YASAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

DESIGN AND OPTIMIZATION OF COMPACT MICROSTRIP PATCH ANTENNAS HAVING BROKEN LOOP FOR UHF RFID READER APPLICATION

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2016

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a dissertation for the degree of master of science.

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ABSTRACT

DESIGN AND OPTIMIZATION OF COMPACT MICROSTRIP PATCH ANTENNAS HAVING BROKEN LOOP FOR UHF RFID READER APPLICATION

Eştürk, Gonca
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RFID (Radio Frequency Identification) is a wireless communication technology, which provides and follows via radio frequency with capable of storing the information label in wireless environment. RFID technolgy, which provides wireless identification and identifier for the objects, was developed around World War II. An RFID system has readers and tags that communicate with each other by radio frequency.

RFID technology comes into increasing use industry as an alternative to the barcode. The advantage of RFID is that it does not require direct contact or line-of-sight scanning. An RFID system consist of three components; an antenna, a tranceiver (often cobined into the reader) and a transponder (the tag). The antenna uses radio frequency waves to transmit a signal that activates the transponder. When transponder is activated, the tag transmits data back to the antenna. The data is used to notify a programmable logic controller to a computer system and stored on a RFID tag, and need a reader. A typical reader is a device that has one or more antennas that emit radio waves and receive signals back from the tag. A typical reader antenna consist of a radio antenna mounted on a substrate.

In this thesis, microstrip patch antennas including a broken loop structure to be used as the reader antenna in RFID systems at the frequency range of ultra high frequency (UHF) are considered. The study contains two type of antennas which are a compact linearly polarized RFID reader antenna and a compact circularly polarized RFID reader antenna. These antennas are smaller in volume as compared to the standard microstrip antennas by providing a smaller ground plane with the usage of broken loop. These designs are simulated, manufactured and measured.

The linearly polarized version of the produced microstrip patch antenna has the frequency range of 863.8-872.9 MHz and almost 9 MHz bandwidth by providing minimum 10 dB return loss, 3 dBi gain and minimum 15 dB axial ratio. The measurement results of the corresponding manufactured antenna are also highly consistent with the simulation results such that there is only 1% frequency shift which may arise from variation in the dielectric constant of substrate and manufacture errors.

The circularly polarized version of the design antenna has the working frequency range of 868-872 MHz in simulation and 853.1-857.7 MHz in measurement by providing again minimum 10 dB return loss, 0.5 dBi gain but maximum 6 dB axial ratio. The measurement results of this version have the difference of about 2% with the simulations.

In the final part of the thesis, the designed and produced antennas are tested in an application of RFID system containing a reader card, a tag antenna and a reader antenna (the ones designed in this thesis). The test results reveal that the mentioned reader antennas provide RFID communication (make the system work well) within a distance of about 30-35 cm.

Keywords: UHF RFID, reader antenna, microstrip patch antenna, broken loop, polarization.

ÖZET

UHF RFID OKUYUCU UYGULAMALARI İÇİN KOMPAKT KIRIK HALKA İÇEREN MİKROŞERİT ANTENLERİN TASARIMI ve OPTİMİZASYONU

Eştürk, Gonca
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RFID (Radyo frekansı ile tanımlama), kablosuz ortamda bilgi etiketlerini depolayan radyo frekanslarını üretebilen ve takip edebilen bir kablosuz iletişim teknolojisidir. Kablosuz olarak tanımlama yapan ve objeleri tanımlamayı sağlayan RFID teknolojisi ilk olarak İkinci Dünya Savaşı yıllarında geliştirilmiştir. Bir RFID sistemi birbirleriyle radyo frekanslarıyla haberleşebilen okuyuculardan ve etiketlerden oluşmaktadır.

RFID teknlojisi barkod teknolojisinin alternatifi olarak endüstriyel alanda hızla yaygınlaşmaktadır. RFID sistemlerin avantajları ise doğrudan bir temasa ya da görüş mesafasinde bir taramaya ihtiyaç duymamasıdır. Bir RFID sistemi üç bileşenden oluşur; anten, alıcı (genellikle okuyucuyla birleşiktir) ve transponder (etiket). Anten, transponderi aktif hale getirecek olan sinyali ileten radyo frekans dalgaları kullanır. Transponder aktif hale geçtiğinde etiket bilgileri antene geri gönderir. Bu bilgi, programlanabilir mantıksal denetleyiciyi bir bilgisayar sistemine bildirmek için kullanılır. Bu bilgi RFID etikette depolanır ve bir okuyucuya ihtiyaç duyar. Tipik bir okuyucu, radyo dalgaları yayan ve etiketten gelen sinyalleri alabilen bir ya da daha fazla antene sahiptir.

Bu tezde, ultra yüksek frekansta (UHF) radyo frekansıyla tanılama sisteminde bir okuyucu anten olarak kullanılmak üzere bir kırık hal yapısı içeren mikroşerit yama antenleri düşünülmüştür. Bu çalışma, biri kompakt bir doğrusal polarizasyonlu RFID okuyucu anteni diğeri dairesel polarizasyonlu bir kompakt RFID okuyucu anteni olmak üzere iki tip anten içermektedir. Bu antenler, kırık halka yapısı kullanılması ile daha küçük toprak düzlem sağlayarak standart mikroşerit antenlere göre hacimce daha küçüktür. Bu tasarımlar simüle edilmiş, üretilmiş ve ölçülmüştür.

Üretilen mikroşerit yama antenin doğrusal polarizasyonlu versiyonu 863.8-872.9 MHz frekans aralığına sahiptir ve en az 10 dB geri dönüş kaybı, 3 dBi kazanç ve en az 15 dB eksensel oran sağlayarak yaklaşık 9 MHz'lik banda sahiptir. Bahsedilen antenin ölçüm sonuçları, simülasyon sonuçları ile oldukça tutarlıdır ki dielektrik katsayısındaki değişiklik ve üretim hatalarından kaynaklanabilecek sadece yüzde 1'lik bir frekans kayması vardır.

Tasarlanan antenin dairesel polarizasyonlu hali, yine en az 10 dB geri dönüş kaybı, 0.5 dBi kazanç ama en fazla 6 dB eksensel oran sağlayarak simülasyonda 868-872 MHz, ölçümde 853.1-857.7 MHz frekans bandına sahiptir. Bu versiyonun ölçüm sonuçları, simülasyon sonuçları ile yüzde 2'lik bir farka sahiptir.

Tezin son kısmında üretilen ve tasarlanan antenler; bir okuyucu kartı, bir etiket anteni ve bir okuyucu anteni (tezde tasarlananlar) içeren bir RFID sistem uygulamasında test edilmiştir. Test sonuçları göstermiştir ki değinilen okuyucu antenler yaklaşık 30-35 cm mesafe içinde RFID iletişimi sağlamaktadır (sistemi iyi bir şekilde çalıştırmaktadır).

Anahtar sözcükler: UHF RFID, okuyucu anten, mikroşerit yama anten, kırık halka, polarizasyon.

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Finally, I would like to thank my Mom, Dad, Sister, Grandparents and my fiance for their love, Support and patience over the years. This thesis is dedicated to them.

TEXT OF OATH

I declare and honestly confirm that my study, titled “Design and Optimization of Compact Microstrip Patch Antennas Having Broken Loop for UHF RFID Reader Application” and presented as a Master Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions, that all sources from which I have benefited are listed in the bibliography, and that I have benefited from these sources by means of making references.

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1 INTRODUCTION

1.1 Scope of the Thesis

Radio Frequency Identification (RFID) is used for recognition of the objects or creatures with radio waves in the specific distance and monitoring. RFID tecnology is widely used in the areas such as manufacturing, automotive, textiles, fuel, logistics, in agriculture, health, security. Radio Frequency Identification (RFID), which was developed around World War II, is a technology that provides wireless identification, tracking capability and is more robust than that of a barcode (Ren et. al, 2012). The aim of this study is to design far-field UHF RFID reader antennas with wide radiation areas and long detection distances. The design reason lies in designing reader antennas which are electically big yet capable of offering powerful a good area distribution within its application area.

Generally, the RFID system at low frequency (LF:125 kHz-134 kHz), high frequency (HF:13.56 MHz) and ultra high frequency (UHF: 840 MHz-960 MHz). Globally each country has its own frequency allocation for UHF RFID applications, such as 840.5-844.5 MHz and 920.5-925.5 MHz in China 846-955 MHz in Europe, 902-928 MHz in North and South of America and 952-955 MHz in Japan and so on. The UHF RFID frequency ranges from 840.5-955 MHz.

In this thesis, microstrip patch antenna design to be used as the reader antenna in Radio Frequency Identification systems (RFID in the European UHF frequency range). The design of UHF microstrip patch antenna along with a compact loop antenna presented for mobile ultrahigh frequency (UHF) radio frequency identification is mentioned, and the simulation and measurement results are given. In addition, the core components of the RFID technology, working structure, required parameters for designing efficient reader antenna are mentioned, and it is informed about the advantages provided with the RFID technology. The linearly polarized version of the produced microstrip patch antenna has the frequency range of 863.8-872.9 MHz and 9 MHz bandwidth, and there exists also the design of circularly polarized version. In the literature, circular polarized microstrip patch antenna for UHF RFID studies, although the circular polarized broken ring microstrip antenna for the first time discussed in this statement (Chen H.-D,Kuo S.-H., Sim C.-Y.-D. and Tsai C.-H, 2012).

1.2 Research Motivation

Loop antennas are normally used as reader antennas in the LF and the HF RFID systems (X. Qing, Z. N. Chen, A. Cai, 2007). Whilst a loop antenna is less than half of-a-wavelength at its operating frequency, it provides robust and even magnetic discipline distribution inside the course perpendicular to the surface of the loop. Such characteristic is desirable for the RFID tagging systems. This is because when the loop is of the length less than 0.5 λ, current flows in a single direction. Such current flow produces magnetic fields which are added in the center region of the loop antenna (G. C. Khan, 2009). As a result, the magnetic area distribution at the space enclosed with the aid of the loop is strong and even. Based on types of objects and applications, the inductively coupled near-field operation or electromagnetically coupled far-field operation are used to transform information between reader antenna and tag (Bijaya Shrestha, Atef Elsherbeni, 2011). The tags placed in this area are successfully detected, but, whilst the running frequency of the antenna rises to the UHF band, the antenna physical length greatly decreases. This decrease of region limits the range of tags to be detected at a single study. If the electric length of the conventional loop antenna at the UHF band is enlarged, the loop antenna cannot produce uniform magnetic subject because the ongoing flowing inside the loop functions nulls and section-inversion along the boundary. As a result, the antenna produces relatively weak magnetic field in certain regions of the antenna and this affects the tag detection. Therefore, the design challenge of the far-field UHF RFID reader antenna lies in creating an electrically large reader antenna with strong and uniform magnetic far-field distribution in the interrogation region. The thesis is on manufacturing a reader antenna in UHF band and providing RFID reader with high performance and low cost. Raido frequency identification technology, is a new generation technology that has been widely used in our everyday life, such as security control, library management system, no-stop parking solution, logistic, jewelry management system, identify an object, an animal or person, to enable item-level management, inventory and asset control. In view of this this thesis is promoting more cost-effective rfid reader, so as to contribute and promote this cutting-edge technology forward.

1.3 Thesis Overview and Outline of the Thesis

In the thesis, two designs of UHF RFID reader antenna are proposed. The configuration of every layout is given. It is followed by the explanation in the principle of the proposed antenna operation. Then, the antenna layout guidelines are declared. The parametric examine is finished on the proposed antenna. After that, the proposed antenna is being prototyped. The measurement of the antenna prototype is performed to confirm the layout. Afterwards, evaluation between the proposed antennas is given. Finally, concluding comments of proposed antenna are supplied.

This thesis can be examined in the 8 chapters; history, RFID tag antenna design properties and problems, microstrip patch antenna and a compact loop antenna is presented, most used antenna complicated impedance matching techniques and size reduction strategies.

In Chapter 2, the core components of the RFID technology, working structure, required parameters for designing efficient reader antenna are mentioned, and it is informed about the advantages provided with the RFID technology.

Chapter 3 includes that overview of patch antenna design and microstrip patch antenna parameters and factors in the design are given, and design parameters which are necessery for designing, are explained.

Chapter 4 focuses the antenna properties which affect the reading distance as frequency, polarization, gain.

Chapter 5 explains all parameters and properties which are used in the design of an antenna, and give information about resonance frequency and input impedance which are important factors for an antenna.

Chapter 6 gives the design of the proposed antenna structures as well as the corresponding simulation and measuement results for the corresponding antennas.

Chapter 7 presents the test results of a full RFID system by using a reader card, a tag antenna and the reader antennas designed in this thesis. Chapter 8 concludes the thesis.

2 INTRODUCTION TO RFID

2.1 What is RFID Technology?

Radio Frequency Identification RFID technology when was developed around World War II, that provides wireless identification, tracking capability, provides identifier for the objects and is more robust than that of a barcode. Radio is a rapidly developing technology that can be used to identify any object wearing an electronic tag by using electromagnetic waves. RFID technology, RFID tag and radio frequency queries are made with a silicon chip to receive and answer, consists of an antenna and coating. This generation has been rapidly developing in lots of services as industries, automotive, textile, fuel oil, logistics, welfare, security system, agriculture and so forth. In RFID system, the reader emits signals via reader antenna. The area and the cohesion of systems are a good deal dependent on the radio frequency which the gadget utilize. The operating frequency can decidedly affect detection area, data receiving-transmitting speed, interoperability, and so on.

The purpose of this system; pass the data to label, to read the information in the label when it is needed. The data in the label can be anything ID as a product, a commodity, a vehicle. To include more detailed information on the label, can be obtained more detailed information about the object or product. Information which read the label and queried to make meaningful are needed on a system. To accomplish this can be used in a data information system or computer.

This system basically consists of two parts; tag and reader parts. Tags are the basic elements of this system. Tags consist of an antenna and small silicon chip. This integrated silicon consists of a radio receiver, memory, logic control, power system and a radio modulator for sending the required answer back to the reader. Tags can be placed directly into the objects (products, packages, vehicles, people, etc.). The required dialog to read recorded information within the chip in the label is carried out via reader and antenna which in the label with radio frequency.

The readers are the another basic elements of the RFID systems. RFID reader sends radio energy impulses to the tag and evaluates the answer from the label. The label detects the energy and sends back to answer. This answer could be the serial number and other information. RFID readers are usually active, constantly emit radio energy and to enter a tag into the reading area.

In order to reader communicate to label, the required energy is provided by creating time-varying magnetic field on depending operating frequency. Reader sends that magnetic field mostly via circular framed antenna. When the current flows in a circular frame antenna, the generated magnetic field strength is calculated with;

$$\mathrm{H} = \frac{\mathrm{I.N.R}^2}{2(\mathrm{R}^2+\mathrm{x}^2)^{3/2}} \tag{2.1}$$

where I= current flowing from the antenna

N= Frame antenna winding number

R= Antenna diameter

X= the distance of the line perpendicular to the plane of the antenna the receiver.

When the current flows in a linear frame antenna, the generated magnetic flux density is calculated with;

$$\mathrm{B}_{\emptyset} = \frac{\mu_o \mathrm{I}}{4\pi \mathrm{r}}(\cos\alpha_2 - \cos\alpha_1) \quad (\mathrm{Weber}/m^2) \tag{2.2}$$

where I =Current

r: the distance from the center of the wire

μ_o: magnetic permeability ($\mu_o = 4\pi x 10^{-7}$Henry/meter)

As a special case given the infinite-length wire where α1=-180^0 ve α2=0^0, this magnetic flux density is calculated as

$$B_\emptyset = \frac{\mu_o I}{4\pi r} \qquad (2.3)$$

In RFID, when the system works as a near-field system (application), the voltage induced in tag coil is found by Faraday’s Law:

$$V = -N.\frac{d\Psi}{dt} \quad (\mathrm{V}) \qquad (2.4)$$

N= Antenna coil winding number

Ψ= Magnetic flux in each winding which is formulated as

$$\Psi = \int \mathrm{B.ds} \quad (\mathrm{Weber}) \qquad (2.5)$$

B= The magnetic fields

S= Winding to the surface area

where B and S is a vector component.

When the system works as a far-field system (application), the resonant frequency on the tag antenna is calculated as

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (\mathrm{Hertz}) \qquad (2.6)$$

Depending on the distance between the reader antenna and tag-induced voltage will change. Accessible working distance is limited because of change this voltage. One of the main parameters of coupling coefficient k;

$$k = \frac{\Phi_2}{\Phi_1} \qquad (2.7)$$

Φ_1=Magnetic flux through the label coil

Φ_2= Magnetic flux through the reader coil

The functions of radio frequency energy label that is sent by the reader contains the carrier signal to perform. Energy supply carrier signal label to send back information with reader provides synchronization. Gets the label signal modulates and sends it back to the reader. This sent signals to the reader antenna label are referred to backscatter signals. Reader that is taken by backscatter signals are decoded. The amount of power received by the reader can be roughly calculated by the following equations;

The equation for forward link calculation:

$$P_{tag}\text{ (dB)} = P_t\text{ (dB)} + \text{Path Loss (dB)} + G_r\text{(dBi)} + G_{tag}\text{(dBi)} \tag{2.8}$$

The equation for reverse link calculation:

$$P_r\text{ (dB)} = P_{tag}\text{ (dB)} + \text{Modulation Loss (dB)} + \text{Path Loss (dB)} \tag{2.9}$$

where P_t: Reader transmit power (generally at most 1 W)

P_{tag}: Power incident on tag

P_t: Reader received power

G_r: The reader antenna gain (generally 6 dBi)

G_t: Tag antenna gain (generally 0 dBi)

RFID transponders achieve in different frequency bands. The unique frequency is controlled by the radio regulatory enterprise in each country. The general frequencies for RFID are 125-134 kHz (LF), 13.56 MHz (HF), 400-960 MHz (UHF), and 2.45 or 5.8 GHz (Microwave) (F. T. Ulaby, E. Michielssen, U. Ravaioli, 2010). Although there are different frequencies used, those are the primary ones. In the UHF band, there are two areas of interest, one around 400 MHz (e.g. 433 MHz) and another around 860 – 960 MHz. Each of the frequency bands has blessings and drawbacks for operation. There exists no single frequency for every utility. When the operating frequency of the antenna increases to the UHF band, the perimeter of the loop antenna becomes comparable to the operating wavelength. Therefore, the loop antenna cannot produce a uniform magnetic field any more since the current flowing along the loop features phase-inversion and current nulls along the circumference (X. Qing, C. K. Goh and Z.N. Chen, September 2009).

2.2 The Working Principles of RFID System

RFID system's communications can be made between a reader which is actually called as transceiver and a tag. Radio frequency identity (RFID) tags are ever growing in use, from the monitoring of additives to the tracking of produce or farm animals throughout processing & manufacturing. They are additionally widely used in the touch-less technology seen today in store and charge cards and banking offerings. With this there was the ever increasing need to lessen the strength required to spark off the RFID tag, even as maximizing the read range. When interrogated by the reader, a tag responds with info regarding identity, still as alternative relevant info looking on the precise application. The tag is, essence, an electrical device commanded by the reader. The practicality and associated capabilities of the RFID tag rely upon two vital attributes: a) whether the tag is of the active or passive type, and b) the tag's operating frequency. Consequently, passive RFID systems are restricted to short read ranges (between reader and tag) on the order of 30 cm to 3 m, looking on the system's band. RFID system use two types of antenna such as dipole antenna for the reception of electric fields and loop antenna for reception of magnetic fields. The antenna uses a magnetic field known as inductive or near field, which looses its strength after a short distance. Thus, it is suited for RFID applications that allows the RFID transponders to be placed very near to the transceiver (J. Uddin, M. B. I. Reaz, M. A. Hasan, A. N. Nordin, M. I. Ibrahimy, M. A. M. Ali, May 2010).

Figure 2.1 shows how an RFID system works. Once activated by the signal from the tag reader (which acts as both a transmitter and a receiver), the RFID tag responds by transmitting the programmed into its electronic chip. After that, the reader forwards the data it received from the RFID tag to a database that can then match the tag's identfying serial number to an authorized system.

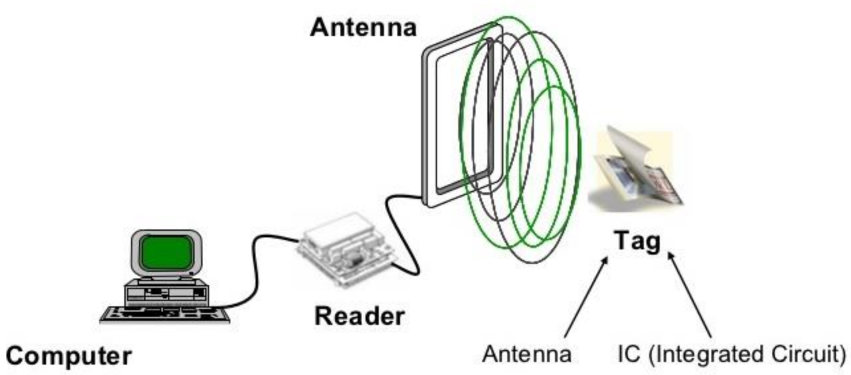


Figure 2.1 Working illustration of RFID system

The antenna of the transponder is the best radiating detail which provides the RF communicate hyperlink from the transponder to the interrogator and vice versa. The general expression for the fields from a radiating sinusoidal current wire supply is given below as;

$$E_\theta = \frac{I_o dz}{4\pi}\left[\frac{j\omega\mu}{r} + \sqrt{\frac{\mu}{\varepsilon}}\frac{1}{r^2} + \frac{1}{j\omega\varepsilon r^3}\right]\varepsilon^{-jkr}\sin(\theta) \tag{2.10}$$

$$E_r = \frac{I_o dz}{2\pi}\left[\sqrt{\frac{\mu}{\varepsilon}}\frac{1}{r^2} + \frac{1}{j\omega\varepsilon r^3}\right]\varepsilon^{-jkr}\cos(\theta) \tag{2.11}$$

$$H_\emptyset = \frac{I_o dz}{4\pi}\left[\sqrt{\frac{jk}{r}} + \frac{1}{r^2}\right]\varepsilon^{-jkr}\sin(\theta) \tag{2.12}$$

where; I_o = the amplitude of the sinusoidal current electrod source

dz = the sinusoidal current filament source length λ 2π

k = wavenumber in free-space

r = radial distance from the sinusoidal current electrod source

$\omega = 2\pi f$, f is the frequency

μ = permeability of the medium

ε = permittivity of the medium

The geometry of the sinusoidal current wire supply is displayed in Figure 2.2. The fields surrounding the radiating element can be identified with the equations (2.10), (2.11), (2.12).

