TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

HASAN HABIB

ON BODY PERFORMANCE EVALUATION OF PASSIVE RFID ANTENNAS INSIDE BANDAGE

Master of Science thesis

Examiner: Prof. Leena Ukkonen and Johanna Virkki
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ABSTRACT

HASAN HABIB: On Body Performance Evaluation of Passive RFID Antennas Inside Bandage
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Radio Frequency Identification (RFID) permits us to remotely exchange information utilizing electromagnetic waves in order to distinguish and track RFID tags by RFID readers. Usually RFID tags contain some code, which is employed for identification purpose. Utilization of RFID's for the detection of objects is becoming more common every day. On the other hand, the field of examining environmental parameters utilizing RFID antennas apparatuses is also evolving number of the environmental parameters are analyzed nowadays utilizing RFID tags, beginning with the identification of a modification of the electric field inside chamber due to change in pressure, to the analysis of change in the body temperature.

In this thesis, development and measurement of RFID tags for the measurement of humidity inside bandage are performed. The basic idea of this measurement is to help the doctors in determining the condition of injury inside bandage, as most visible sign for the doctors to determine the condition of injury is humidness inside the bandage. Usually doctors open bandage to check whether the injury is in good condition or not. Detecting humidity level inside the bandage using RFIDs can help doctors to know status of injury without opening bandage, as opening bandage costs time and effort, also opening in unhealthy conditions can cause infection to the injury.

Three different kinds of passive RFID tags are used to analyze the performance inside the bandage. One commercial RFID tag known as Dogbone designed by Smartrac is used. This antenna is to measure the humidity level in the industrial environments including construction material, health care, and automotive production units. Dogbone is a UHF RFID antenna, which employs RF Micron IC, innovative product that automatically adjust the input impedance in order to accumulate the changes in the external environment and present results in the digitized output. Although Smartrac´s Dogbone antenna is specially designed for humidity measurement, but because of its high sensitive antenna and weak insulation from the body, its performance dwindles greatly because of body and the bandage.

Later on utilizing the brush painting fabrication method for antennas, two type of RFID tags are developed on paper and bandage. Paper utilized for silver brush painting is common A4 paper available for printing purposes while the bandage is made up of Rayon, which is stretchable and commonly used in the first aid kits. Developed antennas are sintered for 15 minutes and 125-degree centigrade, after which their performance is analyzed. Best RFID tags, among all fabricated RFID tags are chosen to do the measurement. Effects of body, bandage and humidity on the performance of RFID tag on paper and bandage RFID tags are analyzed.

Smartrac ”Dogbone” and self-designed RFID tags on paper and bandage lose their performance by coming closer to the body, tags loose more performance when they are closer to the inner side of the arm and they are almost least affected by the outer side of arm. Increase in humidity also reduces performance of RFID tags, but interesting phenomenon observed is the effect by the number of turns of the bandage around the RFID tag on the body. The performance of RFID tag fabricated on paper and provided by Smartrac dwindles by increasing turns of the bandage but it’s interesting to note that the tag developed on bandage is almost unaffected by a number of turns of the bandage. Effect of bandage on the RFID tag fabricated on bandage is quite unique, this phenomenon can be utilized in different fields as measurement results show that RFID tag created using same material provide almost same kind of performance under packaging of same material but this need further studies to get affirmation.

PREFACE

The Mater Thesis “On Body Performance Evaluation of different RFID antennas inside bandage” is performed as a requirement of Masters of Science degree in Electrical Engineering with a major in Electronics, in the Department of Electronics and Communications Engineering at Tampere University of Technology. All the researches and investigations have been done in the Wireless Identification and Sensing Systems. Research Group (WISE) of Rauma Research unit under the supervision of Johanna Virkki and Leena Ukkonen.

I would like to say thanks to my supervisors Johanna Virkki and Leena Ukkonen, for guidance and support during my thesis. I would also like to say thanks to my seniors, working in the lab, who helped me every time whenever I had any issue or ambiguity. Toni, Waqas Khan, Muhammad Rizwan, Naeem Tahir, Jussi Pekka and Toni, you really made my thesis work fast.

Especially thanks to my parents for their intellectual and financial support, which allowed me to converge my attention on thesis rather than on personal obstacles.

Tampere, December 2015

Hasan Habib

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS:

AR	Axial Ratio
IEEE	Institute of Electrical and Electronics Engineers
dB	Decibel
WLAN	Wireless Local Area Network
LHCP	Left Hand Circular Polarization
RHCP	Right Hand Circular Polarization
BAN	Body Area Network
PANs	Personal Area Networks
WBAN	Wireless Body Area Network
AC	Alternating Current
ASK	Amplitude Shift Keying
PSK	Phase Shift Keying
FSK	Frequency Shift Keying
EIRP	Effective Isotropic Radiated Power
EPC	Electronic Product Code
HF	High Frequency
UHF	Ultra High Frequency
IC	Integrated Circuit
IFF	Identification Friend or Foe
ITU	International Telecommunication Union
K	Kelvin
KHz	Kilohertz
NFC	Near Field Communication
RFID	Radio Frequency Identification
RSSI	Received Signal Strength Indication
UHF	Ultra High Frequency
TID	Tag Identificaltion memory
ETSI	European Telecommunications Standards Institute
N	Newton
C	Coulomb
Q	Electric Charge
B	Magnetic Flux Density
Wb	Weber
J	Current Density
M	Magnetization Vector
σ	Conductivity of the Material
γ	Complex Propagation Constant
ω	Angular Frequency of the Wave
X	Imaginary

εr	Dielectric Constant
Ω	Ohm
m	Meter
%	Percentage

LIST OF FIGURES

1. INTRODUCTION

RFID (Radio Frequency Identification) tags are getting common nowadays and their use in different fields of life is enhanced day by day. Personal Area Networks (PANs) are used for data transfer. Data from different personal devices while PANs used over human body are also known as Body Area Networks (BANs).

RFID tags have two basic types active and passive. Active RFID tags are powered partially or fully by the battery while passive RFID tags use power transmitted by an RFID transmitter antenna to power up RFID tag. RFID tags can be used over body to observe changes in body parameters. Interpreting changes in the performance of RFID tags due to changes in the environmental parameter of the body allow us to study body parameters easily and effectively.

Human's and the animal's body often experience some mold or injury, which is usually covered by a bandage for protection. Status of injury inside the bandage cannot be predicted so easily without removing the bandage, Doctors usually remove the bandage to check status of body mold or injury, which often cause irritation for the patient and also give the opportunity to bacteria to effect the injury as molds are usually less prone to infection. The humidity level inside bandage is an effective parameter that can give us better status of condition of mold inside the bandage.

In this thesis, RFID tags are used inside to bandage to tell the humidity level of the injury and this concept can be used later to determine different characteristics of body inside bandage utilizing RFID tags. Wireless and without power detection of humidity level inside bandage will provide a cost effective solution to the doctors, in order to determine the condition of body inside the bandage without even touching the patient. Further enhancement of this concept by utilizing advanced measurement techniques can allow us to measure different characteristics of the body and this can open new avenues of wireless analysis of body parameters.

The performance evaluation of RFID tags provided by Smartrac NFC manufacturer known as Dogbone along with other tags on bandage and paper created using silver brush painting is performed. The complete analysis can provide us an overview of RFID's working inside bandage and effect of humidity on it.

2. HISTORY

Use of electromagnetic waves for detection of objects starts from World War II. In world war, Germany used radio waves for the detection of aircrafts. Radio waves detect all kinds of aircraft in the same way, Germans solved this issue by using indigenously maneuvers, which clearly differentiate German aircraft with other ones, but still this idea is not safe as other countries can also use the same tactics.

Later on British and USA used IFF (Identification, friend or foe systems) with mechanically tunable frequency, which allowed them to detect using six possible identification codes. After 1950s Radar systems that are also used now a days started evolving, these radar systems used UHF (Ultra High Frequency) as current radar systems are used. Usually, radar reflection from the target is substantially delayed, which help them to estimate the distance of the object. Many features of aircraft detection mechanism used in World are also part of the modern RDID systems, including identification of the object using radio signals. For the unique identification of each, object big range of codes separate code for each object, Sensor should be able to tell that which object is detected, information about the position of the object identifier and transmission of relevant information to the object. Figure 2-1 shows friend or foe system, used for identification of aircrafts.

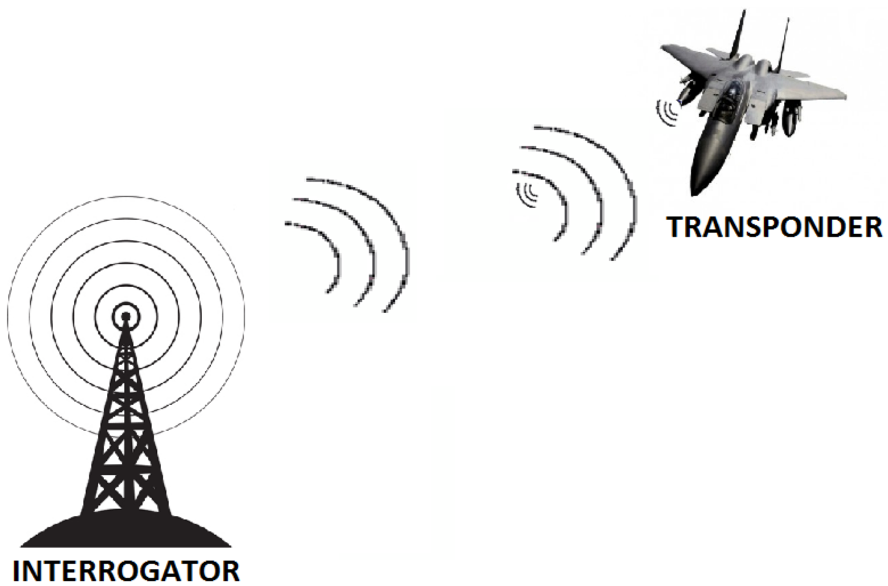

Figure 2-1 *Identification, Friend or Foe System [1].*

The most underlying dynamic of RFID systems from a long time is to increase their capability and decrease its cost, this metric of increasing capabilities and decreasing cost, gained a lot after invention of transistors in 1960s. In the modern RFIDs apart from simply reducing the cost, different technology techniques are also used to make things cheap. As transmitters are quite complicated, use large amount of power and huge so they can be removed by varying some parameters of signals reflected back from receiving object. In a similar way, batteries are usually heavy and cost a lot, design of RFID tags without battery and powering them from any other mean can also reduce the cost, also by using simple circuitry, which is easy to design, and having ability to filter out the noise can provide.

Harry Stockman in 1948 explored backscattered radiation for transfer of information, coil of conventional microphone is used to modulate the position of receiver antenna which affect signal reflected back to the transmitter, transmitter receive the signal and demodulate the signal in the form of sound information. In the figure 2-2, you can see an overview of signal transmitted by antenna and signal sent back by the receiver antenna as backscattered signal.

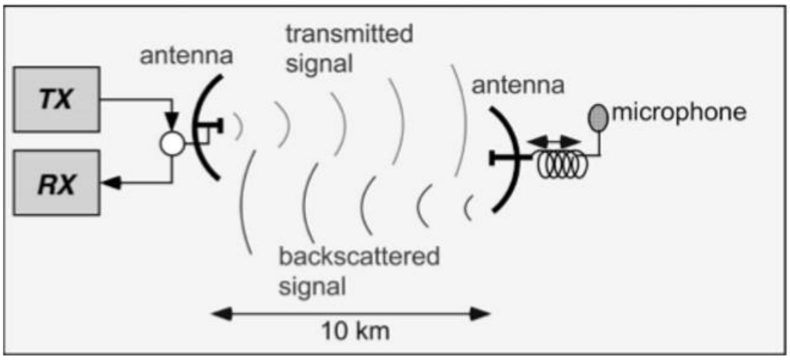

Figure 2-2 *Backscattered Radiation to Communicate* [1]

In 1950s concept of backscattered signal is used to develop inexpensive wireless telephone systems. Later on, development of transistor gave opportunity to rectify the signal using transistor keep size of device small, which also helped in producing second frequency using DC, which is also part of modern antennas. When distance between transmitter and receiver is too short it is not obligatory to transmit the wave and get its reflection, inductive coupling between them can be varied by load present at the transmitter end to produce the signal.

Inductively coupled systems opened new avenues as they had a short range and used low operational frequency, which allowed creation of low-cost compact devices. These devices can be easily created and can be used for simple detection of objects, still used in the retail field to stop theft of products with small ranges and magnetically sensitive antenna oscillates when it come in front of transmitter antenna.

Demand for long range of ID's for detection keep existing even after the 1960s, devices that do not need any battery or use small power, compact and inexpensive are always demanding of time. In 1970's Charles Walton along with others patented transponders which are identified object using resonant frequency, in which radar sweeps through frequencies utilizing inductor and capacitor circuit producing resonant frequency, sudden voltage of device changes when the resonance point comes they can be used for identifying more than one type of devices. Figure 2-3 show resonant circuit for the identification of tag antenna.

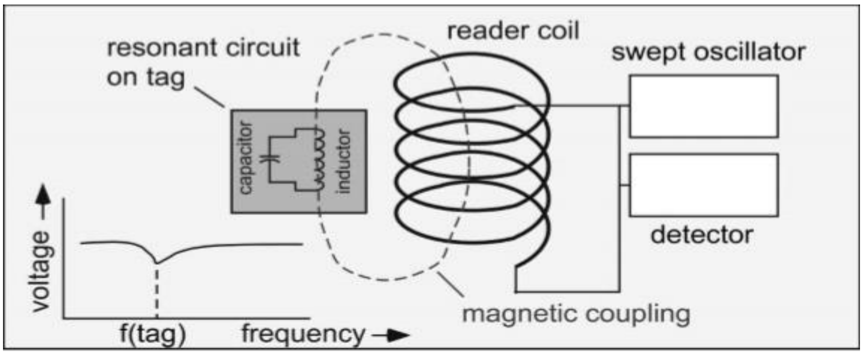

Figure 2-3 *Resonant Circuit for Identification of Tag [1]*

For the development of better tags, need of adding more circuitry, which also add more cost, power utilization and difficult to design but help us to perform better logical operations. For power and communication as in modern systems, RF signal can be transmitted using a transmitter while radio frequency signal can be converted to DC using a diode, which rectifies the signal and transmits current in one direction only, better output DC voltage can be obtained by using a capacitor with diode. Most of the work before 1970's use frequencies lower than current ultra-high frequency band because of high cost of electronic components. Figure 2-4 show DC extraction circuit, which is used to convert the AC signal received by an antenna to DC.

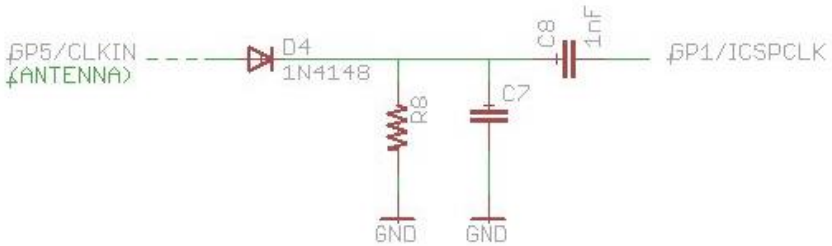

Figure 2-4 *DC Extraction Circuit*

At the start of 1970s, due to a huge decrease in the cost of electronic components, better identification systems are developed using ultra high frequency. The most important benefit of utilizing high frequency is longer range, but they are more affected by noise. After that number of applications of tags entered world market and their number kept increasing including traffic control, object identification and surveillance control.

