EVALUATION OF ISO 18000-6 TYPE-C CLASS 1 GENERATION 2 RFID PROTOCOL ARTIFACTS

by

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ABSTRACT

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In this thesis, we have identified the effect of changes ISO 18000-6 Type-C also known as EPC Class-1 Generation-2 RFID protocol's parameters on the performance of the RFID system. The protocol parameters that changing in the research are Tari, operating frequency, pulse width and modulation index at the constant transmitted power. All the parameters do fall outside the range of the EPC Class-1 Generation-2 protocol; but the power transmited by the RFID reader is under FCC regulations. The research gives detailed behavior of the RFID signal propagation.

A part of this research is to build a high performance software define RFID reader. The RFID reader is being implemented on the National Instruments PXI-RF and FPGA hardware platform and uses NI LabVIEW 8.5 as the software platform. The reader uses the state-machine based software architecture and VISN RFID FPGA toolkit v.1.2.

The experiments were designed to eliminate the effects of the tag's antenna design. The experiments were carried out on four different types of tags, and a general theory is proposed in order to study the deviation of the theoretical data and experimental results. All the experiments are conducted in the anechoic chamber and later two experiments were also carried out in the lab conditions. Study also shows the effect of Tari and frequency on the power received from the tag and time between the tag's response after the reader finishes its command.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

RFID SYSTEMS BASICS

1.1 Introduction

After the commercialization of the internet infrastructure we have instant access to information from a wide variety of sources. Information can be classified in many different ways viz. virtual and physical. in one of the cases it describes the physical objects, states and events. Through the Internet and its associated infrastructure, the problem of delivering information has been solved; whereas the problem of capturing information has not. Current solutions require manual data entry, or manual barcode scanning. More complex and sophisticated solutions are automatic scanning barcodes and machine vision system. The manual solutions are costly, time consuming, and inaccurate at times The current automatic solutions can also be costly. complex and often require significant constraints on the object orientation and environment. Radio frequency identification (RFID) systems are potential solution. In case of RFID system, through attachment of the transponder or tag to the object and the infrastructure of networked reading devices or interrogator, the physical information can be automatically recorded. A class of RFID systems, passive RFID, allows wireless powering of the tags. Passive RFID systems have potential to be very low cost and less constrained automatic data capturing and does not need line of sight communication.

1.2 Brief History of RFID

The RFID technology has been developed to a greater extend since the last decade especially as the wireless data-collection technology after its invention in

1940's. [72][47][12] The first commonly accepted use of the RFID related technology was during World War II. [25] In their and their allies aircraft, the British military installed transponders capable of responding with an appropriate identification, when interrogated by a signal. This technology did not allow determination of exact identification, but rather is an aircraft was their own. This transponder technology, called Identity Friend or Foe (IFF), has undergone continued development and later generations are still used in both military and civilian aircraft.

In 60's and 70's, in an effort to track the military goods safely and securely the technology started evolving. In early 80's railroad companies began using the technology for tracking their railcars. In mid 80's large semiconductor companies became involved, and the there was shift towards the performance improvement, size and cost reduction. In late 80's and throughout 90's as the performance improved, and size and cost decreased, new application emerged, viz. automatic highway tolling, access control, airline baggage handling, inventory management and asset tracking, smart cards, automatic automoblie locking and security system [64][30][68][25] Because of the wide scale development of RFID application around the world there came a need to develop standards and establish regulation. Efforts to develop standards for RFID in various applications are continuing. Standards, though able to drive increased adoption and subsequent reduced costs, run the risk of shifting competition, innovation and thus continued improvements in the technology.

1.3 Classification of RFID systems

RFID systems can be classified in many ways but the two main categories are

- Operating frequency range
    1. LF (9 - 135 kHz)
    2. HF (13.56 MHz)

3. UHF (862 - 870 MHz)
4. SAW (2.45 GHz)

- Type of communication
  1. Passive RFID System
  2. Active RFID System
  3. Semi-Passive and Semi-Active RFID System

1.3.1 Operating frequency based RFID system

The frequency is the important parameter which decides the type of RFID systems, by the type of the frequency it comes to operation of the RFID systems. Near field vs. Far field. Typically radiation from these devices can interfere other radio frequency devices, for this reason it is necessary to allocate specific bands for their use [77] the power level and the bandwidth of operation is regulated by FCC in the United States and ETSI in Europe MPT's radio law in Japan.

Typical LF and HF RFID systems are near field operated in the near field range. In the near field electromagnetic fields are reactive and quasi-staic in nature. The information is transfer by either capacitive or inductive coupled systems. Whereas UHF and SAW RFID systems are far field operated systems where data is transferred using transmission, propagation and reception of electromagnetic waves.

1.3.2 Type of communication based RFID system

This classification is based on the type of tags used for communication. Currently there are four types available in the market as below:

1. Passive Tag
2. Active Tag
3. Semi-Passive Tag

4. Semi-Active Tag

The passive tags are defined as the tags that carry out passive communication and have no on tag power sources. In this case, passive exemplifies the modulation of the carrier wave from the reader in a back scatter mode. The process is fairly simple but require highly intelligent ACIS chip design. Major consideration for this type of communication are the powering of the tag using the carrier wave and then use of the powered integrated circuitry to modulate the carrier wave to effectively transmit the tag's object identifier. A semi-passive tag is defined as a passive tag, as it communicates passively but it has an on tag power supply, which is used to run the logic on the chip and activate sensors if any available. We can see what an on board power supply can do, it enriches the tag to do lot more than just identify itself. The last type of the communication is active communication where active tags are used. These tags uses on board power supply in their communication. Active tags are best suitable for integrating multiple sensor and long range type application. The sub category of the active communication is semi-active, which uses active communication but is communicates when user wants it, i.e. communication is initiated manually.

1.4 Components of The RFID System

A typical RFID system consists of three main components: Tags, Readers, and Middleware/Information Systems, as shown in Figure. The object which needs to be automatically identified is tagged with the RFID tag. The readers are placed in locations where the tags need to be read for the required applications. Readers can be either have a fixed location, like a cellphone tower, or they may be mobile, allowing them to be brought to the tags. Readers read the data that is stored on the tags, often, an object identifier such as the Electronic Product Code (EPC) but possibly historical or other cached information. The readers communicate their captured information to

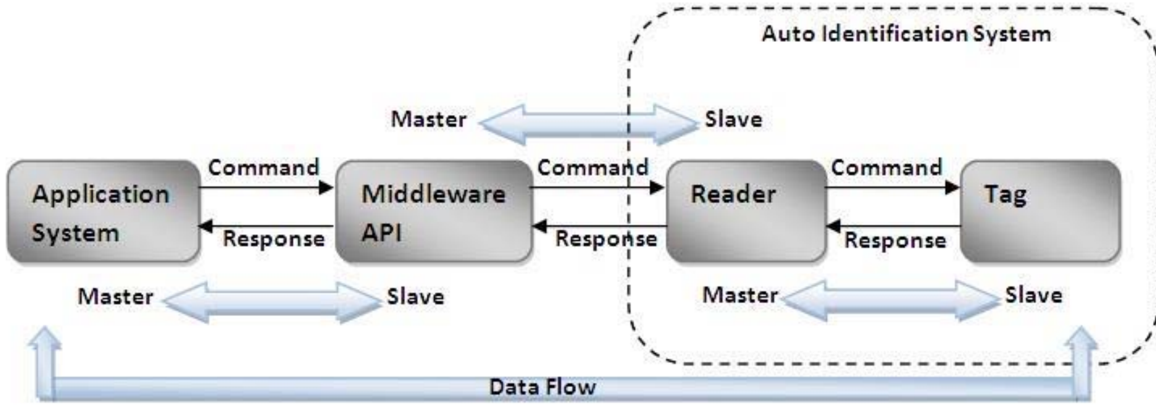


Figure 1.1. Typical RFID System.

[73]

the information system via middle-ware. The Information System utilizes the data obtained from the tags for various applications. A comprehensive of RFID technology is provided in [26]

1. Tag or Transponder: Is on the object that is to be identified and is the data carrier of the system.
2. Reader or Interrogator: Read the data from and writes data to tag.
3. Middleware: Acts a bridge between readers or reader and the information system.
4. Information System: Utilizes the data send by the reader from the tag and runs various application.

Tags may be either active, passive or semi-passive. Active tags have an on-tag power supply while passive tags obtain their power from the signal transmitted by the reader. Semi-passive tags have their own power supply such as a battery to power the tag IC however they use the reader signal to communicate the data back to the reader. An

RFID reader interrogates the tags using radio frequency waves for the data stored in them. Readers communicate with tags using radio frequency waves which allow medium read ranges for passive tags and large read ranges for active tags depending upon the desired application. The radio interface allows readers to communicate with tags even in hostile and non-Line Of Sight (LOS) environments. The data received by the reader is communicated to an information system for data processing purposes.

1.4.1 RFID Reader

The RFID reader or interrogator is a radio transceiver that sends commands and retrieves information that is stored in the tags. The reader emits energy using radio waves to activate and establish communication with the tag. The amount of power delivered by the read is governed by FCC regulation in the United States and ETSI in Europe. [28] [36] The reader generates either amplitude or frequency or both modulated RF waves. The antenna used by the reader sends out the modulated data-carrying signal to query the tag. The reader transmit continuously while listening to tag's response. Since the RFID reader also acts as a receiver, data coming from the tag is received and decode as well. The information received by the reader from the tag is decode and sent to the information system via middleware for further processing.

Since RFID is widely used technology all over the world, there are certain regulatory boards like FCC, ETSI and ITU that governs security issues, standards and specifications for spectrum allocation. [28] [36] Safe power levels for secure communication are specified by these regulatory bodies. A radio device that operates in the ISM band (902 - 928 MHz UHF RFID band in the United States) are required to frequency hop every 0.4 sec. [28] In the ETSI (European Telecommunication Standard Institute) RFID reader are specifically require to listen for any communication in the specified frequency range before initializing their communication. This is know as

Figure 1.2. RFID reader by Sirit Inc.

Listen Before Talk (LBT). These regulation imposes restriction on the RFID reader and hence it affects the RFID system performance like maximum operable range, back scatter signal strength significantly.

Another important part of the reader system is the antenna. The antenna plays a vital role in the transmission and reception of the electromagnetic waves. Reader antenna must have high gain and directivity. Commonly used antenna sin teh UHF RFID reader are patch antennas [13] [42] Directivity of an antenna is defined as the ratio the radiation intensity in a given direction from the antenna to the radiation intensity averages over all direction. [16] It is important to have highly directional antenna for transmission as well as reception as the signal transmitted and received by the reader need to be confined to a specific area. The important parameter for antenna is the gain. Although gain of an antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Equation 1.1 of gain incorporates efficiency and directivity.

$$gain = \frac{Efficiency}{Directivity} \tag{1.1}$$

Another definition of gain is in terms of the radiation intensity and the total input power, generally referred as absolute gain. Equation 1.2 shows the mathematical form of gain.

$$gain = 4\pi \frac{radiationintensity}{totalinput(accepted)power} = 4\pi \frac{U(\Theta,\Phi)}{P_{in}} \tag{1.2}$$

The reader antenna must be able to power the tag for it to respond in the case of transmission and must be able to receive and detect the low power backscatter of the tag. Polarization of the antenna is also another important parameter as in the RFID system reader and tag antenna's polarization must match for efficient communication. Other significant parameters are radiation efficiency and impedance matching.

1.4.2 RFID Tag

The RFID tags or transponders are attached to the object which is to be traced or tracked. The main parts of the tag design is the micro chip IC and the antenna. The type of tags it uses to identify the object can classify the typical RFID systems. On that basis, there are five different classes, which are as follows. [26]

1. Passive Identity Tags
2. Passive Identity Tags with inbuilt sensors
3. Semi Passive Tags
4. Active or Ad Hoc Tags
5. Reader

As we can see that the reader can be also classified as the tag; the primary difference between the tag and the reader is that tag doesn't have information system.

Figure 1.3. RFID Tag widely know as Squiggle by Alien Technology.

As they are independent. The tags can talk, can have memory which can be accessed by reader by issuing specific commands, and they also encode and decode the RF signal.

Figure 1.4. RFID Tag widely know as Bow-Tie by Avery Dennison.

The two fundamental operational principles for the passive UHF RFID tags are:

1. The tag's energy harvesting; and
2. The strength and the clarity of the desired backscattered signal from the tag.[72]

In UHG ISO 180006-C Class 1 Gen 2 protocol the tags respond to the reader commands where it used ASK modulation scheme and may use either FM0 or Miller2,4,8 coding scheme. [4][71]

The tag antenna acts as a coupling element of the tag as it couples with the EM field emitted by the reader. The tag antenna plays a very significant role in passive RFID tags, as it absorb energy from the RF carrier wave and power the tag IC for it to communicate data back to the reader. The extend to which power is transfered from the reader's electromagnetic wave to the antenna and from the antenna to the microchip is provided by the coupling efficiency of the antenna. The impedance matching between the tag IC and the antenna is significant as power transfer is dependent on the matching circuitry.

The efficiency with which electromagnetic waves are reflected by the tag antenna is given by its reflection cross section. Tag antenna is given by its reflection cross section. Antenna that is tuned (resonance) to a particular frequency has a larger reflection cross section at that frequency. Apart from being object identifier, tag also have many other functionality, viz. on board memory, some tags can run anti-collision algorithm, which reduces tag on tag collision and hence are more reliable in data communication.

1.4.3 Middleware and Information System

The Middleware and Information System are the most vital parts of the RFID system. All the data that is read by the reader or interrogator is processed at the Information system. Information system makes the data which is on the tag to actual information. There are various application specific programs running on the Information system, which integrate the reader data and trigger application specific events. There is another system block between the reader and the information system, known as middleware, this sub system supports efficient collection of data obtained by the reader and reduce the data redundancy in the Information system. Some of the important challenges faced by the the middleware are filtering out all the unwanted data or ghost reads, data mining and sorting making the middleware customizable for every reader.

The important functions of an RFID middleware are processing the raw data obtained from the readers, providing an interface to manage multiple readers and encapsulate all the applications as it is possible that different data needs to be routed to multiple or same applications. Middleware usually provides the reader management for easy configuration and deployment of the RFID readers. They can also be integrated with sensors or some other data acquisition source. Data management is a very critical requirement, if not done it will increase the data traffic at the information system. Middleware must filter out redundant and undesirable data and must also route the data to appropriate destinations.

Many implementations of the RFID middleware are possible. Application Level Events (ALE) by EPC Global specification provides a standard interface to obtain filtered, consolidated EPC data from RFID readers and other data sources. [18] The ALE specification provides flexible mechanisms to filter and group raw RFID data. This filtering and grouping capability provides a means to isolate and focus specific and desired applications.

1.5 Influence of Constraints Performance of RFID Systems

We have seen the moan components of the RFID system and how do they interact with each other. The performance specification include range, speed, communication integrity and compatibility. Each individual specification is related either directly or indirectly to all constraints.

1.5.1 Range

Range is constrained by the radiated field strength and electromagnetics. The radiated field is limited by the regulation, and through regulatory and hardware bandwidth constraints, influenced indirectly by communications. Three dimensional orientation and position of the tag relative to the reader environmental influences, and reception, delivery and power consumption of the power by the tag also affects the tag.

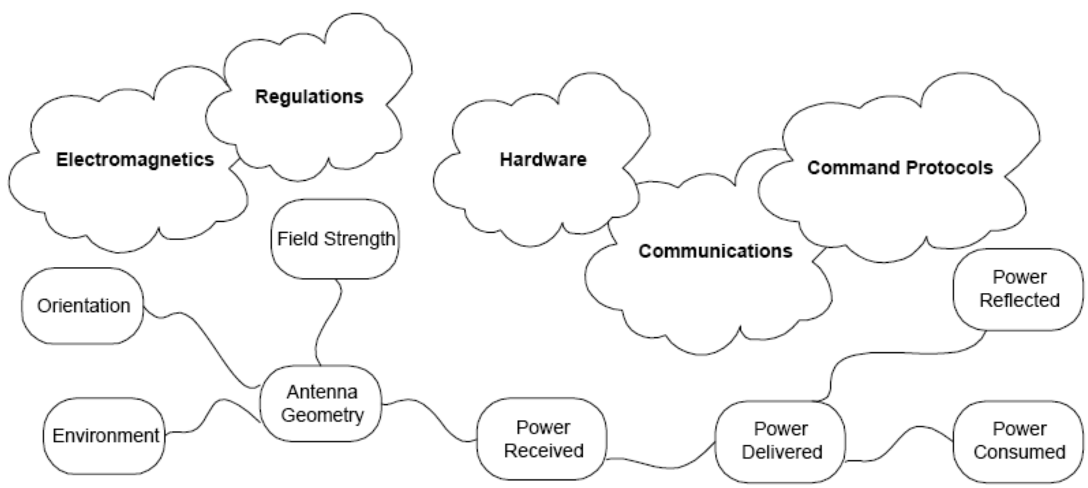


Figure 1.5. Influences on the range and it constraints.
[66]

1.5.2 Speed and Integrity

Another important performance specification is speed of identification. The importance of the speed varies from application to application. In the retail supply chain where there are few reader and many tags speed is the critical requirement whereas in the low traffic area higher speed is not required. Speed is further divided into data rate and identification rate. Data rate is the rate of actual bits trans-

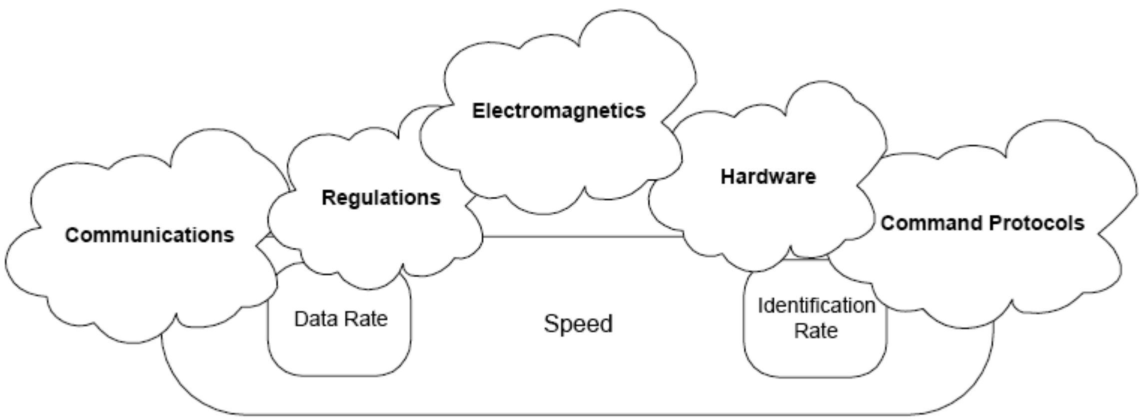


Figure 1.6. Influences on the read speed and it constraints.
[66]

mitted, while the identification rate refers to the performance of the anti-collision algorithm in identifying individual tags. Data rate is not a function of frequency but rather bandwidth, which is regulated by regulation laws and are different in different regions of the world, also the modulation and coding influence the bandwidth. Identification rate refers to tag identification rate per bit rate efficiency. Say, bit rate R and the identification rate T, the protocol efficiency is given by equation 1.3

$$\varepsilon_p = \frac{T[\frac{tags}{s}]}{R[\frac{bits}{s}]} \tag{1.3}$$

The better the anti-collision schemes will have higher efficiency. Anti-collision protocols affects the hardware and indirectly affects the cost of the system.

1.5.3 Standardization and Compatibility

As mentioned, RFID is widely used all around the world. compatibility between different regulatory administrations, and between RFID systems of different vendors in important for the continued adoption of the technology. Some of the compatibility issues are reader talk first where tags are in mute state, and is adopted in the United States. Whereas listen before talk approach is used in Europe. Due do these, there will be different command protocol and different anti-collision algorithm. Standardization fro compatibility is a sensitive issue and can have drastic effect on the adoption of the RFID technology.

CHAPTER 2

PHYSICS OF RFID

RFID systems works on two main frequencies ranges HF and UHF. The electromagnetic waves especially the one used for RFID application operates in this range, hence it is necessary that we understand the fundamental physics of the RFID system. By understanding the physics of RFID we gain the insight on how data is being transferred how the tag harvest power from the reader in the RFID systems. This chapter discusses the physical EM principles behind the propagation of waves in far-field and near-field RFID systems.

2.1 Introduction

An RFID system consider of a reader and tags communicating over the air at the particular frequency. It is important to understand how the reader and the tags communicate and the subtle differences behind the working of the RFID system. The electromagnetic radiation includes radio waves, microwaves, infrared radiation, visible light, UV radiation, X- Rays and gamma rays. Together they form an electromagnetic spectrum as shown in figure below. The following sections provide an overview of the physical principle behind the propagation of EM waves.

2.2 Electromagnetics Fundamental

The electromagnetic radiation laws play an important role in understanding the fundamental working of an RFID system. The foundation for all wireless communication systems is based on the understanding of electromagnetic field theory. Regardless of the form or nature of any wireless communication system, wireless communication is based on the fundamental laws of physics. An electromagnetic wave comprises of two orthogonal time-varying fields: electric and magnetic fields. They form the mathematical basis for electromagnetic wave propagation.

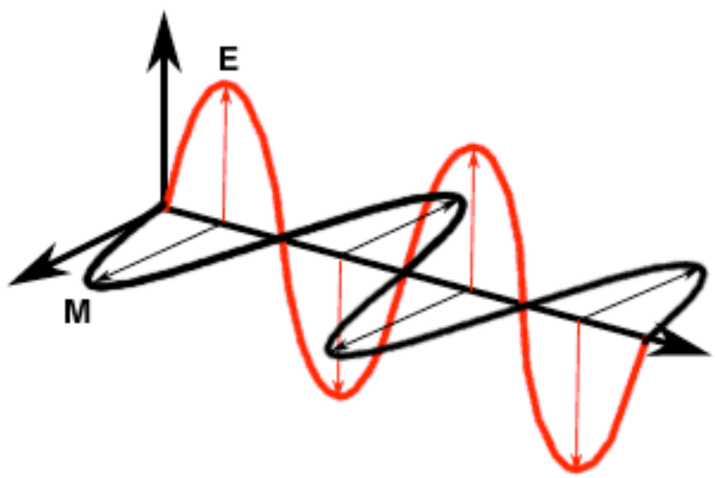


Figure 2.1. Electromagnetic Wave[2].

2.2.1 Electric Field

Electrical field is radiated when a single static charge is accelerated in some direction. It is defined as the vector force exerted on the unit charge. The unit of electric field is Newton per coulomb ($^N/_C$) which is equivalent to volts per meter ($^V/_m$). The strength of the field is given by the ratio of the electric force on a charge at a point to the magnitude of the charge placed at that point. A stationary charged particle in an electric field experiences a force proportional to its charge. Electric field is dependent on the amount of flux or flux density and the permittivity of the material.

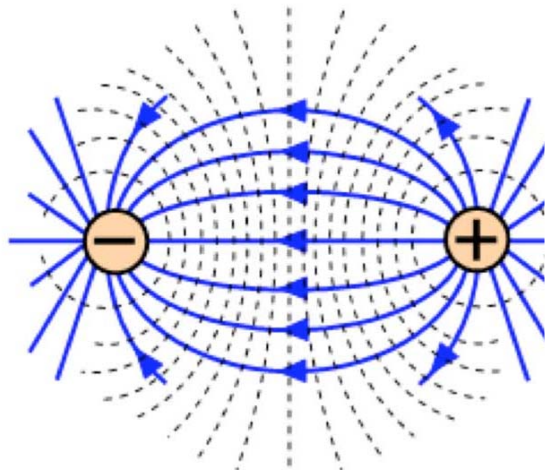


Figure 2.2. Electric Field [2].

$$E = \varepsilon D \tag{2.1}$$

Where, permittivity ε is expressed with respect to the permittivity of the free space and the relative permittivity or the dielectric constant of the material.

$$\varepsilon = \varepsilon_o \varepsilon_r \tag{2.2}$$

where, $\varepsilon_o = 8.854 \times 10^{-12}$.

The energy stored by an electric field is given by

$$U = \frac{1}{2}\varepsilon E^2 \tag{2.3}$$

2.2.2 Magnetic Field

Magnetic fields can be generated by steady current flow through conductor or by magnetic materials. Magnetic field can be expressed as a magnetic field strength (B) and magnetic flux density (H). The attraction and the repulsion property is similar to electrical force between the charges the only difference is electric charges can be separated but magnetic poles always exists in pairs. The unit of magnetic field strength is amperes per meter ($^A/_m$) and the unit for magnetic flux density is weber per square meter ($^Wb/_{m^2}$).

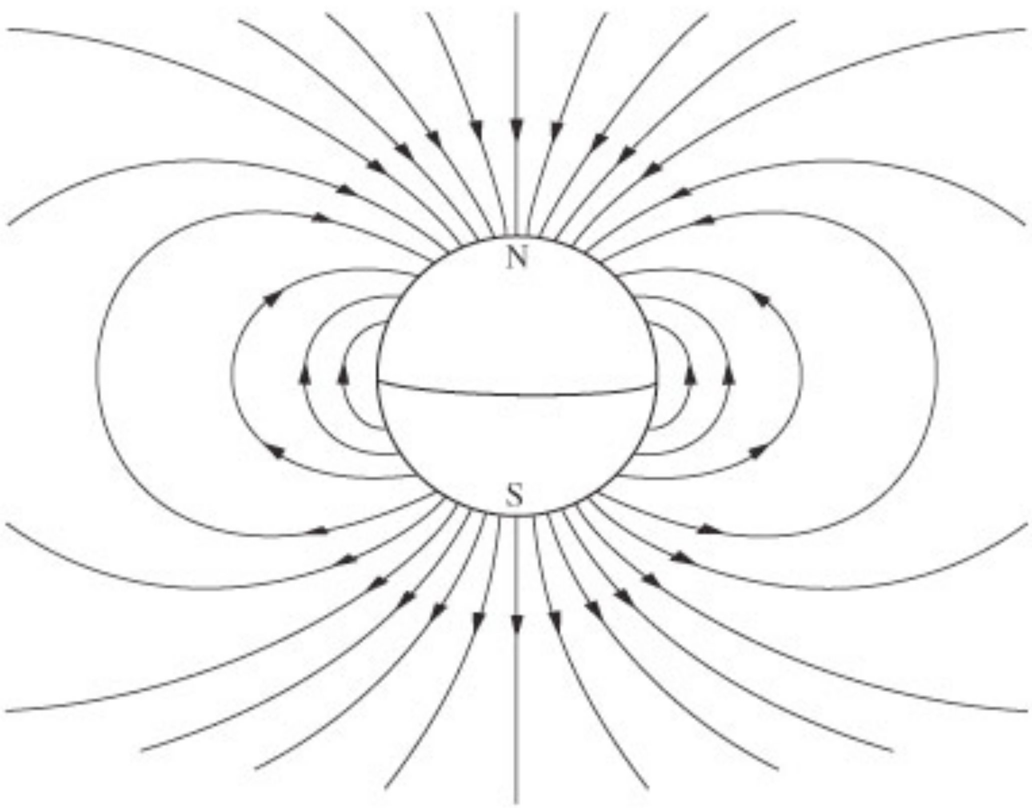


Figure 2.3. Magnetic Field [1].

