DESIGN AND ANALYSIS OF RFID MICROWAVE ANTENNAS

A thesis submitted towards the partial fulfilment of the requirements
for the award of degree of

MASTER OF ENGINEERING
IN
ELECTRONICS AND COMMUNICATION

Submitted by

Richa Dolia

Roll No. 801461024

Under the guidance of

Dr. Rajesh Khanna

Professor

Department of Electronics & Communication Engineering

Thapar University, Patiala-147001

Punjab, India

JULY- 2016

DECLARATION CERTIFICATE

I, **Richa Dolia (801461024)** hereby declare that the work which is being presented in the dissertation entitled "**Design and analysis of RFID microwave antennas**", by me in partial fulfillment of the requirement for the award of the degree of Masters of Engineering in Electronics and Communication submitted in Electronics and Communication Department of Thapar University, Patiala is an authentic work carried out under the supervision and guidance of **Dr. Rajesh Khanna (Professor)**, ECED.

To the best of my knowledge, the content of this project report does not form a basis for the award of any previous degree to anyone else.

Date: 6/7/2016

Place: Patiala

Richa

Richa Dolia

801461024

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

Dr. Rajesh Khanna

Professor (ECED)

TU, Patiala

Countersigned By:

Dr. Sanjay Sharma

Head of Department

ECED, Thapar University

Patiala, 147001

Dr. S.S. Bhatia

Dean of Academic Affairs

ECED, Thapar University

Patiala, 147001

ACKNOWLEDGEMENT

To discover, analyze and to present something innovative is to endeavour on an ungraded path towards and unexplored destination is an onerous adventure unless one gets a true torch bearer to show the right path. I would have never accomplished in completing my work without the cooperation, encouragement and help provided to me by different people. I am getting short of words to reveals my deep regards. I take this opportunity to express my subtle sense of gratitude and respect to all those who supported me through thesis duration. I acknowledge with gratitude and modesty my deficit to **Dr. Rajesh Khanna (Professor)** Electronics & Communication Engineering Department, Thapar University Patiala under whose direction I had the privilege to complete my thesis. I am really very fortunate to have the opportunity to work with him.

I convey my candid thanks to **Dr. Sanjay Sharma (Head of Department),** PG coordinator, **Dr. Amit Kumar Kohli (Associate Professor**) entire faculty and staff of Electronics and Communication Engineering Department for their encouragement and cooperation.

I would like to thank my parents for their years of obstinate love and encourage, they have always desired the finest for me and I admire their determination and sacrifice. Above all I render my thanks to the Almighty who bestowed self-confidence, capability and strength in me to bring this work to completion and not letting me down at the time of dilemma. I am greatly obliged to all my friends, who have amicably applied themselves to the task of helping me with abundant moral support and esteemed suggestions helped in successful completion of the present study.

Richa Dolia

Roll no. 801461024

ABSTRACT

Living in a scenario where automation greatly replaces manual work, we are lucky to be bestowed with RFID technology. It is continuously gaining wide popularity because of the various advantages like high speed, minimized error rates, reduced shrinkage. Various application areas supported by RFID technology include supported automated manufacturing, tracking, management of supply chain, healthcare etc. But considering the other side also, the technology has only found limited implementation because of the lack of robustness and reliability, availability of cheaper alternatives like barcode. Common standards and interoperability also lacks.

Keeping in mind the drawbacks suffered by this technology, microstrip antennas serve as a solution to an extent. As these antennas are low profile, light, compatible with integrated circuits and hence cost efficient. But because these antennas have narrow bandwidth and low gain, therefore methods need to be devised to improve these factors. Using slotting technique, CPW feed and cutting triangular notches at the edges can prove beneficial. The major concern regarding RFID antennas is their size. They should be compact and simple in design so that they can be easily mounted on chip of the object to be tracked.

In this thesis RFID antennas for microwave range are introduced. The central frequencies for these antennas are 2.4 GHz and 5.8 GHz. The antenna design for 2.4 GHz consists of bevelled rectangular patch with rectangular slots and the antenna design for 5.8 GHz contains Jerusalem cross shaped patch with rectangular slots. Both the antennas are CPW fed and support wide bandwidth. The antenna operating at 2.4 GHz can be used for asset tracking, temperature management, vehicle access control, shipping container management, personnel tracking health care, manufacturing, building access control. The antenna can also be used for bluetooth, zigbee, WLAN which all work at 2.4 GHz. The antenna designed for 5.8 GHz can be used for long range access control for vehicles, vehicle identification, supply chain, automated toll collection. RFID antennas at 5.8 GHz has various advantages like more available bandwidth, resistant to conductive object degradation, smaller tag footprint, allows integration of multiple antennas onto compact RF tag and hence giving new signalling schemes. This band supports better signal propagation; manage large capacity real-time location systems efficiently.

INDEX

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AIDC	Automatic Identification and Data Capture
ASIC	Application Specific Integrated Circuit
CMOS	Complementary Metal Oxide Semiconductor
CPW	Coplanar Waveguide
CST	Computer Simulation technology
EPC	Electronic Product Code
HF	High Frequency
LF	Low Frequency
PCB	Printed Circuit Board
RF	Radio Frequency
RFID	Radio Frequency Identification
RTLS	Real Time Location Systems
UHF	Ultra High Frequency
VNA	Vector Network analyzer
VSWR	Voltage Standing Wave Ratio

CHAPTER 1

INTRODUCTION

1.1 HISTORY OF RFID SYSTEM

RFID finds its utilization from the Second World War to the present era usage. The fusion of two technologies namely continuous wave radio generation, given by Ernst F.W. Alexanderson in 1906 and Radar device, developed in 1922 resulted in the concept of RFID. RFID is considered to be discovered by Faraday who gave the concept of mutual induction that forms the basis for supplying power to passive tags which are operating in the near field [1]. In 1948, Harry Stockman proposed it first academically in theory. At this time, RFID was used as a way to make distinction between enemy and allied aircrafts in the war. In 1990s, RFID was integrated into men's daily activities with an example of RFID key cards for enhanced security. In recent history RFID has gained great attention from various commercial sectors [2].

1.2 RFID SYSTEM

RFID is an evolving wireless communication technology for Automatic Identification and data capture (AIDC). The benefits of implementing RFID technology are increased speed in production, low error rates, reduced shrinkage, improved asset tracking etc. Despite these advantages technology finds limited widespread implementation because of insufficient robustness and reliability, cheaper alternatives like barcodes, absence of common standards and interoperability. RFID system is made up of a host computer, a reader, and a tag that comprises of the information regarding the attached object. The establishment of communication link between the reader and tag occurs through wireless connection which is attained through magnetic field coupling or by capturing an electromagnetic wave according to the communication frequency [3]. RFID technology finds its application in logistics transportation, traffic toll collection, employee attendance record, cattle management. RFID is being used at various airports to track passenger's bags so that location of luggage is known at all times. Many countries have started RFID enabled toll system for cars which allow drivers to have a journey in which there is no need to stop for payment. An important advantage of RFID devices over barcode reader is that these devices need not to be positioned precisely relative to the scanner. Frequency bands that are assigned for RFID applications are the low frequency

(LF) 125 KHz, the high frequency (HF) 13.56 MHz, the ultra high frequency (UHF) 0.92 GHZ, and the industrial, scientific and medical (ISM) frequencies 2.45 and 5.8 GHz. For performing operation at low frequency (LF, 125 KHz) and high frequency (HF, 13.65 MHz) bands, information and power are transmitted through magnetic field coupling, whereas electromagnetic wave capture is used at ultra high frequency (UHF, 915 MHZ) and microwave range (MW, 2.4 and 5.8 GHz). UHF and ISM bands are gaining more popularity because they fit suitable for high data transfer rate, far field detection capability, radiative coupling and small antenna sizes as compared to the LF and HF RFID frequencies.

RFID is categorized into three groups: 1) passive 2) active and 3) semi active. In passive tags batteries or maintenance is not required. They gain energy through interrogation signals from the reader and they deliver information through a backscattering modulated signal transmitted by the reader. Passive tag has an antenna which has following uses:

- To produce energy from the reader signal, command and carrier wave (CW).
- To make communication with the reader.

The amount of energy which a tag receives, depends on various factors such as the distance between the tag and the reader, reader transmitter power and efficiency of the tag antennas. The impedance matching between the tag antenna and tag circuit is an indicator for the amount of energy which can be transferred between the antenna and the tag circuit. The target input impedance value is not necessarily 50 Ohm, and hence provides freedom and flexibility in the design of antenna and matching networks. When antenna is not matched, a parasitic imaginary part exists in impedance which can be either capacitive or inductive. It results in power loss and hence reduces the tag's read range. Passive tags enjoy relatively longer lifetime compared to active tags but their reading range is limited. As passive tags have limited functionality therefore active RFIDs came in. An active RFID has its own battery and is capable of performing various tasks like measuring temperature, humidity, vibration and acceleration and even forming a distributed wireless adhoc network. Active tags have limited lifespan but have larger reading rate as compared to that of passive tags. Semi active tags provide higher reading rate than passive tags by using batteries to extend the range and longer lifespan in comparison to active tags, but cost is also high.

1.3 ADVANTAGES AND DISADVANTAGES OF RFID SYSTEMS

1.3.1 Advantages

1). It is multipurpose and has many formats.

2). It has high speed and high accuracy.

3). It reduces man power.

4). It supports multiple reading.

5). It enables complex duplication.

1.3.2 Disadvantages

1). Interference creates problem.

2). It has high cost.

3). The materials used may lead to signal problem.

4). Overloaded reading (fail to read).

1.4 RFID APPLICATIONS

RFID applications are categorized as short range and long range.

Short range applications: Here tag needs to face the reader. Short range applications work in a perfect manner if tag accesses the reader one by one. For example, in access control, only specified person can approach the secure building and there are several divisions in the building and each division contains set of authorized people, who can access particular divisions.

Long range applications: Here tags do not require reader to be near as compared to short range. For ex. in library, tags are placed on every book and user can access the required book shelf for the particular book. This is known as automated inventory control. Readers are capable of reading multiple items from the distance simultaneously. Depending upon the frequency and reader type, reading distance may vary.

I. Security and control applications [2]: RFID system has the potential to be used for security and control access; it can also be used for audit purposes. These applications grant permission to have access to a particular secure zone and also keep a track of who accesses, from which location, at what time and duration. These types therefore can provide building maintenance, departmental security and privacy. And can find their use for equipments and object controls.

II. Patrolling log applications [2]: Security firms can use RFID system to check security guards and use RFID data for several purposes like performance checks. Data might also be used in consideration to unexpected event and audits for a secure area. For patrolling various tags can be fixed in the entire building and security guard is required to swap the reader with each tag (checkpoint) in a sequence within fixed duration and repeat the process. Each swap gets recorded by the reader which transfers it to a computer program.

III. Baggage applications [2]: Baggage handling and package delivery otherwise requires a large number of human resources for performing operations like receiving packages, sorting, assembling and distribution. Error rate can be high due to human intervention which can be reduced with the help of RFID tagging and RFID provides solution for airline industry.

IV. Toll road applications [2]: RFID enables automated toll collection and help in maintaining the traffic flow without the requirement of stopping vehicles for payment. Vehicles can pre pay their toll quarterly, monthly, or yearly or scheme like pay-as-you go can also be applicable. By an application program, the reader is able to recognize and maintain the vehicle entry at each toll.

V. Healthcare RFID applications [2]: RFID can help reduce consultants' time for handling patients and make it possible for consultant to give more time to patients' direct care by saving healthcare resources. RFID is utilized for patients' care which includes patient's movement from one place to another, notes management, sending blood samples, managing beds etc.

1.5 RFID SECURITY

The most dominant issues relate to RFID securities are [2]:

1). Eavesdropping: which means setting up an additional reader in order to record data present on tag.

2).Unauthorised Tag cloning: same privileges gained by copying tag data onto an additional tag.

3). Man in the middle (MIM) attack: Here an external object is acting either as a reader or as a tag in between actual tags and readers.

4). Unauthorised Tag disabling: Here the tag is disabled by an external reader and thus not permissible it to be utilised again.

5). Unauthorized Tag manipulation: The data is manipulated through an external reader.

In order to reduce the difficulties associated with RFID security the techniques used are tag deactivation and encryption, reader analysers, detections in tag ownership, mutual authentication and various data cleaners.

1.6 RFID ANOMALIES

RFID observational data may meet three major anomalies which are recorded with the correct readings [2]. The first anomaly is a wrong reading, where data gets captured at place where it should not be present. The second one is the missed readings in which the reading of the tag doesn't take place on and where the object it is attached to should have been present within its proximity. Duplicate reading is another anomaly in which RFID tag is scanned twice in the database as opposed to scanning at once only.

In order to improve the reading either multiple readers can be installed or multiple tags can be attached. Multiple readers improve the reader rate by having more substantial area under its coverage. While using multiple tags as a solution, identical EPC (Electronic Product code) numbers are housed to the same object and hence making an effort for the reader to at least read one of these tags.

1.7 PHYSICS OF RFID

The reading of an RFID tag doesn't only mean recognizing the backscatter through a simple RF receiver but more than that [2]. For the operation of a passive tag, the reader should supply operation energy to the tag with the help of transmission of an RF continuous wave (CW). The magnitude of the transmitted energy is evaluated through Friis equation (eq. 1). The key physical aspects of antenna involved in energy harvesting are: 1) Antenna gains 2) Reflection coefficients 3) Polarization.

Let G_T and G_R be the gains for transmitting and receiving antennas, respectively. These gains have dependency on the relative physical orientations of the two antennas for supply of energy and energy production. The polar coordinates related to the two antennas are represented as function of Θ and ф for both tag and reader. The maximum energy transfer is said to take place when the centre lines of the planes associated. So while evaluating the amount of power that actually exists at the tag, it is essential to know the relative physical placement of the reader and the tag antennas.

$$P_R = \frac{P_T\ G_T\ (\theta_T, \emptyset_T) G_R (\theta_R, \emptyset_R) \lambda^2 (1-|\Gamma_T|^2)(1-|\Gamma_R|^2)|\hat{P}_T . \hat{P}_R|^2}{(4\pi r)^2} \quad (1.1)$$

P_T: transmitted power

P_R: received power

G_T: Transmitting antenna's gain

G_R: receiver antenna's gain

Γ_T: tag reflection coefficient

Γ_R: reader reflection coefficient

λ : wavength of frequency used

$\hat{P}_T$: polarization of tag antenna

$\hat{P}_R$: polarization of reader antenna

r : distance between tag and reader antenna

The distance present between the reader and the tag is crucial both for the tag powering and ability of the reader's receiver to visualize the changes in radar cross section of the tag antenna. In terms of power P_R must be sufficient to operate the tag where the reader is supplying P_T. The change in the tag reflection coefficient Γ_T alters the power received by the interrogator P_R which forms the basis for decoding the data number from the tag and hence enables the reader to read the backscatter from the tag.

The classification of the tags based on their closeness with the interrogator, defined on the wavelength of the frequency being used is also present. The closer one is known as the near field and the distant one is called as far field. Near field and far field antenna are defined based on the type of coupling.

Near Field antenna: It is meant for using inductive coupling or it uses magnetic field to energize the tag. The tag then responds by producing a disturbance in the magnetic field which is picked by the reader and hence decoded. Near field antenna serves well for short read range applications and are less coarse than far field antennas. They usually serve for indoor environments.

Far field antenna: In order to energize the RFID tag, far field antenna uses capacitive coupling. In this coupling RFID reader's antenna radiates RF energy outward and that energy energizes the tag. Then the tag sends a portion of that RF energy back to the reader's antenna as a response that is known as backscatter. They are available in great variety of shapes and sizes and are able to read tag from few centimetres to more than 30 feet away. Various options are available for far field antenna like polarization, varying gain, and outdoor or indoor use. Stray tag read problem arises in far field antenna because of increased read zone.

1.8 RFID SYSTEM PERFORMANCE

The antenna gain and the frequency limit the reading range when we fix the transmitted power [4]. The power density at R distance from place where the tag is positioned is expressed as:

$$S_1 = \frac{G_{reader} P_{transmitted}^{reader}}{4\pi R^2} \tag{1.2}$$

where G_{reader} : gain of reader antenna

$P_{transmitted}^{reader}$: power transmitted by the reader

Power received by the tag is given as

$$P_{received}^{tag} = S_1 A_{tag} \tag{1.3}$$

where

$$A_{tag} = \frac{G_{tag} \lambda^2}{4\pi} \tag{1.4}$$

$P_{received}^{tag}$: power received by the tag

A_{tag}: equivalent aperture of the tag antenna

G_{tag}: gain of tag antenna

Then

$$P_{received}^{tag} = \left(\frac{\lambda}{4\pi R}\right)^2 G_{reader} G_{tag} P_{transmitted}^{reader} \tag{1.5}$$

Return wave power density at the reader position from the tag is

$$S_2 = \frac{G_{tag} P_{received}^{tag}}{4\pi R^2} \tag{1.6}$$

The power which is received by the reader is

$$P_{back}^{read} = S_2 A_{reader} = S_2 G_{reader} \frac{\lambda^2}{4\pi} \tag{1.7}$$

where P_{back}^{reader}: power received by the reader

Equivalent transmitted power is defined as

$$P_{(EIRP)} = G_{reader} P_{transmitted} \tag{1.8}$$

Then

$$P_{back}^{reader} = \left(\frac{\lambda}{4\pi R}\right)^4 (G_{tag})^2 G_{reader} (P_{(EIRP)}) \quad (1.9)$$

Read Range is the maximum distance up to which the tag is easily monitored. One limitation faced by the range is the maximum distance from where the tag receives sufficient power to be turned on and scatter back. Another associated limitation is the maximum distance from which the scattered signal can be detected by the reader. The smaller of the two distances is the read range.

Theoretically read range r_{max} is calculated using the Friis free space formula

$$r_{max} = \frac{\lambda}{4\pi}\sqrt{\frac{P_t\, G_t\, G_r\, (1-|s|^2)}{P_{th}}} \quad (1.10)$$

where λ: wavelength

P_t: power transmitted by RFID reader

G_t: gain of transmitting antenna

G_r: gain of receiving tag antenna

P_{th}: minimum threshold power necessary to power up the chip

Backscattering power of the tag is given as

$$P_{BS} = S_1 \sigma^{tag} = \frac{G_{reader}\, P_{transmitted}^{reader}\, \sigma^{tag}}{4\pi R^2}, \quad (1.11)$$

where σ^{tag}: backscattering section of the tag which includes both the chip and the antenna.