Later in 1990's possibility of storing significant information and performing simple communication through a simple, integrated circuit, which allowed an extensive increase in commercialization of RFID tags, several companies started production and thus increase in production and decrease in cost of RFID tags made applications that are more general possible.

3. OVERVIEW OF RFID SYSTEMS

Radio Frequency Identification systems are explained in this section. RFID systems consist of two parts, a transmitter (also known as RFID reader) and tag. An RFID transmitter transmits electromagnetic waves to transfer data. Usually tags contain some information, which is used for tracking and identification while performance of RFID tag is used for the analysis of environmental parameters around the tag.

RFID tags are usually mobile and connected remotely using RFID readers. RFID readers are used for reading the tags and they are usually connected to some human intractable device.

3.1 RFID Reader

The RFID reader is most important part of the RFID system, normally RFID reader consists of transmitter and receiver to communicate with the tag. Although both parts of RFID readers are important, but for transmitters it's important to provide proper communication with high accuracy of modulated frequency, baseband and signal information, transmission of signal with the lowest possible spurious component. Efficient conversion of data to modulated signal, high flexibility and precision is required for transmitter. Functionality is also required to turn reader off when no communication is required and to turn on reader again with the same frequency when signal need to be sent.

While for the receiver, it is necessary to provide high sensitivity in order to detect smallest possible signal greater than the thermal noise value, good selectivity of frequencies; so it will ignore signals out of the band and do not consider noise components of environment, adjustable range. Therefore, according to requirements signal from the differential distance could be separated and high flexibility so it will turn it on or off according to the requirements of the system.

Another import issue with RFID tags is license from the regulatory authority to operate in certain frequencies, apart from RFID tags, which do not require any licensing. In Europe, according to European Telecommunications Standards Institute (ETSI), there are some special power and frequency ranges to operate without license. In the case of UHF, frequencies from 865 to 868 MHz are allowed to operate without license but listen before talk requirement is important. Regulators usually provide standards for the spurious frequency components allowed to transmit during communication [1].

RFID readers generally use full duplex communication while communicating with the tags, sending, clock with time for sending the signal to tag and another clock with time for receiving it. As input to the receiver is normally at the same frequency as the trans-emitted signal frequency so it is quite difficult to separate them if both are transmitting and receiving at the same time. Leakage from transmitter to receiver also puts limits to the use duplexer for the communication as little leakage from transmitter to receiver can affect output. This thing is also important limit to the sensitivity of the receiver.

Most common RFID readers consist of clock, RF Oscillator, low noise amplifiers, power amplifiers, mixers, attenuator, power splitter, number of filters and antenna. The signal for transmission is modulated to higher frequency by properly mixing with reference frequency, this signal is transmitted through a power amplifier and out of band frequency signals are removed, using filter. Signal is amplified again, power splitter and power attenuator are used to set adequate power for transmission of signal. Finally signal is amplified using power amplifier and spurious components are removed using filter, signal is transmitted by antenna using multiplexer. On the other hand receiver side receive the signal from same antenna and after removal of noise and other useless components, signal is transferred to two different lines, both of these signals are mixed separately with signal of same frequency but with different phase to get demodulated signal. Finally signal is amplified, filtered and amplified again, most of the time output signal from the receiver is obtained in form of Q and I. Architecture of reader is shown in Figure 3-1, complete block diagram present all basic elements of reader for transmitting and receiving signals [1].

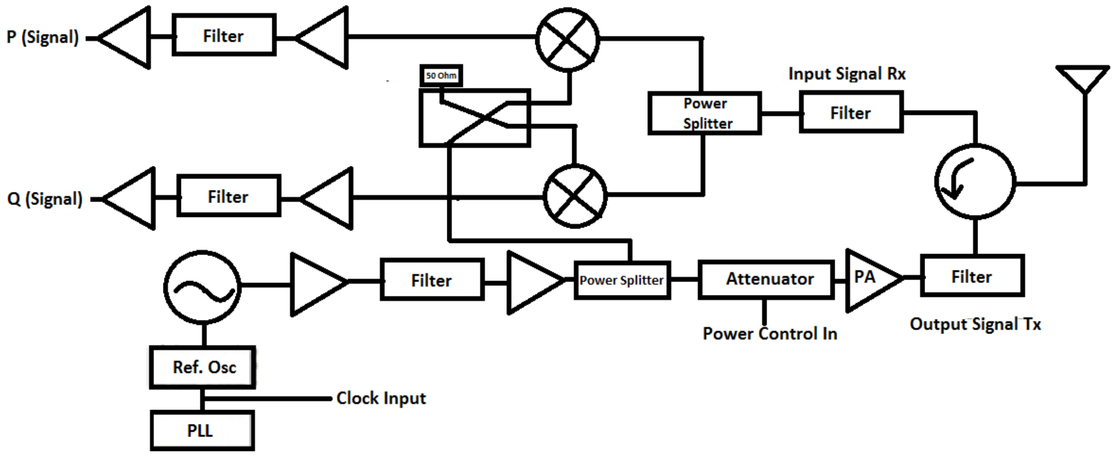

Figure 3-1 *Common RFID Reader Architecture [1].*

3.2 RFID Tags

RFID tags are the basic source for identifying, detecting and analyzing objects; they are also used for measuring the properties of objects. Use of RFID tags is increasing massively and because of massive research on them and production in the bulk, their cost is reduced. RFID tags can be either active, passive or Semipassive, differentiated in term of power used by tag. Details of RFID tags are given below.

3.2.1 Active RFID Tags

Active RFID tags receive the signal using reference from crystal oscillator or local frequency generator powered by its own battery, which provide ability to catch weak signal and communicate even receiving signals with noise. Active RFID is shown below in the figure 3-2 with all of its block elements.

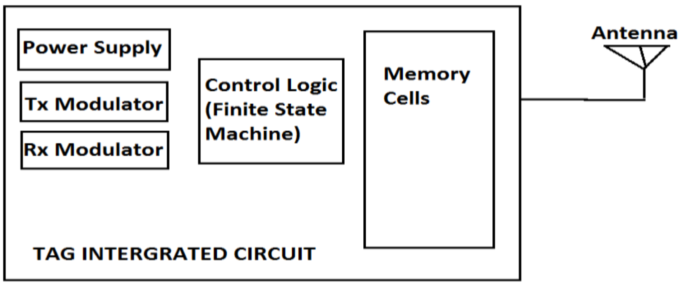

Figure 3-2 *Active RFID Circuit Block Diagram [1].*

Active tags apart from providing long range, immunity to noise and better working suffer from large size, cost and short life. Because of battery, they require maintenance and charging by time too. Apart from that, active RFID tags must meet criteria of regulatory authority for frequency, purity of spectrum and out of band emission. Active tags are commonly used for tracking objects or animals because of their long range. Mechanism of measuring distance is quite simple, on specific direction time delay between transmitting and receiving signal is calculated which with reference to frequency of signal can easily help to determine distance of object from transmitting antenna.

3.2.2 Semipassive RFID Tags

Semipassive tags are the mixture of active and passive RFID tags, they have battery for running the circuit of the antenna and IC but at the same time, they use power received by transmitter antenna. Compulsive tags allow us to increase range, computational and logical abilities of the tag, which also help us to increase their security and functionality too. Compulsive RFID tags transmit back the signal using the same power received from the transmitter after applying rectification to the signal. Circuit of Semipassive RFID tag is shown in figure 3-3.

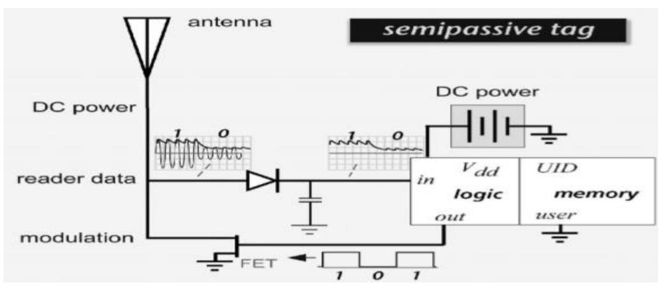

Figure 3-3 *Circuitry of Semipassive RFID tag [1]*

Semipassive RFID tags provide large range and more reliability at the cost of battery, size and complexity. Semipassive RFID tags are considered better than active RFID tags because they use lesser amount of power and provide output even with small battery. Some tags are available in the market, which are incorporated with a lithium battery providing 5 years of operation. In addition, as passive RFID tags transmit signal by using input signal no special regulation from regulatory authority is required.

3.2.3 Passive RFID Tags

Passive RFID tags do not have their internal or external power source to transmit the signal back to the transmitter; they transmit the signal back by utilizing power received by the incoming signal. Actually passive tags rectify the power from the received signal to send the information. Usually, input signal is rectified by diode or set of diode, they provide dc voltage, which smoothen out by capacitors. Received power is also used for demodulation the reader's information if it is required. Figure 3-4 illustrate communication using the passive RFID tags.

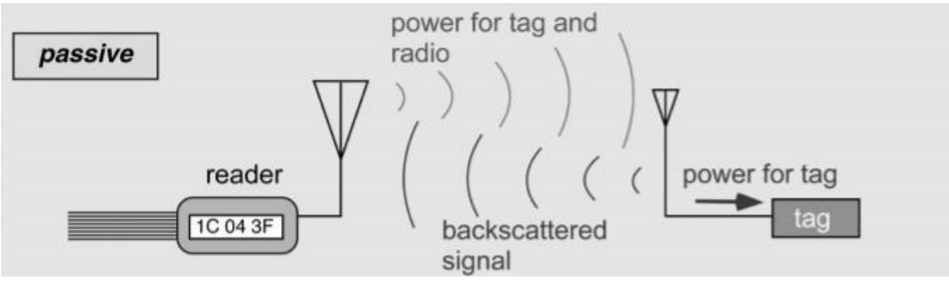

Figure 3-4 *Passive RFID Tag Working [1]*

One of the main reasons for using passive RFID tags is their simple design, no charging hassle, no reference to frequency and low cost. Passive RFID tags also do not require a crystal for frequency generation, no low noise amplifiers or power amplifiers, which save a large amount of cost and complexity. On the other hand, passive tags face the issue of smaller read range in comparison with active RFID tags. Difference of read range between active and passive tags becomes severe in case of UHF-based systems. Another issue faced by passive RFID tags is lowest available power and weak security. Because of a small amount of power available, computational and other logical resources are minimized which also bind for the implementation of the complex security algorithms.

3.2.4 Terminologies of RFID systems

RFID tags basically consist of the reader, antennas and tag. Reader is usually known as an interrogator while tag is known as a transponder. Normally antenna on the tag is integrated on the tag itself, while the antenna of the reader can be integrated or connected by wire to the tag.

Most of the time RFID tags contain Integrated Circuit (IC), which is responsible of storing unique tag IDs and protocol information that cause successful communication between the tag and reader. Usually, reader contains user interface or connection to the computer network, which is the basic source of storing, controlling and displaying the RFID results. Information transferred from the reader to the tag is known as forward link or downlink while information transferred from the tag to the reader is known as uplink or reverse link. Working phenomenon of an RFID system is shown in Figure 3-5 below.

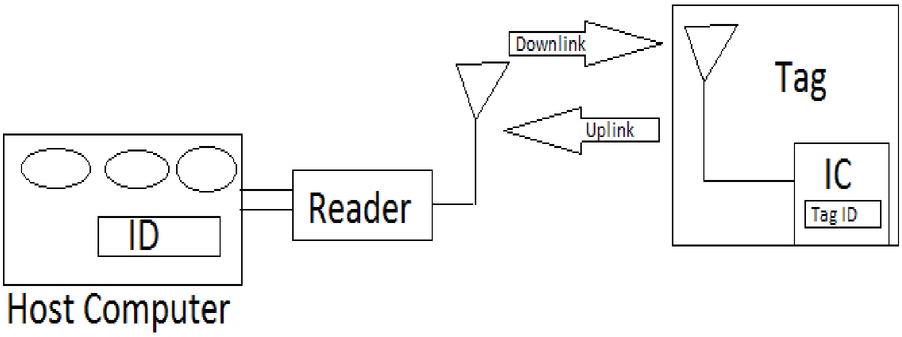

Figure 3-5 *RFID System Working [1].*

3.2.5 Frequency bands of RFID

Usually, RFID systems can operate in frequencies starting from 100 kHz up to 5GHz but due to regulations from regulators they usually operate around small range of frequencies, most of these frequencies can be divided into small bands. Low frequencies usually operate in the frequency range 125 or 134 KHz. Applications in which higher frequencies are required use 13.55 MHz. For the Ultra High frequencies tags utilize band between 860 to 960 MHz and 2.4 to 2.45 GHz. Ultra-high Frequency band usually end at 3 GHz but to make clear difference between these two ultra-high frequency bands, band of 2.4 to 2.45 GHz is known as microwave frequency band. Figure 3-6 presents frequency range of different bands of RFID.

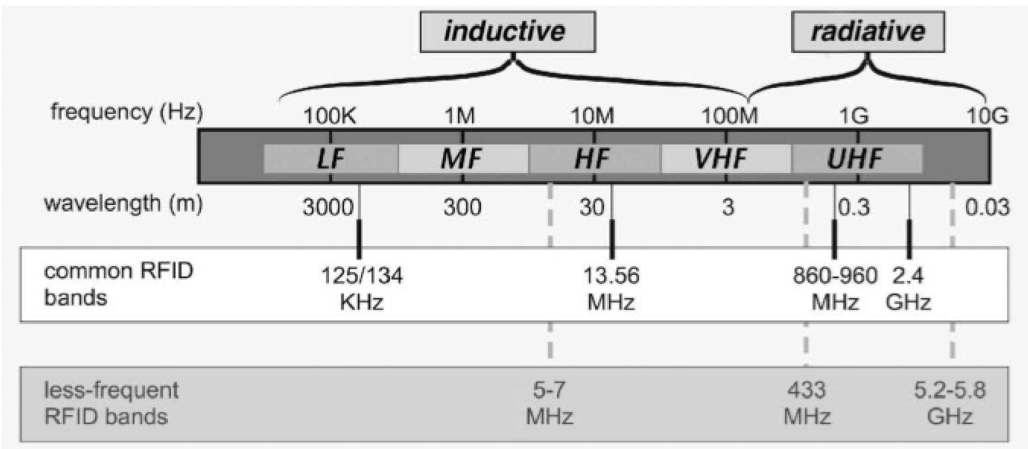

Figure 3-6 *Frequency Bands [1]*

When frequency is higher read range is lower, this can be explained by correspondence of wavelength to frequency using mathematical equations.

$$\lambda = \frac{c}{f} \tag{3.2.5}$$

In the above equation, λ is wavelength, c present speed of waves and frequency is named as f. Electromagnetic waves usually travel with the speed of light which is 3*10^8 m/s^2, wavelength is the distance between successive peaks or troughs of the wave. The wavelength of RFID systems can varry from a few centimeters to 2000 meter. Usually inductive antennas have a larger wavelength while wavelength of radiative antennas is smaller. Most of the energy delivered by these antennas is present in the surrounding field closer to the antenna. Time of communication between the tag and reader is also swift in the region surrounding the antenna because of small distance. In some systems where wavelength is comparable with the size of antenna are known as radioactive coupling systems. Intensity of electromagnetic wave propagated by radioactive-coupled reader falls by square of the distance traveled.

