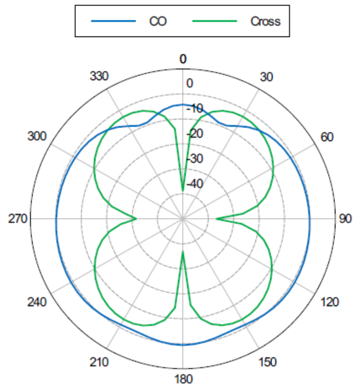

Figure 4.212: **H Plane Co and Cross Radiation Pattern of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.44GHz.**

For the resonance frequency 3.86 GHz the cross-polarization variations in E-Plane are less than -50dB, while for H-Plane it is -20dB. For the resonance frequency 10.44 GHz the cross-polarization variations in E-Plane are slightly less than -30d, while for H-Plane it is 0dB.

The gains of the antenna are 2.87dBi at 3.86 GHz and 1.57dBi at 10.44GHz. The co polarizations are observed to be stable at the resonating frequency3.86 GHz, while it is slightly deviated at 10.44GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial

Ground at the resonance frequencies 3.86 GHz and 10.44 GHz are as shown in Figure 4.213 and Figure 4.214 respectively.

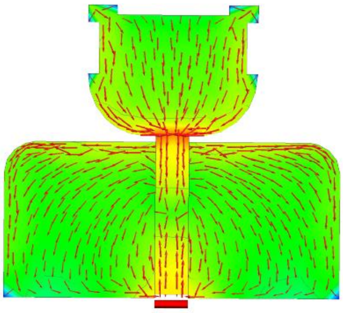

Figure 4.213: **Surface Current Distribution on Radiating Patch Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.86GHz.**

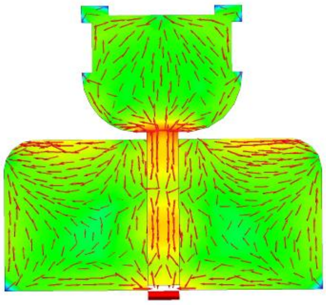

Figure 4.214: **Surface Current Distribution on Radiating Patch Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.44GHz.**

It is observed that, Surface current is linearly distributed at resonance frequencies 3.86GHz while for resonance frequency 10.44 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.86GHz and 10.44 GHz is shown in Figure 4.215.

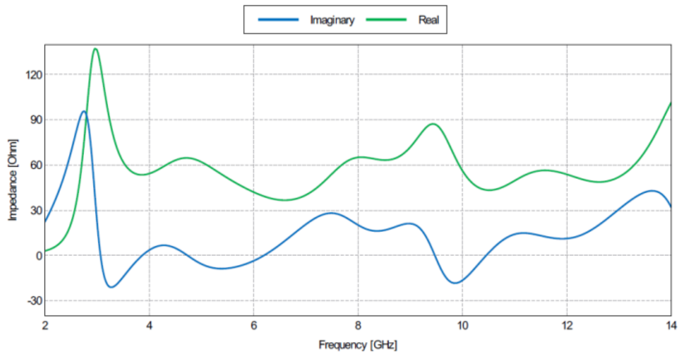

Figure 4.215: **Impedance Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

From the Figure 4.215 it is found that the impedance of the simulated antenna is 53.5-j0.14ohm at resonance frequency 3.86GHz and 43.6-j0.937ohm at resonance frequency 10.44GHz. The corresponding magnitudes of the impedances are |z| = 53.5ohm and |z| = 43.61ohm for the resonating frequencies 3.86 GHz and 10.44 GHz respectively. It is also observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value at resonance frequency 3.86GHz.

Results of the fabricated antenna:

The reflection coefficient of the fabricated antenna is observed to be -24dB and -21dB which is not matching with the simulated results, resonance frequency is tuned at 4.38GHz and 10.01GHz which is not matching with the simulated results. Reflection bandwidth is of 9.09GHz which is not match with simulated results. The comparative results of fabricated antenna and simulated Antenna in terms of reflection coefficient Vs frequency is shown in Figure 4.216. Resonance band frame starts at 3.58GHz and it is up to higher resonance of 12.67GHz, total bandwidth is of 9.09GHz and it is matching with simulated results.

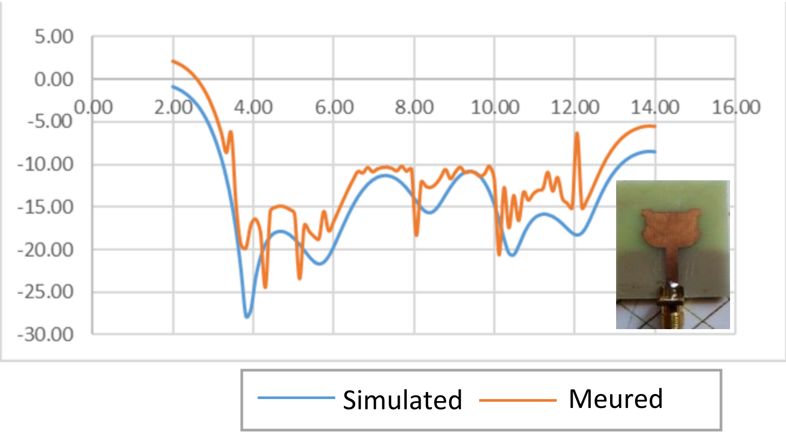

Figure 4.216: **Simulated and Measured Reflection Coefficient Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

Parametric analysis:

In Parametric analysis of this antenna, the shape of original Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground has been changed by expanding two notches at the sides and one notch at the top of the antenna. The length and width of the notches at the sides, top of the antenna have been changed independently keeping the radius of the circle's constant at two lower corners of the antenna, which indirectly create curve shape at the bottom and the effect has been observed. The plot of reflection coefficient vs frequency for change in length and width of vertical notches are shown in the Figure 4.217, 4.218 respectively, and for the change in length and width of a horizontal notch are shown in Figure 4.219 and 4.220 respectively. For Further analysis, the ground gap has been changed and effects are observed which is shown in Figure 4.221.

Effect of change in Vertical notches length and width:

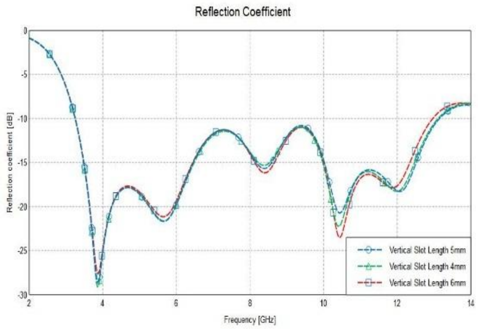

Figure 4.217: **Reflection Coefficient Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground for Vertical Slot Length Changed**.

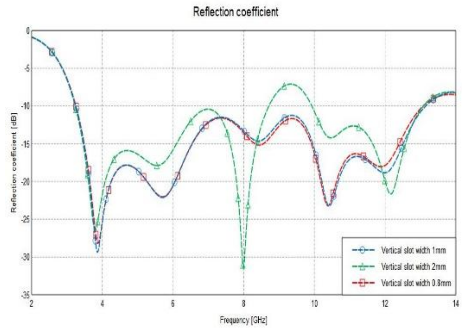

Figure 4.218: **Reflection Coefficient Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground for Vertical Slot Width Changed**.

When length of the vertical notches is decreased by an amount of 1mm, maintaining the width of the vertical notch constant, the antenna resonates at frequencies f_{r1}= 3.86GHz, f_{r2}= 10.40GHz, and the corresponding reflection coefficients are -29.16dB and -22.29dB. The reflection bandwidth is 9.86GHz in the frequency band 3.25GHz-13.18GHz.

When the length of the vertical notch is increased by an amount of 1mm, maintaining the width of the horizontal notch constant, the antenna resonates at frequencies f_{r1}=3.87GHz, fr2=10.43GHz and the corresponding reflection coefficients are -78.65dB and -23.54dB. The reflection bandwidth is 9.87GHz in the frequency band 3.27GHz-13.14GHz.

When the width of the horizontal notch is decreased by an amount of 1mm, maintaining the length of the horizontal notch constant, the antenna resonates at frequencies f_{r1}= 3.85GHz, f_{r2}= 10.41GHz and the corresponding reflection coefficients are -27.48dB and -20.42dB. The reflection bandwidth is 9.71GHz in the frequency band 3.26GHz-12.97GHz.

When the width of the horizontal notch is increased by an amount of 1mm, maintaining the length of the horizontal notch constant, the antenna resonates at frequencies f_{r1}=7.99Hz, f_{r2}= 12.16GHz and the corresponding reflection coefficients are -31.51dB and -21.63dB. The reflection bandwidth is 5.48GHz and 3.15GHz in the frequency bands 3.23GHz-8.71GHz, 9.93GHz-13.08GHz respectively.

Effect of change in horizontal notch length and width:

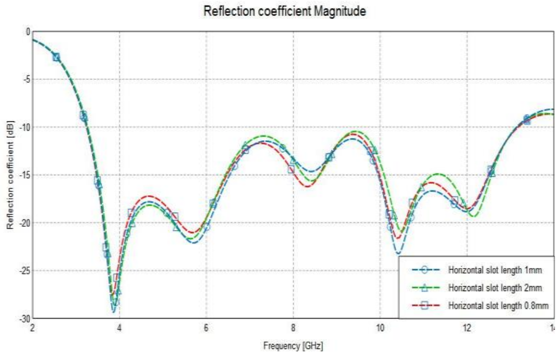

Figure 4.219: **Reflection Coefficient Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground for Horizontal Slot Length Changed.**

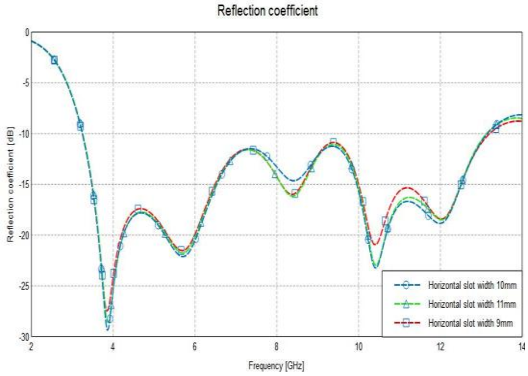

Figure 4.220: **Reflection Coefficient Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground for Horizontal Slot Width Changed**.

