BLOCKING READER: DESIGN AND IMPLEMENTATION OF A PASSIVE
UHF RFID BLOCKING READER

by

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To my Mother Kantha and my Father K.Narayanaswamy
who set an example and made me who I am.

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ABSTRACT

BLOCKING READER: DESIGN AND IMPLEMENTATION OF A PASSIVE UHF RFID BLOCKING READER

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In this thesis I present a low-cost passive UHF ISO 18000-6C Radio Frequency Identification, or RFID, reader that is feasible for mobile and privacy applications. Low cost readers are necessary to achieve the promised cost savings and enhanced revenue generation that the Internet of Things promises to deliver. Low cost readers may be installed virtually everywhere, providing real-time asset monitoring and a host of new and innovative applications yet to be conceived. While pervasively deployed readers provide tremendous benefits, the promiscuous nature of the 18000-6C tags means that the readers also pose a threat to personal security and privacy. Privately owned tags on a person will be read by all nearby readers without that person's consent thereby violating that person's privacy. A low cost reader worn on a person's body can be used as a *Blocking Reader* that prevents these unauthorized tag reads, preserving your privacy. My low- cost reader has been implemented based upon the Chipcon CC1101 chip, and I have characterized its basic read performance. using a monopole antenna, my low cost reader can be utilized as a blocking reader that prevents unauthorized reads of tags within 1m of the reader. Furthermore, when

worn on a person's body, my low-cost reader effectively acts as a Blocking Reader preventing all nearby readers from reading tags located on or in close proximity to the body.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

An RFID (Radio Frequency IDentification) Reader is a device whose primary purpose is to read the identifier stored on all RFID tags located near it. Reader communicates this Tag identifier to the backend information system. RFID is widely deployed in the supply chain industry. It is becoming more ubiquitous by the day. This is good for achieving the applications and such from the Internet of Things but it poses significant security and privacy concerns for individuals since the most widely deployed tags are promiscuous. This means that a person may be easily tracked without their knowledge or their consent. So how secure is the RFID wireless communication? Will the Tags communicate only to authorized Readers. Security and Privacy is an important issue in RFID systems. Low cost RFID readers will enable widely anticipated benefits, and they will also be the source of security protecting our privacy as we wonder through this ubiquitously connected world of our future. Different companies have come up with there own methods of providing security and privacy. It is astonishing how a modest device like an RFID tag essentially just a wireless license plate, can give rise to the complex melange of security and privacy problems [24]. There are some research done in providing privacy. Juels offers a survey of these problems in his paper[24]. Blocker Tag is one possible solution mentioned in his paper [6]. Also S.A. Weis proposes several security mechanisms to make the Tags smarter [44].

In this thesis I present the Blocking Reader. The Blocking Reader is designed to be a low-cost ISO 18000-6C compliant reader whose primary purpose is to legally prevent other readers from reading tags in its vicinity. The Blocking Reader communicates with the Tags and captures it. This prevents other Readers in the vicinity to communicate with this Tag. Blocking Reader is built on a Low-Cost Reader architecture. Also performance of the Blocking Reader is tested. Application of Blocking Reader on person's body (FEKO simulated Human body model) shows how it can preserve consumer's privacy.

1.2 The Threat to Privacy

The promiscuity of RF tags is not unique; magnetic stripe cards, for example, are promiscuous, but we assume that the owner of the card takes the physical responsibility of preventing unauthorized users from physically accessing the card [45]. It is possible to access the information of the Tag by any unauthorized reader. Even if tag contents are protected, individuals may be tracked through predictable tag responses; essentially a traffic analysis attack violating location privacy. Spoofing of tags may aid thieves or spies. Saboteurs could threaten the security of systems dependent on RFID technology through denial of service [49].

Technology is advancing at a faster pace. Need of tagging all the products for having good supply chain management is increasing. RFID has promised to provide that at a very low cost. But what are the risks of this. The Picture 1.1 shows Mr. Jones privacy is breached by knowing all his personal information. Having all this information a advertising company will make his life miserable.

In case of military it is very important to preserve the privacy of all its operations. The enhanced supply-chain visibility that makes RFID so attractive to industry

The consumer privacy problem

Figure 1.1. Potential consumer privacy problems of RFID [24] .

can also, in another guise, betray competitive intelligence[24]. It is a national risk for the military if the enemy forces are monitoring them.

The RFID technology has gained popularity in the supply chain industry making the products visible at real time. But there is a treat to the company if other companies can also get this information. We have already discussed how easy it is to get this information. So it is very important to ensure the privacy by making the RFID Systems more secure. In this Thesis we will discuss how we can make this happen with other devices outside the RFID system.

1.3 Blocking Reader(BR)

In this thesis I present the *Blocking Reader* which blocks the communication between the Reader and Tags. A Blocking Reader is a Reader that prevents other unauthorized Reader from communicating with your Tags and provides a method of security to the system. The Blocking Reader is an external device that can be used in the vicinity of the RFID system and provide with the security. Hence doesn't require any reconfiguration of the RFID system. The blocking is achieved for a very good range of about 1m with a monopole antenna transmitting 19-20dBm of power. Any tags inside this range is blocked from other Readers trying to access the information of this Tag.

Figure 1.2. Blocking envelope around the person.

Blocking Reader uses inventory round of the protocol to its advantage. The Blocking Reader transmits a series of Query commands hence capturing the Tags. The Tags reply to the query with an RN16 value but instead of acknowledging the Tag, the BR transmit another Query command. Now the Tag assumes that the Reader has not received the RN16. So it sends the RN16 again. This is done continuously capturing the Tag. Blocking Reader uses a low-cost Reader architecture design. In this thesis I present a different low-cost Reader architectures and implement BR in the simplest low-cost Reader design.

1.4 Previous Work

Many have come up with different ways to provide privacy and security to the RFID systems. Jules came up with a concept of Blocker Tag [24]. S.A. Weis proposes several security mechanisms to make the Tags smarter [44].

1.4.1 Blocker Tag

Ari Juels proposes a simple blocker-tag scheme for privacy protection [24]. Here blocker tags selectively exploit the tree-walking singulation protocol. Indeed his approach was to participate in the Tag communication in a non-compliant way causing active jamming. Here the the approach is behaving like a Tag and sending a full spectrum of serial numbers. Hence this process will obscure the serial numbers of other Tags. This makes Readers hard to singulate Tags in the field. The blocker tag when carried by a person induces a physical region of privacy protection around the person.

1.4.2 Killer Tag approach

This is a decent approach to consumer privacy, the Tags are killed with the "kill" command whenever necessary as proposed by AutoID Center[45, 3]. In the RFID world all manufactured products are tagged with a unique RFID Tag to keep track of products and its identity. When the products are sold to the consumer, it can be simply be killed with a simple "kill" command. Indeed this approach is inadequate, the killed Tags can't be used. In many RFID applications require Tags to still be active, once killed tags cannot be activated. This approach is already used in practice. There is no cost as such to kill a Tag, but this is a compulsive approach similar to tampering the Tag.

1.4.3 Faraday Cage approach

Metal is known to reflect any RF radiations of certain frequencies. Indeed this can be used to advantage by caging the tags in a container made of metal or foil. We already know that some petty thieves use foil-lined bags for shoplifting. RFID credit cards are prone to digital pickpocketing , foil lined wallets are sold in the market at a starting cost of \$19.85(via SkyMall.com). Also Faraday Cage approach is a physical approach.

1.4.4 Active Jamming approach

Radio jamming is another physical means to block Tags by actively broadcasting high power signals to decrease the signal to noise ratio. Tag jamming creates a noise shield around the Tag. In this approach an illegal broadcast of high power RF signals where done to create disturbance in communication. Hence having a Jamming effect. Unlike blocker tag which is designed to be FCC compliant. Active jamming is already

in practice in jails where they want to jam any cell phone signals. Jamming was also used in world war II to prevent enemies from communicating.

1.4.5 Smart RFID Tag approach

RFID Tags can become smarter by implementing additional features on top or in the protocol making it secure. Many concepts are being proposed by S.A. Weis in his paper and thesis [44, 48].

1.4.5.1 Hash-Lock approach

In this approach[44, 48] the Tag are locked and refuses to give its ID unless unlocked. The unlock code being a meta-ID is only known to a authorized Reader. Hence the privacy of the Tags are preserved even after Tagged products sold to other customers. The meta-ID can be shared between Readers authorizing them to read. But how secure is this approach, snooping can retrieve the Tag ID when communicating with a authorized Reader. Also Meta-ID can be cracked. It also creates inconvenience for the consumer to handle this.

1.4.5.2 Re-encryption approach

Re-encryption approach proposed by Juels and Pappu [25]. It was mainly focused on financial cryptography. The RFID tagged bank notes are prone to privacy and security issues. The serial numbers of the Tags are encrypted with law-enforcement public key. Periodic re-encryption is done to avoid guessing of different appearances. The main drawback of this is the cost of implementation, difficult to re-encrypt every time.

1.4.5.3 Silent Tree-Walking approach

Silent Tree-Walking approach was proposed by S.A.Weis [44]. This concept was proposed mainly to avoid the treat posed by passive eavesdroppers. By encrypting the Reader communication it is possible to avoid passive eavesdroppers to infer the Tag ID. But this approach is not suitable if another active reader is trying to communicate with the Tag.

So none of these approaches suitably preserve the privacy for personal tags. These approaches are suitable only for specific applications. But the concept of blocker Tag is exploited and instead of behaving like a Tag, the Blocking Reader behaves like a Reader. Blocking Reader uses compliant ways to achieve blocking, again inducing a physical region of privacy.

1.5 Implementation

The Blocking Reader is implemented with a Ultra low cost Reader architecture. It uses a CC1101 radio for RF communication. As the name says Blocking Reader is a Reader which blocks. It emulates a Reader in more efficient way hence capturing Tags causing the blocking effects. There is a potential scope for any Reader to just use this concept to turn into a Blocking reader if necessary. The Blocking Reader is designed to be FCC compliant for RFID systems, not transmitting more than 1W power. Blocking Reader uses that same ISO 180006-C GEN2 protocol which Readers use. The Blocking Reader is implemented with a simple Reader architecture and is tested for its working. The performance of the Blocking Reader is tested for different experimental setups. A real time application is done in presence of a Human Body and the results are verified with the simulations done in FEKO.