Inductive coupling of reader and tag falls rapidly as tag move away from the antenna as this fall is uniform along all directions. It is important to note that the insertion of metallic object near the reader object will distort the suddenly also read range of inductive coupled antennas is comparable with the dimensions of the antenna.

In radiative-coupled antennas intensity of electromagnetic field falls slowly with the increase in distance from the antenna, because of smaller wavelength waves can be reflected back from a distant place to the antenna, which also provide relation to the location of tag to power received. When a number of radiative-coupled readers are present in the same read range of the antenna interference between them can occur. Interference is more likely at higher frequencies than lower frequencies, we can deduce radiative-coupled antennas have longer read range than inductively coupled antenna, but radiative-coupled antennas are more prone to interference and can create a complex propagation environment because of shorter wavelength. Figure 3-7 show different antennas with respect to size and frequency bands.

In LF and HF, range of antenna is usually dependent upon antenna size while in UHF input power is a driving source. Antennas which are inductive, they're transmitted signals are simple, but having a small range while radiative antennas are complex with good range, normally UHF antennas are dipole antennas as used in this thesis.

3.2.6 Skin Depth

When an electromagnetic wave strikes on any object, it penetrates into it, the depth of penetration in the object is known as skin depth. The skin depth is dependent upon a number of factors starting from magnetic permeability, electrical conductivity of metallic object to the frequency of operation. Skin depth can be calculated mathematically by:

$$\delta = \sqrt{\frac{1}{\pi\mu 0\sigma f}} \tag{3.2.6}$$

In the above equation µ0 present permeability, σ present conductivity and f is used for frequency. Normally electromagnetic waves at low frequencies can easily cross from thin metal sheets, but thick metal sheets isolates them. As we move to higher frequencies, skin depth decreases and ability of waves to cross the material too. At higher frequencies, normally wavelength is smaller, which can be easily depleted by external factors of environment, on the other hand, lower frequencies have longer wavelength, which keeps them alive easily, independent of external factors.

3.2.7 Bandwidth

It is also important to note that the amount of data that can be transferred through RFID systems is also dependent upon frequency. The higher the frequency, more data patterns can be transmitted in the same time and higher will be bandwidth. To examine this phenomenon, we can use a simple scheme of signals to transmit zero and one. To send any signal 1st, we need to examine the frequency of signal. For this reason some set of waves is examined, then the length of cycles, signal values and separation between signals by examining more waves, we can understand easily that signal with higher frequency will require smaller time to transmit while low-frequency signal need more time for complete trans-mission and analysis.

3.2.8 Antenna Design

Antennas that are inductively coupled mostly use metallic coils for their design. Voltage is induced in the antenna while transmitting signal, which is mainly dependent upon the frequency of operation, the size of the coil and number of turns. Antennas with lower frequency need a higher number of turns, in order to produce signals of larger wavelength. Antennas with a smaller number of turns are used to produce a higher frequency signal and they usually have smaller read range. Usually small inductively coupled antennas use the fertile core to increase the inductance of the antenna.

For the generation of higher frequency coils are not that much useful, most of the ultra-high frequency band use antenna created using dipole design. The normal size of half wavelength is used for creation of a dipole antenna. Creation of antennas smaller than that size often affects bandwidth and performance. Rarely, small coil loop with inductive coupling antennas are used for higher frequency, but they have short read range.

3.2.9 RFID Protocols

Communication protocols are set of rules or systems, which are used to define the method and way of communication between two devices. The protocol is a kind of agreement between devices that what set of signals and symbols are used in what way or pattern for successful transfer of information. Everyone must know the protocols of communication, so others can understand the information easily. Among common standard setting bodies Institute of Electrical and Electronic Engineers (IEEE) is the most common one, its standards are recognized worldwide.

In RFID's these protocols are defined to assign set of frequencies, use case and conversion of information from signal to data and data to signal. Protocols are usually named as IEC-(Some Number), for better understanding, we can analyze ISO 11784 low-frequency standard, which is used for the identification of livestock, this standard, tell us that reader start transmission on turning on with the frequency of 134 KHz and then receive a modulated frequency message at 125 to 134 KHz [2]. It is quite necessary to know that it is impossible at times for RFID tags of different protocol to transfer data. Small difference in transmission and receiving time of data can make signal useless, in the same way, we humans speak at the same time no one can understand or if some of our talks overlap with each other.

3.2.10 RFID Tags On Body

When the RFID tag is placed over the human body, the power received and transmitted by the tag reduces because of absorption of radiation by the body, distortion and reduction of the gain of the tag antenna. Permeability and permittivity changes of RFID tag also affect its working. Read a range of RFID tag can be calculated using [3].

$$dmax(\theta,\vartheta) = \frac{c}{4\pi f}\sqrt{\frac{EIRP}{Pchip}\tau Gtag(\theta,\vartheta)} \qquad (3.2.10)$$

In this equation effective isotropic radiation power is given by EIRP, Pchip is the sensitivity of the chip and gain of RFID tag is presented by G. A gain of antenna G and sensitivity of the antenna is greatly affected by interaction with the human body because of huge dependence on conductivity and dielectric constant of environment.

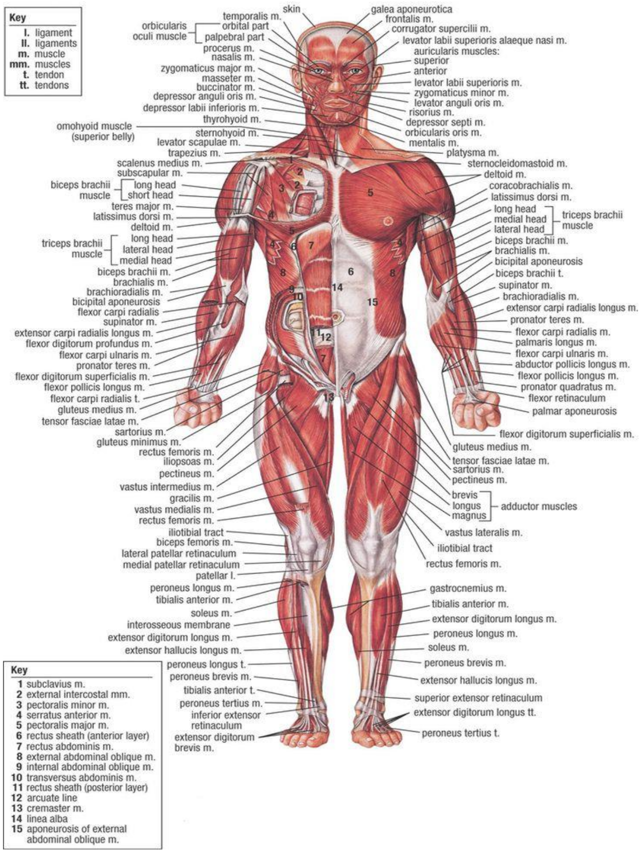

Figure 3-7 *Human Body Anatomy [4]*

As human body is one of the most complex structure and behavior of anatomical features is not completely same for all humans [4]. Figure 3-7 above show different parts of the human body, even if we take into account effects of all of these body parts, a small movement of the antenna from one part of the body closer to others can also cause changes in its working because of differences in permittivity and permeability. Taking effect of each part of the body, which can be largely different, depended upon the psyche and diet habits of the person making on the body, increasing scope of on body effect of antennas to much larger level.

First on body RFID antenna is introduced in 1999 for the long-range data transmission, this antenna is a small planner inverted-F antenna, in which on body effects are considered. The design of this antenna proposed sufficient reduction of transmission power and increase the hours of operation, increasing battery life [5].

After the invention of first antenna and realization of the importance of on body antenna because of reduction in power, better performance and range huge research started in this field. Different type of antennas is designed for the general, military and commercial use, which is able to keep the efficiency of RFID tags high, even working with the human body [6].

To show effects of human body closer RFID antenna detailed research with measurements of antenna performance closer to arm, considering the skin layer thickness, an anatomical feature of the body affecting permeability and permittivity of the antenna is also performed but the detailed effect of each body part and effect on the different antenna is not exactly calculated yet [7].

3.2.11 RFID Tags for Moisture Measurement

From the evaluation of antenna and RFIDs, people tried to measure effects of some reference material, soil condition and paper for the propagation of waves. All of the material mentioned before cause different effect on the propagation of waves and this effect is much different when they are exposed to humidity. As we know permeability and permittivity of water and other materials are different and because of the dependence of waves on permeability and permittivity, the combined effect of material with water on the overall performance of waves effect drastically [8].

The content of water near RFID tags directly cause ohmic losses and these losses of resistance directly effect operating frequency and performance of tag. Researchers tried measuring humidity by allowing one RFID tag to interact with moisture and allowing others to work without independently without interaction of water [9]. RFID tags designed with materials, which are able to absorb moisture are more affected by the effects of humidity than others [10].

Normally water increases the dielectric constant of the environment around the RFID tag causing the antenna to work with decreased performance. For the passive tag reader needs to emit stronger radiation of waves than normal RFID tags, with the same power of radiation reader may not able to get back signal because of loss of power because of humidity [10].

Although the effects of moisture on RFID tags are same, but most of the tags are designed for measurement in the specific environment because effect of other environmental parameters can change their performance and results in the presence of other materials is not that much accurate.

3.2.12 Commercially Available Passive Moisture Tags

Considering the effects of moisture on RFID, a number of moisture measurement tags are designed for the research purpose, but there are only few RFID tags which are commercially available in the market. Tags that are available in the market include.

Dogbone Sensor by Smartrac

Dogbone sensor is a first RFID sensor that is commercially available and designed for the moisture measurement, utilizing RF Micron IC. The operating frequency of Dogbone sensor varies from 860 to 960 MHz UHF band, offer low-cost moisture measurement solutions for humidity measurement on construction material, cardboard, plastic, and stones. Dogbone RFID tag in the moisture conditions is shown in figure 3-8 [11].

Figure 3-8 *Dogbone Tag by Smartrac [11]*

Sensor Tag by IC-TAG Solutions

Sensor tag shown in figure 3-9 is HF 13.56 MHz RFID tag designed by IC-TAG solution inc. Sensor tag is capable of measuring humidity conditions along with moisture, temperature and pressure also detection of gasses. Use of this tag is vast in the different kind of industries [12].

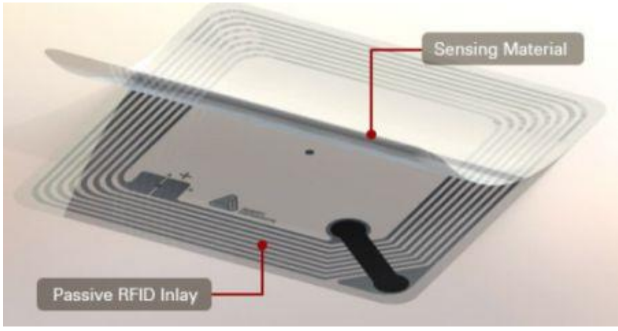

Figure 3-9 *Sensor Tag by IC Tag Solutions [12]*

4. WORKING OF RFID

RFID systems transmit and receive data in the form of signals using electromagnetic waves to understand them completely it's important to understand electromagnetic wave propagation phenomenon.

4.1 Maxwell Equations

As we know RFID systems communicated using electromagnetic waves. Maxwell equation's help us to understand properties of electromagnetic waves is better way, their waves equations are also derived from Maxwell equations. James Clerk Maxwell mathematician and physicist shared Maxwell equations, they are an important source in defining electrical and magnetic fields, their interaction with current and way they are generated. Maxwell equations are also considered as the basis of present electrodynamics, circuits, and optics, in the term of formulas they are set of partial differentiation equations incorporating Lorentz force law.

$$\Delta . E = \frac{\rho v}{\varepsilon} \qquad \text{(Guass' Law)}$$

$$\Delta . H = 0 \qquad \text{(Guass' Law for Magnetism)}$$

$$\Delta \times E = -\mu \frac{\vartheta H}{\vartheta t} \qquad \text{(Faraday's Law)}$$

$$\Delta \times H = J + \varepsilon \frac{\vartheta E}{\vartheta t} \qquad \text{(Amperes 's Law)}$$

Figure 4-1 *Maxwell Equation Formulas*

In the above equations E presents electric field, H presents magnetic field intensity; J is current density and ρ present total electric charge density. Maxwell equations are considered quite important in deriving any of the laws related to electric and magnetic field.

4.1.1 Electric Field

As electromagnetic waves consist of synchronized oscillation of electric and magnetic field and RFIDs communicate using electromagnetic waves, so electric field is quite important factor of communication in RFID systems. Electric Field is the electrical force from or toward per unit charge. Direction of the electric field is calculated by assuming the electric force put on the positive test charge. The electric field is written as V/m and calculated in term of force per unit charge [13]. Electric field in term of formula can be written as

$$E = \frac{F}{q} \quad (4.1.1.1)$$

Where F is the force on unit charge, which can be expressed as

$$F = \frac{KQq}{r\hat{}2} \quad (4.1.1.2)$$

In this equation Q and q are used to express charges, r is the distance between charges and K is constant of space between these charges. Putting the value of F in equation of Electric Field.

$$E = \frac{KQ}{r\hat{}2} \quad (4.1.1.3)$$

In the above equation K is the electric field constant dependent upon the medium while r is used to define the distance from the charge. Effect of electric field in a certain direction can be defined using Maxwell equations, which tell us that the cross product of electric field will be zero while the dot product of electric field will be ratio charge density to electrical permittivity.

4.1.2 Magnetic Field

The magnetic field is considered as combined effect electric current and magnetic materials. As mentioned earlier magnetic field is important component of electromagnetic waves, which are use for transfer of data in RFID systems. To define a magnetic field at any point, we need both direction and magnitude as Electric fields. Magnetic flux density is often expressed by symbol B with units Wbm^{-2} and it can be calculated in term of the number of magnetic field lines passing through unit area. Curl and divergence of magnetic fields can be defined as

$$\Delta.B=0 \quad (4.1.2.1)$$

$$\Delta{*}B=\mu J \quad (4.1.2.2)$$

Above equations show dot product of magnetic flux density is zero, the cross product is equal to current density in permeability of space, and μ presents permeability while J is used to show the density of current.

The current generated Magnetic fields are usually calculated using Ampere's law or Biot Savart Law and defined as B, another important quantity is defined as magnetic field is magnetic field intensity noted as H, its units are Am^{-1}. Magnetic field intensity is equal to magnetic flux density divided permeability minus magnetization of material and it can be given as [14].

$$H = \frac{B}{\mu 0} - M = \frac{B}{\mu}$$

In the above equation M represents magnetization, B as magnetic field and permeability of medium is given as μ.

4.2 Electromagnetic Waves

Waves can be defined as repeated variation in the same manner for the transfer of energy through any space or medium. Movement of waves can be affected by transmission medium. Data in the air is also transferred in the form of waves. Waves are present everywhere, sometimes they can be easily observed in the water or air. Waves can be divided into mechanical waves, in which medium is used for the transfer of energy and electromagnetic waves, which can travel without any medium and they our main subject of interest. The most common types of electromagnetic waves are microwaves, radio waves, x rays and gamma waves.