When length of the horizontal notch is decreased by an amount of 0.2mm, maintaining the width of the horizontal notch constant, the antenna resonates at frequencies f_{r1}= 3.84GHz, f_{r2}= 10.47GHz, and the corresponding reflection coefficients are -27.61dB and -21.67dB. The reflection bandwidth is 9.94GHz in the frequency band 3.24GHz-13.18GHz.

When the length of the horizontal notch is increased by an amount of 1mm, maintaining the width of the horizontal notch constant, the antenna resonates at frequencies f_{r1}=3.89GHz, f_{r2}= 10.49GHz and the corresponding reflection coefficients are -28.68dB and -20.88dB. The reflection bandwidth is 9.87GHz in the frequency band 3.27GHz-13.14GHz.

When the width of the horizontal notch is decreased by an amount of 1mm, maintaining the length of the horizontal notch constant, the antenna resonates at frequencies, f_{r1}=3.85GHz, f_{r2}= 10.41GHz and the corresponding reflection coefficients are -27.48dB and -20.42dB. The reflection bandwidth is 9.95GHz in the frequency band 3.25GHz-13.20GHz.

When the width of the horizontal notch is increased by an amount of 1mm, maintaining the length of the horizontal notch constant, the antenna resonates at frequencies f_{r1}=3.87GHz, f_{r2}= 10.42GHz and the corresponding reflection coefficients are -28.68dB and -22.99dB. The reflection bandwidth is 9.87GHz in the frequency band 3.26GHz-13.13GHz.

Effect of change in ground gap:

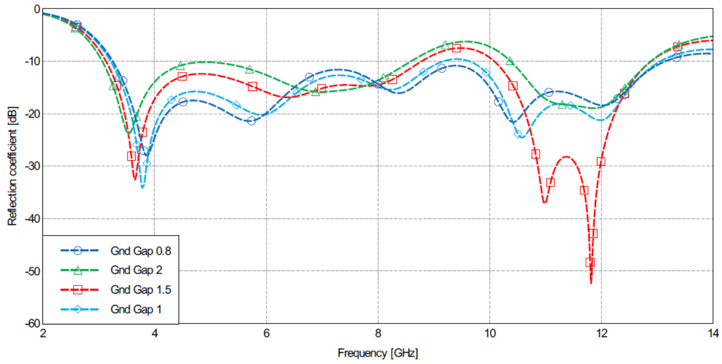

Figure 4.221: **Reflection Coefficient Vs Frequency of Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground for Ground Gap Changed**.

When gap between radiating patch and partial ground is increased by an amount of 0.2mm maintaining the other dimensions constant, the antenna resonates at frequencies f_{r1}= 3.42GHz, f_{r2}= 10.46GHz and the corresponding reflection coefficients are -35.85dB and -24.85dB. The reflection bandwidths are 5.96GHz and 3.42GHz in the frequency band of 3.21GHz - 9.17GHz, 9.64GHz - 13.06GHz respectively.

When gap between radiating patch and partial ground is increased by an amount of 0.7mm maintaining the other dimensions constant, the antenna resonates at frequencies f_{r1}= 3.46GHz, f_{r2}= 11.86GHz and the corresponding reflection coefficients are -32.14dB and -53.12dB. The reflection bandwidths are5.65GHz and 2.5GHz in the frequency bands 3.13GHz - 8.78GHz, 10.09GHz - 12.9GHzrespectively.

When gap between radiating patch and partial ground is increased by an amount of 1.2 mm maintaining the other dimensions constant, the antenna resonates at frequencies f_{r1}= 3.17GHz, f_{r2}=12GHz and the corresponding reflection coefficients are -23.82dB and -21.79dB. The reflection bandwidths are 5.53GHz and 2.5GHz in the frequency bands 3.06GHz - 8.59GHz, 10.39GHz - 12.89GHzrespectively.

Inference:

It is resonating at two frequencies and the bandwidth is up to 10.05GHz. It has a moderate gain, slightly degraded radiation pattern and more smoothness of surface current.

4.14.6. Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground:

The Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground is designed at $L_p = 12.7mm$, $W_p = 15.2mm$, $L_{sub} =$

$39mm$, $W_{sub} = 30mm$, $F_l = 16.01mm$, $F_w = 3mm$. $r_p = 5mm$, $r_g = 3mm$, $W_v = 1mm$, $L_v = 5mm$, $W_h = 10mm$, $L_h = 1mm$, $L_s = 2mm$, $W_h = 10mm$, $W_s = 1mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground are shown in Figure 4.222 and 4.223 respectively.

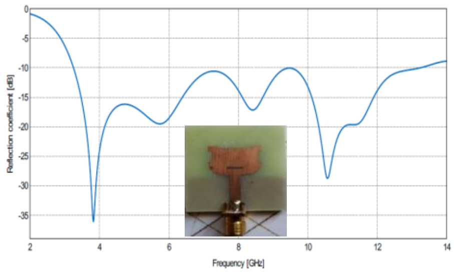

Figure 4.222: **Reflection Coefficient Vs Frequency and of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

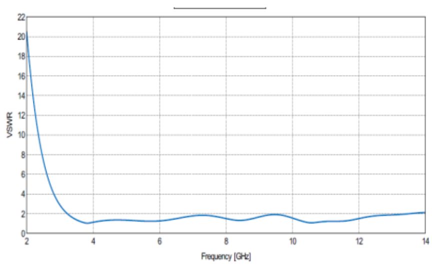

Figure 4.223: **VSWR Vs Frequency and of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

From Figure 4.222 it is found that the Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1}= 3.82GHz, f_{r2}=10.57GHz and the corresponding reflection coefficients are -36.13 dB and -28.7 dB. The reflection bandwidth is 9.98GHz in the frequency band 3.22GHz -13.2GHz. From Figure 4.223 VSWR is observed below 2 in the frequency band 3.22GHz - 13.51GHz and VSWR bandwidth is of 10.29GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.82GHz and 10.57GHz are shown in Figure 4.224 and Figure 4.225 respectively.

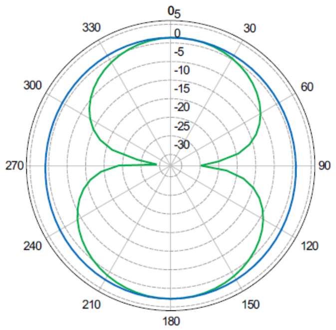

Figure 4.224: **Far Field Radiation Pattern of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.82GHz.**

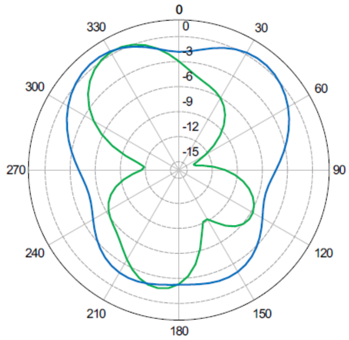

Figure 4.225: **Far Field Radiation Pattern of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.57GHz.**

It is observed that the gains of the Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground are 2.81dBi at 3.82GHz and 1.12dBi at 10.57GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.82GHz and more deviating at frequency10.57GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.82GHz and 10.57 GHz are shown in Figure 4.226 and 4.228. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.82GHz and 10.57GHz are shown in Figure 4.227, 4.229.

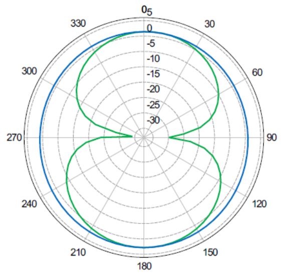

Figure 4.226: **E Plane Co and Cross Radiation Pattern of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.82GHz.**

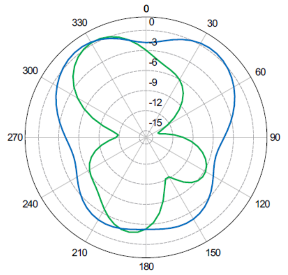

Figure 4.227: **H Plane Co and Cross Radiation Pattern of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.82GHz.**

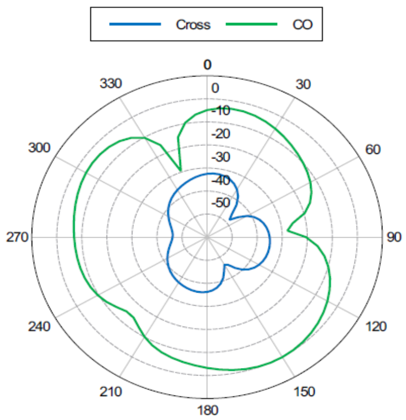

Figure 4.228: **E Plane Co and Cross Radiation Pattern of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.57GHz.**

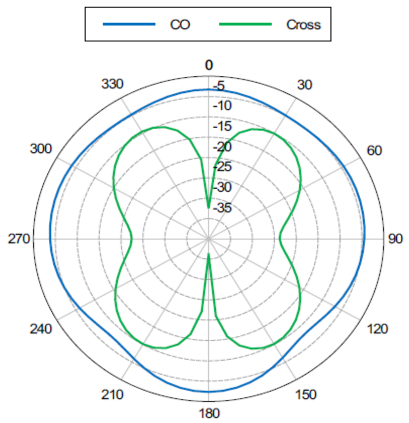

Figure 4.229: **H Plane Co and Cross Radiation Pattern of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.57GHz.**

For the resonance frequency 3.82 GHz the cross-polarization variations in E-Plane are less than -30dB, while for H-Plane it is -10dB. For the resonance frequency 10.57GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is -10dB.