Magnetic field strength and magnetic flux density are related by permeability of the material (μ) is given in equation 2.4.

$$B = \mu H \tag{2.4}$$

The unit of permeability μ is Henries per meter. Permeability is expressed as relative permeability (μ_r) and permeability of free space (μ_0)

$$Mu = \mu_0 \mu_r \tag{2.5}$$

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

The Biot-Savart Law (also known as Amperes law) quantifies the relationship between the electric current flowing through the conductor and magnetic flux.

$$H = \frac{I}{4\pi} \int \frac{dl \times R}{R^3} \tag{2.6}$$

2.3 Maxwell's Equations

A time and space varying electric field has associated magnetic field. Maxwells equations describe the behavior of there EM fields at every point in space and instant in time relative to the position and motion of charged particles. [1][2] Equations below shows the fundamental Maxwells equations

$$\bigtriangledown \times E = -\frac{\partial B}{\partial t} \tag{2.7}$$

$$\bigtriangledown \times H = J + \frac{\partial D}{\partial t} \tag{2.8}$$

$$\bigtriangledown \cdot D = \rho \tag{2.9}$$

$$\bigtriangledown \cdot B = 0 \tag{2.10}$$

Where is E is the electric field strength ($^V/_m$), D is the electric flux density (C/m^2), H is the magnetic field strength (A/m), B is the magnetic flux density (Wb/m^2), equation 2.7 = faradays law, equation 2.8 = Amperes Law , equation 2.9 = Gausss Law for electric field, equation 2.10 = Gausss Law for magnetic field.

The continuity equation for the conservation of charge and current is given as

$$j\omega\rho + \bigtriangledown \cdot J = 0 \tag{2.11}$$

Together with Maxwells equations, they form the fundamental equations of electromagnetics. Along with Maxwells equations some other parameters that helps understanding the propagation of the electromagnetic wave in the medium which are free-space wave number which is given by

$$k_o = \omega\sqrt{\mu_o\varepsilon_o} = \frac{\omega}{c} = \frac{2\pi}{\lambda} = \beta \tag{2.12}$$

And free-space impedance

$$\eta_o = \sqrt{\frac{\mu_o}{\varepsilon_o}} \tag{2.13}$$

2.4 Polarization

The orientation of the electric field vector of an electromagnetic wave defines its polarity and characterizes the electromagnetic wave. Longitudinal wave such as sound wave do not exhibit polarization. In the most general case the locus of the electric field is an ellipse and the wave is called elliptical polarized wave. Under certain circumstances the ellipse may degrade to a circle or a straight line, in that case the polarization state is then called circular or linear respectively. The linearly polarized wave has the angle between Ex and Ey either 0 or 180. Whereas the circular polarized wave is either right handed or left handed.

2.5 Laws Governing Electromagnetics

It is important to understand the laws governing electromagnetics to understand the physics behind RFID systems. Coulomb's Law, Faraday's Law, Gauss's Law and Ampere's Law will be discussed in the following section.

2.5.1 Coulomb's Law

The magnitude of the electromagnetic force between two point charges is directly proportional to the product of the magnitudes of each charge and inversely proportional to the square of the distance between the charges.

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} \tag{2.14}$$

where F is the electostatic force, q1, q2 are the point charges, r is the distance between the point charges and e0 is the permitivitty of free space.

2.5.2 Faraday's Law

Faraday's law states that the induced electromotive force in a closed loop is directly proportional to the time rate of change of magnetic ux through the closed loop. The differential form of Faraday's law is one of the four Maxwell's equations.

$$E = -N\frac{d\phi_B}{dt} \tag{2.15}$$

where E is the electromotive force, N is the number turns in the wire and B is the magnetic flux. The circulation of the electric field vector E around a closed contour is equal to minus the time rate of change of magnetic flux through a surface bounded by that contour, the positive direction of the surface being related to the positive direction of the contour by the right hand rule.

2.5.3 Ampere's Law

Ampere's law relates the integrated magnetic field around a closed loop to the electric current passing through the loop. The circulation of the magnetic field vector H around a closed contour is equal to the sum of the conduction current and the displacement current passing through a surface bounded by that contour, with again the right hand rule relating the senses of the contour and the surface.

$$\bigtriangledown \times B = \mu_o J + \varepsilon_o \mu_o \frac{\partial E}{\partial t} \tag{2.16}$$

The displacement current was added to the Ampere's Law by Maxwell and the corrected law is stated in the unified Maxwell's Equations on electromagnetic theory.

2.5.4 Gauss's Law - Electric Flux and Magnetic Flux

Gauss's law is the electrostatic application of the generalized Gauss's theorem giving the equivalence relation between any flux and electric charges enclosed within a closed surface. The differential form of Gauss's law forms the basis of Maxwell's equations. The total electric flux (defined in terms of the D vector) emerging from a closed surface is equal to the total conduction charge contained within the volume bounded by that surface.

$$\phi = \oint_s E \cdot dA \tag{2.17}$$

The total magnetic flux (defined in terms of the B vector) emerging from any closed surface is zero.

2.6 Antenna

According to IEEE definition an antenna is the a means for radiating or receiving radio waves. [16] In other words, it is a guiding device that will transport the electromagnetic energy from the transmitting source to the radiating element or from the receiving element to the load. The reflected waves from the interface create, along with the traveling waves from the source towards the antenna, constructive and destructive interference patterns , referred as standing waves. Field of antenna is vigorous and dynamic and it plays a very important the field of RFID. Reader antenna must me highly sensitive and very directional whereas tag antenna must me wide-band in order to universal. Some types of antennas are

- Wire Antennas
- Aperture Antennas
- Array Antennas
- Mircostrip Antennas
- Reflector Antennas
- Lens Antennas
- Fractal Antennas

The basic principle to create radiation is that there must be a time-varying current or an acceleration of the charge in the radiating element and vice versa fro receiving antenna.

CHAPTER 3

RELATED WORK

Wireless systems consist of multiple blocks and there is different hierarchy within them. The basic block diagram of the communication system is shown in Figure 3.

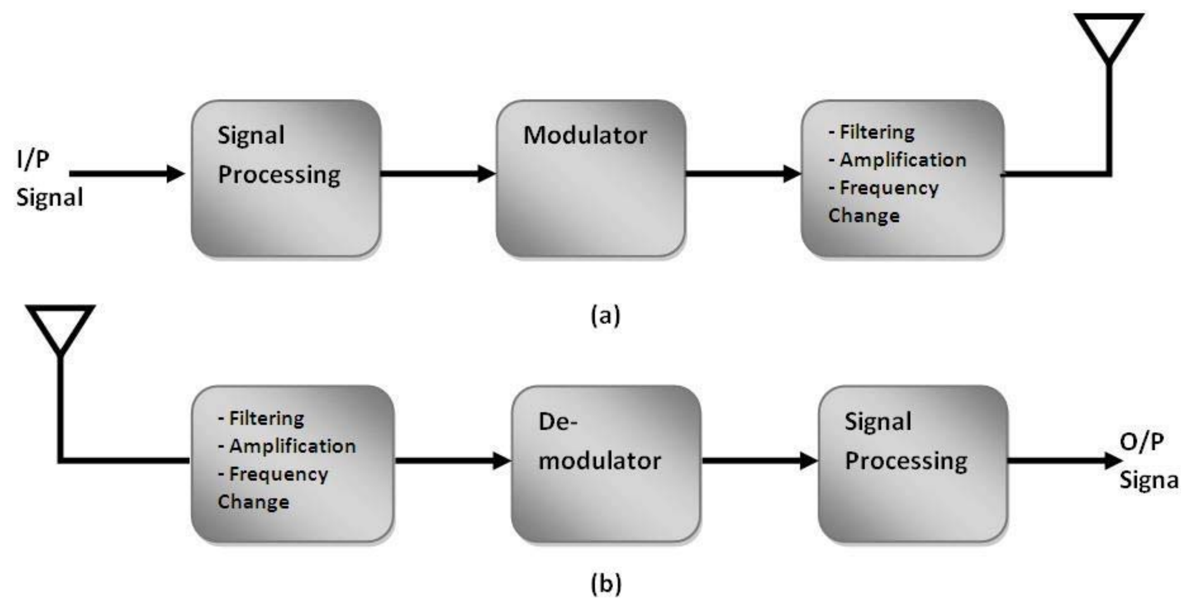


Figure 3.1. Basic Block Diagram of Transmitter and Receiver[4].

In the transmitter and receiver every communication block but the antenna and the power amplifier can be discrete or software configured hardware i.e. also known as a software defined radio. [76][52][37]. Software radio is big leap in the modern communication systems where all the functionality of modern transceivers is integrated on a common hardware platform and is controlled by the onboard software which is implemented on an FPGA and has its own operating system. [37][41][22]

There are many techniques how we can test different aspect of the wireless system both in static as well as dynamic environment. The inventors in [8] have proposed that their invention for an apparatus and method for the wireless testing of Integrated Circuits. The apparatus comprises a test unit external from the wafer and at least one test circuit, which is fabricated on the wafer that contains the Integrated Circuit. The test unit transmits an RF signal to power the test circuit. The test circuit, comprising a variable ring oscillator, performs a series of parametric tests at the normal operating frequency of the Integrated Circuit and transmits the test results to the test unit for analysis. The architecture of the RFID tag ASIC is discussed in [62]. Similarly there are multiple different techniques have been developed for rapid development of the RFID tag ASIC in [74][38][39] for better power performance and impedance matching capability with the tag antenna.

In [6] the inventor talks about the method for testing wireless device uses a waveguide designed for operation beyond cutoff for the frequencies used by the wireless communication. Waveguide used has two ends one of which is used for insertion and removal of the DUT. On the other end has the antenna used to transmit RF communication signal for the DUT. In the external test, the system consists of transmitter and the receiver antenna, and the data is taken in the controlled environment and the data acquired is analyzed the computer. The authors in [33][70][87][50] have researched the performance of the mobile 802.11 wireless protocol in the moving environment. In [65] authors surveyed the characterization of the channel for mobile communications by using different path loss and statistical methods.

In the RFID technology there are multiple ways to test and characterize the RFID system based of the properties of the RFID system mentioned in [3]. In

[7][9][11][10] inventors have proposed the method of testing RFID chip by probing it using the wireless protocol, along with the apparatus and the method for testing a single tag in multiple-tag environment and other RFID testing techniques. The relation between the read-rate vs. frequency vs. distance is established in [56]. The measurement of backscattering from the RFID tag is explained in [58] along with the physics related to its procedure is derived from [40][82][63][15][57].

The effects of nearby objects on the read range of RFID tags, and the impedance, pattern, and radiative efficiency of antennas that closely emulate the tag structures, using measurements and simulations is studied in [24]. Novel antenna design have been developed in the recent years with better impedance matching with the tag ASIC as well as better performance on the different substrate are mentioned in [84][83][32][61][53][54][17][51]. The orientation of the tag antenna and the object to which the tag is tagged with plays an important role in the performance of the RFID system; the conducted research in [21] shows that the content of packages could dramatically reduce the read rate and the research [69] shows the performance degradation of the RFID systems due to tag antenna disorientation. Apart from just identifying tags, there is anti-collision problem in the RIFD systems. Multiple tag collision and multiple reader collision are major issues in this domain. Many algorithms have been developed and analyzed to reduce the tag to tag collision, as well as tag estimation; they are discussed in [14][86][55][29][19][20][79][43][49][48][67], whereas reader collision problems are discussed in [80][81][34][44].

Along with better ASIC and antenna design, for the RFID tags and characterizing them in static and dynamic environment along with tag and reader anti-collision algorithms, there is a need for conformance testing of the wireless protocol used by the RFID system. In this research we perform conformance testing of the ISO 180006-C Class1 Gen2 RFID protocol and observe the behavior in the RFID system.

CHAPTER 4

ISO 180006-C GENERATION-2 PROTOCOL

4.1 Introduction

Class-1 Gen-2 protocol was developed at the Auto-ID center at MIT.[4] This protocol is currently used in supply chain type applications. [31]The operating frequency of this protocol is from 860MHz-960MHz. This band is separated into various regions around the world. In Europe it is from 865MHz-868MHz with 200 KHz channels, whereas in United States and Canada it is 902MHz-928MHz with 500 KHz channel. [66] This document primarily focuses on the United States region. FCC is the govern body which regulates the transmitted power in the specified bandwidth in United States. According to FCC regulation reader can transmit 1W-radiated power and will have to hop the frequency band every 200msec. [28] We will now see the protocol overview and its parts that will be used to develop the PXI systems.

4.2 Protocol Requirements

In this section we will go over the physical layer, tag-identification layer and the protocol parameters.

4.2.1 Physical Layer

The reader sends information to one or more tags by modulating RF carrier using double-sideband amplitude shift keying (DSB-ASK), single-sideband amplitude shift keying (SSB-ASK) or phase-reversal amplitude shift keying (PR-ASK) using a pulse interval encoding (PIE) format. Tags receive their energy from this same modulated RF carrier.

The reader receives information from a tag, by transmitting an unmodulated RF carrier and listening for a backscattered response. Tags communicated by backscatter-modulating the amplitude and/or phase of the RF carrier. The encoding format, selected in response to interrogator commands, is either FM0 or miller-modulated subcarrier. The communications link between the reader and tags is half-duplex, which means that at a time only a reader or tag can talk.

4.2.2 Tag-identifiaction Layer

The reader manages tag population using three basic operation:

- Select: The operation of choosing a tag population for inventory and access. A select command may be applied successively to select a particular tag population based on user-specifed criteria. This operations is analogous to selecting records from a database.
- Inventory: The operation of identifying tags. The reader begins the inventory rounds by issuing Query command and identifying it PC, OID and CRC16 from the tag. Inventory command may consists of many commands.
- Access: The operation of communicating with reading from or writing on to a tag. Access also consists of multiple commands.

4.3 Signaling

The signaling interface between the reader and Tag may be viewed as the physical layer in a layered network communication system. The signaling interface defines frequencies of operation, modulation, data coding, RF envelope, data rates.

4.3.1 Operational Frequencies

The tag must be capable of receiving power from and communicating with the reader within the frequency range from 860 MHz to 960 MHz.

4.3.2 Reader to Tag (R=>T) Communication

The reader communicates with one or more tags by modulating RF carrier wave using DSB-ASK, SSB-ASK and PR-ASK with PIE encoding.[4][71] Reader uses a fixed modulation format and data rates for a duration of an inventory round. The reader sets the data rates by means of the preamble that initiates the round. Tari is the reference time interval for Interrogator-to-Tag signaling, and is the duration of a data-0. Tari + X gives data-1. Figure 4.3.2 shows PIE symbols.

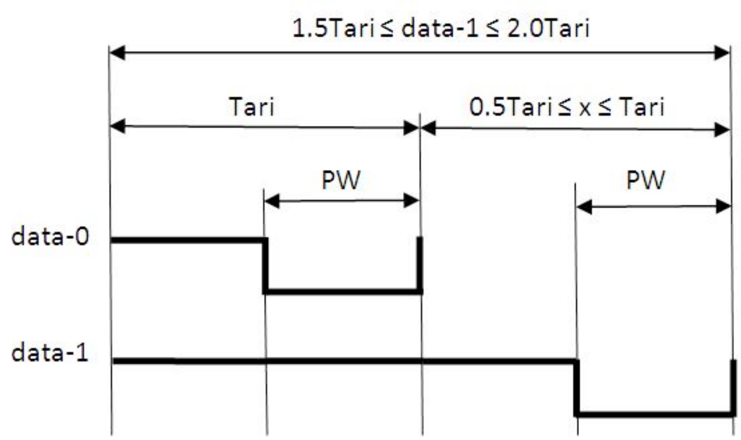


Figure 4.1. PIE - Symbols [4].

The preferred Tari values are shown in the Table 4.1   Basic commands in the Gen-2 protocol are made up of these symbols. Reader will initiate the R => T signaling by sending preamble or frame-sync. Preamble is generally sent before the

Table 4.1. Preferred Tari Values [4]

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

'Query' command and frame-sync is send before any other commands. Figure 4.3.2 shows both the preamble and frame-sync waveforms.

A preamble shall comprise a fixed-length start delimiter, a data-0 symbol, an R=>T calibration symbol (RTcal) and a T=>R calibration (TRcal) symbol. In RTcal, the reader will set RT equal to the length of a data-0 symbol plus the length of a data-1 symbol($RTcal = 0_{length} + 1_{length}$) A tag shall measure the length of RTcal and compute pivot = RTcal/2. Tag will interpret subsequent reader symbol shorter that pivot to be data-0 and subsequent reader symbols longer than pivot to be data-1. The tag will interpret symbol longer than 4 RTcal to be the bad data. Prior to changing RTcal, the reader will transmit continuous wave for a minimum of 8 RTcal. In TRcal, the reader specifies a tag's backscatter link frequency its FM0 datarate or the frequency of its Miller subcarrier, using TRcal and divide ratio in the preamble of the Query command. A tag will measure TRcal compute LF and adjust its T=>R link rate to be equal to LF. TRcal satisfies following condition.

$$1.1 \times RTcal < TRcal < 3 \times RTcal \tag{4.1}$$

A frame sync is identical to a preamble, minus the TRcal symbol. The reader, for the duration of an inventory round shall use the same length RTcal in a frame-synce as it is used in the preamble that initiated the round.

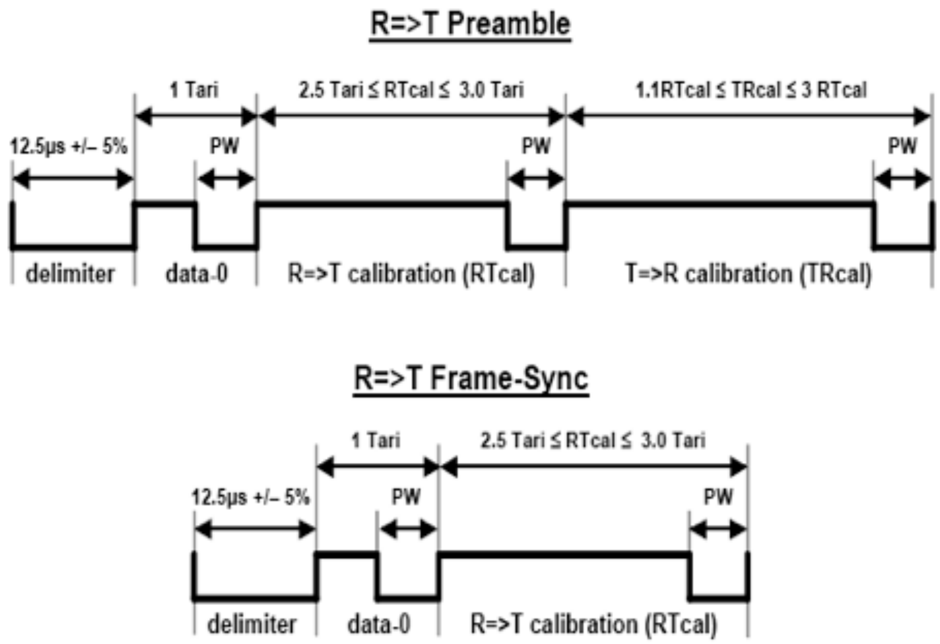


Figure 4.2. R=>T preamble and frame-sync waveforms [4].

4.3.3 Frequency Hopping Spread-Spectrum

When the reader uses frequency hopping spread spectrum signaling, the hopping rate is governed by the local authorities. Also the reader cannot issue any commands before the end of the maximum settling time interval.

4.3.4 Tag-to-Reader Communications

The tag communicates with the reader using back scatter modulation, in which the tag switches the reflection coefficient of its antenna between two states in accordance with the data being sent.

The tag shall back scatter using a fixed modulation format, data encoding and data rate for the duration of an inventory round where "inventory Round" is defined by these command set of commands which includes Query, QueryAdjust, QueryRep, ACK and NAK. Tag selects the modulation format for the round; the reader selects the encoding and data rate by the means of Query command and initiates the round.

The backscatter shall use ASK and/or PSK modulation. The tag vendor selects the modulation format. Tags shall encode the backscattered data as either FM0 baseband or Miller modulation of a subcarrier at the data rate.[71][58]

4.3.4.1 FM0 Baseband

FM0 inverts the baseband phase at every symbol boundary; a data-0 has an additional mid-symbol phase inversion. The state diagram and the basic function is show in Figure 4.3.4.1

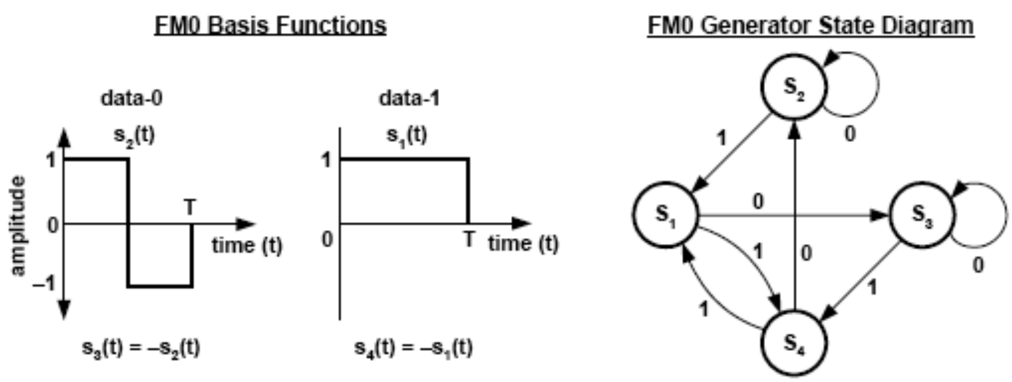


Figure 4.3. FM0 Basis Functions and the State Diagram [71].

The states label $S_1 - S_4$ indicate four possible FM0 symbols.

4.3.4.2 Miller-Modulated Subcarrier

Baseband Miller inverst its phase between two data0-s in sequence. Baseband also places a phase inversion in the middle of a data-1 symbol. the state diagram and the basis function are shown is Figure 4.3.4.2.

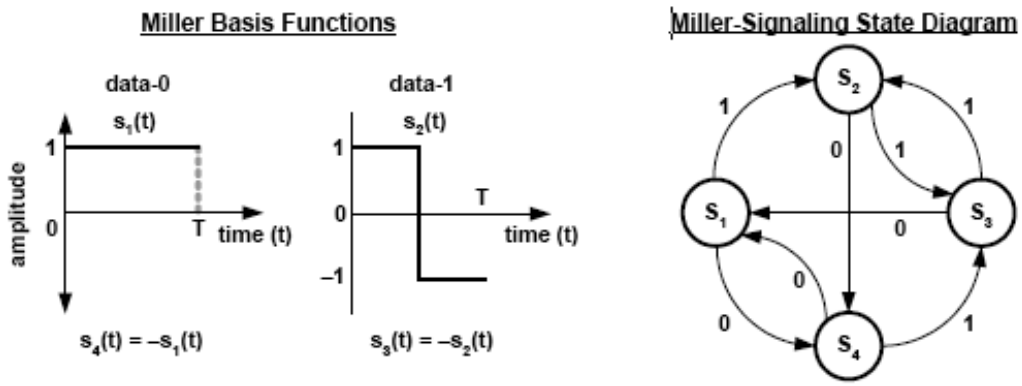


Figure 4.4. Miller Basis Functions and the State Diagram [71].

4.4 Tag Selection, Inventory and Access

This may be viewed as the lowest level in the data link layer of the layered network communication system. Tag memory can be classified as the four distinct banks shown in the Figure 4.4.

- Bank 00 - Reserved: Which contain the kill and access passwords.
- Bank 01 - Object Identification (OID): This shall contain a CRC-16, Protocol-Control (PC) and the Object identifier.
- Bank 10 - Tag-Identification (TID): This contains 8-bits class identifier, 12-bit task mask-designer and higher functionality tag may contain tag and vendor specific data.

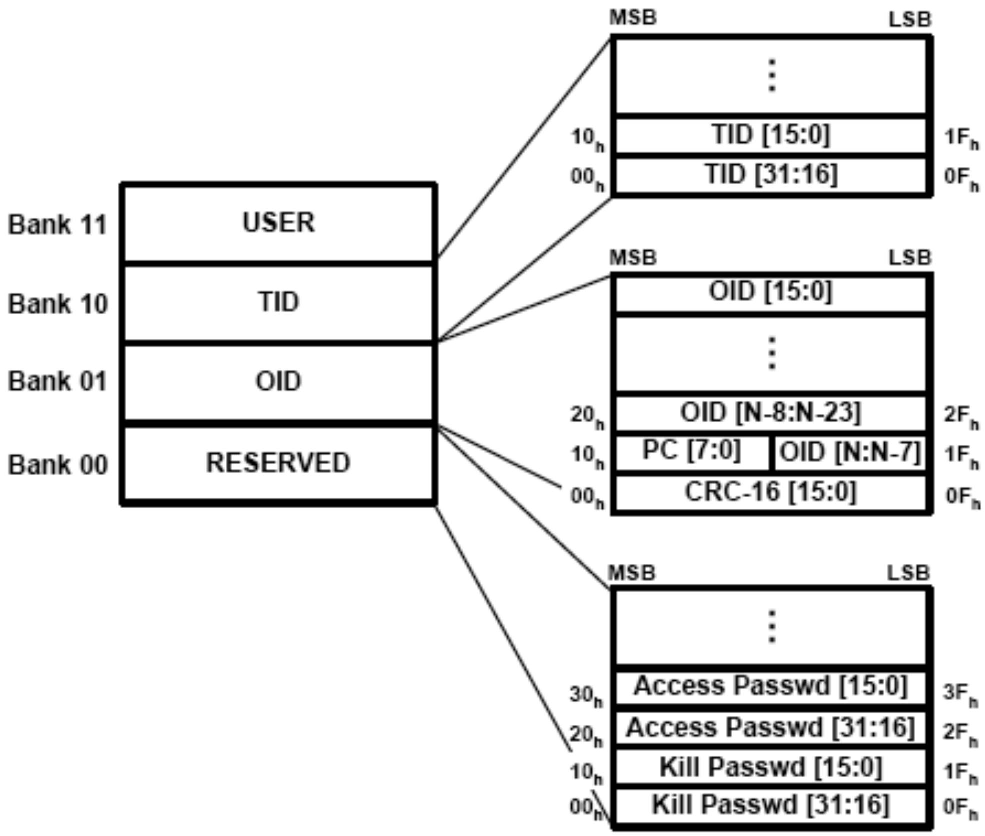


Figure 4.5. Tag Memory Bank [71].

- Bank 11 - User Memory: This space allows specific data storage

The CRC-16 is a cyclic redundancy check that the reader uses when protecting certain R=>T commands, and a tag uses when protecting certain backscatter T=>R sequence. To generate CRC-16 in the mask the reader or tag shall first generate CRC-16 precursor given by

$$x^{16} + x^{12} + x^5 + 1 \tag{4.2}$$

Then takes one's complement of the generated precursor to for the CRC-16. There are specific commands that the reader have to send in order for the tag to respond. The basic command and response sequence from reader to tag and the tag to reader is shown in the Figure 4.4. We can see that tag does take a finite amount of time for replying to reader's commands. The descriptions of timings are as follows.