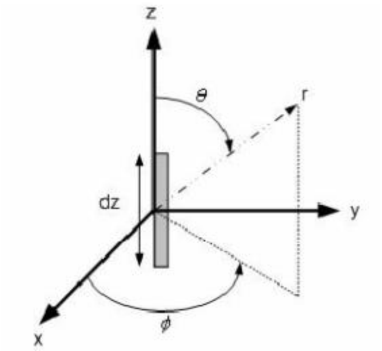


Figure 2.2 Geometrical representation of the sinusoidal current wire source

Inside the near-subject, the electromagnetic power strains are shaped transferring outwards from the radiating detail and then back into the radiating element as shown in Figure 2.3;

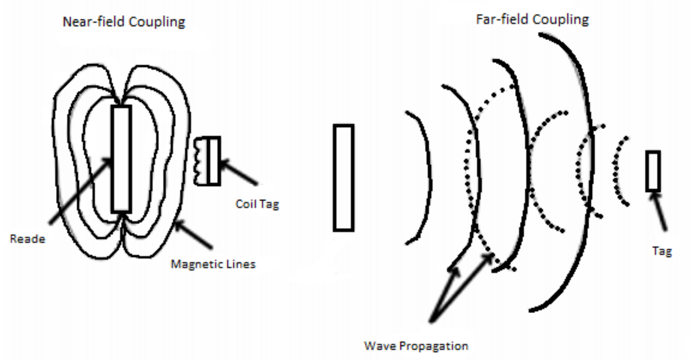


Figure 2.3 The image of inductively and electromagneticly coupling

A close to-area antenna uses inductive coupling this means that that it uses a magnetic field to energize the RFID tag. Near-field coupling take places within approximately one wavelength of a radiating element. Near-field coupling takes place for RFID applications operating in the LF and HF bands with relatively short reading (S Kalaycı, May 2009). A magnetic field is created inside the near-area that allows the RFID reader’s antenna to energize the tag. The tag then responds by growing a disturbance within the magnetic subject that the reader alternatives up and decodes. On the other hand, a far-field antenna uses capacitive coupling (or propagation coupling) to energize the RFID tag. Capacitive coupling happens while the RFID reader’s antenna propagates RF energy outward and that power is used to energize the tag. The tag then sends lower back a portion of that RF strength to the reader’s antenna as a reaction that is called backscatter.

A far-field antennas come in a huge sort of styles and sizes and generally can examine tags among a few centimeters, up to extra than 9 meters away in ideal conditions. Plenty of alternatives are available when selecting a much-area antenna inclusive of linear or circular polarization, varying advantage, and alternatives for indoor or outdoor use. because of the improved examine region whilst the usage of far-subject antennas, stray tag reads (i.e. analyzing accidental RFID tags) tend to be a not unusual issue.

3 MICROSTRIP PATCH ANTENNA DESIGN

3.1 Overview of Microstrip Patch Antenna

Microstrip antenna is composed of a thin metallic patch separated from the conductive ground by a dielectric layer as shown in Figure 3.1. Microstrip antennas are most of the maximum widely used styles of antennas inside the microwave frequency variety, and they're regularly used within the millimeter-wave frequency range as properly. Besides called as patch antennas, microstrip patch antennas consist of a metallic patch of metal that is on top of a grounded dielectric substrate of thickness h, with relative permittivity and permeability ε_r and μ_r. There are many advantages and disadvantage compared to other antennas.

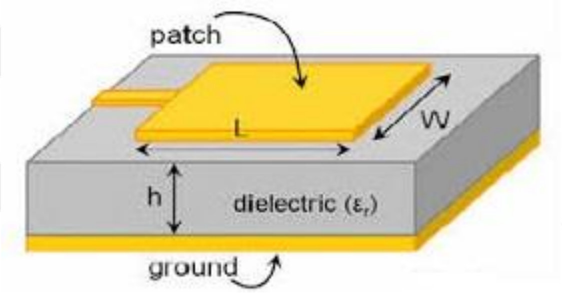


Figure 3.1 A basic microstrip patch antenna

There are many advantages of microstrip antennas as compared to other antennas which can be expressed as

- Weights and volumes less than the others
- It can be produced easily a large number of with low-cost fabrication
- Both are linear and circular polarization format allows
- They are consistent easily with the Microwave Integrated Circuits (MIC)
- The same antenna can be set up to work on more than one frequency

All of these features as well as microstrip antenna has some limitations;

- Generally the bandwidths are narrower
- Radiation gain is less

- There are many dielectric losses.

Metallic patch, although the creation in any way, in terms of facilitating the analysis and performance estimates appears to commonly known formats such as rectangle, square, circle or triangle geometry as shown in Figure 3.2. A microstrip antenna in its simplest form consists of a rectangular shape (or other shapes such as circular, triangular, etc.) on top of a substrate backed by a ground plane (J. L. Volkais, 2007).

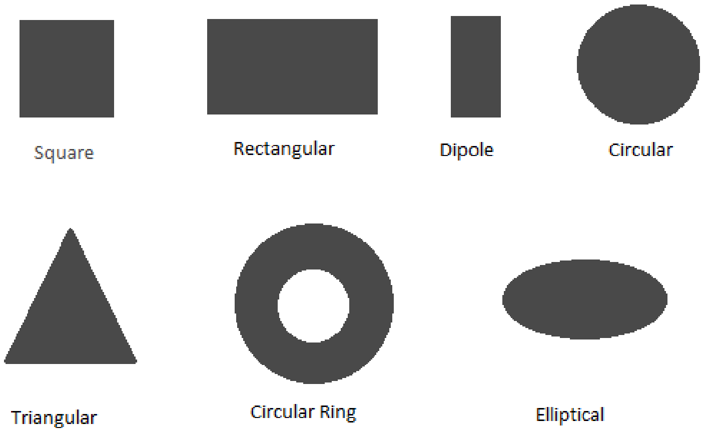


Figure 3.2 Different shapes of microstrip patch antenna

3.2 Microstrip Patch Antenna Parameters and Factors in the Design

3.2.1 Geometry

Geometry selection antenna is one of the most important factors for designing realistic and useful antenna, after a suitable dielectric substrate choice. A thick dielectric layer provides more power, increases of the radiation power and impedance bandwidth increases. but not useful due to weight, dielectric loss and surface-wave loss. Low dielectric permeability (ε_r) shows the same effects with thick layer. The thesis has used rectangular metallic patches as given in Figure 3.3. It is the most widely used format because geometrically analysis, is easy, according to the circular shape provides more bandwidth. According to other shapes to more cooperative and compliant physical optimization and the best suited shape for thin dielectric layer.

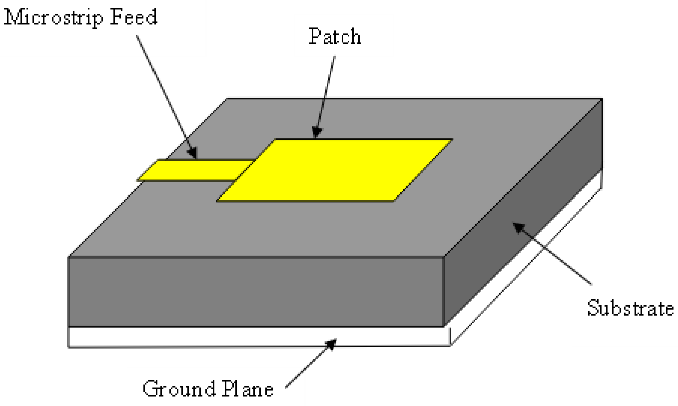


Figure 3.3 A rectangular microstrip patch antenna

3.2.2 Radiation Mechanism and Radiation Characteristics

Radiation in microstrip antenna is created by electrical field distribution between conductive ground plane and metallic patch. This case can be explained with the distribution of surface currents on the patch as shown in Figure 3.4 and Figure 3.5, respectively. An antenna which is connected to a microwave source such as conducting ground plane, load polarization occur the upper and lower surfaces of metallic patch.

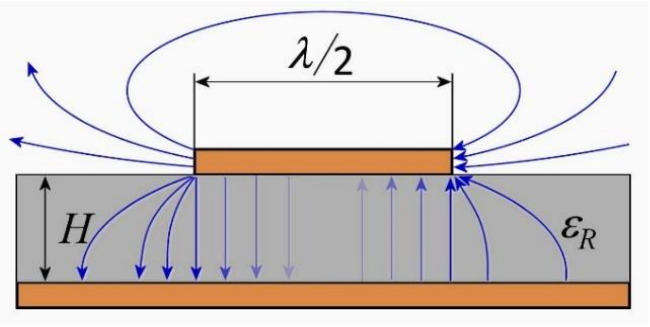


Figure 3.4 The fields on microstrip patch antenna

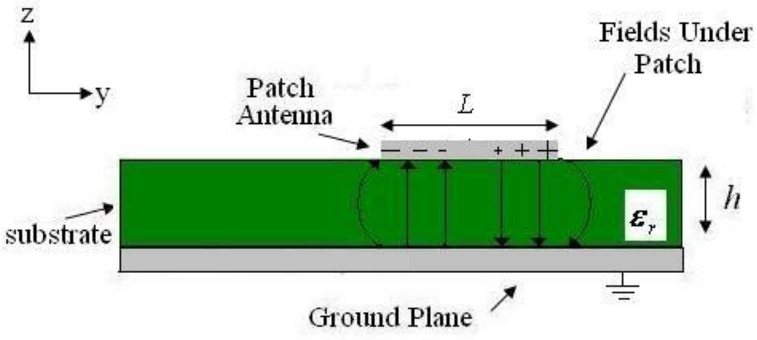


Figure 3.5 The surface currents on microstrip patch antenna

Radiation characteristic is a function of an antenna of power to emit or required power. The characteristic refers to how power is routed. The following illustration in Figure 3.6 shows the general radiation characteristics of an antenna which can be redirected are given. These results can be achieved from the shape;

- A transmitter antenna main lobe should be more bigger and longer than other lobe.

- Back and minor lobes are unwanted instances. In terms of the transmitter antennas, back and minor lobes are represent the energy spent which is not transferred to the main lobe. They represent noise from transmission environment.

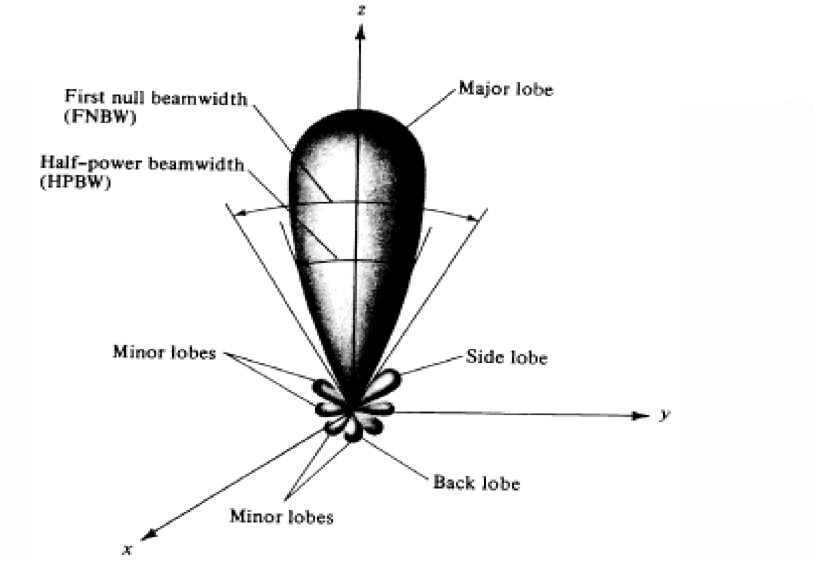


Figure 3.6 A typical antenna radiation pattern

3.2.3 The Reflection Coefficient and the Characterictic Impedance

In high frequency applications, reflection coefficient is an important factor to be reckoned with in microwave transmission line. Each transmission line has a characteristic impedance special of the structure. This impedance is taken generally as 50 Ω. If the line end of any Z_L load is not the same value of impedance which is visible from the entrance, the reflection event occurs. This situation is a reflection coefficient for modeling Γ has been defined, and it is equal to the ratio of the outgoing wave voltage and the returned wave voltage.

$$\Gamma = \frac{V_o^-}{V_o^+} = \frac{Z_{L-}Z_o}{Z_{L+}Z_o} \tag{3.1}$$

3.2.4 Return Loss

Return loss is a parameter that the amount of power does not disappear and the payload as reflection. When the mismatch between transmitter and antenna impedance values is higher, the losses more result from standing waves. Return loss in simulation of antenna can be shown in dB in the below formulation as

$$RL(dB) = -20logI\Gamma I \tag{3.2}$$

Γ=0 or RL=∞ can be considered as perfect match of the impedance between antenna and transmitter. In these cases, concluded that failing to back the power reflected image sequence. In practice this results never is currently unavailable. Instead of the use of the antenna and the desired properties, reflection coefficient, and hence the return loss should be taken to acceptable values.

3.2.5 Gain and Radiation Efficiency

Because of being passive structures, antennas don’t have gain of active devices such as amplifiers. Radiation efficiency is defined as a factor that represents antenna gain. Because of the radiation efficiency is always lower than 100%, the antenna gain is always lower than antenna directivity. This efficiency quantifies the losses in the antenna and is defined as the ratio of radiated power (Pr) to input power (Pi). Gain is an important factor that occurred, antenna losses in determining. gain passes through as the concentration ability to an angular space area to antenna power.

$$G = e_{r.}D \tag{3.3}$$

where $\mathrm{e_r}$ is the efficiency of radiation. Efficiency of radiation is a measure of the rate of losses dielectric and surface wave which related directly with total radiation power, input power, transmission loss and structure. The radiation efficiency is;

$$e_r = \frac{P_r}{P_r+P_c+P_d+P_{sur}} \tag{3.4}$$

For a less lossy dielectric material, transmission loss, $\mathrm{P_c}$, and dielectirc loss $\mathrm{P_d}$, can be neglected. Radiation power for rectangular patch type microstrip antenna, h is the layer thickness, k_o is the free-space wavenumber.

$$P_r = 40k_o^2(k_oh)^2\left(1-\frac{1}{\varepsilon_r}+\frac{2}{5\varepsilon_r^2}\right) \tag{3.5}$$

The waves which are not sent directly due to the losses in antenna, remains to the surface of the child of metallic layers or radiate the other directions. This waves are called the surface-wave and is called the power of this surface wave strength;

$$P_{sur} = 30\pi k_o^2\frac{\varepsilon_r(x_o^2-1)}{\varepsilon_r\left(\frac{1}{\sqrt{x_o^2-1}}+\frac{\sqrt{x_o^2-1}}{\varepsilon_r-x_o^2}\right)+k_oh\left(1+\frac{\varepsilon_r(x_o^2-1)}{\varepsilon_r-x_o^2}\right)} \tag{3.6}$$

The input power is transformed into radiated power, surface wave power and a small portion is dissipated due to conductor and dielectric losses. Surface waves are guided waves captured within the substrate and partially radiated and reflected back at the substrate edges. Surface waves are more easily excited when materials with higher dielectric constants and/or thicker materials are used. Surface waves are not excited when air dielectric is used. Antenna gain can also be specified using the total efficiency rather than just the radiation efficiency. This total efficiency is a combination of the radiation efficiency and efficiency linked to the impedance matching of the antenna. Orienting the antenna (D) can explained as the energy density in the main lobe. So how much power in the main lobe means that antenna directed extremely well. This is equal to the rate of the density of a given direction of radiation in isotropic antenna. A patch antenna radiates power in certain directions which is desired and we say that the antenna has directivity (usually expressed in dBi). If the antenna had a 100% radiation efficiency, all directivity would be converted to gain. Typical half wave patches have efficiencies well above 90%.

3.2.6 Polarization

Antenna polarization is a very important parameter when choosing and designing an antenna. It helps to have a good clamp of all the condition of this subject. Most communications systems use either vertical, horizontal or circular polarization. Knowing the difference between polarizations and how to maximize their benefit is very important to the antenna user.

Polarization is the direction of wave radiated by the antenna. It is a factor of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector (Hasse R., Demir V., Hunsicker W., Kajfez D. and Elsherbeni A., 2008). There are two very common kind of polarization; linear polarization and circular polarization. In Figure 3.7, a random wave propagation characteristics for linear polarization is depicted.

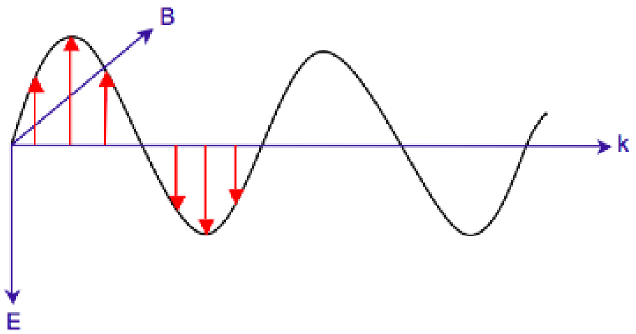


Figure 3.7 A random linear polarization view

Given the spread of the wave radiation on the screen parallel E_x-H_y plane, if get out of any straight line in any direction, in this case, the polarity of the wave is linear polarization. Here amplitude changing over time but straight line remain constant.

If the projection falls on the screen as given in Figure 3.8 where amplitude fixed but the direction changes over in time, the wave is called circular polarization.

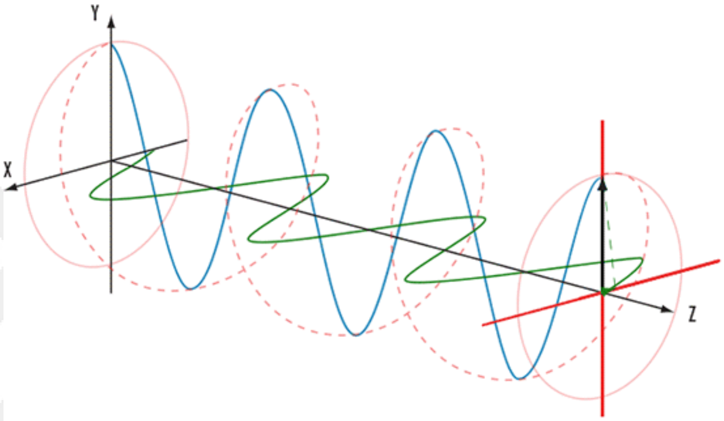


Figure 3.8 A random circular polarization view

In a linear polarization wave, AR= 0 or ∞ and electric field x and y components have the same phase ($\emptyset_{\mathrm{x}} = \emptyset_{\mathrm{y}}$); but circular polarity up to the x and y components are electric field ($\mathrm{E}_x = \mathrm{E}_y$) has the same amplitude and there is a relation between phases as $\emptyset_x - \emptyset_y = 90^o$. Microstrip antennas is the biggest advantage in this topic is a patched microstrip antenna can be designed to linear and/or circular polarization.

In some cases, the only way RFID Design Principles to fulfill a system requirement is to use a circularly polarized reader antenna. Thus, a sacrifice of 3-dB power loss due to a polarization mismatch among a circularly polarized reader antenna and a linearly polarized tag antenna overcomes the hassle of tag orientation. Polarization efficiency is involved to evaluate the mismatch. This factor is defined as the ratio of the actual power received by an antenna to the possibele maximum received power which can be accomplished by optimising the matching condition between the polarisation of incident wave and that of the receiving antenna. That is why, these days, the primary companies offer specially circularly polarized reader antennas. On the equal time, the linearly polarized antennas are also available in the market for limited RFID applications. Inside the case of linearly polarized reader and tag antennas, the vast polarization misalignment may additionally reason a extreme electricity loss, which in its turn can doubtlessly result in a fault at the part of the RFID gadget.

3.2.7 Bandwidth

The bandwidth of an antenna means the range of frequencies that the antenna can operate. The bandwidth of an antenna is defined as the range of frequencies within which the performance of the antenna, with respect to some characteristics, conforms to a specified standard (James, J.R., and P.S. Hall(Eds), 1989). In other words, there is no unique characterization of the bandwidth and the specifications are set to meet the needs of each particular application. There are different definitions for antenna bandwidth standard.