The gain of the antenna is 2.81dBi at the frequency 3.82 GHz and 1.12dBi at the frequency 10.57GHz. The co polarizations are observed to be stable at the resonating frequency 3.86 GHz, while it is slightly deviated at the frequency 10.44GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated at the resonance frequencies 3.82 GHz and 10.57 GHz are as shown in Figure 4.230 and 4.231 respectively.

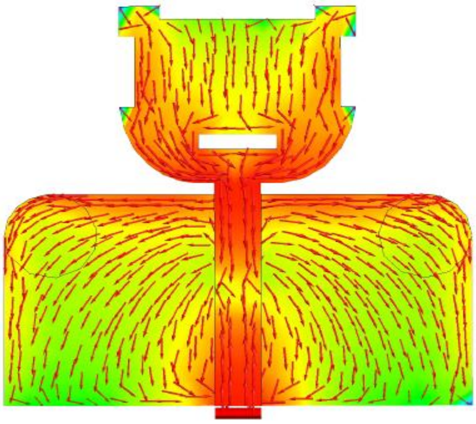

Figure 4.230: **Surface Current Distribution on Radiating Patch Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 3.82GHz.**

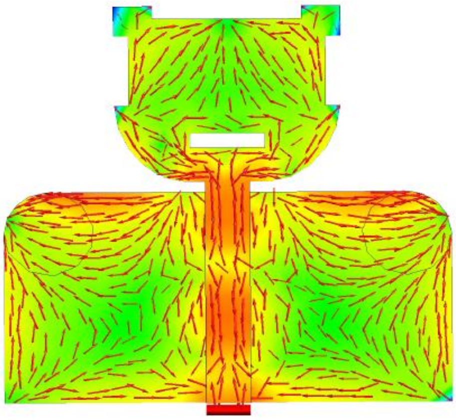

Figure 4.231: **Surface Current Distribution on Radiating Patch Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at 10.57GHz.**

It is observed that, Surface current is linearly distributed at resonance frequencies 3.82GHz while for resonance frequency 10.57 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground at the resonance frequencies 3.82GHz and 10.57 GHz are shown in Figure 4.232.

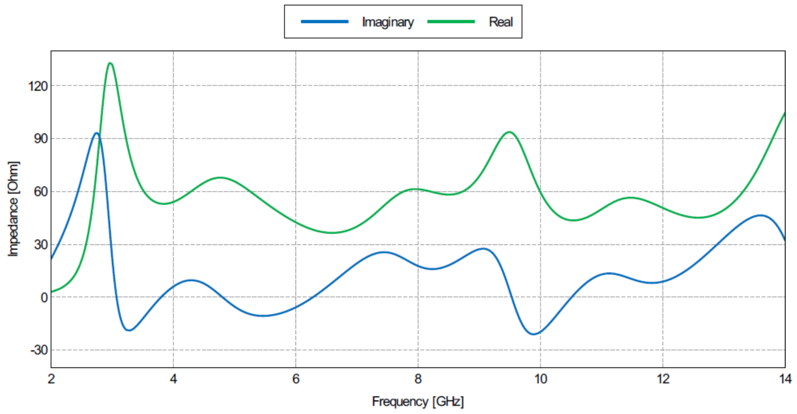

Figure 4.232: **Impedance Vs Frequency of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

From the Figure 4.232 it is found that the impedance of the simulated antenna is 53.1 + j1.51 ohm at resonance frequency 3.82GHz and 43.6 + j2.14 ohm at resonance frequency 10.57GHz. The corresponding magnitudes of the impedances are |z| = 53.12ohm and |z| = 43.65ohm.

It is observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value at resonance frequency 3.82GHz.

Results of Fabricated antenna:

The reflection coefficient of the fabricated antenna is observed to be -27dB and -25dB which is not matching with the simulated results, resonance frequency is tuned at 4.1GHz and 10.64GHz which is not matching with the simulated results as shown in Figure 4.233. Reflection bandwidth is of 8.06GHz which is not matching with simulated results. It is due to the slight variations in the dimensions of the slots in the fabricated antenna compared with dimension used in simulated antenna.

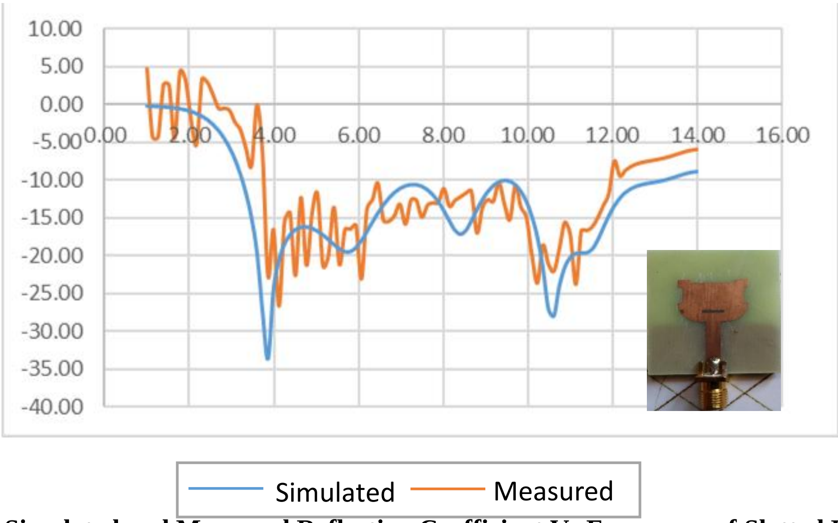

Fig.4.233: **Simulated and Measured Reflection Coefficient Vs Frequency of Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner in Partial Ground.**

Inference:

It is resonating at two frequencies and the bandwidth is improved from10.05GHz to 10.29GHz. It has a moderate gain, improved radiation pattern and the concentration of surface current at the center part is distributed.

4.14.7. Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground:

The Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground is designed at $L_p = 12.7mm$,$W_p = 15.2mm$, $L_{sub} = 39mm$, $W_{sub} = 30mm$, $F_l = 16.01mm$, $F_w = 3mm$, $r_p = 5mm$, $r_g = 3mm$, $W_v = 1mm$, $L_v = 5mm$, $W_h = 10mm$, $L_h = 1mm$, $L_x = 2mm$, $L_y = 1mm$, $W_s = 1mm$.It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here. The partial parametric analysis of this antenna is already covered in previous design and the partial analysis by changing the position of the slot is discussed in the design to follow and hence the parametric analysis of the antenna is needless to be discussed here.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground is shown in Figure 4.234 and 4.235 respectively.

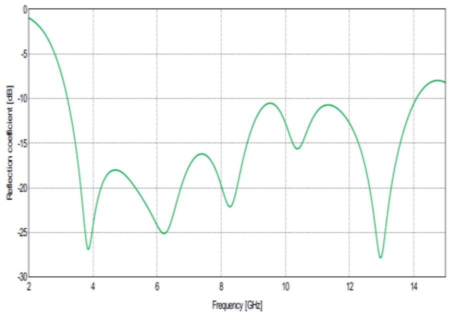

Figure 4.234: **Reflection Coefficient Vs Frequency and of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground.**

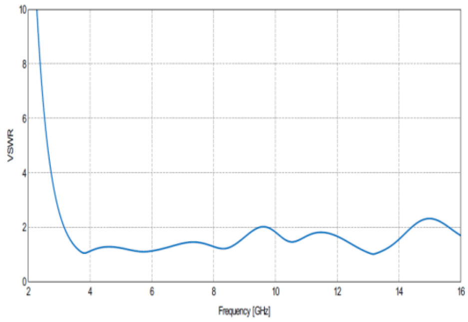

Figure 4.235: **VSWR Vs Frequency and of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground.**

From Figure 4.234 it is found that the Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1}=3.85GHz, f_{r2}=12.97GHz and the corresponding reflection coefficients are -26.91dB and - 27.89dB. The reflection bandwidth is 10.87GHz in the frequency band 3.25GHz-13.14GHz. From Figure 4.235 VSWR is observed below 2 in the frequency band 33.16GHz-14.5GHz and VSWR bandwidth is 11.34GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at the resonance frequencies 3.85GHz and 12.97GHz are shown in Figure 4.236 and 4.237 respectively.

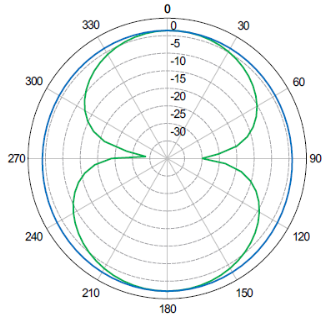

Figure 4.236: **Far Field Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 3.85GHz.**

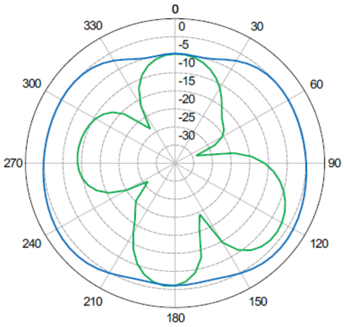

Figure 4.237: **Far Field Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 12.97GHz.**

It is observed that the gains of the Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground are 2.84dBi at frequency 3.85GHz and 1.71dBi at frequency 12.97GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.85GHz and more deviating at frequency 12.97GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at the resonance frequencies 3.85GHz and 12.97 GHz are shown in Figure 4.238 and 4.240 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at the resonance frequencies 3.85GHz and 12.97GHz are shown in Figure 4.239 and 4.241 respectively.