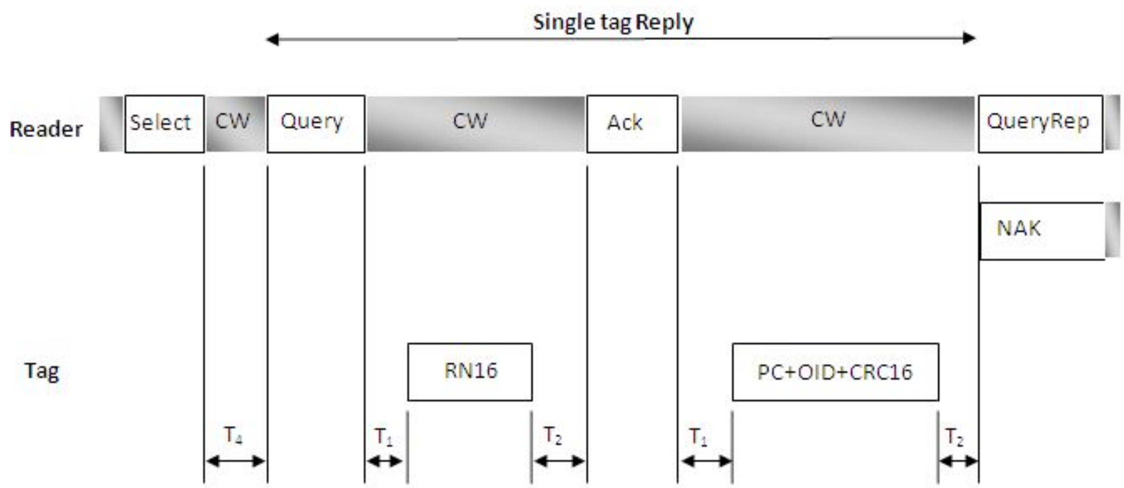


Figure 4.6. Single tag reply and timings [4].

- T1 - Time from the end reader's transmission to tags response.
- T2 - Time from the end of the tags response to the reader's transmission.
- T3 - Time the reader waits before it issues another command
- T4 - Time between two successive reader commands.[4]

4.5 Gen2 Commands

This section talks about the general inventory and access tag commands. Used in the inventory round.

4.5.1 Select

This command selects a perticular tag population based on the user defined criteria. The select commands have following parameters Target, Action, Membank, Pointer, Length, Mask and Truncate.

4.5.2 Query

This commands initiates the inventory round and decides which tags participate in the round. Query commands contains a sot count parameter 'Q'. upon receiving query command tag will pick a random value any where in between 0 and 2^Q-1 and will load them in their slot counter. If the tags have picked a non-zero value it goes to arbitrate state and waits for QueryAdjust or QueryRep command. If it the tag has zero value in its slot counter tag will backscatter an RN-16. The reader acknowledges the tag with the ACK command using the same RN-16. The acknowledge tag transits to the acknowledge state and back scatters PC, OID and CRC-16. After that the reader issues QueryRep and will initiate another tag to reply. If the tag fails to receive ACK within time T2 it will return to arbitrate.

4.5.3 QueryAdjust and QueryRep

After issuing a Query to initiate an inventory round, the reader typically issues one or more QueryAdjust or QueryRep commands. The QueryAdjust repeats previous Query command with different 'Q' value, but does not include new tags in the round. The QueryRep repeats previous Query without changing 'Q' and it also does not include new tags in the round.

4.5.4 ACK

The reader send this command to acknowledge a single tag. If the reader issues an ACK to a tag in the reply or acknowledged states, then the echoed RN-16 shall be the RN-16 that the tag previously backscattered as it transitioned from the arbitrate state to reply state. The tag reply to the ACK is PC, OID, CRC-16

4.5.5 NAK

The reader will issue this command when reader receives no response from the tag after T2 time. NAK will make tag got o arbitrate state unless they are in ready or killed. NAK will be pretended with a frame-sync.

4.5.6 Req-RN

The reader will implement Req-RN on tag in order for a tag to backscatter new RN16.

4.5.7 Read

This allows reader to read part or all of the Tag's reserved, OID, TIO or user memory. This command has three fields viz. MemBank which specifies what area to read, WordPtr which specifies the starting word address for memory read, WordCount which specifies the number of 16-bit to be read. Read command also includes the Tag's handle and CRC-16. If a tag receives a read with valid CRC-16 but an invalid handle it will ignore read command

4.5.8 Write

This command allows reader to write a word in the Tag's reserved , OID, TID a or user memory. It has following fields, MemBank which specifies where write occurs. WordPtr whcih specifies word address for memory write and data.

We can see that there is no limit to the number of tags in the environment. If there is more than one tag in the reader's interrogation zone we are more likely to have collision. In the typical RFID systems we use Aloha based anti-collision algorithms. Where during the initialization state reader will send 'Query' command and one of the parameter of that is 'Q' value. Depending on what the value of 'Q' is tag will automatically select a random number anywhere between 0 - 2Q-1 and store it in their slot counter. Now every time tag receives 'Query-Rep' command it will decrement its slot counter and when the value in the slot counter is zero, it will transmit the 16 bit Random number which was send by the reader. The vast variation of the anti-collision algorithm exists in time domain; they can be either deterministic approach or probabilistic approach. [26][49][67]

CHAPTER 5

RESEARCH METHODOLOGY

5.1 Introduction

There are several tag designs available in the market today with different chip inlays and many different antenna design, and most of the UHF passive tags uses the ISO-180006-C Class 1 Generation 2 protocol. Due to increase of the popularity of the RFID in supply chain and various other application, we need high performance RFID system. Most of the research done in the market are performance testing in different environment. This chapter focuses on the development of the NI-PXI reader and its hardware and software components and it also describes the test procedures in detail. The test procedures in the research tests the performance of the RFID system by varying the ISO-180006-C Class 1 Generation 2 protocol parameter

5.2 PXI RFID Reader

The research methodology developed will use the RFID Reader in LabVIEW 8.5 on the National Instruments PXI-RF hardware and IF-RIO. The software architecture of the RFID Reader will have state machine architecture. In order to run this software tool we will require the following hardware:

1. NI PXI-5610 - RF Upconverter
2. NI PXI-5441 - Arbitrary Waveform Generator
3. NI PXI-5600 - RF Downconverter
4. NI PXI-5142 - Digitizer
5. NI PXI-8106 - PXI Controller

6. NI PXI-5640R - IF RIO
7. NI PXI-1044 - PXI Chassis
8. Magma PCI Express Chassis
9. Patch RFID Antennas
10. RF cables

The basic system architecture of this system is shown in Figure 5.1.

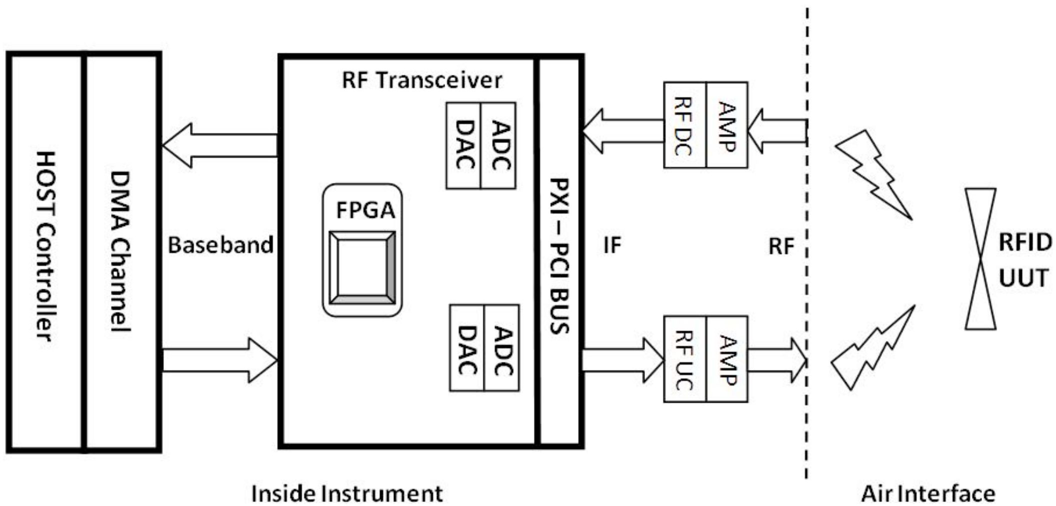


Figure 5.1. RFID Test System block diagram [78].

The software requirement for the reader development is as follows:

1. LabVIEW 8.5 Professional Development Suite
2. LabVIEW FPGA 8.5
3. NI RIO 2.1
4. NI RFSG 1.2
5. NI RFSA 1.5
6. NI Spectral Measurements Toolkit v.2.1
7. NI Advance Signal Processing Toolkit v.7.5

The Reader developed will have the characteristic shown in the Table 5.1, which shows how much the user can vary the physical parameters according to the hardware that we will be using for the RFID Tag-Reader analyzer.

Table 5.1. Software Specifications for GEN-2 reader and the Protocol [78]

Item	Software Specifications	EPC-Requirements	Units
Center Frequency	800 - 1000	860 - 960	MHz
Frequency Accuracy	1	10	ppm
Command Modulation	DSB-ASK or PR-ASK	DSB/SSB-ASK or PR-ASK	
Response Demodulation	ASK	ASK or PSK	
Power On-Off time	0-5000	<500	sec
Command encoding	PIE	PIE	
Response Encoding	FM0 or Miller 2,4,8	FM0 or Miller 2,4,8	
Command Data rate	22.22 - 160	26.78 - 128	Kbps
Link Frequency	20 - 800	40 - 640	KHz
Tari	5.0 - 30	6.25 -25	sec
Tari Adjust Step	0.04		sec
Turnaround Time T1	Can be measured	Max(RTcal,10Tpri)	sec
Turnaround Time T2	3.0 - 100	3.0 - 20	Tpri
Turnaround Time T3	6.0 -100	>0.0	Tpri
Delimiter	0.0 - 100	12.5	sec
RTcal	1.0 - 5.0	2.5 - 3.0	Tari
TRcal	1.0 - 5.0	1.1 - 3.0	RTcal
Divide Ratio	8, 64/3	8, 64/3	

From the specification listed in the above Table the user can go out of boundary of the EPC Class 1 Generation 2 protocol. Hence, we can test the performance of the protocol by varying its timing parameters and can evaluate it on its boundary and study its behavior, which will allow us to come up with the better metric for the RFID system.

The PXI-system will act as the reader where we are going to connect the receiver antenna to RF-Downconvertor and transmitting antenna to RF-Upconvertor. The RF-Upconvertor combined with the Arbitrary Waveform Generator form the RF-Signal Generator and the RF-Downconvertor combined High Speed Digitizer forms RF-Signal Analyzer. Once we introduce FPGA transceiver which will be IF-RIO board, it will replace arbitrary waveform generator (AWG) and high speed digitizer as it will be done on the FPGA. Figure 5.2 shows the experiment setup.

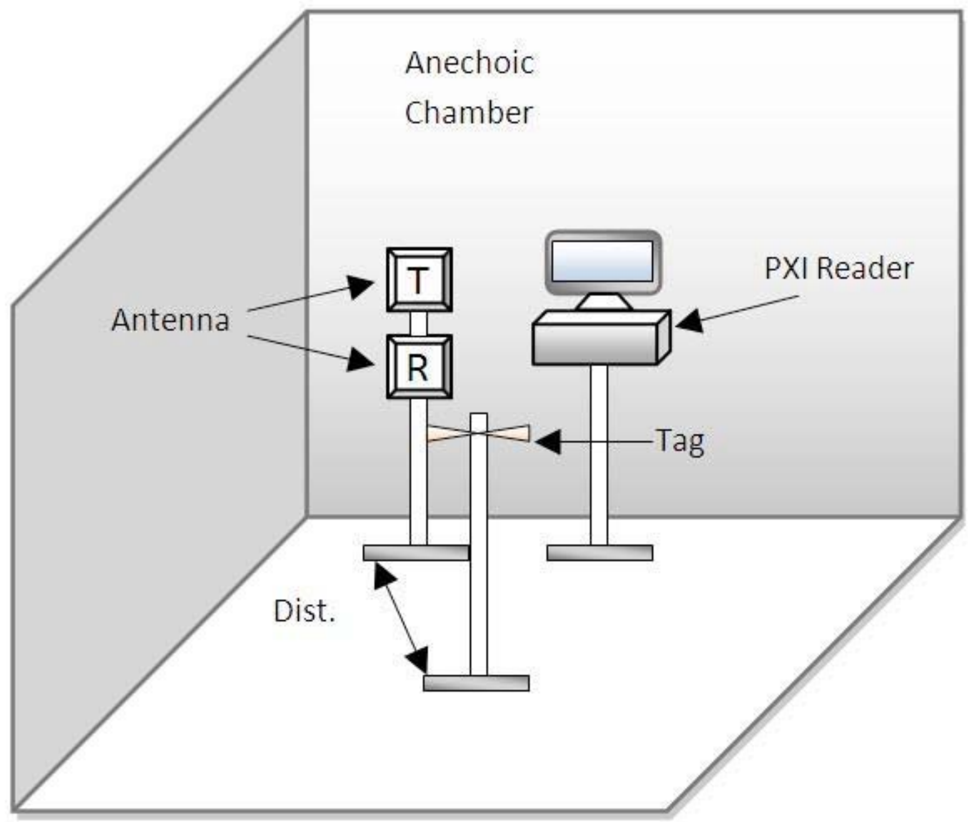


Figure 5.2. Test Setup.

The actual connection of the PXI modules in the PXI chassis is shown in Figure 5.2 since the NI-5640R is the PCI card, we use magma express chassis in order to connect the PCI card to the PXI controller using express card slot and create a PCI-PCI bridge.

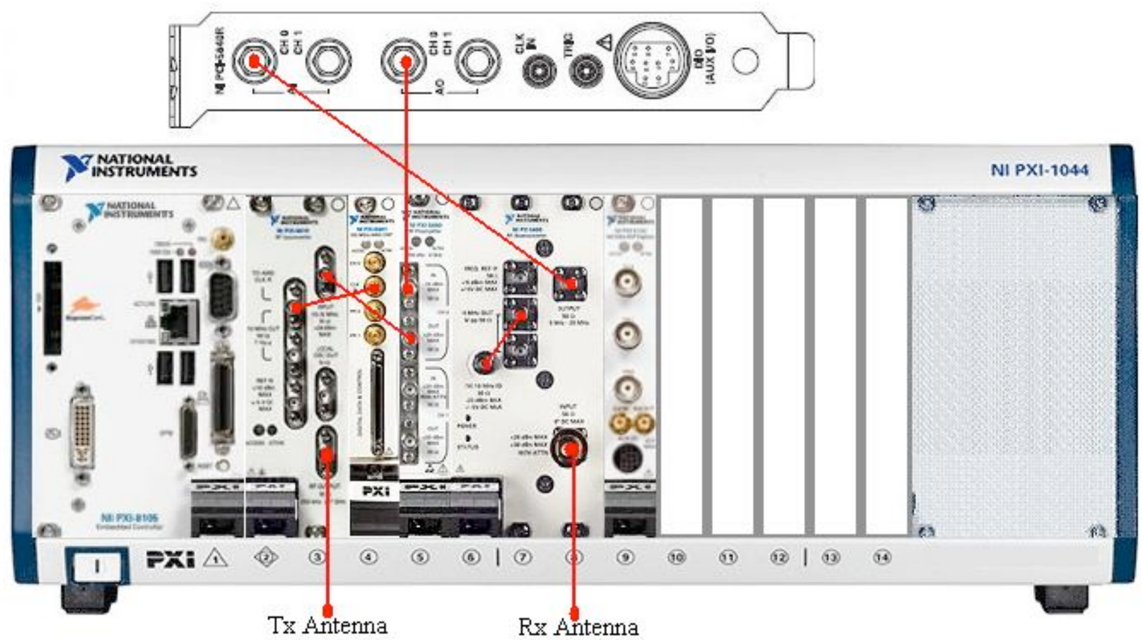


Figure 5.3. Hardware configuration of the PXI modules.

5.3 Software Development and Reader Architecture

In this section we talk about the software and toolkit used for the software defined RFID reader. The main software architecture used to implement the reader is the state machine architecture in LabVIEW. The state machines are used in applications where distinguishable states exists. Each state can lead to one or multiple states, and can also process flow. Many application has a initialization state followed by the default state where the program waits for the different actions to be performed. In the RFID Reader C1G2.vi in the initialization, initializes the IF-RIO i.e. PCI-5640R and the upconverter and downconverter using VISN_RFID GEN2RE_Initialize Hardware.vi show in Figure 5.4 and outputs the Instrument handle which will be used throughout the code.

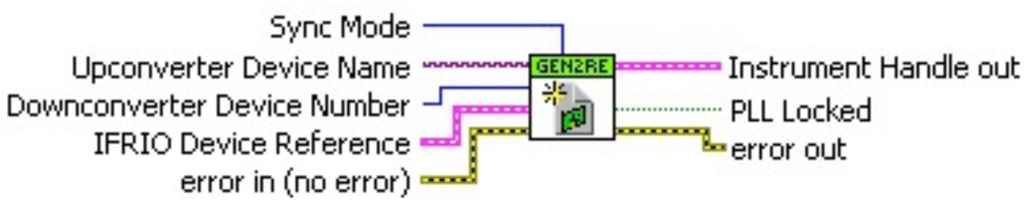


Figure 5.4. VISN_RFID GEN2RE_Initialize Hardware.vi.

The next state is Configuration where VISN_RFID GEN2RE_Configure Hardware.vi shown in Figure 5.5 takes in the power level and offset and configures the upconverter and downconverter for the user settings.

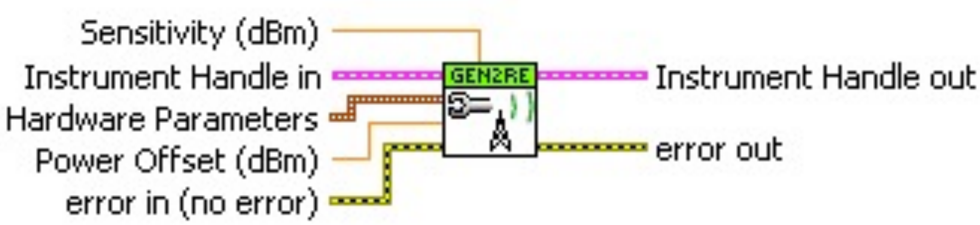


Figure 5.5. VISN_RFID GEN2RE_Configure Hardware.vi.

The nest state after configuration is the get command state where the user can actually imports the "command file.ini" using VISN_RFID GEN2RE_Get Command.vi shown in the Figure 5.6 and generates command list and command table.

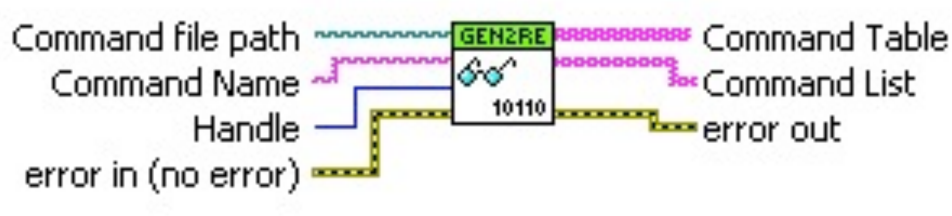


Figure 5.6. VISN_RFID GEN2RE_Get Command.vi.

Here the user can change all the parameters he wants for example changing the value of 'Q' and so on.

The next state is the default state in this case it is No Action, where the program waits for further event on the front panel. Once the value on the front panel is changed it will put respective states into its shift register and then repeat its cycle accordingly. Say the user has pick what command he wants to send and then click on the SEND boolean button on the front panel. Following states will occur in sequence

- Send and Receive
- Decode
- Response Frame Analysis
- Refresh Spectrum

In the Send and receive state, we use VISN_RFID GEN2RE_Download to Hardware.vi which encodes the command bits and download the bit stream in to the FPGA of the hardware module. Once the bit file has been downloaded on to the FPGA we initiate the communication by using VISN_RFID GEN2RE_Send and Receive.vi, which starts the hardware to send the command and acquire the response. Both these function are shown in Figure 5.7 and 5.8

Once the IQ data has been received, the program transits to Decode state. Where, VISN_RFID GEN2RE_Locate Signal.vi is used to locate the command and response frame and extract the response frames from the whole signal. After that the

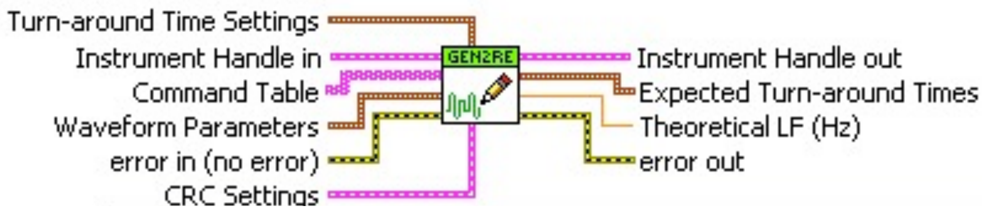


Figure 5.7. VISN_RFID GEN2RE_Download to Hardware.vi.

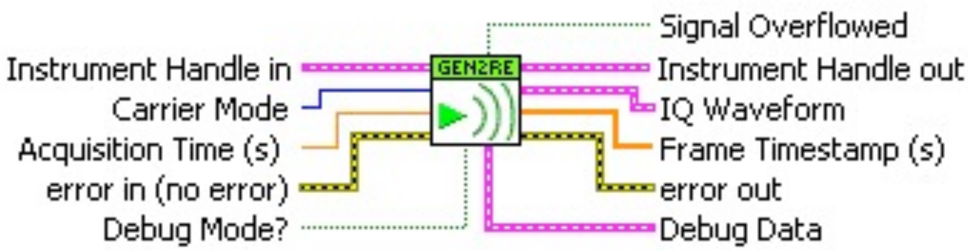


Figure 5.8. VISN_RFID GEN2RE_Send and Receive.vi.

signal is passed to the VISN_RFID GEN2RE_Decode Signal.vi where it decodes the signal and provide the data and information of the response. Both these function is shown in Figure 5.9 and 5.10

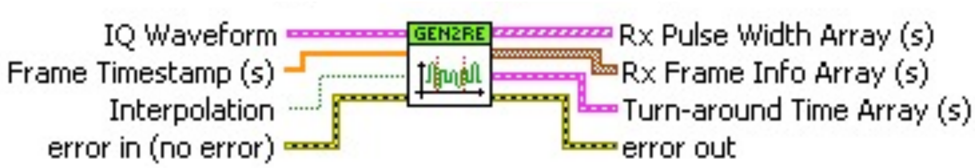


Figure 5.9. VISN_RFID GEN2RE_Locate Signal.vi.

The next state is Response Frame Analysis, where the signal received is processed in order to extract various information. The functions used here are VISN_RFID GEN2RE_Turn-around Time Analysis.vi which measures the turn around time between frames, second is VISN_RFID GEN2RE_Frame Spectrum Analysis.vi which

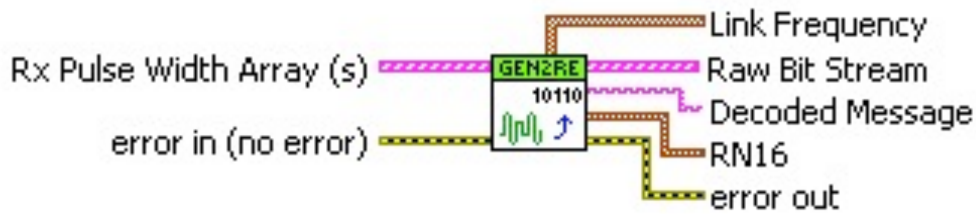


Figure 5.10. VISN_RFID GEN2RE_Decode Signal.vi.

calculates the spectrum of the selected of the selected waveform segment, third one is VISN_RFID GEN2RE_Amplitude of Response.vi which measures the amplitude of the response waveform. Lastly it is VISN_RFID GEN2RE_Delta RCS of Response.vi which measures the delta RCS parameter of the tag. All the four functions are shown in figure 5.11 5.12 5.13 and 5.14

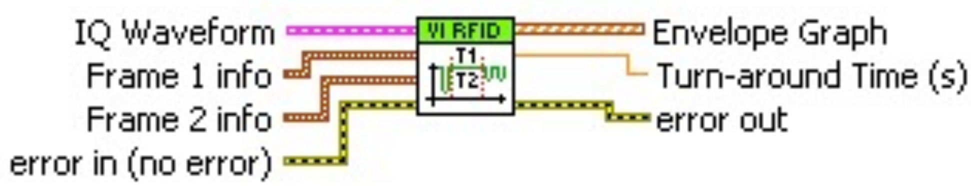


Figure 5.11. VISN_RFID GEN2RE_Turn-around Time Analysis.vi.

Figure 5.12. VISN_RFID GEN2RE_Frame Spectrum Analysis.vi.

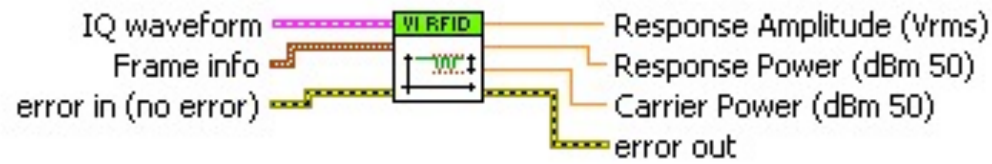


Figure 5.13. VISN_RFID GEN2RE_Amplitude of Response.vi.

Figure 5.14. VISN_RFID GEN2RE_Delta RCS of Response.vi.

The next state is Refresh Spectrum where the spectral measurements are calculated, for this VISN_RFID GEN2RE_Frame Spectrum Analysis.vi shown in Figure 5.12 which is used to calculate the spectrum of the selected wavefrom segment and VISN_RFID GEN2RE_Time Waveform Analysis.vi which calculate the RF envelope parameters of the selected waveform segment like rise time, fall time modulation depth and ripple. Both of these function is shown in the Figure 5.15

Figure 5.15. VISN_RFID GEN2RE_Time Waveform Analysis.vi.

5.4 Test Methodology

5.4.1 Experiment 1

In this Experiment we are going to test for the affect of the Tari and frequency on the time T1 for the tag's response. This test will be conducted in the anechoic chamber as to make sure that the effect is limited to the protocol and not the environment. For this experiment we will be using the RFID reader.vi program. We will set the Hardware Configuration in the software programs as shown in the Table 5.2:

Table 5.2. Software Configuration for Experiment 1

Field	Settings
IFRIO Device Name	RIO0::INSTR
Upconverter Device Name	rfuc
Power Level (dBm)	10 dBm
Downconverter Number	2
Carrier Mode	Burst
Reference Level (dBm)	-15dBm
Acquisition Time	15msec
Center Frequency	840MHz*

* Frequency will be changing as we conduct the experiment. Once we are set the hardware configuration is set then run program. The EXIT led will be GREEN is the configuration is set correctly and RED if there is some mismatch in the any of the hardware configuration. The names given in this test are specific to the PXI RF System in the Texas RF Innovation and Technology Center. Once the hardware

configuration is set the SEND led will start blinking which means all set to send and receive commands and response respectively.

After the setting the hardware configuration click on the SEND boolean button and wait for the response. once you receive the response , the time period T1 is automatically measured and can be seen in the "Turn-arounD Time" tab. Next step is increase the frequency and click the SEND button, repeat the process till 990 MHz. Once reached that frequency change the value of the Tari and repeat the above above steps. After we have sweep all the value of Tari for the entire range of frequency. Click on the EXIT boolean button and the window will pop where the user will enter the appropriate file name for that experiment. The data collected will be analyzed in the following chapters.