Return loss is a measure of reflection from an antenna. 0 dB means that all the power is reflected; hence the matching is not good. -10 dB means that 10% of incident power is reflected; meaning 90% of the power is accepted by the antenna. So, having -10 dB as a bandwidth reference is an assumption that 10% the energy loss. Referring to Figure 3.9, the value of bandwidth can be calculated in the form of percentage as formula (3.7) below;

$$Bandwidth = \frac{f_2 - f_1}{f_2 + f_1} x100\% \tag{3.7}$$

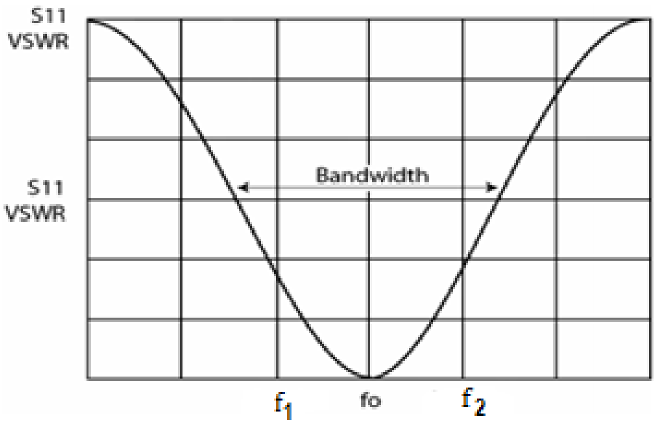


Figure 3.9 Impedance bandwidth definition

3.3 Microstrip Patch Antenna Feed Techniques

This section includes the most used feed techniques. In general, whatever the feeding technique name, main objective is to ensure compliance with the impedance. achieve harmony to impedance guarantees to pass to metallic patch a huge portion of the transmitted power from supply. On the other hand, a feeding technique for an antenna compatibility is very important also it is to focus on. Feeding methods are listed below;

3.3.1 Probe Feed

Probe feed technique is created by a probe is soldering through to the dielectric layer from metallic patch as shown in Figure 3.10. The probe can be any conductor or coaxial cable. Probe should be placed in the coordinate where provided the best impedance harmony.

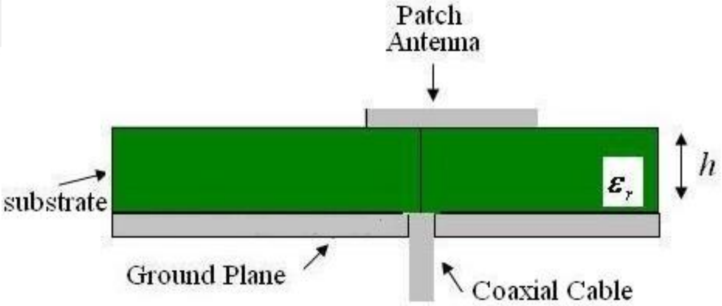


Figure 3.10 A coaxial feeding view

There are also some limitations in this method:

- Because of solder and the conductor pass through the surfaces, radiation efficiency become lower why fringing on surface current.
- Requires use of many solder in array antenna is not good farmland.
- For thick dielectric layer antennas, the probe cable requires long, it causes lower gain.

3.3.2 Microstrip Feed

In microstrip feed, power is transferred metallic with the help of a thin conductive which is illustrated in Figure 3.11. The main advantage of the technique, feeding the same item from the metallic patch in case of a planar structure formation. This condition is a surface wave-reducing situation. It can be easily adapted to the antenna. Metallic patch is a continuation of the feed strip. However as the thickness of the dielectric substrate being used, increases, surface waves and specious feed radiation also increases, which bassinet the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

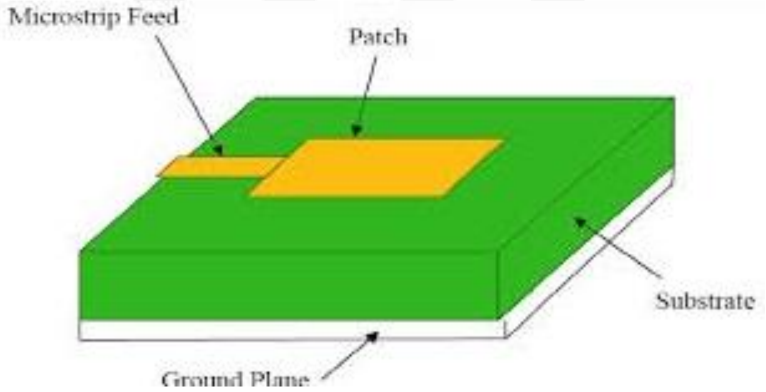


Figure 3.11 A microstrip feeding view

Microstrip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be consider as extension of patch. It is simple to model and easy to match by controlling the inset position. However the disadvantage of this method is that as substrate thickness increases, surface wave and spurious feed radiation increases which limit the bandwidth.

3.3.3 Aperture Coupled Feed

In this feeding technique, the feeding system is separated by a second place from the metallic patch (Figure 3.12). Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The aperture coupled feed eliminates feed-line radiation and also allows thick substrate as a probe reactance which is not an issue (M. Ramesh and Y. Kb, 2003).

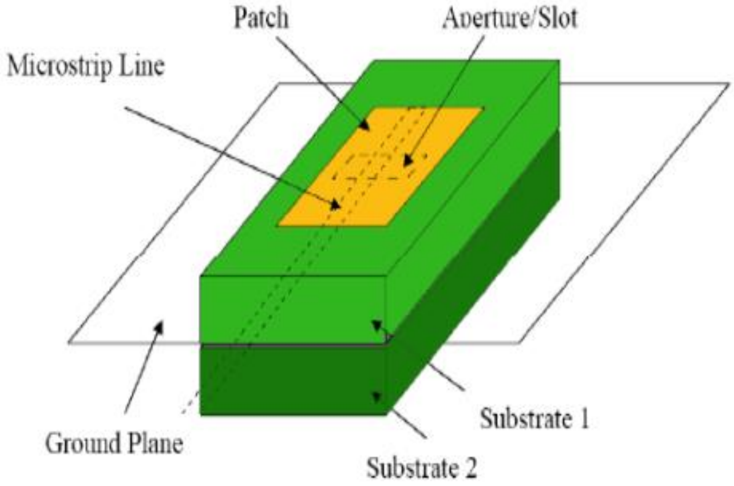


Figure 3.12 Aperture-coupled feed

The coupling aperture is typically focused descender part of the patch, main to decrease cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is decided by using the shape, length, dimensions and place of the aperture, for the reason that floor plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch (S K Behera, 2008).

4 THE EFFECTS OF ANTENNA PROPERTIES ON THE READ DISTANCE

In passive backscatter RFID structures, the operational energy required by means of the tag is transmitted from the reader. This calls interest to the full overall performance of the radio link among the reader and the tag. The properties of the reader or the tag, including transmitting electricity, antenna benefit, running frequency, radar pass-segment, nice factor, powerful aperture or scatter aperture, polarization, and receiver sensitivity, are considered as a few primary elements affecting reading distance.

4.1 The Effect of Antenna Gain

Antenna gain affects the read distance of the passive backscatter RFID system, in which the reflection of electromagnetic waves from the object is used for data transmission from the tag to the reader. According to Friis transmission equations in free space, the read distance R is proportional by formula as;

$$R = K\lambda/4\pi . \sqrt[4]{P_t G_t^2 G_r^2 / P_r} \tag{4.1}$$

where the λ is the wavelength, P_t is the power transmitted by the reader, G_t is the gain of the transmitting antenna, G_r is the gain of receiving tag antenna, P_r is the receiving power of the reader antenna, and K is system (modulation) loss. Equation (4.1) demonstrates that both reader antenna gain and tag antenna gain affect the read distance of the passive backscatter RFID system. Furthermore, contrast to tag antenna gain, reader antenna gain affects read distance remarkably.

4.2 The Effect of Antenna Frequency

The operating frequency ranges for common passive backscatter RFID systems are 868 MHz, 915 MHz, 2.45 GHz, and 5.8 GHz. Correspondingly, wavelengths for these frequencies are 0.3456 m, 0.3279 m, 0.1224 m, and 0.0517 m. According to equation (4.1), the read distance is directly proportional to the wavelength used. Via the usage of a lower frequency, i.e. an extended wavelength, the read distance can be expanded. In some instances the RF signal from the reader to the tag has to propagate thru an absorbing material. Thus, the frequency used has an effect on the propagation losses in the material. Since antenna dimensions are proportional to the wavelength used, a lower frequency and a longer wavelength mean a larger tag size. In most cases, the antenna size is a proscribing factor inside the miniaturizing of passive RFID device tags. normally, folded dipole antennae and microstrip patch antenna are used as tag antenna.

4.3 The Effect of Antenna Polarization

The polarization inequality between the transmitting antenna and receiving antenna can be termed the polarization mismatch. The amount of power extracted by the antenna from the incoming signal will not be a maximum on account of the polarization loss (C.A.Balanis, 1997). Thus, antenna polarization mismatch affects the read distance of the passive Backscatter RFID system. Assuming that the electric field of transmitting antenna or incoming wave can be expressed as

$$\hat{E}_{inc} = \hat{\rho}_{wave}. E_{inc} \qquad (4.2)$$

where $\hat{\rho}_{wave}$ wave is the unit vector of the wave, and the polarization of the electric field polarization of receiving antenna can be expressed as

$$\hat{\rho}_{rec} = \hat{\rho}_{rec} \qquad (4.3)$$

where $\hat{\rho}_{rec}$ is its polarization vector, and the polarization loss can be taken into account by introducing a polarization loss factor. The polarization loss factor (PLF) is defined as

$$PLF = \left|\hat{\rho}_{wave}.\hat{\rho}_{rec}\right|^2 = \left|cos\varphi_{\rho}\right|^2 \qquad (4.4)$$

where φ_ρ is the angle between the $\hat{\rho}_{wave}$ and the $\hat{\rho}_{rec}$. Typically, the polarization loss issue PLF is expressed in decibels. From (4.4), it's far regarded that the electricity loss starts to increase notably with the attitude of polarization mismatch growing. In some cases, the use of circularly polarized antennae on the reader improves the RFID system performance. In those cases, the effect of polarization mismatch can be neglected and angle between the reader antenna and the tag antenna has no effect on the read distance. However, if the tag antenna is linearly polarized, but the reader antenna is circularly polarized, there is a 3 dB power loss, irrespective of the angle between the antenna, compared to the case in which the polarization matched, linearly polarized antenna are used on both the reader and the tag.

Circular polarization enables to acquire or transmit through antennas without considerably converting the output voltage. In lots of applications, these antennas running at low power density, whilst the transmitting power is low and the transmission distance is long. The circular polarization (CP) is the combination of nonorthogonal modes independently excited by way of an willing slot and open termination at the stop of the CPW line. Because of this, the proposed antenna can generate a linear polarization in any direction and also allow a symmetrical radiation sample.

UHF RFID device usually undertake linearly polarised antennas as tag antennas because of their low fee and easy fabrication. but, most RFID systems are used to hit upon cell objects, for instance, in RFID utility of deliver chains, the shipment on that is installed a tag may be transported along side a deliver chain. If the reader antenna linearly polarised, it's possible that the tag antenna and the reader antenna can be aligned orthogonally to each other. While that happens, the reader will now not be capable of read or software RFID tags. Subsequently, RFID reader antennas regularly undertake circular polarization to make certain in most of the instances the device can carry out efficiently (O. Bostan, 2014). As a result, the polarization efficiency among reader antenna in round polarisation and a tag antenna in linear polarization is 0.5 (or -3 dB).

5 DESIGN OF AN UHF MICROSTRIP PATCH ANTENNA

In this thesis, two different types of microstrip antennas for RFID systems have been designed in UHF band (865- 868 MHz for Europe).

5.1 UHF Antenna Design

Microstrip patch antennas in this thesis have been designed for UHF frequency specifically 868 MHz as center frequency. Microstrip patch antenna (also known as printed antennas) is a popular type of antennas. A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a groundplane as Figure 5.1. Common microstrip antenna radiator shapes are square, rectangular, circular and elliptical, but any continuous shape is possible. Some patch antennas contain a dielectric substrate and some of them suspend a metal patch in air above a ground plane using dielectric spacers; the resulting structure is less robust but provides better bandwidth.

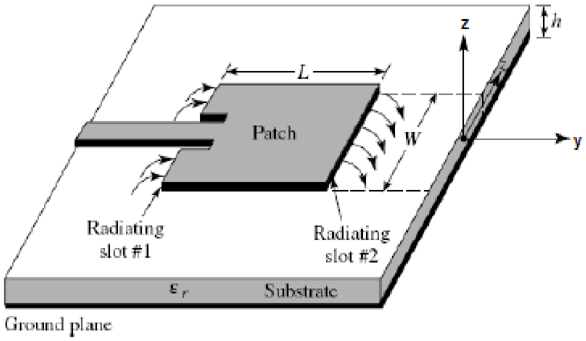


Figure 5.1 The dimensional view of microstrip patch antenna

Microstrip antennas are also relatively inexpensive to manufacture and design because of the simple 2-dimensional physical geometry. They are usually employed at UHF because the size of the antenna is directly tied to the wavelength at the resonance frequency. A single patch antenna provides a maximum directive gain of around 5 dBi (C. A. Balanis, 1997). It is relatively easy to print an array of patches on a single (large) substrate using lithographic techniques. Patch arrays can offer several better gains than a single patch at little extra value; matching and phase adjustment can be accomplished with published microstrip feed structures, once more within the equal operations that form the radiating patches. An advantage inherent to patch antennas is the ability to have polarization diversity. Patch antennas can easily be designed to have Vertical, Horizontal, Right Hand Circular (RHCP) or Left Hand Circular (LHCP) Polarizations, using multiple feed points, or a single feedpoint with asymmetric patch structures. This unique property allows patch antennas to be used in many types of communications links that may have varied requirements. Various types of antennas have been designed for ultra-high frequency (865-868 MHz for Europe) to test with respect to efficiency. A commercial RF and Microwave Design Software from AWR Corporation (Applied Wave Research) was used to design and simulate antenna projects.

First of all Eq. (5.1) is used to calculate the approximate dimensions of the antennas;

$$L = 0.49 \times \frac{c}{f\sqrt{\varepsilon_r}} \tag{5.1}$$

where c is the speed of light in air (3×10^8 m/s), f is resonant frequency of antenna, ε_r is dielectric constant of substrate and L is length of antenna. This formula gives the length of the antenna (patch). This is important for designing to be precise as the length affects the operating frequency of the antennas. Then, the length of ground plane is calculated. The area of the ground plane should be three times bigger than the area of the patch to radiate efficiently. After these calculations, all the parameters of dielectric material and the ground plane dimensions of the antenna are given to AWR Microwave Office. After these calculations, all the parameters of dielectric material and the ground plane dimensions of the antenna are given to AWR Microwave Office. The followings are some hints that affect the dimensions and the behavior of antenna. With the increase in substrate thickness, the fringing fields from the edges increase, which increases the extension length, there by decreasing the resonance frequency. Besides, the bandwidth of the antenna increases (Srivastava, D.K., Vishwvakarma, B.R., Saraswat, R.C., Saini, J.P, 2007). With decrease in permittivity, size of patch and bandwidth increases due to increase in fringing fields (Srivastava, D.K., Vishwvakarma, B.R., Saraswat, R.C., Saini, J.P, 2007). A higher permittivity reduces the patch size and the extent of the fringing fields. Consequently, the radiation is due to a narrow magnetic current ring around the patch periphery, which normally gives asymmetric radiation patterns. A thicker substrate, on the other hand, does not reduce the patch size significantly, but extends the zone of the fringing fields, thus resulting in a broad radiation ring (James, J.R. and Hall, P.S, 1989). Fringing fields are the fields thar are responsibe for radiation as seen in Figure 5.2.

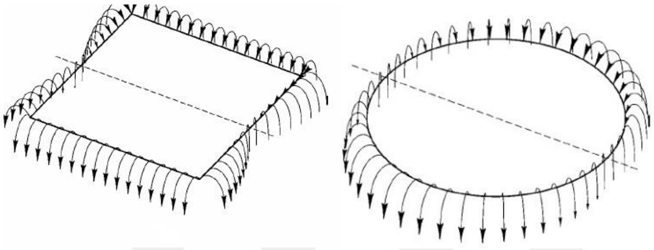


Figure 5.2 The fringing fields

5.2 Design Procedure and Steps

In general, patch antennas have the length of half-wave structures at the operation frequency of fundamental resonant mode. Since the fringing field acts to extend the effective length of patch, the length of the half-wave patch is slightly less than a halfwavelength in the dielectric substrate material. Approximate value for the length of a resonant half-wavelength path is given by Eq. (5.1). Then, all other the dimensions of the patch antenna are calculated based on equations (5.2) and (5.3). The width is given by

$$W = \frac{c}{2f_o}\sqrt{\frac{\varepsilon_r+1}{2}} \tag{5.2}$$

where f_o is the resonant frequency of the patch antenna. The effective dielectric constant for the case of (W/h > 1) is given by Eq. (5.3);

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{1+\frac{12h}{W}} \tag{5.3}$$

Effective length, which is illustrated in Fig. 5.3, is calculated by Eq. (5.4)

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{5.4}$$

Length extension is;

$$\Delta\mathrm{L} = 0.412\mathrm{h}\frac{(\varepsilon_{\mathrm{reff}}+0.3)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.264\right)}{(\varepsilon_{\mathrm{reff}}+0.258)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.8\right)} \tag{5.5}$$

where;

h=substrate thickness

Actual patch length,

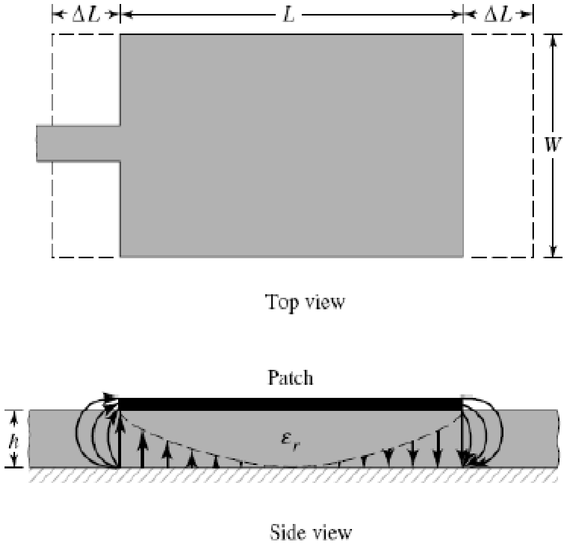


Figure 5.3 Physical and effective length of microstrip antenna (Balanis, 2005)

$$L = L_{eff} - 2\Delta\mathrm{L} \tag{5.6}$$

The resonant frequency,

$$f = \frac{c}{2(L+\Delta\mathrm{L})\sqrt{\varepsilon_{\mathrm{reff}}}} \tag{5.7}$$

with c is the speed of light.

Microstrip feed line use for patch antenna determine to be fed for 50 ohm for line impedance (Z_o) is calculated by;

$$z_o = \frac{60}{\sqrt{\varepsilon_{reff}}} ln\left[\frac{8h}{W_f} + \frac{W_f}{4h}\right] \tag{5.10}$$

where;

h=substrate thickness

Z_o=line impedance

The feed point must be located at that point on the patch, where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point. In this case we use PSO to obtain the optimum feed depth, where the return loss (RL) is most negative (i.e. the least value). According to (Hasse R., Demir V., Hunsicker W., Kajfez D. ve Elsherbeni A., 2008) there exists a point along the length of the patch which gives the minimum return loss.

$$R_{in}(y = y_o) = R_{in}(y = 0)cos^4(\pi * y_o/L) \tag{5.12}$$

where, $$R_{in}(y = 0) = 0.5 * (G_1 \mp G_{12}) \tag{5.13}$$

$$Z_c = \left\{\begin{array}{c} \frac{60}{\sqrt{\varepsilon_{reff}}} ln\left[\frac{8h}{W_o} + \frac{W_o}{4h}\right] \\ \frac{120}{\sqrt{\varepsilon_{reff}}\left[\frac{W_o}{h}+1.393+0.667ln\left[\frac{W_o}{h}+1.444\right]\right]} \end{array}\right\} \tag{5.14}$$

where,

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_o}\right)^2 & W \ll \lambda_o \\ \frac{1}{120}\left(\frac{W}{\lambda_o}\right) & W \gg \lambda_o \end{cases} \tag{5.15}$$

and,

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{sin\left(\frac{k_o W}{2}cos\theta\right)}{cos\theta}\right] J_o(k_o L\ sin\theta) sin^3\theta d\theta \tag{5.16}$$

6 DESIGN AND SIMULATION OF RFID READER ANTENNAS

6.1 The Proposed UHF RFID Antennas Structure

In this thesis, firstly, the used dielectric substrate is selected by taking into consideration the gain, efficiency, good radiation pattern and so on. The antennas are designed by using Roger RO4003C which is one of the products of Rogers Corporation as dielectric material (Rogers Corporation, 2016). Its product features are; dielectric constant is ε_r = 3.55 and tangent loss is tan δ = 0.027, thickness is h = 1.524 mm. The reasons of this substrate selection are low-loss property, plenty plates of availability in Yasar University Antennas and Microwave Laboratory and easy manufacturing.

Most RFID antenna labels on the market are linearly polarized, at the same time, many RFID reader structures use circular polarized antennas to make certain that tags can be examine in any orientation. Those antennas are frequently targeted via their circular advantage and axial ratio. Because tag variety strongly depends on antenna advantage, it is crucial to recognize the courting among the linear advantage of an antenna and its circular advantage. For the proper functioning of the standard microstrip antenna, the ground plane which is located on the back side of the antenna is recommended to be at least twice the size of the microstrip patch antenna. By using the formulations in Chapter 5, the dimensions of a standard patch antenna at 868 MHz center design frequency is calculated for RO4003C substrate. A simulation view of traditional microstrip patch antennas fed by a microstrip line with a 100 Ω quarter-wavelength transformer matching network is depicted in Figure 6.1 where the dimensions are also given in Table 6.1.