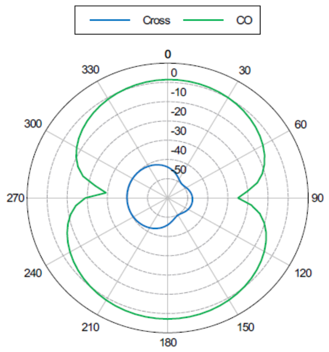

Figure 4.238: **E Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 3.85GHz.**

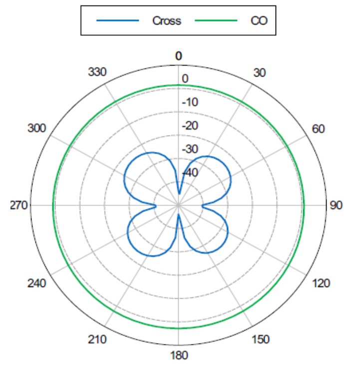

Figure 4.239: **H Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 3.85GHz.**

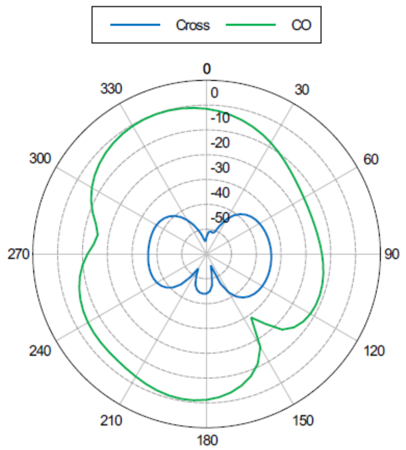

Figure 4.240: **E Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 12.97GHz.**

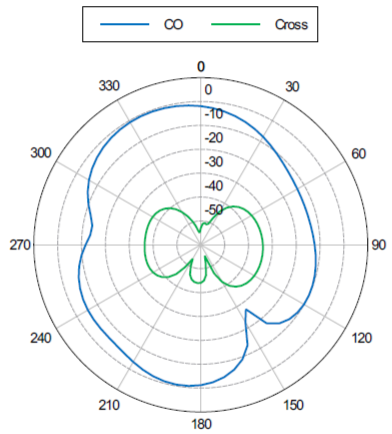

Figure 4.241: **H Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 12.97GHz.**

For the resonance frequency 3.85 GHz the cross-polarization variations in E-Plane are less than -40dB, while for H-Plane it is -20dB. For the resonance frequency 12.97GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is -30dB.

The gains of the antenna are 2.84dBi at frequency 3.85 GHz and 1.71dBi at frequency 12.97GHz. The co polarizations are observed to be stable at the resonating frequency3.85 GHz, while it is slightly deviated at frequency 12.97GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at the resonance frequencies 3.85 GHz and 12.97 GHz are as shown in Figure 4.242 and 4.243 respectively.

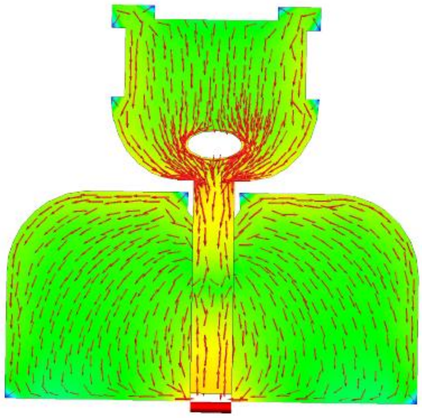

Figure 4.242**: Surface Current Distribution on Radiating Patch Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 3.85GHz.**

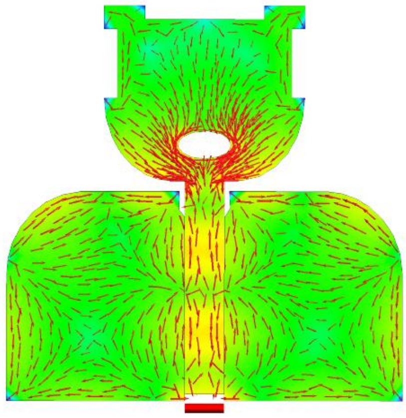

Figure 4.243: **Surface Current Distribution on Radiating Patch Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at 12.97GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 3.85GHz while for resonance frequency 12.97 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground at the resonance frequencies 3.85GHz and 12.97 GHz is shown in Figure 4.244.

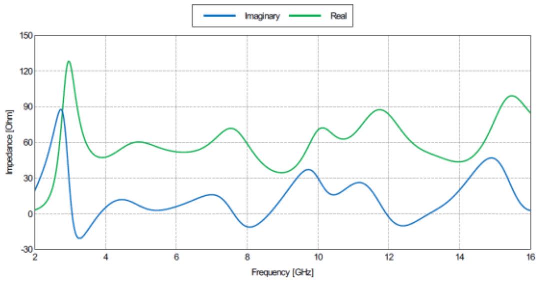

Figure 4.244**: Impedance Vs Frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Half Circle Notch in Partial Ground.**

From the Figure 4.244 it is found that the impedance of the simulated antenna is 47.3+j0.524 ohm at resonance frequency 3.85GHz and 53.81-j2.857ohm at resonance frequency 12.97GHz. The corresponding magnitudes of the impedances are |z| = 47.3ohm and |z| = 53.88 ohm for the resonating frequencies 3.85 GHz and 12.97 GHz. It is observed that the impedance goes on decreasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequencies at 3.85GHz.

Inference:

It is resonating at two frequencies and the bandwidth is improved from 11.34GHz to 11.37GHz. It has a moderate gain; improved radiation pattern and impedance is near to the ideal value.

4.14.8. Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground:

The Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground is designed at $L_p = 12.7mm$, $W_p = 15.2mm$, $L_{sub} = 39mm$, $W_{sub} = 30mm$, $F_l = 16.01mm$, $F_w = 3mm$. $r_p = 5mm$, $r_g = 3mm$, $W_v = 1mm$, $L_v = 5mm$, $W_h = 10mm$, $L_h = 1mm$, $L_x = 2mm$, $L_y = 1mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground are shown in Figure 4.245 and 4.246 respectively.

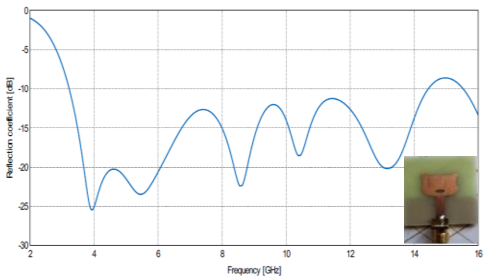

Figure 4.245: **Reflection Coefficient Vs Frequency and of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

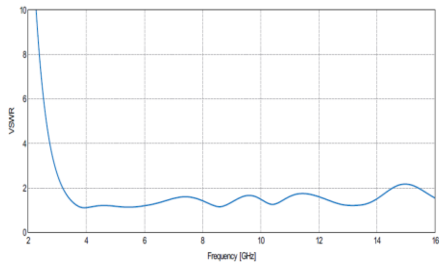

Figure 4.246: **VSWR Vs Frequency and of Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

From Figure 4.245 it is found that the Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1} =3.93GHz, f_{r2} =13.15GHz and the corresponding reflection coefficients are - 25.48dB and - 20.19dB. The reflection bandwidth is 11.22GHz in the frequency band 3.22GHz-14.44GHz. From Figure 4.246 VSWR is observed below 2 in the frequency band 3.19GHz-14.56GHz and VSWR bandwidth is of 11.37GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.93GHz and 13.15GHz are shown in Figure 4.247 and 4.248 respectively.

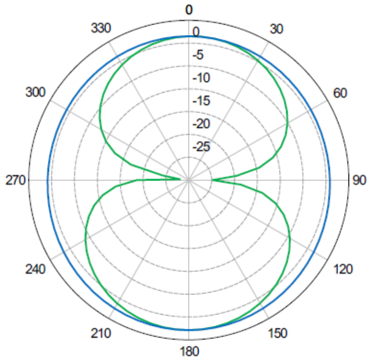

Figure 4.247: **Far Field Radiation Pattern of Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.93GHz.**

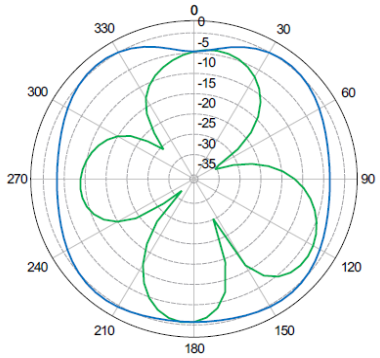

Figure 4.248: **Far Field Radiation Pattern of Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 13.15GHz.**

It is observed that the gains of the Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground are 2.88dBi at frequency 3.93GHz and 0.85dBi at frequency 13.15GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.93GHz and more deviating at frequency13.15GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.93GHz and 13.15 GHz are shown in Figure 4.249 and 4.251. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.93GHz and 13.15GHz are shown in Figure 4.250 and 4.252 respectively.