Electromagnetic waves start propagation when radiation come out from any electromagnetic process. We can also say electromagnetic waves as shown in figure 4-2 are harmonized pattern of electric and magnetic field, which move in vacuum with speed of light and bit slower in other materials. Light, which we are able to see, is one of the best examples of electromagnetic waves.

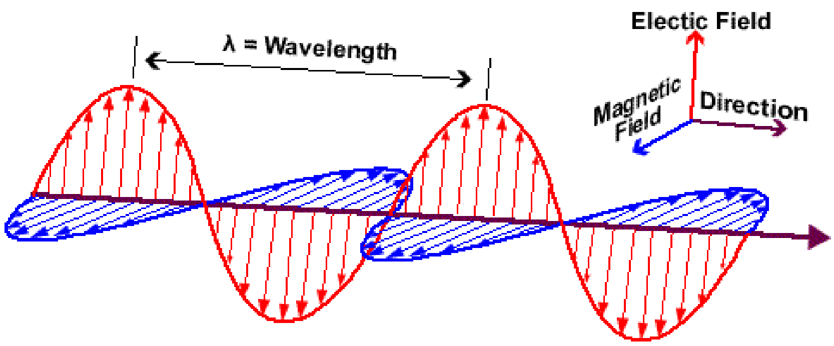

Figure 4-2 *Electromagnetic Waves [15]*

Electromagnetic waves usually only consist of radiations with no mass, they are pure energy wave, transmitted by electric and magnetic field moving in different phases. They are also described as a stream of photons and basic difference between different electromagnetic radiations is the amount of energy and wavelength. Difference of wavelength and energy make them to cause different effects, for example, wavelength of RF signals is contained a small amount of energy and long enough, so our eyes are not able to see them [15].

4.3 Polarization

Polarization is attribute of the waves, oscillating in more than one orientation. Electromegnatic waves, used for communication in RFID systems posses property of polarization. Polarization of waves generated by antenna can help us to predict signal and suitable orientation of RFID tag. The electric field of electromagnetic waves can oscillate in any direction (normal with respect to wave) irrespective of actual movement of waves. For the wave moving in direction of X, electric and magnetic fields can oscillate in any Y-Z direction keeping themselves perpendicular to each other. Some common polarization schemes of electromagnetic waves are defined below [16].

Linear Polarization

When Electric or magnetic field of electromagnetic waves vary only in one given plane. They are known as linearly polarized. Linearly polarized waves orientation is defined using the polarization direction of electric field, as shown in figure 4-2. Which also give an overview of magnetic field perpendicular to electric field.

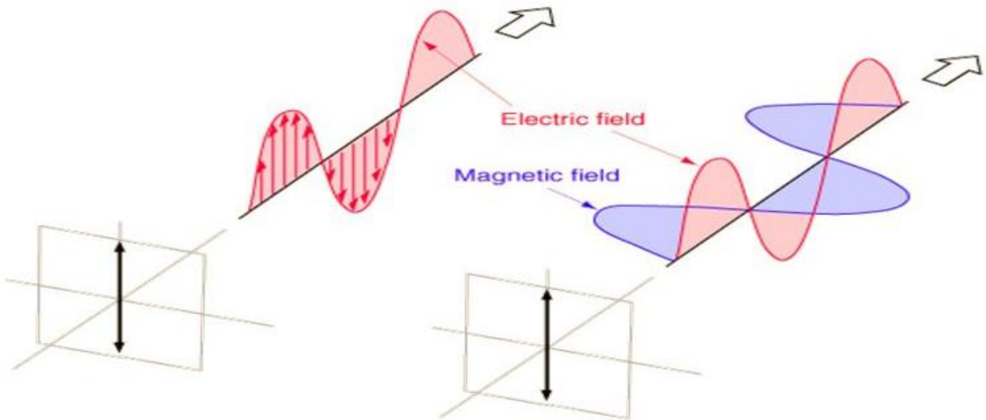

Figure 4-3 *Linearly Polarized Waves [16]*

Circularly Polarized

When an electric field of electromagnetic waves oscillates only within x-y plane, mean electromagnetic waves keep their shape same, but rotate around the axis they are known as circularly polarized as shown in figure 4-4. When the wave is moving and its electric field is, rotating in clockwise direction polarization is known as left circular polarization (LHCP), on the other hand, if the electric field rotate anticlockwise polarization is known as right circular polarization (RHCP).

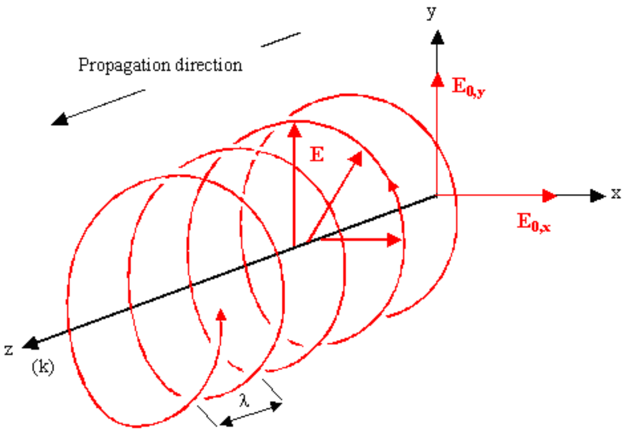

Figure 4-4 *Circular Polarization [16]*

Elliptical Polarization

When an electrical field vector is in the form of eclipse in only plane and moving in the normal in direction of waves, in other words, the electric field is varying in two planes with change in amplitude is known as elliptical polarization as shown in figure 4-5. Elliptically polarized waves can be expressed as two waves, which are moving in phase quadrature and linearly polarized. Axial ratio in the case of elliptical polarization varies from one to infinity. Same as in circularly polarized waves, if the elliptically polarized wave is rotating in anti-clockwise direction it is known as right circular polarized and vice versa.

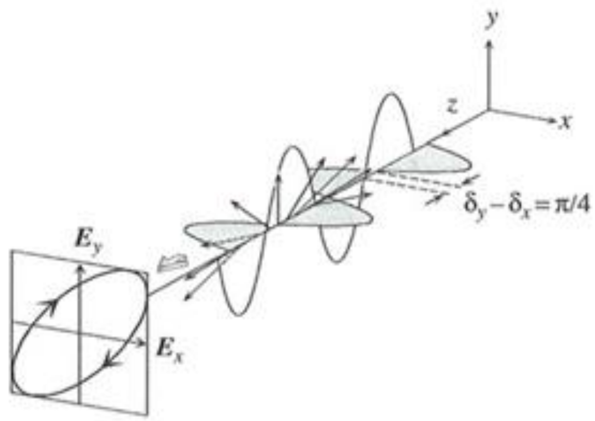

Figure 4-5 *Elliptically Polarized Waves [16]*

4.4 Communication by Waves

Communication through electromagnetic waves is common in the modern world; information is converted in the form of signal, which in case of RFIDs propagated as electromagnetic waves while at the other end receiver change information in waves again to the data. Electromagnetic waves transmitted by RFID readers should be enough powerful so they will easily reach tag and tag would be able to send back signal utilizing the power of waves.

Process of converting some properties of waves to add information to them. Usually in the case of electromagnetic waves, baseband information is added to the wave along with the altering frequency to carrier frequency. Carrier waves, which are unmodulated, are changed according the signal parameters. Power position, frequency, and power are important factor of modulation.

$$V(t)= m(t) . \cos(\dot{\omega}ct) \quad (4.4.2.1)$$

In the above equation, m(t) presents information of the signal, $\dot{\omega}$ as angular frequency and t as time.

After successful modulation, waves are transmitted through an antenna and captured back through receiver antenna, which demodulate the signal to get actual information from the wave. For proper demodulation, modulation must be defined in a specific way and in the case of RFID's modulation is usually performed using Amplitude Shift Keying (ASK), Phase Shift Keying (PSK) and Frequency Shift Keying (FSK), all of these modulation schemes are shown in figure 4-6.

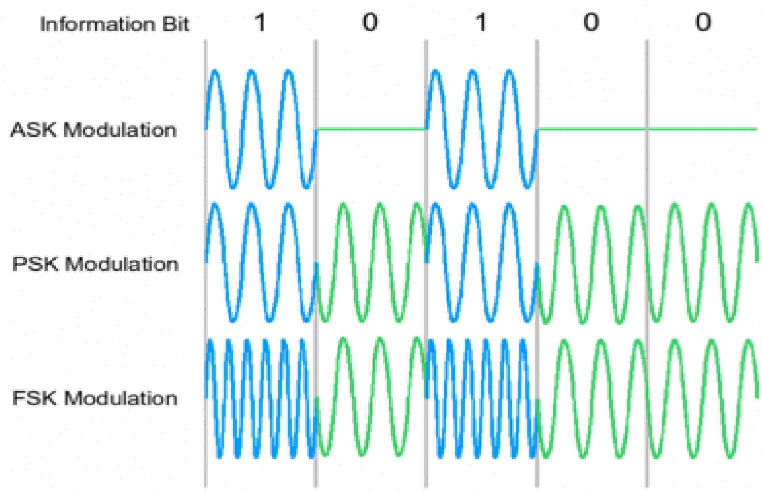

Figure 4-6 *Modulation Schemes [17]*

4.5 Basics of Antenna

Antenna is basically conducting device, which convert electric signals to radio waves and radio waves to electronic signals. Usually, antennas are connected with RFID readers while tag acts itself as an antenna. Antenna is tuned circuit, which radiate the power received, all antennas that are passive; perform in the same way while receiving the signal as they do in transmitting the signal.

For continuous operation of the antennas, signals must be fed into their input continuously. Different coupling techniques are employed by antennas to provide high efficiency without losing charges as mentioned above, including radiative capacitive and inductive coupling. RFID tags normally use inductive coupling for communication with reader at lower frequencies.

4.5.1 Generation of Radiations

In order to generate radiation from antenna, signals are fed to the antenna in the form of electrons. Each free electron executes 14.1 million cycles of motion in one second if we know the total number of charges per cubic length of antenna we can calculate radiation, figure 4-7 below the radiating electron while traveling radiating from center to the direction of the arrows [18].

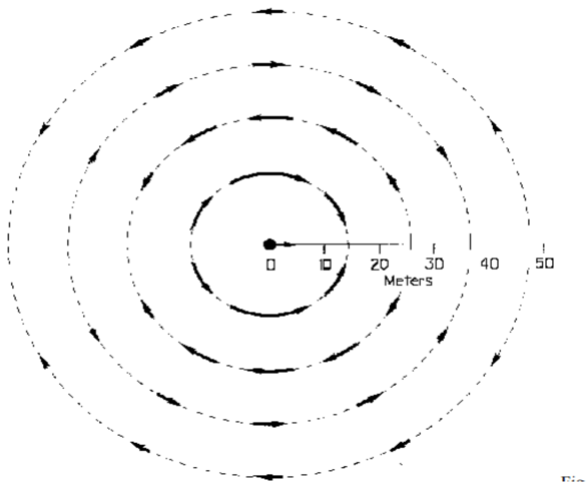

Figure 4-7 *Radiation Field of Electrons by Their Movement [18]*

Current varying in a one part of antenna is the basic source of producing electric and magnetic field. Which produces a radiating field in all directions. Fields from antenna radiation can be divided into three parts, near field, radiating near field and far field of antenna as shown in figure 4-8.

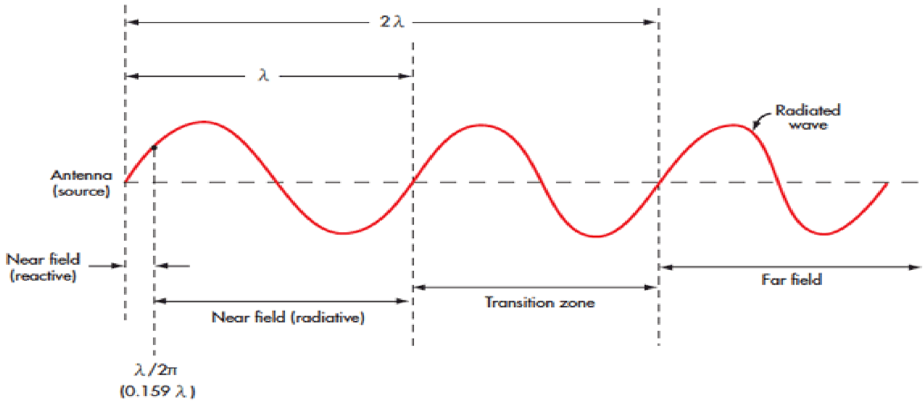

Figure 4-8 *Fields of Antenna [19]*

4.5.2 Parameters of RFID Antenna

Some of the important parameters considered in the case of RFID's are [20]:

Radiation resistance is the resistance offered to the input signal because of radiation emission by antenna, it is different from Ohmic resistance, which normally occur because of hindrance offered by material releasing heat.

Resistivity losses are the resistance offered to this input signal because of antenna elements its same as Ohmic resistance. Total resistance offered to the signal is the sum of resistivity losses and radiation resistance.

Bandwidth of the antenna is the frequency range in which antenna operates smoothly in the best way by keeping the certain required standards of signal alive. Bandwidth of the antenna can also be defined as the effectiveness of antenna to transmit or receive signals with the certain range of frequencies. Bandwidth of antenna can be given as

Bandwidth = Frequency Tolerance + Frequency of subcarrier + Max data rate

Feed Impedance is defined as the changing impedance of the antenna along with its length. Normally variation of electrical signal occurs along with the length of an antenna, usually voltage increases, and current fall while moving toward the end of the antenna. As impedance is the ratio of voltage to current and load impedance is important factor in the working of antenna, because of this reason feed impedance also become an important factor of the antenna.

A gain of an antenna is usually dependent upon the size of the antenna, which also increase the cost of the antenna. Most RFID's use near field antennas when tag and antennas are quite close to each other and in the near field, these near fields form closely coupled antenna. To maintain high performance of antenna coupling of the antenna must be considered into account.

Directivity of Antenna is defined as the ratio of the maximum power density to average power from the antenna. Actually, it is used to measure radiation of antenna in one direction with a comparison of all other directions.

$$Directivity = \frac{Maximum\ Power}{Average\ Power}$$

Radiation Pattern is a graphical representation of the radiation emitted by the antenna. Electric and magnetic fields are divided into two different planes to plot their radiation patterns are perpendicular to each other. The radiation pattern of an antenna is usually plotted in decibels or on a logarithmic scale.

Axial Ratio is actually given by the proportion of the major axis to minor axis and given by [21]:

$$Axial\ Ratio = \frac{Major\ Axis}{Minor\ Axis}$$

While major and minor axis are defined from polarization, in circular polarization both axis are equal to each other.

4.5.3 Dipole Antennas

Dipole antennas are the most basic type of antennas used quite commonly nowadays, they are designed by using two kinds of conductive materials, which are almost symmetrical. Electric current for transmitting the signal is applied to generate radiation while the antenna receives radiations to obtain the signal. Usually one side of the antenna is connected to circuit through conducting wire and the other is grounded.