1.6 Summary

It is surprising that a modest device like a RFID Tag is lacking personal security. And being naked to any justified interrogators to attain secure data of the Tag. The thesis ensures privacy of the RFID Tag with a low cost ISO 18000-6C compliant Blocking Reader. BR can be used to block the communication between your Tag and any unauthorized Reader in the vicinity. A low-cost Reader design architecture is used in the Blocking Reader hence having a low cost of implementation. The BR uses inventory round of the protocol for blocking. The Tag replies to the communication of the BR. Hence the Blocking Reader is actually blocking and not jamming. Laboratory experiments prove that the BR can deliver a maximum blocking range of about 1m. 1m of envelope around the BR is like a shield inside which no Tags can be read. BR provide personal privacy for a person wearing the device. Laboratory experiment shows a maximum blocking envelope of about less than 1m when used a 5 gallon filled water bottle. The concept of BR can be used in other RFID systems with inventory round. The BR provides scope for implementing it on the Tag. Finally Blocking Reader can provide a solution to personal privacy issues of the Tag.

CHAPTER 2

ELECTROMAGNETIC'S OF RFID

2.1 Introduction

It is important to know the Electromagnetic's of Radio Frequency Identification(RFID), the physics concerning the communication between reader and tag. Knowledge of the fields and different laws governing the entire RFID System communication will help us to give more insight to analysis. The thesis consist of analysis of RF Radiation patterns of the Blocking reader. The RF front end of the blocking reader design consists of proper selection of the type of modulation, frequency and power. This chapter gives a small introduction to all the theories involved in the communication like Electric field, Magnetic field theory, equations governing them, modulation, antenna theory, multi-path and polarization.

2.2 Basic RFID System

A typical RFID system is as shown in the Figure 2.1. It consists of a Reader which readers the Tag information and transmits to the back-end information system for further processing. Unlike barcodes the Tags communicate wirelessly transmitting the identifier to the Reader. There are different types of RFID systems.

RFID systems can be classified based on frequency and based on communications. In this thesis we will only talk about passive UHF RFID system. UHF systems are far field operated systems where data is communicated through electromagnetic waves. UHF band allowable in US for RFID communication is 902-928 MHz. Passive RFID systems consists of Passive UHF Tags. Passive Tags are battery-less that de-

Figure 2.1. A Typical RFID System.

rives power from the Reader for communication. Some passive Tags are as shown in the Figure 2.1. ISO 180006-C GEN 2 protocol used in the passive systems is explained in chapter 4. Now let us see some physics of RFID.

2.3 Electric Field

The ancient Greeks observed that when the fossil resin, amber was rubbed, small light-weight objects were attracted [50][40]. Not until eighteen century it was quantified that it was due to electric charge. The electric charge is either positive or negative. Positively charged due to the lack of electrons and negatively charged due to the presence/accumulation of electronics. This charge can be placed due to electrostatic induction.

Coulomb in 1785 using his very sensitive torsion balance, on the force between like charges, followed by further investigations in 1787 to cover the attractive case, which gave direct quantitative verification of the inverse square law, it is now uni-

versally known as Coulomb's Law [51]. Hence he saw a force field between these two bodies which can be represented from the from this equation below.

$$F = \frac{1}{4\pi\epsilon_o} \frac{q_1 q_2}{r^2} \quad (2.1)$$

Here F is electrostatic force, r is the distance between the charged bodies, q1, q2 are the charges on the respective bodies and ϵ_o is the permittivity of free space.

The electric field can be defined as force a charged body experiences per unit charge. The unit of electric field is Newton per coulomb (N/C) which is equivalent to volts per meter (V/m). If E is the electric field, F is the coulombs force experienced by the charged body with charge Q then

$$E = \frac{F}{Q} \quad (2.2)$$

Electric field is dependent on the dielectric constant of the medium. So if E_0 is the electric field in the free space and E is the Electric field in the medium with the relative permittivity of ϵ .

$$E = \epsilon E_0 \quad (2.3)$$

if, $\epsilon_o = 8.854 \times 10^{-12}$ and ϵ_r is the relative permittivity of the medium then,

$$\epsilon = \epsilon_o \epsilon_r \quad (2.4)$$

The energy (U) stored by an electric field is given by

$$U = \frac{1}{2} \epsilon E^2 \quad (2.5)$$

2.3.1 Gauss's theorem of Electric field

Gauss's theorem relates the flux through a closed surface S to the charge enclosed by that surface [51].

$$\phi_e = \oint_s E \cdot dA \quad (2.6)$$

2.4 Magnetic Field

Studies on electromagnetism began after Faraday's discovery of electromagnetic induction in the year 1831, a phenomenon that was later theorized by Maxwell in 1873 with the concept of fields [20]. The utilization of magnetic materials like iron, hematite, magnetite etc have been done for centuries. We all know about the navigation compass. Gilbert considered earth as a giant magnet to explain the compass.

Magnetic Field is denoted by two vectors magnetic field strength $\vec{B}$ unit (A/m) and magnetic flux density $\vec{H}$ unit (Wb/m^2). The flux density and magnetic field strength are related by permeability of the material (μ). The relation is shown in the following equation

$$\vec{B} = \mu \vec{H} \quad (2.7)$$

and

$$\mu = \mu_0 \mu_r \quad (2.8)$$

Where, $\mu_0 = 4\pi \times 10^{-7} \text{ H/m}$.

2.4.1 Ampers Law

When Oersted observed a deflection in a small compass needle in the vicinity of a wire carrying current, he taught this might be due to a magnetic field created by the wire. The Ampere law states that the magnetic field intensity, as measured by a small compass at a distance r from a straight current $\vec{I}$, is described as

$$|\vec{H}| \propto \frac{\vec{I}}{r} \quad (2.9)$$

for which the directions of $\vec{I}$ and vector $\vec{H}$ are related by the right hand screw rule, as shown in Figure 2.2 [20].

Figure 2.2. Ampere Law: Right hand thumb rule.

The Biot-Savart Law stating the relationship between the electric current flowing through the conductor and magnetic flux is as follows.

$$H = \frac{I}{4\pi} \int \frac{dl \times R}{R^3} \quad (2.10)$$

2.4.2 Gauss's theorem of magnetic field

The magnetic equivalent of Gauss's theorem for the electric field for a closed surface S is given by,

$$\phi_m = \oint_s B \cdot dS = 0 \quad (2.11)$$

2.5 Maxwell Equations

Maxwell formulated the laws of electromagnetism by hydrodynamic analogy, basing them on faraday's concept of fields [20]. These equations constitute fundamental laws of physics so every macroscopic fields obeys Maxwell's equations in their entirety. Dynamic fields are the most complex compared to Static. However, certain features of dynamic field can be analyzed as though the field were static, then the field is called as quasi-static.

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad (2.12)$$

$$\nabla \times H = J + \frac{\partial D}{\partial t} \quad (2.13)$$

$$\nabla \cdot D = \rho \quad (2.14)$$

$$\nabla \cdot B = 0 \quad (2.15)$$

2.6 Antenna

Antennas serve as transducers between electromagnetic waves traveling in free space and guided electromagnetic signal in circuits [22]. Basically antennas acts as a interface that converts wired systems into wireless systems. So it is important to have

good knowledge of this device which has a very important role in the performance of a system. An RFID system is a wireless system, with power less than 1W for passive systems, it is very important for any design engineer to have knowledge of basic antenna operational parameters including input impedance, efficiency, radiation pattern, directivity, gain and noise temperature. In this section we will very briefly discuss about different types of antennas used in RFID systems and its gain. The reader antennas must be very directional and sensitive. And tag antennas must be wide-band, in some cases low cost compact design. In RFID system there are two sets of antennae used, one is with the reader and other in the tag.

2.6.1 Reader Antenna

Reader antennas should be directional and sensitive as mentioned earlier. Most of the time multiple antennas are connected to the Reader. The reader antenna is mostly a smart antenna where the gain, sensitivity, protocol parameters can be changed. There are readers like Voyantic reader which can be used to do tag analysis, environment analysis by changing these parameters. An EPC-compliant antenna costs up to \$500 [11]. Some of the reader antennas are mentioned below.

- Coil Antennas
- Patch Antennas
- Etched Antennas
- Monopole Antennas
- Lens Antennas
- Fractal Antennas

Figure 2.3 shows a Alien linear antenna with 5.90dbi gain and operates at 902-928MHz. A Patch antenna is designed in FEKO and simulated for 915 Mhz and the radiation patterns are as shown below.

Figure 2.3. RFID Reader antenna (picture courtesy of alien Reader).

Figure 2.4. Patch antenna 3D gain pattern as simulated in FEKO.

Figure 2.5. Patch antenna gain polar plot.

2.6.2 Tag Antenna

Tag antennas as we mentioned earlier should be wide band and is constrained to cost. Due to this a lot of research is done in this field and there are thousands of antenna designs. The tag antennae are usually connected to the chip directly. Most commonly used tag antennas are

- Coil Antennas
- Etched Antennas
- Monopole Antennas
- Inlay Antennas

A alien squiggle inlay ALN-9640 tag is shown in Figure 2.6. The radiation pattern simulated by FEKO is shown in Figure 2.7

Figure 2.6. An alien squiggle tag.

Figure 2.7. Gain pattern of alien squiggle tag.

Figure 2.8. FEKO 3D plot of alien squiggle tag.

2.7 Polarization

The electromagnetic field consists of electric and magnetic field vectors which are orthogonal to each other as show in the Figure 2.9. The property of waves which orients itself during oscillations is called polarization. There are different types of polarizations they are

- Linear
- Circular
- Elliptical

Figure 2.9. A typical electromagnetic wave.

Based on the application of RFID systems the type of the polarization is considered. It is very important to have knowledge of polarization in RFID because, the readability of the tag depends on the orientation of the tag.

2.8 Multipath

The term multipath denotes the possibility of EM wave propagation along various paths from the transmitter to the receiver [9]. Due to multipath the radiation pattern of the transmitter changes. In RFID if the radiation pattern of the reader antenna changes the readability of the reader changes. This is the sole reason for the difference in the radiation pattern of the reader in different environment. The reflection, absorption of radiations by the objects around the reader constitute the environment characterization. Even presence of human changes the radiation pattern of the antenna [14]. The effect of multipath increases with the distance between the transmitter and receiver. In this thesis we have done simulation experiments of human body showing how the radiation pattern changes. One of the reason is the reflection of RF radiations around the human body.