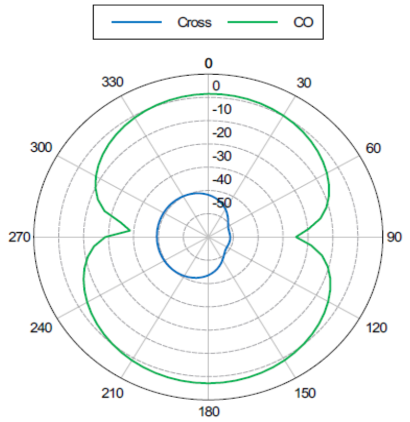

Figure 4.249**: E Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.93GHz.**

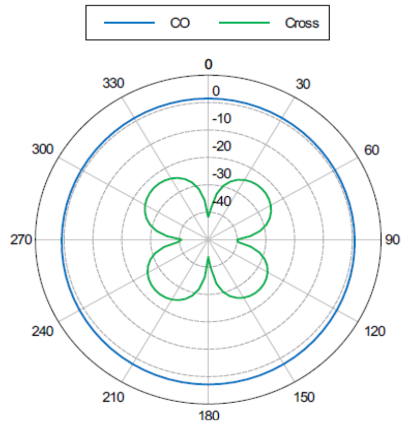

Figure 4.250: **H Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.93GHz.**

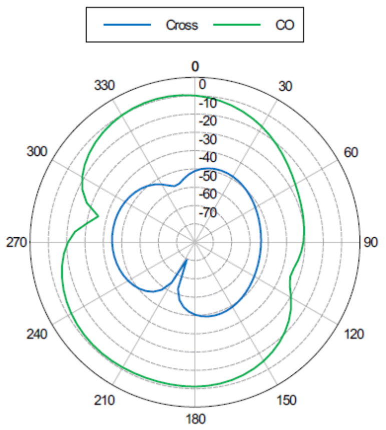

Figure 4.251: **E Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 13.15GHz.**

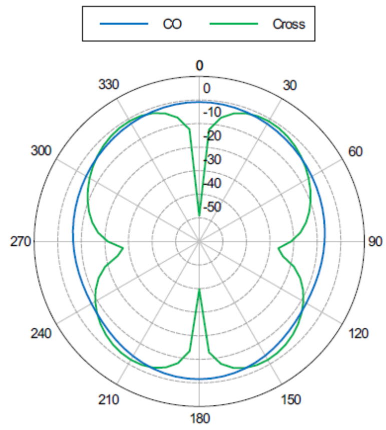

Figure 4.252: **H Plane Co and Cross Radiation Pattern of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 13.15GHz.**

For the resonance frequency 3.93 GHz the cross-polarization variations in E-Plane are less than -40dB, while for H-Plane it is -20dB. For the resonance frequency 13.15GHz the cross-polarization variations in E-Plane are slightly less than -40dB, while for H-Plane it is -10dB.

The gain of the antenna is 2.88dBi at frequency 3.93GHz and 0.85dBi at frequency 13.15GHz. The co polarizations are observed to be stable at the resonating frequency 3.93 GHz, while it is slightly deviated at frequency 13.15GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.85 GHz and 13.15 GHz are as shown in Figure 4.253 and 4.254 respectively.

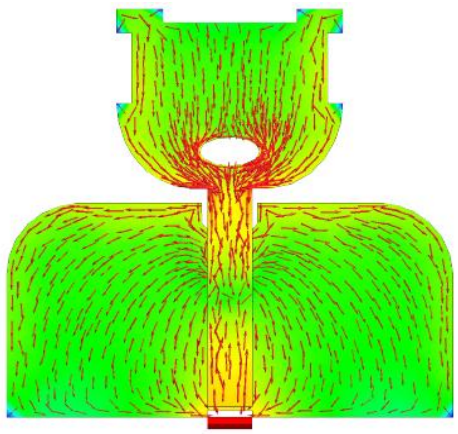

Figure 4.253: **Surface Current Distribution on Radiating Patch Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.85GHz.**

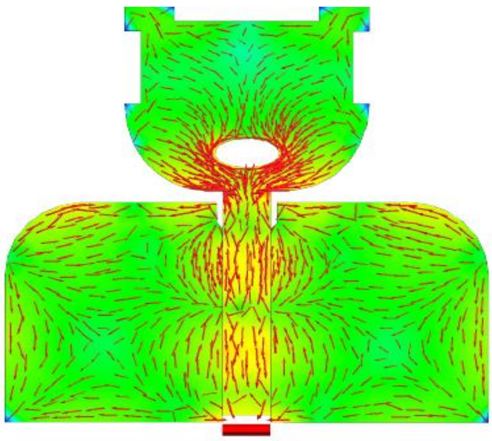

Figure 4.254: **Surface Current Distribution on Radiating Patch Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 13.15GHz.**

It is observed that, Surface current is linearly distributed at resonance frequencies 3.85GHz while for resonance frequency 13.15 GHz the flow of current is erratic over entire radiating patch.

Impedance:

The plot of impedance vs frequency of the simulated Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.93GHz and 13.15 GHz is shown in Figure 4.255.

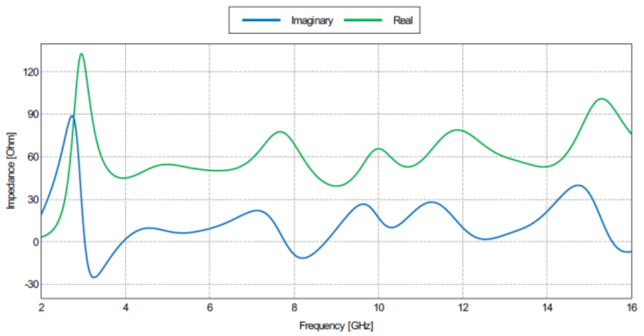

Figure 4.255: **Impedance Vs Frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

From the Figure 4.255 it is found that the impedance of the simulated antenna is 44.99-j0.5217ohm at resonance frequency 3.93GHz and 58.57+j6.309ohm at resonance frequency 13.15GHz. The corresponding magnitudes of the impedance are |z| = 47.3ohm and |z| = 53.88 ohm for the resonating frequencies 3.93 GHz and 13.15

GHz. It is observed that the impedance goes on increasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequency at 13.15GHz.

Measured Results:

The reflection coefficient of the fabricated antenna is observed to be -27dB and -20dB which is not matching with the simulated results, resonance frequency is tuned at 4.25GHz and 10.11GHz which is not matching with the simulated results. Reflection bandwidth is of 8.63GHz which is also not match with simulated results. It is due to the slight variations in dimensions of fabricated antenna compared with simulated one.

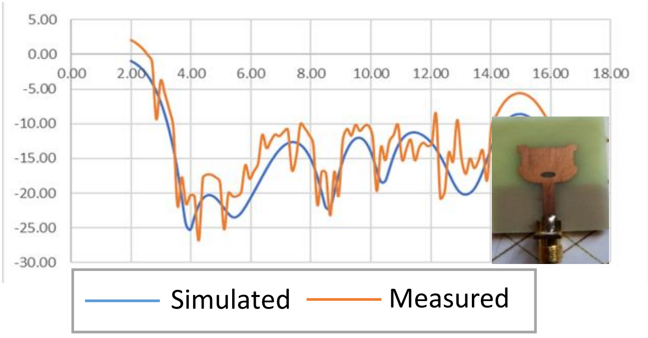

Fig.4.256: **Simulated and Measured Reflection Coefficient Vs Frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

Parametric Analysis:

In Parametric analysis of this antenna, the dimensions are maintained constant, only the position of oval slot position has been changed and the effect is observed. For parametric analysis the oval slot position of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground is shifted towards left, right by an amount of 1mm, 2mm, 4mm respectively and also in upward direction by an amount of 2mm, 4mm independently and the plot of reflection coefficient vs frequency is plotted. Figure 4.257, 4.258, 4.259 respectively, shows the results due to variation in position of oval slot.

Effect of oval slot position moved towards left side:

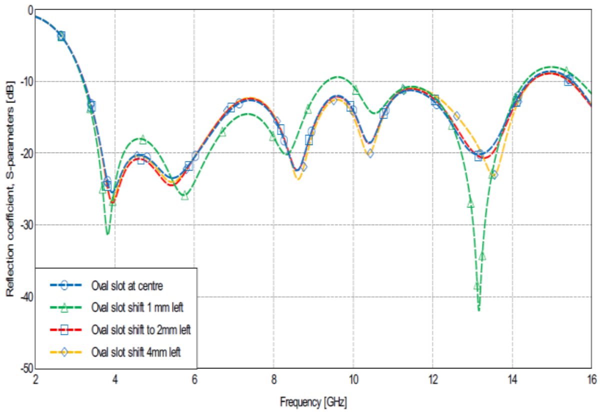

Fig. 4.257: **Reflection Coefficient Vs Frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground of Oval Slot Towards Left Shift.**

When the position of oval slot is moved towards left side by an amount of 1mm, the antenna resonates at frequencies, f_{r1}=3.91GHz, f_{r2}=13.21GHz and the corresponding reflection coefficients are -32dB and -42.30 GHz. The reflection bandwidths are 6.13GHz and 4.45GHz in the frequency bands 3.20GHz -9.33GHz, 9.88GHz -14.33GHz respectively.

When the position of oval slot is moved towards left side by an amount of 2mm, the antenna resonates at frequencies f_{r1}=3.95GHz, f_{r2}=13.86GHz and the corresponding reflection coefficients are -26.9dB and -20.66 dB. The reflection bandwidth is 11.26GHz in the frequency band 3.22GHz -14.48GHz.

When the position of oval slot is moved towards left side by an amount of 4mm, the antenna resonates at frequencies f_{r1}=3.94GHz, f_{r2}=13.54GHz and the corresponding reflection coefficients are - 26.68dB and - 23.11dB. The reflection bandwidth is 11.27GHz in the frequency band 3.22GHz -14.49GHz.

Effect of oval slot position moved towards right side:

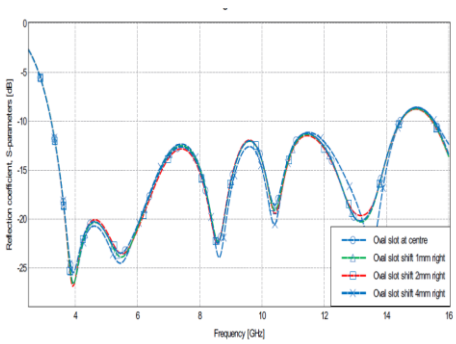

Fig. 4.258: **Reflection Coefficient Vs Frequency of Oval Shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground of Oval Slot Towards Right Shift.**

When the position of oval slot is moved towards right side by an amount of 1mm, the antenna resonates at frequencies f_{r1}=3.21GHz, f_{r2}=13.18GHz and the corresponding reflection coefficients are -26.72dB and -22.7 GHz. The reflection bandwidth is 11.2278GHz in the frequency band 3.22GHz -14.44GHz.