If changes are made in the chip impedance of the tag in accordance with the data stored in tag, σ^{tag} will get changed and hence the return wave which emerges from the tag and reaches the reader will also change, making amplitude modulation and demodulation possible.

1.9 POLARIZATION

The antenna polarization is important in RFID because of the various possible orientations of the tagged item relative to the reader antenna [2]. Regarding traditional use of radio, transmitting antennas are mainly vertical, and radio receivers are kept on flat surface existing parallel to the earth in which case manufacturer will include the antenna with the polarization with respect to vertically polarized transmitting antennas, and are mounted vertically to achieve same polarization as that of transmitting antennas. But when the placement of RFID tags is done on an item it is not easy to fix the orientation of the item throughout the item lifecycle at all possible locations where the tag may read. So in RFID circular polarization is supported for the reader antenna. Due to the requirements of phasing and dual feed configuration, it is not feasible for the tag antenna to be circularly polarized and is generally some form of a dipole antenna. Having circularly polarized antenna for the reader and tag antenna orientations placed in parallel planes ensures suitable tag performance in many situations. Typically circularly polarized antennas are not having that great range as compared to linearly polarized antennas. Circularly polarized antennas find their use when reader/tag orientations vary. Practically linearly polarized antennas find their use when maximum distance is required and reader/tag orientation is kept fixed.

In typical RFID system, the tags are designed to have either dipole, omnidirectional type antenna or a combination of two dipole antennas. The radiation pattern of the dipole antenna allows the tag to intercept most of the incident signal irrespective of the tag orientation with respect to the reader's antenna and has dipole antenna with gain around 2.2 dBi. The RFID readers are designed to operate with the patch (directional) type antennas. Thus the power of radiated signal stay focussed toward a passive tag. And normally the gain for the circularly polarized patch antenna is to be of the order of 6 dBi.

1.10 CHALLENGES IN RFID ANTENNA DESIGN

Various challenges faced by RFID antenna designers are antenna structure, antenna size, bandwidth, operating mode, radiation pattern, polarization, mutual coupling between multiple antennas, and antenna scattering. The reader antennas are generally designed to be circularly polarized and are mainly patch and spiral antennas. In some exceptional cases, reader antennas can also be linearly polarized. Eroded or printed antennas are widely used in the tag, and the dipole is the typical structure used for tag antenna. They are generally linearly polarized but in few special cases circular polarized antennas might be used. The antenna specifications are finalised based on their applications [5].

(a). **Meandered antennas**: Resonant antennas with the wire folded back and forth are called meandered antennas. Here resonance takes place in much more compact structure than otherwise. These antennas are widely used to minimize the physical size of the radiating elements present in wire antennas like monopole, dipole and folded dipole antennas. The tuning of this antenna is easily possible by trimming which is realized by holes punching through the antenna trace.

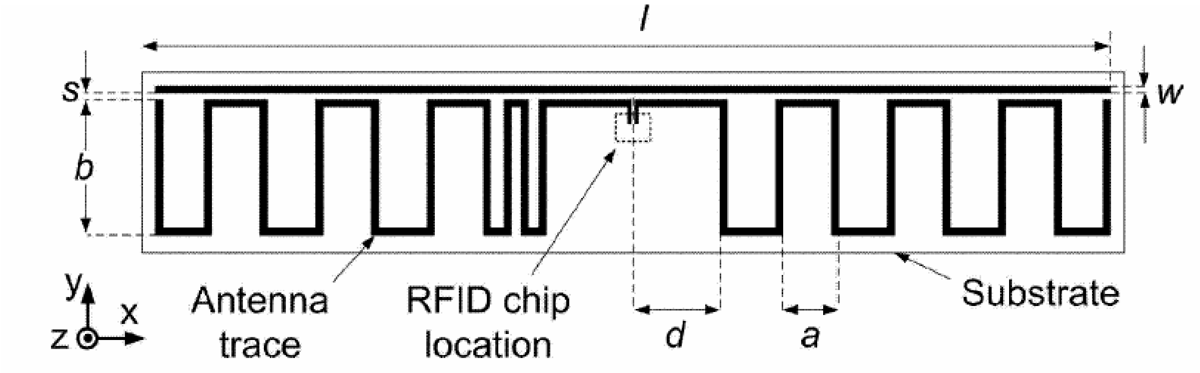


Fig 1.1 Meandered antenna [5]

(b). **Text antennas**: Manufacturer logos or brand names acts as an option to be used as a radiating element of the RFID tag antenna and can promotes advertisement.

Fig 1.2 Text antenna [5]

(c). **Fractal antennas**: Antennas with self similar shapes to maximize the length are called fractal antennas. The construction of such shapes is executed by applying iterations of iterative algorithms. Such iterations are applied to an initiator (an initial structure) to result in a structure called generator which repeats numerous times at different scales. It is capable of taking various shapes. For example koch fractal, minkowski island fractal etc. Fractal antennas facilitate compact, low cost provision for various RFID applications as these are small and versatile.

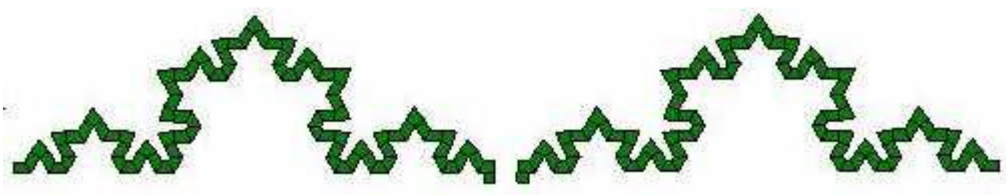


Fig 1.3 Fractal antenna [5]

(d). **Dipole antennas**: Dipole antenna contains two identical conductive elements such as metal wires or rods, which are symmetrical. Fractal dipole antennas also exist. Examples of such antenna include Koch dipole. The indentation angle is been used as a variable for matching the RFID antenna with IC impedance.

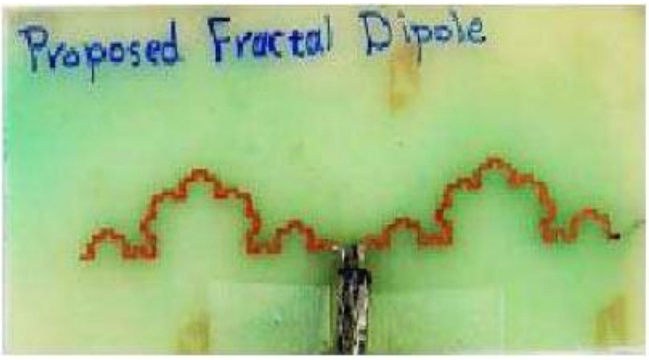


Fig 1.4 Fractal Dipole antenna [5]

(e). **Loop antennas**: consist of loop (or loops) of wire, small loop antennas with a size much smaller than a wavelength possess low radiation resistance and high reactance in a way that their impedance is difficult to match to a transmitter. As a consequence these antennas are mostly used as receiver antennas, where impedance mismatch loss will not affect much.

Loop antennas responds to the time changing magnetic flux density $\vec{B}$ of the incident EM wave. The induced voltage across the loop's terminal is directly proportional to time change of the magnetic flux ϕ through the loop, and it is in turn proportional to the area S which is enclosed by the antenna. This can be expressed as

$$V \propto \frac{d\phi}{dt} \propto w|\overrightarrow{B}|S \tag{1.12}$$

By increasing the area (S) entrapped by the loop, the induced voltage can be increased and hence the read range of the tag gets increased.

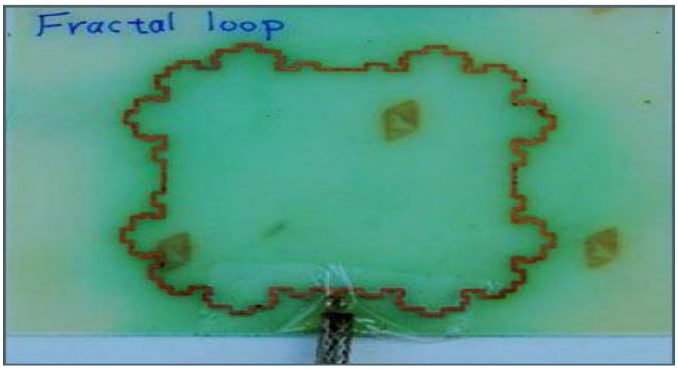


Fig 1.5 Loop antenna [5]

(f). **Inverted F antennas**: Inverted F antenna which is a modified version of quarter wave monopole antenna provides good solution for the passive tags to be read near and on metallic objects efficiently. Metal degrade the antenna performance by lowering its radiation efficiency. And metalized objects like aluminium cans are used commonly in many RFID system applications. While maintaining the resonant length, the height of the antenna can be minimized by having the existence of radiating element in parallel with the ground plane. Various shapes and designs are possible in these antennas based on their application and specifications. The types that exist are like planar inverted F antenna and wire type inverted F antenna.

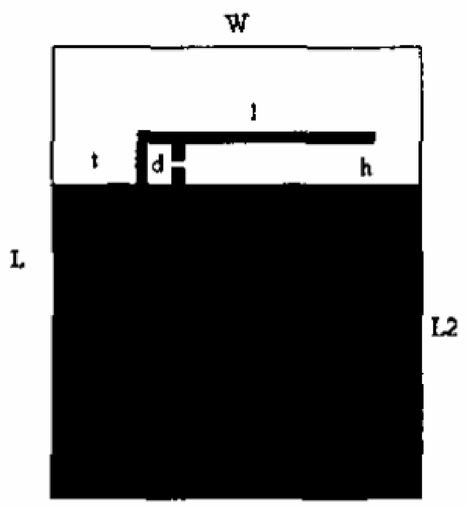


Fig 1.6 Inverted F antenna [5]

(g). **Patch antenna**: is a low profile antenna consisting of a sheet or patch of metal mounted over a large sheet of metal known as ground plane. Patch antennas are low cost, can be easily fabricated, and are well suitable for metallic objects since their bodies can be utilized as ground plane. By making slots of different size and shape on the patch, they can serve for various applications. The use of patch antennas in RFID devices will play a very significant role for the upcoming information communication technology which will be utilized in the concept of Internet of things (IOT).

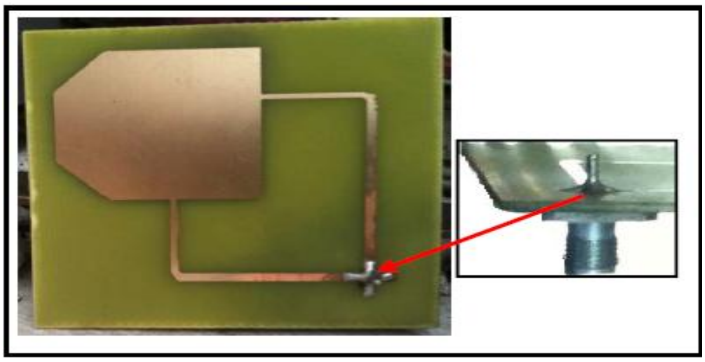


Fig 1.7 Patch antenna [6]

The RFID tags which can be read in multiple ways by the reader with least error probability and high speed are desirable. Very accurately designed antennas are required by the fast handheld readers for different purposes as some actions follow high speed reading of tags and get utilized for automated systems. If one or more readings turn out to be wrong, then the subsequent operations get affected adversely.

The range from reader to tag can be increased by adopting genetic algorithms to optimize the design of patch antennas. This in turn also provides optimization for impedance matching with the chip. The performance of RFID tags is dependent on various factors like [7]: i) tag position ii) direction of the tag iii) angle of reader antenna iv) material of object and v) surrounding environment. When an RFID tag is fixed to a metallic object, the antenna performance is hugely degraded because of the reactance change in the antenna impedance.

1.11 IMPEDANCE MATCH BETWEEN TAG ANTENNA AND CHIP

The impedance matching of the antenna with the chip directly affects the operation of the tag circuit that whether it is able to retransmit sufficient energy to accomplish the backscattering communication and hence limits the reading range [4]. The chip which is attached to the antenna should have impedance equal to the conjugate of the antenna impedance. This enables maximum transfer of power in between the chip and the antenna. The impedance match problem is more acute in RFID antennas designed for microwave band. Conventionally the tag antenna impedance is 50 ohm or 75 ohm but the impedance of the chip can be any random value or frequently variable and may have a different value when the driving power is varied. Therefore it is a crucial requirement to have proper impedance match of antenna and chip. There are various ways of designing tag:

1). Design and develop integrated circuit chip.

2). Design antenna in a way that it match the existing chip.

3). Add matching network to the designed antenna.

Having integrated circuit chip requires huge investment and long research duration whereas designing the antenna in order to match the chip is more practical and convenient. Adding the matching network increases the cost and size. The antenna should be designed in such a way that by adjusting its structure it is able to match the chip.

The equivalent circuit of the tag:

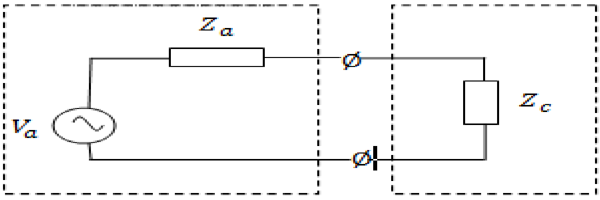


Fig 1.8 Equivalent circuit of the tag [4]

$$Z_a = R_a + jX_a \quad (1.13)$$

$$Z_c = R_c + jX_c \quad (1.14)$$

Z_a: antenna impedance

Z_c: chip impedance

Complex power reflection coefficient s

$$s = \frac{Z_a - Z_c^*}{Z_a + Z_c} \quad (1.15)$$

The power reflection coefficient is given by

$$|s|^2 = \left|\frac{Z_a - Z_c^*}{Z_a - Z_c}\right|^2 = \left|\frac{(R_a - R_c) + j(X_a + X_c)}{(R_a + R_c) + j(X_a + X_c)}\right|^2 = \left|\frac{(\frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c}) - 1}{(\frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c}) + 1}\right|^2 \quad (1.16)$$

Let

$$\frac{R_a}{R_c} + j\frac{X_a + X_c}{R_c} = r + jy = \bar{Z}_a \quad (1.17)$$

$\bar{Z}_a$ be the antenna impedance which is normalized to the chip impedance’s real part, then

$$|s|^2 = \left|\frac{\bar{Z}_a - 1}{\bar{Z}_a + 1}\right|^2 \text{ or } \quad |s| = \frac{\bar{Z}_a - 1}{\bar{Z}_a + 1} \quad (1.18)$$

Smith chart which is based on this transformation is used to define the impedance matching of the antenna and the chip. Like the conventional normalized impedance, real and imaginary part of the $\bar{Z}_a$ can be marked on smith chart. The distance from the centre point of smith chart to the point of each $\bar{Z}_a$ defines the magnitude of the power reflection coefficient s. The trace of impedance points which maintains constant distance from the centre point and forms the concentric circle and is known as equivalent power reflection circle. Smith chart’s centre point forms the perfect match point and the outermost circle is the complete mismatch case, i.e. |s|=1.

1.12 ENVIRONMENTAL CONSTRAINTS

The effects of environmental factors need to be understood in order to design suitable antennas for RFID tags. Liquids and metals affect the electromagnetic waves and hence play significant role in the antenna performance. Materials having high value for dielectric constant or lossy like liquids attenuate RF energy by absorbing and therefore detune tag antennas. This way they reduce radiation efficiency. Metals can either reflect or absorb RF energy which depends on the shape of the metal. When the metallic structure is present then only the electric field's normal component and magnetic field's tangential component are present near the metallic structure surface. Therefore any RFID tag which is dependent on either electric field's tangential component or magnetic field's normal component will have serious degradation in its performance when attached to or near to a metallic surface. Moreover by placing RFID tag close to a metallic surface various changes occur in parameters of the tag antenna like changes in input impedance, efficiency, radiation pattern, directivity.

The changes brought in tag antenna impedance will result in two issues:

- First change is in the tag antenna's resonant frequency as resonant frequency is expressed as

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1.19}$$

  L: inductance of the circuit

  C: conductance of the circuit

  As changes occur in reactive part of the impedance which lead to resonant frequency change. This is referred as detuning and degrades read range.

- The second problem caused is impedance mismatch. The designing of the antenna is in a way that it closely matches the RFID tag chip impedance. But due to the metallic surface, antenna impedance is affected and hence mismatch occurs and transfer of power from tag antenna to the chip will also reduce.

The possible solutions for this problem are to use patch antenna which has defined ground plane for its operation. This antenna will not get affected too much an extent when mounted on a metallic object as the ground plane forms a part of design. Another possible solution is design a tag antenna which can use electromagnetic fields which

1.13 DESIGN OF RFID SYSTEM FOR MICROWAVE BANDS

The tag and reader designed for the microwave band often use specific ASICS which are meant for some special RFID systems and at times use coaxial cable for connecting the antenna with the ASIC [4]. The impedance of coaxial cable is 50 ohm.

The tag which contains a microchip transmitter and the antenna must be having small size, profile, and low cost for easy and valuable use. The tag must be attached to the object which needs to be identified. The RFID systems working at two frequency bands of 2.45 GHz and 5.8 GHz should meet the requirements of reliability and anti-interference.

In reader, where a single antenna serves both purposes of data transmission and reception, requires several operations to be performed at the reader RF front end as the communications occurs in both directions simultaneously. So in order to reduce this hardware realization difficulty we can use the reader having two antennas. One antenna will serve data transmission and the other will serve for data reception. The reader can also have more than two antennas in which a certain sequence need to be followed by the reader to switch on only the particular antenna at a time, and switching off the other antennas. This way interference between the antenna signals is avoided.