Table 6.1 The parameters of the designed microstrip patch antenna without segmented loop

$Ground\ width$	206 mm
$Ground\ Length$	180 mm
W	101 mm
L	90 mm
ε_{reff}	3.50

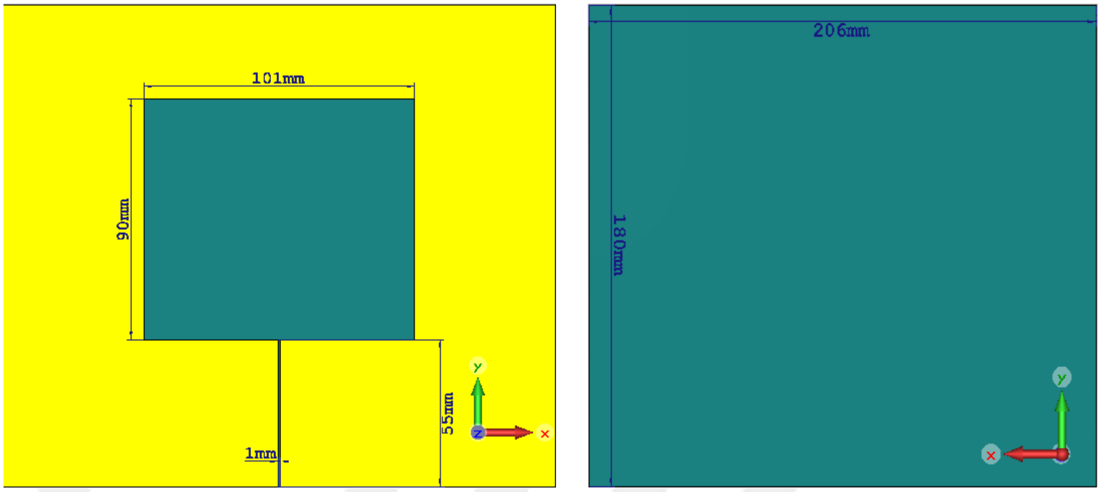


Figure 6.1 CST model of a traditional rectangular patch on Roger RO4003C at 868 MHz

The reflection coefficient (S_{11} values) for the traditional antenna given in Figure 6.1 is shown in Figure 6.2. The resonance frequency is found to be 868.9 MHz with S_{11} value lower than -10 dB, which is so close to the desired center frequency of 868 MHz. So, the equations given in Chapter 5 are verified with this simulation result.

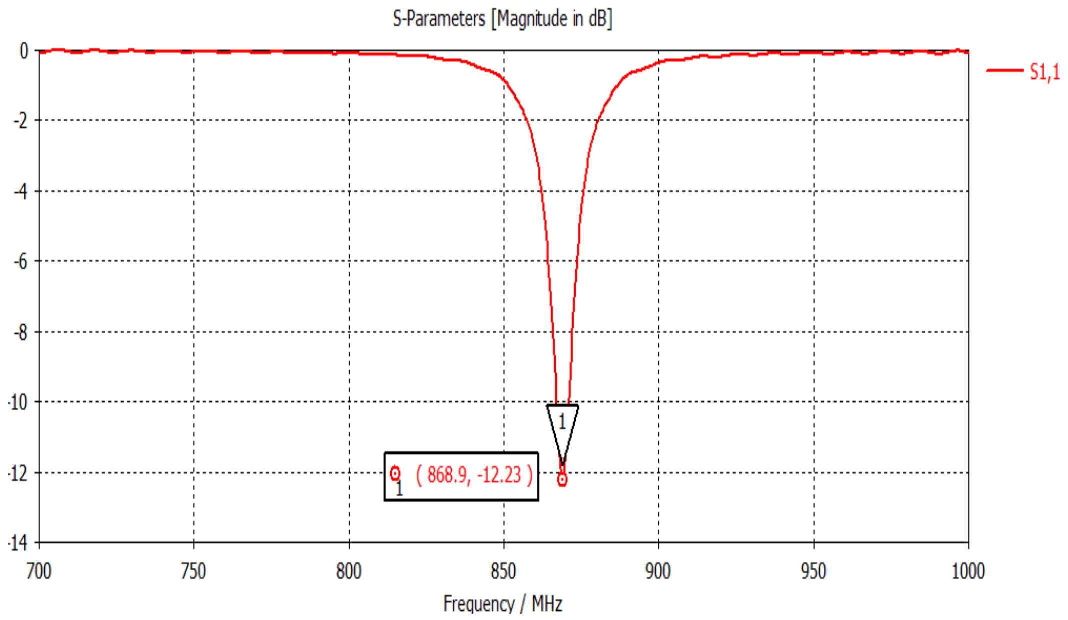
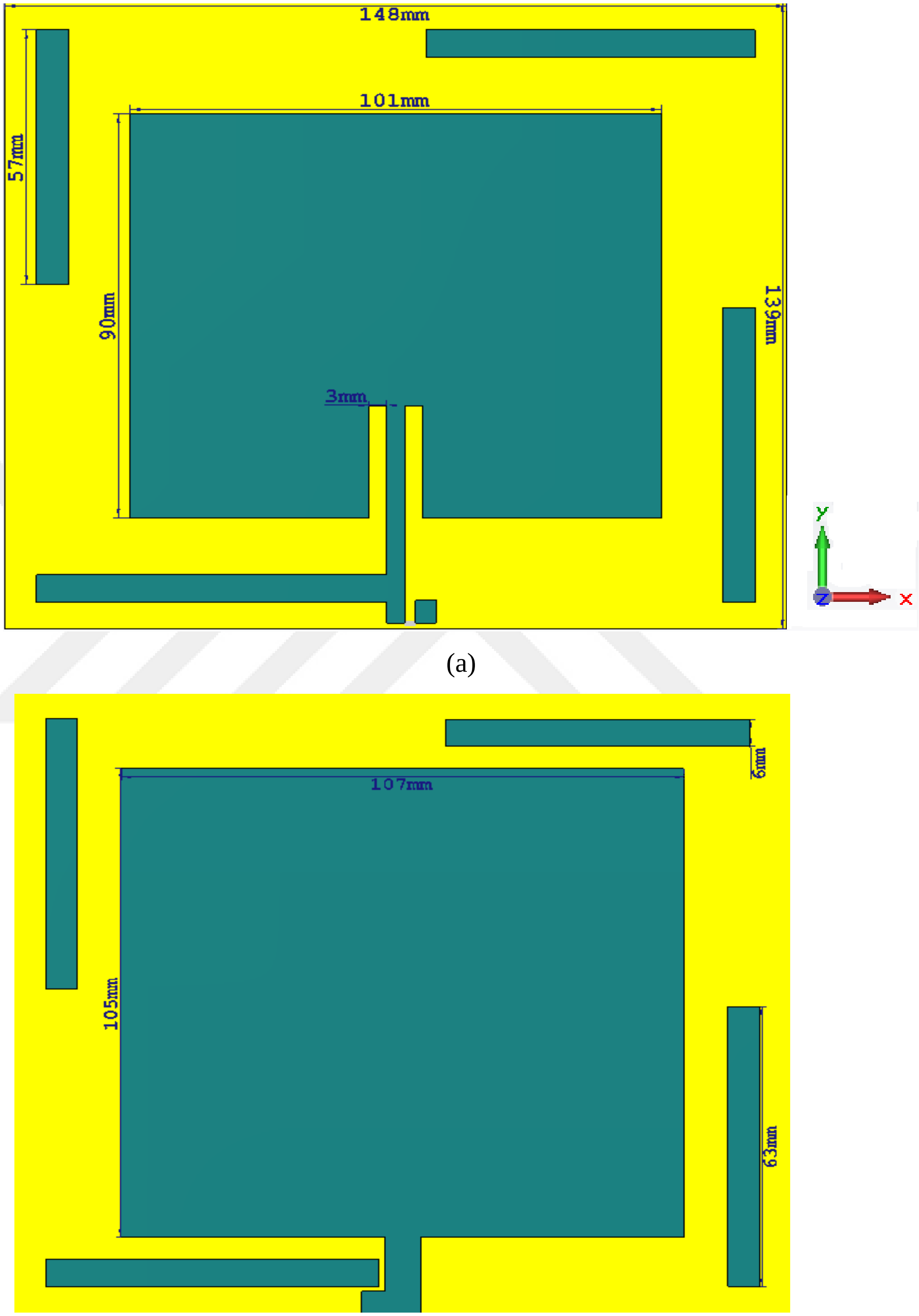


Figure 6.2 The reflection coefficient (S_{11} parameter) of the traditional antenna in Figure 6.1.

The ground plane of above antenna is found as an area of approximately 206 mm x 180 mm as shown in Figure 6.1. This simulation was made just for understanding of the before and after the optimization was made to better understand. This ground plane area is evaluated to be too large; thus, another antenna structure which is more compact than the traditional one is considered. Due to the ground is too large, and a compact structer is requested. One of the objectives of this thesis is to reduce the area of the total antenna, segmented loops makes us to achieve a smaller structure.

For this purpose, a designed antenna structure (linearly polarized version) as shown in Figure 6.3 is proposed. In linear polarization design, substrate dielectric constant has been taken as 3.55 which is given as the suggested value for the applications in specification datasheet of RO4003C. The structure consists of of broken loop (parasitic elements) on the both side of the antenna, and by this way it is obtained much more smaller ground plane size and in total, a compact antenna. The paramatization and optimization tools in CST Microwave Studio provide that shows effect of the properties changing, find the parameter which maximize or minimize a given effect or fulfill a certain goal. This tool can optimize any property of the model that can be parameterized, such as the dimensions or positions of a component or the materials properties. The results of the formula predicted but then downsized the antenna structure which is presented as shown in Figure 6.3. Placement of the patch antenna inside the segmented loop is chosen to achieve as compact antenna structure as possible, although this approach has a tradeoff in blocking part of the magnetic flux through the loop (Bijaya Shrestha, Atef Elsherbeni, 2011). The initial dimensions of the antennas are obtain by utilizing the equations in Chapter 5, and the corresponding values are given in Table 6.2. Afterwards, by benefiting from the study of (Bijaya Shrestha, Atef Elsherbeni, 2011) and using CST Microwave Studio 2015, the final design for the linearly polarized version is achieved where the corresponding final dimensions are given in Figure 6.3 and Table 6.2 in detail. Table 6.1 and Table 6.2 show the differences in dimensions such that total ground area of the traditional patch antenna is 206 mm × 180 mm = 3.70 cm^2 whereas total ground area of the proposed microstrip patch antenna is 148 mm × 139 mm = 2.06 cm^2. Therefore, the proposed linearly polarized antenna makes about %55.6 reduction in the total area of the antenna as compared to the traditional microstrip patch antenna.



(a)

(b)

Figure 6.3 (a) Designed linearly polarized patch antenna from top view (b) linearly polarized patch antenna bottom view in CST Microwave Studio

Table 6.2 The initial parameters of the designed microstrip patch antenna

$Ground\ Width$	148 mm
$Ground\ Length$	139 mm
W	101 mm
L	90 mm
ε_{reff}	3.50
L_{eff}	91 mm
ΔL	0.63 mm

As the second design, a circularly polarized version is considered. The circular polarization modulation is always used in the RFID system. Its basic feature is that logical zero is transmitted as the left hand circulary polarized (LHCP) wave, and a logical one is represented by right hand circulary polarized (RHCP) wave (W. L. Stutzman and G. A. Thiele, 2000). CP antennas can be realized when two orthogonal modes of equal amplitude are excited with a 90° phase difference. For creating circular polarization antenna, a corner truncated square patch is used to replace the normal square patch, which will improve the circular polarization performance of the antenna and its port characteristics. Axial ratio is a parameter that is important for antenna design which is circulary polarized. it is obvious that segment variations between the excitation signals purpose adjustments inside the axial ratio. these factors degrade the sign even supposing a perfect CP sign (axial ratio=0 dB) has been transmitted and the obtained CP signal exhibits statistical steady with its axial ratio.

The truncated part of the patch is calculated below equations;

$$Q = \frac{c\sqrt{\varepsilon_{eff}}}{4xfxh} \tag{6.1}$$

$$\frac{c}{a} = \sqrt{\frac{\Delta S}{S}} \tag{6.2}$$

where

Q = quality factor

ε_{eff} = effective dielectric constant

a = square patch length

h = thickness of antenna

f = resonant frequency

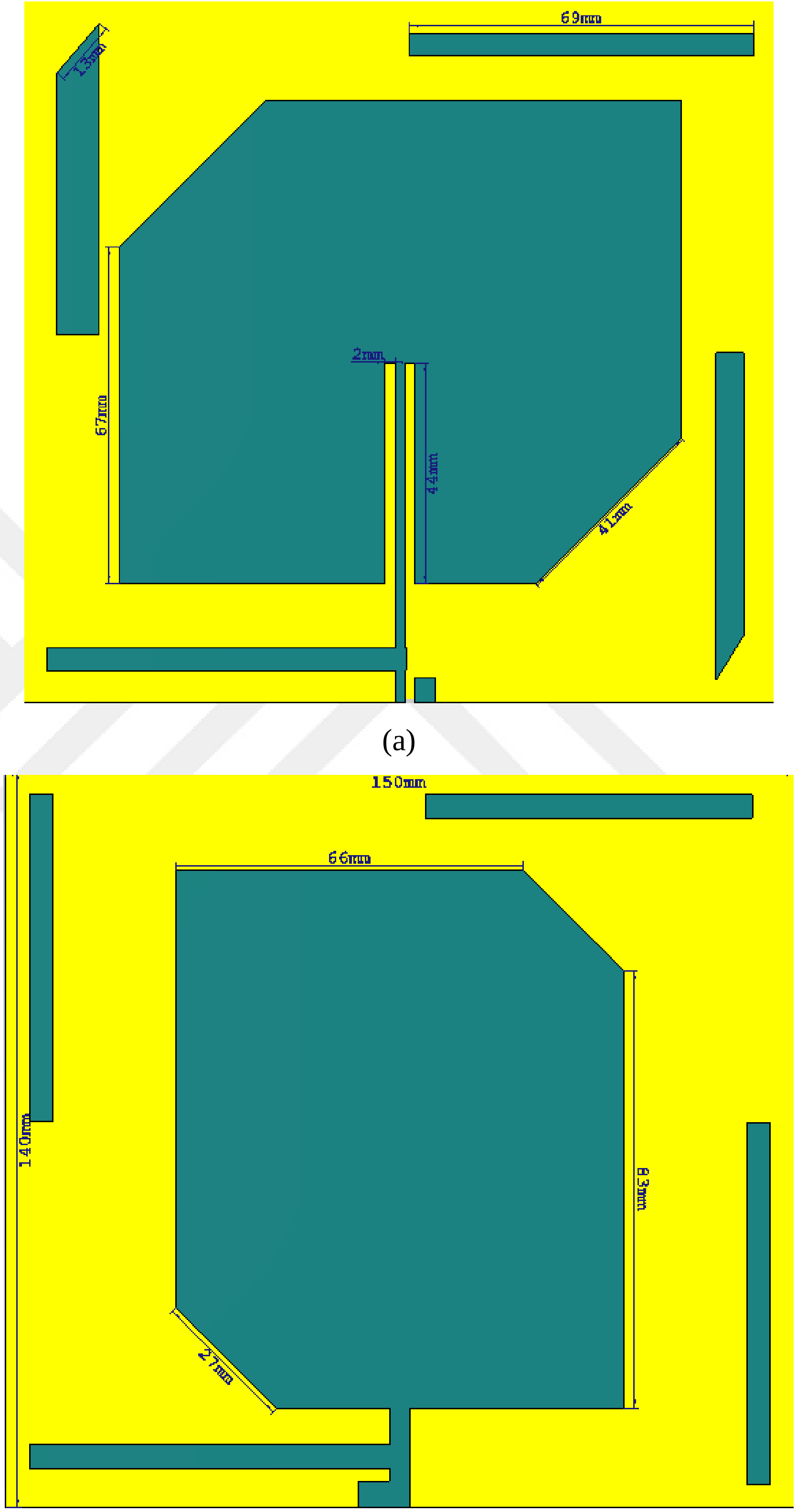
C = truncated size

c = speed of light

Truncated size effect on the return loss and AR of the antenna. The increasing the trim size improves the AR bandwidth and achieves better impedance matching. However, over truncating of the patch will degrade all the bandwidths. The gain of the antenna is hardly affacted by truncated size so that the results are not exhibited, so in practical design, truncation can be optimization for specific design requirement.

The resonant frequency selected for design is 868 MHz. Design of circular polarization procedure include of some extras steps different from linear as adding trim on the patch as shown in Figure 6.4. Parametric studies are conducted to provide more detailed information about the antenna design and optimization. The parameters below consist of the truncation of the patches, the height of the parasitic patch, feeding line and the scale of the ground plane.

While designing linearly polarized antenna, substrate dielectric constant is taken as 3.55, after the measurement results obtained for linearly polarized antenna, it is decided to take dielectric constant as 3.38 according to RO4003C material’s datasheet for the circularly polarized antenna. The initial dimensions are again obtained by utilizing from the equations in Chapter 5. Besides, the design has been trim to benefit from a change made to the ground as shown in Figure 6.4(b). This design has created a completely different design from the design of the study of (Bijaya Shrestha, Atef Elsherbeni, 2011).



(a)

(b)

Figure 6.4 (a) Designed circularly polarized patch antenna from top view (b) circularly polarized patch antenna bottom view

6.2 Simulation and Measurement Results of Linearly Polarized RFID Reader Antenna Design

In this section, simulation and mesaurement results of the linearly polarized UHF reader antenna, which is designed and given in Section 6.1, are given. Simulations are obtained with the CST Microwave Studio. Theoretically, the desired results can be fully achieved when the calculated values performed in the simulation environment.

For these types of applications to get more places on PCB and to get greater efficient results, antenna must be rectangular. So that width of the antenna is close to length of the antenna after it has been optimized. Thus the new width is 101 mm. Then the length of ground is calculated by way of thinking about the idea of the area of the ground plane need to be two times larger than the vicinity of the patch for better performance. In this part of the polarization, which CST Programme’s own calculator and optimizer tools, has been used. In this thesis, patch antenna is feeding microstrip feed way. Strength is transferred to metallic with the assist of a skinny conductive. The primary gain of the technique, feeding the same item from the metallic patch in case of a planar structure formation. This circumstance is a floor wave-lowering state of affairs. it may be effortlessly tailored to the antenna. Metal patch is a continuation of the feed strip; however, because the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The characteristic impedance of different points is critical. The characteristic impedance of second thickest component is preferred to be 50 ohm. There are special lengths for antenna designs. these are λ/2 and λ/4. In every λ/2 distance, the feature impedance repeated itself. As it is mentioned before, to prevent mismatch situation of antenna and reader, characteristic impedance of the port point must be 50 ohm.

In this section, four distinctive forms of graphs referred to as return loss (S_{11} parameter), 3D form of gain and polar form of advantage in special attitude, axial ratio could be described.

S_{11} parameter suggests how a great deal power radiates and what percentage of power could be lost. As it can be seen in Figure 6.5 below, at the frequency of 868.92 MHz which is very close to the desired center frequency of 868 MHz, S_{11} parameter is equal to -14.22 dB in the simulations carried out by CST Microwave Studio. It is able to understand that by using the equation (6.3) given below, only 3.71% power is lost (disappeared) and the remaining 96.3% is transferred to the antenna.

$$S_{11}(\text{dB}) = 10\log10(P_{\text{reflected}} / P_{\text{incident}}) \tag{6.3}$$

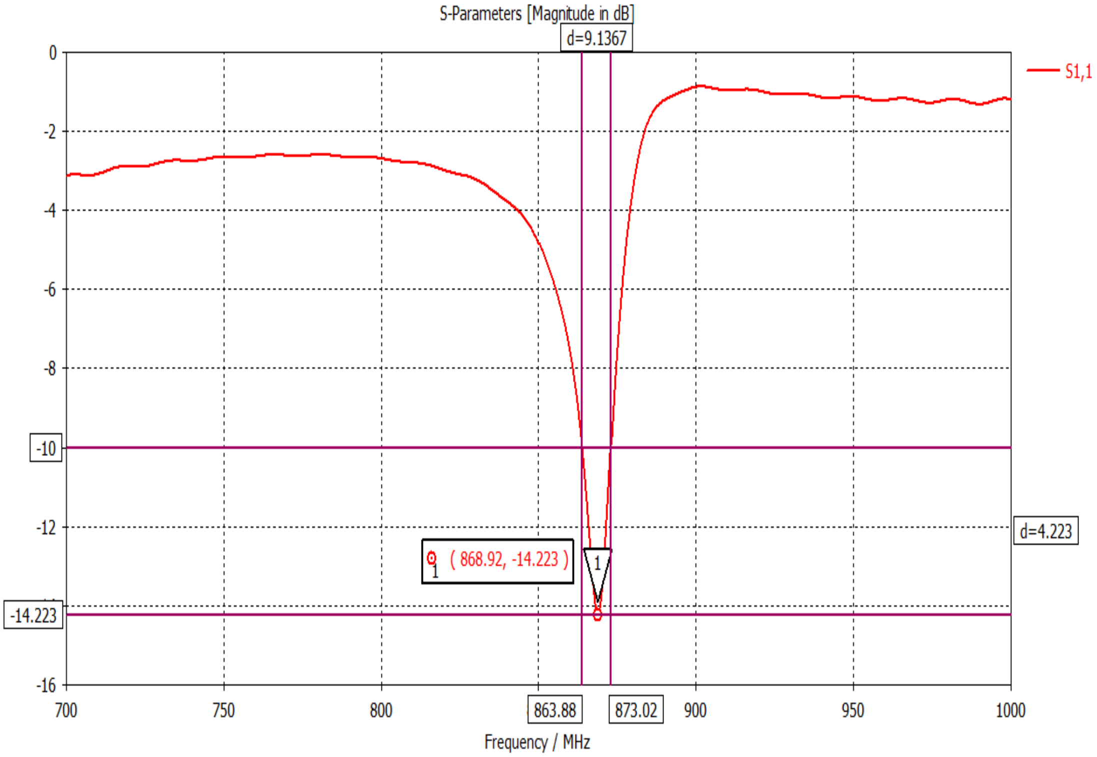
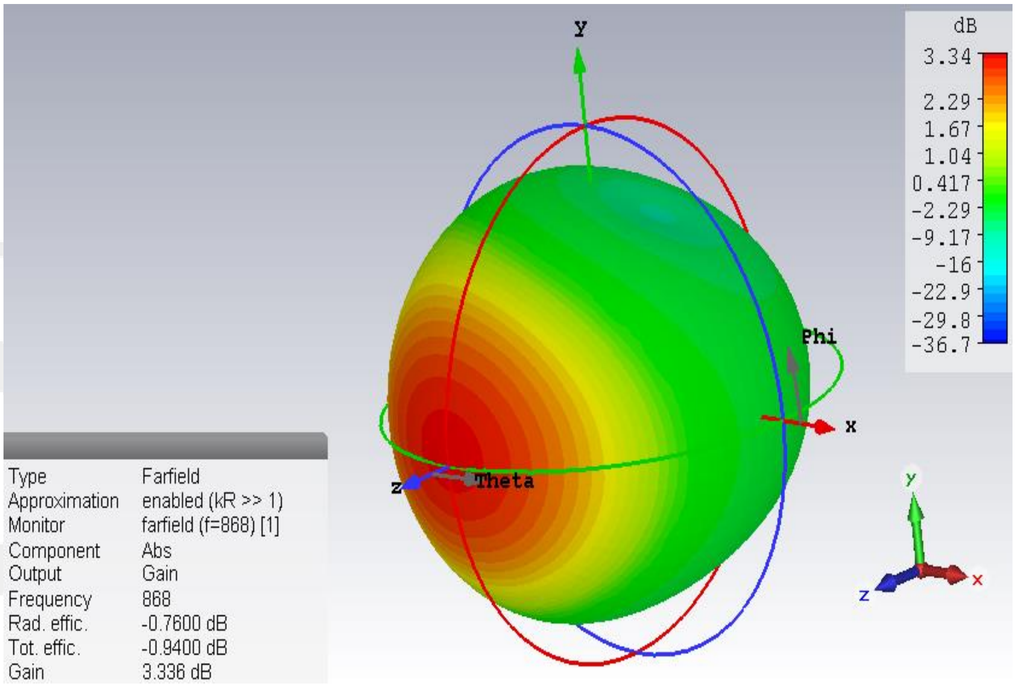


Figure 6.5 Simulated S_{11} of the linearly polarized antenna

Again as seen from Figure 6.5, the -10 dB bandwidth ranges from 863.88 to 873.02 MHz, which covers the European UHF RFID band. The overall banwidth, which is about 9.1 MHz, is relatively narrow and is restrained with the aid of the integrated structure of the antenna layout together with both the loop and the patch. It is also stricken by interplay of the loop and the patch and the exceedingly small length of the patch ground plane.