The simplest form of the dipole antenna can be a simple copper wire of fixed length. The Feed point impedance of the antenna depends heavily upon the length of the antenna, because of this thing dipole antennas normally perform in the best way with narrow bandwidth. Dipole antennas are not that much better while working with wide bandwidth frequencies creating a poor match for transmitter and receiver [22]. Full-wave dipole antennas are more directional than other antennas, half wave dipole antennas are antenna designed by some conductive material usually copper equal to the half wavelength size [23]. Figure 4-9 show horizontal dipole antenna.

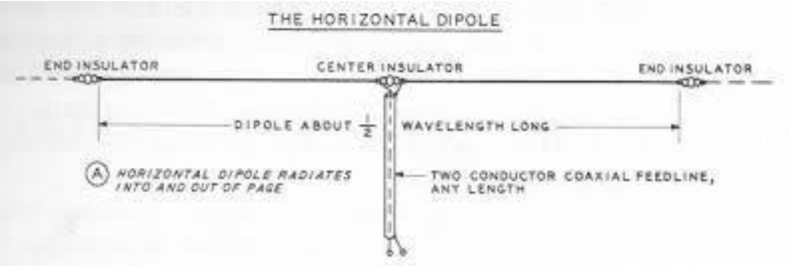

Figure 4-9 *Dipole Antenna [23]*

4.5.4 Antenna of Passive RFID Tag

Passive RFID tags contain antenna, which is usually made up of substrate material, these antennas are usually not powered up by any energy source, they use energy supplied by transmitter antenna. As passive RFID antennas do not any potential, so the biggest challenge of passive RFID tag is to create a voltage difference between antenna input and ground. Potential difference in antenna allow us to power up RFID tag IC. Example of antenna and IC on passive RFID tag is shown in figure 4-10.

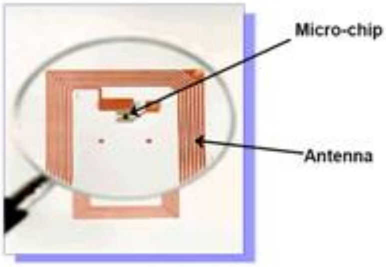

Figure 4-10 *Passive RFID Antenna and IC [24]*

RFID tags work utilizing thousand timeless power than the common cell phone. Actually, antennas in RFIDs are energy harvesting devices apart from working as a reader. The relative ability of the tag to power up itself is known as read sensitivity, as the read sensitivity, increase, the probability of the tag to turn on also increase. On the other hand, ability of tag to reflect back received radiations after receiving them is known as back scattered radiation. Ability to transmit back signal is quite important so it is important to perform complete interaction with RFID tag so backscattered radiation must be higher [25].

Read a range of passive RFID tag and its performance heavily dependent upon the material used in the antenna, material on which tag is placed and the IC. Another important factor is size of the antenna, as size of antenna increases, it becomes more competent to receive signals and send signals back [25].

4.5.5 Important Factors of Antenna Design

Antenna design in the RFID systems is affected by different factors, changes in these parameters often change performance and working changes antenna, important parameters of antenna are

Frequency Range

The frequency range in which antenna is operating cause big effect on antenna, higher frequency range yield lower wavelength and better performance of antenna even when its size in small. The frequency range of UHF RFIDs is defined for every country around the globe, so antennas in the every country are also designed according to regulation of the country.

Dimensions of Antenna

As explained earlier size of the antenna is an important factor in defining antenna chatacteristics, usually the size of the antenna is half of wavelength. Shape of antenna is the basic source for defining the pattern of signals and also for some cases wave propagation direction, which also define the **di**rection in which tag can be placed.

Usage of Antenna

According to the application, usage of the antenna may change and cause severe effects on working parameters. For example, if antennas are used in the RFID cards, they must be embedded inside. Mobility of the tag is also important factor, for this reason Doppler shift must be considered in designing antenna. Antenna design is also dependent upon other factors including regulatory authority constrains, environment around the antenna, orientation of antenna and other radiations present in the environment.

Environmental Constrains

Antennas must be designed in the way that they should work perfectly under different environmental conditions, for example, tags cannot be developed on the soft paper in the case of usage inside water. It is important to note that humidity conditions, temperature, and pressure should be in consideration.

4.5.6 RSSI Value

Received Signal Strength Indicator commonly known as RSSI, it is measured by power of receiving signals. RSSI is normally measured before intermediate frequency amplification at intermediate amplifier. As RSSI basically, tell about the power of the signal received by the receiver, so higher the RSSI, much better. RSSI is usually expressed in dBm, RSSI value is maximum when it reaches zero and it gets more negative, when the power of the signal decrease.

RSSI value gives overview about the power lost due to directivity, gain and resistance of reader and tag antenna. RSSI also reflects the effect of medium, objects around the tag antenna, working on tag, resistance of the circuit and noise. Therefore, by analyzing RSSI, we can get a clear overview of the all effects affecting the performance of RFID tag.

4.6 Wearable RFID Tags

Wearable antennas include all of those antennas, which are specially designed to work being worn. Watches with Bluetooth and Google glasses, which use Wi-Fi, are common type of wearable devices. As in this thesis, RFID tags are used on body inside bandage for the measurement. Effects of body on the RFID tag antenna and its signals need to be considered.

4.6.1 Body Area Networks

When RFID antennas or any other communication occurs closer to the human body, special standard of communication is defined and networks of communication present on the body is known as a body area network. BAN's are highly optimized for low power devices and communication occur, usually around or inside body of the person. Body Area networks are providing number of applications including detection, communication, medical related and personal entertainment solutions [26]. Some of the applications of body area networks are shown below in figure 4-11.

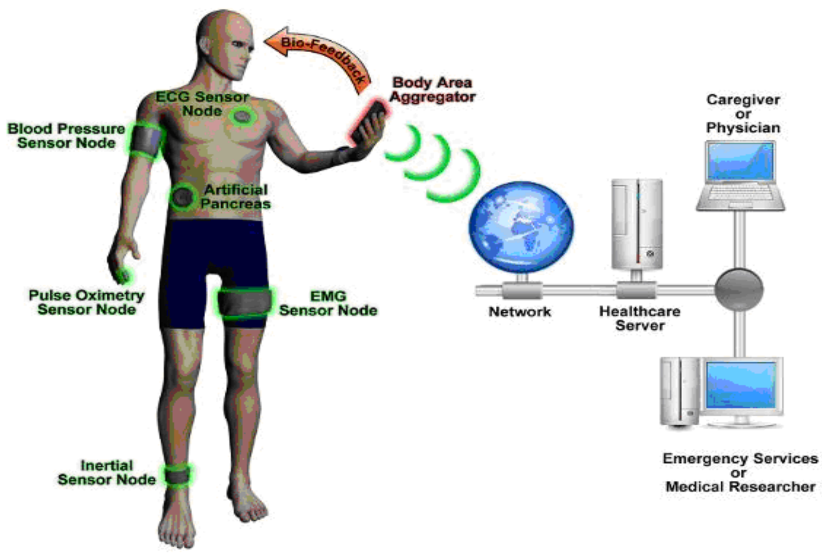

Figure 4-11 *Health Application of Body Area Networks (BANs) [26]*

For the body area networks using RFIDs, the RFID tag is the most important part as it acts like a sensor and contain some memory too. Tag antennas used in the body area networks must be lightweight, compact, flexible, having stable performance closer to the body and they should send the radiation away from the body.

When RFID tag antennas or any other antenna communicates between any device and body within a short range of 10 meters, network is known as Personal Area Network. Personal Area Networks are often referred, as PAN's, laptops, mobile phones, and all other devices network are also part of personal area networks [27].

4.6.2 Impact of Human Body on RFIDs

RFID tags are heavily affected because the human body due to a number of reasons, including a huge change in permeability and permittivity. According to study when RFID tag is placed on the forehead of the person as shown in figure 4-12 at the different distances of 10cm, 100cm, and 1000cm, its performance will not be that much affected by the change in distance from the RFID reader than it get affected by the removal of the tag from forehead of the human body [28].

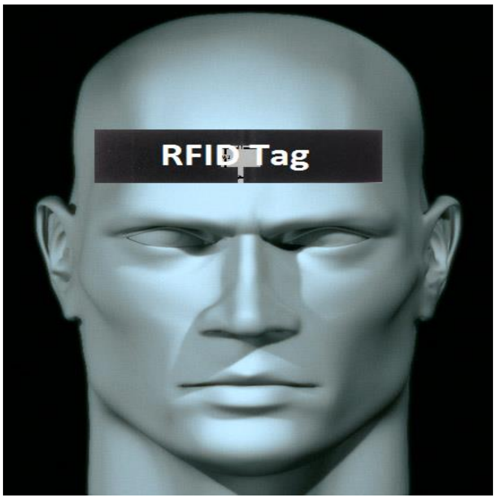

Figure 4-12 *RFID Tag on Head*

Although interaction of RFID's with human body is happening from long time, but analysis of RFID tags on different parts of the body needs detailed research as every orientation and place of body, possess different characteristics [28].

4.6.3 Applications of RFID Tags inside bandage

Globally around 50 million people are injured only by road accidents and in the most of cases doctors cover injuries by bandage and open them regularly to analyze condition. [29] Basic idea behind the opening of the bandage is to check whether injury turned inflamed, bruised or infected by germs and bacteria, Normally the humidity level of injury change because of a change in its condition depending upon its state. To analyze the state of injury, doctors usually open bandage and it is quite disturbing for patients and also for the doctor to open the bandage in order to check the condition of injury. Most known and commonly observable factor for the doctors to check the condition of injury is the humidity level of the injury.

Therefore, by measuring humidity conditions inside bandage, doctors can get an idea of the inner condition of injury, which can save them to opening bandage just for checking. Often in inadequate medical facilities and unhealthy conditions of environment opening up the bandage cause exposure of injury to the germs and bacteria can cause more damage than good to the injury. In the all of the above given cases, doctors can calculate the humidity level by placing RFID reader at predefined distance and measuring change in RSSI value of RFID tag inside the bandage. Change in condition of injury can change humidity level and also RSSI value received by the RFID reader. Interpreting RSSI value of the can guide doctors in the great way about the time to change the bandage.

5. COMPONENTS OF MEASUREMENT

In this section, every component used for the measurements is explained in details.

5.1 RFID Measurement Tools

In our measurements, we used two kinds of RFID tools, one for the measurement and analysis of the tag and other for the measurement of the on body characteristic, second case is also used for analyzing the effect of humidity on the tag.

5.1.1 RFID Measurement Cabinet

To measure RFID tag parameters in a convenient way, anechoic measurement chamber is used. Anechoic chamber absorb the radiation using the Radiation Absorbent Material (RAM) in order to provide the space, which is free from echo and reflection. In the large anechoic chamber, testing of aircraft can also be performed [30].

Tagformance Anechoic measurement chamber as shown in figure 5-1 is cost effective anechoic chamber, which contain optional functionalities of automatic tag rotation of objects up to 10 kg using its software, to observe the radiation pattern and effects because of different orientation on the performance of RFID tags. External dimensions of the chamber are 120 x 80 x 80 cm, basically, RFID chamber contains following [31].

- Quick Release Antenna with the ability to change polarization up to 90 degrees.
- Standard Patch or Wideband Antenna for the UHF frequencies.
- Directional Couplers and RF cables.
- Shielding Effectiveness goes up to 90dB

Figure 5-1 *Voyantic Anechoic Chamber [31]*

5.1.2 Mercury M6 Reader

Although anechoic chamber is free from reflection and echo of radiations which affect actual results, but it is not possible to go inside the small anechoic chamber for on body measurement. For the measurement on the body Mercury M6 RFID reader, shown in figure 5-2 is used, which is designed by Thinkmagic company.

Figure 5-2 *Mercury M6 Reader [32]*

Mercury M6 is small reader with the dimensions of 3.4 x 19 x17. 8 cm, have the ability to attach four different antennas on four ports. Mercury M6 can be used for all kinds of application, including outdoor and indoor. The interesting thing about Mercury m6 reader is able to provide power for Ethernet cable and to use it wireless by using Wi-Fi. Power range of Mercury M6 reader is higher than most of its alternatives, operating at +5 to +31.5dBm with both AC and PoE power options. Mercury M6 can read up to 750 tags per second and it is highly sensitive, having the ability to read tags until 9.114 meters [32].

5.2 RFID Tags

RFID tags are basic elements of any RFID system, they are also basic sensor for all of the measurements. In our case, as tags are used for on body measurement, it is quite important to consider tags immunity to the environmental parameters. In order to keep high performance and to allow them working in the perfect way, under the influence of body, selection of the tags is quite important decision.

For the high performance of RFID tag on body and under the guidance of IEEE 802.15 standard for the body area networks, the UHF frequency band is chosen for the measurement [33]. Some benefits of UHF frequency band include sending more amount of energy using small size of antenna, ability to send signal to longer distance, usage of single loop antenna and able to ignore electronic noise.

In the measurement three kinds of tags are used, one tag by Smartrac known as sensor patch, other two tags are fabricated in lab on paper and bandage.

5.2.1 Dogbone RFID Tag

Smartrac developed Dogbone RFID tag, which is world first commercial RFID tag designed for humidity measurement. The antenna of the tag act as RLC Circuit, which allow it to take effect of the environment into account. This tag is designed to digitize the environmental effect and transmit it wirelessly using UHF Gen 2 protocol, but having certain limitations. In our case, we utilized real-time data of the signal to measure environmental changes in the performance of tag [11].

Dogbone RFID tag shown in figure 5-3 work between the frequency ranges of 860 to 960 MHz, having antenna size of 89 x 24mm. Dogbone RFID has the unique ability to use in different environments including construction material, healthcare, and automotive industry. Dogbone tag is in use for taking account of humidity in different application because of low cost and easy installation anywhere, in any material, it contains the 64 bits of TID memory, EPC memory of 128 bits and 144 of user bit memory. Smartrac's Dogbone RFID tag is using RF Micron's Magnus®S2 IC and it is a passive tag. RF micron is an innovative product that automatically adjusts input impedance in order to correct the changes occurred by the change of external environment. This keeps the tag to oscillate at the same frequency with same reflective power [34].

Figure 5-3 *Dogbone RFID Tag*

5.2.2 RFID Tag on Paper

For analyzing the performance of the commercial tag inside the bandage in a better way and to know about the effect of paper on the RFID tag, four new tags are developed on Paper. The performance of these tags is analyzed and the best ones are chosen. The RFID tag on paper is developed using silver brush painting, which is fast and convenient method allowing to fabricate antenna using one layer to fabricate antenna of the tag. [35] Apart from reducing time of painting, it also reduces the ink material usage. Antenna is brushed utilizing Metalon HPS-021LV Silver Screen ink on the paper having protection cover on the sides where we don't want to paint. HPS-021LV is a conductive ink of silver and used

to establish conductive marks on the substrates from low to high temperature, this ink is specially developed for screen-printing and can be used on different material including paper, glass and silicon [36]. Tag is painted using HPS-021LV ink all over the paper, just leaving the IC area. After painting, IC and open area is scissored to get the tag developed. Later on, sintering is performed for 15 minutes and 125-degree centigrade and followed by attachment of tag IC using conductive epoxy by Chemtronics [37].
Properties of paper used for RFID tag are shown in Table 1.