The antennas used for microwave band must meet the following requirements:

- must be small in size in order to get easily attached to the object
- support omnidirectional coverage
- transfer maximum possible signal to ASIC
- be robust
- Polarization should be in such a way that it matches the enquiry signal invariant to the physical orientation of the object.
- be cheap

1.14 MODEL FOR THE MICROWAVE PASSIVE RFID OVER MULTIPATH ENVIRONMENT

I. Path loss model for forward link [8]

The most popular model is one in which the RF signal intensity is inverse square law of the separating distance of the transmitter and the receiver in free space

$$P_r = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r P_t \tag{1.20}$$

G_t: effective aperture of transmitting antenna

G_r: effective aperture of receiving antenna

d : separation distance between the antennas

λ : wavelength in free space

The path loss model is expressed using the below equation:

$$P_r = P_t\left(\frac{\lambda}{4\pi}\right)^2 \left|\frac{G_{l_1}}{l_1} + \sum_{i=1}^{n}\frac{R_i G_{l_i} e^{-j\Delta\phi_i}}{l_i}\right|^2 \tag{1.21}$$

l_i: path length of the ith path

and i=1 for direct path

G_{l_i}: products of receiving and transmitting antennas field radiation pattern function for the ith path

R_i: reflection coefficient for each individual reflection

$\Delta\emptyset_i$: $2\pi\frac{l_i-l_1}{\lambda}$ is the phase difference in between the direct path and reflection path

The individual reflection can have either single reflection coefficient or product of more reflection coefficients depending on the environment.

A model which predicts the LOS propagation's path loss is described with the following relationship:

PL= $PL_0(d_0)$ + 10 $\gamma_1 \log_{10}(d/d_0)$ d<d_B

PL= $PL_0(d_0)$ + 10 $\gamma_1 \log_{10}(d_B/d_0)$ + …..+ 10 $\gamma_2 \log_{10}(d/d_B)$ d≥ d_B

$PL_0(d)$: path loss in dB at distance d_0 which in indoor environment is approximately 1m.

γ_1, γ_2 : path loss

d_B : breakpoint distance and expressed as

$d_B = \frac{4h_t h_r}{\lambda}$

II. Tag power sensitivity and Reader sensitivity

Tag sensitivity is defined as the minimum signal power required powering the tag at the location of the tag. It is a function of various factors like tag antenna gain, chip impedance, threshold power, sensitivity of the chip and matching of tag antenna with chip impedance.

III. The Reverse link

Passive RFID tags use modulation of the power reflected from the tag antenna in place of radio transmitters. A part of P_r is utilized by the tag to have operational energy for the microchip circuit present in the tag and the other part of P_r gets reflected by the microchip towards the tag antenna and then reradiated by it into air. The amount of P_r is varied by changing the chip's input impedance to have backscatter communication. The power P_f is reflected by the tag and it is being proportional to the incident wave's power density

$$P_f = s.\sigma \quad (1.22)$$

s: power density at the tag location

σ: radar cross section. It is used to express ability of object to reflect electromagnetic waves

The power density s is expressed as:

$$s = P_r G_r / A_{e\_tag} \quad (1.23)$$

P_r: power received by tag through multipath environments

A_{e_tag}: effective area of RFID tag antenna which is commonly also known as effective aperture

For reader antenna we define

$$A_{e\_reader} = \frac{\lambda^2 G_t}{4\pi} \quad (1.24)$$

The received power P_{f_reader} for the reader antenna is given as

$$P_{f\_reader} = P_r \left(\frac{\lambda}{4\pi d}\right)^4 G^2{}_t G_r \quad (1.25)$$

1.15 ORIGIN OF PROBLEM

Barcode readers had been in use since 1969 for the purpose of automatic identification and data capture (AIDC). Once the use of barcode started for supermarket checkout systems, they picked commercial success. But the concern with them is that these devices need to be positioned precisely relative to the scanner. Eradicating this drawback a new wireless technology was introduced known as RFID (Radio Frequency Identification). Here device to be tracked need not be positioned directly in front of the scanner. RFID works for wider range and supports high speed, accuracy. Multiple reading is also enabled by it.

RFID UHF band has been in widespread use. But due to several advantages present in microwave range as well like wider bandwidth, flexible enough, better propagation, higher speed, high accuracy, this band also surfaced and found its application.

1.16 GAPS

- The proposed RFID antennas are compact and support wide bandwidth, but their gain is not that high, which was the gap observed.
- RFID antenna at 5.8 GHz is completely omnidirectional but the antenna at 2.4 GHz is not perfectly omnidirectional.
- The tag antennas been CPW fed are easily compatible with any device. But the tag chips on which we need to mount these tag antennas have impedance values other

than the conventional values of 50 or 75 ohms. Therefore we require impedance matching circuit which increases the complexity and cost of the system.

1.17 OBJECTIVES

- Design, simulate and parametrically make a study of CPW fed bevelled rectangular patch antenna with rectangular slits for 2.4 GHz RFID passive tag antenna application.
- Design, simulate and parametrically make a study of miniaturized CPW fed Jerusalem cross shaped patch antenna for 5.8 GHz RFID passive tag antenna application.
- Perform analysis for the antenna's geometry and compare the theoretical results with the simulated results.
- To fabricate the designed antenna through PCB technology and then perform testing through VNA.
- To publish research papers for the work done.

1.18 METHODOLOGY

The entire process carried out to accomplish the project is mentioned below:

- The aim of thesis is to design passive RFID antenna for microwave range. The literature survey for the same was carried out. Various types of RFID antenna that have already been existing are inkjet deposited antenna , diamond shaped antenna, antennas with protruding stub in the ground plane, slot antenna, fractal antennas, wearable textile antennas. Here designing of CPW fed compact slot patch antenna structure which has wide bandwidth is been carried out.
- In order to design antenna for 2.4 GHz RFID application, initially rectangular patch was designed, studied and then modifications were done on it. Triangular notching was done at the corners of patch and rectangular slots were introduced to have the desired band.
- To have antenna at 5.8 GHz initially a criss cross shaped patch antenna was designed, studied and then modifications were done to it. Finally a jerusalem cross shaped patch antenna with small rectangular slots cut in the ground plane was designed. Both the antennas fulfil the requirement for RFID tag antennas. Miniaturization is achieved by making slots and CPW feed helps in attaining wide

bandwidth. Small size of antenna enables its easy mounting on the tag chip and thereafter on the object to be tracked.

- Dimension of the antennas were finalized by using design equations and parameteric sweep.
- The proposed antennas were simulated through CST (Computer Simulation Technology) Microwave Studio. It acts as a leading tool for accurate and speedy examination of high frequency devices. The parameters like radiation pattern, gain, return loss, impedance bandwidth, VSWR, axial ratio etc. will be studied through their respective graphs which results from CST microwave Studio tool.
- Then the fabrication of antennas was done using PCB technology. After the fabrication of the antenna SMA female connector was soldered to the antenna's printed microstrip line for the purpose of coupling. Then the finalized antenna was tested through the Vector Network Analyzer. The fundamental concept behind high frequency network study include incident, reflected and transmitted waves which travel along transmission lines and it should provide accurate measurement of all these waves. During impedance measurements accuracy enhancement techniques should be considered to correct effective source match, effective directivity and frequency tracking errors.
- The radiation pattern of the antenna could be measured by placing it inside an anechoic chamber along with reference horn antenna.

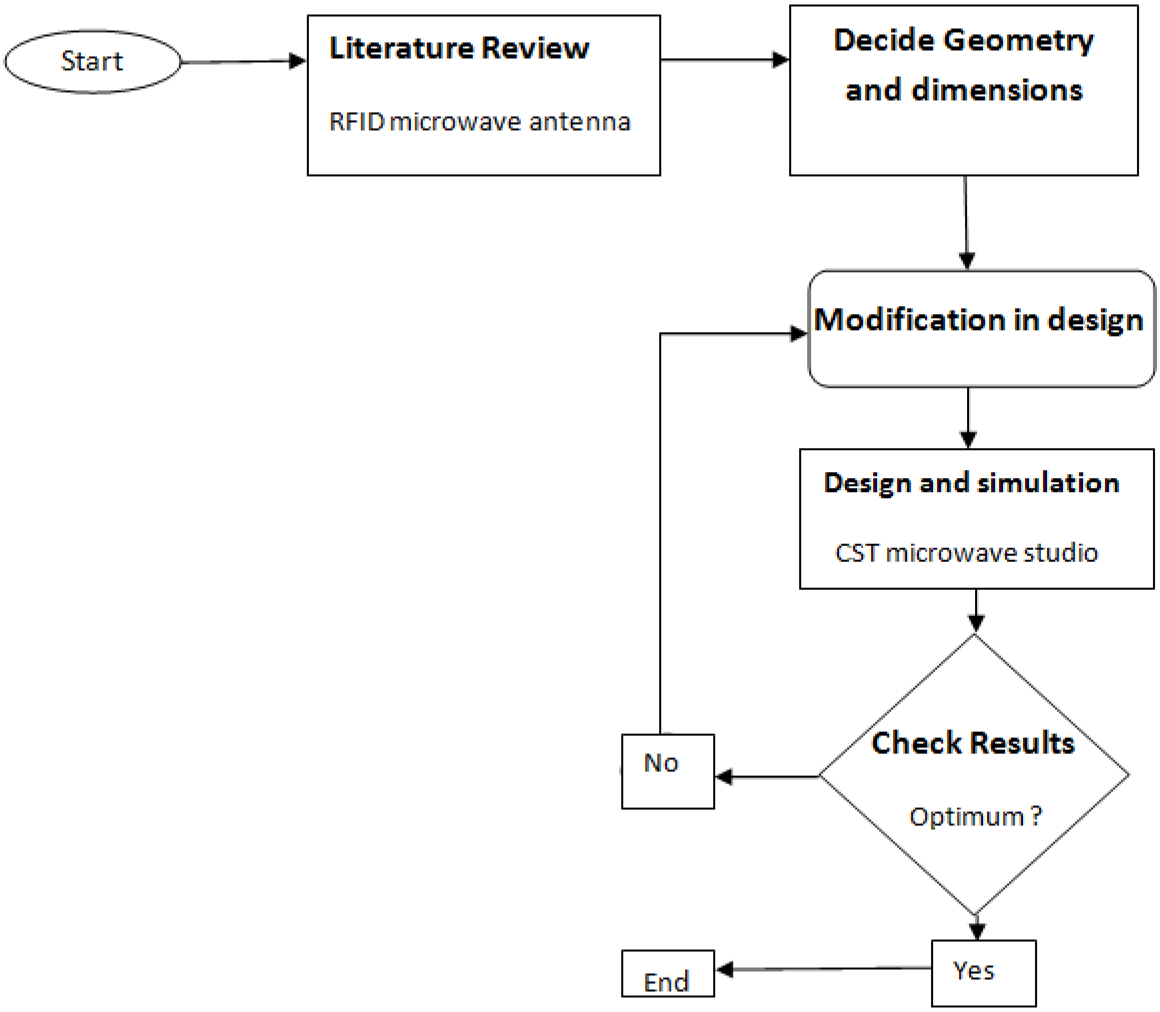


Fig 1.9 Flow chart of methodology

1.19 WORK COVERED IN THESIS

Two RFID antennas in microwave range of 2.4 GHz and 5.8 GHz are designed. 2.4 GHz RFID antenna is a bevelled rectangular patch antenna with two rectangular slits been etched out. 5.8 GHz RFID antenna is a compact cross shaped patch antenna with four rectangular slits been removed from the ground plane. Both antennas are fed with coplanar waveguide (CPW) which provide bandwidth enhancement and compatibility with any microwave device. Microwave range RFID antenna suffers from standing wave nulls defect in the presence of metallic environment. Therefore to solve this problem special tag antennas which usually have metallic ground need to be designed. The simulation and fabrication of the proposed antennas was carried out and thereafter testing was done. A comparative study between simulated and measured results for both the designed antennas was also done.

1.20 ADVANTAGES OF 2.4 GHz RFID BAND

- 2.4 GHz band is worldwide exempted from license which is advantageous when compared to 902-928 MHz band.
- It also supports wider bandwidth contrary to UHF bands. More channels are available in case of wide bandwidth.
- Because of good reflections from metal surfaces, better propagation takes place in cluttered surroundings.
- It propagates well through non conductive materials like wood based products, plastics, synthetic garments etc.
- Flexible and cheap antennas which can withhold sufficient bending can be achieved.

1.21 DISADVANTAGES OF 2.4 GHz RFID BAND

- The propagation distance is reduced for the same power.
- When range exceeds 1m, multipath effects and fading is required to be considered.
- At microwave frequencies, moisture contained substances may show energy absorbing properties.
- It is more prone to electronic noise as compared to other lower UHF bands.
- Spread spectrum radios, Bluetooth, TV devices, microwave ovens also share same spectrum as allocated for 2.4 GHz RFID.
- Process of regulatory approvals is still an ongoing process.

1.22 ADVANTAGES OF 5.8 GHZ RFID BAND

- It acts as a best option for real time location system (RTLS) as regards its price and accuracy.
- Systems based on such high frequencies provide data transportation between tags and receivers at higher speed. High data transfer rate proves useful for tracking, locating and communicating with various tags in motion like people, vehicles, and equipments. Tags at 5.8 GHz can be read with 250 Km/h speed accurately. The data rates provided by 5.8 GHz band falls from 2 Mb/s to 100 Mb/s.
- These systems support transmission of a wireless signal through leaky wave, by reflection that take place in crowded spaces like refinery.
- Such higher radio frequencies enable manufacturing of small devices which bear great efficiency for real time location systems and RFID tags (active).

- High traffic is present in other RFID bands of 433 MHz, 900 MHz and 2.4 GHz and suffers from low frequency signal disturbances which arise from other wireless devices. Therefore the receiver's complexity increases in order to reject such interference and noise so to maintain the quality of signal which increases complexity and price of the unit. Hence 5.8 GHz larger band are better as they are not that cluttered and nicely manage large capacity RTLS.
- Signal at 5.8 GHz has shorter wavelength as compared to other signals of RFID band and can easily pass through narrow spaces. It also has the ability to pass through similar kind of materials like waves of 433 MHz band. Therefore its penetration through holes present in obstacles is better. The Fresnel diffraction zone is also the smallest for 5.8 GHz band. Due to short wavelength at this frequency, antennas and other components like tags are smaller and energy efficient.
- 5.8 GHz band offers communication range which is similar to other frequency bands of RFID and the range is 0-1 km. But the bit error rate (BER) is less because of less crowded bandwidth. 75 MHz bandwidth is supported by 5.8 GHz ISM band and is twice of bandwidth supported by 2.4 GHz band.
- The electronics design present at 5.8 GHz is better. Here the antenna design can use transmission lines and hence leads to smaller and cheaper circuit boards. It results in very compact, energy efficient and lower cost device. Tags can be easily made in a single chipset for 5.8 GHz band.
- 5.8 GHz has compatibility with CMOS technology. And CMOS technology has various advantages it is a mature technology with low bias voltage (<3V), low power consumption, high level integration, and compatible with micromachining techniques (MEMS). Through CMOS technology it is also possible to build both analog and digital circuits in a single chip.

All the above points support great technological superiority for 5.8 GHz devices like purelink technology.

1.23 LIMITATIONS WHICH EXIST AT 5.8 GHZ RFID BAND

- At this frequency we have very directive antennas with very narrow bandwidth.
- Only few microchips available to provide modulation or processing of the signal.
- The bandwidth problem can be solved by using CPW fed slot antennas and using other conventional techniques for bandwidth improvement.

1.24 THESIS ORGANIZATION

Chapter 1: The detailed description of RFID technology is mentioned. It covers history, advantages, disadvantages, applications, physics of RFID, system performance. Different types of RFID antennas, environmental constraints and model for microwave passive RFID over multipath environment is also covered. It also includes origin of problem, gaps, objective, methodology, thesis organization.

Chapter 2: A brief survey of design techniques related to RFID microwave antenna has been done which helped in understanding the different requirements of reader and tag antenna. Various types of antenna like inkjet deposited antenna, fractal antenna, slot antenna, antennas with protruding stub in ground plane, textile antennas have been covered.

Chapter 3: In this chapter designing of CPW fed bevelled rectangular patch antenna with two rectangular slots made on the patch is carried out for 2.4 GHz RFID application. The design and simulation is executed in CST microwave studio. Fabricated and simulated results become part of this chapter. Simulated results cover return loss, smith chart, gain, radiation pattern, axial ratio, VSWR, surface current distribution. The patch design equations and the design analysis are also covered. The return loss after testing of antenna through Vector network analyzer (VNA) is mentioned as well.

Chapter 4: This chapter includes design of miniaturized Jerusalem cross shaped patch antenna with rectangular slots present on ground plane. The antenna is CPW fed and serves to be an RFID tag antenna for 5.8 GHz band. Simulated results, design analysis and equivalent model for the designed antenna are presented. The return loss after testing of antenna through Vector network analyzer (VNA) is mentioned as well.

Chapter 5: The conclusion of thesis work and the scope of future work have been covered here. Measures to improve the gain of antenna are discussed.

1.25 CONCLUSION

The RFID system has been studied in all aspects regarding its background, physics involved, advantages, disadvantages and applications. The outline of thesis work is mentioned. The benefits and limitations of the chosen frequency for designing of the antenna for this project work are also covered.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The various design techniques of RFID microwave antenna are mentioned here. Different ranges of RFID require different types of antenna like UHF antennas are generally loop antennas, meandered antennas whereas microwave RFID antennas are mostly patch antenna. The techniques which came up successively for RFID microwave antennas design are discussed below.

2.2 PROGRESS OF RFID MICROWAVE ANTENNA

D. Ma et al. (2006) designed broadband CPW fed RFID antenna at 5.8 GHz. The designed antenna is having a rectangular patch along with folded slot that is made on the upper part of the substrate and it can also be visualized as a wider slot excited by top loaded monopole. The antenna is very compact having size of 16mm*15 mm and is designed on FR4 substrate with thickness of 1.6 mm. The bandwidth supported by this antenna is 26% and gain is 2.9-3.3 dBi [9].

Matti Mantysalo et al. (2009) presented an inkjet deposited antenna for 2.4 GHz applications. Here the antenna is designed using inkjet deposited conductors and then the electrical properties of this technology are evaluated and then a patch antenna is designed for 2.4 GHz. The paper is focussed on different design techniques which support high conductivity at low temperatures which is less than that required for nano particle sintering for the manufacturing process the substrate used is thin PET films. UV is used after printing to activate the catalytic material and then the printed patterns are passed through metal growth procedure. This method combines the high conductivity of PCB technology with the versatility of digital printing. The designed antenna is having low production cost because of relative fast printing speed and requirements of small number of process steps [10].