Figure 2.10. Multipath geometry showing EM waves reflections.

2.9 Friis Equation

Friis equation represents the power relation between transmitter antenna power and receiver antennas power as shown in the Equation 2.16. This equation is applicable only in ideal conditions. So it is assumed that the antennas are in unobstructed free space and there is no multipath. The received power P_r at the receiver antenna placed at a distance R can hence be calculated if we know P_t the power transmitted and gains of transmitter(G_t) and receiver(G_r) antennas.

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2 \quad (2.16)$$

CHAPTER 3

THEORY OF BLOCKING

3.1 Introduction

In this chapter we will discuss about the theory behind Blocking. Previous work from Juels, S.A. Wies and others came up with different approaches to provide privacy and security to the RFID systems as discussed in section 1.4. Some concepts and approaches like killer Tag, smart Tag are application specific, Tag jamming is illegal and faraday's cage has practical limitations. So in this thesis we have a new approach to blocking called Blocker Reader where we block the Readers from reading the Tag using Tag capture approach. This approach is similar to blocker tag but here blocking reader acts like a Reader. An external device called Blocking Reader captures your Tags and not allow other Readers to Read the Tag. In this chapter we discuss the concept of Tag capture and see how the Blocking Reader use this to block the Readers.

3.2 Inside a Passive RFID Tag

A passive UHF RFID Tag has no battery to power. It uses the carrier wave power from the Reader to energize the circuitry and transmit the encoded ID. So the Tags reply at the same frequency as the Reader. Tags antennas are hence designed to be wide-band in 902-928MHz. Typically tuned to have maximum gain at center frequency 915MHz.

Figure 3.1 shows some basic blocks that are present inside a passive Tag. Passive Tags now come as a single chip IC connected to an antenna. Inside the chip

Figure 3.1. Block diagram showing inside of the Tag and its filter.

we show impedance matching circuit, filter and analog/digital block for our understanding. The impedance matching circuit matches the impedance of the antenna. Analog/digital block hold the Tag ID and does all the required processing. Filter block is an important block for our understanding of Tag capture. It filters and selects a high power signal from noise and other signals.

Tags are wide-band receivers, it is important for a Tag to identify at the frequency slot. In case of multiple Reader environment Tags receive many signals in the frequency band 902-928MHz. Readers continuously does frequency hopping looking for which slot the Tags reply. Tags follow a simple technique to choose which Reader to reply to. Tag just identifies the maximum power signal and chooses to reply in

that channel. So its filter block which identifies higher power signal and filters out all the other signals as shown in the Figure 3.1. This is done simply to avoid collisions, it starts replying in this selected slot and other readers are not communicated with. It is quite obvious to note that now the Tags have locked to this frequency slot and continues to communicate with this Reader provided the Reader maintains the same slot and power level. This may be due to filter capacitors and inductors maintaining the charge and hence filter parameters. This is a Tag capture condition. But FCC part 15 regulations allow the Reader to stay in the slot for a maximum of 400ms. Hence it depends on the Reader frequency hopping, power ramping etc.

3.3 Reader Physics

In this section we will discuss about the communication physics of the Reader pertaining to the Tag capture mentioned in previous section. The Reader comply under FCC part 15.247 for digital modulation systems. Maximum allowable output power is 1W(+30 dBm). Also average time of occupancy on any frequency shall not be greater than 0.4s within a 20s period. Also for frequency hopping if the 20dB bandwidth of the hopping channel is less than 250kHz, the Reader shall use at least 50 hopping frequencies. Maximum allowed 20dB bandwidth of the hopping channel is 500kHz.

In practice Readers follow techniques that can provide maximum readability, maximum range and avoid collisions. Readers might follow slot occupancy as shown in the Figure 3.2. Here slots refers to the frequency slots occupied during hopping. Freq1-4 represents different instances of frequency hopping. Typically the slot occupancy time might vary from 300ms to 20ms. Readers spending more time in a slot simply means that Reader is reading the Tag continuously in this slot period. Since the readability of a Tag depends on the slot occupancy time, we can say that the

Figure 3.2. Reader frequency hopping and slot occupancy.

Tag capture also depends on the slot occupancy time. During frequency hopping the Reader take time in moving to different slot. This may be due to processing time or the transceiver frequency hopping limitations. Sometime it would be necessary to increase the power when a Reader doesn't detect any Tags in the previous slot. It takes time for processor of the Reader to make necessary changes in power. Due to all these reasons there might be a slight delay for the next slot to start. This might be sufficient for other Readers to capture the Tag.

CHAPTER 4

ISO 180006-C GENERATION-2 PROTOCOL

4.1 Introduction

A protocol is a language that a machine understands. Protocols are needed in hardware to achieve coordinated action in the presence of complicating factors such as communication channels that impose long and possibly varying delays or deliver messages unreliably or out-of-order, bounded buffers or other scarce resources that may cause deadlocks, and components that have unpredictable delays and other non-deterministic behavior [14]. The protocol used in the design is ISO 180006-C class 1 Gen 2 protocol. This was developed at the Auto-ID center at MIT [3]. This standardized for passive UHF RFID systems for communication at 860MHz-960MHz [3]. The protocol has commands that are used to establish communications between reader and tag. The interrogator modulates the carrier wave 902MHz-928MHz and the following commands are sent. Based on the commands sent the passive RFID tag will backscatter and sends commands by further modulating. The UHF band is separated into various regions around the world. In Europe it is from 865MHz-868MHz with 200 KHz channels, whereas in United States and Canada it is 902MHz-928MHz with 500 KHz channel. [46]

4.2 Reader Protocol Layers

The thesis implements a passive UHF RFID Reader, which reads Class-1 identity tags. The Class-1 tags are a passive backscatter tags with the following minimum features:

- An object identifier (OID),
- A tag identifier (TID),
- A 'kill' function that permanently disables the Tag,
- Optional password-protected access control, and
- Optional user memory [3].

In case of a reader it should be able to comply on the requirements mentioned in the physical layer, Tag-identification layer and the protocol parameters.

4.2.1 Physical Layer

A physical layer is a fundamental layer underlying the logical data structure of a protocol. It is a layer which determines the means the basic hardware does the communication. Here the Gen2 protocol pertaining to the Reader transmitting information to one or more tags is done by modulating the RF carrier using double-sideband amplitude shift keying (DSB-ASK), single-sideband amplitude shift keying (SSB-ASK) or phase-reversal amplitude shift keying (PR-ASK) using pulse-interval encoding (PIE) format. Tags being a passive tag need energy to do communication, so it receives their operating energy from the reader sent modulated RF carrier.

The Tags communicate with the Reader by backscatter-modulating the amplitude and/or phase of the RF carrier signal. FM0 or Miller modulated subcarrier are the encoding formats used by the Tag verses PIE of the Reader. Since the tags are passive, a half-duplex communication is appropriate.

4.2.2 Tag-identification Layer

The Reader needs to manage the Tag population so that it can read multiple tag more efficiently. This is achieved by performing these basic operations:

- **Select:** This is a command used by the Reader to select a user specified group of Tags from the population. Which is same as selecting records from a database.
- **Inventory:** The inventory consists of multiple commands. The reader begins the inventory round by the Query command. This inventory is the core that identify the tags and request the information from the tag like PC, OID, and CRC-16.
- **Access:** The Access also consists of multiple commands. As the name specifies access consists of set of commands that are used by the reader to access core information from the tag. Usually it comprises of identifying the tag first and then the access operation is done.

4.3 Reader Protocol Parameters

In this section we will discuss about the different signal parameters. The detailed discussion of the physical layer in the sections of signaling interface. Which defines frequencies, modulation, data coding, RF envelope, data rates and the parameters required for RF communication.

4.3.1 Operational Frequencies

A Reader choses to operate at particular frequency range from 860MHz to 960MHz determined by the local radio regulations and by the local radio regulations and by the local radio-frequency environment.

4.3.2 Reader-to-Tag ($R \Rightarrow T$) communications

4.3.2.1 Modulation

As mentioned earlier the reader shall communicate using DSB-ASK, SSB-ASK, or PR-ASK modulation. The reader modulates the RF carrier signal in one of these modulation schemes with PIE encoding to communicate with the tag. The data rate is set by means of the preamble that initiates the round.

4.3.2.2 Amplitude Shift Keying (ASK)

Figure 4.1. Reader to Tag RF modulation envelope [3].

The Figure 4.1 and Table 4.1 shows the modulation parameters for the tari value $6.25\mu s$ to $25\mu s$. The carrier signal is modulated by varying the envelope of the signal in ASK. The amplitude is varied by encoding the '0's and '1's in the signal. Mostly the signal is having two amplitudes, one low amplitude for a '0' and high for a '1'. It can change according to the encoding formats. The protocol uses Pulse

Table 4.1. RF Envelope Parameters [3]

Parameter	Symbol	Minimum	Typical	Maximum	Units
Modulation Depth	$(A-B)/A$	80	90	100	%
RF Envelope Ripple	$(M_h = M_l)$	0		$0.05(A-B)$	V/m
RF Envelope Rise Time	$(t_{r,10-90\%})$	0		$0.33T_{ari}$	μs
RF Envelope Fall Time	$(t_{f,10-90\%})$	0		$0.33T_{ari}$	μs
RF Pulsewidth	PW	$\text{MAX}(0.265T_{ari}, 2)$		$0.525T_{ari}$	μs

Interval Modulation (PIE). The On-Off Keying is another type of modulation which the protocol uses. It is similar to ASK where the signal is on/off for a duration creating an on/off envelope.

4.3.2.3 Reader power-up/down waveform

The reader power-up/down RF envelope will comply with the Figure 4.2 and Table 4.2. Here the carrier signal level will rise monotonously from its 10% level until at least ripple limit M_l . Similarly when the carrier level fallen below 90% level for power down, it can fall monotonically until the power-off limit M_s .

Figure 4.2. Reader power-up/down RF envelope [3].