5.4.2 Experiment 2

In this Experiment we are going to test for the affect of the Tari and frequency on the power received form the tag's response. This test will be conducted in the anechoic chamber as to make sure that the effect is limited to the protocol and not the environment. For this experiment we will be using the RFID reader.vi program. We will set the Hardware Configuration in the software program is shown in Table 5.3:

* Frequency will be changing as we conduct the experiment. Once we are set the hardware configuration is set then run program. The EXIT led will be GREEN is the configuration is set correctly and RED if there is some mismatch in the any of the hardware configuration. The names given in this test are specific to the PXI RF System in the Texas RF Innovation and Technology Center. Once the hardware configuration is set the SEND led will start blinking which means all set to send and receive commands and response respectively.

Table 5.3. Software Configuration for Experiment 2

Field	Settings
IFRIO Device Name	RIO0::INSTR
Upconverter Device Name	rfuc
Power Level (dBm)	10 dBm
Downconverter Number	2
Carrier Mode	Burst
Reference Level (dBm)	-15dBm
Acquisition Time	15msec
Center Frequency	840MHz*

After the setting the hardware configuration click on the SEND boolean button and wait for the response. once you receive the response , the power received will be is automatically measured and can be seen in the "Tag Analysis" tab. Next step is increase the frequency and click the SEND button, repeat the process till 990 MHz. Once reached that frequency change the value of the Tari and repeat the above above steps. After we have sweep all the value of Tari for the entire range of frequency. Click on the EXIT boolean button and the window will pop where the user will enter the appropriate file name for that experiment. The data collected will be analyzed in the following chapters.

5.4.3 Experiment 3

In this Experiment we are going to test for the affect of the pulse width of Tari and frequency on the power received form the tag's response. This test will be conducted in the anechoic chamber as well as in the NH 131 RFID Lab in order to make sure that the effect of the noisy and noise free environment on the protocol.

For this experiment we will be using the RFID sweeper.vi program. We will set the Hardware Configuration as shown in 5.4:

Table 5.4. Software Configuration for Experiment 3

Field	Settings
IFRIO Device Name	RIO0::INSTR
Upconverter Device Name	rfuc
Power Level (dBm)	10 dBm
Downconverter Number	2
Carrier Mode	Continous
Reference Level (dBm)	-15dBm
Acquisition Time	15msec
Center Frequency	860MHz*
Sweep Delay	20m
Sync Mode	Synchronized

* Frequency will be changing as we conduct the experiment. These settings will be in the "Advance Settings" tab of the RFID sweeper.vi program. Once we are set the hardware configuration is set then run program. The EXIT led will be GREEN is the configuration is set correctly and RED if there is some mismatch in the any of the hardware configuration. The names given in this test are specific to the PXI RF System in the Texas RF Innovation and Technology Center. Once the hardware configuration is set the 'Start' led will start blinking which means all set to send and receive commands and response respectively.

After the setting the hardware configuration, Click on the Sweep Test tab and set the following as the Frequency Setting:

- Higher Frequency: 960 MHz

- Lower Frequency: 860 MHz
- Frequency Step: 5 MHz

Power Setting:

- Higher Power Level: 10 dBm
- Lower Power Level: 10 dBm
- Power Level Step: 1 dBm

click on the Start boolean button and wait for the response. once you receive the response , the power received will be is automatically measured the plot will be plotte on the Measured Power Graph and the response can be seen on the Amplitude vs. Time graph. Next step is increase the pluse width and click the Start button, the value of the Pulse width is 0.95. The data collected will be analyzed in the following chapters. In this experiment we collect the data for three different values of Tari viz.

- 6.25 μsec
- 12.5 μsec
- 25 μsec

In order to see the effect of the change on Tari on these parameters as well.

5.4.4 Experiment 4

In this Experiment we are going to test for the affect of the Modulation Depth of carrier and frequency on the power received form the tag's response. This test will be conducted in the anechoic chamber as well as in the NH 131 RFID Lab in order to make sure that the effect of the noisy and noise free environment on the protocol. For this experiment we will be using the RFID sweeper.vi program. We will set the Hardware Configuration as shown in 5.5:

* Frequency will be changing as we conduct the experiment. These settings will be in the "Advance Settings" tab of the RFID sweeper.vi program. Once we are set

Table 5.5. Software Configuration for Experiment 4

Field	Settings
IFRIO Device Name	RIO0::INSTR
Upconverter Device Name	rfuc
Power Level (dBm)	10 dBm
Downconverter Number	2
Carrier Mode	Continous
Reference Level (dBm)	-15dBm
Acquisition Time	15msec
Center Frequency	860MHz*
Sweep Delay	20m
Sync Mode	Synchronized

the hardware configuration is set then run program. The EXIT led will be GREEN is the configuration is set correctly and RED if there is some mismatch in the any of the hardware configuration. The names given in this test are specific to the PXI RF System in the Texas RF Innovation and Technology Center. Once the hardware configuration is set the 'Start' led will start blinking which means all set to send and receive commands and response respectively.

After the setting the hardware configuration, Click on the Sweep Test tab and set the following as the Frequency Setting:

- Higher Frequency: 960 MHz
- Lower Frequency: 860 MHz
- Frequency Step: 5 MHz

Power Setting:

- Higher Power Level: 10 dBm
- Lower Power Level: 10 dBm

- Power Level Step: 1 dBm

click on the Start boolean button and wait for the response. once you receive the response , the power received will be is automatically measured the plot will be plotte on the Measured Power Graph and the response can be seen on the Amplitude vs. Time graph. Next step is increase the modulation depth and click the Start button till the value of the modulation depth is 100%. The data collected will be analyzed in the following chapters. In this experiment we collect the data for three different values of Tari viz.

- 6.25 μsec
- 12.5 μsec
- 25 μsec

In order to see the effect of the change on Tari on these parameters as well.

CHAPTER 6

EXPERIMENT 1: TARI VS. T1

6.1 Introduction

In this chapter we will discuss the data that we collected from the experiment 1 that were conducted in the previous chapter. In the experiment 1 we measure time T1 with varying Tari and the frequency. Experiment 1 was conducted in the anechoic Chamber , i.e. clean environment and free from any radio frequency reflection. In this experiments the tags used were as follows:

- Avery Dennison Bowtie Tag
- Avery Dennison Tripod Tag
- Alien Squiggle Tag
- Texas Instruments (TI) Tag

6.2 Data Analysis and Evaluation

In this experiment we will be varying the 'Tari' parameter of ISO-180006-C Class 1 Generation 2 protocol and will measure T1 which is the time from the end of the reader's command to the the tags response. The 3-D plots shown in Figure 6.1, 6.3, 6.5, 6.7 for Bow-Tie, Tripod, Squiggle and TI tags.

6.3 Conclusion and Observation

Before jumping to the conclusion we know following parameter about the protocol.

$$Data0 = T_{ari} \tag{6.1}$$

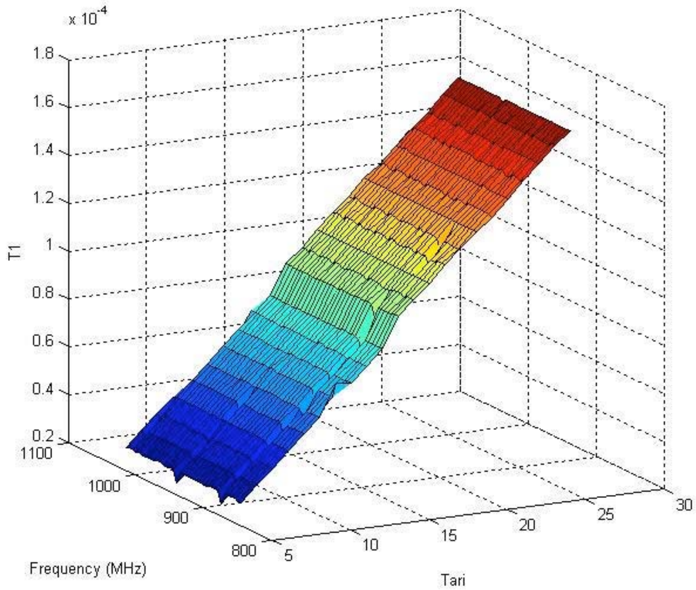


Figure 6.1. 3-D Plot of the Bow-Tie Tag T1 vs. Frequency vs. Tari.

$$Data1 = (1 + x)T_{ari} \tag{6.2}$$

In this experiment we choose x = 0.5 The Interrogator-to-Tag calibration symbol. A tag shall measure the length of RTcal and compute the pivot which is $\frac{RTcal}{2}$ and will interpret the reader symbol longer than pivot to be data 1. Also prior to changing RTcal the reader should transmit CW for a minimum of 8 RTcal.

$$RTcal = Data0 + Data1 \tag{6.3}$$

The TRcal is Tag-to-Interrogator calibration symbol. The reader will specify a tag's backscatter link frequency. Using TRcal and divide ratio (DR) in the preamble and payload a Query command initiates the inventory round. 6.5 shows the realtionship between LF, TRcal and DR

$$RTcal = y.(RTcal) \tag{6.4}$$

In this experiment we choose y = 2

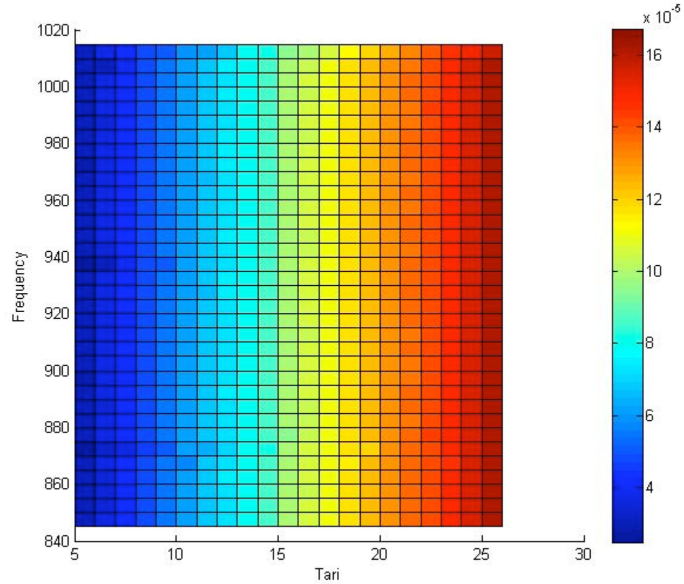


Figure 6.2. Intensity Plot of the Bow-Tie Tag T1 vs. Frequency vs. Tari.

$$LF = \frac{DR}{TRcal} \tag{6.5}$$

$$T_{pri} = \frac{1}{LF} \tag{6.6}$$

$$T1 = max(RTcal, 10 \times T_{pri}) \tag{6.7}$$

Hence from this we can actually calculate the theoretical value of the time T1 for different values of Tari. The Table **??**

From the Figure 6.9 we can see that an Generation 2 RFID tag is out of specification for the Tari 15μsec to 25μsec. Alien Squiggle Tag follows the ideal tag timings whrerewas the TI tag is skewed a bit. Also the avery dennison bow-tie and tripod tag are very identical in their behaviour. All the data used are the average T1 timings for different frequencies i.e varying from 830MHz to 990MHz.

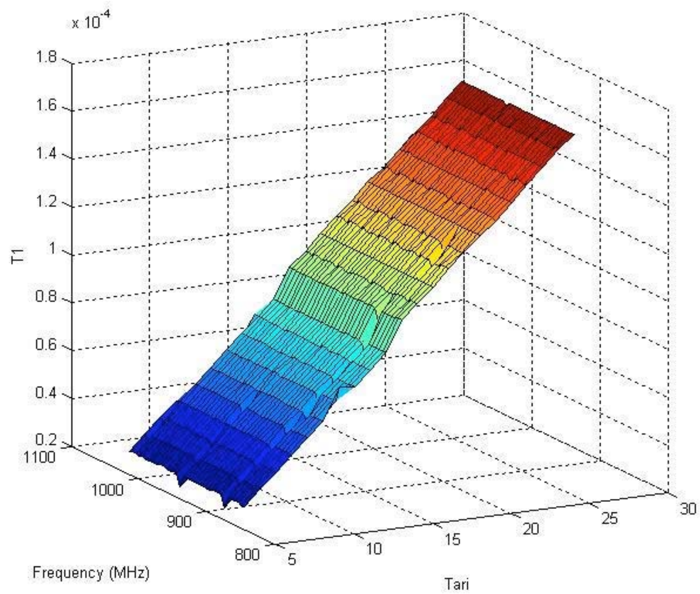


Figure 6.3. 3-D Plot of the Tripod Tag T1 vs. Frequency vs. Tari.

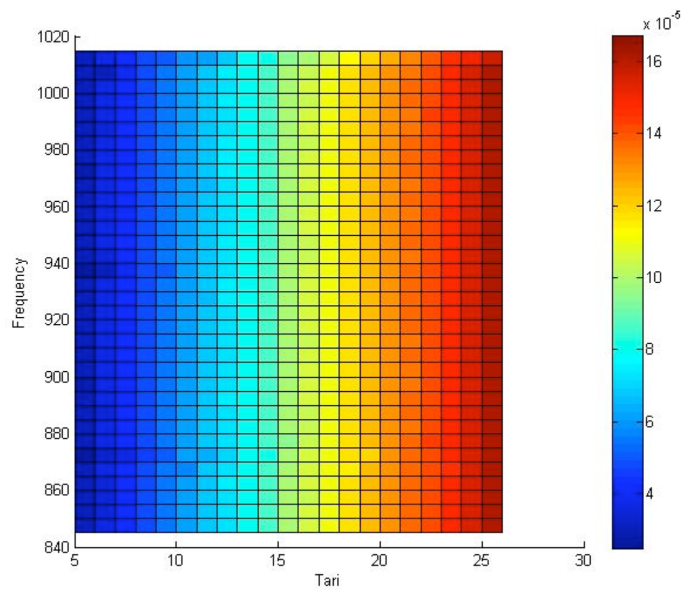


Figure 6.4. Intensity Plot of the Tripod Tag T1 vs. Frequency vs. Tari.

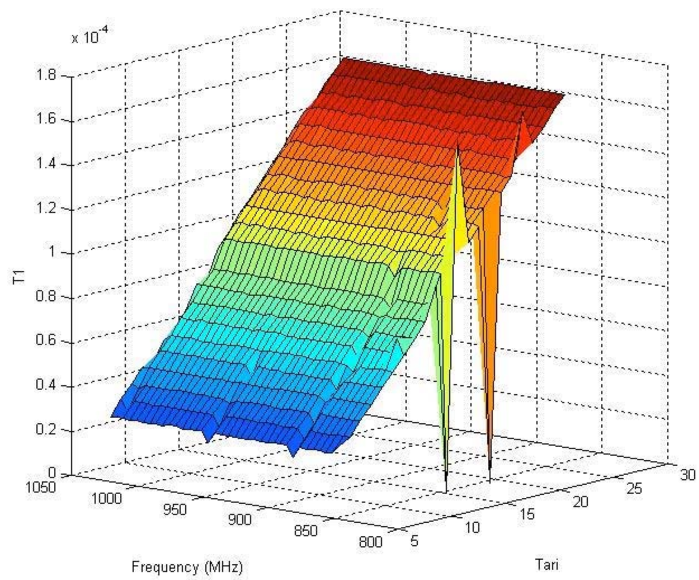


Figure 6.5. 3-D Plot of the Squiggle Tag T1 vs. Frequency vs. Tari.

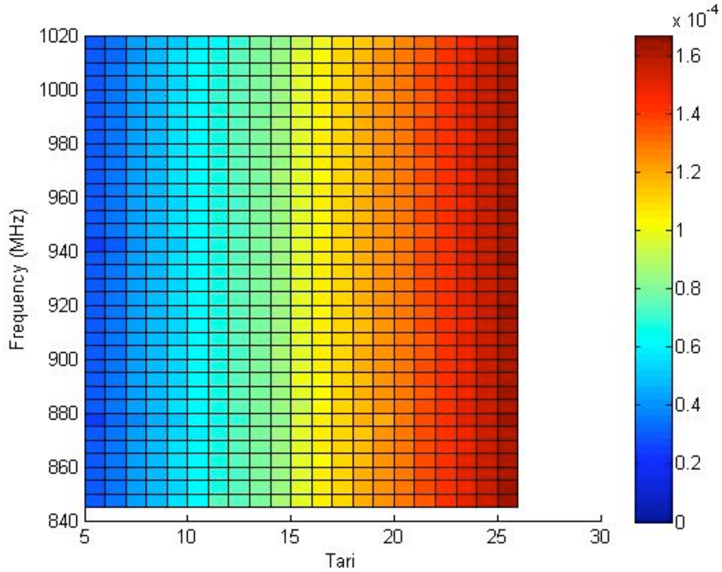


Figure 6.6. Intensity Plot of the Squiggle Tag T1 vs. Frequency vs. Tari.

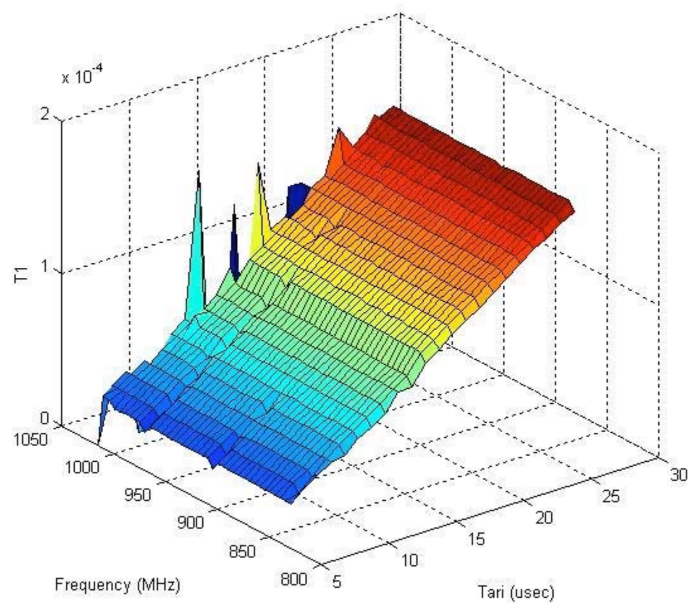


Figure 6.7. 3-D Plot of the TI Tag T1 vs. Frequency vs. Tari.

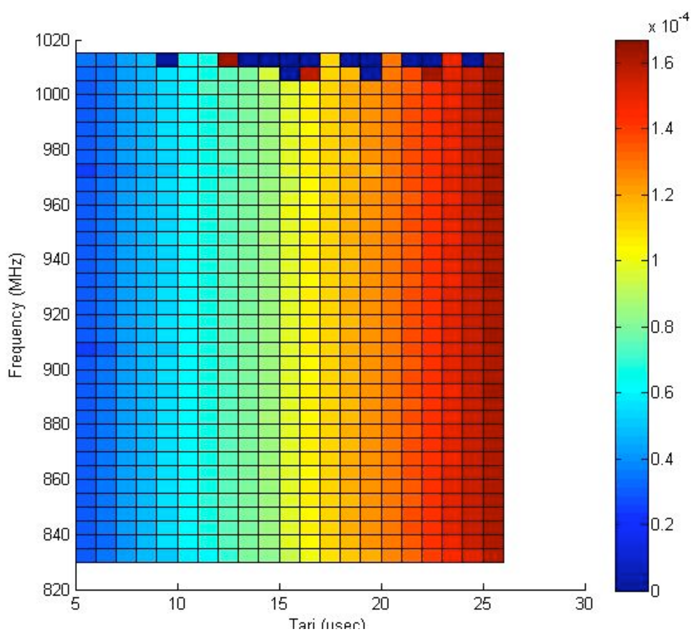


Figure 6.8. Intensity Plot of the TI Tag T1 vs. Frequency vs. Tari.

Table 6.1. Ideal vs. Measured T1 for Different Tags (in$\times 10^{-3}$ seconds)

Theoretical Tari	Squiggle	Bow-Tie	Tripod	TI Tag
0.0295	0.0295	0.0295	0.0295	0.0297
0.0361	0.036	0.0357	0.0356	0.0359
0.0403	0.042	0.0419	0.0412	0.0419
0.0446	0.0465	0.0484	0.0488	0.0484
0.0553	0.0551	0.0545	0.0545	0.0549
0.0612	0.061	0.0607	0.0609	0.061
0.0657	0.0685	0.0674	0.0674	0.0679
0.077	0.0735	0.0732	0.0732	0.0709
0.0805	0.0801	0.0797	0.0797	0.0795
0.087	0.0867	0.086	0.0862	0.0866
0.0949	0.0925	0.0956	0.095	0.0985
0.0998	0.099	0.106	0.1065	0.105
0.1059	0.1056	0.111	0.1112	0.112
0.112	0.1116	0.117	0.116	0.117
0.1177	0.1177	0.12	0.13	0.119
0.1236	0.1236	0.13	0.132	0.13
0.1309	0.1304	0.136	0.136	0.136
0.1379	0.136	0.142	0.142	0.112
0.1284	0.1329	0.149	0.15	0.149
0.1266	0.1319	0.143	0.143	0.155
0.1504	0.1496	0.149	0.149	0.161
0.1612	0.1609	0.155	0.155	0.167

Table 6.2. The Range of Tari for out of Specification T1

Tags	Tari (μsec)
Squiggle	21 - 23
Bow-Tie	18 - 25
Tripod	18 - 25
TI Tag	17 - 25

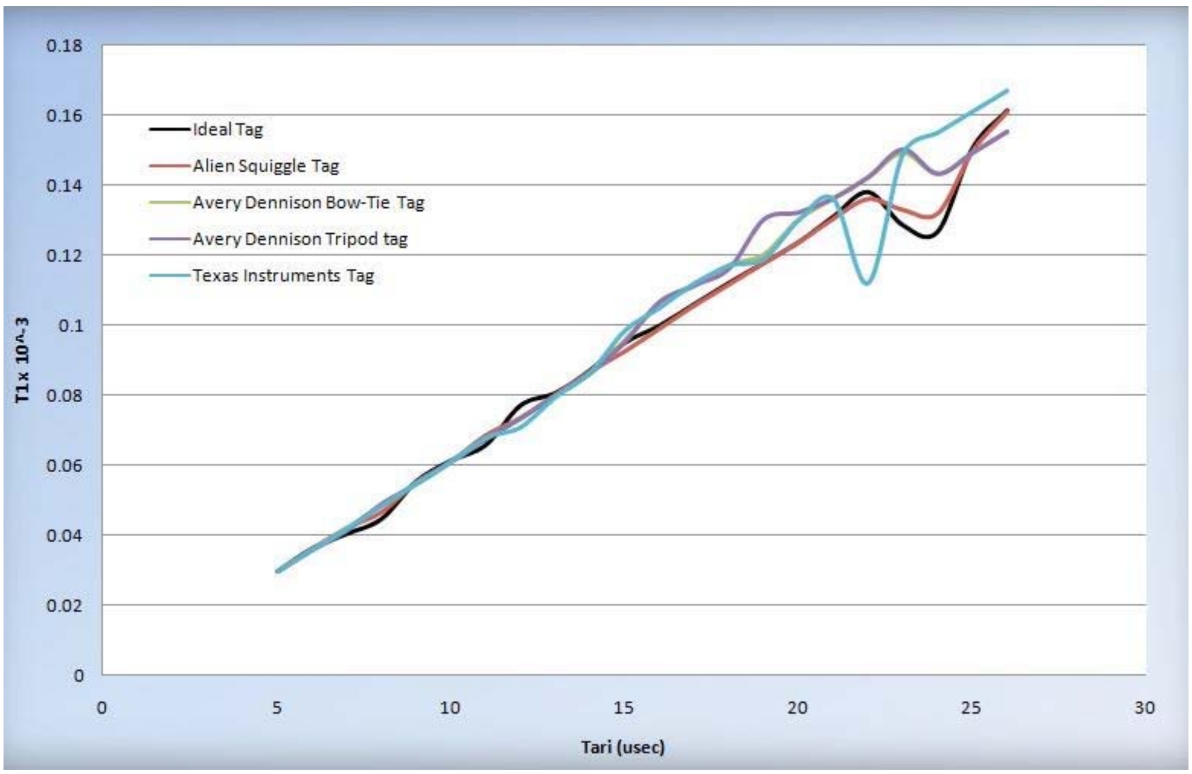


Figure 6.9. Ideal T1 and Actual T1 measured from Real Tags.

CHAPTER 7

EXPERIMENT 2: TARI VS. POWER RECEIVED

7.1 Introduction

In this chapter we will discuss the data that we collected from the experiment 2. In experiment 2 we measure the power received from the tag at different values of Tari, across the whole frequency range 860-960 MHz. This experiment was conducted in the anechoic chamber, i.e clean environment free from any RF reflection. In this experiment the tags used were as follows:

- Avery Dennison Bowtie Tag
- Avery Dennison Tripod Tag
- Alien Squiggle Tag
- Texas Instruments (TI) Tag

7.2 Data Analysis and Evaluation

In this experiment we will be varying the 'Tari' parameter of ISO-180006-C Class 1 Generation 2 protocol and will measure the received power from the tag.

7.3 Conclusion and Observation

Power received by the tag can be given by Friis free-space transmission formula,

$$P_{RX_{tag}} = P_{TX_{reader}} G_{reader} G_{tag} (\frac{\lambda}{4\pi R})^2 \tag{7.1}$$

Where $P_{RX_{reader}}$ is the power transmitted by the reader, G_{reader} is the gain of the reader antenna and G_{tag} is the gain of the tag antenna, λ is the wavelength of the

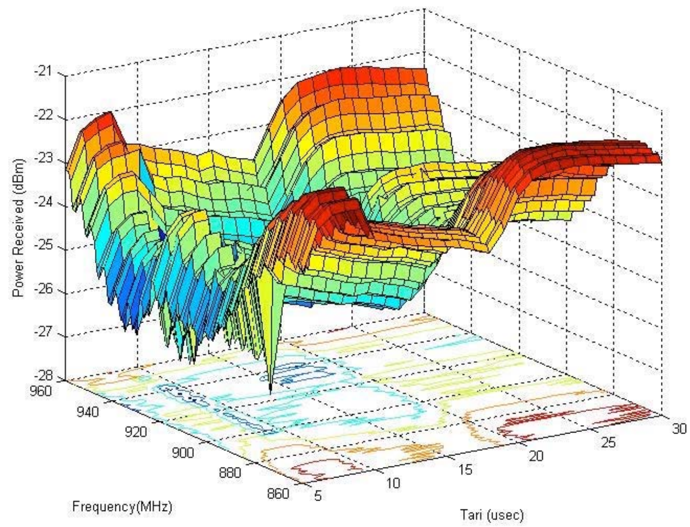


Figure 7.1. 3-D Power Plot of Bow-tie Tag.

transmitting frequency, and R is the radius of the sphere or in other words distance between the reader and tag antenna. Now there will be backscatter loss when the tag transmit the signal back to the reader, which is given by B_L. Hence, the final power received by the reader antenna is given by equation 7.2

$$P_{RX_{reader}} = P_{TX_{reader}} G^2_{reader} G^2_{tag} (\frac{\lambda}{4\pi R})^4 B_L \tag{7.2}$$

Hence looking at the 7.2 we can see that received power is dependent on reader and tag antenna gain, operating frequency and the distance between the reader and tag and the backscatter loss and the reader transmitted power and independent of the protocol parameter Tari. From this given relation we should have constant power plot for different Tari. From the data plots in Figure 7.1 7.3 7.5 7.7 we can see an erratic but constant type of behavior at the Tari 15±3μsec for all the four type

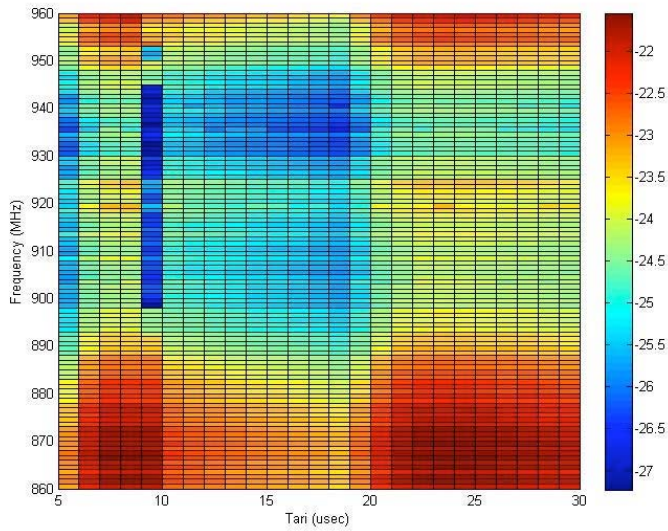


Figure 7.2. Intensity Power Plot of Bow-Tie Tag.

of tags and hence can conclude that it is not according to the specification of the ISO-180006-C Class-1 Generation 2 protocol.