When the position of oval slot is moved towards right side by an amount of, the antenna resonates at frequencies f_{r1}= 3.92GHz, f_{r2}=13.18GHz and the corresponding reflection coefficients are - 26.82dB and - 19.65dB. The reflection bandwidth is 11.23GHz in the frequency band 3.22GHz -14.45GHz.

When the position of oval slot is moved towards left right by an amount of 4mm, the antenna resonates at frequencies f_{r1}=3.95GHz, f_{r2}=13.52GHz and the corresponding reflection coefficients are - 26.51dB and - 22.7dB. The reflection bandwidth is 11.23GHz in the frequency band 3.22GHz - 14.45GHz.

Effect of oval slot position moved towards upward side:

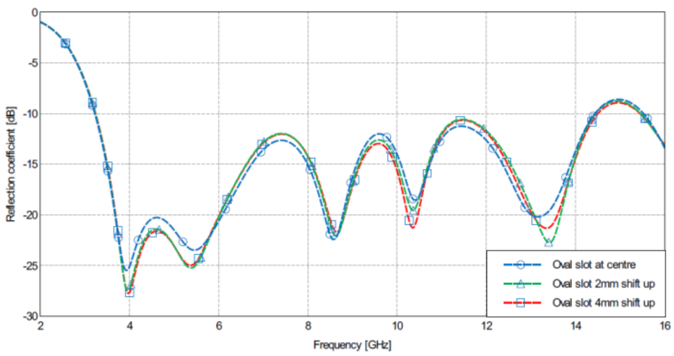

Fig.4.259**: Reflection Coefficient Vs Frequency of Oval shape Slotted Key Shape Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground of Oval Slot Towards Upward Side.**

When the position of oval slot is moved towards upward side by an amount of 2mm, the antenna resonates at frequencies f_{r1}=3.96GHz, f_{r2}=13.36GHz and the corresponding reflection coefficients are -27.72dB and -23.8 GHz. The reflection bandwidth is 11.2227GHz in the frequency band 3.23GHz -13.43GHz.

When the position of oval slot is moved towards upward side by an amount of 4mm, the antenna resonates at frequencies f_{r1}=3.97GHz, f_{r2}=13.35GHz and the corresponding reflection coefficients are - 27.71dB and - 21.3dB. The reflection bandwidth is 11.2698GHz in the frequency band 3.23GHz - 14.49GHz.

Inference:

It is resonating at two frequencies and the bandwidth is improved from 11.34GHz to 11.37GHz. It has a moderate gain; improved radiation pattern and impedance is near to the ideal value.

4.14.9. Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground:

The Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground is designed at $L_P = 12.7mm, W_P = 15.2mm, L_{sub} = 39mm$, $W_{sub} = 30mm, Lp = 12.7mm, F_l = 16.01mm$, $F_w = 3mm, r_g = 3mm, r_p = 5mm, W_v = 1mm$, $L_v = 5mm$, $L_h = 1mm$, $W_h = 10mm$, $L_{x1} = 2mm$, $L_{y1} = 3mm$, and for second ellipse which is used to create groove shape slot $L_{x2} = 1mm$, L_{y2}=$2mm$ It is $W_{sub} = 30mm$ simulated using CADFEKO simulation software. The results of the simulated antenna are presented here and sample results are compared with fabricated antenna.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground are shown in Figure 4.260 and 4.261 respectively.

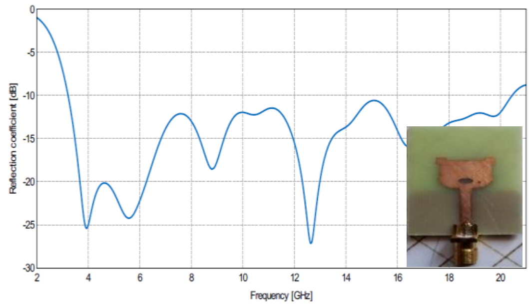

Figure 4.260: **Reflection Coefficient Vs Frequency and of Oval Shape Slotted Key Shaped Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

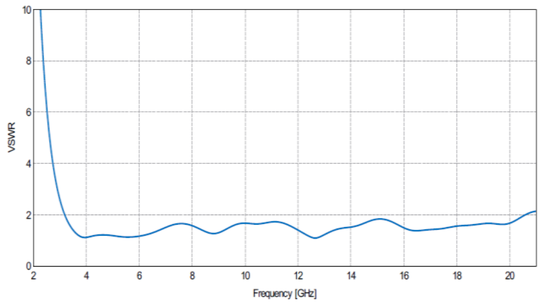

Figure 4.261: **VSWR Vs Frequency and of Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

From Figure 4.260 it is observed that the Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground is resonating at two frequencies. The resonance frequencies are f_{r1} = 3.94GHz, f_{r2} =12.65GHz and the corresponding reflection coefficients are -25.3dB, and -27.17 dB. The reflection bandwidth is 17.24GHz in the frequency band 3.21GHz-20.45GHz. From Figure 4.261 VSWR is observed below 2 in the frequency band 3.18GHz-20.59GHz and VSWR bandwidth is 17.41GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.94GHz and 12.65GHz are shown in Figure 4.262 and Figure 4.263 respectively.

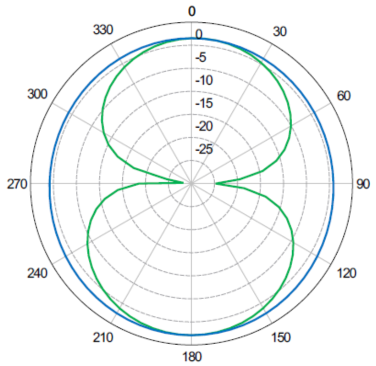

Figure 4.262: **Far Field Radiation Pattern of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.94GHz.**

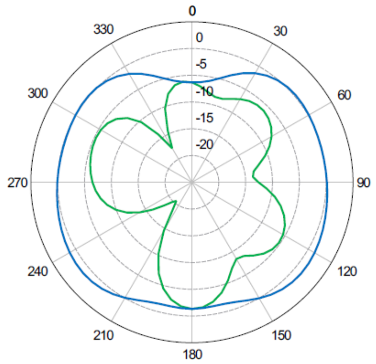

Figure 4.263: **Far Field Radiation Pattern of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 12.65GHz.**

It is observed that the gains of the Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground are 2.89dBi at 3.94GHz and 1.54dBi at 12.65GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.94GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.94GHz and 12.65GHz are shown in Figure 4.264 and 4.266 respectively. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated Oval Shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded

Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.94GHz and 12.65GHz are shown in Figure 4.265 and 4.267 respectively.

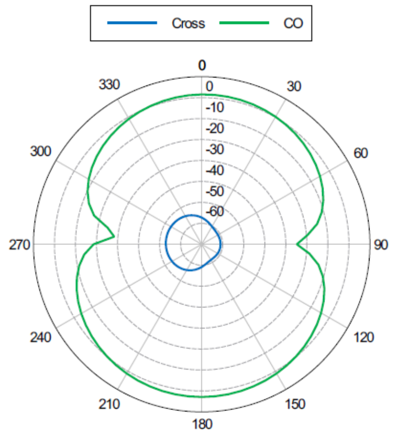

Figure 4.264: **E Plane Co & Cross Radiation Pattern of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.94GHz.**

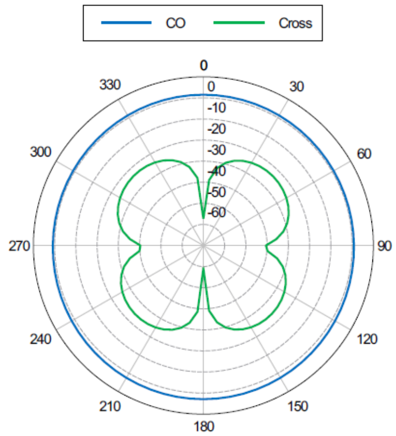

Figure 4.265: **H Plane Co & Cross Radiation Pattern of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.94GHz.**

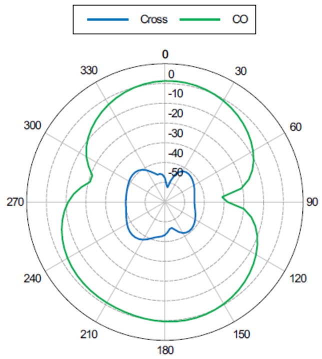

Figure 4.266: **E Plane Co and Cross Radiation Pattern of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 12.65GHz.**

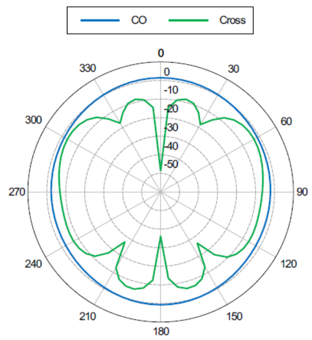

Figure 4.267: **H Plane Co and Cross Radiation Pattern of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 12.65GHz.**

For the resonance frequency 3.94GHz the cross-polarization variations in E-Plane are less than -60dB, while for H-Plane it is -30dB. For the resonance frequency 12.65 GHz the cross-polarization variations in E-Plane are slightly less than -30dB, while for H-Plane it is 0dB. The gain of the antenna is 2.89dBi at 3.94GHz and 1.54dBi at 12.65GHz. The co polarizations is observed to be stable at the resonating frequencies 3.94 GHz, while it is slightly deviated at 12.65GHz from ideal radiation pattern.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.94GHz and 12.65 GHz are as shown in Figure 4.268 and 4.269 respectively.