Table 4.2. Reader power-up/down waveform parameters [3]

Parameter	Definition	Minimum	Typical	Maximum	Units
T_r	Rise time	1		500	μs
T_s	Settling time			1500	μs
T_f	Fall time	1		500	μs
M_s	Signal level when OFF			1	% full scale
M_l	Undershot			5	% full scale
M_s	Overshoot			5	% full scale

Table 4.3. Preferred Tari Values [3]

Tari Value	Tari Tolerance	Spectrum
6.25μ sec	$\pm 1\%$	DSB-ASK, SSB-ASK or PR-ASK
12.5μ sec	$\pm 1\%$	DSB-ASK, SSB-ASK or PR-ASK
25μ sec	$\pm 1\%$	DSB-ASK, SSB-ASK or PR-ASK

4.3.2.4 Data rates

The Reader shall communicate with the Tari values as shown in the Table 4.3. With time width values fixed for '0's and '1's with reference to Tari value the data rate changes. The data rate chosen is very important. Some Reader design doesn't allow some data rates. This effects the performance of the system. So selection of a Reader design is also dependent on the data rate. Later will discuss about the selection of a data rate for good architecture design of the reader. The Gen 2 compliant Tari values are shown in the Table 4.3.

4.3.2.5 Data encoding

The Reader to Tag communication use Pulse Interval Modulation as a data encoding scheme. T_{ari} is the reference time interval for interrogator-to-tag signaling, and is the duration of data-0 [3]. The PIE symbols are as show in the Figure 4.3. Showing the PIE, where the high value is CW at higher amplitude and low values is the CW at lower amplitudes.

Figure 4.3. PIE symbols [3].

4.3.2.6 Reader to Tag Preamble and Frame-sync

A reader will begin any communication with the Tag with either preamble or a frame-sync. In the inventory commands the Query command is the most important as the reader states with this command. The preamble precedes this query command only. Whereas the frame-sync precedes every other commands.

The preamble and frame-sync is as shown in the Figure 4.4. Preamble consists of a fixed-length delimiter, a data-0 symbol, an $R \Rightarrow T$ calibration (RTcal) symbol, and a $T \Rightarrow R$ calibration (TRcal) symbol. Frame-sync is same as preamble expect the last TRcal symbol.

Figure 4.4. The Preamble and Frame-sync [3].

- **RTcal:** The reader can set the length of $RTcal = 0_{length} + 1_{length}$. So that the tag can measure $RTcal$ and calculate $pivot = RTcal/2$. Now the tags will interpret a symbol smaller than $pivot$ as data-0 and longer as data-1. Also the Tag shall consider signals longer than 4 $RTcal$ as bad data. A CW is transmitted for a minimum of 8 $RTcal$ before changing $RTcal$.
- **TRcal:** A $TRcal$ length is chosen by the Reader to specify the link frequency(LF). This LF is used by the tag to determine its FM0 data rate. The LF is calculated from the equation 4.1. Where DR is the Divide ratio already known by Tag specified by the manufactrer.

$$LF = \frac{DR}{TRcal} \quad (4.1)$$

4.3.2.7 Frequency-Hopping Spread-Spectrum (FHSS)

The FHSS signaling of the Reader shall comply on the FCC regulations. It shall comply on the RF envelope shown in the Figure 4.2. So it is important to consider these regulation in the reader design.

4.3.3 Tag-to-Reader ($T \Rightarrow R$) communications

4.3.3.1 Modulation

Modulation shall be same as reader, as explained earlier in the sections 3.3.2.1 - 3.3.2.3.

4.3.3.2 Data encoding

The backscattered data from the Tag shall be encoded by FM0 baseband or Miller modulation of a subcarrier at the data rate.

- **FM0 baseband:**

FM0 encoding or the bi-phase space is as shown in the Figure 4.5. The FM0 basis functions showing the data-0 and data-1. And the FM0 generator state diagram labels, S_1 - S_4 , indicating four possible FM0-encoded symbols.

- **Miller-modulated subcarrier**

Miller encoding is as shown in the Figure 4.6. The FM0 basis functions showing the data-0 and data-1. And the FM0 generator state diagram labels, S_1 - S_4 , indicating four possible Miller-modulated subcarrier symbols. In this encoding the duty cycle of the symbols is measured at output and is between 45% to 55%. A Miller encoding signaling shall end with a "dummy" data-1 bit at the end of signal transmission.

Figure 4.5. FM0 basis functions and generator state diagram [3].

Figure 4.6. Miller basis functions and generator state diagram [3].

4.3.4 Link timings

The link timing of the communication between the Reader and Tag is shown in the Figure 4.7. Table 4.4 consists of link timing parameters. A inventory command consists of Query command which initiates the round. The Query command consists of DR and M values(which is discussed in later sections); the preamble that precedes

Inventory round of a single tag reply shown in Figure 4.7 shows the reader transmitting CW for a duration of T_4 which is minimum of $2RT_{cal}$. The Reader shall use a constant $R \Rightarrow T$ link rate, if a change of $R \Rightarrow T$ link rate is required to be changed then a CW for a minimum of $8RT_{cal}$ is transmitted to indicate there is a change in data rate. When a Query is communicated with the tag the Tag sends RN16 after a time T_1 as shown. Reader waits for time T_2 and sends Ack command. Now the tag reply with a command consisting of PC, OID and CRC16. An QueryRep or QueryAdjust is sent by reader to acknowledge that OID is valid. Else a NAK command is sent.

Table 4.4. Link timing parameters [3]

Parameter	Minimum	Typical	Maximum	Description
T_1	$MAX(RT_{cal}, 10T_{pri}) \times (1 - FT) - 2\mu s$	$MAX(RT_{cal}, 10T_{pri})$	$MAX(RT_{cal}, 10T_{pri}) \times (1 - FT) + 2\mu s$	Time from interrogator transmission to tag response, measured at antenna terminal.
T_2	$3.0T_{pri}$		$20.0T_{pri}$	Time from last falling edge of the last bit of the Tag response to first falling edge of a Reader signal.
T_3	$0.0T_{pri}$			Time an Reader waits, after T_1 , before it issues another command
T_4	$2.0T_{pri}$			Minimum time between Reader commands

4.3.5 Reader Commands and Tag replies

Reader-to-Tag commands shall have the format shown in the Table 4.5. Each and every command shall have a command code preceding the commands. It is unique to every command. The Table 4.5 indicates the codes and length of the few commands. The Tags shall ignore invalid commands. Following shall be the reasons for the commands to be invalid.

- If the current Tag state is incorrect.
- Command not supported by Tag.
- If the parameters are incorrect.
- If the CRC error is detected.
- An incorrect section is specified.
- Other unrecognized encoding/signaling.

A CRC-5 is 5 bits of length is defined by the polynomial shown in the Equation 4.2. The preset value is 01001 and residue 00000.

Table 4.5. Commands [3]

Command	Code	Length(bits)	Required?	Protection
QueryRep	00	4	Yes	Unique command length
ACK	01	18	Yes	Unique command length
Query	1000	22	Yes	Unique command length and CRC
QueryAdjust	1001	9	Yes	Unique command length
Select	1010	>43	Yes	CRC-16
NAK	11000000	8	Yes	Unique command length

Table 4.6. Select command [3]

	Command	Target	Action	MemBank	Pointer	Length	Mask	Truncate	CRC-16
# of bits	4	3	2	2	EBV	8	variable	1	16
Description	1010	000:S0 001:S1 010:S2 011:S3 100:SL 101:RFU 110:RFU 111:RFU	See Table 4.7	00:RFU 01:OID 10:TID 11:User	Starting Mask Address	Mask Length (bits)	Mask value	0:Disable 1:enable	

$$Polynomial = X^5 + X^3 + 1 \quad (4.2)$$

4.3.5.1 Select (Mandatory)

The Select command implemented by the Reader/Tag selects a particular Tag population. The Select command comprises of the following bits as shown in Table 4.6. Based on the Target, Action, MemBank, Pointer, Length and Mask fields the Tag matching and non-matching criteria is specified. The response to the Action parameters is as shown in Table 4.7.

Table 4.7. Tag response to action parameter [3]

Action	Matching	Non-Matching
00	assert SL or inventoried $\rightarrow$ A	deassert SL or inventoried $\rightarrow$ B
01	assert SL or inventoried $\rightarrow$ A	do nothing
10	do nothing	deassert SL or inventoried $\rightarrow$ B
00	negate SL or $(A \rightarrow B, B \rightarrow A)$	negate SL or $(A \rightarrow B, B \rightarrow A)$

Table 4.8. Query commands [3]

	Command	DR	M	T _R ext	Sel	Session	Target	Q	CRC-16
# of bits	4	1	2	1	2	2	1	4	5
Description	1000	0:DR=8 1:DR=64/3	00:M=1 01:M=2 10:M=4 11:M=8	0:No pilot tone 1:Use pilot tone	00:All 01:All 10:~SL 11:SL	00:S0 01:S1 10:S2 11:S3	0:A 1:B	0-15	

4.3.5.2 Query (Mandatory)

Query command is the most important command in the inventory round. It initiates and specifies the complete operation of Reader and Tag. This command is extensively used by the Blocking Reader. For any tag to respond query is the trigger command. If a Tag, in response to the Query, draws a zero slot value from its RNG, then its reply to a Query shall be with a RN16 value, otherwise the tag shall remain silent [3]. Table 4.8 shows the bits of the command. The *DR* is *TRcal* divide ratio which sets the $T \Rightarrow R$ link frequency. *M* is the cycles per symbol which sets the $T \Rightarrow R$ data rate and modulation format. *T_Rext* bit is used to determine if pilot tone should be prepended for $T \Rightarrow R$ preamble. The *Sel* bits which tags respond to the Query. The *Session* determines which session on inventory round is selected. *Target* selects the inventoried flags A or B. *Q* determines the number of slots in the round.

Table 4.9. QueryAdjust command [3]

	Command	Session	UpDn
# of bits	4	2	3
Description	1001	00:S0 01:S1 10:S2 11:S3	110: Q=Q-1 000: No change to Q 011: Q=Q-1

Table 4.10. QueryRep command [3]

	Command	Session
# of bits	2	2
Description	00	00:S0 01:S1 10:S2 11:S3

4.3.5.3 QueryAdjust (Mandatory)

A QueryAdjust command is sent by the Reader to adjust the Q parameters of the inventory round only. It consist of the following bits as shown in the Table 4.9. A QueryAdjust is always prepended by a frame-sync. In response to this command the Tag shall send RN16 command. QueryAdjust command consist of *command*, *session* and *UpDn*. The *UpDn* determines if the Tag shall increment/decrement the Q or have the Q value to be same.