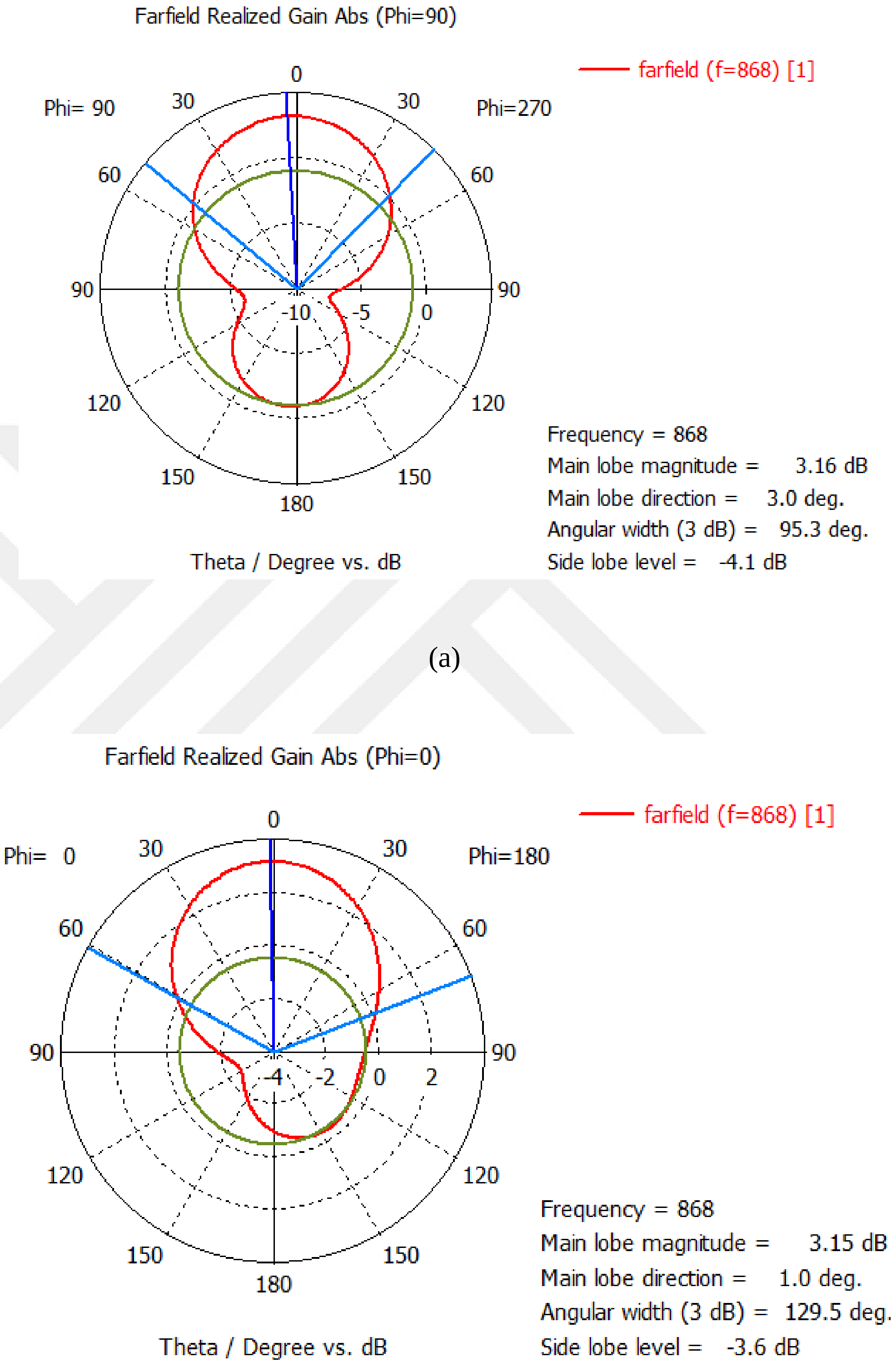
After S_{11} parameter performance, far field gain simulation results are observed. For the purpose, the gain performance at the desired center frequency of 868 MHz is examined. As shown in 3D gain plot in Figure 6.6, the maximum gain is about 3.3 dBi at the broadside for the frequency of 868 MHz. This gain level is a little bit lower than the standard gain of a microstrip patch antenna (5 dBi); however, this gain reduction is compansated with the reduction in the total area of the designed antenna (makes much more compact structure). Therefore, size reduction of the patch comes at a cost of reductions in bandwidth and gain.



```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=868) [1]
Component       Abs
Output          Gain
Frequency       868
Rad. effic.     -0.7600 dB
Tot. effic.     -0.9400 dB
Gain            3.336 dB
```

Figure 6.6 Gain of linearly polarized microstrip patch antenna

As the third antenna parameter in the application, the realized gain and the radiation characteristics are investigated. The radiation characteristics is important to understand at which solid angle (or solid beam) a reasonable radiation exists. Therefore, it can be concluded (calculated) at which angles a healthy communication is possible. To be given in the axial ratio results, since the designed antenna is linearly polarized, the definitions of principal E-plane and H-plane are possible. So, in this part, the polar radiation patterns are given for E-plane and H-plane for 868 MHz at Figure 6.7(a) and Figure 6.7(b), respectively. The E-plane corresponds to yz plane according to Figure 6.7(a) which refers to ϕ = 90° and 270° constant planes; and H-plane corresponds to xz plane according to Figure 6.2(a) which refers to ϕ = 0° and 180° constant planes.

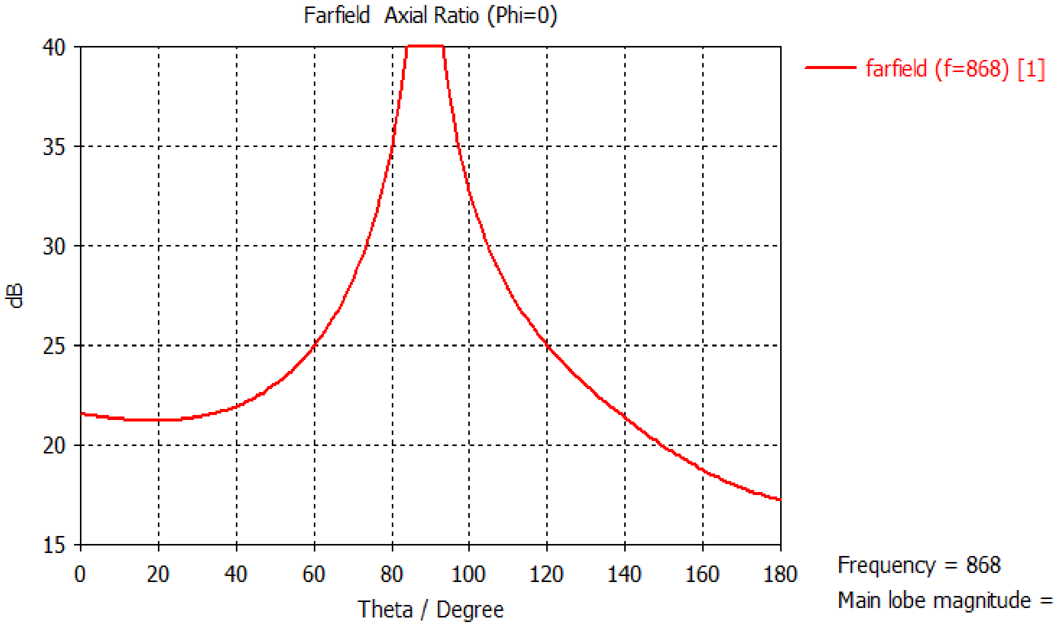


(a)

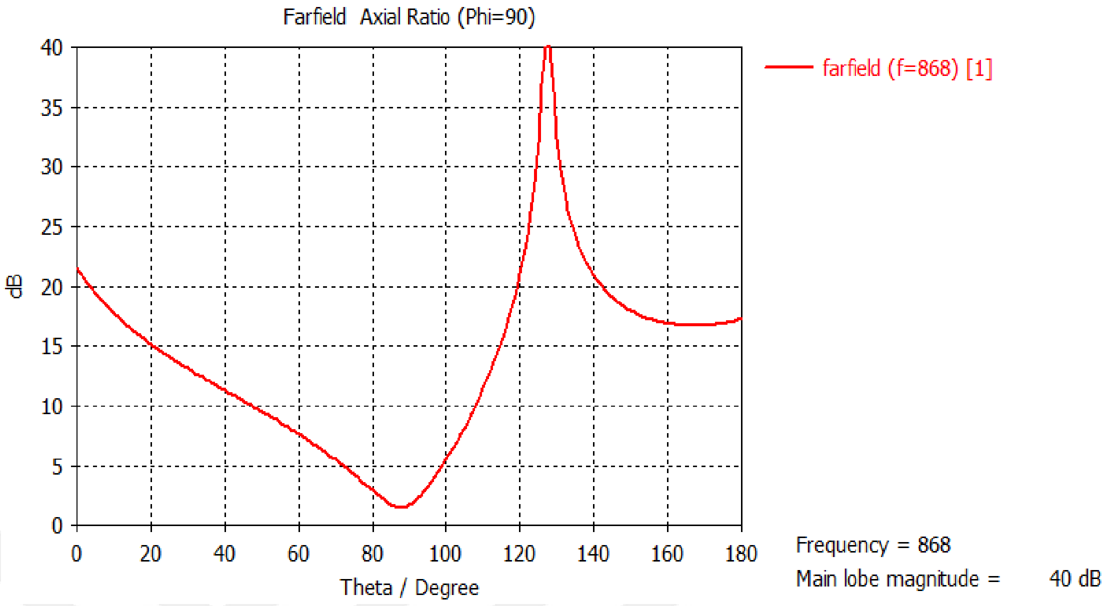
Figure 6.7 (a) E-plane Realized Gain Pattern (yz plane) (b) H-plane Realized Gain Pattern (xz plane) for linearly polarized antenna

When the radiation patterns in both principal planes are observed, it can be concluded that the designed antenna is not perfectly omnidirectional but shows almost uniform patterns in both planes. The 3-dB angular beamwidth, which is measure of antenna working angle range, is wide (almost 95 and 130 degrees) in both planes. So, the designed antenna can be used in wide angle ranges.

The final parameter to be considered in the simulation is the axial ratio. Although axial ratio in linearly polarized antenna is not as important as circularly polarized, it should be handled out to decide whether the antenna is linearly polarized or not. Theoretically, an antenna should have infinite axial ratio to be classified as linearly polarized. However, practically, an antenna having higher than 15 dB axial ratio is usually considered as linearly polarized antenna. The axial ratio patterns for E-plane and H-plane are given in Figure 6.8(a) and Figure 6.8(b), respectively. According to the results in these figures, the antenna has more than 20 dB axial ratio at the broadside (theta = 0 degrees in both planes). Therefore, the antenna is linearly polarized at the broadside. Besides, the antenna has more than 15 dB in overall angle range in ϕ = 0° plane, and along +z and –z axes in ϕ = 90° plane at which the antenna can be considered as linearly polarized. The antenna only shows circular behaviour characteristics along +y axis, which is not the broadside direction.



(a)



(b)

Figure 6.8 (a) Axial Ratio Pattern (ϕ=0°) (b) Axial Ratio Pattern (ϕ=90°) for linearly polarized antenna

After the acquire of all simulation results where the antenna satisfies most of the desired spesifications at 868 MHz such as being more than 10 dB return loss, a reasonable gain, a wide beamwidth and linearly polarized characteristics, the designed antenna is manufactured by using Mits Autolab PCB Prototype Machine at Yasar University Antenna and Microwave Laboratory. The produced antenna is depicted in Figure 6.9.

Figure 6.9 The front and back view of produced linearly polarized UHF RFID reader antenna

After the manufacturing of the antenna, the measurement results are obtained for S_{11} parameter, realized gain and axial ratio at the broadside. For this purpose, the equipments such as N9912A Fieldfox Agilent RF Analyzer and test setups in Yasar University Antenna and Microwave Laboratory are used. Then, the results are compared with the simulation results.

As the initial results, the reflection coefficient, S_{11} parameter of the produced antenna is measured with N9912A Fieldfox Agilent RF Analyzer where the measurement setup is given in Figure 6.10.

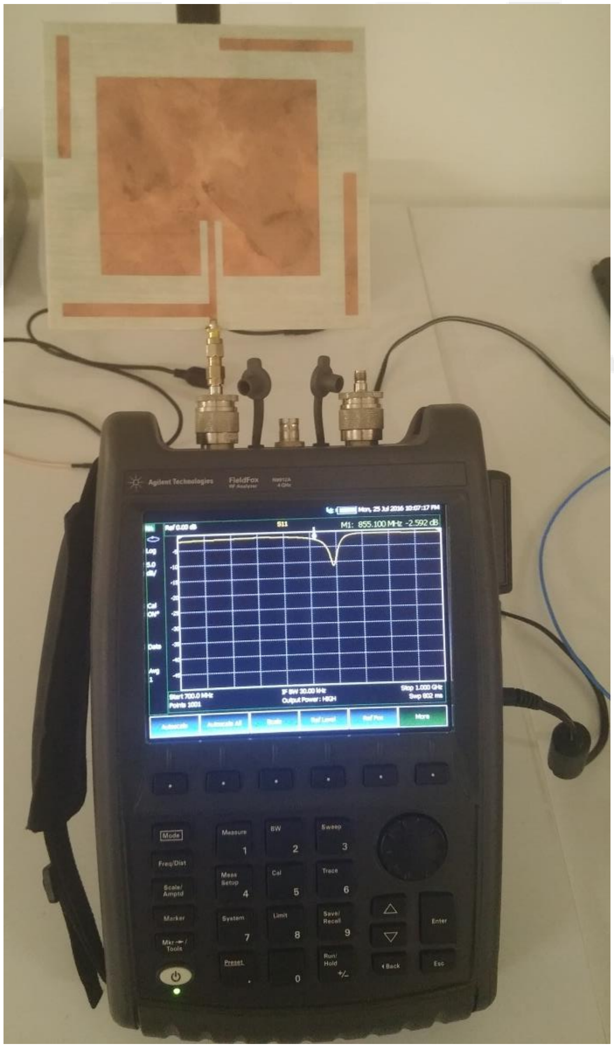


Figure 6.10 The setup for S_{11} measurement of linearly polarized antenna

The corresponding measured S_{11} results along with simulation results are shown in Figure 6.11. While the simulation results give the optimum operating frequency of about 868 MHz, the measurement results have a dip at about 877 MHz. Nevertheless, the simulation and measurement results are considered to be highly consistent such that the difference is just about one percentage. This slight difference is caused by manufacturing errors and mostly the variation in the dielectric constant of the substrate, RO4003C. The dielectric constant for the mentioned substrate is suggested as 3.55 in the applications, although their average measurement results is given as about 3.38 after chemical process. In the design and simulations of the linearly polarized version of the antenna, the dielectric constant is taken as 3.55 in order to obey the suggestion for the applications in the datasheet of RO4003C. However, when the results in Figure 6.11 are examined, the resonant frequency for the measurement is found to be greater than that of simulation. Therefore, the substrate used in the production should have a dielectric constant smaller than 3.55. Since the difference between the simulation and measurement results is so slight, another iteration in the design and production of the linearly polarized antenna is not employed by using a smaller dielectric constant. However, in the design of the next version (circularly polarized version), the dielectric constant is taken to be as 3.38.

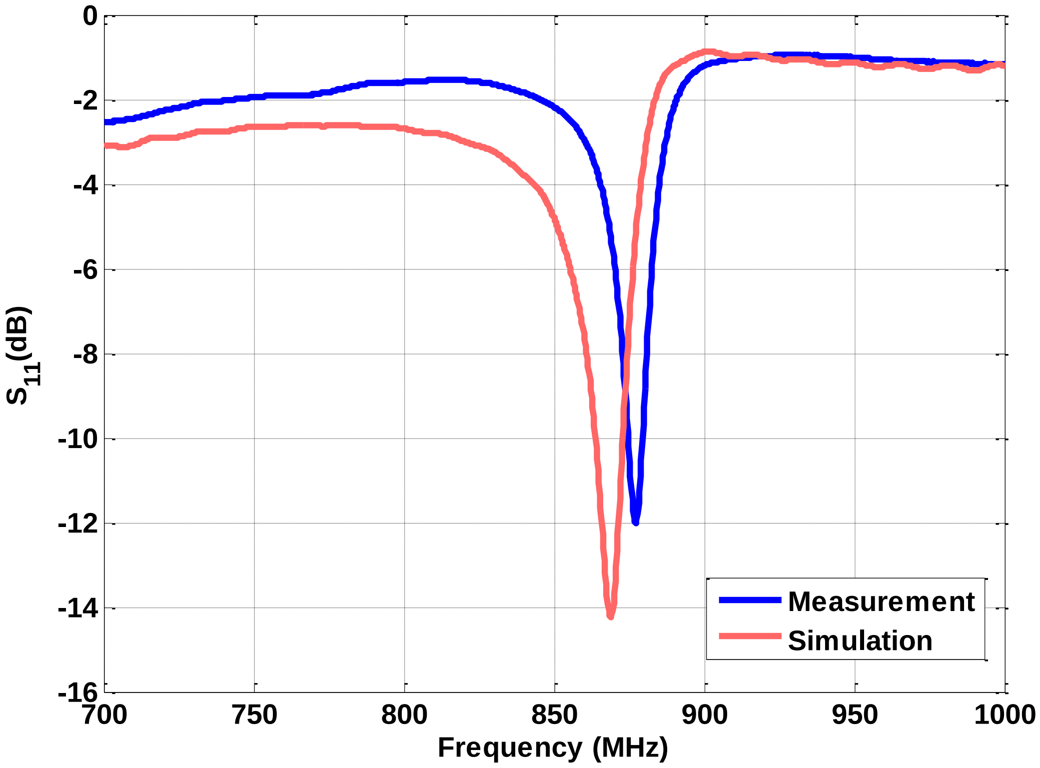


Figure 6.11 S_{11} measurement and simulation results for linearly polarized antenna

After the reflection coefficient (S_{11}) measurement, the gain of the antenna is measured at the broadside. For this purpose, one of the standard gain measurement method, which uses Friss Transmission equation and an antenna whose gain is known at the measured frequency, is carried out. The Friss Transmission equation for two linearly polarized antenna is simply formulated in dB scale as

$$P_r(dB) - P_t(dB) = 20log\left(\frac{\lambda}{4\pi R}\right) + G_r(dBi) + G_t(dBi) \tag{6.4}$$

where P_t: Transmitted power in dB or dBm

P_r: Received power in dB or dBm

λ: wavelength which is about 345 mm at 868 MHz

G_t: Realized gain of the transmitter antenna (or reference antenna whose gain is known)

G_r: Realized gain of the receiver antenna (or test antenna whose gain is unknown)

R: distance between antennas

When a network analyzer such as N9912A Fieldfox Agilent RF Analyzer in Figure 6.10, the left hand side of the equation (6.4) turns to be S_{21}(dB) measurement. By considering the gain measurement method described above, a setup is constructed at Yasar University Antenna and Microwave Laboratory, which is depicted in Figure 6.12. In this setup, the distance between the antennas, *R* in (6.4), is kept as 1 meter, and the antennas are connected to two ports of the network analyzer, which is not clearly visible in Figure 6.12. The blue antenna in the setup is the ultrawide band log-periodic antenna (Spectran Hyperlog 60180) operating within the frequency range of 680 MHz-18 GHz, and it is used as the reference antenna in the calculations. This antenna has about 3 dBi realized gain at the frequency region of interested 850-880 MHz. The log-periodic antenna contains several printed dipoles oriented horizontally with respect to earth; therefore, it can be said to have horizontal polarization. Thus, the designed and manufactured antenna is placed in a horizontal way to get perfect polarization matching.