Table 7.1. Power Received (dBm) Range for various Tari - Bow-Tie

Tari (μsec)	Power Received	Frequency
5 -10	-21.5 - -26	860 - 960 MHz
10 -15	-23.5 - -26	860 - 960 MHz
15 -20	-23.5 - -26.5	860 - 960 MHz
20 -25	-21 - -24	860 - 960 MHz

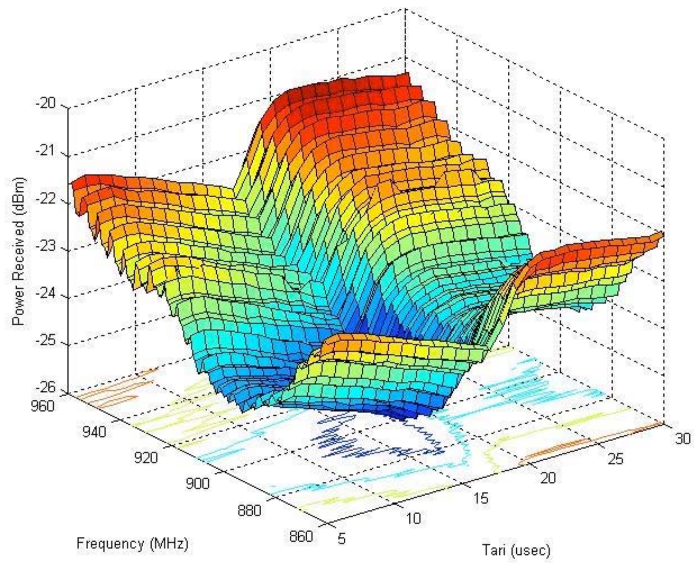


Figure 7.3. 3-D Power Plot of the Tripod Tag.

Table 7.2. Power Received (dBm) Range for various Tari - Tripod

Tari (μsec)	Power Received	Frequency
5 -10	-21 - -24.6	860 - 960 MHz
10 -15	-22 - -25	860 - 960 MHz
15 -20	-22.5 - -25.5	860 - 960 MHz
20 -25	-21 - -23.5	860 - 960 MHz

Table 7.3. Power Received (dBm) Range for various Tari - Squiggle

Tari (μsec)	Power Received	Frequency
5 -10	-19.5 - -22	860 - 960 MHz
10 -15	-19.5 - -23	860 - 960 MHz
15 -20	-20.5 - -24	860 - 960 MHz
20 -25	-18.5 - -21	860 - 960 MHz

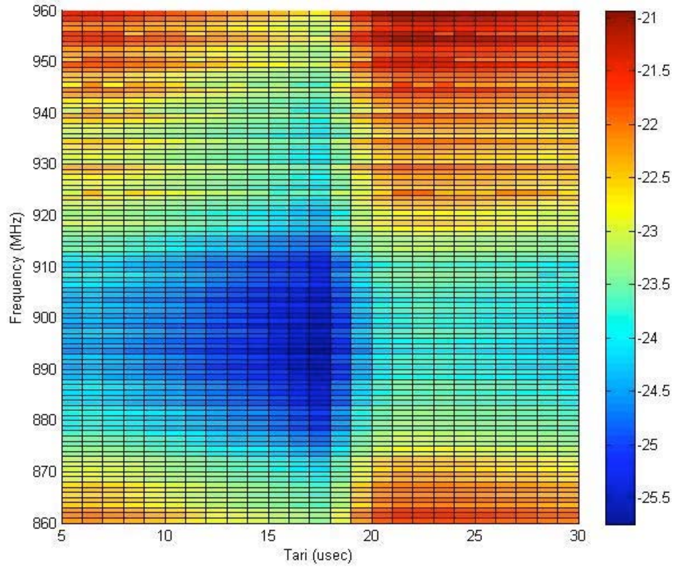


Figure 7.4. Intensity Power Plot of Tripod Tag.

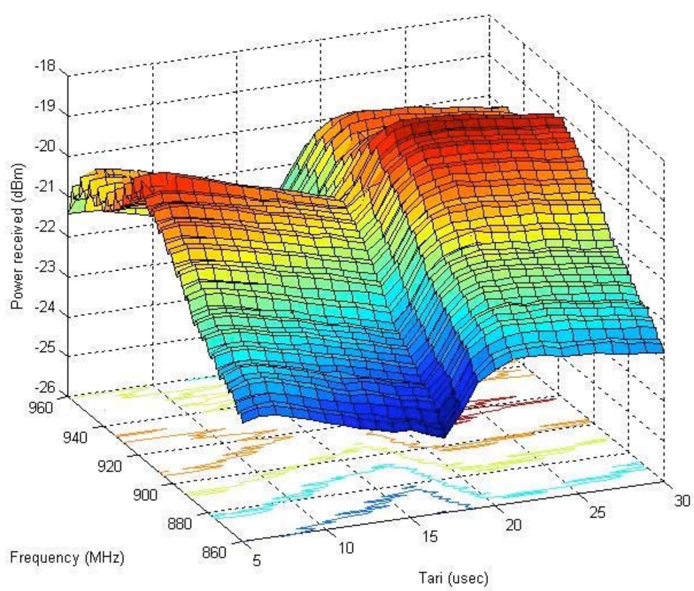


Figure 7.5. 3-D Power Plot of Squiggle Tag.

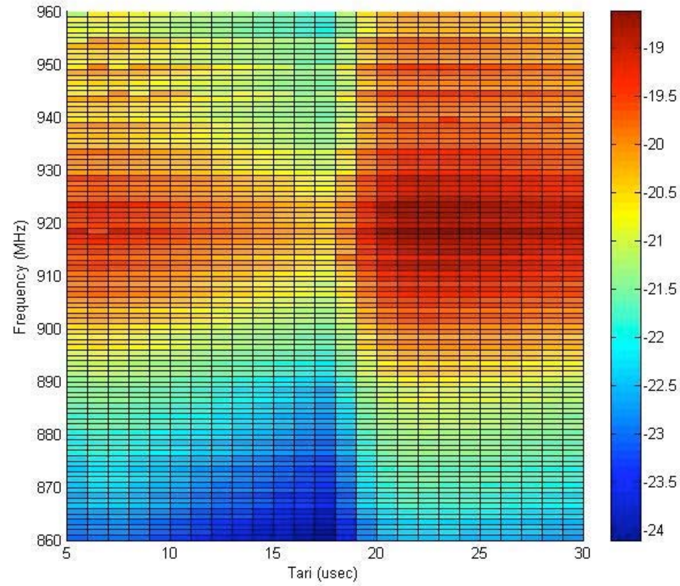


Figure 7.6. Intensity Power Plot of Squiggle Tag.

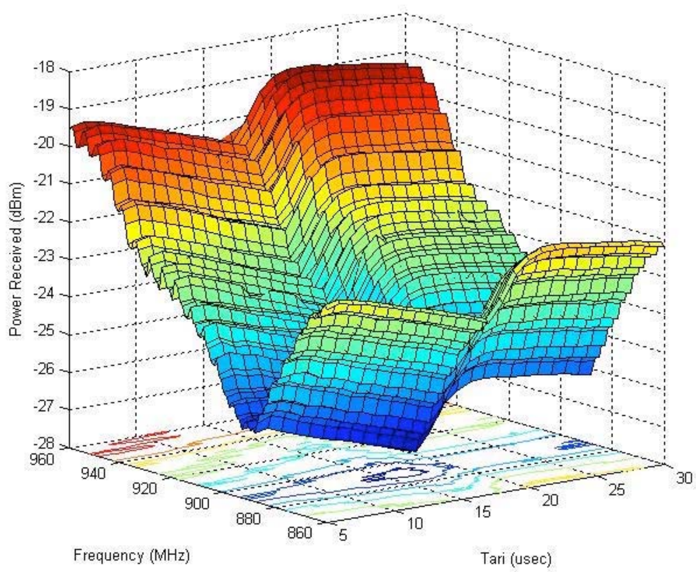


Figure 7.7. 3-D Power Plot of TI Tag.

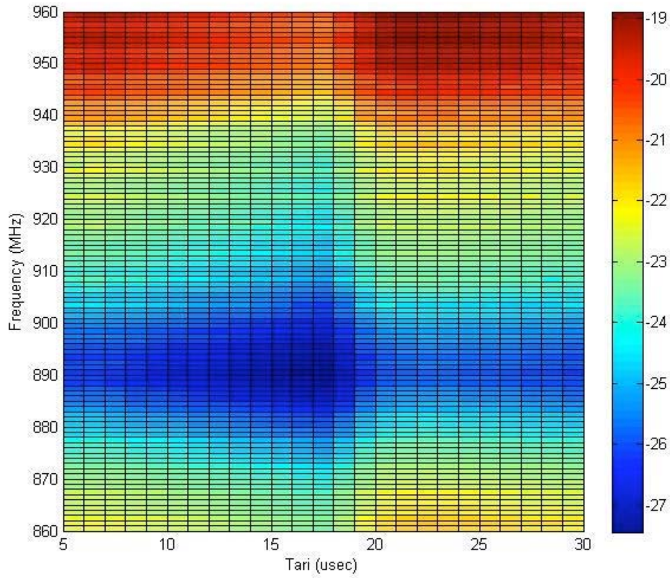


Figure 7.8. Intensity Power Plot of TI Tag.

Table 7.4. Power Received (dBm) Range for various Tari - TI Tags

Tari (μsec)	Power Received	Frequency
5 -10	-19 - -26	860 - 960 MHz
10 -15	19.5 - -27	860 - 960 MHz
15 -20	-20 - -27	860 - 960 MHz
20 -25	-19 - -23	860 - 960 MHz

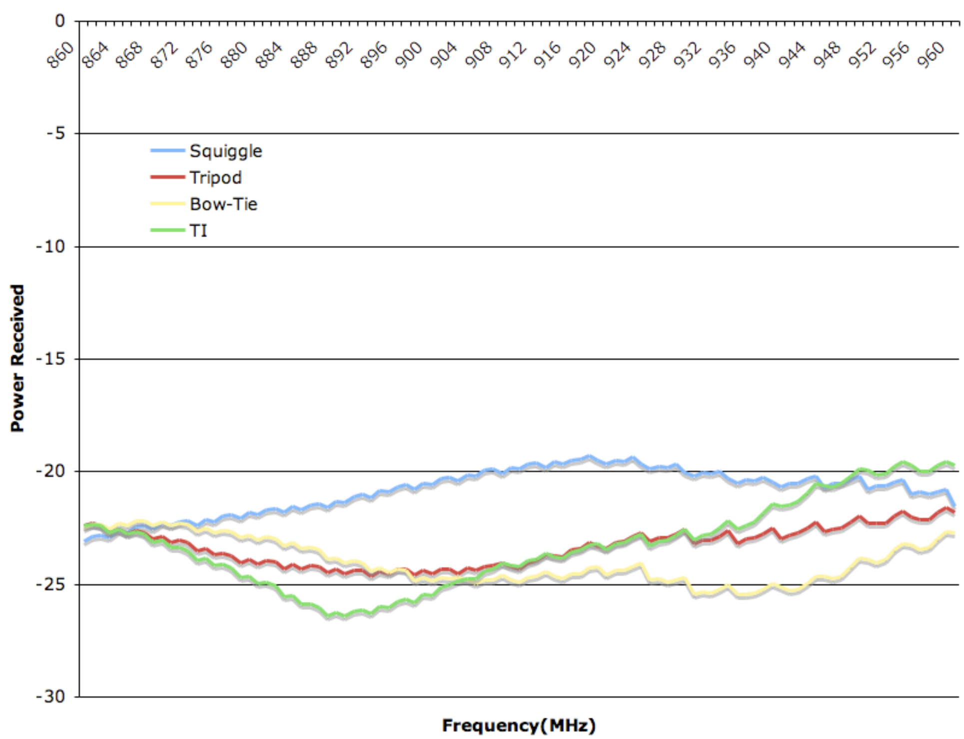


Figure 7.9. Frequency Response of different tag.

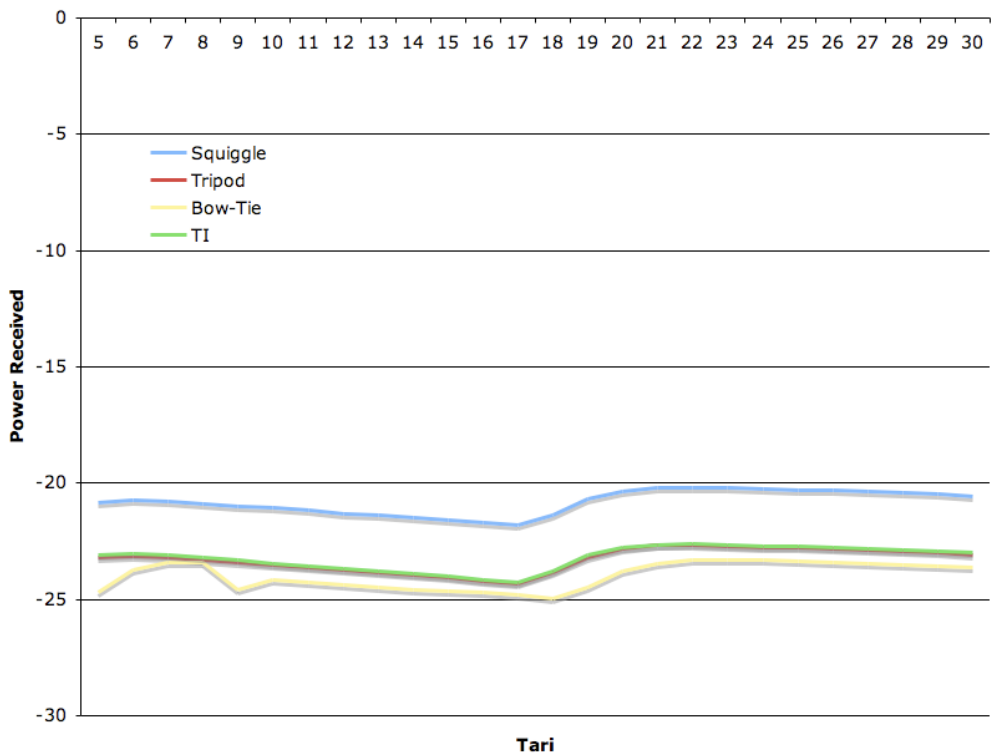


Figure 7.10. Power Received at different Tari.

CHAPTER 8

EXPERIMENT 3: PULSE WIDTH VS. POWER RECEIVED

8.1 Introduction

In this chapter we will discuss the data collect form the experiment 3 and 4 that were conducted in previous chapter. In Experiment 3 we measure the received tag power while varying the frequency and pulse width of Tari. Experiment 3 was conducted in the anechoic Chamber , i.e. clean environment and free from any radio frequency reflection and also in the RFID lab NH 131. In this experiments the tags used were as follows:

- Avery Dennison Bowtie Tag
- Avery Dennison Tripod Tag
- Texas Instruments (TI) Tag

This experiment is conducted on multiple tags and in different environment in order to remove any discrepancy of the effect of the type of the tag used. These experiments will also evaluate the tag and its performance when the protocol is tweaked and can also determine the boundaries on the protocol where the tag can work.

8.2 Data Analysis and Evaluation

In this experiment we varied the pulse width of the 'Tari' Paremeter of the ISO-18000-6 Tpye-C a.k.a. EPC Class-1 Generation-2 protocol and measured the received power from the tag at different frequencies. Also we took the measurement at three different values of 'Tari' which are

- 6.25 μ sec

- 12.5 μ sec
- 25 μ sec

8.2.1 Avery Dennison Bow-tie Tag

The Figure 8.1, 8.2 and 8.3 shows the 3D plot intensity plot and the contour plot of the power received from the avery dennison bow-tie tag at different pulse width of Tari for different frequency varying from 860-960 MHz.

In the Figure 8.4, 8.5 and 8.6 shows the plot of the test data acquired in the chamber and we can see that there is a definite dip in the power received for frequency range between 875MHz - 890MHz for different value of pulse width of Tari.

8.2.2 Avery Dennison Tripod Tag

The Figure 8.7, 8.8 and 8.9 shows the 3D plot intensity plot and the contour plot of the power received from the avery dennison tripod tag at different pulse width of Tari for different frequency varying from 860-960 MHz in the NH 131 RFID Lab.

In the Figure 8.10, 8.11 and 8.12 shows the plot of the test data acquired in the chamber and we can see that there is a definite dip in the power received for frequency range between 875MHz - 890MHz for different value of pulse width of Tari in the Anechoic Chamber.

8.2.3 TI Tag

The Figure 8.13, 8.14 and 8.15 shows the 3D plot intensity plot and the contour plot of the power received from the Texas Instruments tag at different pulse width of Tari for different frequency varying from 860-960 MHz in the NH 131 RFID Lab.

8.3 Observation and Conclusion

According to the ISO 18000-6 Type-C, Class-1 Gen-2 Protocol the range of the RF Pulse width [MAX(0.265Tari,2) to 0.525Tari]. For the pulse width of Tari, according to the protocol specification the typical value is between 0.3 to 0.6 and we can see all the tags working in those range. While stepping out of the required range of pulse width the tags do respond at pulse width in the range 0.2 - 0.3 and 0.6 - 0.8. Hence we can operate on the boundaries and still can meet the specification. In the same experiment we did vary the value of Tari in order to see its impact on the performance.The Figure **??** and **??** at different modulation depth for three different Tari and Pulse Width of 0.5 in Anechoic Chamber and in NH 131 Lab respectively

The Figure 8.16 we can see that the power received do change with different values of Tari, apparently we can see that the the performance is slightly better at Tari = 25 μsec Similarly for the test in the lab we do see the variation of the power received but average difference is about ± 2 dBm and it does meet the specification of the protocol.

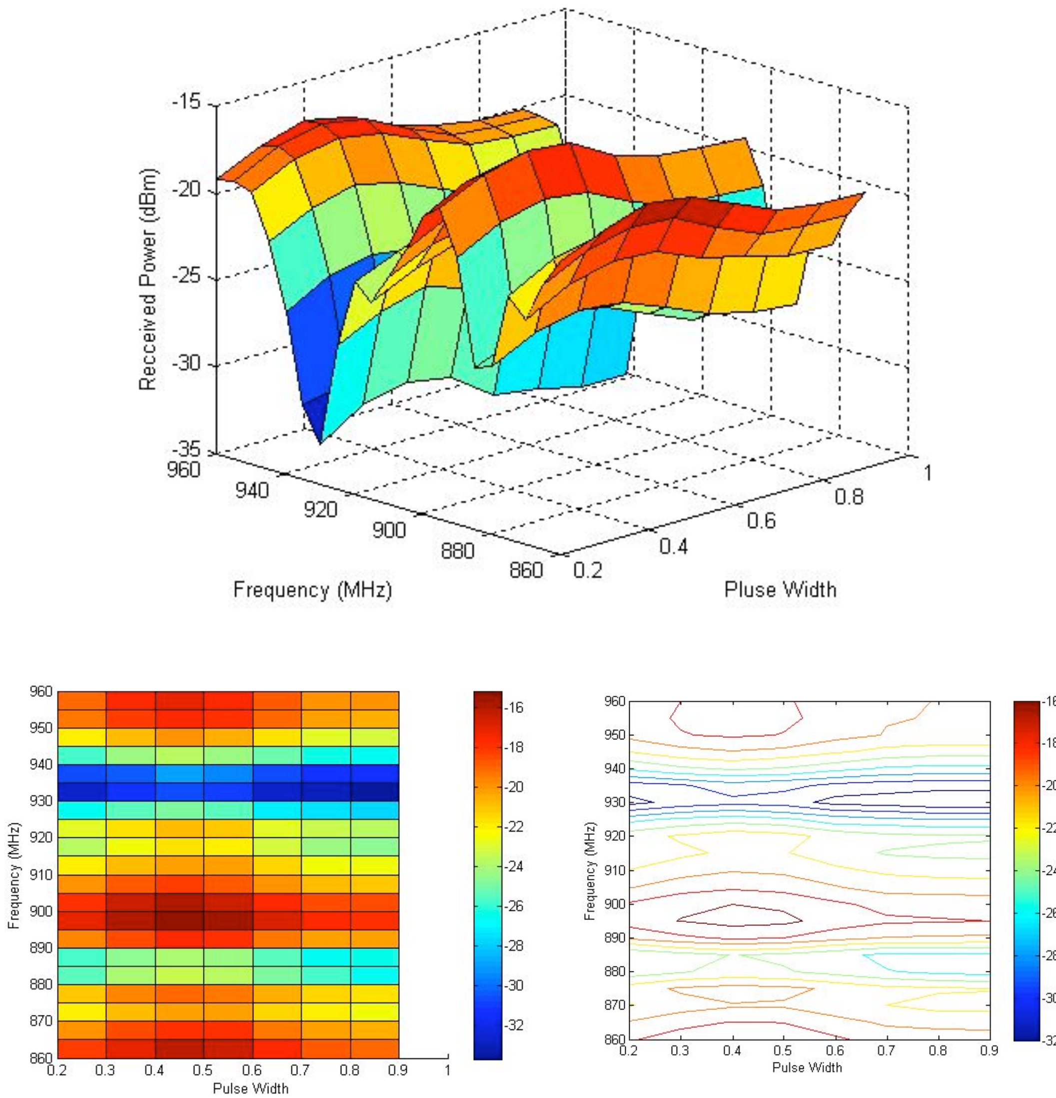


Figure 8.1. Bow-Tie Tag at Tari = 6.25μsec in the Lab NH 131.

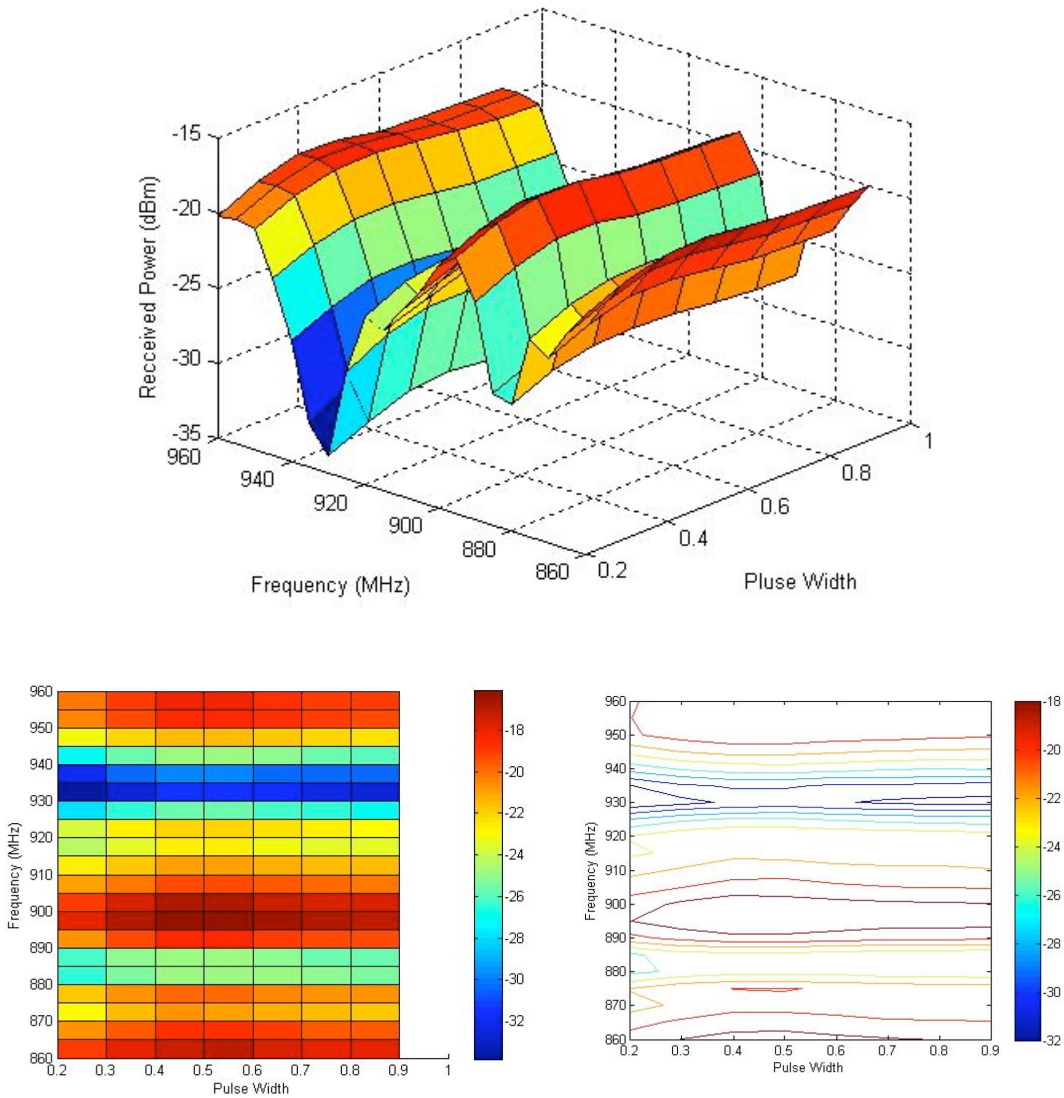


Figure 8.2. Bow-Tie Tag at Tari = 12.5μsec in the Lab NH 131.