4.3.5.4 QueryRep(mandatory)

QueryRep command shall be implemented by the Tag and Reader to decrement the slot value. The Tag shall respond with RN16 if the Slot value is '0'. Table 4.10 shows the command bit of QueryRep.

Table 4.11. ACK command [3]

	Command	RN
# of bits	2	16
Description	01	Echoed RN16 or handle

Table 4.12. NAK command [3]

	Command
# of bits	8
Description	11000000

4.3.5.5 ACK(mandatory)

ACK command is a acknowledgment given by the Reader to a signal Tag. It is a command which just replies with the same RN16 sent by the Tag. The command bits are as shown in the Table 4.11.

4.3.5.6 NAK(mandatory)

A NAK command is implemented by Reader and Tag to command all Tags to return to arbitrate state. Table 4.12 shows the command bits.

4.4 Summary

ISO 180006-C GENERATION-2 PROTOCOL is designed for a specific purpose. To have a standardized communication layer for all the Tags. Tag Vender use this extensively now. Implementing this in the Reader requires understanding of timings and different commands. The low cost Reader designs have limited memory. A part of protocol can be implement for the basic operation of the Reader. In the next chapter we will discuss about implementation of this protocol in the Blocking Reader.

CHAPTER 5

READER ARCHITECTURE

5.1 Introduction

A Typical RFID Reader consists of a Central Processing unit, a RF front-end and server interface as shown in the Figure 5.1.

Figure 5.1. Basic functional blocks of a RFID Reader.

RFID Readers come in many designs. The cost of a typical UHF RFID passive Reader varies from \$1,295 (for Alien ALR-9800) to \$25,000 (for a Reader test equipment). The UHF Readers available in the market are designed solely for specific applications. Some are designed for performance, some are designed for doing tag

analysis. But all this Reader systems contain all this basic functional blocks shown in the Figure 5.1.

5.2 Low-Cost Reader Requirements

Research is still going to come up with a low cost RFID systems so that it can be extensively used in many applications. The RFID Reader Tag technology replaces the barcode technology. Barcodes and the barcode readers costs a lot less compared to a RFID tag and reader. Currently a RFID passive tag is greater than 8 cents and a typical low cost Reader is about \$200-\$500. But a barcode reader is as low as \$18. So it is important to have a Ultra low-cost Reader and Tag. A lot of research is going on on designing a low cost UHF passive tags. The Auto-ID Center is developing low-cost radio frequency identification (RFID) based systems with the initial application as next generation bar-codes[45]. Based on the assumptions on the deployment of RFID technology the estimated cost of a passive tag in 10 years would be \$0.02 [32]. So a 0.01cent tag and 10 dollar reader can change the use of RFID systems. And we could see its deployment in many fields and applications.

5.3 Possible Low-Cost Reader Architectures

The design presented in this paper has the following design constraints

- The cost the Reader design should be as low as 30\$.
- The Reader should comply on Gen 2 protocol.
- Reader functionality should support read/write information to tags.
- Radiated power should not exceed 1W.
- Achievable read of 100 tags/sec.

Each objective has its own challenges. To reduce the cost of the reader we have to compromise on different parameters like performance, read rate, read range etc. The performance of this reader will be less compared to other readers. But the reason for this design is the use of this reader in an application where there is no requirement of high processing readers, as discussed earlier. On research there were lots of designs that were feasible. By knowing the functionalities of the blocks, the design is put together. This level of design will reduce the cost of the design, knowing the cost of each and every block. Achieving the first design constraint is very important, this requires the knowledge of other parameters also. Parameters like power, type of modulation, frequency, protocol etc should be considered. Some of the low cost basic designs are shown.

5.3.1 Duo-PIC separate TX-RX design

In this design the transmitted and received signal are separately processed with separate processing units as shown in the Figure 5.2. The two processing units communicate with each other through the data bus. So basically this design has two modules. The transmitter module and the receiver module. The transmitter module consists of a processor, transmitter, impedance matching circuit and an antenna. The receiver module consists of a processor, receiver, impedance matching circuit and an antenna. Here the two modules are isolated in analog domain and communicate each other digitally. When looked at this design we might think there are unnecessary modules. But when a low cost processor is used, it is cheap to dedicate a processor to one function. Here a low cost low functional microprocessor can be used and can be dedicated to one function like transmit/receive. The Gen 2 protocol can be written in such a way that the transmitter/receiver module will only transmit/receive and communicate each other using interrupts. The transmitter and receiver can be so

chosen to work only for the 902-928 MHz ranges. Therefore it reduces the cost on the impedance matching circuit. The Table 5.1 shows set of components that can be used. It also shows the total cost of the Reader.

Advantages of this design are:

- Simple Design.
- Easy to implement the Gen 2 protocol.
- Can further reduce the cost by using low cost IC's.
- Eliminates the requirement of circulator.

Disadvantages of this design are:

- Difficult to find IC's with specific functionality, mostly RF IC's.
- Parallel processing, difficult to handle timings.
- Isolation of antennas.

Figure 5.2. Architecture of Duo-PIC separate TX-RX design.

Table 5.1. Duo-PIC separate TX-RX design: parts and cost

Components	Type of IC/CKT	Cost(\$)
Processor	C8051F320	3.16 x 2
Transmitter	MTX-103-915DR-B	9.2048
Receiver	MRX-005-915DR-B	8.98520
Ethernet controller and Connector	ENC28J60/SO-ND and 609-1059-2-ND	3.6 + 0.9072
Antenna (Monopole)	509-ANT-915-06A	7.0 x 2
Matching CKT	Discrete Balun and Components	4
Board and other miscellaneous	2 Layer PCB	15
Total Cost		62.0172

5.3.2 Duo-PIC separate TX-RX uni-antenna design

The Duo-PIC separate TX-RX uni-antenna design is an improvement over the Duo-PIC separate TX-RX design. Considering the advantages and disadvantages the Duo-PIC separate TX-RX design can be improved. The Duo-PIC separate TX-RX uni-antenna design is as shown in the Figure 5.3. Architecture of Duo-PIC separate TX-RX uni-antenna design uses a circulator which can eliminate the problem of isolation of two antennas. Further more the impedance matching circuit can be clubbed to single circuit reducing the cost of the design.

This circuit will also have other disadvantages adding to the Duo-PIC separate TX-RX design like

- The design of the circulator for UHF frequencies is bit difficult.
- Cost of the circulator increases design cost.
- Using one antenna reduces the power transmitted to passive tags.

The Table 5.2 shows list of components and its costs. Here you can see the cost of the circulator is potentially increases the cost of the overall design. The total cost of this design considering we use this components is \$77.71.

Figure 5.3. Architecture of Duo-PIC separate TX-RX uni-antenna design.

Table 5.2. Duo-PIC separate TX-RX uni-antenna design: parts and cost

Components	Type of IC/CKT	Cost(\$)
Processor	C8051F320	3.16 x 2
Transmitter	MTX-103-915DR-B	9.2048
Receiver	MRX-005-915DR-B	8.98520
Ethernet controller and Connector	ENC28J60/SO-ND and 609-1059-2-ND	3.6 + 0.9072
Antenna (Monopole)	509-ANT-915-06A	7.0
Matching CKT	Discrete Balun and Components	4
Board and other miscellaneous	2 Layer PCB	15
Circulator	SS-SC24A	22.7
Total Cost		77.7172

5.3.3 Uni-PIC separate TX-RX design

In each and every design there is step-wise improvements this will eventually indicate how the final design is come up. The architectural design is as shown in the Figure 5.4. In this design a good performance processor is used with both transmitter and receiver circuit to be different. Here the problem of parallel processing can be eliminated. Also it eliminates the requirement of the other processor reducing the cost. But proper choice of a 16-bit processor like a micro-controller should be used. Disadvantages are same as Duo-PIC separate TX-RX design.

Figure 5.4. Architecture of Uni-PIC separate TX-RX design.

Table 5.3. Uni-PIC separate TX-RX design: parts and cost

Components	Type of IC/CKT	Cost(\$)
Processor	C8051F320	3.16
Transmitter	MTX-103-915DR-B	9.2048
Receiver	MRX-005-915DR-B	8.98520
Ethernet controller and Connector	ENC28J60/SO-ND and 609-1059-2-ND	3.6 + 0.9072
Antenna (Monopole)	509-ANT-915-06A	7.0 x 2
Matching CKT	Discrete Balun and Components	4
Board and other miscellaneous	2 Layer PCB	15
Total Cost		58.8572

5.3.4 Uni-PIC separate TX-RX Uni-antenna design

In case of this design it is an improvement over Uni-PIC separate TX-RX design like that of transition from Duo-PIC separate TX-RX design to Duo-PIC separate TX-RX uni-antenna design. This design has advantages of elimination of parallel processing and elimination of two antennas topology with no isolation problems. Some

of the advantages like reduced costs by eliminating one antenna and a processor. But also includes complexity of design with the circulator.

Figure 5.5. Architecture of Uni-PIC separate TX-RX Uni-antenna design.

Table 5.4. Uni-PIC separate TX-RX Uni-antenna design: parts and cost

Components	Type of IC/CKT	Cost(\$)
Processor	C8051F320	3.16
Transmitter	MTX-103-915DR-B	9.2048
Receiver	MRX-005-915DR-B	8.98520
Ethernet controller and Connector	ENC28J60/SO-ND and 609-1059-2-ND	3.6 + 0.9072
Antenna (Monopole)	509-ANT-915-06A	7.0
Matching CKT	Discrete Balun and Components	4
Board and other miscellaneous	2 Layer PCB	15
Circulator	SS-SC24A	22.7
Total Cost		74.5572

5.3.5 Single processor transceiver design

This Single processor transceiver design as shown in the Figure 5.6 can be said as a simplest design. In this design there is a powerful PIC memory sufficient to hold the protocol. A Transceiver that does both transmit and receive of RF signals. The choice of a transceiver IC is very important for this design. And should be able to comply on all the parameters discussed earlier. Again the processor used here should be a 16-bit micro-controller to handle the transceiver. We also note that there is no need for the circulator in this design as the transceiver can do half duplex communication. There is no problem of isolation in this circuit as the design has one antenna.