(a) (b)

Figure 6.12 Gain measurement setup in Yasar University Antenna and Microwave Laboratory

The initial measurement is realized for 877 MHz which is optimum operating frequency for the given antenna, and the measured S_{21} value is found to be 25.5 dB. By employing (6.4), the realized gain of the linear polarized version of the designed antenna is found to be about 2.8 dBi at the broadside. This result is again consistent with the realized gain of about 3.15 dBi at the resonant frequency of 868 MHz in the simulations. The realized gain measurement is also repeated for 868 MHz, and the measurement gain is evaluated as about 2.2 dBi.

The final measurement for linearly polarized antenna is carried out for axia ratio performance. For this purpose, a setup to be described in detail in the next section is employed. The axial ratios at both 868 MHz and 877 MHz are measured to be higher than 15 dB at broadside, which supports the simulation results. These axial ratio results reveal that the produced antenna can be considered as a linearly polarized antenna.

6.3 Simulation and Measurement Results of Circularly Polarized RFID Reader Antenna Design

In this section, simulation and measurement results of the circularly polarized UHF reader antenna whose design is given in detail in Section 6.1. Simulations are obtained also with the CST Microwave Studio as linear one. Theoretically, the desired results can be fully achieved when the calculated values performed in the simulation environment. On this part, three distinctive forms of graphs referred to as as return loss (S_{11} parameter), gain and Axial Ratio (AR) could be described.

As in the case of linearly polarized version, the reflection coefficient (S_{11}) simulation results for the circularly polarized antenna depicted in Figure 6.4 are given in Figure 6.13.

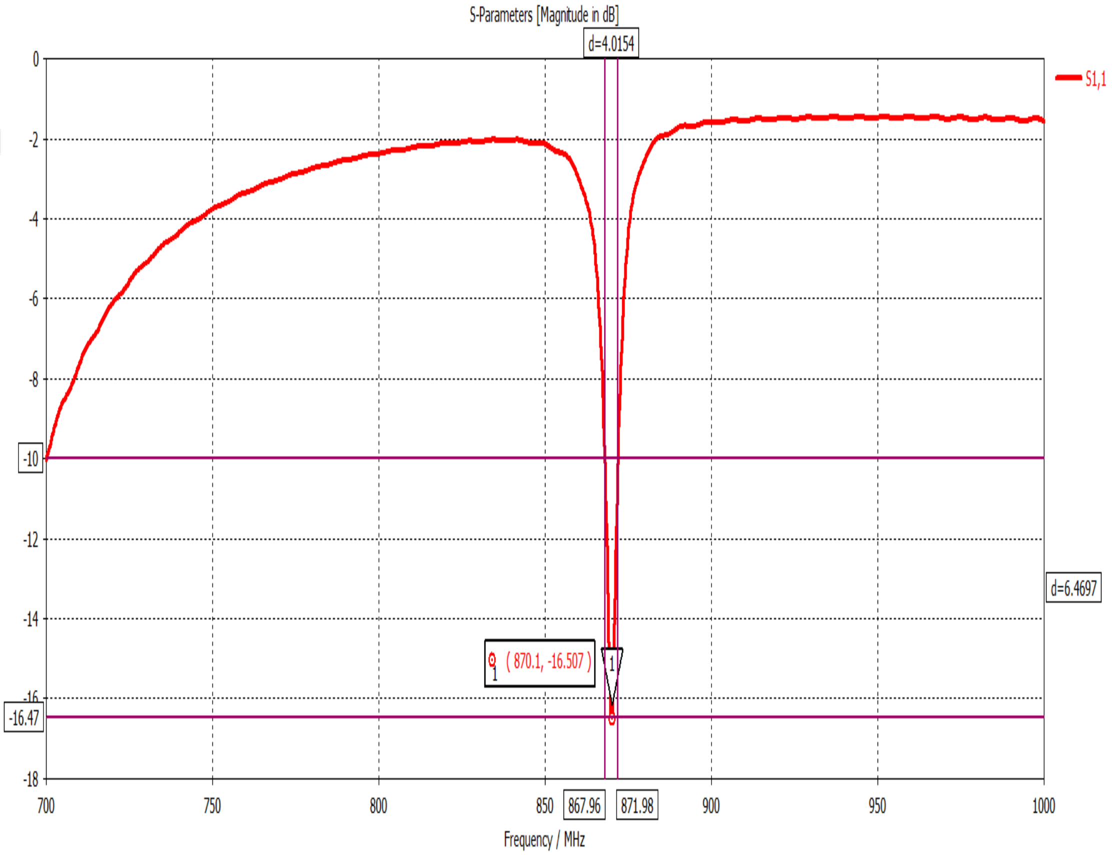


Figure 6.13 Simulated S_{11} of the circularly polarized antenna

According the results given in Figure 6.13, the resonant frequency is found to be almost 870 MHz, which is close to the desired design frequency of 868 MHz. The -10 dB frequency bandwidth is about 4 MHz, where 868 MHz falls into that bandwidth. The linearly polarized version is expressed to have narrow bandwidth. The mentioned circularly polarized version has further narrower bandwidth, which is a result at the expense of making the antenna circularly polarized.

Current distribution along the segmented loop and the entire patch of the proposed antenna is shown in Figure 6.6. It is unidirectional along the loop. The current distribution also shows that polarization type.

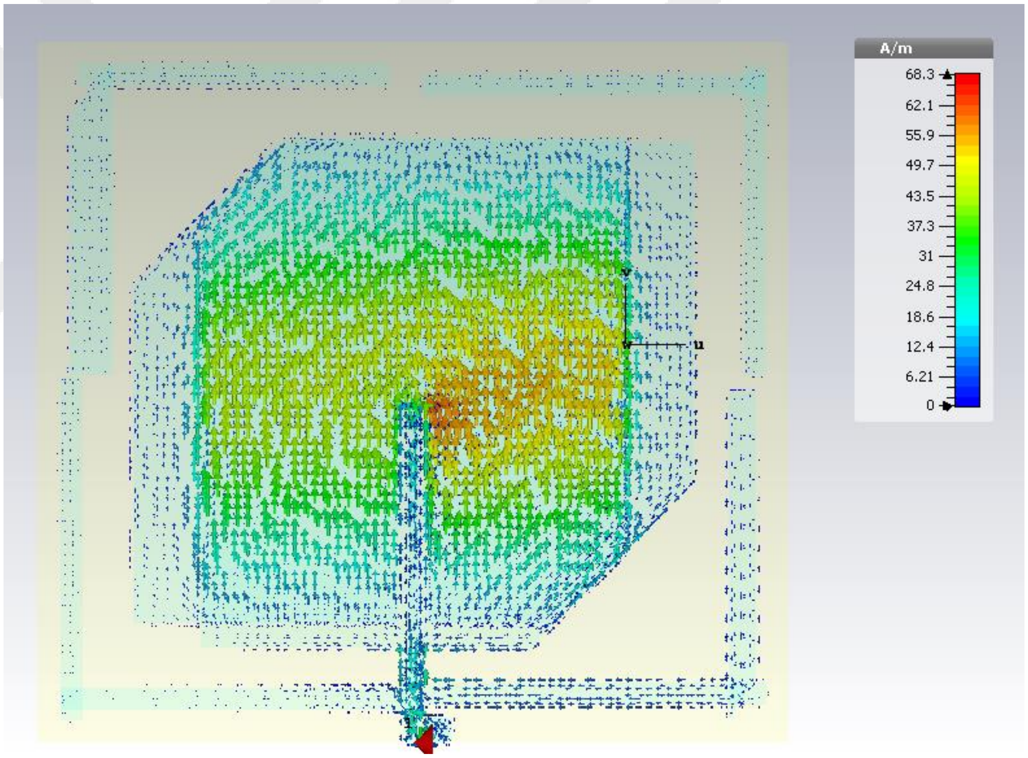


Figure 6.14 Current distributions of proposed antenna

The next parameter to be focused on is the axial ratio, which is one of the crucial parameter for a circularly polarized antenna. Theoretically, if the axial ratio is 0 dB, then the antenna has circular polarization. However, since it is very difficult to get perfect 0 dB axial ratio; practically, an antenna having axial ratio of at most 3 dB can be called as circularly polarized antenna. However, at some challenging cases, this value can be increased to 5 dB or 6 dB (M. Seçmen, 2011). The circularly polarized antenna designed in this thesis is very challenging; therefore, the threshold for the axial ratio is kept to 6 dB in this design. In Figure 6.15, the axial ratio pattern at ϕ = 90° constant plane for the given circularly polarized antenna is shown.

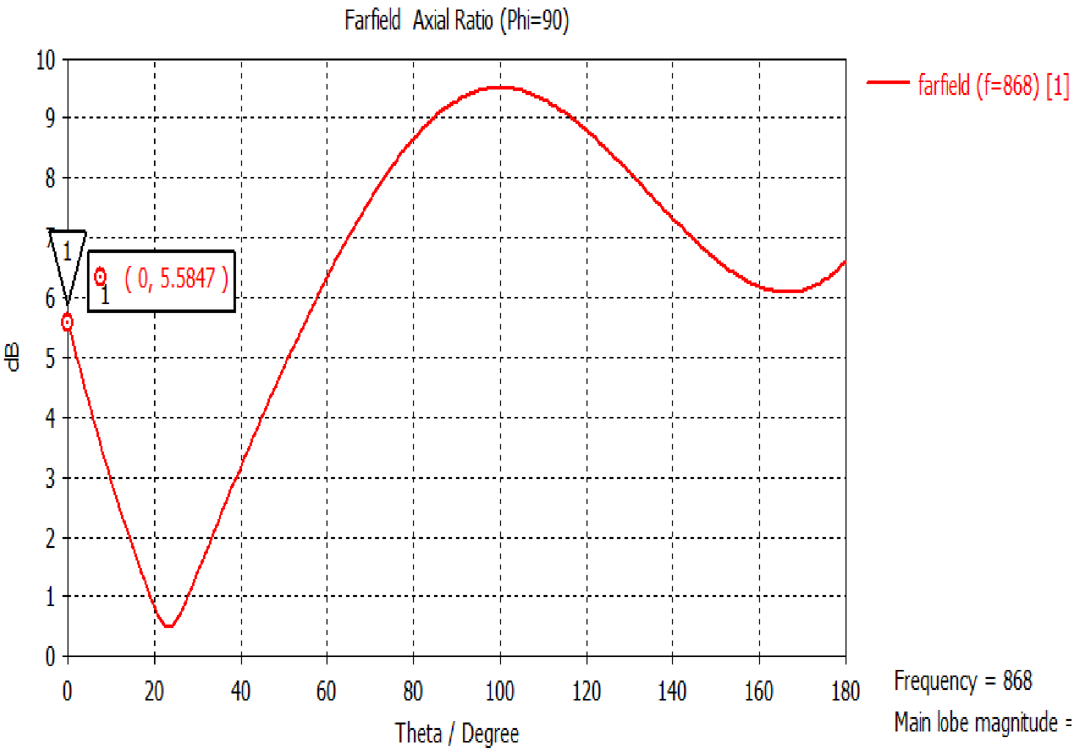


Figure 6.15 Simulation results for axial ratio pattern at 868 MHz and ϕ=90°

According to the results in Figure 6.15, the axial ratio at the broadside is found to be about 5.58 dB which is lower than the threshold value of 6 dB. Besides, at the angle beamwidth of about 60 degrees (from 0 degrees to 60 degrees), the axial ratio is lower than 6 dB; and this antenna can be handled as moderately circularly polarized antenna within this beamwidth.

Finally, the gain radiation pattern of the circularly polarized is investigated. In Figure 6.16, the gain radiation pattern at ϕ = 90° constant plane for the given circularly polarized antenna is given. The antenna gain at the broadside is about -1 dBi, which can be considered as a low gain. However, the reduction in the gain at the broadside is compansated for an improvement in the axial ratio for circular polarization performance. The gain within the angle beamwidth of 60 degrees at which good circular polarization performance is observed, has the maximum value of about -0.25 dBi. The broadside of the designed antenna is considered at θ = 0° (corresponds to +z axis in Figure 6.3) in Figure 6.15 and Figure 6.16. However, when the angle of θ = 180° is considered in both Figure 6.13 and Figure 6.14, which can be considered as backside of the designed antenna, the antenna has about 6.5 dB axial ratio and 1.2 dBi gain. Therefore, the angle of θ = 180°, which corresponds to –z axis in Figure 6.3, may be also considered as broadside of the designed antenna for another application.

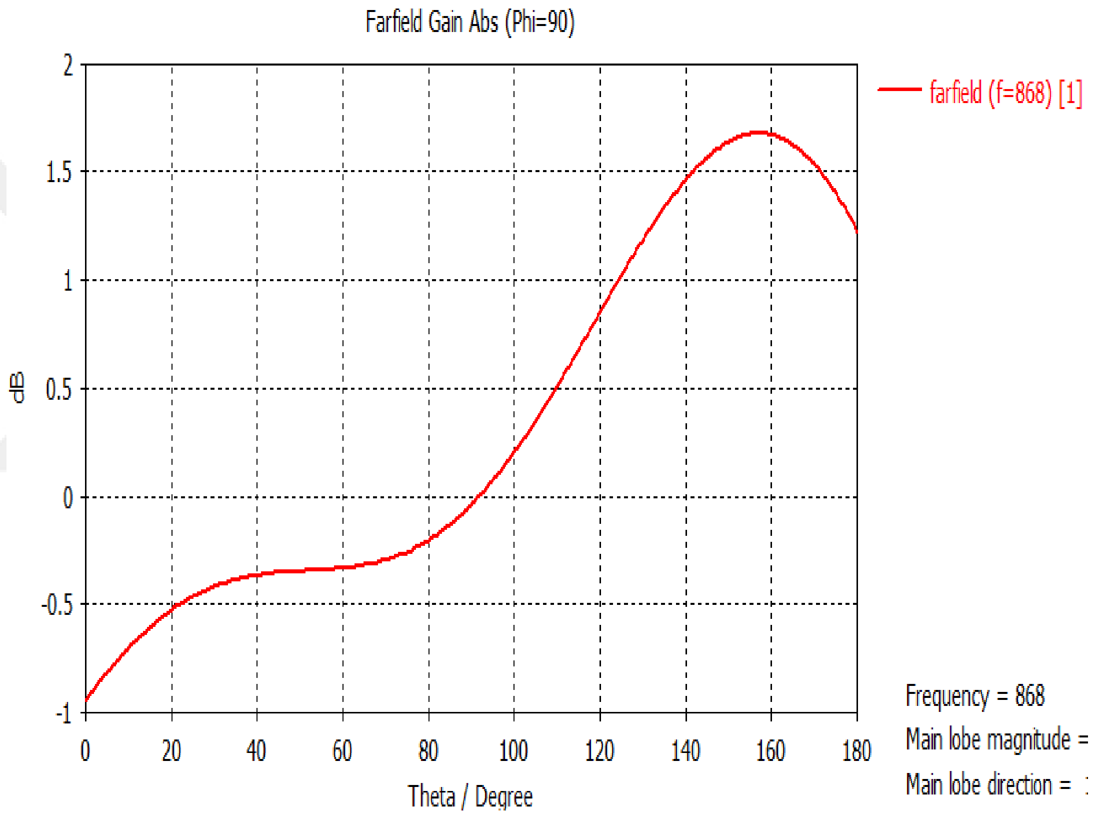


Figure 6.16 Simulation results for gain radiation pattern at 868 MHz and ϕ=90°

After these simulation results, the designed circularly polarized antenna is produced whose photographs of the front and back sides are given in Figure 6.17.

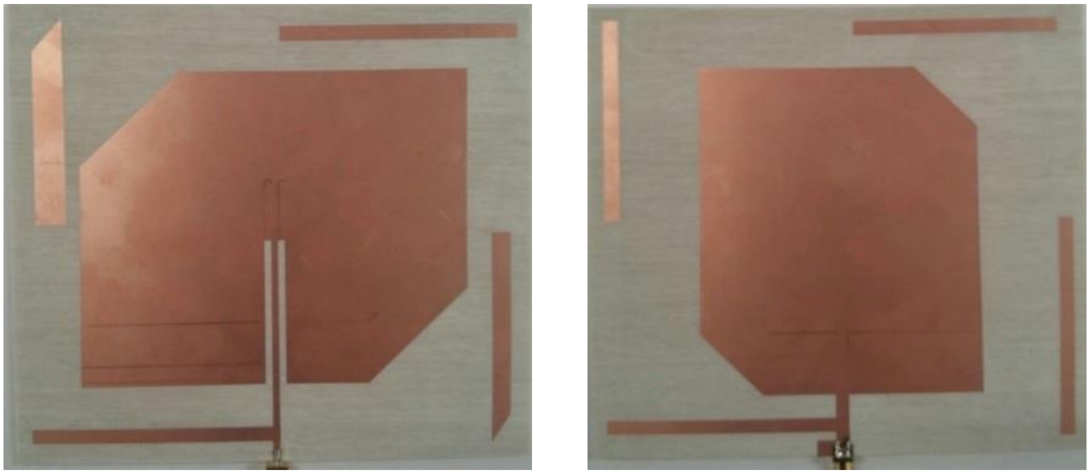


Figure 6.17 The front and back views of the produced circularly polarized compact UHF RFID reader antenna

As being similar to the linearly polarized version, the parameters of reflection coefficient (S_{11} parameter), axial ratio at broadside and realized gain at the broadside is measured in this circularly polarized antenna, and the measurement results are compared with those of simulation.

As being the first parameter, the measured S_{11} values as well as the results of simulation are given in Figure 6.18. The simulation results indicate that the resonant frequency is about 870 MHz in addition to 10 dB return loss bandwidth of 4 MHz. On the other hand, the measurement results give a resonant frequency of about 855 MHz and a frequency bandwidth of 853.1 MHz-857.7 MHz for $S_{11} \leq -10$ dB. When the results in Figure 6.18 are compared, it can be seen that there is about 2% frequency shift in the resonant frequencies of simulation and measurement results. This discrepancy between these results again probably arises from the value of dielectric constant of RO4003C. By considering measured and simulated reflection coefficient results of linearly polarized antenna in Figure 6.10, the dielectric constant of the substrate is changed to 3.38 in the design of circularly polarized antenna. However, when the results in Figure 6.18 are examined once more, it can be observed that the resonant frequency obtained by measurement is lower than the simulation; whereas, it is higher in the case of linearly polarized antenna. Therefore, by just looking at the results in Figure 6.18, it can be understood that the dielectric substrate used in the laboratory for the production should be greater than 3.38. Besides, by combining this extraction with the results in Figure 6.12, it can be concluded that this value should be between 3.38 and 3.55.

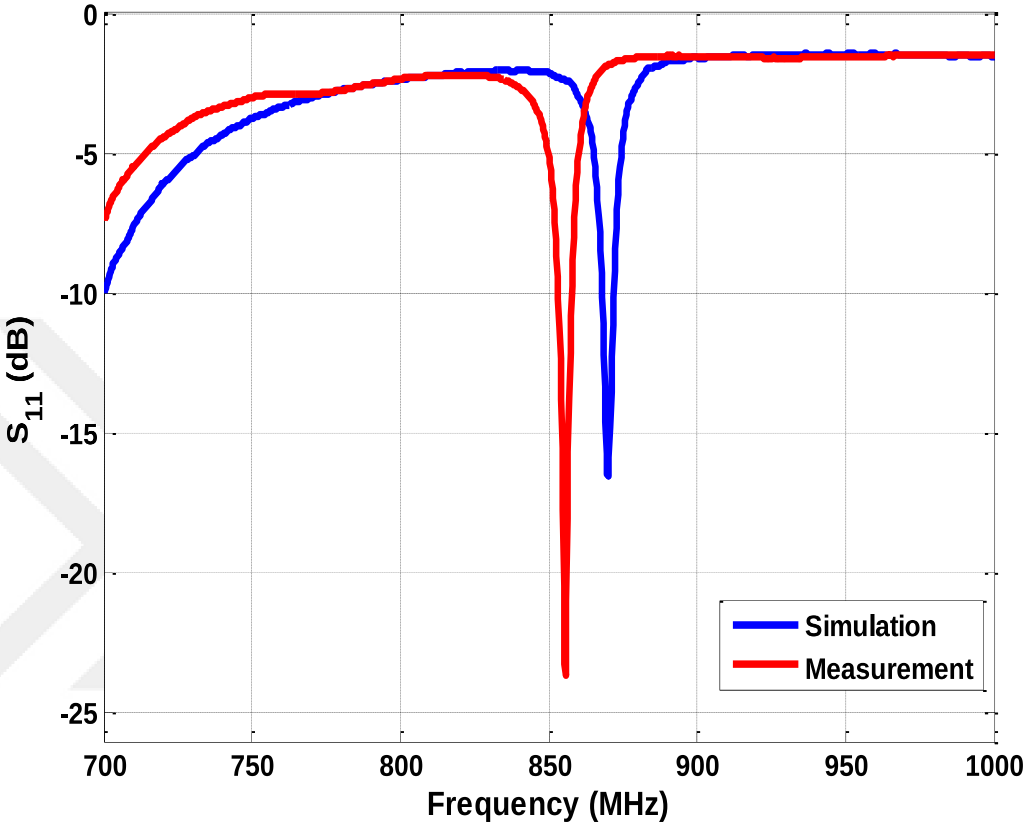
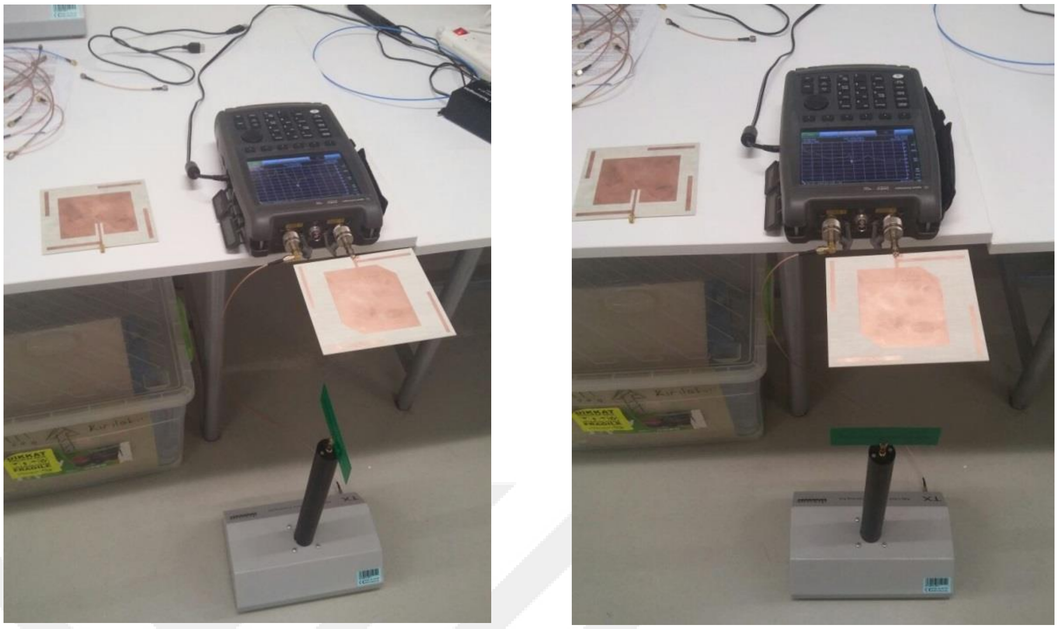


Figure 6.18 S_{11} results of circularly polarized antenna

Since the difference between the results of simulation and measurement is not so severe, the design and manufacturing is not repeated for a different dielectric constant value.