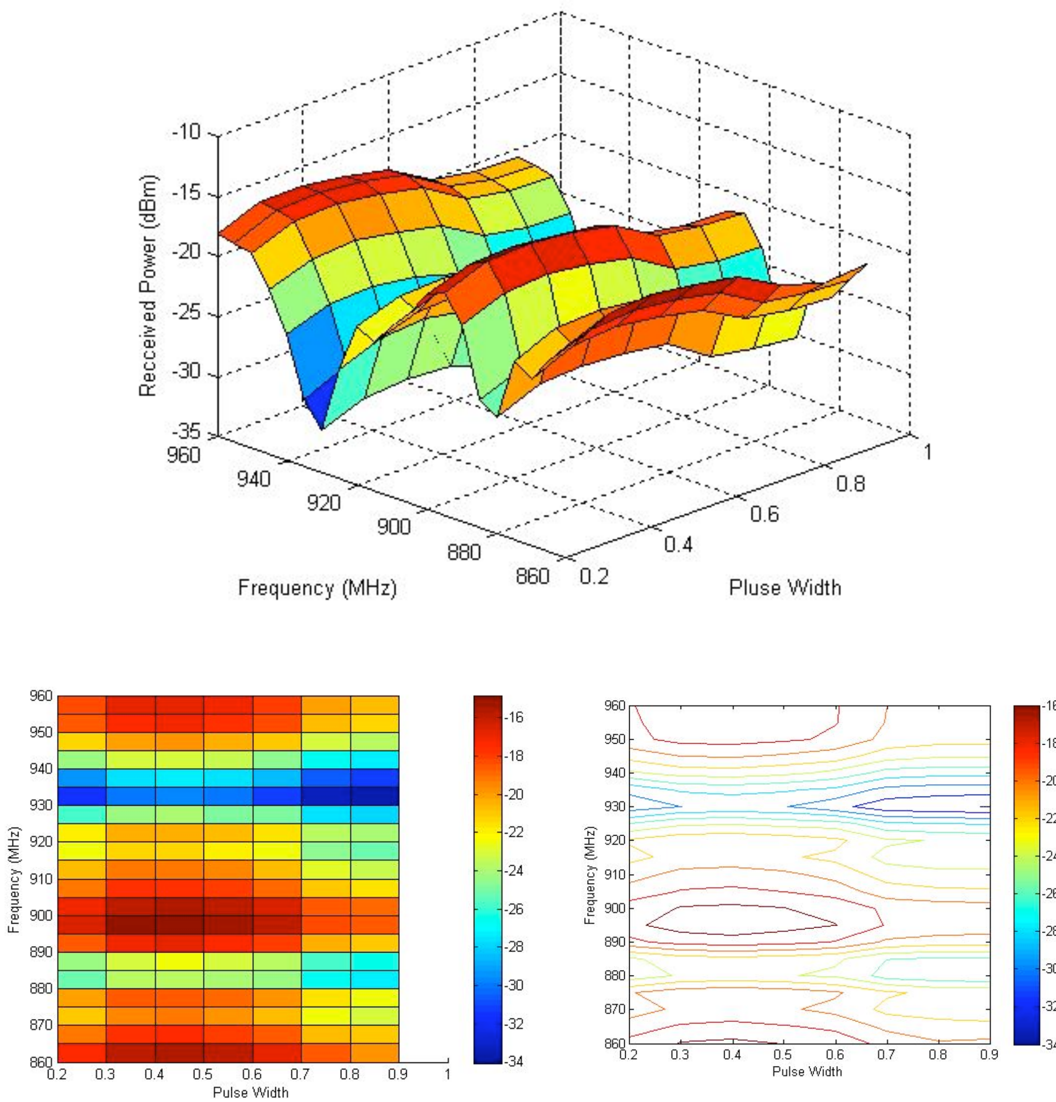


Figure 8.3. Bow-Tie Tag at Tari = 25μsec in the Lab NH 131.

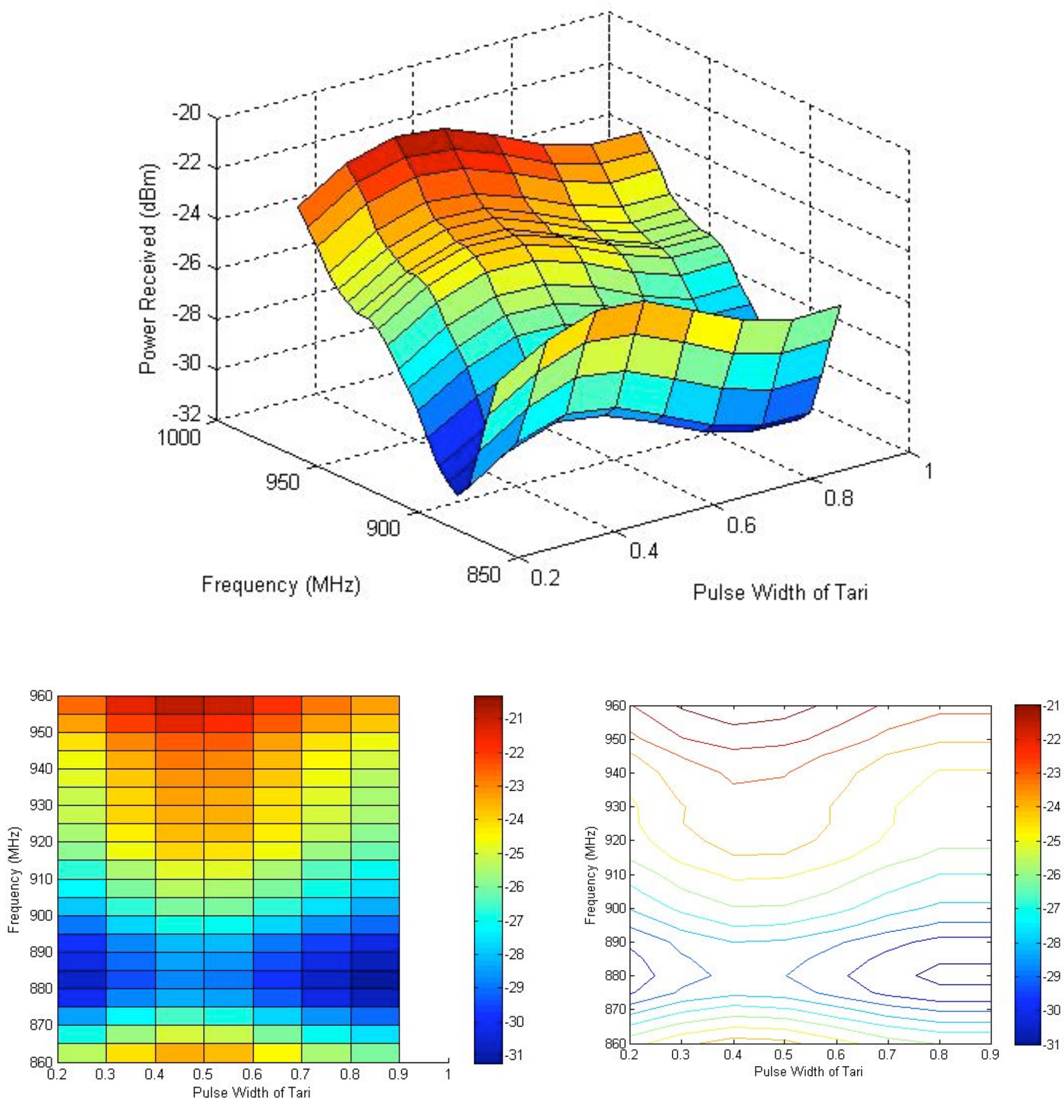


Figure 8.4. Bow-Tie Tag at Tari = 6.25μsec in the Anechoic Chamber.

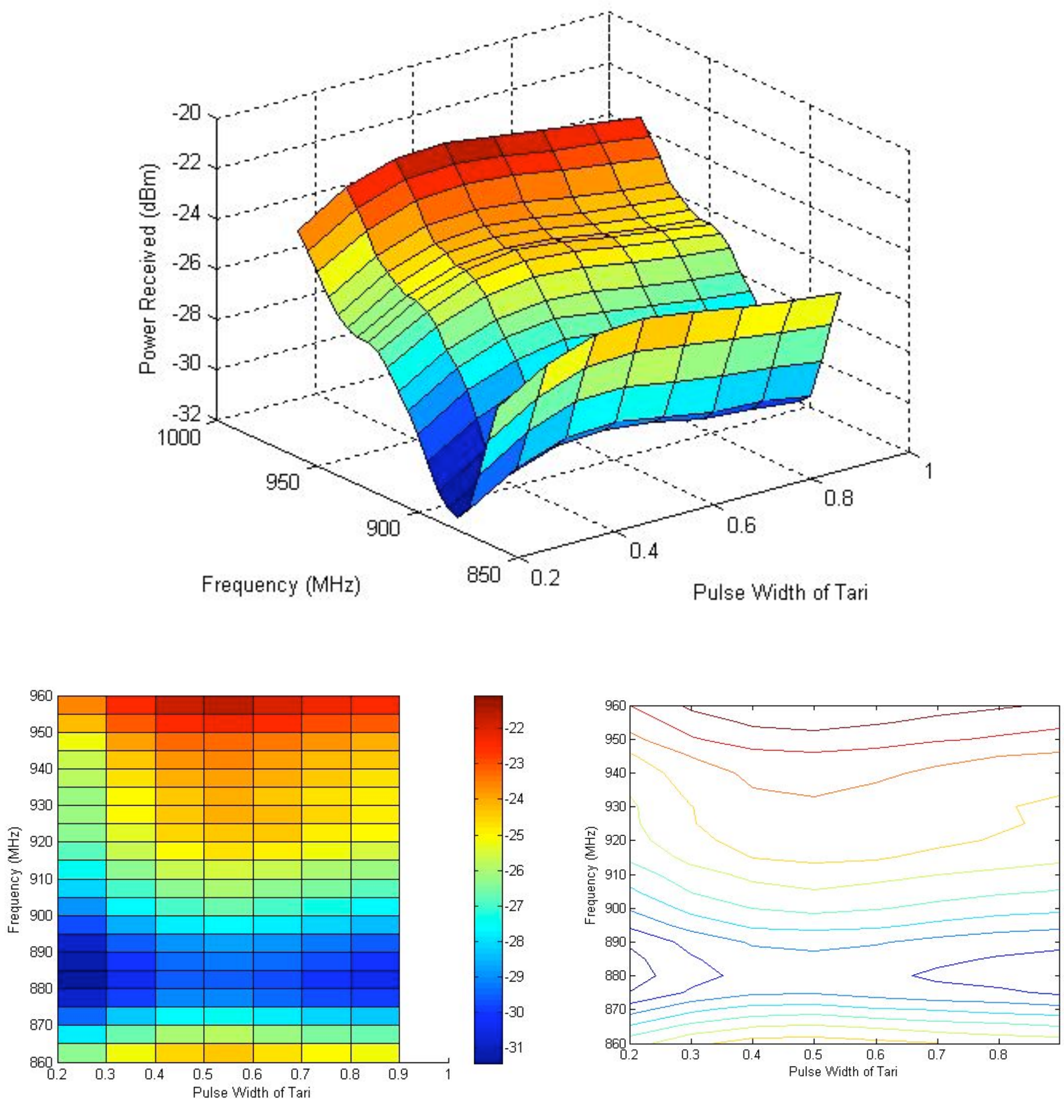


Figure 8.5. Bow-Tie Tag at Tari = 12.5μsec in the Anechoic Chamber.

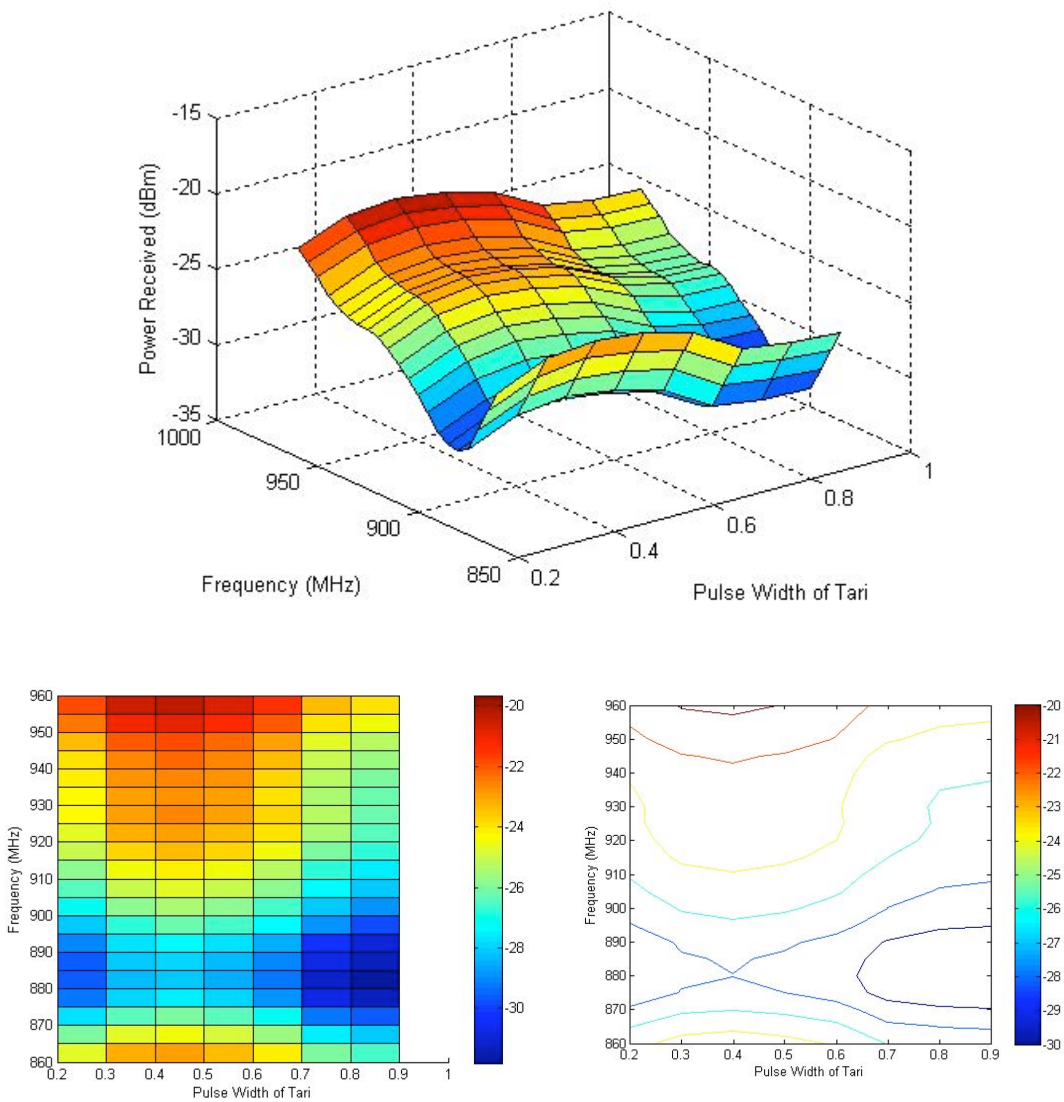


Figure 8.6. Bow-Tie Tag at Tari = 25μsec in the Anechoic Chamber.

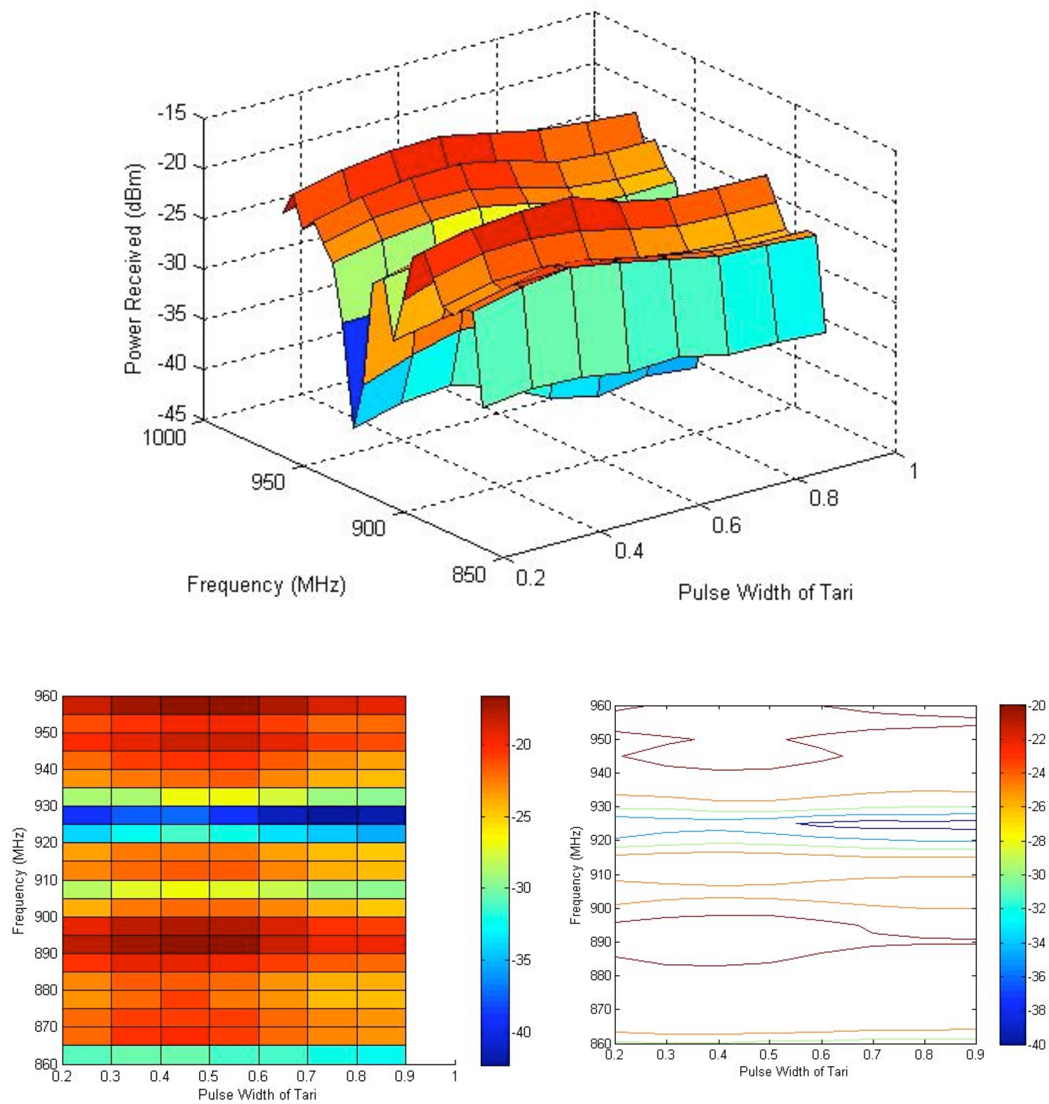


Figure 8.7. Tripod Tag at Tari = 6.25μsec in the Lab NH 131.

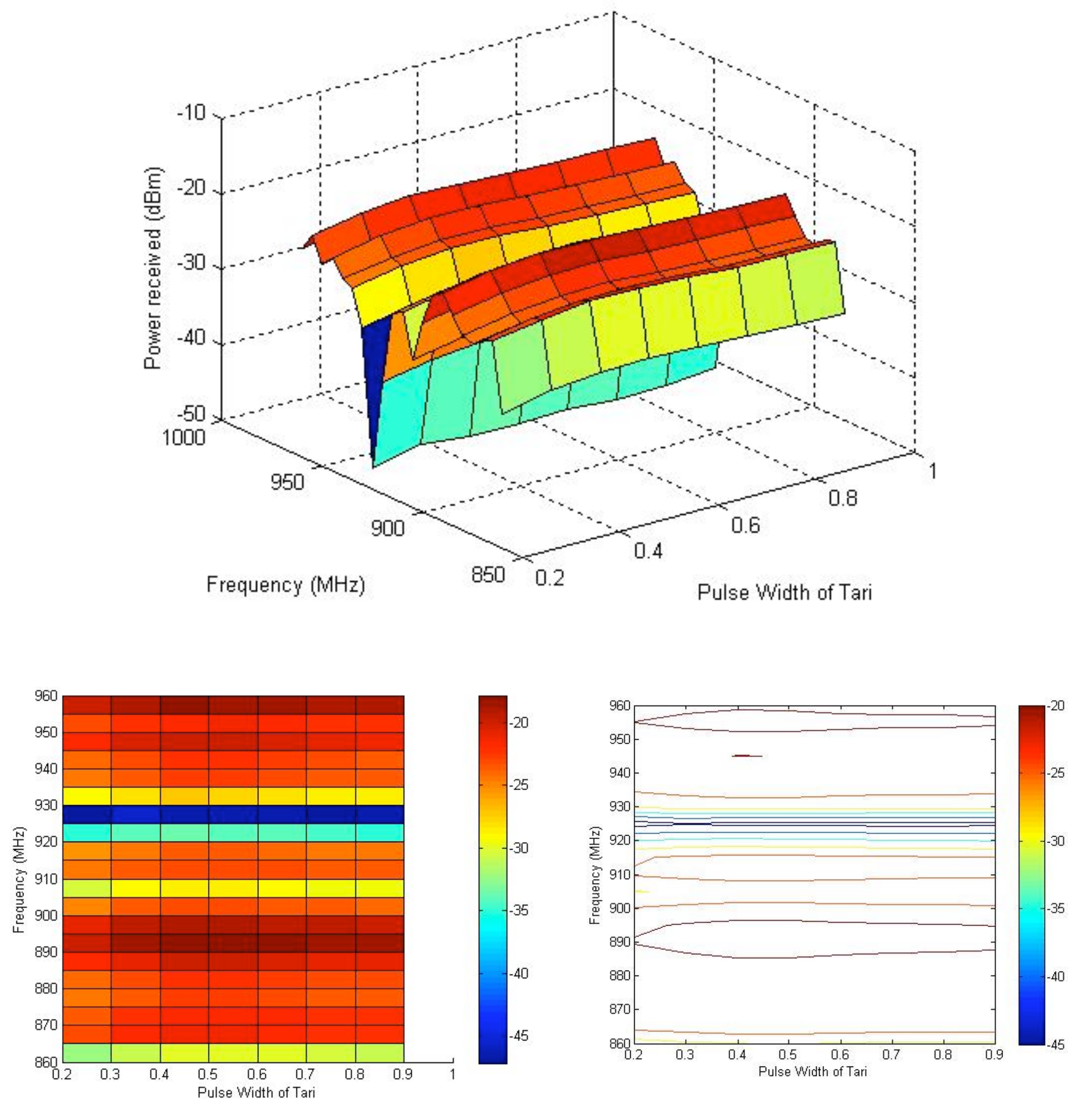


Figure 8.8. Tripod Tag at Tari = 12.5μsec in the Lab NH 131.

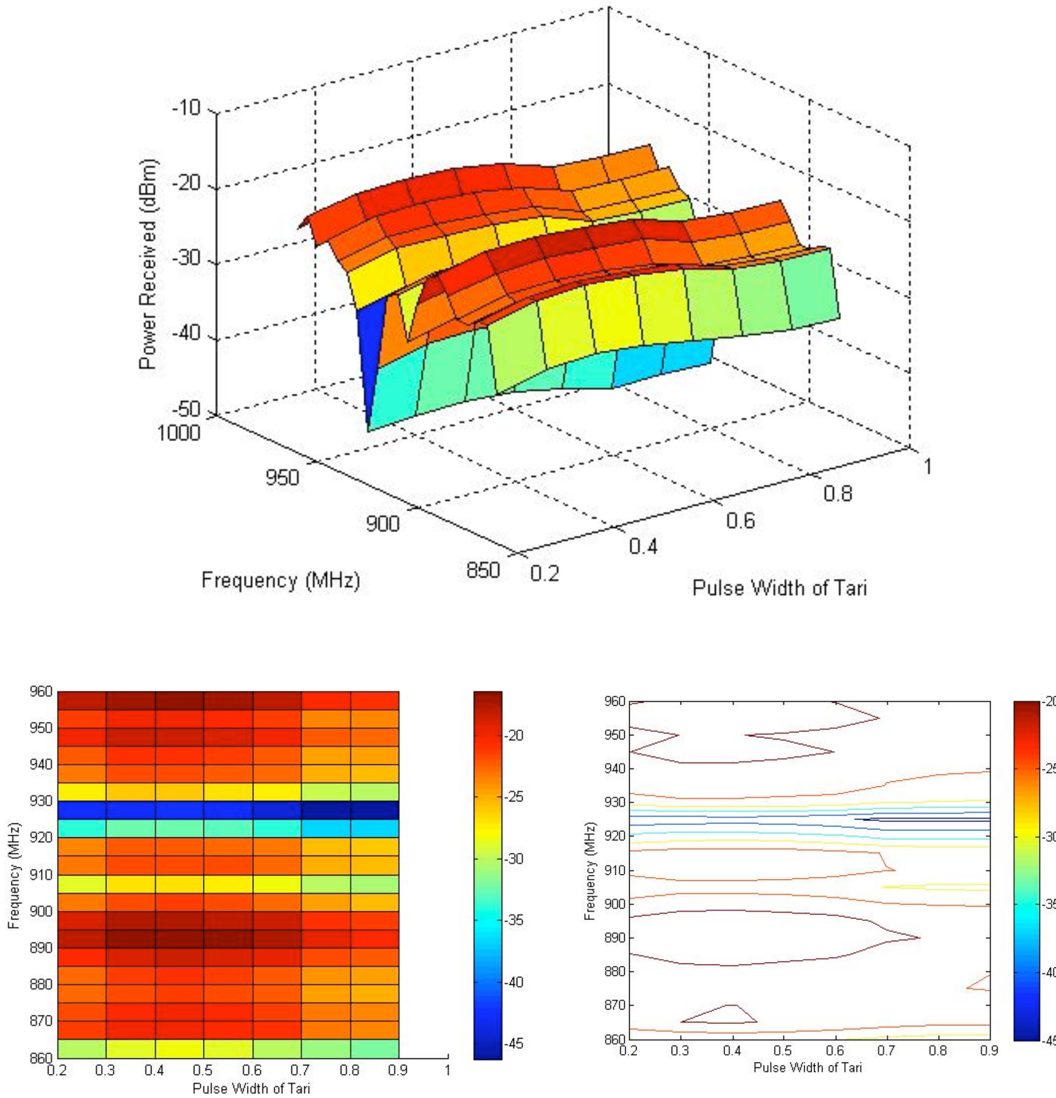


Figure 8.9. Tripod Tag at Tari = 25μsec in the Lab NH 131.

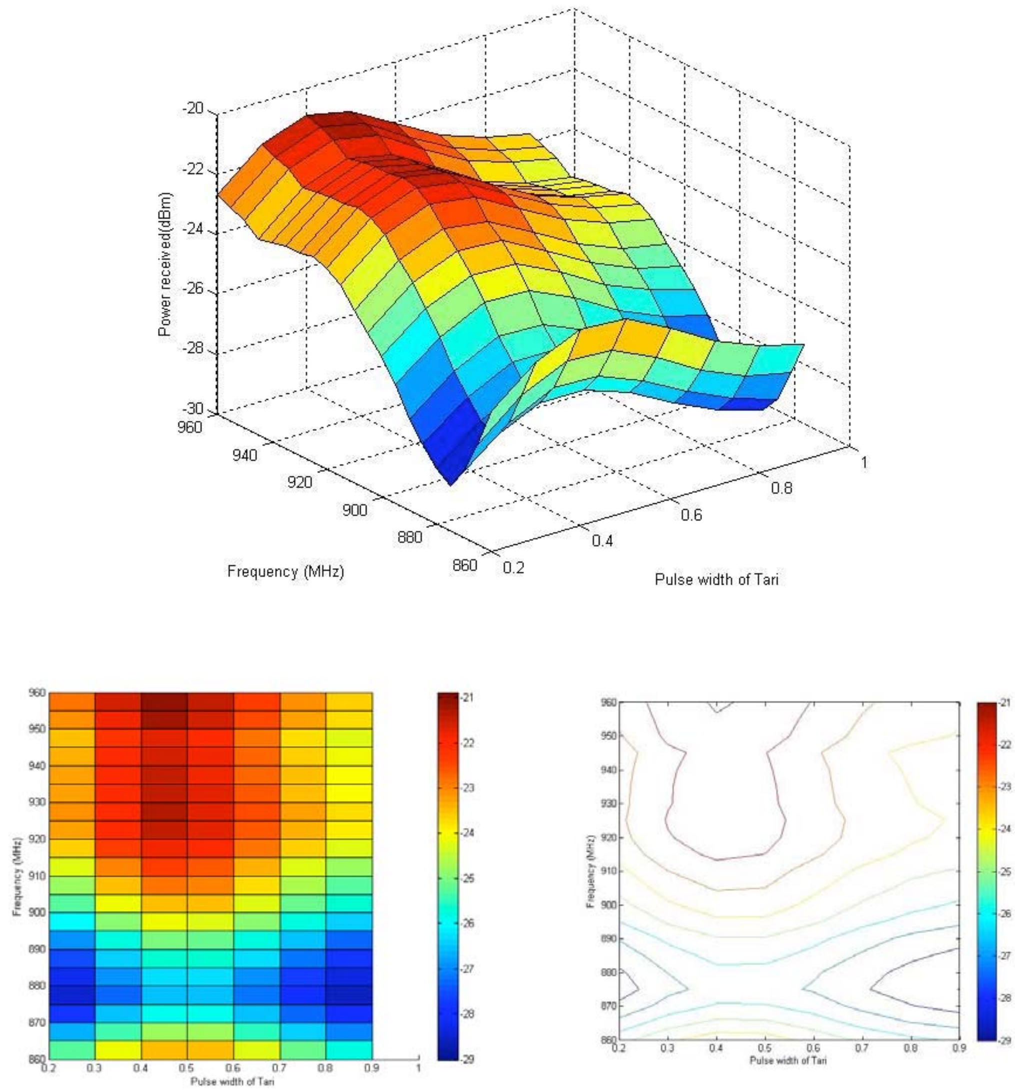


Figure 8.10. Tripod Tag at Tari = 6.25μsec in the Anechoic Chamber.