Mursyidul Idzam Sabran et al. (2011) designed a dual band diamond shaped antenna for RFID application. The designed antenna is having radiating element in shape of diamond which is simple structure and enable antenna to perform in dual band frequency. The resonating frequencies attained with this antenna are at 912 MHz and 2.457 GHz. A square aluminium plate is provided at the back of the substrate at a 5mm air gap with the help of PCB stand and it increases the gain of the antenna making it suitable for RFID application. The size of the radiating element has control over the lower frequency band whereas the higher frequency is controlled by the radius of the dual orthogonal quadrant at the radiating element edges [11].

J.R. Panda et al. (2011) proposed a printed 2.4 GHz/5.8 GHz dual band monopole antenna with a protruding stub in the ground plane for WLAN and RFID applications. The antenna is having two resonance paths, one path is supported by the folded strip of the radiating element and the other is present in the protruding stub in the ground plane. The design of the antenna is completed by having a non-conductor backed folded strip with a microstrip feedline. By finely tuning the lengths of the two resonant paths, a dual band is achieved. The antenna supports two resonant frequencies of 2.4 GHz and 5.81 GHz, which are the center frequencies for WLAN and RFID applications. It can also be used for zigbee operation [12].

X.Y. Teng et al. (2012) proposed a compact CPW fed omni directional monopole antenna for WLAN and RFID applications. The designed antenna structure is an inverted trapezoid patch which is loaded with T shaped patch and a Π shaped slot. The trapezoid patch lower end is connected at the end of the CPW line. The Π shaped slot is responsible for resonant mode at 5 GHz. Good gain characteristics and omnidirectional radiation in the desired frequency bands of 2.36 GHz to 2.5 GHz and 5.01 GHz to 6.33 GHz are achieved [13].

Zeng Wen-bo et al. (2013) proposed a dual band RFID slot tag antenna for ITS application. The dual band of antenna includes RFID frequency band of 902-928 MHz and microwave band of 2.45 GHz. This antenna is having comb-shaped printed slot and is etched on single side of FR4 PCB. Good performance with regard to impedance matching and transmission of power between the antenna and the RFID chip is obtained. The reading range of 5.2 meters at UHF band and 12.6 metres at microwave band is achieved. So this antenna serves good for Intelligence transportation system (ITS) applications [14].

Chitra Varadhan et al. (2013) designed triband antenna structure for RFID system deploying fractal geometry. Here two triband antennas are presented and are meant for the RFID reader and the other one for the RFID tag. The fractal structure used for the reader antenna design is modified fractal tree structure, where in each iteration, the angle between the two twigs gets reduced by half. This geometry supports miniaturization as well as leads to multiband or broadband antennas. The tag antenna design is depending upon recursive rectangular structures. The reader antenna resonates at 3.6, 5.8 and 8.2

GHz. The operating frequencies of tag antenna are 3.9, 5.9 and 8.2 GHz. The applications supported by this antenna are logistics management, traffic toll collection, and tagometry [15].

M.E. de cos et al. (2013) designed polypropylene based dual band CPW fed monopole antenna. The proposed antenna's ground plane is having two symmetrical trapezoids on either side of coplanar waveguide line. Polypropylene based antennas are very cheap and can also be manufactured using laser micromachining, hence no additional processing is needed. They are light weight, moisture robust and exhibited good radiation characteristics, similar to that of an antenna or conventional rigid dielectric substrate. And so this antenna can be used for 2.45 GHz and 5.8 GHz dual band RFID application. By optimizing the dimensions of the designed antenna, it can also be used in wearable WLAN applications [16].

H. Nornikman et al. (2013) presented a dual layer rectangular microstrip patch antenna with H slot for 2.4 GHz range applications. This antenna is having two layers with H slot patch present on the upper layer. The bandwidth of the proposed antenna lies in between 2.39 GHz and 2.48 GHz frequencies. The performance of this antenna can be improved by using embedded split ring resonator (SRR) added dielectric resonator on the patch antenna and the gain improvement can be attained by using array of antenna [17].

Nasser Ojanoudi et al. (2013) designed compact H-ring antenna with dual-band operation for wireless sensors and RFID tag systems in ISM frequency bands. The antenna operates at 2.45 GHz and 5.8 GHz. By having only H-shaped patch, resonance at lower frequency (2.45 GHz) is achieved. The antenna is small sized and serves to be a good candidate for RFID applications. In the proposed antenna good dual band operation is obtained by having H shaped slot generates additional surface current paths and hence additional resonance gets excited. This results in wider impedance bandwidth specifically at higher band [18].

Son Xuat Ta et al. (2013) proposed circularly polarized crossed dipole on an HIS (high impedance surface) for 2.4/5.2/5.8 GHz WLAN applications. The designed antenna is having two printed dipoles, coaxial line, and HIS reflector. The HIS reflector is made of compact two dimensional array of square patches which is printed on substrate and help achieve broad impedance and AR bandwidth performance and good unidirectional gain patterns. Each trident shaped arm of the dipole is broken into three branches of different lengths, which help achieve operating frequency in the 2.4/5.2/5.8 GHz WLAN bands. The trident arm contains compact meander line and its end is shaped like an arrowhead to miniaturize its size. To achieve CP radiation, the dipoles are crossed through a vacant quarter printed ring that enables broadband characteristics [19].

Guo Liu et al. (2013) designed dual band microstrip RFID antenna with tree like fractal structure. The tree like pattern which is present on both sides must be aligned perfectly. After applying tree like structure on the simple patch the notch response is attained by means of mu-negative (MNG) resonator which blocks the electromagnetic (EM) propagation inside the patch and hence divides the band of operation into two with the designed frequencies of operation. The proposed antenna covers dual band RFID applications. Antenna response is affected by the height above the ground plane of fractal structure. The narrower line width, larger branch length, and higher dielectric constant of the substrate help in lowering the resonant frequency [20].

Wenbin Zeng et al. (2014) presented miniaturized I shaped slot circularly polarized RFID antenna. In the centre of the square patch I-shaped slot was made having inclination angle of 45°. This helps achieve circular polarization. Further antenna design includes cutting four slits on the patch which help reduce the size of antenna. By adjusting the dimension of I shaped slot good axial ratio performance is obtained [21].

Ma Chao et al. (2014) proposed two types of compact dual band RFID planar antennas. In this paper two antennas having unequal lengths, rounded arm U shaped antenna and round patched antenna are presented. It is having microstrip lines on both the side of substrates and satisfies dual bands with their length difference. Meander shape is made on the lines to reduce its size and modification of the microstrip arm is done to get tree form. Thus we obtain two types of symmetric antennas that realize multiple bands along with miniaturization. The operating frequency is 1.8 GHz and 2.4 GHz [22].

M. Virili et al. (2014) presented a wearable textile antenna which is magnetically coupled to flexible active electronic circuits. Here textile wearable electronic module and is characterized by magnetic coupling of antenna to active circuitry. The heterogeneous transformer which is having primary and secondary windings present in the antenna and in its substrate provides the coupling. The aim of the antenna and transformer design is maximize the transfer of power between the antenna and the load present in the secondary winding. The interaction of radiation with human is reduced by the presence of ground plane. The proposed system area of operation lies in the ISM/SRD frequency band (2.4 GHz) [23].

Huihui Li et al. (2014) proposed a modified miniature tri band CPW fed antenna is having two U shaped, four L shaped and two F shaped branches in order to achieve multi band performance. These branches serve as additional resonators which make the antenna resonate at multiple frequency bands at 0.915 GHz, 2.45 GHz, 3.5 GHz and 5.8 GHz. Two L shaped branches help achieve lower bands (0.915 GHz and 2.45 GHz) while the other two give higher bands (3.5 GHz and 5.8 GHz).The F- shaped branches enable compact antenna characteristic. This single antenna is suitable for triple band RFID application and multiband WiMAX/WLAN applications [24].

I-Fong Chen et al. (2015) designed a novel reduced size RFID reader micro strip antenna for UHF band applications. This antenna is having two substrates of same size, thickness and permittivity with spacing of 50 mm between them, one substrate acts as patch and the other acts as a metal reflector. Dual microstrip line and ground loop reside on the patch. The tuning of pattern shape can be done by adding metal reflector beneath the patch. The proposed antenna is 37% smaller in comparison to rectangular patch due to the surrounded ground [25].

Qiang Liu et al. (2015) designed a dual-band, directional microstrip antenna at 0.92/2.45 GHz for handheld RFID reader applications. The proposed antenna is having three substrate layers, two patches, an air layer filled between circular patch on the top of substrate and square patch exixting on middle substrate, a ground plane, dual feed network which feeds quadrature signals present across bands of 0.92 and 2.45 GHz. The antenna is compact in size and circularly polarized [26].

Le Chang et al. (2015) presented a compact single feed dual mode antenna for active RFID tag application. This antenna is having a slotted patch and a foam spacer. The two slots present are perpendicular to each other and are fed by two microstrip lines which meet at the feeding point. The proposed antenna supports two operating modes: dipole mode when placed in free space and patch mode when placed on metal surface. It operates in microwave frequency and contains no ground plane [3].

A.E. Hamroui et al. (2015) presented a new design of a small sized dual band printed antenna for RFID applications. This antenna is having two monopoles of different lengths. The two monopoles are combined at their lower ends and fed by CPW. The CPW feed provides advantage of easy integration of antenna with microwave integrated circuits. The longer monopole serves for lower frequency band of 2.4 GHz whereas shorter monopole is dominant at higher frequency of 5.8 GHz. This antenna is having sufficient gain and is low profile, low cost [27].

M.A. Malek et al. (2015) proposed a dual band CPW fed transparent antenna for active RFID tags. This antenna is designed with AgHT-8 thin film which is having silver coated polyester acting as conductive layer and substrate of polyethylene terephthalate (PET). AgHT-8 has transparency above 80% which helps provide ability of laminating the tag devices surface with low chance of detection. This antenna is having smaller thickness and lighter structure as compared to non-transparent designs [28].

Thirumalai T. et al. (2015) designed a low power based slotted patch antenna supporting RFID reader applications. The proposed antenna is having metallic rectangular patch. The patch is having a slot at the center. The sensitivity to feed position and slot width is used as a flexible way of fulfilling various requirements of RFID applications. RFID system requires wide variety of patch antennas as different objects are present which should hold the tag [29].

Bhushan Bhimrao Dhengale et al. (2015) presented 5.8 GHz ISM band microstrip antenna for RFID application. The designed antenna is having rectangular patch and fed with microstrip line. Firstly the antenna is designed using standard design equations of rectangular patch. Then another antenna with reduced size is designed which provides increase in overall gain and maintains good low return loss. This reduced size antenna size provides better range coverage and better speed as gain is high. The bandwidth attained is 380 MHz in 5.8 GHz ISM band [30].

Adil Zaman Babar et al. (2015) proposed U slot microstrip patch antenna supporting truncated corners. Its performance improvement was attained by using EBG structures. It is dual band antenna with circular polarization (CP) in the lower band. Circular polarization is achieved by having truncated edges of U shaped slot patch. By deploying mushroom type EBG (Electromagnetic Band Gap) structures on the substrate, the return loss, gain, AR (axial ratio), directivity of the antenna improved. By EBG the surface waves, sidelobe backlobe levels and cross polarization gets reduced. The designed antenna gave dual band at 3.6 GHz and 5.8 GHz [31].

Le Chang et al. (2016) proposed a dual environment active RFID tag antenna which can be mounted on metallic objects. The designed antenna is having meandered microstrip line, a patch with a slot and a foam spacer. The microstrip line passes the two slots off center in order to support two different operating modes under different working environments. When the antenna is having free space condition then the 50 ohm load is present due to the slot mode of the antenna or the radiation is contributed only by the slot at the input port. And when the antenna is placed on a conductive surface, the slot mode supports high impedance at the input port while the patch mode radiates as it is matched [32].

2.3 CONCLUSION

The literature survey of various designing techniques for RFID microwave antennas has been studied in detail. The different requirements of these antennas in terms of shape, size, material, polarization, gain, radiation pattern have been understood through this survey. The knowledge of techniques for improving the results in terms of bandwidth, polarization and other factors is facilitated through the papers studied.

CHAPTER 3

DESIGN OF CPW FED BEVELLED RECTANGULAR PATCH ANTENNA WITH RECTANGULAR SLOTS FOR RFID TAG ANTENNA APPLICATION AT 2.4 GHz

3.1 INTRODUCTION

In this chapter a new microwave range RFID antenna is proposed. The proposed antenna is having simple design structure enabling small sized antenna for 2.4 GHz RFID application. Slotting and bevelling techniques are used in the antenna design for improving the return loss characteristics and bandwidth. Because this antenna is compact, and linearly polarized it serves best as tag antenna. Regarding RFID application the given antenna can be used for asset tracking, temperature management, vehicle access control, shipping container management, personnel tracking health care, manufacturing, building access control. The antenna can also be used for bluetooth, zigbee, WLAN which all work at 2.4 GHz.

3.2 ANTENNA CONFIGURATION

The designed antenna (shown in Fig. 3.1) is having rectangular patch with bevelled ends. The overall size of the antenna is 46mm*43mm and the size of the patch is 38mm*25mm. Two rectangular slits are inserted in the patch. This antenna is fed by coplanar waveguide (CPW) and etched on FR4 substrate having thickness of 1.6 mm and ϵ_r=4.3. The center width of CPW feed line is 3 mm and 0.5 mm gap is present between one side of the strip and the ground plane.

By having triangular notches at corners of the rectangular patch, balance is obtained between vertical and horizontal electric currents which are present which are present on the patch. This will help achieve good impedance characteristics and improve total bandwidth of antenna. The CPW feed technique used in the proposed antenna is one in which etching is done on only one side of the substrate. This enables removal of misalignment between the radiation patch and ground. Therefore this antenna becomes easily compatible with other microwave devices.

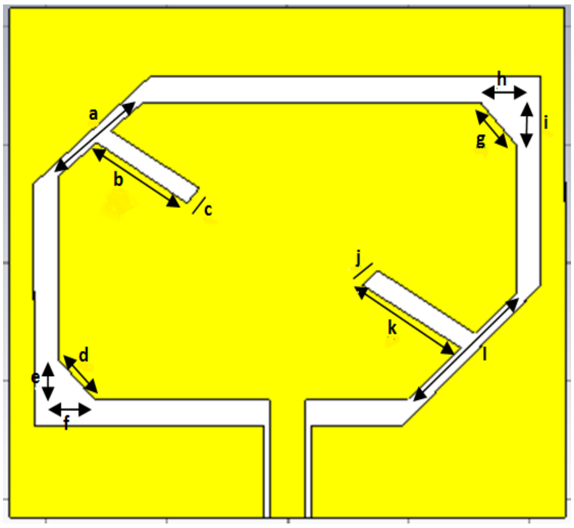


Fig. 3.1 Designed antenna operating at 2.4 GHz

Table 3.1 Paramters dimension

S.No.	Parameters	Value (mm)
1.	A	9.35
2.	B	9.5
3.	C	1.6
4.	D	4.53
5.	E	3.4
6.	F	3
7.	G	4.7
8.	H	3
9.	I	3.6
10.	J	1.77
11.	K	9.7
12.	L	12.73

3.3 DESIGN STEPS

The step by step designing of the antenna alongwith their return loss curves is shown below:

1. A rectangular patch antenna (Fig. 3.2) with patch dimension as 38mm*25mm is designed. The resonant frequency achieved by this antenna is at 2 GHz (Fig. 3.3).

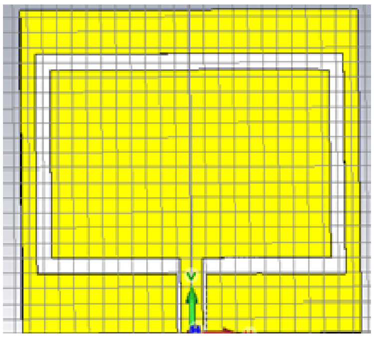


Fig. 3.2 Rectangular patch antenna

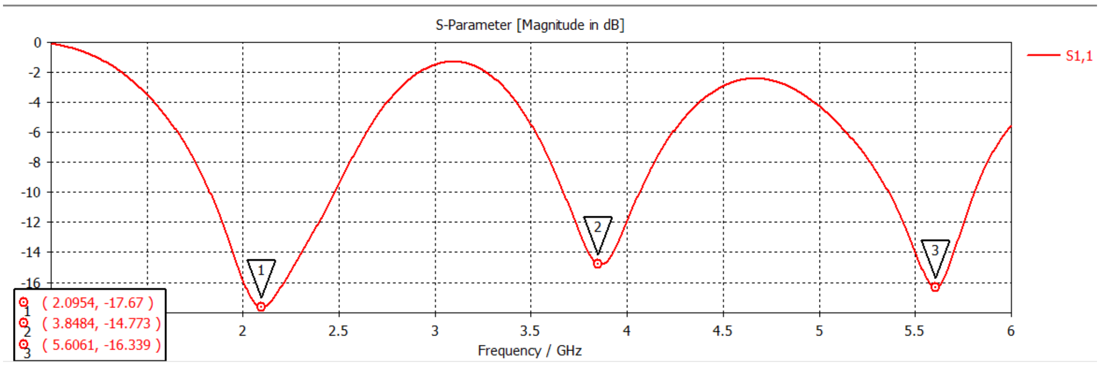


Fig. 3.3 Return loss v/s frequency

2). Triangular notches are made at the corners of the antenna and then the return loss is studied for this particular design (Fig 3.4). The resonant frequency is shifted to 2.17 GHz with improved return loss and bandwidth (Fig 3.5).