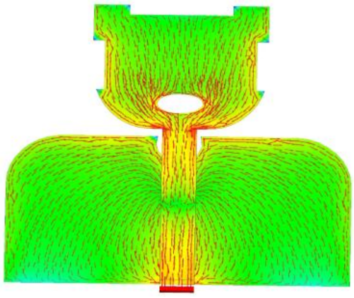

Figure 4.268: **Surface Current Distribution on Radiating Patch of Oval Shape Slotted Key Shaped Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 3.94GHz.**

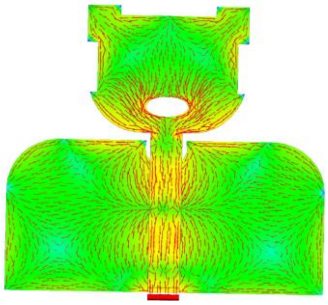

Figure 4.269: **Surface Current Distribution on Radiating Patch of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at 12.65GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 3.94GHz, while for resonance frequency 12.65 GHz the flow of current is erratic over entire radiating patch. It is observed that at 12.65GHz current flow indicates, TE_{01} mode is excited.

Impedance:

The plot of impedance vs frequency of the simulated Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground at the resonance frequencies 3.94GHz and 12.65 GHz is shown in Figure 4.270.

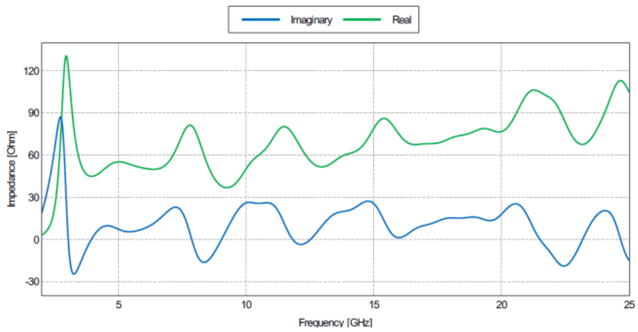

Figure 4.270: **Impedance Vs Frequency of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

From the Figure 4.270 it is found that the impedance of the simulated antenna is 45-j0.0413 ohm at resonance frequency 3.94GHz and 54+j2.27 ohm at resonance frequency 12.65GHz. The corresponding magnitudes of the impedances are |z| = 45 ohm and |z| = 54.04ohm for the resonating frequencies 3.94 GHz and 12.65 GHz. It is observed that the impedance goes on increasing with the increase in resonance frequency and the impedance is approximately matched with the ideal value for resonance frequency at 12.65GHz.

Results of fabricated antenna:

The reflection coefficient of the fabricated antenna is observed to be -27dB and -20dB which is not matching with the simulated results, resonance frequency is tuned at 4.18GHz and 10.21GHz which is not matching with the simulated results. Reflection bandwidth is of 13.71GHz which is also not match with simulated results. It is due to the slight variations in dimensions of fabricated antenna compared with simulated one.

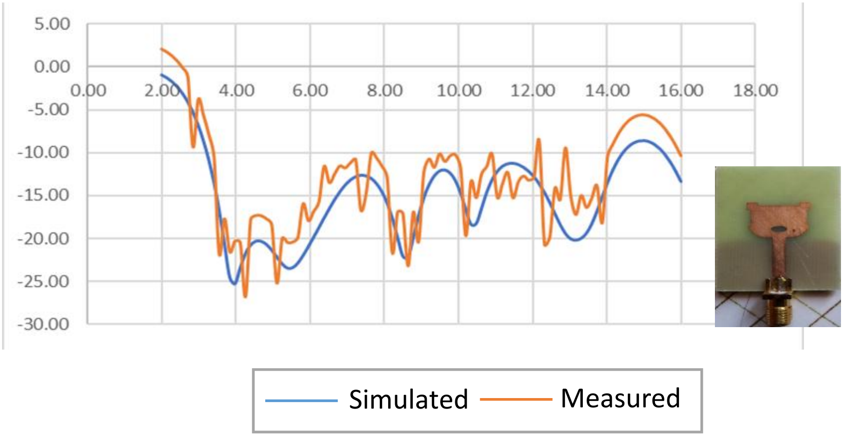

Fig. 4.271: **Simulated and Measured Reflection Coefficient Vs Frequency of Oval shape Slotted Key Shape Modified Monopole Rectangular Microstrip Patch Antenna with Rounded Corner and Groove Shape Notch in Partial Ground.**

Inference:

It is resonating at two frequencies and the bandwidth is drastically improved from 11.37GHz to 17.41GHz. It has a moderate gain; improved radiation pattern and impedance is near to the ideal value.

4.15. 1 × 2 Simple Square Patch Array Antenna:

The 1 × 2 Simple Square Patch Array Antenna is designed at $L_g = 27mm$, $W_g = 70mm$, $L_p = 15mm$, $W_p = 15mm$, $h = 1mm$, $F_{l1} = 15mm$, $F_{w1} = 2mm$, $F_{l2} = 15mm$, $F_{w2} = 3mm$. It is simulated using CADFEKO simulation software. The results of the simulated antenna are presented here.

Reflection and VSWR Bandwidth:

The plot of reflection coefficient vs frequency and VSWR vs frequency of are shown in Figure 4.272 and 4.273 respectively.

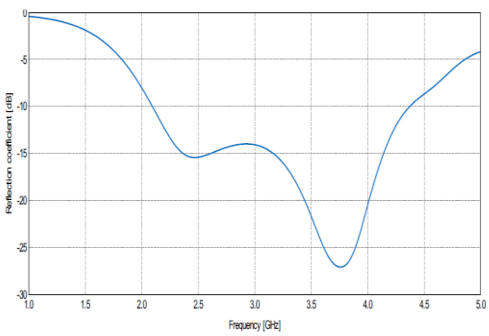

Figure 4.272: **Reflection Coefficient Vs Frequency and of 1 × 2 Simple Square Patch Array Antenna.**

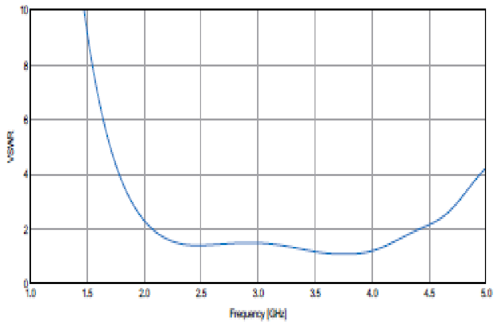

Figure 4.273: **VSWR Vs Frequency and of 1 × 2 Simple Square Patch Array Antenna.**

From Figure 4.272 it is observed that the1 × 2 Simple Square Patch Array Antenna is resonating at single frequency. The resonance frequency is 3.75GHz and the corresponding reflection coefficient is -27.08 dB. The reflection bandwidth is 2.278GHz in the frequency band 2.09GHz -4.372GHz. From Figure 4.273 VSWR is observed below 2 in the frequency band 2.073GHz-4.411GHz and VSWR bandwidth is 2.33GHz.

Far Field Radiation Pattern:

The far field radiation pattern of the simulated 1 × 2 Simple Square Patch Array Antenna at the resonance frequency3.75GHz is shown in Figure 4.274.

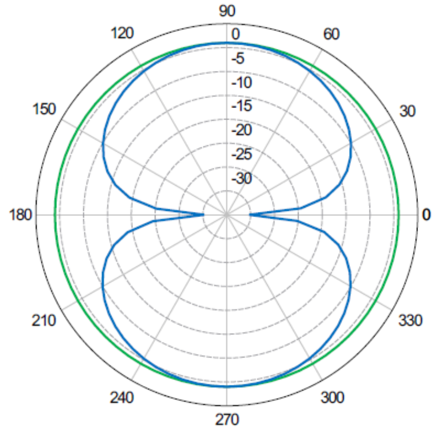

Figure 4.274: **Far Field Radiation Pattern of 1 × 2 Simple Square Patch Array Antenna at 3.75GHz.**

It is observed that the gain of the 1× 2 array antenna is 1.05dBi at 3.75GHz. The radiation pattern is nearly matching with the ideal radiation pattern expected at resonance frequency 3.75GHz.

E and H Plane Co and Cross Polarization:

The E plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated 1 × 2 Simple Square Patch Array Antenna at the resonance frequency 3.75GHz is shown in Figure 4.275. The H plane Co Polarization field radiation pattern and cross polarization field radiation pattern of the simulated 1 × 2 array antenna at the resonance frequencies 3.75GHz is shown in Figure 4.276.

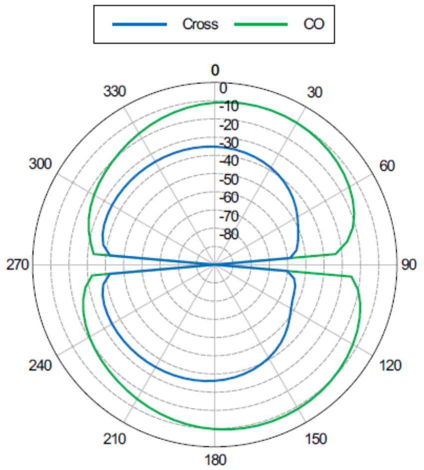

Figure 4.275: **E Plane Co and Cross Radiation Pattern of 1 × 2 Square Array Antenna at 3.75GHz.**

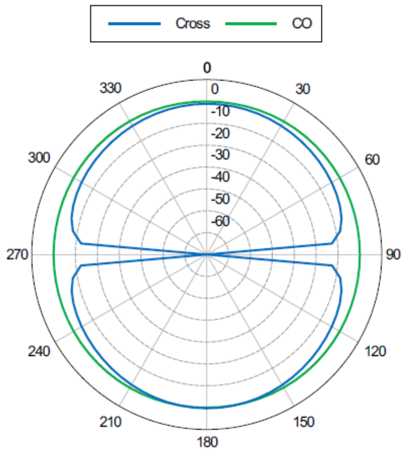

Figure 4.276: **H Plane Co and Cross Radiation Pattern of 1 ×2 Square Array Antenna at 3.75GHz.**

For the resonance frequency 3.75 GHz the cross-polarization variations in E-Plane are less than -30dB, while for H-Plane it is 0dB.The gain of the antenna is 1.05dBi at 3.75GHz. The co polarization is observed to be stable at the resonating frequencies 3.75 GHz.