The next measured parameter is the axial ratio. In this part, since the resonant frequency obtained by measurement is about 855 MHz, the axial ratio is only measured at this frequency along the broadside direction. For this purpose, a measurement setup is constructed, and the measurement is realized with two steps described in Figure 6.19.



(a) (b)

Figure 6.19 Axial Ratio Measurement in Laboratory (a) First step (b) Second step

When the procedure given in Figure 6.19 is examined, it can be understood that the axial ratio is obtained by the difference of received powers obtained by two different orientations of the linearly polarized antenna (the green one in Figure 6.19). At the mentioned setup, the test antenna whose axial ratio value is desired to be measured is kept constant. The other antenna, which should be sufficiently linearly polarized, is oriented at two orthogonal polarizations (vertical in Figure 6.19(a) and horizontal in Figure 6.19(b)). The linearly polarized antenna used for this purpose is a printed dipole antenna in Yasar University Antennas and Microwave Laboratory operating around 915 MHz. The measurement procedure can give axial ratio value roughly such that the linearly polarized antenna should rotate 360 degrees in the configuration given in Figure 6.19 for a more accurate results. With this measurement method, the measured axial ratio at the mentioned frequency of 855 MHz is found to be almost 6 dB at the broadside. This value is close to 5.58 dB broadside axial ratio at the resonant frequency of 870 MHz obtained by simulations given in Figure 6.15.

The final measured parameter for the circularly polarized antenna is the realized gain at the broadside. The measurement setup described in Figure 6.13 of Section 6.2 for linearly polarized antenna is realized also for the circularly polarized antenna. The gain measurements are carried out at 855 MHz and 868 MHz. The measured realized gain at the broadside are found to be almost 0.5 dBi and 0 dBi for 855 MHz and 868 MHz, respectively. When the simuation gain result in Figure 6.16 for 868 MHz is considered, there is nearly 1 dBi gain difference between the simulation and measurement results.

7 DESIGN OF EXPERIMENTS FOR THE PROPOSED UHF RFID SYSTEM

7.1 Experimental Setup

The working principle of RFID system is mainly based on a communication between reader and tag. The reader provide to read data on the transceiver. This reading occur via a reader antenna and receiver module, which is connected with reader antenna. Figure 7.6 shows how to work reader module via reader antenna and tag. The task of the reader is to read and write the information of tag by converting the analog signal to the digital form. The passive tag which is the cheapest one, does not have its own power supply, it works with the electromagnetic energy. Unlike the others, active tag have its own power supply to generate own circuit and response signal. With these features, it has high performance but high cost as well. In the project, passive tag was chosen as a tag antenna.

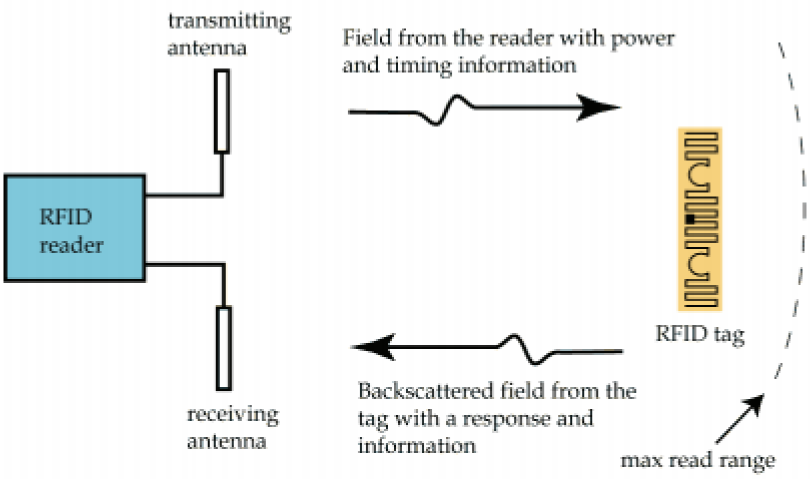


Figure 7.1 Overview of a passive RFID system

These communication modules offer a diffusion of communication possibilities to the manage and area degree and it may be integrated into diverse combinations, forming tremendous community nodes from smallest to largest automation solutions. Transmitter module converts the preferred information into some alerts that can be carried by using antenna or in another explanation it modulates the informations and sends it to the antenna. After the transmitted informations which is carried through the antenna is taken with the aid of the goal antenna, the receiver module absorbs the statistics comes from signal and send it to the reveal.

In this thesis, the receiver and transmitter modules of RS500 RFID reader are used. RS500 is a communication module that is manufactured by IMPINJ Factory, and it contains microprocessor which is called MSP430 (Impinj RS500, 2016). This module can work effectively at European UHF RFID frequency band of 865-868 MHz, and in this module there is transceiver (transmitter-receiver) system. The photograph of the used RS500 Reader is given in Figure 7.2.

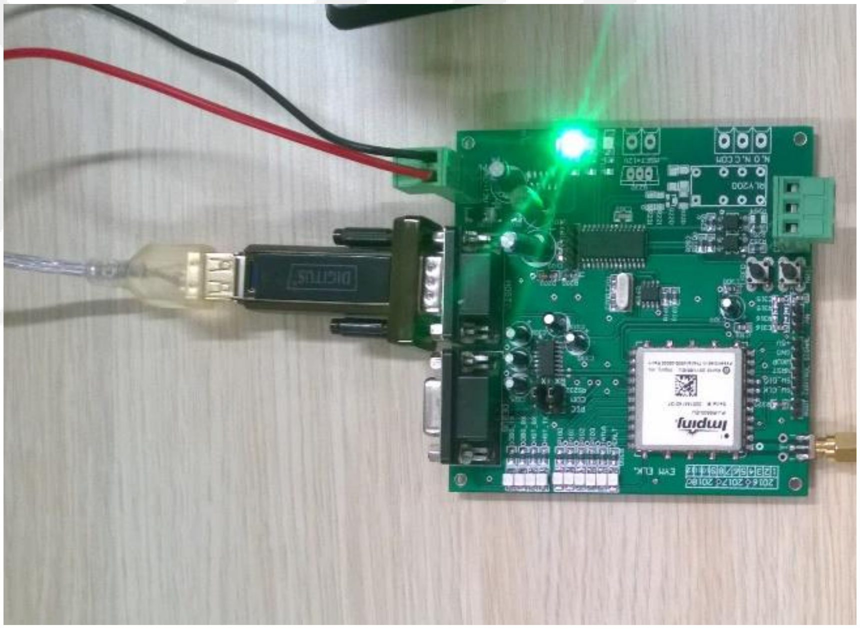


Figure 7.2 RS500 Reader

The main features of this reader module is summarized as;

- 23 dBm maximum output power
- Rx sensitivity -65 dBm
- Fail safe boot loader adds reliability during field
- Fully tested with regional compliance worldwide
- Small 30 mm x 32 mm surface mount package, shielded for noise immunity and prevent unwanted radiation

- IMPINJ Radio Interface (IRI)
- Supports a single antenna, mono-static reader operation

The main key applications of this reader module is summarized as;

- Consumables Authentication
- Access Control
- Process Control
- Appliances
- Printers
- Low-cost handhelds

In addition to the properties and important points described above, the key points regarding to RF performance of the reader are given in Table 7.1.

Table 7.1 The Operation Features of RS500

RF Input-Output Impedance	50 ohm
Operating Frequencies	GX: 902 - 928 MHz EU: 865 - 868 MHz
Power Consumption	2.5 watt
Tx Output Power	+10 to +23 dBm
Temperature In Open Area	-20 °C to +70 °C

As described in Table 7.1, the reader can supply about +23 dBm at the design frequency of 868 MHz. However, as given in Chapter 6, the produced antennas have resonant frequencies of 877 MHz and 855 MHz for linearly and circularly antennas, respectively. Therefore, since the system tests are considered to be done at 877 MHz for linearly polarized antenna and 855 MHz for circularly polarized antenna, the power levels generated (transmitted) by the reader are checked at 855 MHz, 868 MHz, and 877 MHz before passing into the experimental setup for system tests. For this purpose, a measurement setup photographed in Figure 7.3 is formed. Here, the output of RS500 module is connected to input of Spectrum Analyzer (SA) mode of N9912A RF Analyzer. However, since the maximum power level of +23 dBm can be harmful to the RF Analyzer, a 30 dB attenuator is put between the output of the reader and the input of the Field Analyzer. Therefore, the maximum power entering to the RF Analyzer becomes at most -7 dBm which keeps the network analzer in the safe level in terms of power level.

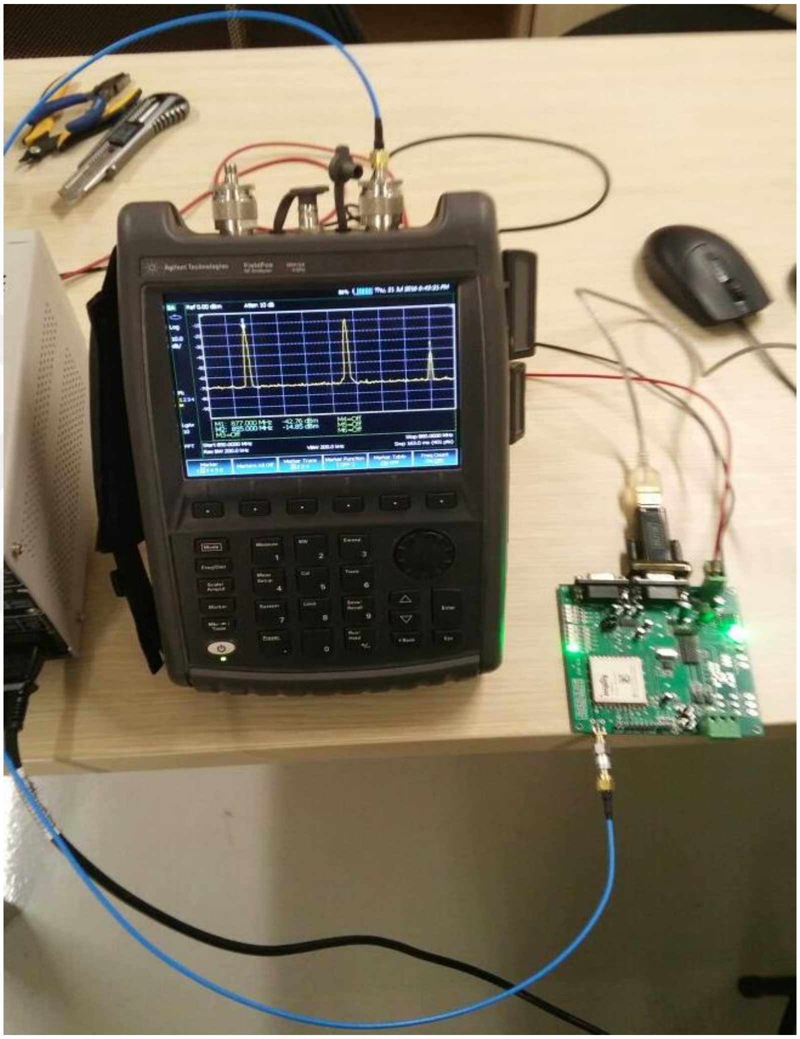
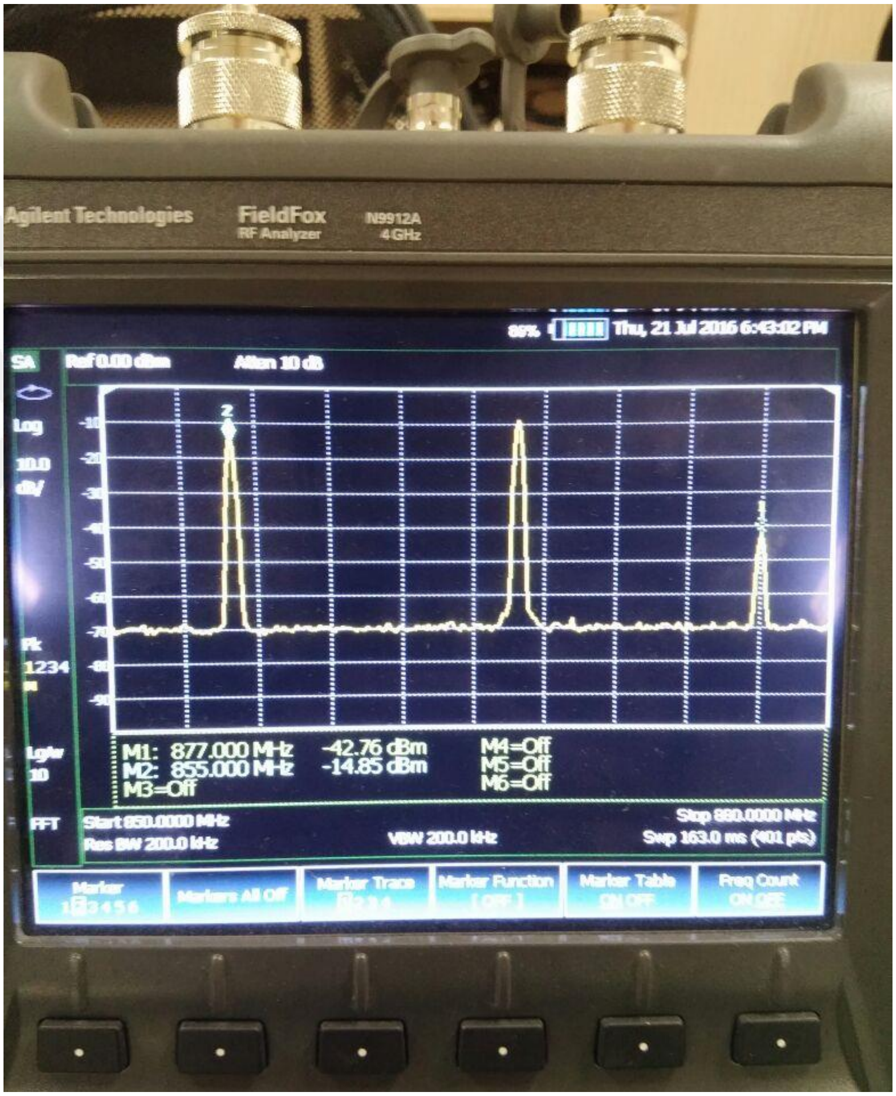


Figure 7.3 Power measurement for RS500 is a communication module

The measured power levels are given in Figure 7.4. Here, it should be noticed that since there is a 30 dB attenuator at the output of RS500 module and a 1 meter low-loss cable having a loss about 1 dB at this frequency, the real power level generated by the reader is about 31 dB more than the ones seen in Figure 7.4. Although it is not clearly visible in Figure 7.4, the measured power level as the input to the RF Analyzer is about -9 dBm at the frequency of 868 MHz. Thus, the power generated by RS500 at 868 MHz is about +22 dBm, which is consistent with the given power level of +23 dBm at the specification sheet of RS500. The power levels measured by other frequencies are demonstrated as -14.85 dBm and -42.76 dBm for 855 MHz and 877 MHz, respectively. Therefore, the power generated by RS500 module corresponds to about +16 dBm and -12 dBm, respectively.



M1: 877.000 MHz -42.76 dBm
M2: 855.000 MHz -14.85 dBm
M3=Off
M4=Off
M5=Off
M6=Off
Start 850.0000 MHz
Res BW 200.0 kHz
VBW 200.0 kHz
Stop 880.0000 MHz
Swp 163.0 ms (401 pts)

Figure 7.4 Power level values for RS500 module at different frequencies

When these generated power levels at 855 MHz and 877 MHz are considered, although the power level generated at 855 MHz is not highly lower than the power level of 868 MHz, the level at 877 MHz is significantly lower than the level at 868 MHz. Therefore, a healthy RFID communication with RS500 at 877 MHz does not seem to be so possible; on the other hand, it can be applicable when 855 MHz is selected. Therefore, the frequency of RS500 reader module is set to 855 MHz in the system tests with circularly polarized reader antenna. However, since the power level is too low at 877 MHz, the frequency is set to 868 MHz in the system tests with linearly polarized reader antenna.

The RFID tag antenna used in the experimental setup for system tests is given in Figure 7.5. It is a type of printed dipole antenna operating at UHF frequency band. Although there is no datasheet specifications for this antenna, the gain for this type of tag antenna is at most 0 dBi (Parra A. P. L., Pantoja J. J., Neira E., Vega F., 2016).

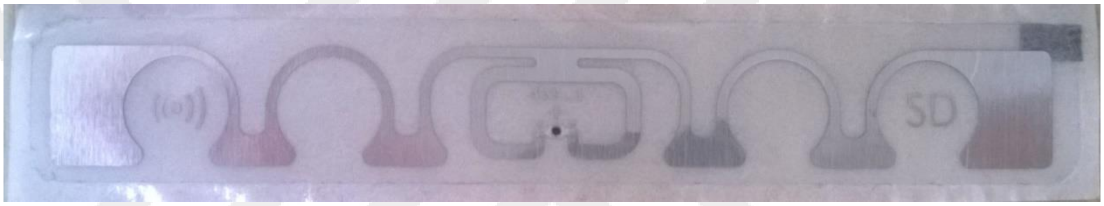


Figure 7.5 Tag antenna used in system tests

7.2 Experimental Results

The experimental setup for the full system tests described in Section 6.1 is initially realized with linearly polarized antenna in order to measure the reading (communication) distance of RFID system. Due to the reason of low power level described in Section 6.1, the operation frequency of RS500 module is adjusted to 868 MHz instead of 877 MHz. Then, the designed linearly polarized antenna is connected to the output of RS500 Reader module as shown in Figure 7.6. When RS500 reader module is just on the transmitter mode such that it sends the power but makes no reception, there is only one green light (LED) continuously glowing on the reader card as shown in Figure 7.6.