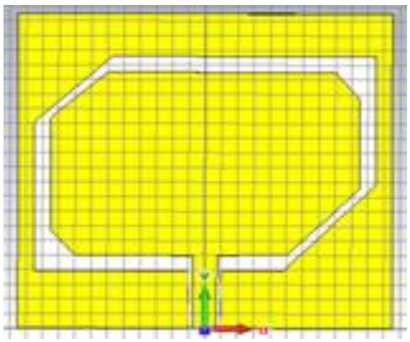


Fig. 3.4 Beveled antenna

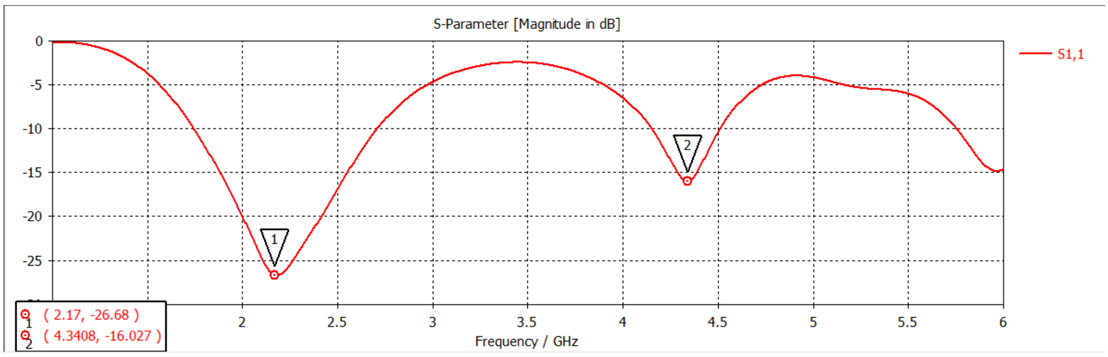


Fig. 3.5 Return loss v/s frequency

3). The parameteric analysis by varying the width of central microstrip line was carried out and studied. The return loss graph for the same is depicted in Fig. 3.6. The best return loss was obtained for 3mm width so it was kept as final width.

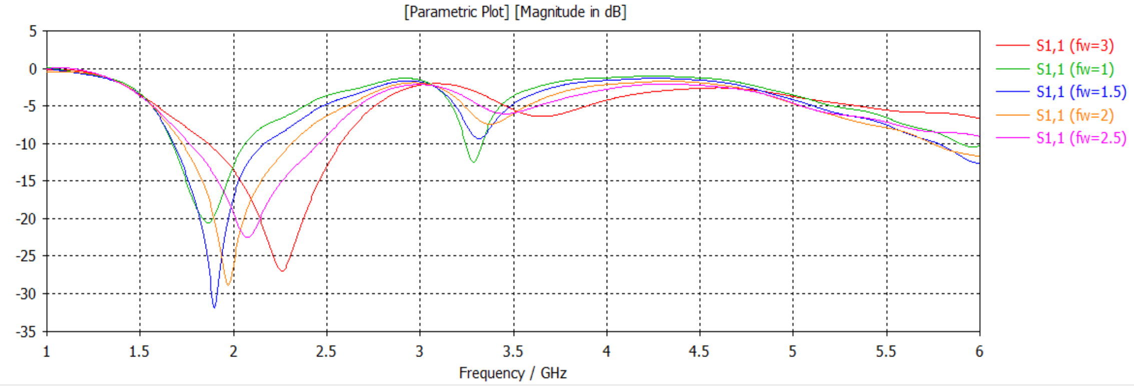


Fig. 3.6 Return loss after parametric analysis

4). The final design (Fig. 3.7) is having rectangular slits been inserted which further reduce the size of the antenna and moves the resonant frequency to 2.26 GHz (Fig. 3.8). The designed antenna is having required frequency of 2.4 GHz covered in its band with return loss of -18 dB.

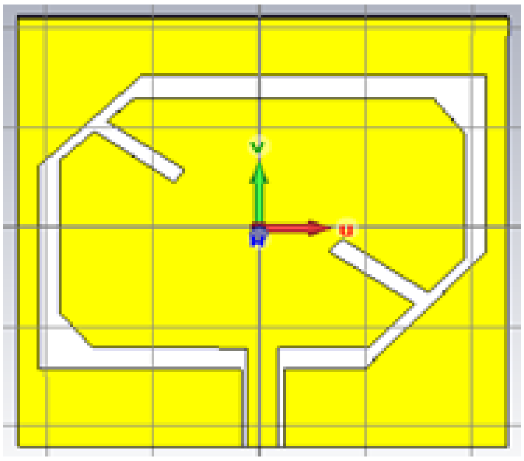


Fig. 3.8 Final antenna design for 2.4 GHz

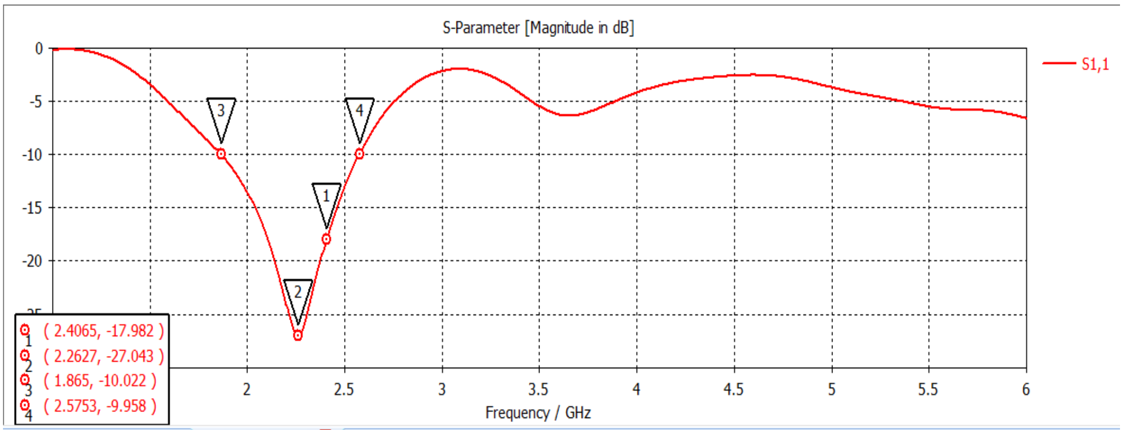


Fig. 3.9 Return loss v/s frequency

3.4 MATHEMATICS OF PATCH DESIGN

The dimensions of the rectangular patch are calculated as:

Width of the patch is:

$$w = \frac{c}{2f_0\sqrt{\frac{\epsilon_r+1}{2}}} \tag{3.5}$$

Length of the patch:

$$l = \frac{c}{2f_0\sqrt{\epsilon_{eff}}} - 0.824h\frac{(\epsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \tag{3.6}$$

Effective dielectric constant:

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12(\frac{h}{W})}}\right) \tag{3.7}$$

where f_0: resonating frequency

h: height of patch

w: width of patch

ϵ_r: dielectric constant of substrate

ϵ_{eff}: effective dielectric constant

l: length of the patch

The length and width calculated from the above equations for 2.4 GHz frequency turns out to be 38.01 mm and 29.42 mm. But the actual length and width is 38mm and 25 mm respectively. So the error present in width dimension is 15%.

3.5 SIMULATED RESULTS

The designed antenna is having its central frequency at 2.3 GHz and the bandwidth attained is 720 MHz as shown. The band covered by this antenna starts at 1.8 GHz and ends at 2.57 GHz (Fig. 3.10).

3.5.1 Return Loss: It represents the power loss in the signal which gets reflected due to discontinuity present in transmission line. The discontinuity can be attributed to mismatch with the load. It is expressed as ratio.

$$RL(dB) = 10 \log_{10}\frac{P_i}{P_r} \tag{3.1}$$

where P_i: incident power, P_r: reflected power

Return loss measures how nicely lines or devices are matched. High value of return loss specifies good matching and it is desired. For the designed antenna, the return loss at 2.4 GHz is -18.17 dB (Fig. 3.10).

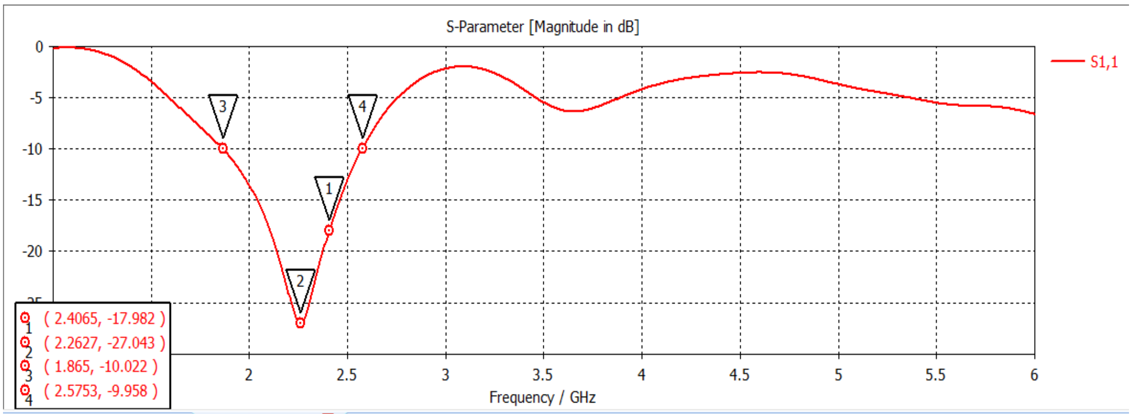


Fig. 3.10 Return loss v/s frequency

3.5.2 Smith chart: It is a plot on complex reflection coefficient plane and its scaling is in terms of normalized impedance, normalized admittance or both. The normalization impedance used commonly is 50 ohms. Locus of points present on smith chart and which cover range of frequencies are used for visual representation of:

- The extent of inductiveness or capacitiveness of load across the frequency range.
- The extent of matching of a particular component.
- Difficulty of matching present at various frequencies.

The impedance matching of the proposed antenna is 50.2 ohm at 2.4 GHz represented through smith chart in Fig. 3.11.

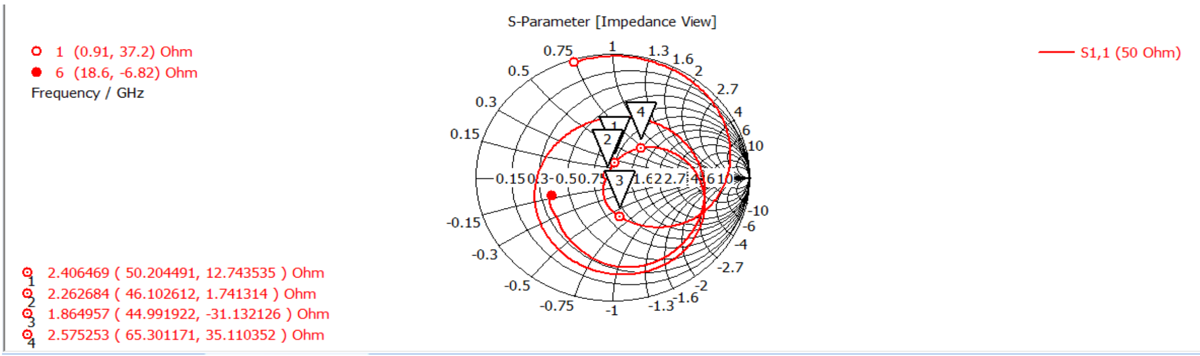


Fig. 3.11 Smith chart

3.5.3 VSWR (Voltage Standing Wave ratio): It is a numerical measurement of how nicely the antenna is impedance matched with the transmission line to which it is connected. VSWR can also be refered as standing wave ratio(SWR).

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.2}$$

Where Γ: reflection coefficient / S_{11}/ return loss

Physically VSWR means the ratio of maximum and minimum amplitude of a standing wave. The standing wave is formed along the transmission line when power is reflected back as antenna is not properly matched to the receiver. The range of VSWR lies from 1 to ∞. For the perfect matching case VSWR equals to 1. Practically it should be near to 1. The VSWR of this antenna is 1.34 as shown in Fig. 3.12.

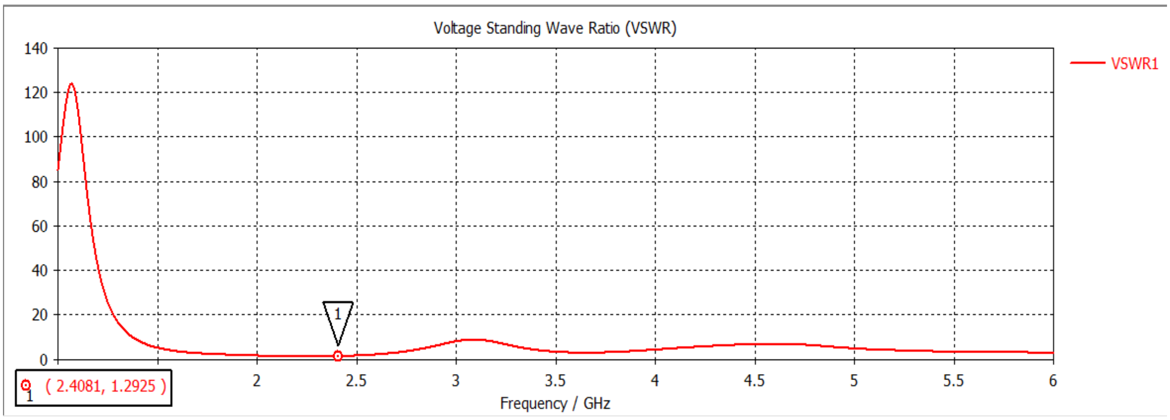


Fig. 3.12 VSWR v/s frequency

3.5.4 Antenna gain and directivity: Gain is described as the ratio of antenna's power produced by it from a far field source presnt on the antenna's beam axis to the power which is produced by a hypothetical lossless isotropic antenna. The unit used to express gain is " decibels – isotropic" (dBi).

Directivity doesn't include electrical efficiency of antenna and it is defined in a particular direction as the ratio of radiation intesity of antenna in the given direction to the mean radiation intesity.

$$G = E_{antenna} * D \tag{3.3}$$

where $E_{antenna}$: efficiency

$$D(\theta, \emptyset) = \frac{U(\theta,\emptyset)}{\overline{U}} \tag{3.4}$$

where $U(\theta, \emptyset)$: radiation intesity in given direction

$\overline{U}$: mean radiation intesity

The gain attained by the given antenna is 2.2 dBi and directivity is 3.1 dBi as shown in Fig. 3.13 and Fig. 3.14 respectively.

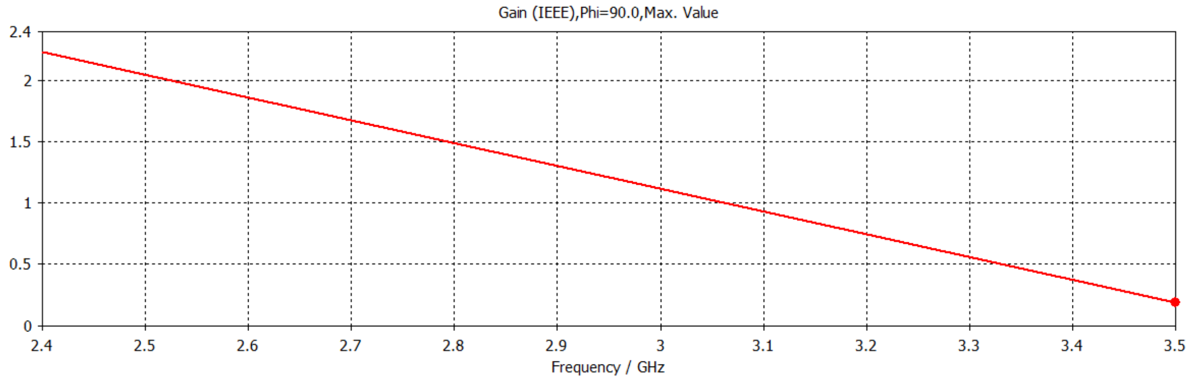


Figure 3.13 Gain of antenna v/s frequency

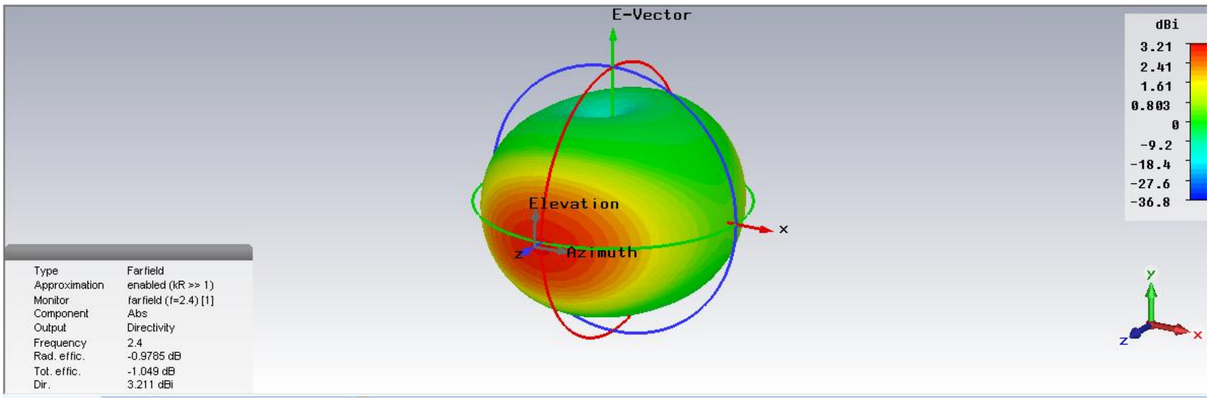


Fig. 3.14 Farfield pattern (directivity)

3.5.5 Radiation Pattern : It is variation in the antenna's radiated power depending on the direction away from the antenna. In the antenna's far field we can observe this power variation with respect to the arrival angle. The 3-D far field radiation pattern is shown in Fig. 3.14. E field radiation pattern is shown in fig 3.15 a. for which ϕ=0. H field radiation pattern is shown in Fig. 3.15 b. for which θ=0.