Surface Current Distribution:

The Surface Current Distribution patterns of the simulated 1 × 2 Simple Square Patch Array Antenna at the resonance frequencies 3.75GHz is as shown in Figure 4.277.

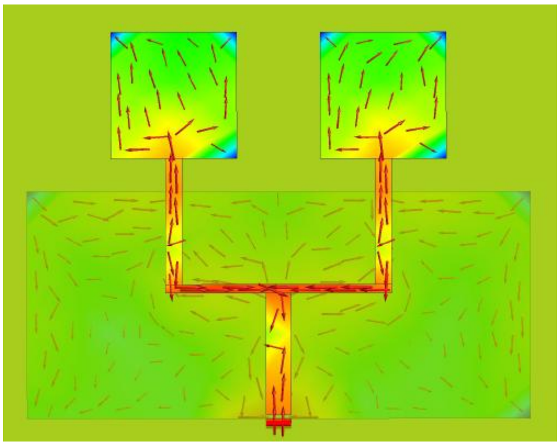

Figure 4.277: **Surface Current Distribution on Radiating Patch 1 × 2 Square Array Antenna at 3.75GHz.**

It is observed that, Surface current is linearly distributed at resonance frequency 3.75GHz.

Impedance:

The plot of impedance vs frequency of the simulated 1 × 2 Simple Square Patch Array Antenna at the resonance frequencies 3.75GHz is shown in Figure 4.278.

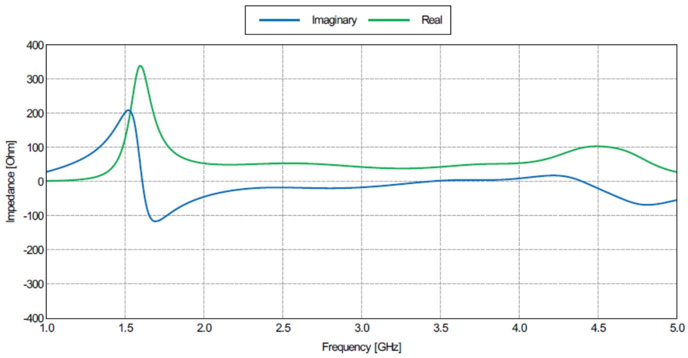

Figure 4.278: **Impedance Vs Frequency of 1 × 2 Square Array Antenna.**

From the Figure 4.278 it is found that the impedance of the simulated antenna is 50.8 + j4.39 ohm at resonance frequency 3.75GHz. The corresponding magnitude of the impedances is |z| = 50.98 ohm for the resonating frequency 3.75 GHz. It is observed that the impedance is matched with the ideal value for resonance frequency at 3.75GHz.

Inference:

It is resonating at single frequencies and the bandwidth is improved from 80MHz to 2.33GHz by using the concept of array. It has a moderate gain; more directed radiation pattern and impedance is near to the ideal value.

Chapter 5

Conclusion and Future scope

This chapter presents the conclusions of the undertaken research work which is discussed in the preceding chapters and the further research avenues are listed out.

5.1 Conclusion:

The fatal disease Cancer is the major cause of death all over the world. Among the different categories breast cancer shares the major percentage in females. For the timely and precise diagnosis, the researchers have suggested the new method, referred as microwave imaging. In microwave imaging technique the WB antenna plays the key role in microwave imaging technique. And hence the research work is mainly focused on the design of wideband Microstrip Patch Antenna.

The thorough literature survey about wideband antenna literature has been carried out. The papers presented by the researchers in 1958, 1972 to 2018, total 104 papers related to the research work have been studied. The researchers have claimed to achieve the bandwidth up to 11GHz.

To design and simulate the microstrip antenna CADFEKO simulation tool has been used and selected antennas have been fabricated using FR4 substrate. CADFEKO provides the design based on two independent factors: Equivalent Magnetic Current around the patch and Electric Current Distribution on surface of the patch. The Electric Current Distribution on surface of the patch has been used to design the antennas. This technique is also classified as Integral Equation Methods and Differential Equation Methods. The Integral Equation Method has been selected for the design. Integral Equation Method uses Maxwell’s Equation to formulate the electromagnetic problems in term of unknown currents.

The design and simulation start from Basic Simple Rectangular microstrip Patch Antenna with Probe Feeding. The results are observed in terms of Resonance frequency/frequencies, reflection coefficient, bandwidth, radiation pattern, current distributions, and impedance. The parametric analysis has been done by varying the dimensions. The fundamental rectangular microstrip patch antenna with probe feeding has been modified as U-slot microstrip patch antenna, U slot microstrip patch antenna with defective ground, T-slot microstrip patch antenna, T slot microstrip patch antenna with defective ground, Capacitive loaded T-slot microstrip patch antenna with defective ground, Notch cut I-slot loaded microstrip patch antenna have been designed. For these designs the achieved bandwidth ranges from 65MHz to 2.4GHz with moderate gain. These designs suffer from the inductive effect of the probe which is used for the feeding.

The problem of probe feeding has been overcome by using microstrip line feeding technique. The design and simulation of microstrip line feeding antenna starts from microstrip line feed Simple Rectangular microstrip Patch Antenna. The results are observed in terms of Resonance frequency/frequencies, reflection coefficient, bandwidth, radiation pattern, current distributions, and impedance., The parametric analysis has been done by varying the dimensions. The microstrip line feed rectangular microstrip patch antenna has been modified as Single corner cut rectangular microstrip antenna, Single corner cut rectangular microstrip antenna with partial ground and Multiple corner cuts rectangular microstrip antenna with partial ground. For these designs the achieved bandwidth ranges from 120MHz to 4.21GHz with moderate gain.

For the further improvement in bandwidth monopole antenna has been designed with microstrip line feeding. The results are observed in terms of Resonance frequency/frequencies, reflection coefficient, bandwidth, radiation pattern, current distributions, and impedance., The parametric analysis has been done by varying the dimensions. The microstrip line feed monopole microstrip patch antenna has been modified as Monopole Lower corner rounded rectangular microstrip patch antenna with partial ground, Monopole Lower corner rounded rectangular microstrip patch antenna with rounded corner in partial ground, Monopole Modified Lower corner rounded rectangular microstrip patch antenna with partial ground, Monopole key shaped rectangular microstrip patch antenna with partial ground, Monopole key shaped slotted rectangular microstrip patch antenna with partial ground, Monopole key shaped oval slotted rectangular microstrip patch antenna with rounded corner and half notch in partial ground, Monopole key shaped oval slotted rectangular microstrip patch antenna with rounded corner and groove shape notch in partial ground and Monopole Modified key shaped oval slotted rectangular microstrip patch antenna with rounded corner and groove shape notch in partial ground. For these designs the achieved bandwidth ranges from 5.03GHz to 17.41GHz with moderate gain.

In addition to this work the concept of array antenna has been studied. And the array of 1x2 simple rectangular microstrip patch antenna has been designed and simulated. The results of the array antenna have been compared with a simple rectangular microstrip patch antenna with partial ground. It is found that bandwidth of the antenna array is increased by an amount of 430MHz and the radiation pattern is more directed as compared to simple rectangular microstrip patch antenna with partial ground.

5.2 Future scope:

- Band Notch functions can be implemented in future to avoid interference of wireless band.
- Same structure can be converted to circular polarization, suitable for high speed wireless application.
- The high gain printed UWB notched array antennas can be designed for radar applications.

PATENT FILED

Dr. Gajanan Kashiram Kharate, Dnyaneshwar Dadaji Ahire, Indian Patent (Filed), 201721038401, 2017 “**Ultra -Wideband Microstrip Patch Antenna for Biomedical Application.**”

RESEARCH PUBLICATIONS

The following are the list of papers published

Papers Published in International Journals

1. D. D. Ahire, G. K. Kharate, “Defective Ground Corner Rounded Ultra-Wideband Microstrip Patch Antenna for Bio-Medical Applications" ICTACT Journal On Microelectronics, ISSN 2395-1680, Volume: 03, ISSUE: 04, pp 462-466, JANUARY 2018,
2. D. D. Ahire, G. K. Kharate, “Corner Cut Wide Band Microstrip Patch Antenna for Biomedical Applications”, International Journal of Computer Applications (0975–8887), Volume 180–No.15, pp12-16, January 2018
3. D. D. Ahire, G. K. Kharate, “Dual band microstrip patch antenna for wireless applications,” International Journal of Computer Technology and Applications, 9(10), pp. 1-11, 2016
4. D. D. Ahire,“Performance enhancement of Microstrip patch antennas using slotting: A Review,” International Journals of Advance foundation and research in Computer, Vol.2, Issue 8, pp. 1-6, Aug- 2015
5. D. D. Ahire, “Defective ground structure microstrip patch antenna for ISM, Wi-MAX and C-band using U-slotted structure,” International Journals of Advance foundation and research in Computer, Vol.2, Issue 10, pp. 1-8, Oct-2015

Papers Published in International Conferences

1. D. D. Ahire, G. K. Kharate, “Capacitive Loaded Notch Cut Slotted Wideband Microstrip Patch Antenna,” Proceedings of International Conference on “Contents, Computing and Communication”, *2017,* ISBN No:978-93-5107-22-8.
2. D. D. Ahire, G. K. Kharate, “Corner rounded UWB Monopole rectangular Microstrip patch antenna,” Applied Electromagnetics Conference (AEMC), 2017, *IEEE Explorer*, DOI: 10.1109/AEMC.2017.8325719
3. Ahire Dnyaneshwar Dadaji, Joshi J.G., Shyam S. Pattnaik, “Metamaterial Based Microstrip Patch Antennas: A Review,” Proceedings of 3rd International Conference on Recent Trends in Engineering & Technology, (ICRTET’2014), ISBN No:978-93-5107-22-8, 28-30 March 2014 ELSEVIER Publication 2014

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