One disadvantages of this design is it can mostly be used in low power applications, hence the range decreases. A passive RFID Tag uses power from the reader for communication so it is required for the Reader to switch between transmit and receive quickly. The power constraints can be over come by a simple amplifier circuit.

On research and careful consideration this architecture is considered for the design of the Passive UHF RFID Reader in this paper. Important reasons being the simplest design and low cost.

Let us see how the Single processor transceiver design can comply on the design constraints. Cost of the total design should not exceed 30\$. The cost discretion is as shown in the Table 5.5 below. From the table we can see that the cost is complied with less that 30\$. The next constraint was to see if the design could comply on the Gen2 protocol. Here the transceiver and the RF circuit used should be able to comply on the protocol. CC1101 is the transceiver used in this design this IC is design by Chip Con. The description of the IC CC1101 is as mentioned below. On research this IC was considered as a better option for this design. The next constraint was the on supporting read/write of the tags. This shouldnt be a problem with the

80C51F320 micro-controller being a programmable which can be programmed to do these functions. The output power of the CC1101 can be programmable up to +10 dBm making a way below the 1W power, it supports for connection of an amplifier to boost the power. So this design complies on the design constraints.

Figure 5.6. Architecture of single processor transceiver .

Table 5.5. List of Parts and Cost for Single processor transceiver design

Components	Type of IC/CKT	Cost(\$)
Processor	C8051F320	3.16
Transceiver	CC1101	2.55
Antenna (Monopole)	509-ANT-915-06A	7.0
Matching CKT	Discrete Balun and Components	4
Board and other miscellaneous	2 Layer PCB	15
Total Cost		31.71

Table 5.6. Cost comparison of different Reader designs

Design	Cost
Duo-PIC separate TX-RX design	62.0172
Duo-PIC separate TX-RX uni-antenna design	77.7172
Uni-PIC separate TX-RX design	58.8572
Uni-PIC separate TX-RX Uni-antenna design	74.5572
Single processor transceiver design	31.71

5.4 Amplifier

An amplifier is important in Single processor transceiver design as the maximum output power that can be achievable with CC1101 transceiver is + 10dBm. The protocol allows a maximum power of +30dBm [3]. So we could use an external amplifier that can amplify the signal. Some advantages of using amplifier are

- Will increase read range.
- Keeps the Tags in active state.
- Gives an opportunity to design a simple reader with no limit to power.

Some disadvantages of using amplifier are

- Increased cost.
- Will also amplifies the noise in the channel.
- Some loss in data due to inbuilt filters.

5.5 Summary

A low cost UHF RFID Reader can be used in different applications. One of the important application we intend to use this design is for a Blocking Reader. Now a low cost Blocking Reader can be used to preserve privacy of the Tags. Later in this thesis we discuss how this design is implemented and show the performance of the working Blocking Reader.

CHAPTER 6

IMPLEMENTATION

6.1 Introduction

The Blocking Reader uses the Reader design shown in Figure 5.6. This looks like a simple design but implementation of this requires proper selection of the IC's that satisfies the basic requirements.

6.2 Circuit Diagram

6.2.1 Processor

The processor used in this design is C8051F320. The processor is having a 16Kbytes of Flash sufficient to program a Blocking Reader. It supports all USB and UART modes which provides interface to the server. 25/21 digital I/O ports and 16-bit programmable counter array which can be used to interface with the transceiver. The processor is high speed with pipelined instruction architecture executing 70% of instructions in 1 or 2 clock cycles provides a fast programming of transceiver IC. It is having a throughput of 25MIPS with a clock of 25MHz. It comes in the packaging of 32-pin LQFP. The μ Controller connections are as shown in the Figure 6.6.

6.2.1.1 Programming

The 8051 μ C chip include on-chip Silicon Labs 2-Wire (C2) debug circuitry. It allows a non-intrusive, full speed, in-circuit debugging. A full access to 16KB flash, 2304 bytes of on chip memory and registers. Debugging logic supports setting break point, single stepping, run and halt commands. The thesis use a Keil μ Vision 3 for

writing the code in assembly, C and Hex formats. The 8051 μ C connected to USB is used to dump the program.

6.2.1.2 USB and UART

The μ Controller chip has SMBus/ I^2 C, Enhanced UART, and Enhanced SPI serial interfaces are implemented in hardware. The presence of Universal Serial Bus (USB) function controller with eight flexible endpoint pipes, integrated transceiver and have a RAM of 1K FIFO. The Figure 6.6 shows the connection to a USB connector. Pin 4,5 are D+ and D- of the μ C chip is connected to D+ and D- of the USB connector. Pin 8 of μ C chip is the V_{bus} which is connected to V_{bus} of μ C chip.

6.2.1.3 Transceiver connections

The μ Controller chip programs the transceiver controlling the RF front end. Port 0 is connected to the transceiver. The connections are as shown in the Figure 6.6. The V_{ref} pin 27(P_{0.7}) of μ Controller chip is connected to the GD₂ of the transceiver. Similarly pin 28(P_{0.6}) to GD₀, pin 31(P_{0.3}) to CS_n, pin 32(P_{0.2}) to S₁ and pin 2(P_{0.0}) to Sclk of the transceiver respectively. The transceiver allows serial programming, it contains various configuration, status and control registers which are accessible. The configuration is called 4-wire serial configuration and data transfer which is later discussed in further sections.

6.2.2 Transceiver CC1101

The Blocking Reader uses a transceiver chip from Chipcon (later bought by TI) known as CC1101. CC1101 is a wonderful low-cost low-power sub-1GHz RF transceiver. It is not solely designed for a RFID purpose like a TI 100\$ Reader chip. But the cost and functionality of the chip is very impressive.

Some Analog and Digital Features of CC1101 that satisfy the design constraints of the UHF RFID Reader are

- Operates at 315/433/868/915 MHz ISM/SRD. Blocking Reader requires 915 MHz.
- Extended frequency band 779-928 MHz.
- Allows OOK and flexible ASK shaping.
- Suitable for frequency hopping with $90\mu\text{s}$ settling time.
- Programmable data rate from 1.2 to 500 kBaud. Blocking Reader requires 80 kBaud.
- Programmable output power up to +10 dBm. FCC allows up-to +30 dBm for RFID Readers.
- In built Packet Handling, supports easy programming of Reader commands.

Figure 6.1. Pinout top view [1] .

The transceiver Pin Configuration is shown in the Figure 6.1. Description of some important pins of the chip are

- **SCLK:** It is a digital input for serial configuration interface, clock input.
- **S0(GDO1):** It is a digital output for serial configuration interface, data output. and can be used as optional output pin when CSn is high.
- **GDO2:** Its is a digital output pin generally used for test signals, FIFO status signals, clear channel indicator, clock output, down-divided from XOSC and serial output RX data
- **GDO0(ATEST):** It is a digital I/O pin. Generally used for outputting test signals, FIFO status signals, clear channel indicator, clock output, down-divided from XOSC and serial RX/TX data.
- **CSn:** It is a digital input used for chip selection and serial configuration interface.
- **RF_P:** It is an RF I/O pin, a positive terminal for RF I/P signal to LNA and O/P signal from PA.
- **RF_N:** It is an RF I/O pin, a negative terminal for RF I/P signal to LNA and O/P signal from PA.
- **SI:** It is a digital input for serial configuration interface.

6.2.2.1 Application Circuit

The application circuit of CC1101 transceiver is as shown in the Figure 6.2. The circuit shows various connections. To the left of the CC1101 we can see digital interface. The digital interface is the interface connected to the processor. The matching circuit is right of the CC1101, this combination of inductors and capacitors determine the frequency of operation. The values of the components are as shown in the Table 6.1.

Figure 6.2. A typical application circuit for 915 MHz [1] .

Table 6.1. Bill of material for the application circuit [1]

Components	Value	Manufacturer
C15	100nF $\pm$ 10%, 0402 X5R	Murata GRM1555C series
C81	27pF $\pm$ 5%, 0402 NPO	Murata GRM1555C series
C101	27pF $\pm$ 5%, 0402 NPO	Murata GRM1555C series
C121	1.0pF $\pm$ 0.25pF, 0402 NPO	Murata GRM1555C series
C122	1.5pF $\pm$ 0.25pF, 0402 NPO	Murata GRM1555C series
C123	3.3pF $\pm$ 0.25pF, 0402 NPO	Murata GRM1555C series
C124	100pF $\pm$ 5%, 0402 NPO	Murata GRM1555C series
C125	100pF $\pm$ 5%, 0402 NPO	Murata GRM1555C series
C126	2.2pF $\pm$ 0.25%, 0402 NPO	Murata GRM1555C series
C127	2.2pF $\pm$ 0.25%, 0402 NPO	Murata GRM1555C series
C131	1.5pF $\pm$ 0.25pF, 0402 NPO	Murata GRM1555C series
L121	12nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
L122	18nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
L123	12nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
L124	12nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
L125	9.1nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
L131	12nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
L132	18nH $\pm$ 5%, 0402 monolithic	Murata LQG15HS series
R171	56k Ω $\pm$ 1%, 0402	Koa RK73 series
XTAL	26.0 MHz	NDk, AT-41CD2

6.2.2.2 Radio Control

The transceiver is having a built-in state machine that can be used in switching between different modes. It clearly shows how different command strobes can be used to change the states. It is important for the thesis as the Blocking Reader need to know the operational states. The status register *MARCSTATE* contains the current state number, the number are as shown in the state diagram. To design a Reader it is important to know when to switch between in the transmitter mode to receiver mode. In case of a passive tag communication power plays important role. So the switching time should be as small as possible. The radio control state diagram is as shown in the Figure 6.3.

6.2.2.3 Packet Handling Hardware Support

CC1101 transceiver is having built-in hardware support for packet oriented radio protocols. The Gen2 protocol is a packet oriented protocol so it makes it easy to program the CC1101. The packet handler can be configured to add preamble, sync word and the CRC. And also programmed not to send any of these. The thesis uses packet handling but configures the transmitter not to send any preamble, sync or CRC. As the blocking reader uses the same Gen2 Reader protocol the preamble or frame sync is different from that the packet handling of CC1101. Later in this chapter we will discuss the configuration of different registers and see how the Gen2 packet is sent. The packet format is as shown in the Figure 6.4.

Figure 6.3. Complete radio control state diagram [1].