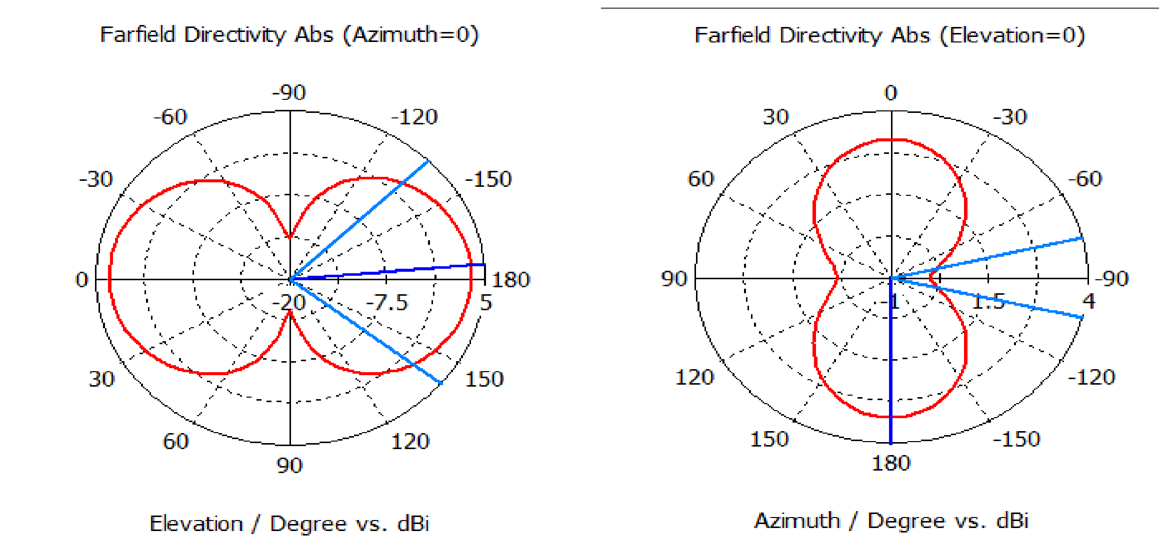


Fig. 3.15 Azimuthal and elevation radiation pattern

3.5.6 Current Distribution: The current/ field distribution over the patch are used to know the electromagnetic behaviour of antenna in detail. The surface current disrtibution for the proposed antenna is given in Fig. 3.16. It is observed from the figure that current is at its peak around the edges of microstrip line and around the edges of the left rectangular slot present on the patch.

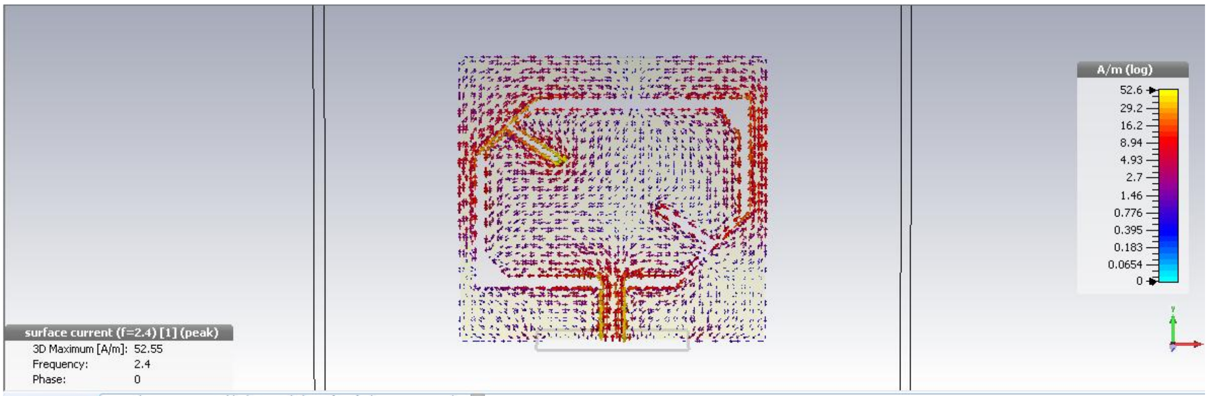


Fig. 3.16 Current distribution of antenna at 2.4 GHz

3.5.7 Axial ratio: It is the ratio of E field's orthogonal components. For circular polarization, field consists of two orthogonal components of E field which are having equal amplitude and the axial ratio for circular polarization is 1(0 dB). For special linear polarization cases, infinite axial ratio is defined. The axial ratio for proposed antenna is 21 (Fig. 3.17), which specifies it to be linearly polarized.

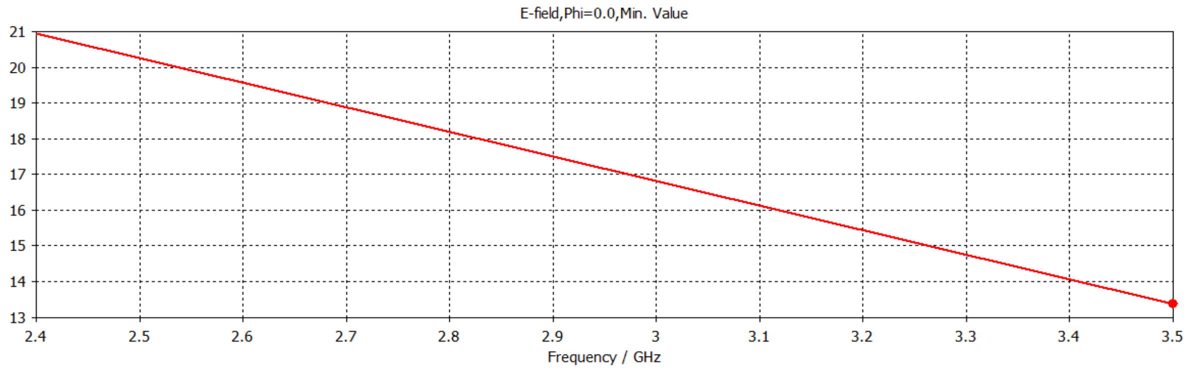


Fig. 3.17 Axial ratio v/s frequency

3.6 FABRICATION AND MEASUREMENTS RESULTS

After optimizing the geometrical specifications, the simulated beveled rectangular patch antenna for 2.4 GHz RFID was fabricated on FR4 dielectric substrate (ϵ_r=4.4, tanδ=0.0024, thickness h=1.6). The fabrication is done through photo lithographic method which requires ultraviolet light of appropriate wavelength and photo resist whih is sensitive to this particular wavelength. Two types of photo resist material exist, positive and negative. The photo resist developer dissolves in it the exposed part of positive photo resist whereas the negative photo resist gets hard. The following step by step process is followed for the fabrication of microstrip patch antenna.

After having computer aided design of the proposed antenna geometry, its negative is printed on transparent sheet which acts as the mask. Single sided copper clad substrate is nicely cleaned using acetone and the allowed to dry. This is done in order to ensure proper conductivity as impurities residing on copper surface bring discontinuity in and hence alters the resonant frequency. After this lamination through negative photo resist film is done on cleaned and dried copper. Then it is exposed to ultra violet (UV) light. After developing the copper clad substrate it is etched through FeCl_3(Ferric chloride) solution. This etched substrate is then rinsed in water and thereafter dried. The photo resist which still remains is removed with the help of sodium hydroxide. The photograph of finally fabricated antenna is presented in Fig 3.18.

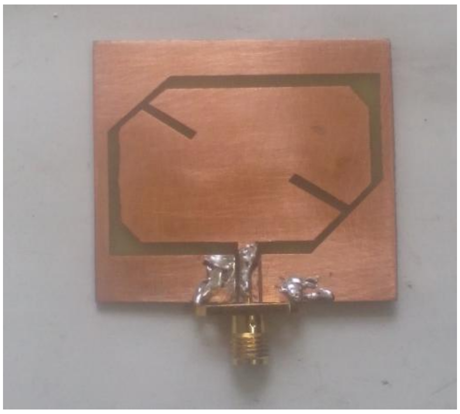


Fig. 3.18 Photograh of the fabricated antenna for 2.4 GHz

The return loss (Fig. 3.19) of the final fabricated antenna was measured and tested through Agilent E5071C vector network analyzer present in antenna research laboratory, Thapar University, Patiala. The measured return loss is having value of -26.64 dB at 2.43 GHz. This marks the first band and its bandwith is 439.3 MHz. The availability of this band makes the antenna applicable for the RFID application at 2.4 GHz. The second band covered is having its central frequency at 1.9 GHz with a bandwidth of 89 MHz. The value of return loss at 1.9 GHz is -25.9 dB. A graph containing both simulted result as well as measured result is shown in Fig. 3.20. The slight variation present in both the results can be attributed to the fabrication process, connector losses. The return loss is reduced in measured result but is still below -10 dB and hence makes the antenna available for practical use.

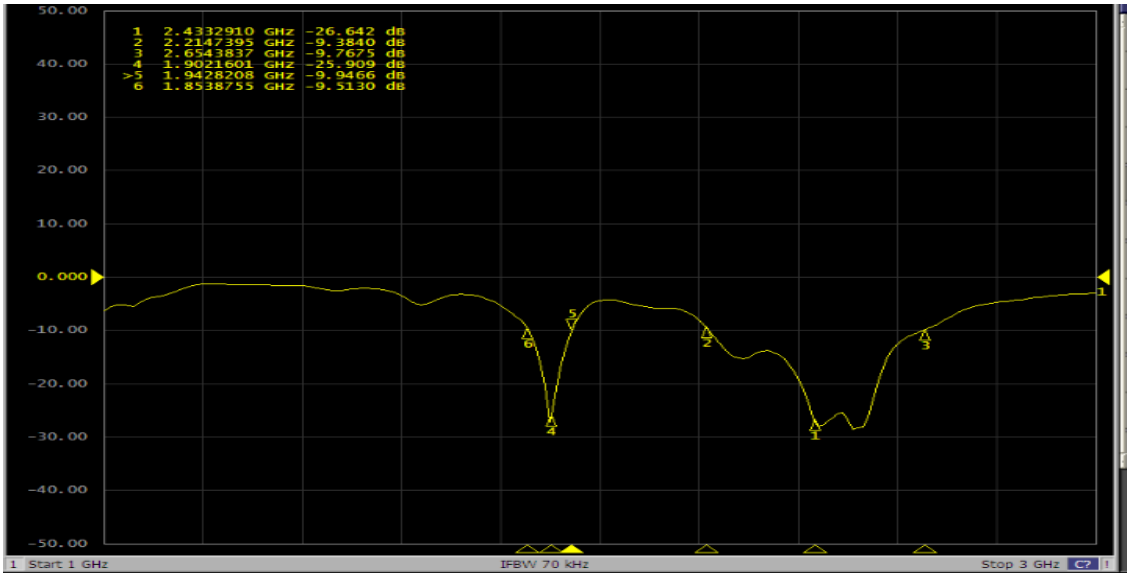


Fig. 3.19 Measured return loss v/s frequency

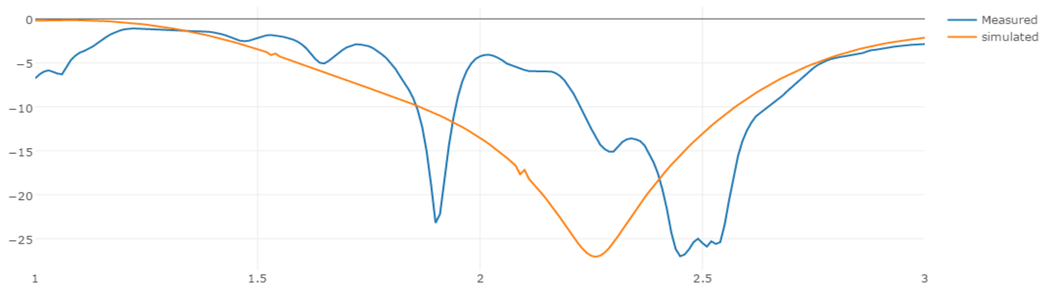


Fig. 3.20 Comparison of measured and simulated return loss

3.7 CONCLUSION

A beveled rectangular patch antenna with two rectangular slots and fed by CPW feed is designed. The rectangular slots placed on the patch help in size reduction and excite additional resonant modes which enhance antenna's impedance bandwidth.Triangular notches placed at the corners of the patch bring changes in current distribution and therefore excite resonant modes differently as compared to simple rectangular patch without bevelling. This help us achieve the desired band. This antenna was targeted to be an RFID tag antenna at 2.4 GHz range. As it is having linear polarization and is compact in size, it fulfills to be an RFID tag antenna. The wide impedance bandwidth of 720 MHz is achieved through simulation and its gain is 2.2 dBi. This antenna when placed on tag chip must match to the chip impedance for maximum power transfer. Hence impedance matching circuits can be used to achieve the same.

CHAPTER 4

DESIGN OF MINIATURIZED, CPW FED JERUSALEM CROSS SHAPED PATCH ANTENNA WITH RECTANGULAR SLOTS ON THE GROUND PLANE FOR RFID TAG ANTENNA APPLICATION AT 5.8 GHz

4.1 INTRODUCTION

In previous chapter RFID antenna at 2.4 GHz was introduced and in this chapter another microwave range antenna operating at 5.8 GHz is proposed. The design of this antenna was chosen to be Jerusalem cross as it is symmetrical, and occupies less space therefore provide very compact, simple antenna. Slotting is done on the ground which helps improve return loss. The designed antenna can be used for long range access control for vehicles, vehicle identification, supply chain, automated toll collection.

4.2 ANTENNA CONFIGURATION

The dimension of the proposed antenna (Fig. 4.1) is 20mm*30mm. The antenna is having cross shaped patch and is of 2mm width. The length of vertical strip is 22.5 mm and the length of horizontal strip is 12 mm. The antenna is etched on Rogers RT 5880 substrate with ϵ_r=2.2 and its height is 1.6mm. Four rectangular slots are also inserted on the ground plane. The feed used is CPW (coplanar waveguide). In CPW feeding, etching is carried out on only one side of the substrate and therefore helps in removing misalignment between the radiation patch and ground. Hence this antenna becomes compatible with any microwave device.

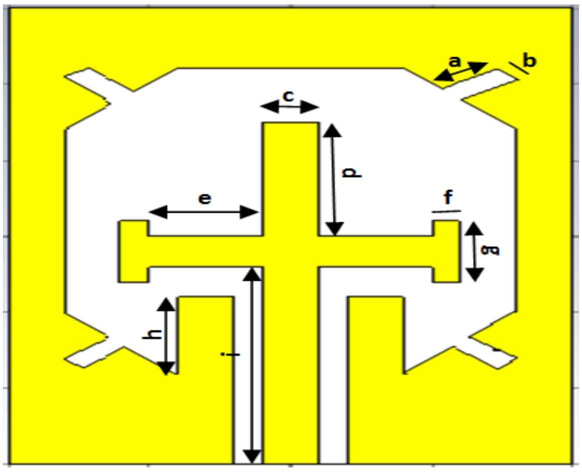


Fig. 4.1 Proposed antenna design at 5.8 GHz

Table 4.1 Parameter dimensions

S.No.	Parameter	Value (mm)
1.	a	2.3
2.	b	2.72
3.	c	2
4.	d	7.5
5.	e	5
6.	f	1
7.	g	4
8.	h	5.06
9.	I	13

4.3 DESIGN STEPS

1). Criss cross shaped patch antenna with vertical slit of 22.5 mm length, 2mm width and horizontal slit of 12 mm, 2 mm width is made (Fig. 4.2). The central resonating frequency is achieved at 5.8 GHz with return loss of -14 dB (Fig. 4.3). The impedance matching of this design is 33.8 ohm which is very poor.

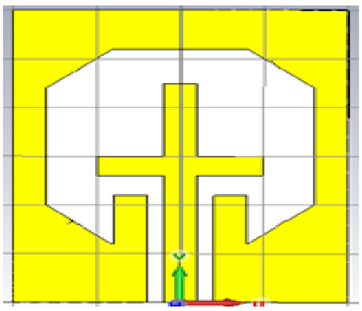


Fig. 4.2 Criss cross shaped patch antenna

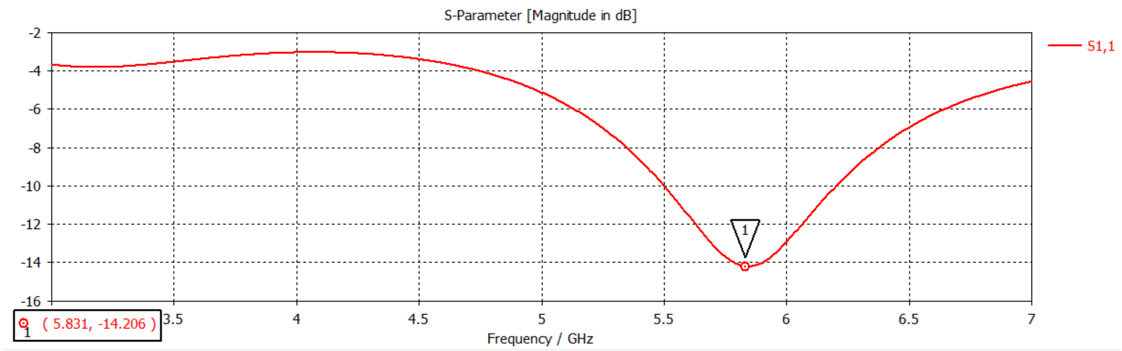


Fig. 4.3 Return loss v/s frequency

2). Rectangular slits of 4mm height and 1mm width are introduced on both sides of the patch (Fig. 4.4). Introduction of slits improves return loss which now become as -21.9 dB (Fig. 4.5). The impedance matching also improves by attaining value of 43 ohm.

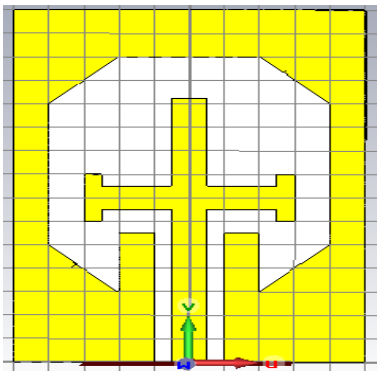


Fig. 4.4 Jerusalem cross shaped patch antenna

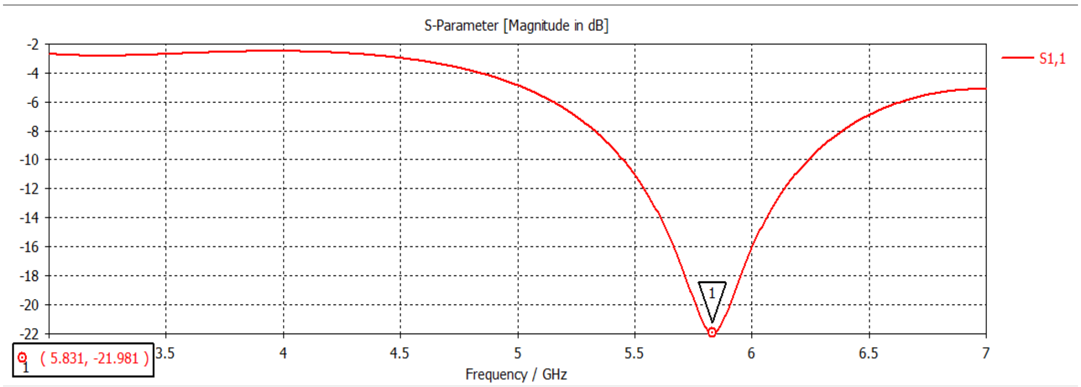


Fig. 4.5 Return loss v/s frequency

3). In the final design (Fig. 4.6) four rectangular slits are cut on the ground. The return loss for this antenna is -24 dB and impedance match is 45 ohm. So this slotting further improves the return loss.