Table 1 *Paper Properties*

Basic Weight	80 gram per meter square
Thickness	109 micrometers
Opacity	95%
Roughness	180 milliliter per minute
Bulk	Centimeter cube per gram

After successful development of the tag, performance of all tags is analyzed and the best ones are chosen. Dimensions of tags are given below in table 2 with diagram in figure 5-4.

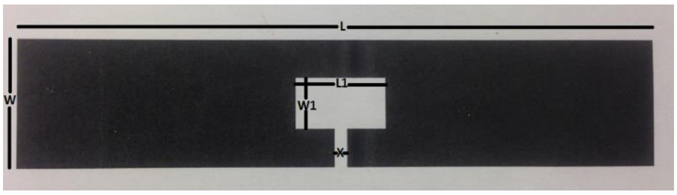

Figure 5-4 *Tag Dimensions*

Table 2 *Dimensions of Tag on Paper*

Parameter	L	W	W1	L1	X
Value in millimeters	100	20	14.3	8.125	2

RFID tags on paper employ UCODE G2iL integrated circuit (IC), which is able to provide large range and high sensitivity to the tag, these tags are best suitable for single port antennas and work quite well in noisy environments. UCODE G2iL IC has 128 bits of memory. Apart from these benefits, these tags allow us to design small and cost effective antennas [38].
Four of the RFID tags antenna geometries are brush painted on paper and the UCODE G2iL IC is attached on them, later performance of all tags is compared using the Tagformance closed chamber. Analysis of all four RFID tags includes oscillating frequency,

tag physical condition and read range. After a complete analysis best tag between four is chosen.

Later on, whole analysis is performed on one of the best selected tag as shown below in figure 5-5.

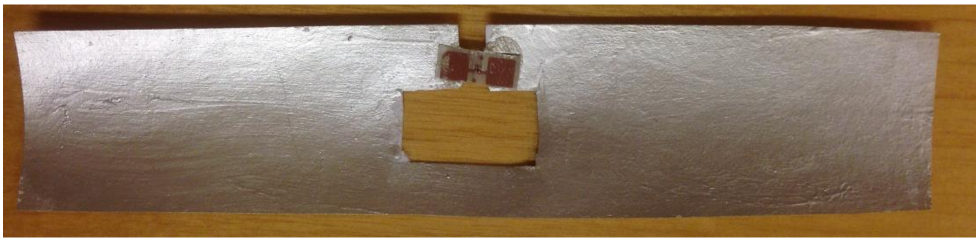

Figure 5-5 *RFID Tag on Paper*

5.2.3 RFID Tag on Bandage

Apart from the tag developed on paper, another tag is fabricated on the bandage, which allowed us to measure tag with only bandage effect. Part of bandage is scissored from actual bandage and the same process of brush painting is applied as performed in paper tag. Dimensions of tag are same as used for the tag development on paper. Bandage used for the development of tag is also made up of rayon, this is kind of elastic bandage with absorbent inner layer and outer layer contain porous nets with high-density polyethylene [39].

RFID tags antenna geometry is brush painted on two pieces of the bandage show in figure 5-6; after painting tag IC is attached and rendition of tags is compared using Tagformance. RFID tag with better performance is chosen.

Figure 5-6 *Selected RFID Tag on Bandage*

6. MEASUREMENTS

For the performance evaluation of all RFID tags in details, with the consideration of the effect of bandage, body and humidity level. Measurements of different passive RFID tags are performed. The sum of all measurements provide us sufficient details to get the conclusive relation between the performance of RFID tags with the effect of different parts of body, turns of the bandage and humidity level. The figure 6-1 below shows placement of RFID tag on the different parts of body.

Tags are analyzed using Tagformance for initial parametric analysis, which helped in getting better overview and working details of tags. After that, tags are placed in open space, where the performance of tags is analyzed in comparison with results of closed chamber. At last other measurements of the body are performed.

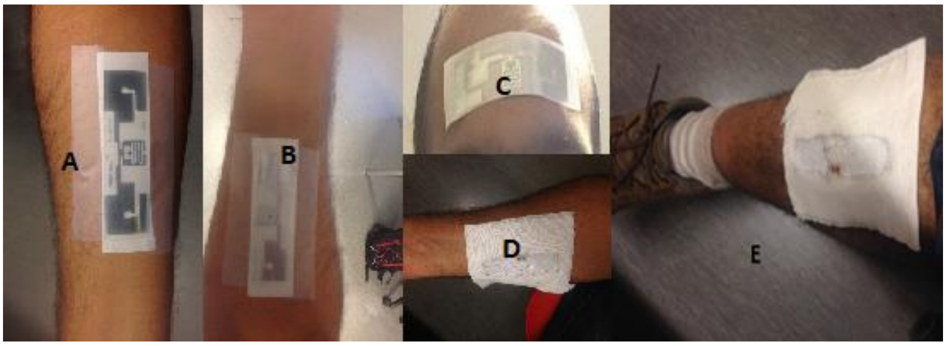

Figure 6-1 *Different RFID Tags Placement While Taking Measurements (A) Dogbone Tag placed on Hairy Side of Arm (B) Dogbone Tag Placed on Non-Hairy Side of Arm (C) Dogbone Tag Placed on Forehead (D) Tag on Rayon Bandage Placed on Non-Hairy Side of Arm (E) Tag on Rayon Bandage Placed on Front Side of Leg*

6.1 Orientation Analysis of Tag

The orientation sensitivity of the tag with respect to angle from reader antenna is an important factor to determine polarization and type of antenna. Initial studies about RFID tags show that performance of RFID tags on body stays better when they are acting as a dipole. Although the shape of the antennas gives us an idea about the type of the RFID tag, but results of radiation pattern of tag can give us a clear message that the antenna is acting as a dipole or not. All of our measurements are taken using the Tagformance closed chamber, which is free from reflections and external noise, results show all tag antennas are working as a dipole.

Tagformance calculates the orientation sensitivity at particular angle of the tag by rotating the tag and analyzing the orientation sensitivity through reader of the Tagformance closed chamber. The radiation pattern of the tag is premeditated using Voyantic accessory of tag rotation system, it allows the RFID tag to rotate in the particular direction. Tagformance utilize signals received by the reader back from tag inside an anechoic chamber to draw an radiation pattern of the RFID. Horizontal radiation pattern of Dogbone RFID tag is shown is figure 6-2, horiontal radiation pattern of RFID tag on paper is shown in figure 6-3 and figure 6-4 presents horizontal radiation pattern of RFID tag on bandage. Orientation sensitivity at particular angle is expressed in the diagram as radius of circuilar diagram and its unit is dBm while angle shows orientation of the tag from reader antenna.

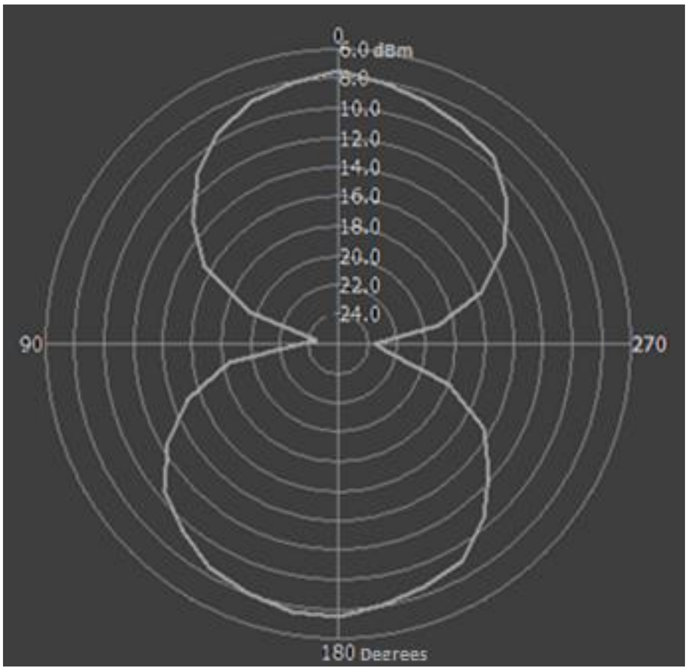

Figure 6-2 *Radiation Pattern of Dogbone RFID Tag*

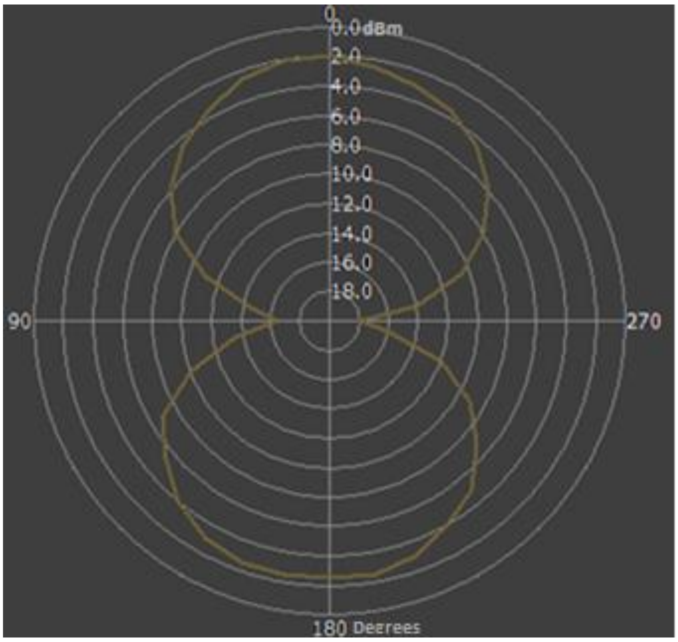

Figure 6-3 *Radiation Pattern of RFID Tag on Paper*

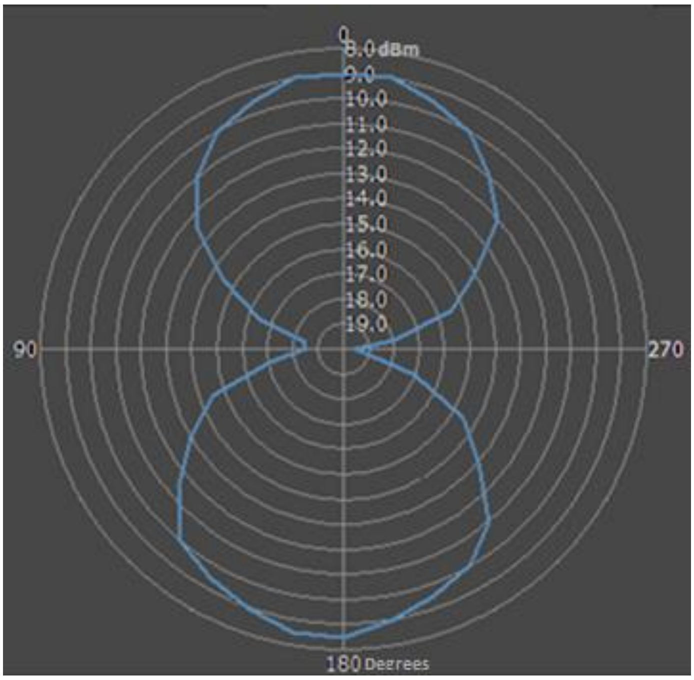

Figure 6-4 *Radiation Pattern of RFID Tag on Bandage*

6.2 Read Range

Using the Tagformance closed chamber read range of RFID tags is calculated, read range measurement provide us clear idea about frequencies where the tag is working with utmost range and also about the maximum possible range. Read range of RFID tag is given by:

$$Rtag = \frac{\lambda}{4\pi}\sqrt{\frac{EIRP}{Ptag}}$$

In the above equation EIRP is equivalent isotropic radiated power transmitted by the antenna, P tag is tag sensitivity and λ is the wavelength. At the particular frequency, we can get the value of EIRP and PTag by reader, value of wavelength can be obtained by taking the inverse of frequency. Putting all of values allow us to calculate read range of the RFID tag at a particular frequency [40].

Tagformance closed chamber is used to measure the read range of RFID tag, Read range is analyzed by increasing power of the RFID tag and analyzing received power. Read range is analyzed between 800 to 1000 MHz as shown in figure 6-5. Figure 6-5 show that the Dogbone RFID tag's read range stays maximum (around 7.6 meters) between the frequency ranges of 880MHz to 960 MHz. Results of RFID tag on paper show, read range of RFID tag touch maximum value of 8.6dBm at 870 MHz and it stays almost same closer to 8.5m from 850 MHz to 900 MHz. For the RFID tag on bandage measurements show that reads a range of RFID tag on bandage stay a maximum around 6.75m between 910MHz to 960MHz.

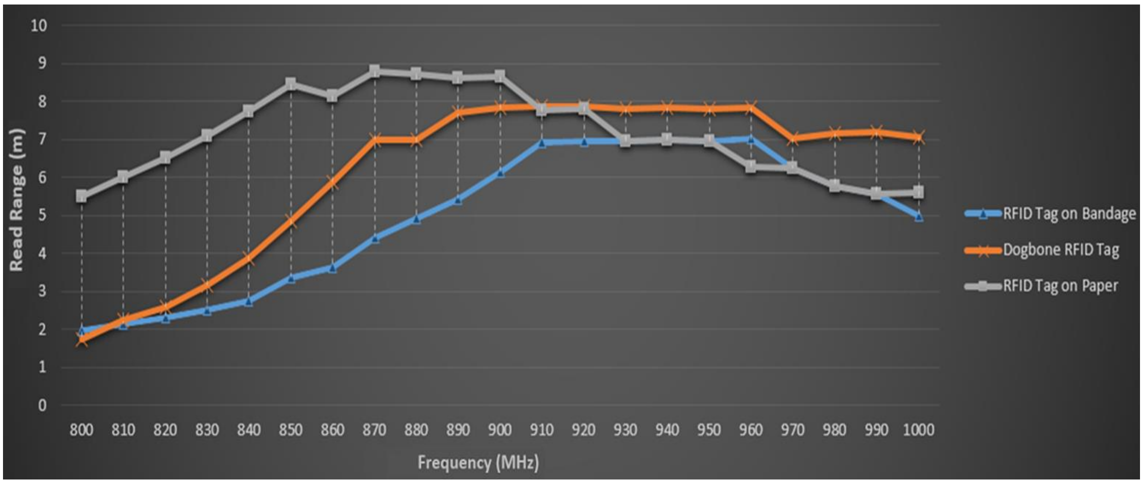

Figure 6-5 *Read Range Difference Between Different RFID Tags*

6.3 Power on the tag forward

Although tag needs constant amount of power to turn on but power provided by the transmitter to turn on tag vary, it depends upon power transmitted by the reader, losses of environment, power received by tag and antenna gain with respect to particular frequency. The minimum amount of power required by transmitter to turn on RFID tag at a particular frequency is known as the Power on tag forward [41].

In this measurement, the first test antenna is used to measure the power required to turn on the tag inside an anechoic chamber, then Dogbone RFID tag by Smartrac followed by others are used. Results are shown in figure 6-6, for the Dogbone RFID tag measurement show it require the minimum power of -15 dBm to turn on tag from 905 to 950 MHz, while for RFID tag on paper minimum power is same -15dBm but from 870 to 900MHz. In the case of RFID tag on bandage power to tag forward move, around -14dBm from 910 to 960 MHz.