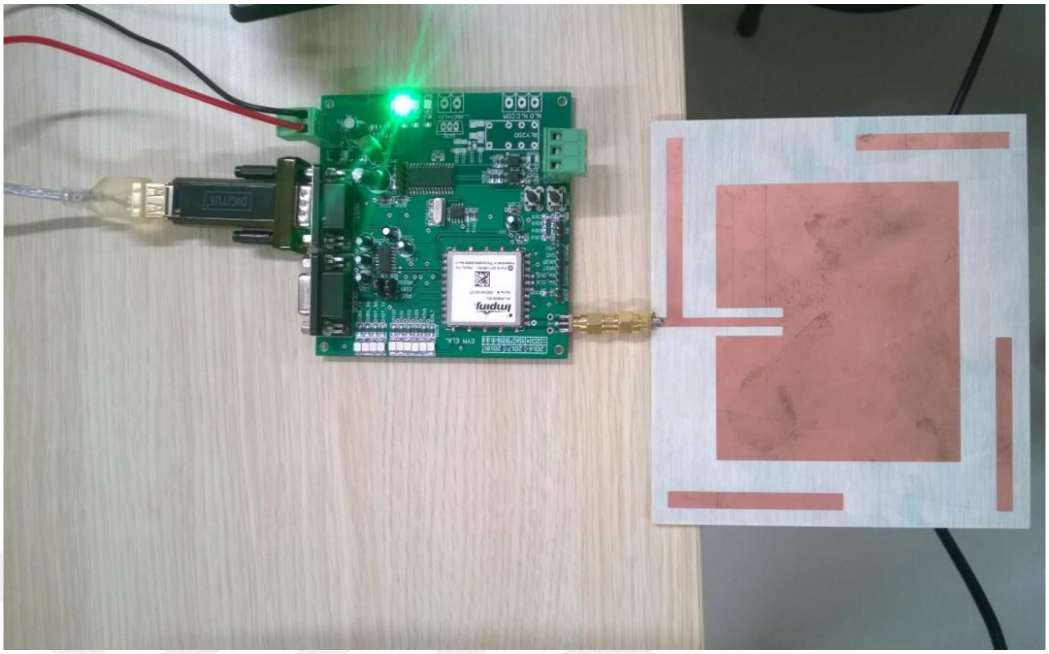
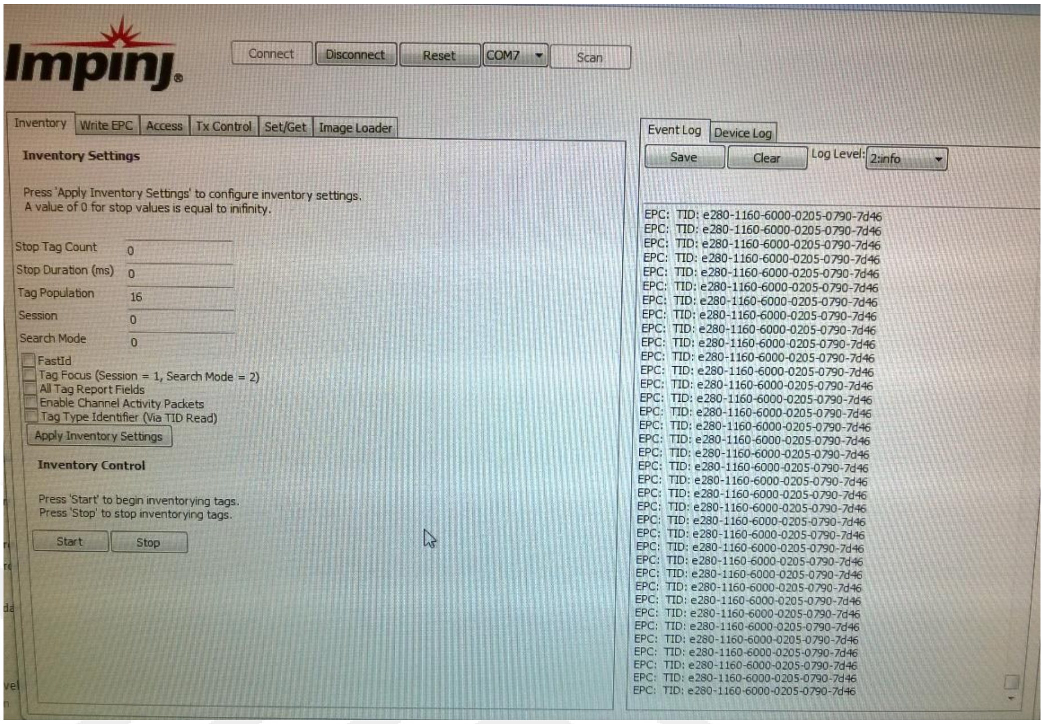


Figure 7.6 The view of reader module and linearly polarized UHF RFID antenna connection

When necessary arrangements are done on the software of RS500 Module (Impinj software), the reader module begins to work as a transceiver. So, the reader module simultaneuosly sends and receives power. A screenshot photograph belonging to this arrangement is given in Figure 7.7. Here, after the proper frequency and power level values are set correctly, the activation for transceiver module is employed by pressing “Start” on the “Inventory Control” for the Figure 7.7 given below. Afterwards, the transmitted data, which is carried by the antenna, is taken by the tag antenna. Then, the receiver channel of the module absorbs the data comes from the tag antenna and send it to the monitor given in Figure 7.7 via module RS500. The procedure is experimentally depicted in Figure 7.8 such that there are three green lights (LEDs) on the reader module. One of the green LED as being different than the one in Figure 7.6 becomes continuously “ON” when the reader is adjusted to transceiver mode. The third green LED intermittently blinks when a tag antenna is approached to the reader antenna and a receiving data from tag antenna is properly taken and processed within the reader module. When a properly processed data is captured by the reader module, the identification code (ID) of the chip (module) on the tag antenna is addressed and presented in the software snapshotted in Figure 7.7 below “Event Log”.



Inventory Settings

Press 'Apply Inventory Settings' to configure inventory settings.
A value of 0 for stop values is equal to infinity.

Stop Tag Count 0
Stop Duration (ms) 0
Tag Population 16
Session 0
Search Mode 0

☐ FastId
☐ Tag Focus (Session = 1, Search Mode = 2)
☐ All Tag Report Fields
☐ Enable Channel Activity Packets
☐ Tag Type Identifier (Via TID Read)

Inventory Control

Press 'Start' to begin inventorying tags.
Press 'Stop' to stop inventorying tags.

Log Level: 2:info

```
EPC:  TID: e280-1160-6000-0205-0790-7d46
EPC:  TID: e280-1160-6000-0205-0790-7d46
EPC:  TID: e280-1160-6000-0205-0790-7d46
EPC:  TID: e280-1160-6000-0205-0790-7d46
EPC:  TID: e280-1160-6000-0205-0790-7d46
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EPC:  TID: e280-1160-6000-0205-0790-7d46
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Figure 7.7 A view of software for RS500 reader module

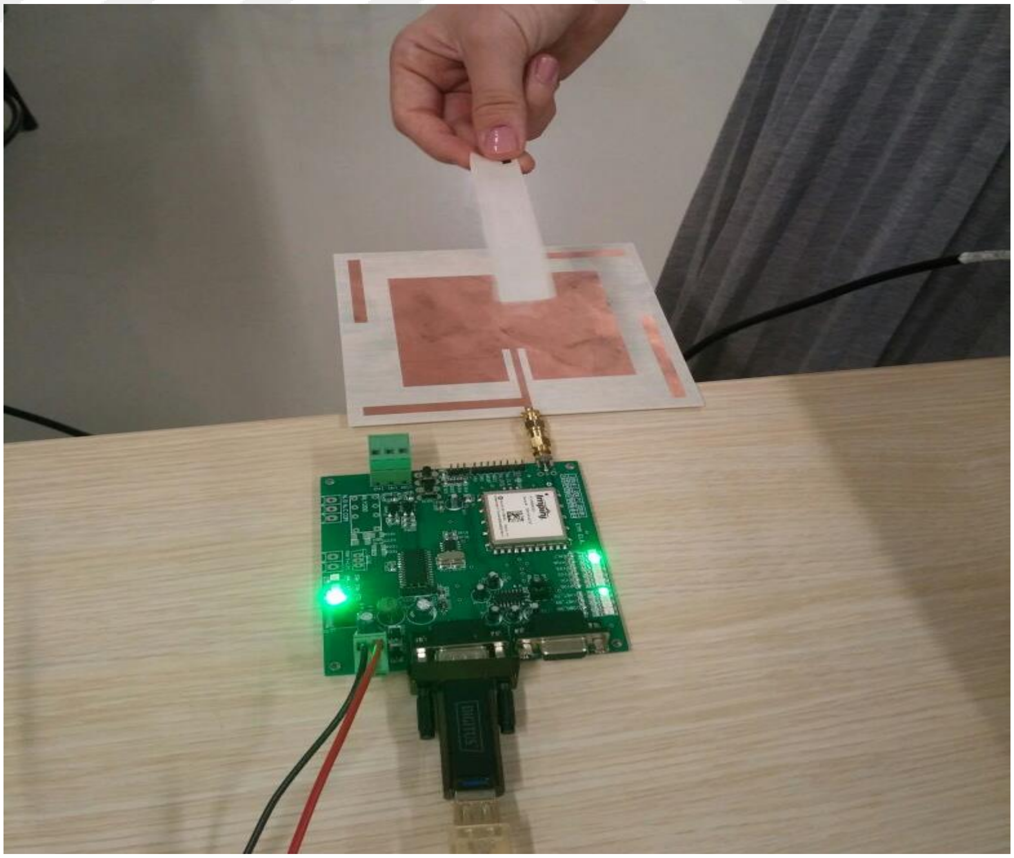

Figure 7.8 The measurement of reader antenna's reading distance

By carrying out experimental setup described above for linearly polarized reader antenna designed in this thesis, it is experimentally observed that RFID tag is correctly identified by the system (reader module) within the distance up to 15-20 cm. So, the reading distance of the RFID with linearly polarized antenna is found to be about 15 cm-20 cm.

This experimental study is repeated for circularly polarized antenna. When the configuration in Figure 7.8 is observed, it should be noticed that the tag antenna is oriented in a vertical direction in order to match the linear polarization of the designed reader antenna. On the other hand, as the advantage of the circular polarization, a proper identification is possible regardless of the orientation of the tag antenna. However, since the axial ratio of the circularly polarized antenna is not perfectly 0 dB, the reading distance at some orientations of the tag antenna can be greater than the distance at another orientation. In the experimental study for circularly polarized antenna, the linearly polarized reader antenna is replaced by the circular reader antenna in the same orientation such that the feed line of the circular antenna is again along the same direction as given in Figure 7.8. As being different than the linearly polarized antenna, two tests regarding to reading distances at two different orientations of tag antenna are realized. The tag antenna is positioned exactly same configuration with the one in Figure 7.8 (vertical orientation), and then it is rotated 90 degrees to get horizontal orientation. The possible reading distances measured for these two orientations are about 30-35 cm and 10-15 cm for vertical and horizontal orientations, respectively. The reading distance for horizontal orientation can be considered worst case (minimum reading distance), and the distance obtained for vertical orientation can be regarded as best case (maximum reading distance).

The reading distances obtained by design of experiments can be verified (checked) by using the Friss transmission equation (Stutzman & Thiele, 1998). However, as given in Chapter 2, the Friss transmission equation for RFID system is highly different from the standard Friss transmission equation. The modified Friss transmission equation for RFID system should include forth-and-back mechanism and mismatch/modulation (system) loss. Therefore, this equation can be given in normal and dB scale as (Parra A. P. L., Pantoja J. J., Neira E., Vega F., 2016)

$$\mathrm{P_r} = \mathrm{P_t}\frac{\mathrm{G}_{reader}^{2}\mathrm{G}_{tag}^{2}\lambda^{4}PLF^{2}K}{(4\pi\mathrm{R})^{4}} \tag{7.1}$$

$$P_r(dBm) - P_t(dBm) = 40log\frac{\lambda}{4\pi R} + 20log G_{reader} + 20log G_{tag} + 20log PLF + 10log K \qquad (7.2)$$

When the equations (7.1) and (7.2) are taken into account to find the reading distance *R* with Friis transmission equations, there are many parameters in these equations which can be found or obtained by independent experiments or experimental setups. For example, P_t(dBm), which is transmitted power of RS500, can be found by applying the procedure described in Chapter 7.1 with Figure 7.3 and Figure 7.4. The gain of reader and tag antennas can be obtained with gain measurement technique given in Chapter 6.2 with Figure 6.11. Axial ratio, and regardingly Polarization loss factor (PLF) can be measured with the method given in Chapter 6.3 with Figure 6.17. On the other hand, it is very hard to measure the loss term of *K* in (7.1) consisting of mismatch between tag antenna and chip impedance of RFID tag and modulation loss with an independent experiment (Parra A. P. L., Pantoja J. J., Neira E., Vega F., 2016). Therefore, the value of *K* in (7.1) can be calculated after all other values except reading distance are found and the reading distance is measured with experiment given in Figure 7.1 or Figure 7.8. This loss term varies significantly such that it can be as high as 15 dB-20 dB (Parra A. P. L., Pantoja J. J., Neira E., Vega F., 2016). Therefore, the verification of the reading distances with modified Friss transmission equations given in (7.1) and (7.2) is a very difficult task.

Instead of direct usage of Friss transmission equations in (7.1) and (7.2), the reasonability of the measured reading distances is checked with comparison method. In this method, a third antenna is used the reader antenna and all other devices and parameters are kept with the one given at this section. The third antenna used for the comparison is a standard 2 by 1 array of microstrip patch antenna implemented again on RO4003C substrate. The patches are truncated at the corner in order to make the antenna circular polarization as shown in Figure 7.9. This antenna is designed, simulated, manufactured by other undergraduate students at Department of Electrical and Electronics in Yasar University as a Senior Design Project. The measured gain and axial ratio values at the frequency of 868 MHz for this antenna are 6.7 dBi and 3 dB, respectively. This antenna is of course much larger in volume as compared to the designed antennas in this thesis; therefore, it is not preferred as a compact antenna, and it is just used for comparison. When the reading distance measurement in Figure 7.1 (or Figure 7.8) is employed with this reference antenna, a stable RFID communication is achieved up to the distance about 100 cm.

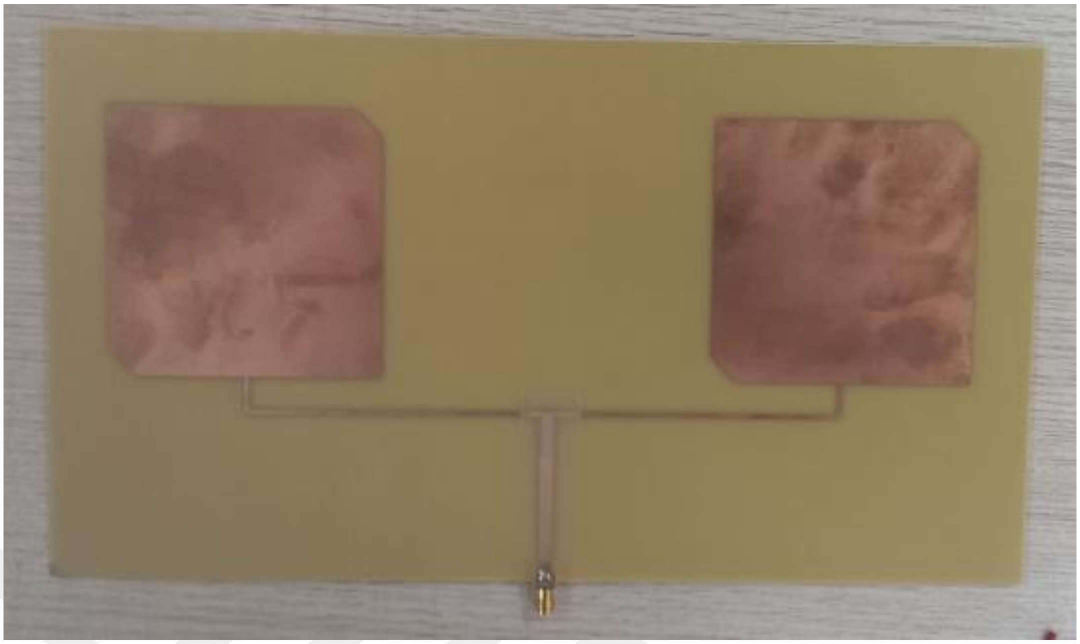

Figure 7.9 The reference reader antenna for distance comparison

By considering the values in the experiment with this third reference reader antenna at 868 MHz as P_t = +22 dBm transmitted power, G_{reader} = 6.7 dBi reader gain, R = 100 cm and keeeping all other values as constant in (7.2) with the experiments done with the designed antenna in the thesis; the reading distance for circularly polarized antenna at 855 MHz with P_t = +16 dBm transmitted power and G_{reader} = 0.5 dBi reader gain is calculated approximately as 35 cm by using (7.2) and comparison technique. This distance is consistent with the measured reading distance of 30-35 cm for circularly polarized antenna.

When these calculations are applied for the linearly polarized antenna, the reading distance at 868 MHz with P_t = +22 dBm transmitted power and G_{reader} = 2.2 dBi reader gain is calculated approximately as 66 cm by using (7.2) and comparison technique. However, the measured reading distance of 15-20 cm for linearly polarized antenna is moderately lower than the value found by this comparison method. The reason behind this discrepancy is most probably the usage of the produced linearly polarized antenna at a frequency (868 MHz) as being different than the resonant frequency of the manufactured antenna (877 MHz) in the system tests.

8 CONCLUSIONS

In this thesis, a linear and circular polarized, compact, broken ringed microstrip patch antenna is designed for the RFID systems in the UHF band. RFID reader antennas was introduced which is designed, simulated, and manufactured. During the design of antennas, the dimensions are changed because of getting most optimize results. While the operating frequency, S_{11} paremeter and bandwidth are measured with using network analyzer. Axial ratio (AR), front and rear back of the beam radiation (F/B), lobe side levels (SLL) and gain are the most important parameters of the selection and design of the antenna elements which forms the most important part of the RFID systems.

In RFID applications, circularly and linearly polarized antenna elements are used in order to ensure the effectiveness of the communication between tag that placed in any direction and the reader. A segmented loop technique is implemented to mimic the characteristic of an electrically small loop antenna and to produce a uniform aperture magnetic field distribution at UHF. In both versions, the broken ring structure has eight parts and they are placed as four at the top and four at the bottom of the dielectric material in a way that the consecutive parts will establish a constant with each other. Linear polarized patch antenna has a spread on the top layer and the ground plane is located at the bottom layer. The patch lenght is adjusted to achieve a smooth resonance at a frequency of 877 MHz which is manufactured, and circularly polarized reader antenna achieve a smooth resonance at a frequency of 855 MHz as explained previous chapter, because of the affect of the dielectric constant on the design. The whole experiment and simulation results shows that, simulation and manufactured antennas are conveniencely relation between each other. As to the antenna’s real-time experimental results, reader antennas which is made production, are useful and efficient for the places where will be use.

The circular polarized rectangular trunced shape antenna has many advantages compared to the other microstrip patch antennas. Simulation results shows that the designed antenna is capable of generating circular polarization with acceptable axial ratio. The antennas are thin and compact with having broken loops with the use of low dielectric constant substrate material. These features are very necessery for worldwide portability of wireless communication equipment and identification.

In this study, two design of far-field UHF RFID reader antenna, namely the linear polarization a compact UHF reader antenna and namely the circular polarization a compact UHF reader antenna, have been presented in this work. Although there are samples for compact reader antennas in the literature, this study is important to it is both compact and circular polarized. The parametic studies have been heloed to provide design guidelines for the realization of the proposed antennas. From the parametric studies, it is found that some parameters directly affect the distributions of the antenna while some have shown insignificant affect on the field distribution. Although not to measured the actual value of the antenna because of the module features, distance gives moderate results.

REFERENCES

Balanis C.A., Antenna Theory and Design, 2nd edn, John Wiley, USA, 1997.

Behera S K, “Novel Tuned Rectangular Patch Antenna As a Load for Phase Power Combining” Ph.D Thesis, Jadavpur University, Kolkata.

Bostan O., “Design and implementation of a compact and long range monostatic UHF RFID reader with read point extension,” M. Sc. Thesis, Istanbul Technical University, January 2014.

Chen H.-D., Kuo S.-H., Sim C.-Y.-D. and Tsai C.-H., “Coupling-feed circularly polarized RFID tag antenna mountable on metallic surface”, IEEE Trans. Antennas Propag., vol. 60, no. 5, pp. 2166-2174, 2012.

Hasse R., Demir V., Hunsicker W., Kajfez D. ve Elsherbeni A., “Design and analysis of partitioned square loop antennas”, Journal of ACES, cilt.23, no.1, s.53-61, 2008.

Impinj RS500 RAIN RFID Reader, http://www.impinj.com/products/reader-chips/indy-rs500-rfid-sip/#Documentation

James, J.R., and P.S. Hall(Eds), Handbook of Microstrip Antennas, Peter Pereginus, Londan, UK, 1989.

Kalaycı S., Design of a Radio Frequency Identification (RFID) Antenna, May 2009.

Khan G. C., "Near-Field UHF RFID Reader Antenna Design", 2009.

Parra A. P. L., Pantoja J. J., Neira E., Vega F., “On the backscattering from RFID tags installed on objects,” 10th European Conference on Antennas and Propagation (EUCAP) 2016, pp. 1-5, Davos, Switzerland, April 2016.

Qing X., Chen Z. N., Cai A., "Multi-loop antenna for high frequency RFID smart shelf application", IEEE Antennas and Propagation International Symposium, Jun. 2007, pp. 5467–5470.

Qing X., Goh C.K. and Chen Z.N., “Segmented loop antenna for UHF near- field RFID Applications”, IEEE September 2009.

Ramesh M. and Kb Y., “Design formula for inset fed microstrip patch antenna,” Journal of Microwaves and Optoelectronics, vol. 3, no. 3, pp. 5-10, 2003.

Ren Ankang, Changying Wu, Yao Gao, and Yong Yuan, “A Robust UHF Near-Field RFID Reader Antenna” IEEE Transactions on Antennas and Propagation, Vol. 60, No. 4, April 2012.

Rogers Corporation, http://www.rogerscorp.com/documents/726/acs/RO4000-LaminatesData-sheet.pdf

Secmen M., “Multibandand Wide band Antennas for Mobile Communication Systems”, Recent Developments in Mobile Communications – A Multidisciplinary Approach, s. 158-159, Intech, 2011.

Shrestha B., Elsherbeni A., “UHF RFID Reader Antenna for Near-Field and Far-Field Operations” Fellow, IEEE, 2011.

Srivastava D. K., Vishwvakarma B. R., Saraswat R. C., Saini J. P., Investigation of Effect of Substrate Thickness and Permittivity of Rectangular Microstrip Antenna for Bandwidth Enhencement, IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007), 20-22 December India, 970-973, 2007.

Stutzman W. L. and Thiele G. A., Antenna Theory and Design, New York: John Wiley and Sons, Inc., 2000.

Uddin J., Reaz M. B. I., Hasan M. A., Nordin A. N., Ibrahimy M. I., Ali M. A. M.,” UHF RFID antenna architectures and applications” Scientific Research and Essays Vol. 5(10), pp. 1033-1051, 18 May 2010.

Ulaby F. T., Michielssen E., Ravaioli U., Fundamentals of Applied Electromagnetics, 6th edition, New York: Prentice Hall Inc., 2010.

Volkais J. L., Antenna Engineering Handbook, 4th edition, McGraw Hill Companies, 2007.