6.2.2.4 Programming of CC1101

The transceiver can be programmed by connecting to the micro-controller. The transceiver can be programmed to different modes. The buffer data of the transceiver

Figure 6.4. Packet format of CC1101 [1] .

can be read or written to the buffer memory. The 4 wire SPI-bus configuration can be used to read the status information.

6.2.3 Amplifier

The amplifier used in this design is RF5110 a 3V GSM power amplifier. This is a high efficiency power amplifier Some important features are

- Operates at frequency ranges from 800 MHz to 900 MHz.
- Controllable output power with maximum power output of +36dBm.
- Needs a signal 2.7 to 4.8 supply voltage.
- Optimum efficiency of about 57%.

The application circuit diagram is as shown in the Figure 6.5

Figure 6.5. Application circuit diagram of RF5110 [2] .

6.3 CC1101 Register Settings

6.3.1 Data Rate

MDMCFG3 is a 8 bit register $DRATE_M[7 : 0]$, which contains the mantissa of the data rate and $MDMCFG4[DRATE_E[3:0]]$ is the exponent defined by the Equation 6.1.

$$R_{DATA} = \frac{(256 + DRATE_M) \cdot 2^{DRATE_E}}{2^{28}} \cdot f_{XOSC} \quad (6.1)$$

The data rate is configured for 80 kBaud. The value chosen for MDMCGG3 is 0x93(h) and $DRATE_E[3:0]$ is '1011'(d).

6.3.2 Frequency

The frequency can be configured by setting 3 frequency control words $FREQ0$, $FREQ1$ and $FREQ2$ which are 8 bit length each. It is defined by the Equation 6.2.

The center frequency is selected to be 915 MHz for this the value of the registers are 0x3B, 0x31 and 0x23 respectively.

$$f_{carrier} = \frac{f_{XOSC}}{2^{16}} \cdot FREQ[23 : 0] \quad (6.2)$$

6.3.3 Bandwidth

The channel bandwidth can be set by the MDMCFG4 register which contains $CHANBW_E[1 : 0]$ and $CHANBW_M[1 : 0]$ as specified in the Equation 6.3. A default value of 203kHz is chosen, value being 0x2D.

$$BW_{channel} = \frac{f_{XOSC}}{8 \cdot (4 + CHANBW_M) \cdot 2^{CHANBW_E}} \quad (6.3)$$

6.3.4 Modulation

The Blocking Reader requires ASK modulation. It is selected by setting $MOD_FORMAT[2 : 0]$ as 011.

Other register settings of the transceiver are as shown in the table 6.2

Table 6.2. Final register settings

Register	Value	Desicription
FSCTRL1	0x0C	Frequency synthesizer control
FSCTRL0	0x00	Frequency synthesizer control
FREQ2	0x23	Frequency control word, high byte
FREQ1	0x31	Frequency control word, middle byte
FREQ0	0x3B	Frequency control word, low byte
MDMCFG4	0x7B	Modem configuration
MDMCFG3	0x93	Modem configuration
MDMCFG2	0x34	Modem configuration
MDMCFG1	0x22	Modem configuration
MDMCFG0	0xF8	Modem configuration
CHANNR	0x00	Channel number
DEVIATN	0x62	Modem deviation setting
FREND1	0xB6	Front end RX configuration
FREND0	0x11	Front end RX configuration
MCSM0	0x18	Main Radio Control State Machine configuration
FOCCFG	0x1D	Frequency Offset Compensation Configuration
BSCFG	0x1C	Bit synchronization Configuration
AGCCTRL2	0x07	AGC control
AGCCTRL1	0x00	AGC control
AGCCTRL0	0x91	AGC control
FSCAL3	0xEA	Frequency synthesizer calibration
FSCAL2	0x2A	Frequency synthesizer calibration
FSCAL1	0x00	Frequency synthesizer calibration
FSCAL0	0x1F	Frequency synthesizer calibration
FSTEST	0x59	Frequency synthesizer calibration
TEST2	0x88	Various test settings
TEST1	0x31	Various test settings
TEST0	0x09	Various test settings
FIFOTHR	0x07	RXFIFO and TXFIFO thresholds
IOCFG2	0x29	GDO2 output pin configuration
IOCFG0D	0x06	GDO0 output pin configuration
PKTCTRL1	0x04	Packet automation control
PKTCTRL0	0x01	Packet automation control
ADDR	0x00	Device address
PKTLEN	0xFF	Packet length

6.4 Complete Circuit Diagram

Figure 6.6. Complete circuit diagram of Blocking Reader.

6.5 Summary

Using a low cost Reader design, Blocking Reader is developed. PIC C8015F320 provided a very good processing power with a 16Kbyte flash and 25MHz clock. The radio CC1101 is very powerful chip with easy to program packet handling and data rate. Flexible ASK shaping, suitable frequency hopping and programmable power up to +10dBm provided with a optimum blocking range. Amplifier RF5110 is a low cost chip provided amplification of power improved the blocking range. The complete circuit diagram is as shown in Figure 6.6. Schematic designed in National Instruments Multisim 10.2. Complete Blocking Reader is estimated to be less than \$30.

CHAPTER 7

PERFORMANCE

7.1 Introduction

This chapter contains different experiments and results to illustrate the performance of Blocking Reader. As the name specifies the Blocking Reader blocks the communication between Reader and Tag. Blocking Reader communicates with the Tag and Captures it. It uses the protocol against the Reader. A Sirit 501 Passive UHF RFID Reader is used in all the experiments. Alien Squiggle Gen2 Tag is used. And the Blocking reader with amplifier.

7.2 Tag Response

7.2.1 Experimental setup

In this experiment I would like to show the Tag response to the Query command of the Blocking Reader. The setup consist of a squiggle Tag, Blocking Reader and NI system used as sniffer. The NI system used in this experiment is National Instrument PXI-8106 embedded controller solely designed for LabView. Sniffer program displays the RF-915 MHz commands in time domain. In this experiment we basically use this NI system to show the Blocking Reader command and the Tag response.

7.2.2 Tag Response Results

The Figure 7.1 shows the RN 16 response of the Tag for the Query command of Blocking reader. Figure 7.2 shows the timings of $BR \Rightarrow Tag$ communication. Blocking Reader sends Query for every 1.4ms. Query commands are 0.8ms of length later the

Figure 7.1. Tag Response as shown by Sniffer .

Figure 7.2. Tag Response as shown by Sniffer showing the timings.

BR is programmed to send carrier wave for 0.6ms. In this time the Tag responds to the Query of BR.

7.3 Maximum Tag Response Range

7.3.1 Experimental setup

The setup is as shown in the Figure 7.3. The NI sniffer is placed next to the Tag and the BR is moved away from the Tag. The Tag response is seen in the sniffer and for every Tag response the value of voltage readings also noted. Here the BR power is set for $V_{apc}=1.6V$ of amplifier which gives 9-8dBm.

Figure 7.3. Experimental setup for Tag response range.

7.3.2 Results for Tag Response Range

The Figure 7.4 shows Tag RN16 voltage with respect to distance from the Blocking Reader. As BR moved away from the Tag the voltage value of the Tag response is reducing. At 1.1m the Tag stops responding to the BR query. There is an interesting pattern after 1.1m. It is too complex to say the reason for this pattern. We can say it might be due to multi-path, the places where Tag is not responding, it might have destructive interference. Finally we conclude that the maximum Tag response range is 1.1m for a +6-9dBm power of BR.

Figure 7.4. Tag response range.

7.4 Illustration of Blocking

7.4.1 Experimental setup 1

In this experiment a Sirit Reader and Tag are placed at 0.9m apart. And a Blocking Reader is placed at a distance of D from the Tag as shown in the Figure 7.5. In this setup a optimum distance is selected between the Sirit Reader and the Tag where there is very good read rate. The Blocking reader is brought closer to the Tag and the Distance from the tag to the Blocking Reader and Tag is plotted verses the read rate as seen in the Sirit Reader.

Figure 7.5. Experimental setup1 of Blocking Reader illustration .

7.4.2 Results for experimental setup 1

The Results are as shown in the Figure 7.6 is for experimental setup shown in the Figure 7.5. Here we can see that when the blocking reader is moved away from the Tag the Read Rate readings of the Sirit Reader are taken. There are absolutely

no read until there is Blocking Reader is moved to a distance of 1.3m. There are two different readings taken. One with the Vapc value of the Amplifier 1.6V which can give a maximum power of +6.8 dBm and Vapc value 2.6V which can give a maximum power of + 21dBm. For Vapc= 1.6V there is a maximum blocking range of about 1.3m and for Vapc=2.6V the maximum blocking range of 1.35m.

Figure 7.6. Graph of distance (D) vs read rate for experimental setup1.

Figure 7.7 shows that read rate calculated with the same setup distance varying till 5.4m. In this experiment we could see some interesting patterns. The blocking reader is able to block in some distances after that 1.3m. But the some times its not. In this Figure 7.7 the read rate is measured for distances from the tag varying from 0.3m to 5.4m. The graphs are drawn for two Vapc values 1.6V which gives about

9.1 dBm power and 2.6V which gives about 21 dBm of power. Also there is a sine wave plotted, just for explanation purpose. Here we can clearly see the pattern of reads are following the same pattern as sine wave. Where there is a positive peak of the sine wave we can notice that the blocking reader is actually blocking in some cases after 1.3m. As the blocking reader uses 915 MHz frequency for communication. Power follows the pattern of sine wave for the communication. So this might be a possible reason. It should be noted that there is multi-path and reflections due to other objects around also causing some patterns. Assuming a reflected wave from floor if we plot a Friis power adding two EM waves the power up-down follows the wave pattern of that frequency. It is obvious because of the phase, the adding can be constructive and destructive.

7.4.3 Experimental setup 2

In this setup the Sirit Reader and the Blocking Reader are kept at a constant distance of 1.5m apart and the Tag is moved away from the blocking reader as shown in the Figure 7.8. The negative values of the distances indicate that the tag is moved away from Blocking Reader and towards the Sirit Reader.

7.4.4 Results for Experimental setup 2

In this experimental setup 2 we can see that when the Tag is moved away from the Blocking Reader (BR) and Sirit Reader (SR) it can hardly be read except at one point. But when Tag is moved towards the SR away from BR then we can see that until certain point the Tag is not read. After the Tag passes 0.9m mark the SR starts reading the Tag. We can explain this phenomenon by the free space power equation, Friis equation.