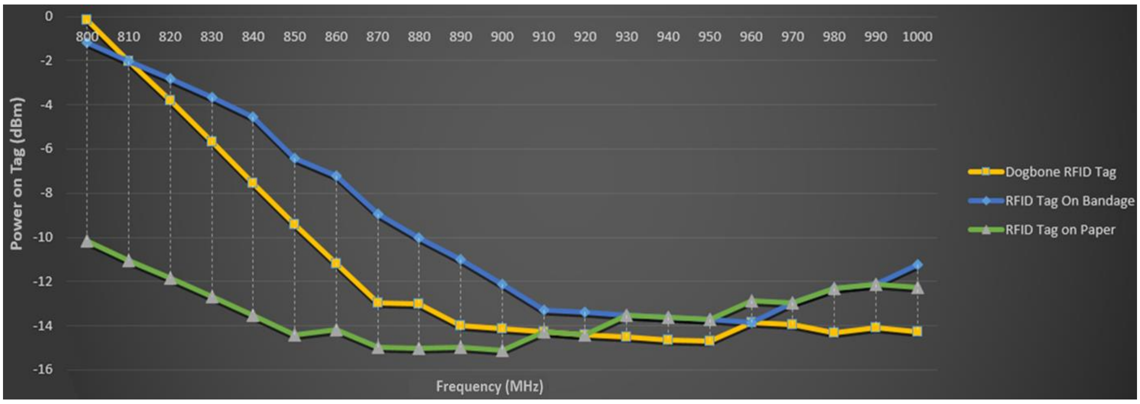

Figure 6-6 *Power on RFID Tag Forward*

6.4 Power on Tag Reverse

After receiving the power from the reader, RFID tag sends back signal to the reader, energy is lost due to environmental losses, usage of power by RFID tag gain and directivity of the antenna. Power on tag reverse is also known as return power, it is power received by the RFID reader back from the tag at a particular frequency. [41]

In this measurement power received by RFID tag back to the reader is calculated, Tagformance anechoic chamber is used for this measurement. Results shown is figure 6-7 present return power from the Dogbone RFID tag, RFID tag on paper and RFID tag on bandage.

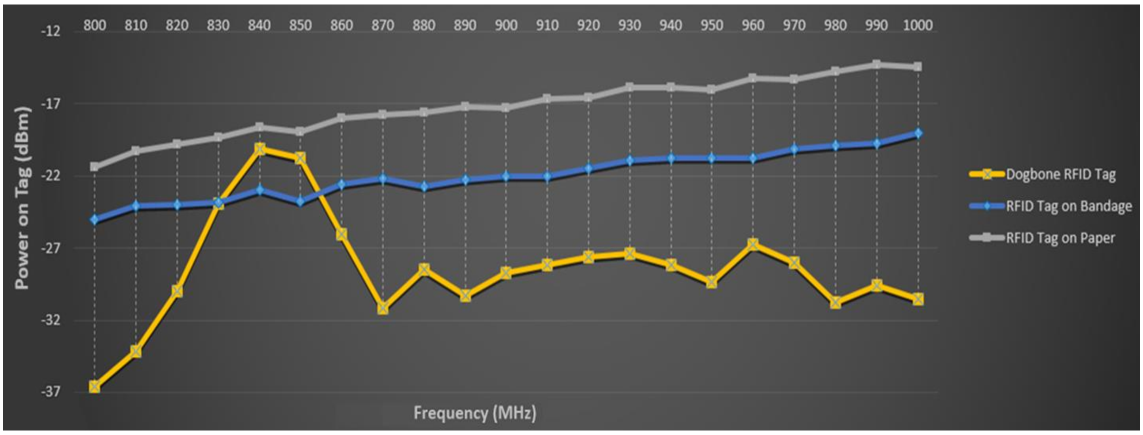

Figure 6-7 *Power on RFID Tag Reverse*

6.5 Effect of Environment

After successfully analyzing tags using Tagformance, tags are placed on the front of the Mercury M6 reader utilizing Thermophore stand in order to analyze their performance. Tags are placed in the way that the polarization of tags matches polarization of the reader antenna. First, we calculated the RSSI value of tag by placing them at the distance of 100cm and providing power of 10dBm but after analyzing all results, it is discovered that this distance is too long and power is too small for making comparisons of sequels for all results. For the Dogbone RFID tag distance is reduced to 25 cm and power to 22dBm after decreasing the distance by gradual steps and increasing power by the steps of 4dBm, decrease in the distance is performed after analyzing the performance of the tag placed inside the bandage with high moisture conditions.

First RFID tags are placed on Thermophore stand as shown in figure 6-8 and their RSSI values are measured. After completely analyzing the effect of air, tags are placed on the body. Four parts of the body are selected for the measurement, which is completely different in term of structure and body type as shown in figure 6-9. Body parts include arms, inner side which is more linked to the flesh having no hair, outer side of the arm, which is closer to the bone and also having flesh, front side of leg, which is hairy and closer to the bone having a lesser amount of flesh than the outer side of arm and last is forehead which quite hard contains flesh inside but more attached to the outer bone of the head.

Figure 6-8 *Thermophore Stand for Placing RFID Tag*

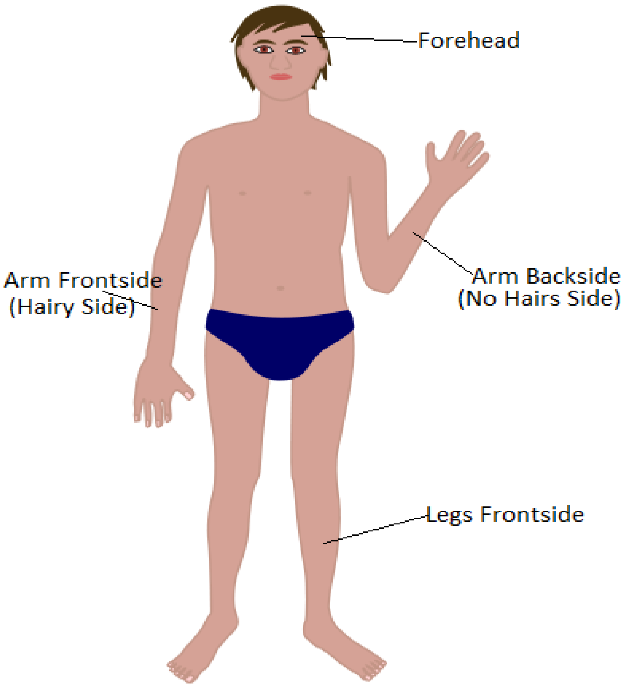

Figure 6-9 *RFID Tag on Different Parts of Body*

When Dogbone RFID tag is placed on different parts of body its value of its RSSI decreased, RSSI value of tag alone on thermophore stand is 51dBm.

In the same way, RFID tag on paper and bandage is analyzed on thermophore stand and on different parts of the body. Placement of tags are also the same including front side of the arm, back side of arm, front side of leg and forehead. The figure 6-10 below show comparison of RSSI values with relation to the placement of thermophore (open air) and different parts of body.

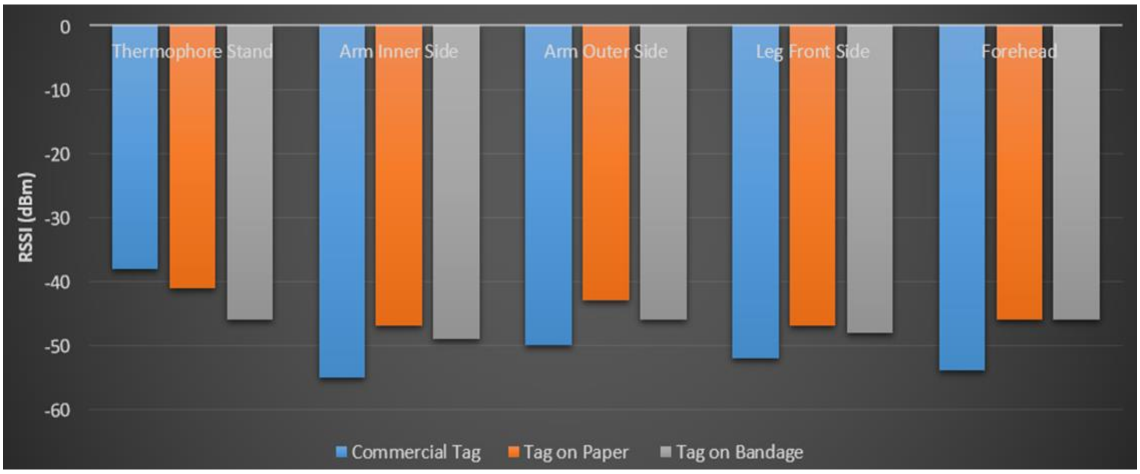

Figure 6-10 *Change in RSSI Value of RFID Tags by Changing Placement*

We can see from the above graph, RFID tags lose their maximum performance when they are placed on the inner side of arm, performance of tags are maximum when they were alone on Thermophore stand. On the other hand, performance of commercial Dogbone RFID is most affected by the placement on the body.

6.6 Effect of Bandage

Effect of bandage on RFID tags is analyzed in this section.

6.6.1 Effect of Bandage on Body

To analyze the effect of bandage on the RFID tags, on the inner side of arm tags is placed, which do not contain any hair. The inner side of the arm is selected because performance of almost all RFID tags stayed there at the lowest level in comparison with all other places on the body. The First Dogbone RFID tag is placed on the inner side of the arm and RSSI value is measured, then tail end of the bandage is placed on the front of the tag and RSSI value of the tag is noted again. The bandage is folded on arm later and a number of turns of the bandage around arm increased step by step after measuring the values for each step; measurement gives us a clear overview of the bandage effect on the RFID tag.

Following the same way RFID tag on paper and RFID tag on bandage is placed on the inner side of the arm and RSSI value of the tag is measured by increasing turns of the bandage. It is quite interesting to note that RFID tag on rayon bandage is not that much affected by a number of turns of bandage in comparison to other tags. This behavior also gives us idea that covering tag by the same kind of material provide us much better performance than any other material used for the tag, but this thing needs affirmation by testing this method on any other kind of tags.

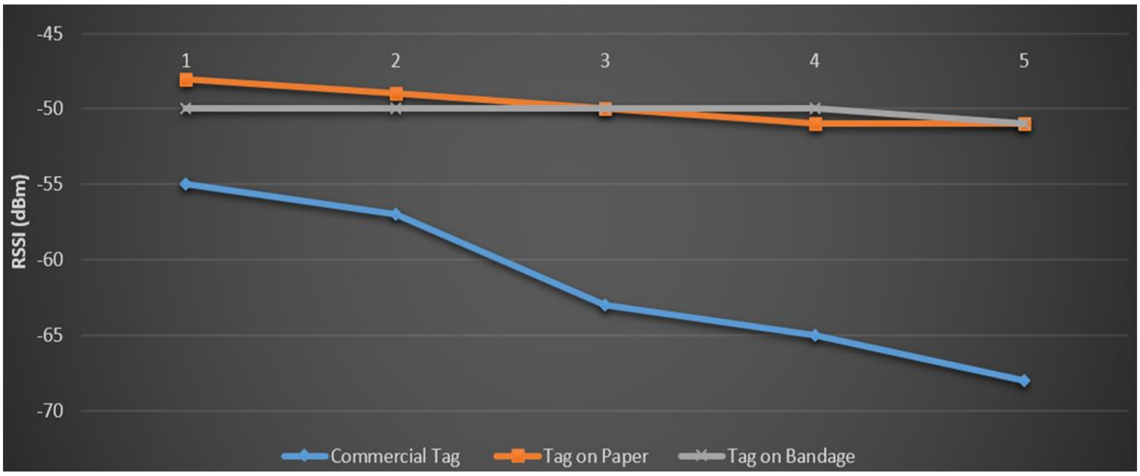

***Figure 6-11** Effect of Bandage on Different RFID Tags*

In the above figure, 6-11 we can see the performance of RFID is affected maximum by commercial tag and almost stayed constant by the tag on bandage.

6.6.2 Effect of Bandage inside Anechoic Chamber

To analyze the effect of bandage on the read range of RFID tags first Dogbone RFID tag is placed in an anechoic chamber and change in the read range of RFID tag with respect to each turn of the bandage is calculated, later on, other tags are used to analyze the effect. The results of change in read range by turns of the bandage are almost similar to the effect of bandage on body calculated using RSSI value; First Dogbone RFID tag is analyzed and its read range decrease by increasing number of turns. The effect of reading range on the turns of the bandage is shown in figure 6-12.

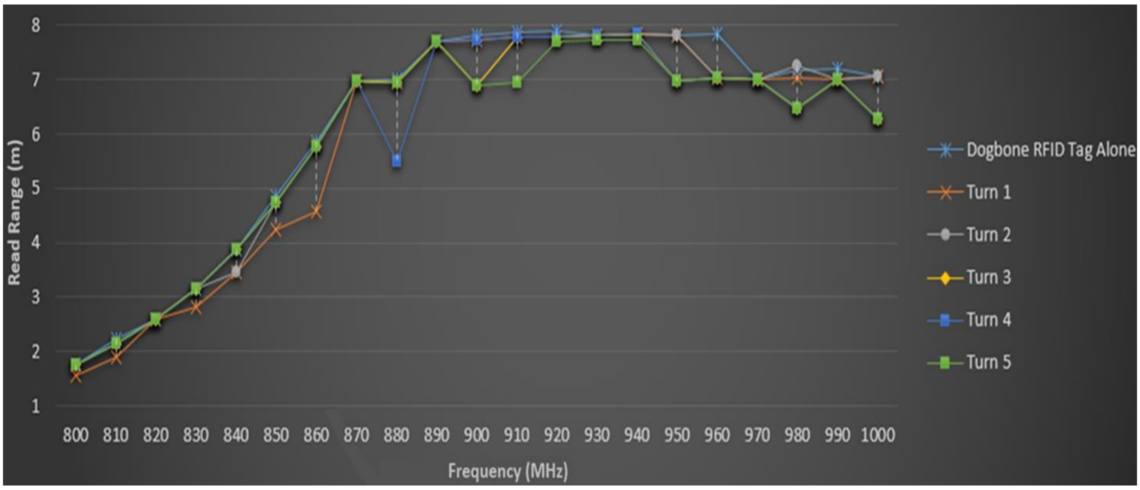

***Figure 6-12** Read Range of Dogbone RFID Tag by Increasing Number of Turns*

Read a range of RFID tag on paper shown in figure 6-13 also follow the same pattern, it looses its read range by increasing a number of turns. Following the same procedure to check the effect of read range, tag is placed in an anechoic chamber and then number of turns are increased after measuring read range at each step.