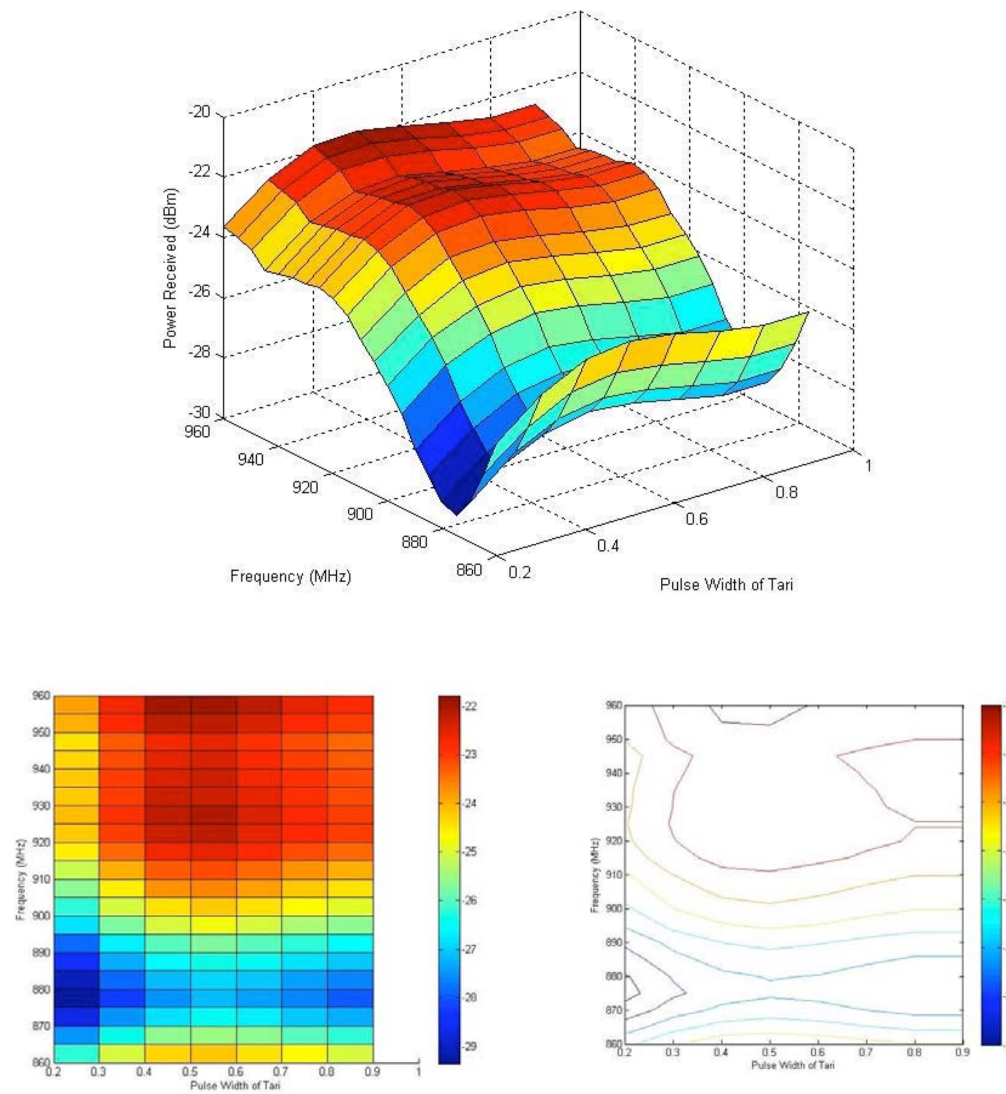


Figure 8.11. Tripod Tag at Tari = 12.5μsec in the Anechoic Chamber.

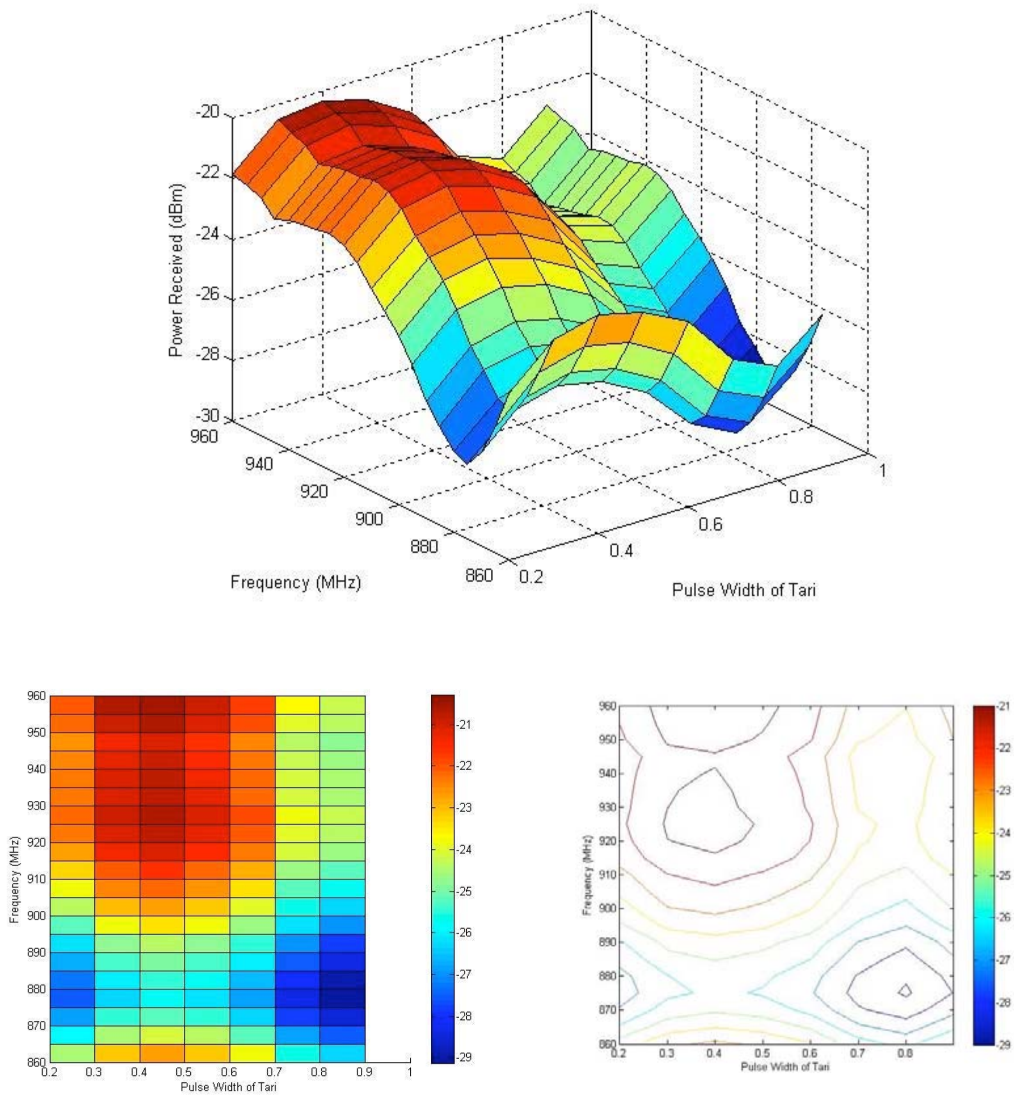


Figure 8.12. Tripod Tag at Tari = 25μsec in the Anechoic Chamber.

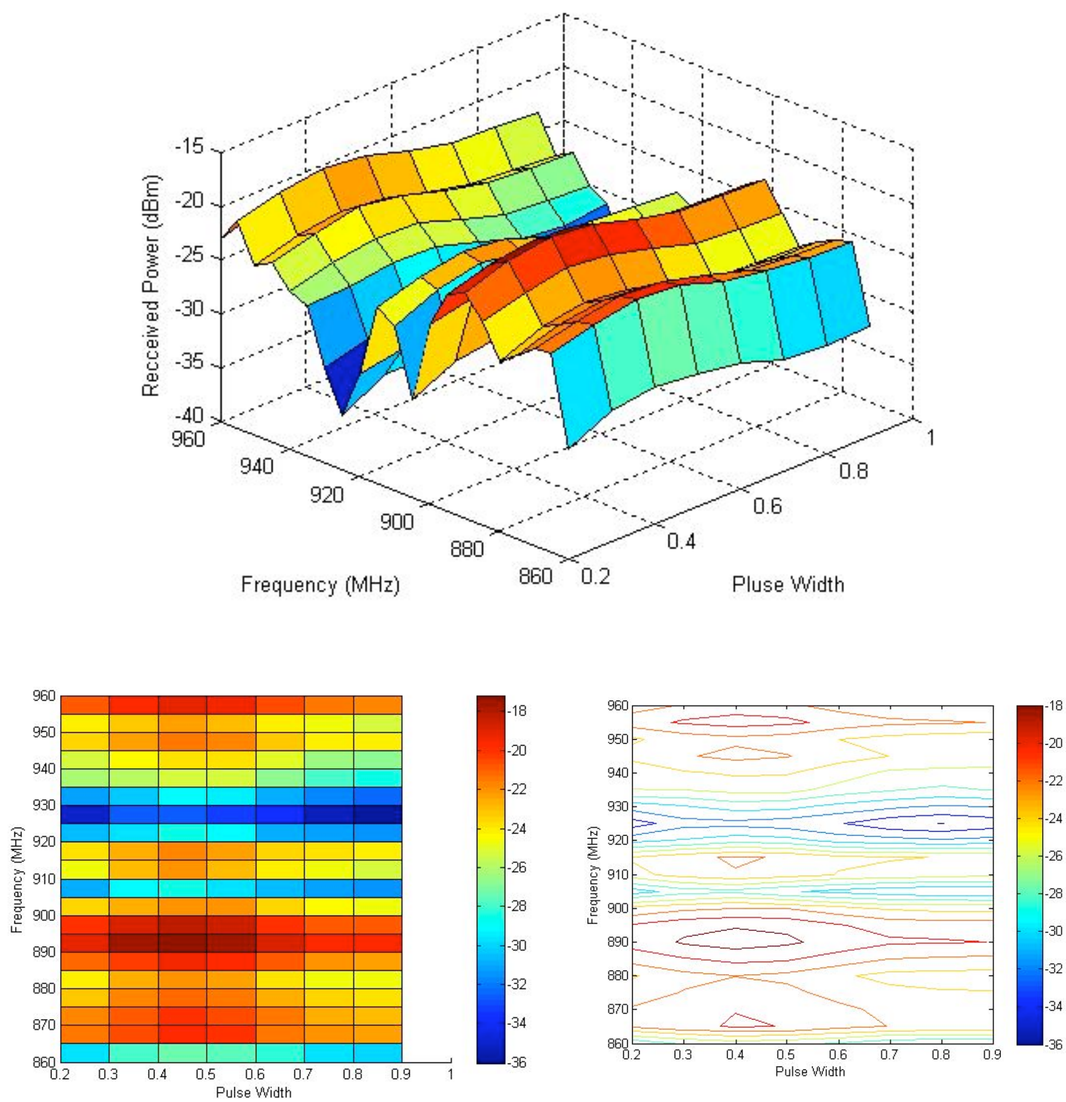


Figure 8.13. TI Tag at Tari = 6.25μsec in the Lab NH 131.

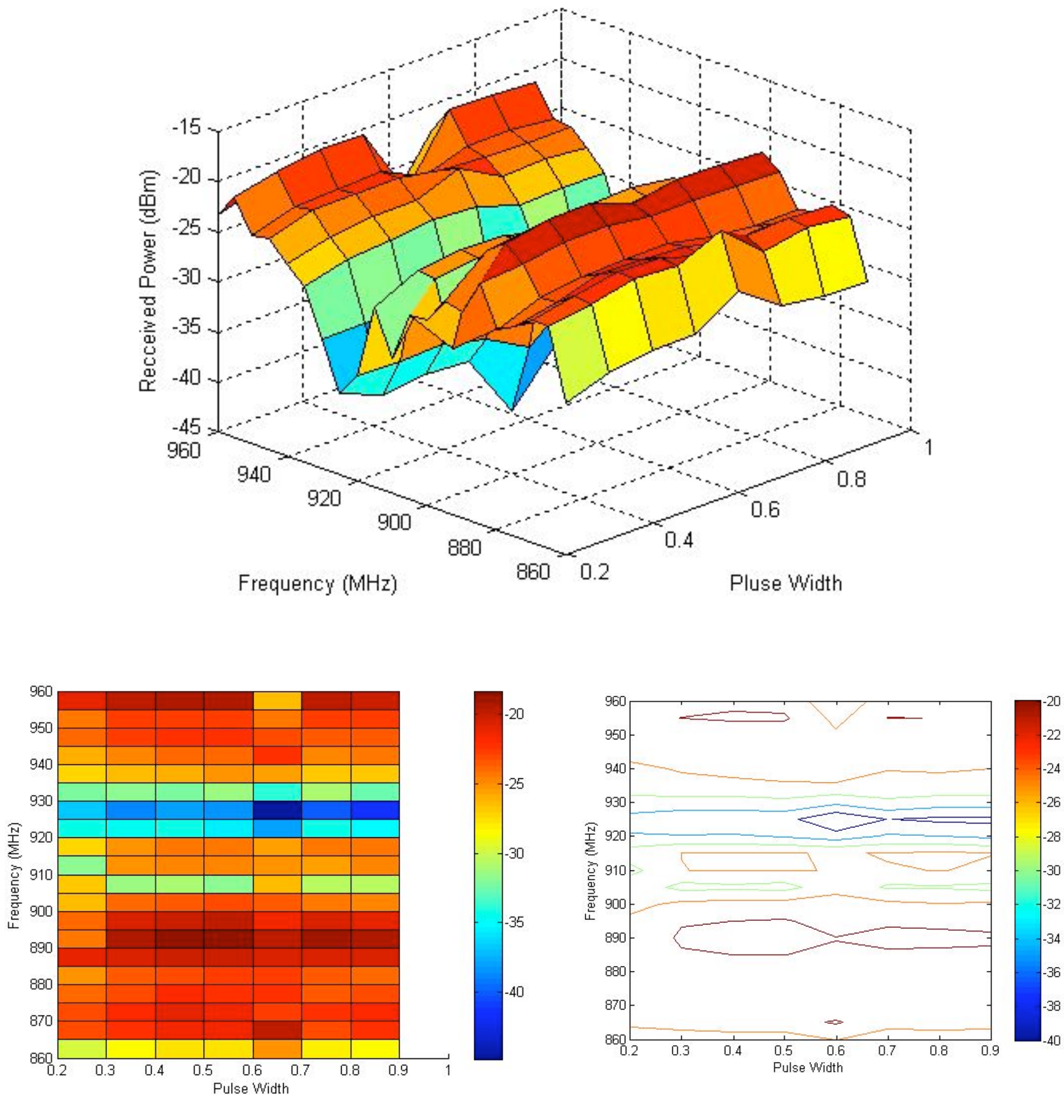


Figure 8.14. TI Tag at Tari = 12.5μsec in the Lab NH 131.

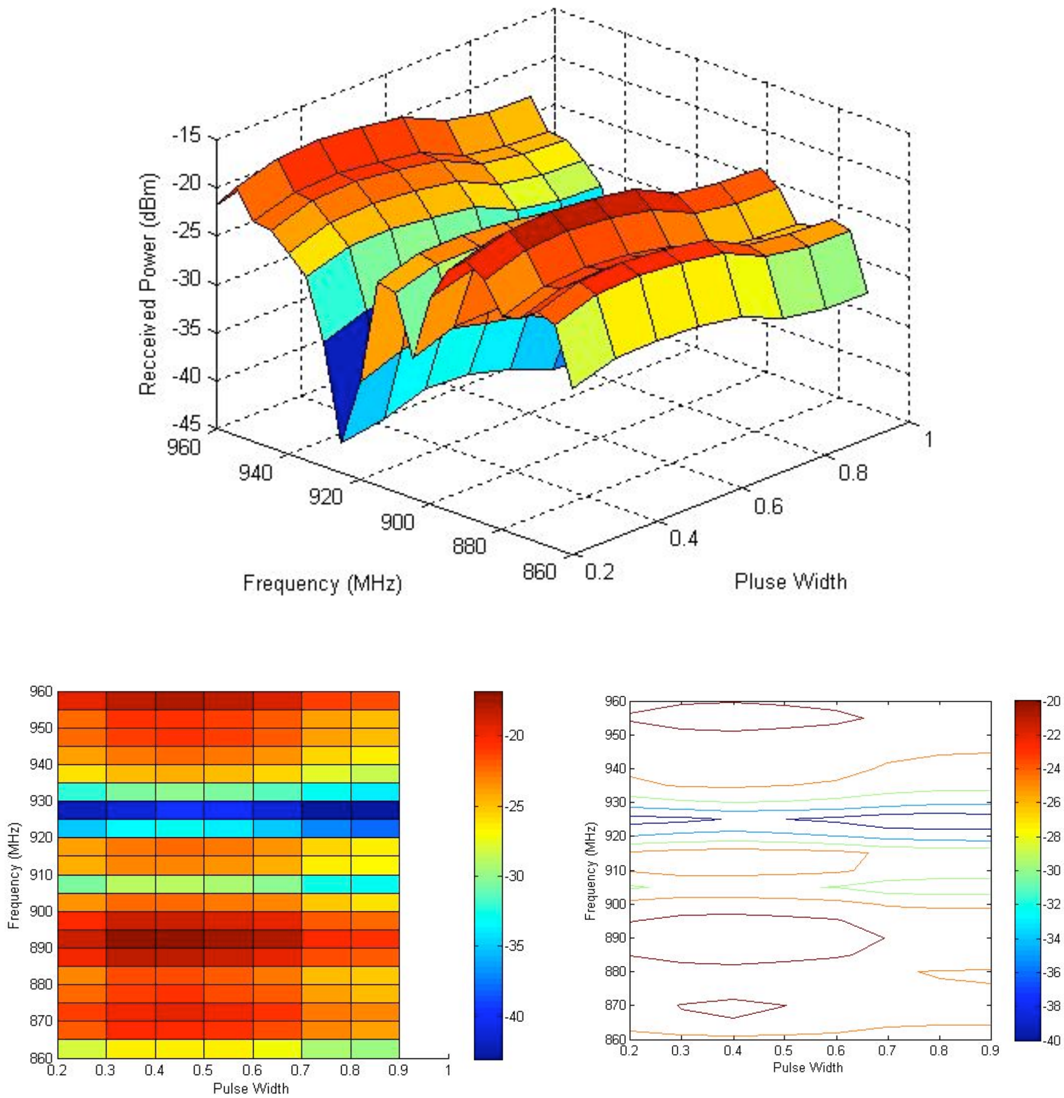
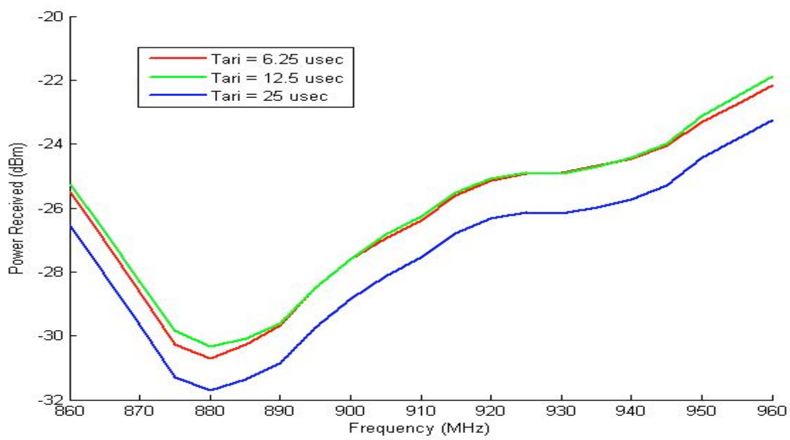


Figure 8.15. TI Tag at Tari = 25μsec in the Lab NH 131.



(A)

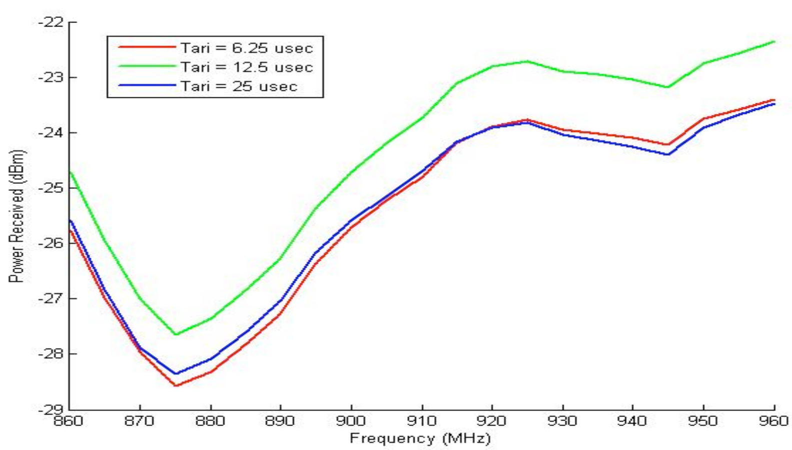
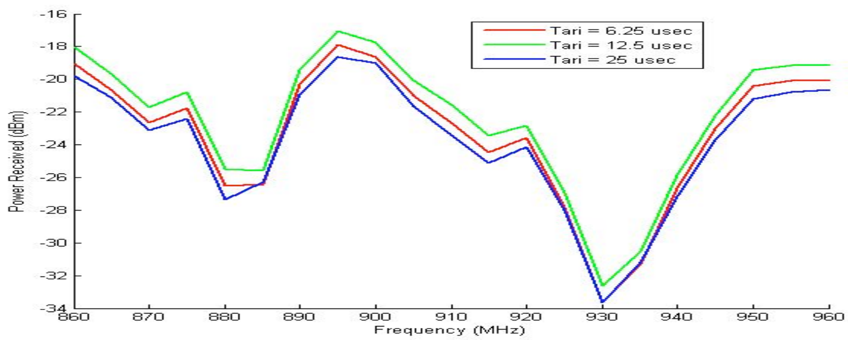
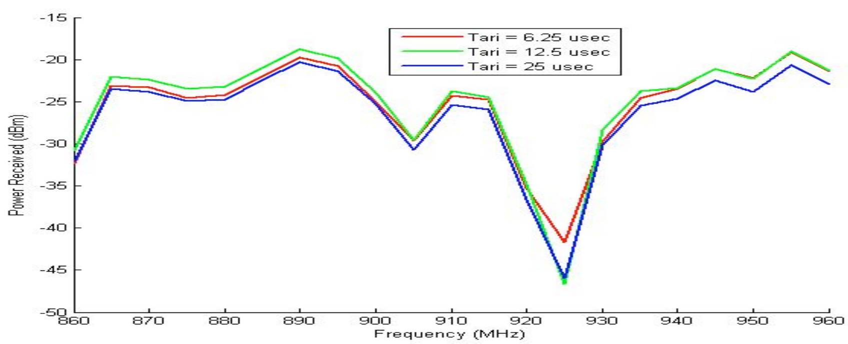


Figure 8.16. Power received from (A) Bow-Tie and (B) Tripod Tag.



(A)



(B)

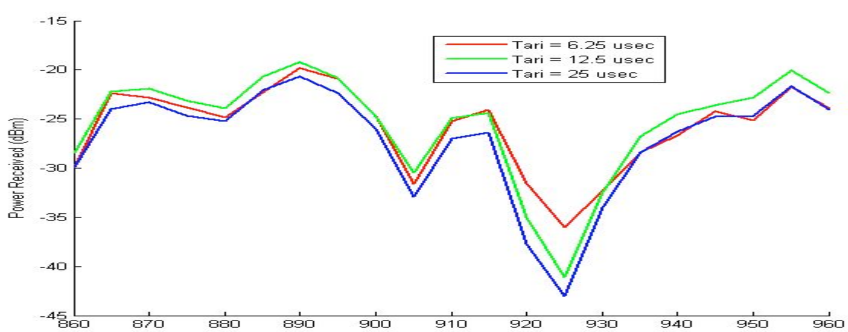


Figure 8.17. Power received from (A) Bow-Tie and (B) Tripod Tag.

CHAPTER 9

EXPERIMENT 4: MODULATION INDEX VS. POWER RECEIVED

9.1 Introduction

In this chapter we will discuss the data collected from the experiment 4. In Experiment 4 we measure the received tag power while varying the frequency and modulation index of the carrier wave. Experiment 4 was conducted in the anechoic Chamber , i.e. clean environment and free from any radio frequency reflection and also in the RFID lab NH 131. In this experiments the tags used were as follows:

- Avery Dennison Bowtie Tag
- Avery Dennison Tripod Tag
- Texas Instruments (TI) Tag

This experiment is conducted on multiple tags and in different environment in order to remove any discrepancy of the effect of the type of the tag used. These experiments will also evaluate the tag and its performance when the protocol is tweaked and can also determine the boundaries on the protocol where the tag can work.

9.2 Data Analysis and Evaluation

In this experiment we varied the Modulation Index of the 'Tari' Paremeter of the ISO-180006-C Class 1 Generation 2 protocol and measured the received power from the tag at different frequencies. Also we took the measurement at three different values of 'Tari' which are

- 6.25 μ sec
- 12.5 μ sec

- 25 μ sec

9.2.1 Avery Dennison Bow-tie Tag

The Figure 9.1, 9.2 and 9.3 shows the 3D plot intensity plot and the contour plot of the power received from the Avery Dennison Bow-Tie tag at different Modulation Index for different frequency varying from 860-960 MHz.

The Figure 9.4 , 9.5 and 9.6 shows the test data acquired in the anechoic chamber. As one can observe that the power received for all the frequencies are identical, but interesting behavior can be noticed in the frequency band of 875MHz - 890 MHz, where there is a dip in the power received.