Figure 7.7. Graph of Distance (D) vs Read Rate.

Here there are two Readers, as we move away from the Reader power received at that point decreases. So When the Tag is moved away from the SR and BR the power received by the Tag from SR and BR decreases with distance. Here the Blocking Reader power is more than SR power as the BR is closer to SR. So it is very clear that the Tag should block any thing in this region.

Now when the Tag is moved between the SR and BR . Away from BR and towards SR the BR power received decreases and SR power received by the Tag increases hence at certain point the Tag starts to Read as show in the Figure 7.9.

Figure 7.8. Experimental setup2 illustrating blocking.

In the Figure 7.10 we have plotted the Sirit Reader power and the Blocking Reader power with the help of the Friss free space power equation. This is the theoretical power value not considering any path losses or any multipath constructive and destructive interference. Here also we can see some interesting patterns. The Sirit reader states reading the Tag when the Tag is 0.9m away from the Blocking Reader and then stops reading. Later in next 0.3m that is 1.2m it starts reading again and stop. This pattern repeats for 1.5m but this time the sirit reader power is soo high that the blocking reader effects are overcome.

Figure 7.9. Graph of read rate with BR and SR fixed.

Figure 7.10. Comparing Friss Power for SR and BR with Read Rate.

7.5 Blocking Envelope

7.5.1 Blocking Envelope Around the Tag

In this experimental setup shown in the Figure 7.11 the Tag and Sirit Reader are kept at a fixed position 2.1m apart and the Blocking Reader is moved around the Tag. Here only the first read is taken moving away from the Tag at every angle. This indicates the envelope around the Tag where the Blocking Reader is successfully blocking irrespective of any other settings.

Figure 7.11. Setup illustrating blocking envelope around Tag.

7.5.2 Results

The polar Figure 7.12 shows the maximum blocking distance the blocking reader should be present to successfully block a Tag. We can clearly see it is a envelope pattern matching the monopole radiation pattern. The average distance around the Tag was observed to about 0.9m.

Figure 7.12. Blocking envelope around the Tag .

7.5.3 Blocking Envelope around the Blocking Reader

In the setup shown in Figure 7.13 the Sirit Reader and Blocking Reader are fixed with a distance between them of 2.1m. The Tag is moved around the Blocking Reader to not the maximum blocking distance. The value of the Vapc is 2.6V hence the Blocking Reader is radiating a power of about +21dBm. Here at each angle of 30 degree the Tag is moved closer and away from the Blocking Reader and a maximum distance where the Sirit Reader just starts to read is noted down.

Figure 7.13. Setup illustrating blocking envelope around Blocking Reader.

7.5.4 Results

The results of the experimental setup shown in the Figure 7.13 is plotted in the polar graph as shown in the Figure 7.14. Here we can see that the Blocking Reader has created an envelope around inside which the Tag is blocked from any communication from other readers.

Figure 7.14. Blocking envelope around the Blocking Reader.

7.5.5 Blocking Envelope Vertical Axis

The setup is as shown in the Figure 7.15, here the setup is same as the previous experiment instead of moving the horizontal axis the Tag is moved in the vertical axis. For every 45 degrees the distance between from the Blocking Reader is varied and the value of maximum blocking distance is noted.

Figure 7.15. Setup illustrating blocking envelope in vertical axis.

7.5.6 Results

The results of this setup is shown in the polar Figure 7.16. The pattern looks similar to the monopole radiation pattern in the Z axis. Obviously it should match with that pattern as the power of Blocking Reader at 0 and 180 degrees are low due to the nulls at that point the Tag is easily read by the Sirit Reader. We can see at 0 degrees the maximum blocking distance is just 0.01m.

Figure 7.16. Blocking envelope in vertical axis results.

CHAPTER 8

BLOCKING READER IN PRACTICE

8.1 Introduction

Blocking Reader can be used to preserve privacy. The ability of the blocking reader to actually block the communication between the Reader and Tag can serve as a device that can be used in places where the privacy of the product should be preserved. In places like warehouse, hospital, residential areas etc the privacy of the products are important. So if there is a blocking reader then the products can be preserved from being read by some third party or unauthorized Readers.

8.2 Warehouse

Companies store there products to be marketed in the warehouse. If the products are tagged with RFID tags it would be easy for any person with powerful Reader to read all the Tags and know lot of this information about the demand and sales of the company itself. Now it would become important for the company to preserve the privacy. If there is a low cost Blocking Reader in the warehouse it can prevent any external third party venders to read the products in the warehouse. Hence we can preserve the privacy of the company by preventing the third party from reading the company tags.

Advantages of using the Blocking Reader in the Warehouse

- A low cost product can ensure the privacy.
- Creating a shield around the warehouse.
- Easily configurable parameters like range.

- Can be controlled from ethernet.
- Isolated envelopes of blocking.

Disadvantages of using the Blocking Reader in the warehouse

- Require multiple Blocking Readers for bigger warehouse.
- Will cause interference to other signals.
- Needs to be turned off even an authorized person needs to read.

8.3 Blocking Reader Around Human Body

In this section we will discuss about how Blocking Reader works around Human Body. Previous research has shown that the presence of Human causes deformation in the read zones of a typical passive RFID systems [7]. Human body tissue is a lot of liquids and the major part is water. The property of water is absorption of RF radiations. Due to the reflection and absorption of these RF radiation the RF radiation pattern is too deformed. In the Figure 8.1 shows an simulation of a monopole antenna in presence of Human Body, 0.3m in front of it.

A Blocking Reader can be used to prevent an unauthorized read of a persons RFID enabled credit cards. Also Prevent unauthorized reads of personal things at a public place. An important application will be to block the unauthorized read of your human implanted tags in the public place causing breach of privacy, leading to tracking.

Figure 8.1. FEKO simulation of monopole antenna in front of human body.

Figure 8.2. FEKO simulation of monopole antenna near hip of human body.

8.3.1 Blocking Reader around human body setup

The experimental setup to verify the Blocking Reader working on a person is done on FEKO as shown in the Figure 8.3. But to verify these we used a 5 gallon filled water bottle for practical experiments instead of a live subject. It is assumed that the 5 gallon water bottle has same effects on the RF radiation patterns. Assumptions are made considering human body is full of fluids. In this setup the Blocking Reader is placed or strapped to a water bottle. The water bottle with the Blocking Reader is rotated around and the Tag is moved from the Blocking Reader towards the Sirit Reader. The maximum blocking distance D is noted.

Figure 8.3. Setup for blocking reader around a human body(water bottle) .

8.3.2 Results

The Graph 8.4 shows the maximum distance of blocking around the water bottle. In this we can clearly see a depreciation of blocking range. This is mainly due to the deformation in the radiation patterns caused by absorption and reflection [7]. At 180 degrees the maximum blocking distance is 0, in this position water bottle is in between the Blocking Reader and Tag. So there is absolutely no communication between Tag and Blocking Reader. So concluding, Blocking Reader can work around person. Human presence had a know limited effect, but results shows considerable blocking envelope around the person.

Figure 8.4. Maximum blocking distance measured around water bottle .

CHAPTER 9

CONCLUSIONS AND FUTURE WORK

9.1 Conclusions

Blocking Reader creates an envelope around which the Tag is preserved from being read by any unauthorized Readers around. The Blocking Reader can be used to ensure privacy of a passive UHF RFID systems. It uses same protocol as the Readers hence are designed to be FCC compliant. The concept of the Blocking Reader is by capturing the Tag and not allowing other Readers to communicate. This is done by sending series of Query commands. Tags reply to this command with a RN16 whenever it see this command. Hence the communication is always incomplete. When other unauthorized Readers try to communicate with the Tag it just receives a series of RN16 values and the TID of the Tag is still secure. Hence blocking the communication.

The Blocking Reader is designed to all the constraints of FCC Part15. The Tags reply to the Blocking Reader with the RN16 value. It follows the same power pattern as the Reader. It matches with the FEKO power patterns for monopole antenna. Blocks the Tag even if the Reader and BR power levels are same. Hence from all these reason we can prove that the Blocking Reader is not jamming but blocking.

The BR creates an envelope around and is comparable to the power radiated. For a power radiated by a Blocking Reader of 19-21 dBm there is a maximum blocking distance of 1.3m and for 6-9 dBm power the maximum blocking distance is observed to be 1m. With all the experiments done in a laboratory environment. A optimum maximum distance is calculated. So It can be concluded that a Blocking reader can

provide with a good authorized blocking. And can the Blocking envelope can be controllable.

Blocking Reader can be strapped to a person and provide personal privacy for all his Tags. From laboratory experiments I have concluded that it can create an secure envelope of about 1m around the person called blocking envelope. This envelope successively blocks any unauthorized Readers trying to read the persons Tags.

I conclude that the Blocking Reader is a Low cost device. With cheap hardware privacy of the RFID systems can be preserved. Also in doing this research we have noticed a potential for using this hardware design for making a full blown Ultra-Low Cost Readers. Hence reducing the cost of a Reader by a factor of 10.

The concept used here is foolproof. It can easily be used by any RFID systems as it uses the same protocol used by the respective systems. All RFID systems uses inventory round for accessing the TID of the Tag. Hence implementing this concept in inventory round will ensure privacy of other systems also.

9.2 Future Work

The Blocking Reader concept can be used for other RFID systems where the protocol has a inventory round. The Blocking Reader Architecture can be used for designing a Ultra-Low Cost UHf RFID Readers. The concept can be implemented on the Tags to make a Tag emulator. A tag emulator emulates the Tags. So if unauthorized Readers trying to access the Tags, Tag emulator will respond instead of the Tag, hence blocking. Like blocker tag we can call it passive blocker reader. If we use this concept on Tag creating a Blocking Reader Tag we can further reduce the cost to few cents. Here a strong wide band Tag is implemented with Blocking Reader protocol. When an unauthorized Reader tries to communicate with your Tag, you will

be having this Blocking Reader Tag which sends Query when energized. This Query is misunderstood by other Tags in the field for Reader command and continuously send RN 16. Here a Tag is captured by a Tag. So there is a lot of potential for the Blocking Reader. The RFID is a stupendous world yet to be explored.

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BIOGRAPHICAL STATEMENT

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