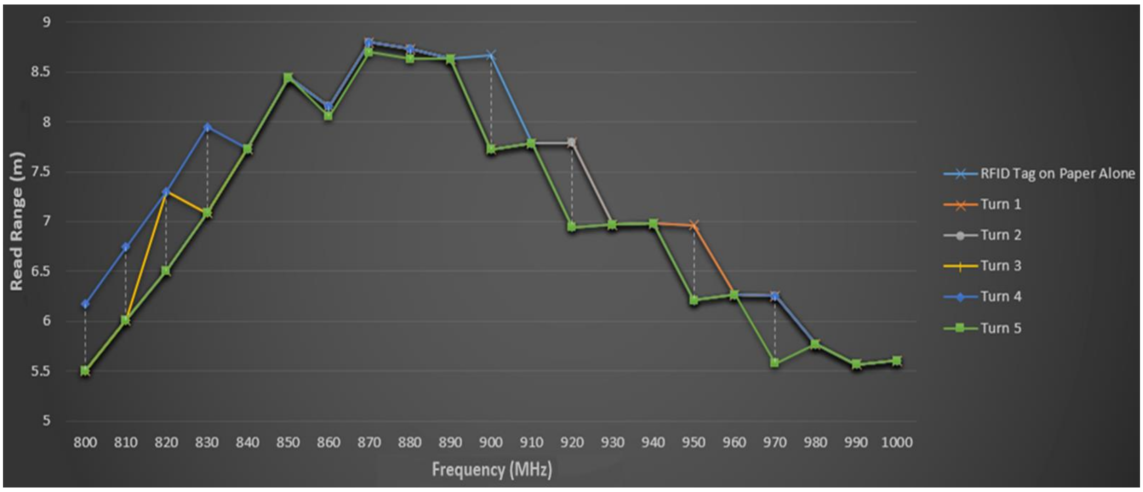

Figure 6-13 *Effect of Turns of Bandage on Read Range of RFID Tag on Paper*

Read range of RFID tag on bandage is shown in figure 6-14. Read range of RFID tag on bandage has small change in comparison to other tags and same for frequency between 900 to 920 MHz. Read range of RFID tags on bandage have sudden peaks at second and third turn of bandage around 930 and 940 MHz.

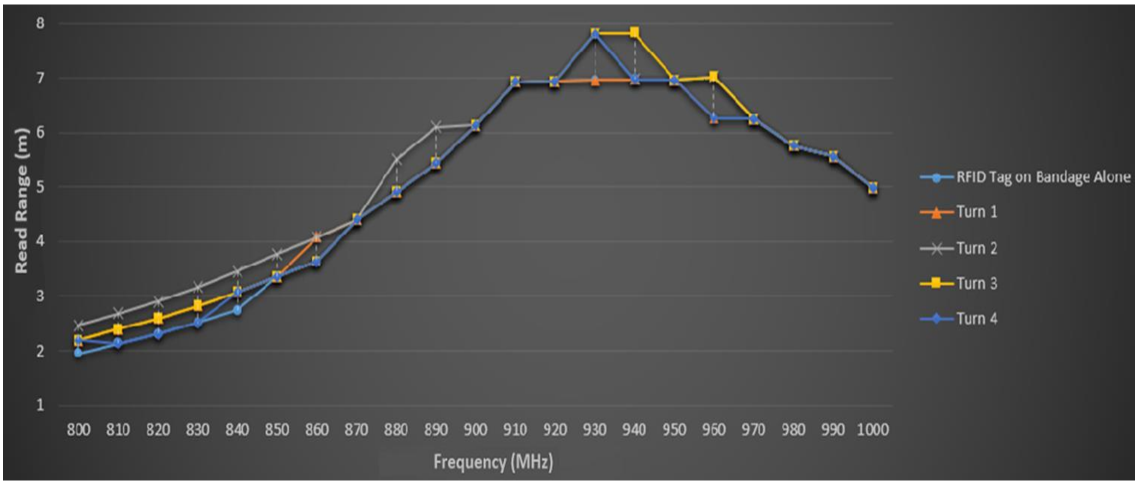

Figure 6-14 *Effect of Turns of Bandage on Read Range of RFID Tag on Bandage*

6.7 Effect of Humidity

Last step of measurement, which is also an important one as it can help a number of doctors to decide when they can change the bandage of person without removing bandage to check the condition of injury.

6.7.1 Effect of Humidity on RSSI of RFID Tag

After analyzing RFID tags with respect to the environment, tags are placed inside bandage on the inner side of arm with five turns. Humidity measurement of RFID is performed by adding small droplets of water and measuring the humidity level using RFID tag inside bandage, which is first, analyzed using humidity measurement device.

The result shows that the RSSI value of the Dogbone RFID tag falls drastically by adding water, it goes from -68dBm at 30% humidity to -73dBm at 63% by adding droplets twice. Dogbone RFID tag appeared much sensitive to the water droplets, adding water droplets when tag is attached on the body make it almost undetectable.

Later on, effect of humidity is analyzed for RFID tag on the paper and table 3 below shows the relation of RSSI values to the humidity level of RFID tag on paper inside bandage. RSSI value of RFID tag on paper inside bandage goes from -51dBm to -52dBm when humidity level is increased from 27% to 58% and when humidity level is increased further to 75% its RSSI value goes to -53dBm.

Table 3 *Humidity Level Inside Bandage with Respect to RSSI Value of RFID Tag on Paper*

Humidity	RSSI(Paper Tag)
27%	-51dBm
58%	-52dBm
75%	-53dBm

Finally, effect of humidity on RFID tag on bandage is analyzed as shown in table 4. When humidity level inside bandage is increased from 27% to 58%, RSSI value goes from -51dBm to -53dBm and this value stay unaffected on increasing humidity from 58% to 75%.

Table 4 *Humidity Level Inside Bandage with Respect to RSSI Value of RFID Tag on Bandage*

Humidity	RSSI (Bandage Tag)
27%	-51dBm
58%	-53dBm
75%	-53dBm

6.7.2 Effect of Humidity on Read Range of RFID Tag

To analyze the effect of humidity on the read range of tags, tags are placed in an anechoic chamber and equal droplets are added to all tags are added. The effect of humidity on the read range is almost similar to RSSI, by turning the tag wet read range of RFID tag decreases. Measurement of humidity level inside an anechoic chamber is difficult, so the only effect of droplets is calculated.

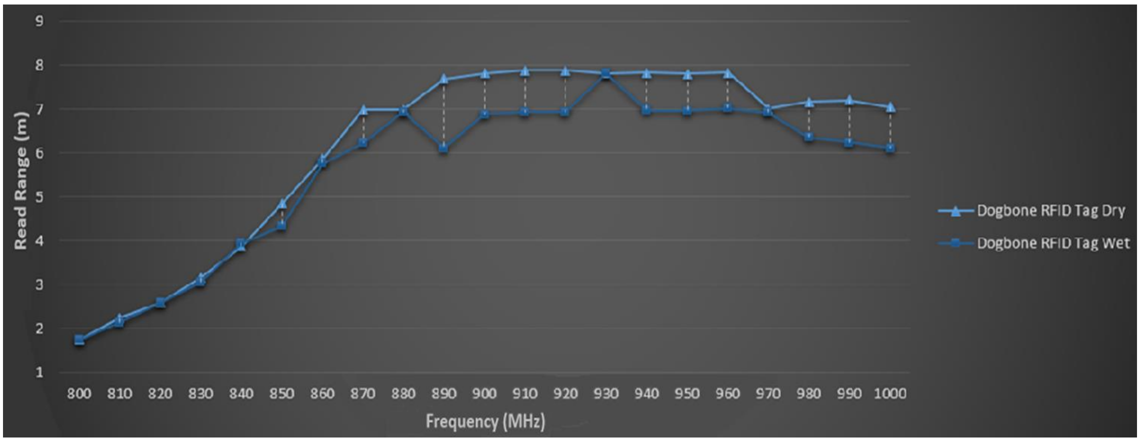

Figure 6-15 *Effect of Water on Read Range of Dogbone RFID Tag*

Read range of all kinds of RFID tags decrease because of water droplets, figure 6-15 show effect of humidity on Dogbone RFID tag, figure 6-16 show effect on the RFID tag on paper and effect of RFID tag on bandage is shown in figure 6-17.

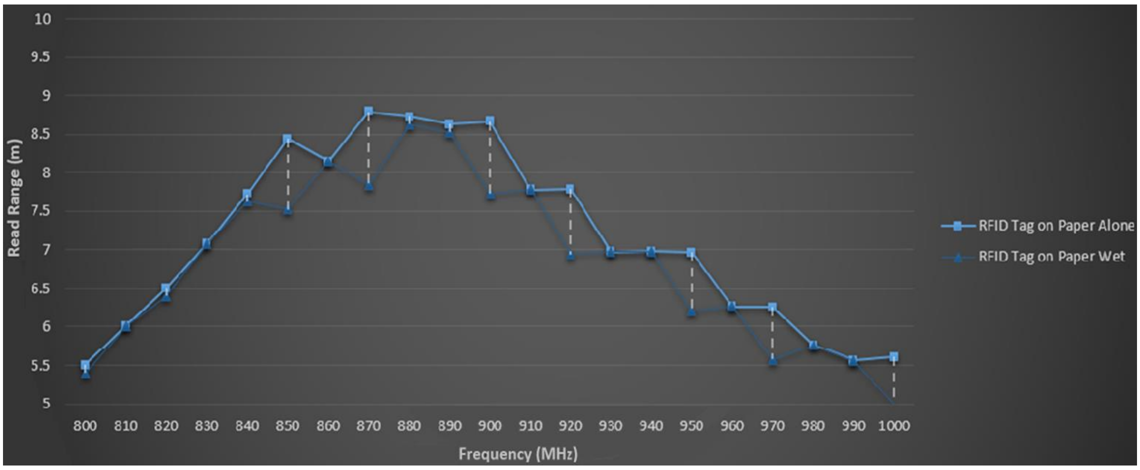

Figure 6-16 *Effect of Water on Read Range of RFID Tag on Paper*

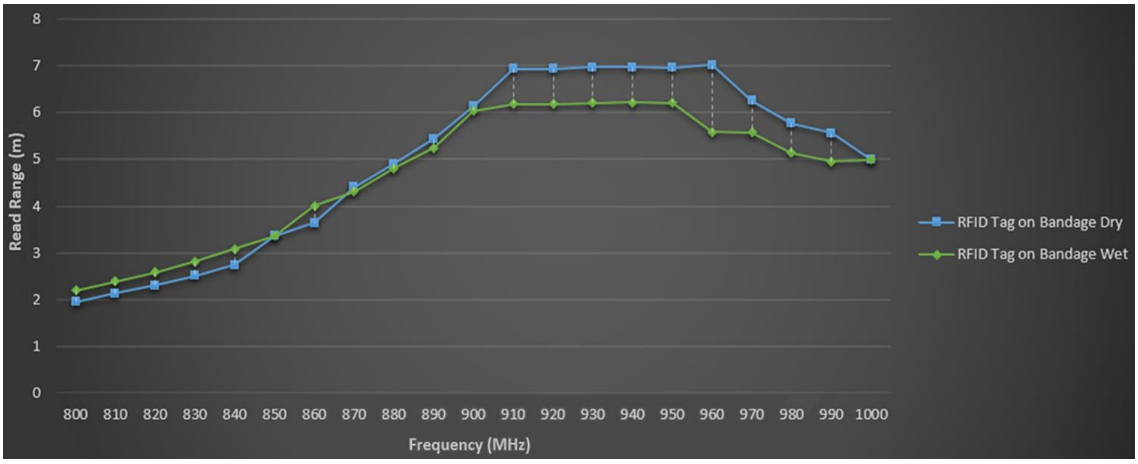

Figure 6-17 *Effect of Humidity on Read Range of RFID Tag on Bandage*

6.8 Analysis

The results tell us about detailed performance evaluation of RFID tags, according to the results RFID tags lose their efficiency by bringing them closer to the body. Permeability and permittivity of the body are different and these parameters are quite effective in deciding the performance of RFID tag. Permeability of human fats is higher than air and its highest in the case of human skin, this trend stays almost same for permittivity. Because of closeness of human skin and fats on the inner side of arms performance seems to be lower, other parts of the body demonstrate the effect of permeability and permittivity in the same way.

Another reason behind the decrease in performance is the change in impedance RFID tag antenna. Human body usually forms capacitance with RFID tag and this capacitance sum up in overall impedance of the RFID tag antenna. Change in impedance can cause impedance-mismatching, change in S parameters and the oscillating frequency of the tag. Small effect on the RFID tag on bandage and large effect on Dogbone RFID tag could be because of insulation. As installation of RFID tag on bandage is thick enough to isolate tag antenna from body in a better way than Dogbone RFID tag.

Bandage effect on the Dogbone RFID tag and tag on paper, as we increase turns of bandage permeability and permittivity contributes more to the RFID tag as well as impedance matching decrease, dwindling the performance of RFID tag. In the case of RFID tag on bandage change permeability and permittivity because of the bandage covering contribute in the same manner as because of the tag itself. Effect of bandage on the change of impedance is also minimized, which could be the reason behind the minimum effect on the performance of RFID tag on increasing the turns of the bandage.

Almost same kind of phenomenon occurs by changes in humidity level around the tag, as a water drop creates capacitance between themselves and RFID tag antenna, causing a change in impedance, affecting the performance.

7. CONCLUSION

In the Master's Thesis, performance evaluation of the Passive RFID tags utilizing commercial tag, tag fabricated on paper and a tag on bandage piece is performed. Effects of different parts of body, turns of the bandage and humidity on the RFID tags are analyzed.

Basic target behind measuring these effects is to know about the condition of humans and animals injury inside the bandage. Humidity level is one of the most visible sign to determine the condition of injury. Doctors usually open the bandage to check the condition of injury. In unhealthy conditions, opening and closing of bandage just to analyze the condition of injury can cause more bad than good. By utilizing RFID tag inside bandage injury condition can be easily analyzed by interpreting performance of tag to humidity level inside the bandage.

Three kinds of analysis is performed, one utilizing the commercial Dogbone RFID tag is analyzed in details. It is observed that the performance of RFID tag is lowest on the inner side of the arm, which is not hairy in comparison with the other side, front side of leg and forehead. By increasing turns of the bandage performance level of the tag falls, increasing humidity around the tag also decrease performance of tag.

Two other types of RFID tags are developed in a lab using silver brush painting to analyze performance in details. One of the tag is fabricated on paper and another on ray-on bandage. The performance of tag on paper is almost similar to the Dogbone RFID tag, but its performance is more affected by the front side of leg than the inner side of the arm. The tag on paper also loses its performance by increasing the number of turns of the bandage but this effect is not that much drastic than Dogbone RFID tag. Increasing the level of humidity decrease performance of the tag with constant intervals, these intervals allow us to interpret performance of the tag in to a certain range of humidity level inside the bandage.

For the RFID tag using rayon bandage, although the effect of body parts remains similar to Dogbone RFID tag, but by the increasing number of turns around the RFID tag made by bandage itself, the performance of the tag stayed almost unaffected. The performance of the tag also dwindles with some intervals by increasing the humidity level inside the bandage.

One of the most interesting effect analyzed in this thesis is the performance of RFID tags that are developed using a bandage. RFID tags fabricated on bandage almost work in the same manner under bandage as they work normally, this property of RFIDs can allow us to save the performance issues when they are working in the covering created by some other material but this need further studies for complete judgment.

For the further studies, effect of different materials on bandages and different kinds of tags can be studied on different parts of the body, other than already examined. In addition to that, some relation of body parts to the performance of RFID tag need to be evaluated, as this can help us to determine the effect of a body part on the RFID tag without applying performance evaluation. The phenomenon of no effect on the performance of RFID tag to the turns of the bandage also needs to be tested using different tags, as this can give us a simple solution of packing the tags, keeping the best possible performance.

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