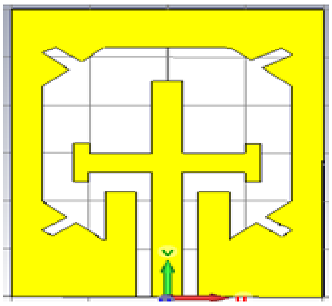


Fig. 4.6 Final design of antenna operating at 5.8 GHz

4). The chosen dimensions of the various structures present in the designed antenna were finalized after having the parametric study enabled by varying the parameters to get the best result. The results obtained after applying parametric sweep are shown below. Results obtained after varying length of the horizontal strip of the cross are shown in fig 4.7 a. Here the return loss for all the three dimensions is overlapping. Return loss obtained after varying width of the horizontal strip, height of the vertical strip, and width of the vertical strip is shown in fig. 4.7 b, c and d respectively. The dimension which gave the best value for return loss was kept as the final value for the designed antenna.

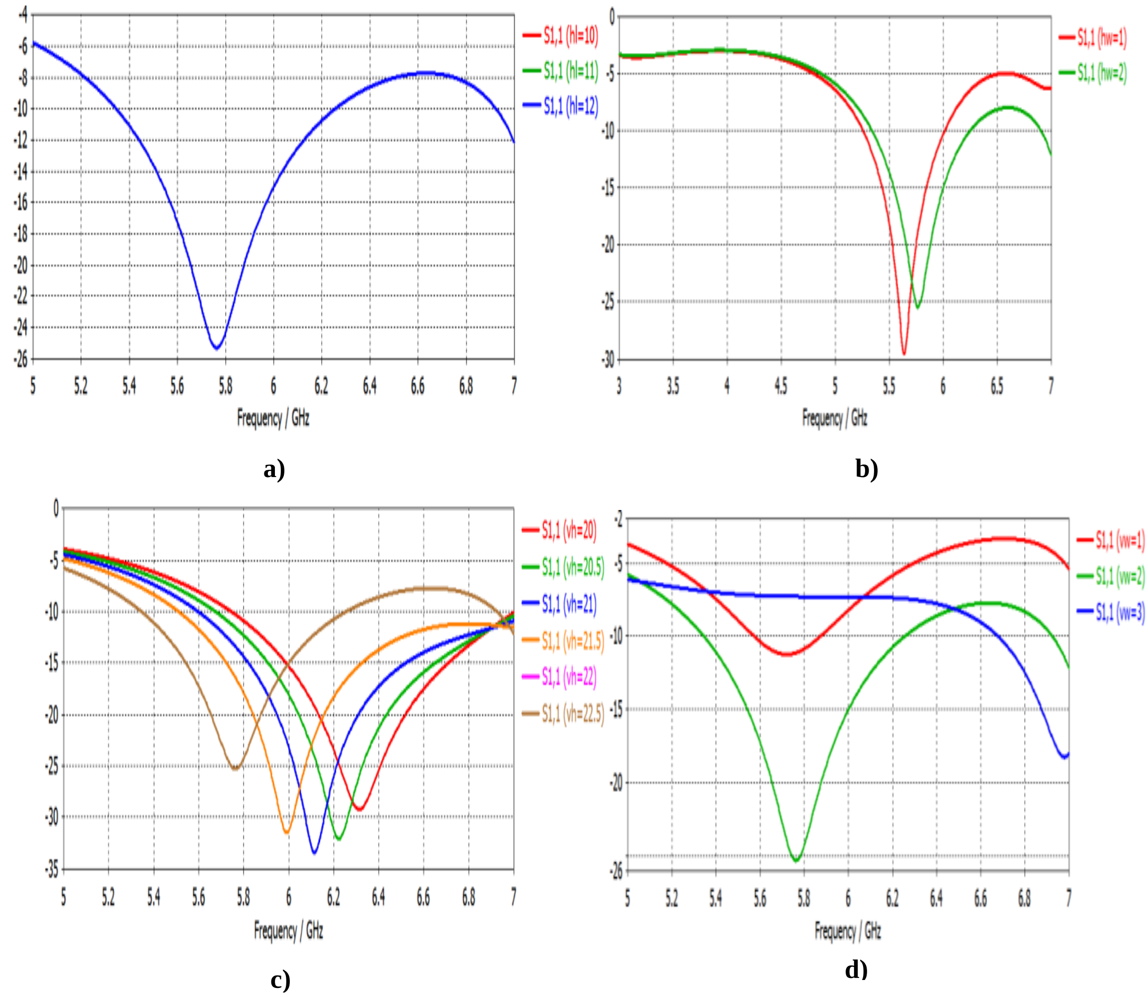


Fig. 4.7 Parametric sweep results

4.4 EQUIVALENT MODEL OF DESIGNED ANTENNA

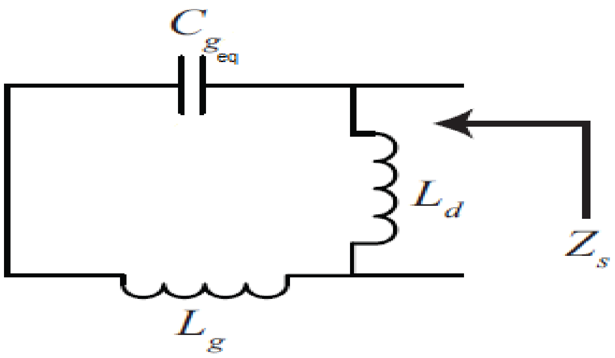


Fig. 4.8 Equivalent circuit model for 5.8 GHz RFID antenna

While determining resonant frequency and the reflection coefficient's phase, the surface impedance (Z_s) plays a crucial role. The surface impedance is expressed as parallel combination of Jerusalem cross impedance (Z_g) and grounded dielectric's surface impedance (Z_d), by following the transmission line approach.

The surface impedance can be expressed as:

$$Z_s(\omega) = Z_g \parallel Z_d = \frac{j\omega L_d(1-\omega^2 L_g(C_{g_{eq}})}{1-\omega^2(C_{g_{eq}})(L_d+L_g)} \quad (4.1)$$

ω: angular frequency

L_d: grounded dielectric slab's inductance

L_g: Jerusalem cross grid's inductance

$C_{g_{eq}}$: equivalent grid capacitance formed in the gap present between the cross and the ground

The resonating frequency can be calculated by equating the denominator of eq. (1) to zero and it is given by:

$$f_r = \frac{1}{2\pi\sqrt{(C_{g_{eq}})(L_g+L_d)}} \quad (4.2)$$

The surface impedance at the resonant frequency is very high. The effective permittivity (ϵ_{re}) is given as:

$$\epsilon_{re} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} F(\frac{w}{h}) \quad (4.3)$$

$$\text{and } F(\frac{w}{h}) = (1+\frac{12h}{w})^{-1/2} + 0.041(1-\frac{w}{h})^2, \quad \frac{w}{h} <= 1 \quad (4.4)$$

$$(1+\frac{12h}{w})^{-1/2}, \quad \frac{w}{h} >= 1 \quad (4.5)$$

h: thickness of dielectric slab

w: width of microstrip line

The characteristic impedance (Z_0) is expressed as

$$Z_0=\frac{\eta}{2\pi\sqrt{\epsilon_{re}}}\ln\{\frac{8h}{w}+0.25\frac{w}{h}\} \quad , \frac{w}{h}<=1 \quad (4.6)$$

$$=\frac{\eta}{\sqrt{\epsilon_{re}}}\{\frac{w}{h}+1.393+0.667h\,(\frac{w}{h}+1.444)\}^{-1} \quad , \frac{w}{h}>=1 \quad (4.7)$$

η: impedance of free space

Capacitive and inductive values of equivalent circuit model are given as:

The gap capacitance is given as:

$$C_{ga}=2\epsilon_0\epsilon_{re}\frac{K(k)}{k`(k)}d \quad (4.8)$$

ϵ_0: permittivity of free space

$$\frac{K(k)}{K`(k)}=\frac{1}{\pi}\ln\{2\frac{1+\sqrt{k}}{1-\sqrt{k}}\} \quad 0.707\leq k\leq 1 \quad (4.9)$$

$$=\frac{\pi}{\ln\{2\frac{1+\sqrt{k}}{1-\sqrt{k}}\}} \quad 0\leq k\leq 0.707 \quad (4.10)$$

$K=\tan^2(\frac{a\pi}{4b})$ $\quad$ $a=\frac{w_{cap}}{2}$

$b=\frac{(w_{cap}+g)}{2}$ $\quad$ and $k`=\sqrt{1-k^2}$

where w_{cap} : width of rectangular slits attached to the criss cross patch

d : length of side rectangular slits connected to the criss cross patch

g : gap present between the patch and the ground present on the same side of the substarte

$$C_{g_{eq}}=3*C_{ga} \quad (4.11)$$

As the gap between the patch and ground is present on three sides therefore $C_{g_{eq}}$ is defined thrice the value of C_{ga}.

The inductive component (L_g) is evaluated through the following formula

$$L_g=\frac{Z_0\sqrt{\epsilon_{re}}}{c}\,l \quad (4.12)$$

z_0 and ϵ_{re} are obtained from previous equation only by changing the width as w_{ind}.

w_{ind} : width of the criss cross strips

l : length of the criss cross strip

The above equation is applicable only when the condition of l being very much smaller compared to the wavelength of interest is fulfilled.

The inductive component L_d is given as:

$$L_d = \mu_0 h \tag{4.13}$$

where h : thickness of dielectric slab

$$\eta(\text{free space impedance}) = \sqrt{\frac{\mu_0}{\epsilon_0}} \tag{4.14}$$

After performing calculations, the results are as follows:

$C_{ga} = 5.22 * 10^{-14}$ F

$C_{g_{eq}} = 3 * C_{ga} = 3 * 5.22 * 10^{-14} = 15.66 * 10^{-14}$ F

$L_g = 3.8 * 10^{-9}$ H

$L_d = 2.02 * 10^{-9}$ H

$f_r = 5.27 * 10^{-9} = 5.27$ GHz

The antenna is designed at 5.8 GHz. But the results obtained theoretically give resonating frequency at 5.27 GHz. So there is error of 9.14 %.

4.5 SIMULATED RESULTS

4.5.1 Return Loss

The central resonating frequency of the proposed antenna is at 5.78 GHz and the supported bandwidth is 900 MHz (Fig 4.9). The band covered by this antenna is having its starting frequency at 5.34 GHz and ending frequency at 6.24 GHz. The return loss at 5.8 GHz is -24.44 dB (Fig. 4.9).

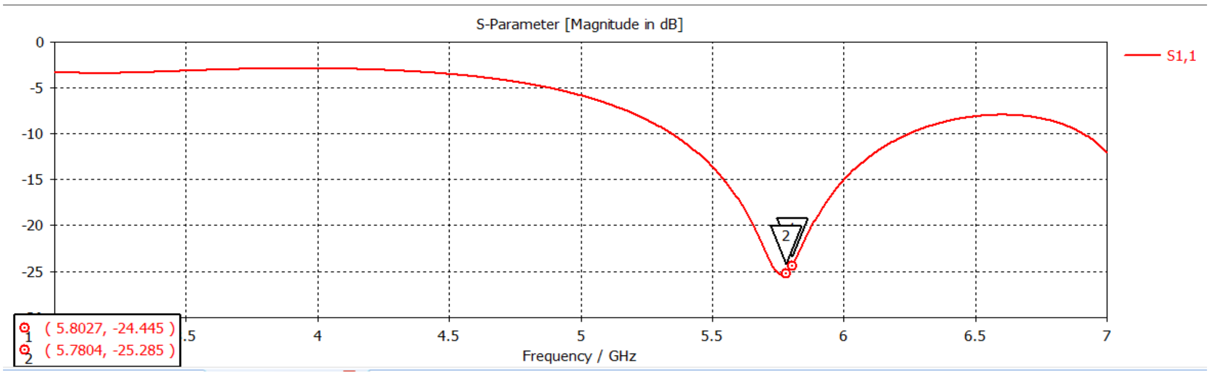


Fig. 4.9 Return loss v/s frequency

4.5.2 Smith Chart

The impedance matching of 45.24 ohm is achieved (Fig. 4.10). Antenna is considered to be perfectly matched at 50 ohm and the designed antenna shows good matching.

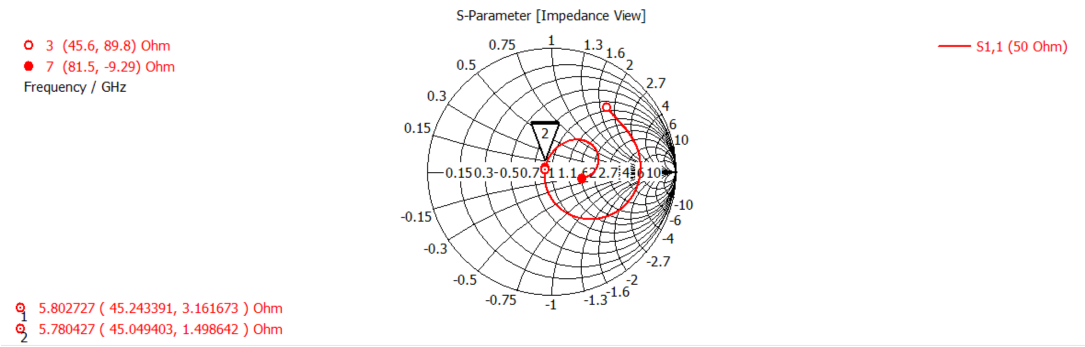


Fig. 4.10 Smith chart

4.5.3 VSWR

VSWR of 1.18 is supported by this antenna at 5.8 GHz (Fig. 4.11). Ideally its value should be 1 and so the value of 1.18 is good enough.

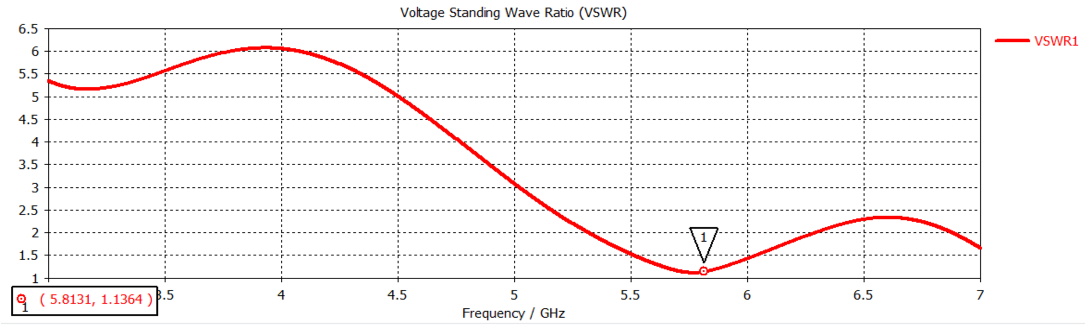


Fig. 4.11 VSWR v/s frequency

4.5.4 Gain and Directivity

The antenna gain is 3.7 dBi (Fig. 4.12). The use of Rogers RT 5880 substrate instead of commonly available FR4 has helped in improving the gain to this value. The directivity of this antenna is 4.11 dBi at 5.8 GHz as shown in Fig. 4.13

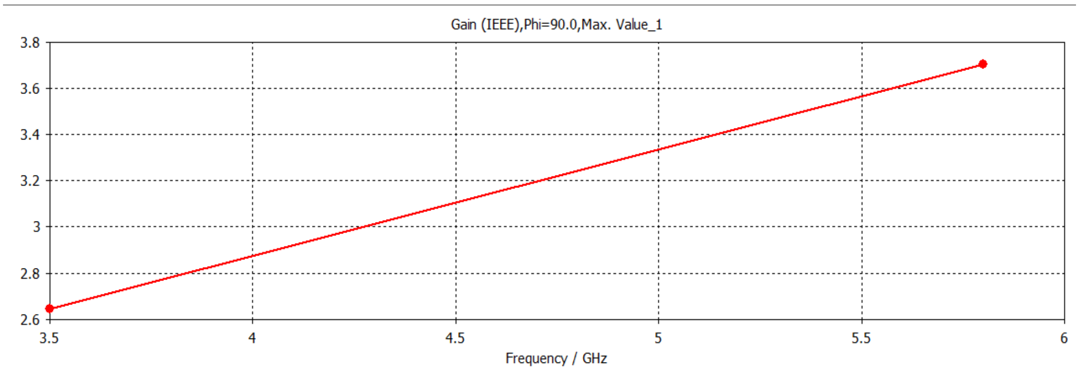


Fig. 4.12 Gain of antenna v/s frequency

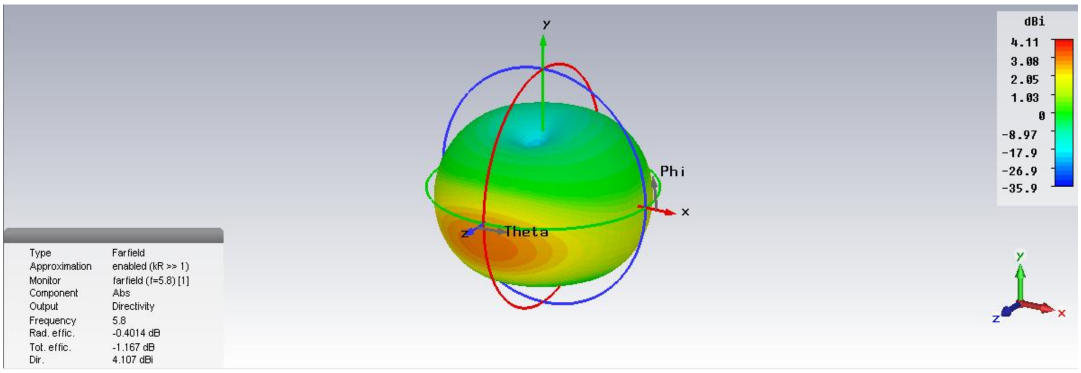
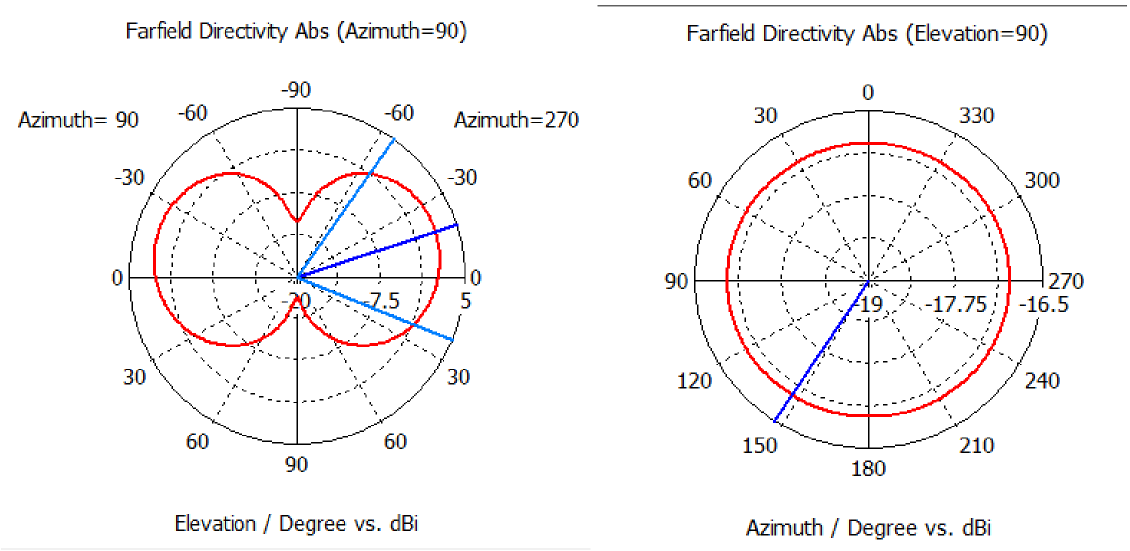


Fig. 4.13 Farfield (Directivity) 3-D pattern

4.5.5 Radiation Pattern at 5.8 GHz

In Fig. 4.14 a. E field radiation pattern is shown for which ϕ=0. H field radiation pattern is shown in Fig. 4.14 b. for which θ=0. The designed antenna is perfectly omnidirectional in H field.



a) b)

Fig. 4.14 Azimuthal and elevation radiation pattern

4.5.6 Axial ratio

The antenna is linearly polarized as its axial ratio is 17 (Fig. 4.15). As it is linearly polarized therefore it serves well as a tag antenna. Antenna is considered to be circularly polarized if its axial ratio is less than 3.

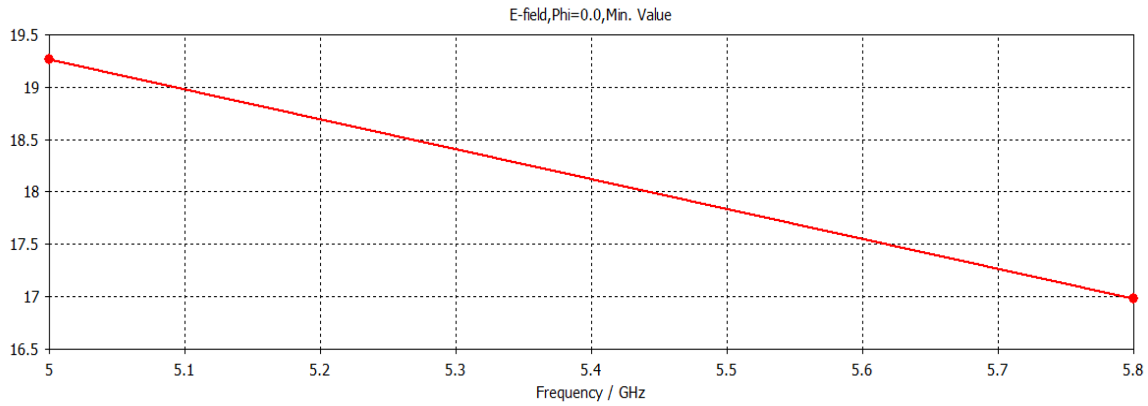


Fig. 4.15 Axial ratio v/s frequency

4.5.7 Current Distribution

The surface current distribution in Fig. 4.16 show that maximum current exists at the lower edge of the vertical cross, rectangular slits on the ground plane and outer edges of ground. Current distribution figure helps us understand that the current path deviates due to the presence of slots and therefore affects the resonant frequency modes.

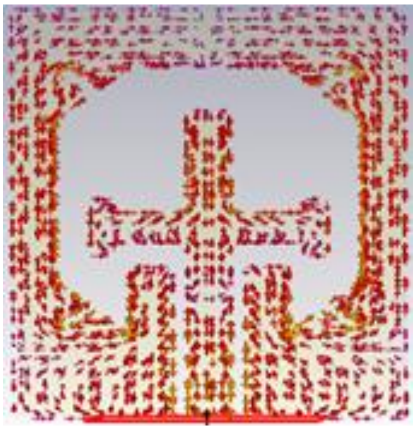


Fig. 4.16 Surface current at 5.8 GHz

4.6 CONCLUSION

A miniaturized Jerusalem cross shaped patch antenna with four rectangular slots cut on the ground plane is designed. It is fed by coplanar waveguide. The slots placed on the ground plane help improve return loss. This antenna was targeted for 5.8 GHz RFID tag antenna application. As the antenna is very compact, linearly polarized and fully omnidirectional in nature, it fulfils the requirement for tag antenna. It is having wide simulated bandwidth of 900 MHz and the measured bandwidth is 890 MHz. This antenna when mounted on tag chip should match the impedance of chip for maximum power transfer. So we can use impedance matching circuit to achieve the same. 5.8 GHz band is advantageous due to various reasons like more available bandwidth, resistant to conductive object degradation, smaller tag footprint, allows integration of multiple antennas onto compact RF tag and hence giving new signalling schemes. This band supports better signal propagation; manage large capacity real-time location systems efficiently. It is also having high data rate modulation and better electronics design.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In this thesis, new microwave RFID antennas are proposed. Presently RFID finds its widespread use for automatic identification and data capture. Microwave range of RFID covers two bands of 2.4 GHz and 5.8 GHz. Designing antennas for these two ranges require antenna to be compact, omnidirectional or having hemispheric coverage. The two proposed antennas meet the requirement of small size and are having wide bandwidth. The antenna at 5.8 GHz is having wide simulated bandwith of 900 MHz and its gain is 3.7 dBi whereas antenna at 2.4 GHz has 720 MHz of simulated bandwidth and gain of 2.2 dBi. The wide impedance bandwidth can be attributed to the CPW feed been used which also makes the antenna to be compatible with any microwave device. Sufficient high gain is achieved for 5.8 GHz antenna due to the use of Rogers RT5880 substrate. The antenna at 5.8 GHz is very small and fully omnidirectional as compared to antenna at 2.4 GHz. The interference suffered at 2.4 GHz is high. The slotting technique applied to antennas has provided an aid in size reduction and in achieving the desired frequency bands. The modifications applied to the ground plane have also proved beneficial. The antennas are having good return loss below -10 dB. They can be used for various purposes like asset tracking, vehicle access control, personnel tracking health care, automated toll collection, supply chain etc.

The software utilization in this process provided minimization of the processing time for the calculation and simulation of the proposed design. Drawing an overall conclusion all the objectives of the project work that is compact size, wide bandwidth and improved return loss have been implemented and achieved successfully.

5.2 FUTURE SCOPE

The thesis work of designing RFID microwave antennas can be carried further by following techniques to improve gain and further minimize the size of the antenna. The improvement in antenna gain provides wider range of tracking. Smaller the size of the antenna easier it will be to mount that antenna on the object to be tracked.

Techniques followed for gain improvement are:

- Use PBG (Photonic Band Gap) structures. In this technique we can place metal pads around the patch antenna which will suppress the surface waves present in substrate and hence improve the antenna gain. It will also reduce mutual coupling and interference.
- Design an array of multiple patches.
- Partial removal of substrate.
- Change of dielectric.

As the tag antenna needs to be mounted on tag chip and the impedance of chip may be any value other than conventional value of 50 or 75 ohm. We need to match the impedance of antenna with that of the chip. And for that we need to design impedance matching circuits like using balun or transformer.

LIST OF PUBLICATIONS

- Richa Dolia, Rajesh Khanna, “Compact, CPW fed, slotted patch antenna for 2.4 GHz RFID application” communicated in International Journal of Microwave and Optical Technology *(*IJMOT).
- Richa Dolia, Rajesh Khanna, “Compact, modified E shaped, dual band patch antenna for LTE band number 42”, published in 47th symposium on Modern Information and Communication Technologies for Digital India (MICTDI), Chandigarh, 9th April, 2016
- Richa Dolia, Rajesh Khanna, “Miniaturized, Notched Rectangular Slot Antenna for Ultrawideband”, published in IEEE International Workshop on Antenna Innovation and Modern Technologies (iAIM), Ahmedabad, 26th December, 2015.

REFERENCES

[1] Syed Ahson, Mohammad Ilyas, "RFID Handbook Applications, Technology, Security and Privacy," *CRC press, Taylor and Francis Publisher*, 2008.

[2] Peter Darcy, Prapassara Pupunwiwat, Bela Startic, "Deploying RFID challenges, solutions, and open issues," *INTECH Open Access Publisher*, 2011.

[3] Le Chang, Han Wang, Zhijun Zhang, Yue Li, Zhenghe Feng, "Compact single feed dual mode antenna for active RFID tag application," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 11, pp. 5190-5194, 2015.

[4] Ming Tao Zhang, Fu Shun Zhang, Wu Tu Wang, Yong Chang Jiao, "Design of antennas for RFID applications," *INTECH Open Access Publisher*, 2009.

[5] Ahmed M.A. Saloma, "Antennas of RFID tags," *INTECH Open Access Publisher*, 2010.

[6] M.I. Sabran, S.K.A. Rahim, M.S.A Rani, M.Z.M. Nor, "A single band dual-fed circular polarization microstrip antenna for RFID applications," *IEEE International RF and Microwave Conference (RFM)*, pp. 137-140, 2011.

[7] Navjot Kaur, Diana Seguna Velandia, William Whittow, David Barwick, Ehidiamen Iredia, Neil Parker, Neil Porter, Paul P. Conmway, Andrew A. West, "Design and performance of a flexible metal mountable UHF RFID tag," *IEEE 65th Electronic Components and Technology Conference (ECTC)*, pp. 2120-2126, 2015.

[8] Wei Fu, Jianguo Ma, "Propagation model and performance analysis for short range microwave passive RFID systems," *Pacific Asia Conference on Circuits, Communications and Systems (PACCS)*, pp. 228-231, 2009.

[9] D. Ma, W. X. Zhang, "Broadband CPW fed RFID antenna at 5.8 GHz," *Electronic Letters*, vol. 42, no. 22, pp. 1258-1259, 2006.

[10] M. Mantysalo, P Mansikkamaki, " An inkjet deposited antenna for 2.4 GHz applications," *AEU International Journal of Electronics*, vol. 63, no. 1, pp. 31-35, 2009.

[11] Mursyidul Idzam sabran, S.K.A. Rahim, Amuda Yusuf Abdul Rahman, Tharek Abdul Rahman, Muhammad Zairil Muhammad Nor, Eziral, " A dual band diamond shaped antenna for RFID application," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 979-982, 2011.

[12] Jyoti R. Panda, Rakesh S. Kshetrimayum, "A printed 2.4 GHz/5.8 GHz dual band monopole antenna for WLAN and RFID applications with a protruding stub in the ground plane," *National Conference on Communications (NCC)*, pp. 1-5, 2011.

[13] X.Y. Teng, X.M. Zhang, Z.X. Yang, Y. Wang, Y. Li, Q.F. Dai, Z. Zhang, " A Compact CPW fed omni directional monopole antenna for WLAN and RFID applications," *Progress In Electromagnetics Research Letters*, vol. 32, pp. 91-99, 2012.

[14] Zeng Wen bo, Li Xiang yang, Liu Ji Xiang, "A dual band RFID slot tag antenna for ITS application," *3rd International Conference on Consumer Electronics, Communications and Networks*, pp. 5-7, 2013.

[15] Chitra Varadhan, Jayaram Kizhekke Pakkathilam, Malathi Kanagasabai Ramprabhu Sivasamy, Rajesh Natarajan, Sandeep kumar Palaniswamy, "Triband antenna structures for RFID systems deploying Fractal geometry," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 437-440, 2013.

[16] M.E de Cos, F. Las Heras, "Polypropylene based dual band CPW fed monopole antenna *," IEEE Antennas and Propagation Magazine*, vol. 55, no. 3, pp. 264-273, 2013.

[17] H. Nornikman, F. Malek, N. Saudin, N.A. Zainuddin, M. Md. Shukon; M.Z.A. Abd Aziz, B.H. Ahmad, M.A. Othman, "Dual layer rectangular microstrip patch antenna with H slot for 2.4 GHz range applications," *3rd International Conference on Instrumentation, Communications, Information Technology, and Biomedical Engineering (ICICI-BME)*, pp. 44-48, 2013.

[18] Nasser Ojaroudi, Mohammad Ojaroudi, "Compact H-ring antenna with dual band operation for wireless sensors and RFID tag systems in ISM frequency bands," *Microwave and Optical Technology Letters*, vol. 55, no. 4, pp. 697-700, 2013.

[19] Son Xuat Ta, Ikmo Park, Richard W. Ziolkowski, "Circularly polarized crossed dipole on an HIS for 2.4/5.2/5.8 GHz WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 1464- 1467, 2013.

[20] Guo Liu, Liang Xu, Zhensen Wu, "Dual band microstrip RFID antenna with tree like Fractal structure," *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 976-978, 2013.

[21] Wenbin Zeng, Guo Liu, Ming Li, Liang Xu, "Miniaturized I-shaped slot circularly polarized RFID antenna," *3rd Asia Pacific Conference on Antennas and Propagation (APCAP)*, pp. 357-358.

[22] Ma Chao, Yang Guohui, Kong Weidong, Shi Shaorui, Wang Erchao, "Two kinds of miniaturized dual band RFID planar antennas," *3rd Asia Pacific Conference on Antennas and Propagation (APCAP)*, pp. 558-561, 2014.

[23] M. Virili, H. Rogier, F. Alimenti, P. Mezzanotte, L. Roselli, "Wearable textile antenna magnetically coupled to flexible active electronic circuits," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 209-212, 2014.

[24] H. Li, Y Zhou, L Wang, "Modified miniature tri band CPW fed antenna for RFID applications," *session 3P13b SC4: RFID Antennas*, 2014.

[25] I-Fong Chen, Chia mei Peng, Crwan Lin Chen, "A novel reduced size microstrip antenna for RFID reader in UHF band applications," *Asia Pacific Symposium on Electromagnetic Compatibility (APEMC)*, pp. 410-412, 2015.

[26] Qiang Liu, Junyu Shen, Jungang Yin, Mongli Liu, Yuanan Liu, "Compact 0.92/2.45 GHz dual band directional circularly polarized microstrip antenna for handheld RFID reader applications," *IEEE Transactions on Antennas and Propagation, vol. 63, no. 9*, pp. 3849-3856, 2015.

[27] A.E. Hamraoui, El H. Abdelmounim, J. Zbitou, H. Bennis, M. Latrach, "A new design of a compact CPW fed dual band printed antenna for RFID applications," *International Conference on Wireless Networks and Mobile Communications*, pp. 1-4, 2015.

[28] M.A. Malek, S. Hakimi, S.K. Abdul Rahim, A.K. Evizal, "Dual band CPW fed transparent antenna for active RFID tags," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 919-922, 2015.

[29] Thirumalai T.; Kashwan K.R.; "Low power slotted patch antenna for RFID tag reader applications," *International Conference on Electrical, Electronics, Signals, Communication and Optimization (EESCO)*, pp. 1-5, 2015.

[30] Bhushan Bhimrao Dhengale, Deepak C. karia, "A 5.8 GHz ISM band microstrip antenna for RFID applications," *International Conference on Nascent Technologies in the Engineering Field (ICNTE)*, pp. 1-4, 2015.

[31] Adil Zaman Babar, S. Bashir, Muhammad Salman Khan, "U slot microstrip patch antenna with truncated corners and its performance improvement using EBG structures," *12th International Conference on Applied Sciences and Technology (IBCAST)*, pp. 564-570, 2015.

[32] Le Chang, Han Wang, Zhijun Zhang, Yue Li, Zhenghe Feng, "A dual environment active RFID tag antenna mountable on metallic objects," *IEEE Antennas and Propagation Letters*," vol. pp, no. 99, pp. 1-1, 2016.

.

ME Thesis

ORIGINALITY REPORT

19%	7%	18%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Hawrylak, Peter, Leonid Mats, and Marlin Mickle. "Physics and Geometry of RFID", RFID Handbook Applications Technology Security and Privacy, 2008. Publication	3%
2	Ahsan, Kamran. "RFID Components, Applications and System Integration with Healthcare Perspective", Deploying RFID - Challenges Solutions and Open Issues, 2011. Publication	1%
3	cdn.intechopen.com Internet Source	1%
4	Chang, Le, Han Wang, Zhijun Zhang, Yue Li, and Zhenghe Feng. "Compact Single-Feed Dual-Mode Antenna for Active RFID Tag Application", IEEE Transactions on Antennas and Propagation, 2015. Publication	1%
5	www.jpier.org Internet Source	1%
6	A. Salama, Ahmed M.. "Antennas of RFID Tags", Radio Frequency Identification	1%