9.2.2 Avery Dennison Tripod Tag

The Figure 9.7, 9.8 and 9.9 shows the 3D plot intensity plot and the contour plot of the power received from the Avery Dennison Tripod tag at different Modulation Index for different frequency varying from 860-960 MHz.

The Figure 9.10 , 9.11 and 9.12 shows the test data acquired in the anechoic chamber. As one can observe that the power received for all the frequencies are identical, but interesting behavior can be noticed in the frequency band of 875MHz - 890 MHz, where there is a dip in the power received.

9.2.3 TI Tag

The Figure 9.13, 9.14 and 9.15 shows the 3D plot intensity plot and the contour plot of the power received from the Texas Instruments tag at different Modulation Index for different frequency varying from 860-960 MHz.

9.3 Conclusion and Observation

According to the ISO 180006-C Class 1 Generation 2 Protocol specification, the Modulation Depth is anywhere between 80—% and 100%. As we can see from the test results we have varied Modulation Depth from 20% to 100% for three different Tari which is within the specification of the protocol. The Figure 9.16 shows the power received for three different Tari at Modulation Depth = 90% in Anechoic Chamber

As we can see the variation in the power received for different values of Tari. We notice that the tags performance is mediocre at Tari value of 12.5μsec. Also from the 3-D plots we can see that the tags do responds to the reader commands for modulation depth below 80% and but and interesting behavior can be seen between the frequency range of 875 MHz - 885MHz where the response of the tag weakens for all the tags. Figure 9.17 shows power received at three different Tari for pulse width of .5 and MI = 90%.

From the Figure 9.17 we do see the variation of the power received but average difference is about ± 2 dBm and it does meet the specification of the protocol.

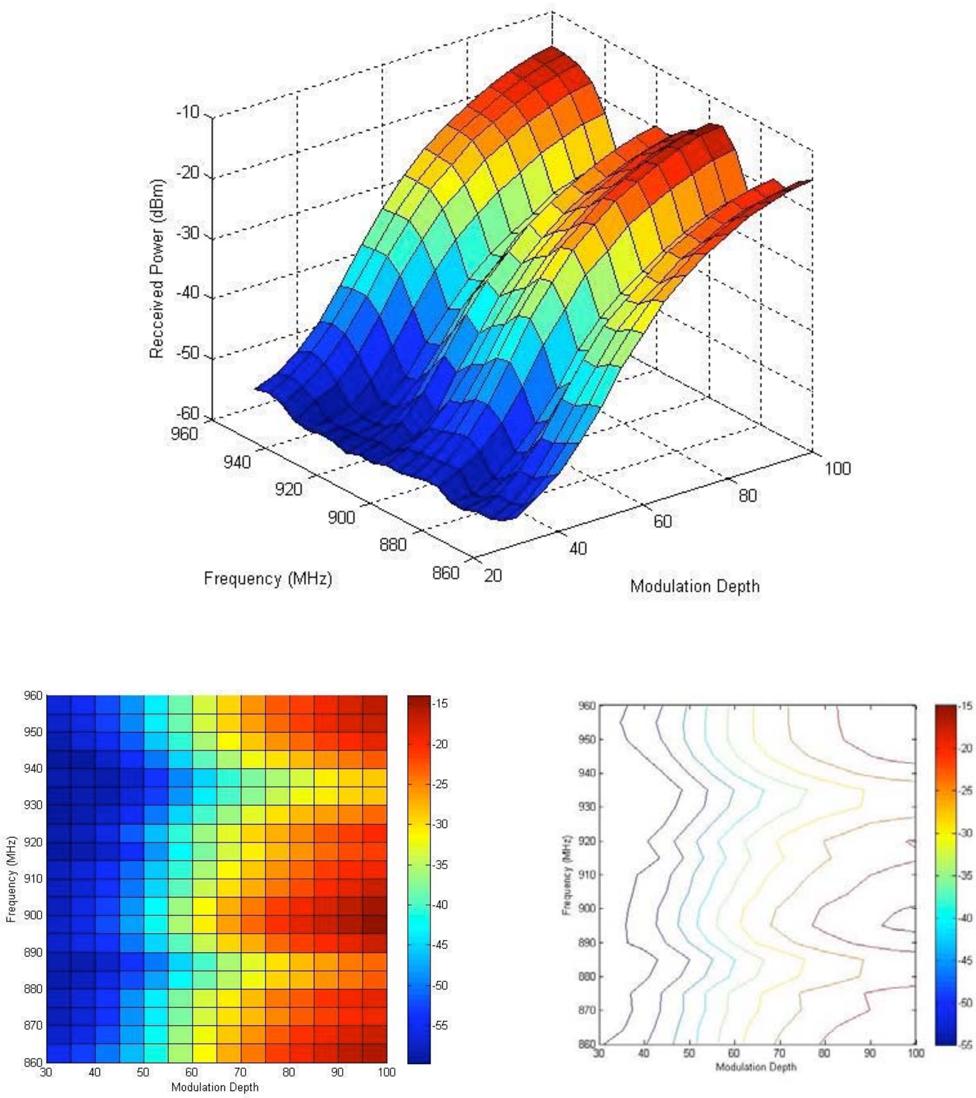


Figure 9.1. Bow-Tie Tag at Tari = 6.25μsec in the Lab NH 131.

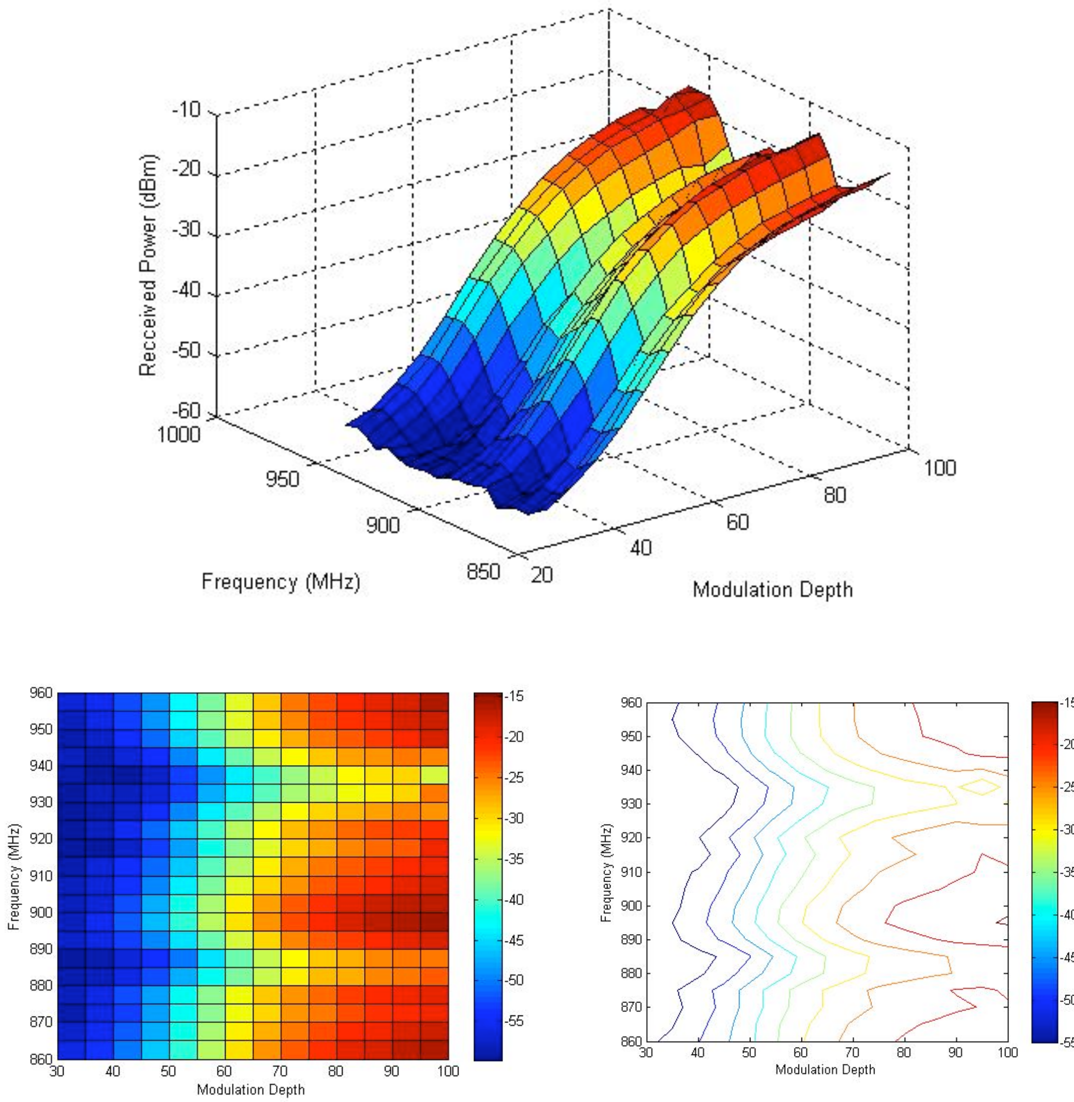


Figure 9.2. Bow-Tie Tag at Tari = 12.5μsec in the Lab NH 131.

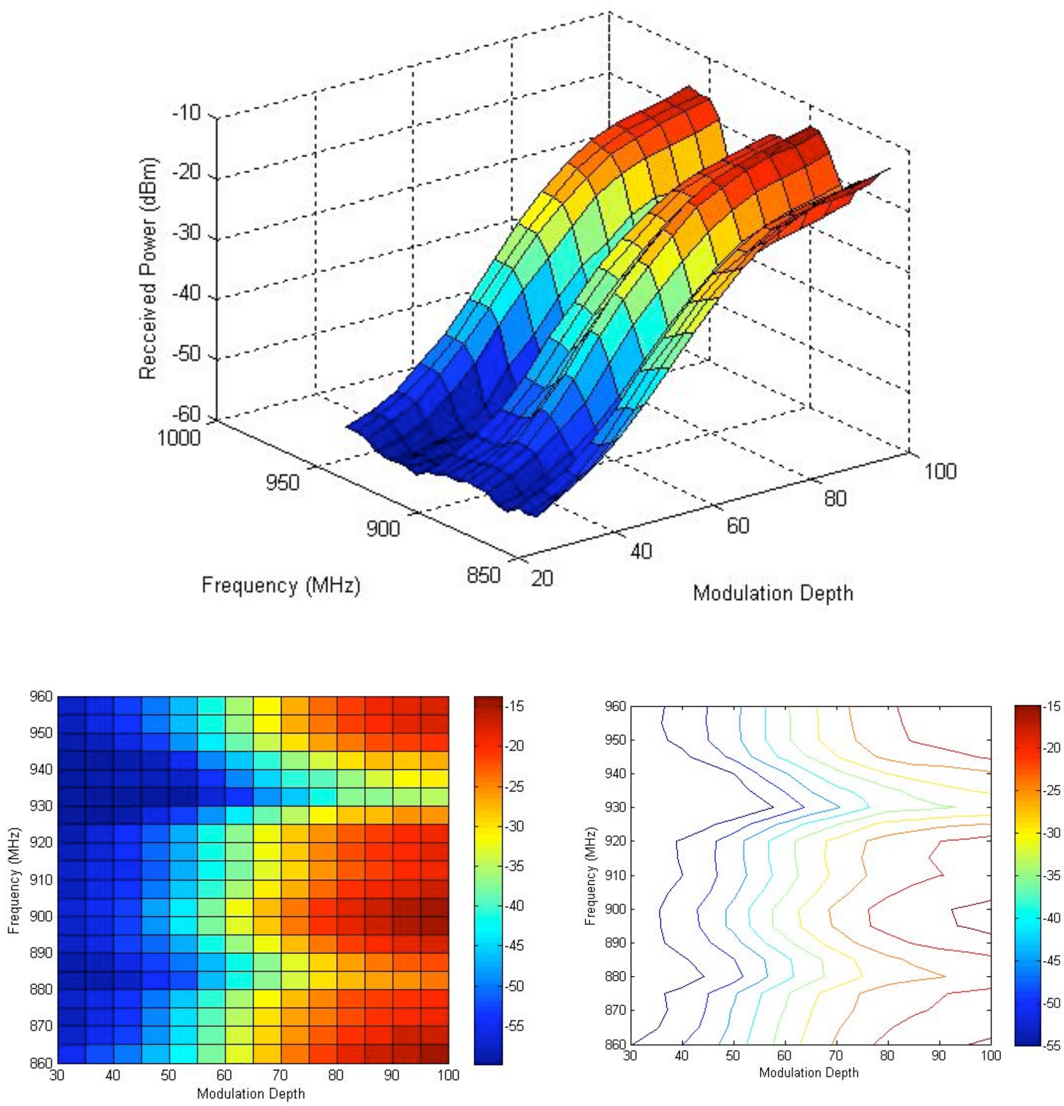


Figure 9.3. Bow-Tie Tag at Tari = 25μsec in the Lab NH 131.

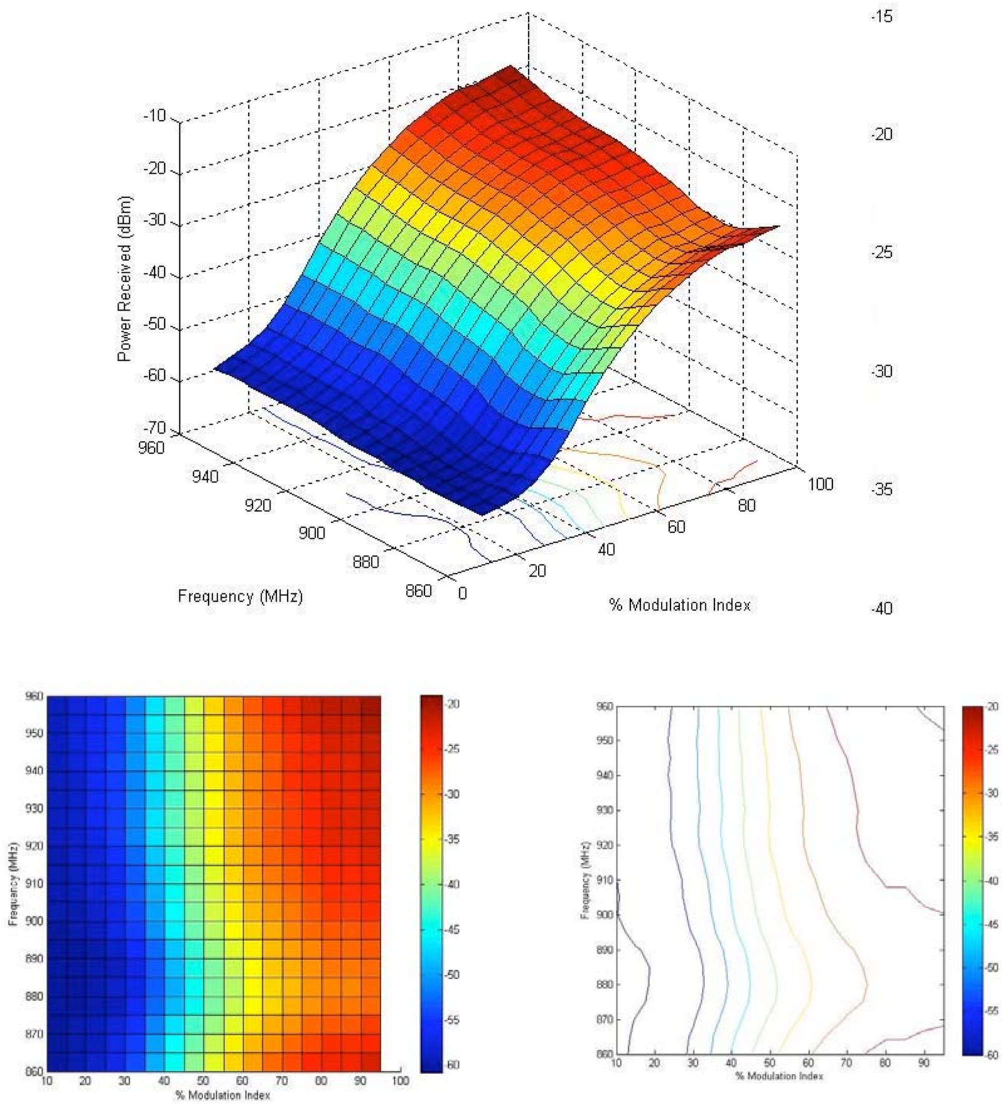


Figure 9.4. Tripod Tag at Tari = 6.25μsec in the Anechoic Chamber.

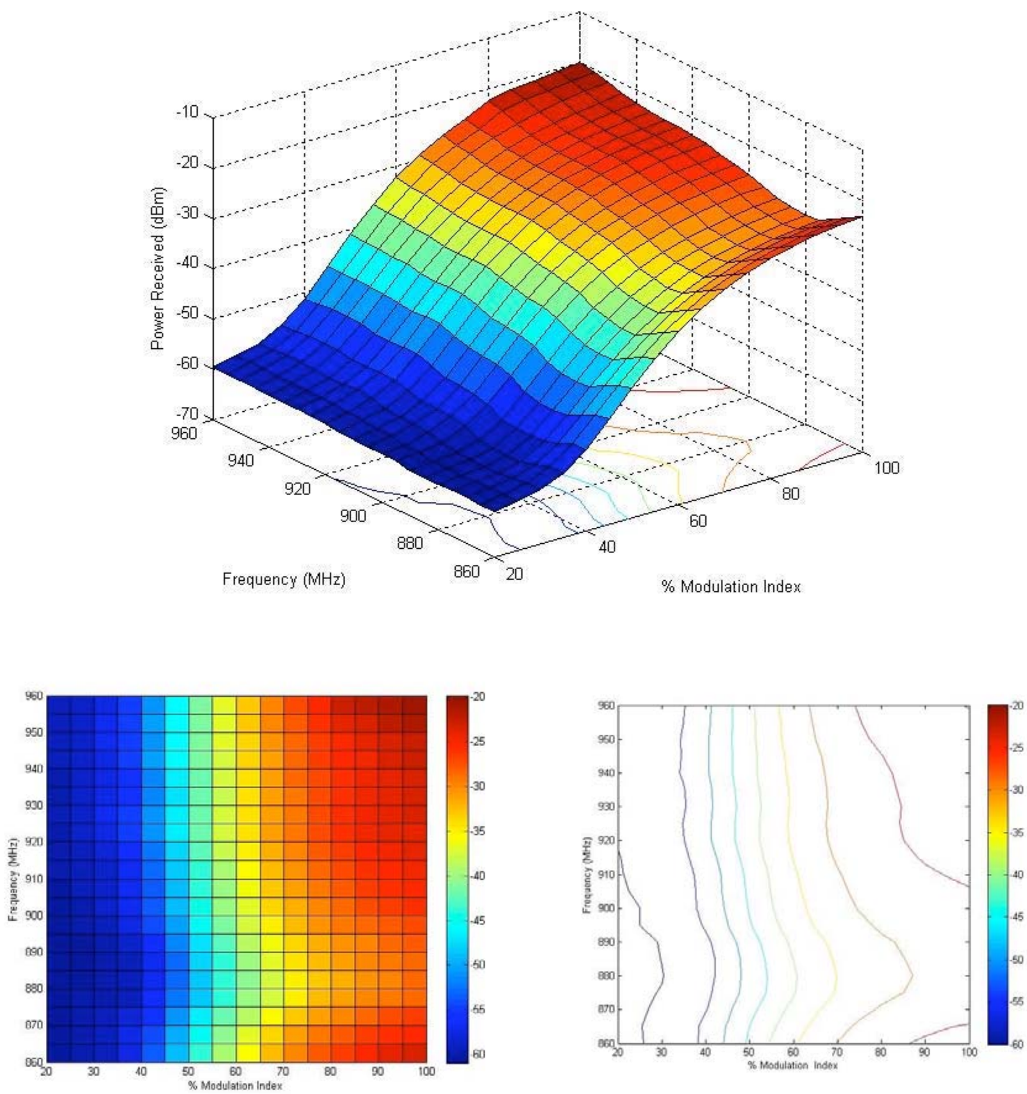


Figure 9.5. Tripod Tag at Tari = 12.5μsec in the Anechoic Chamber.

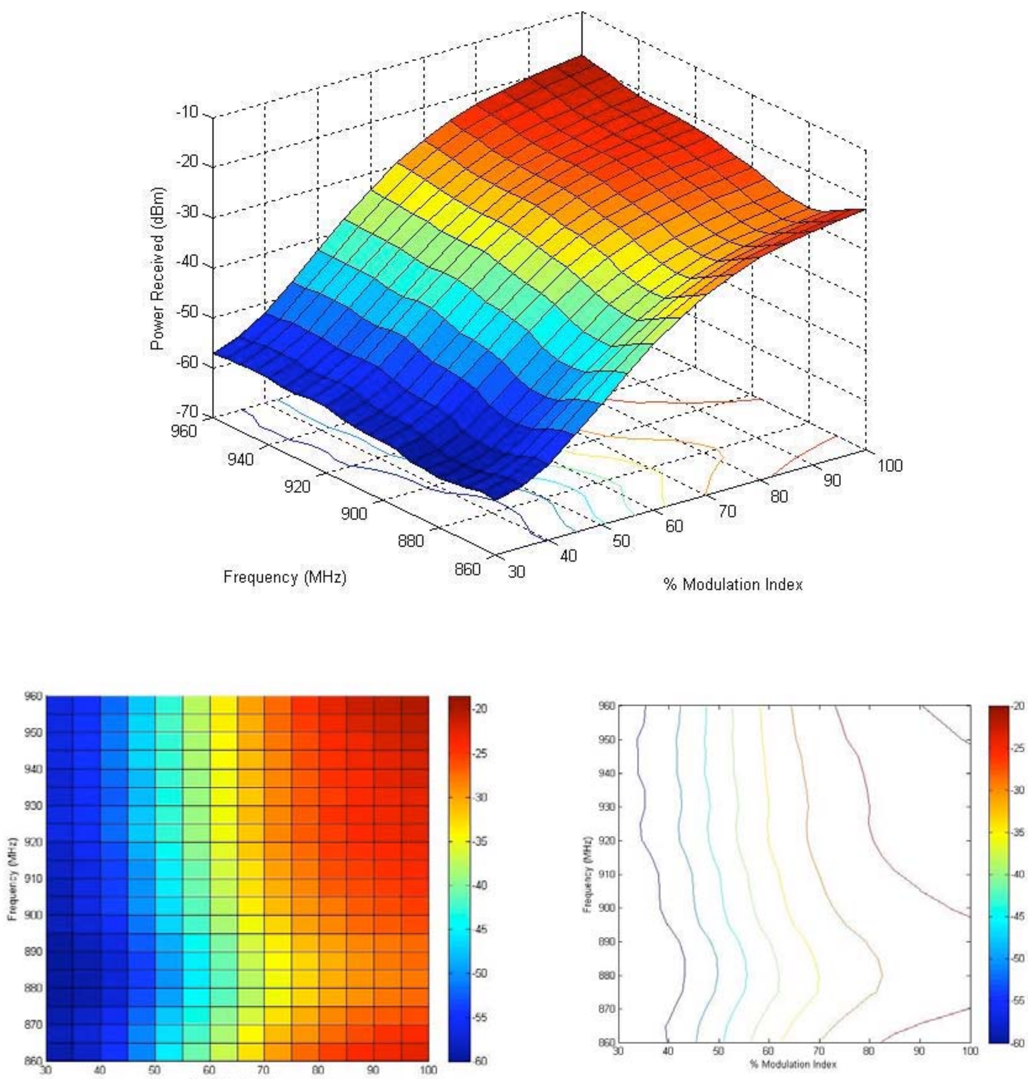


Figure 9.6. Tripod Tag at Tari = 25μsec in the Anechoic Chamber.

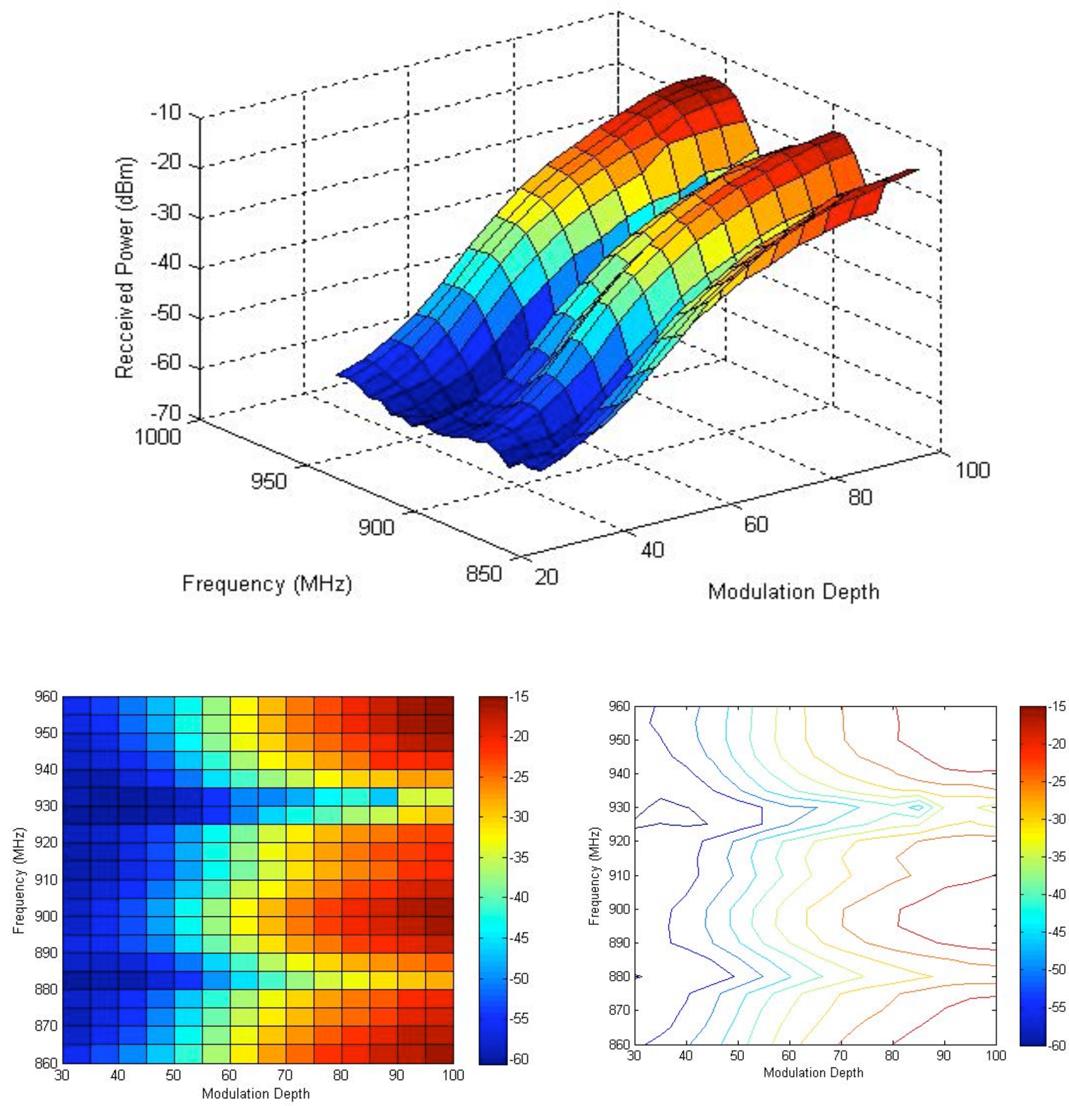


Figure 9.7. Tripod Tag at Tari = 6.25μsec in the Lab NH 131.

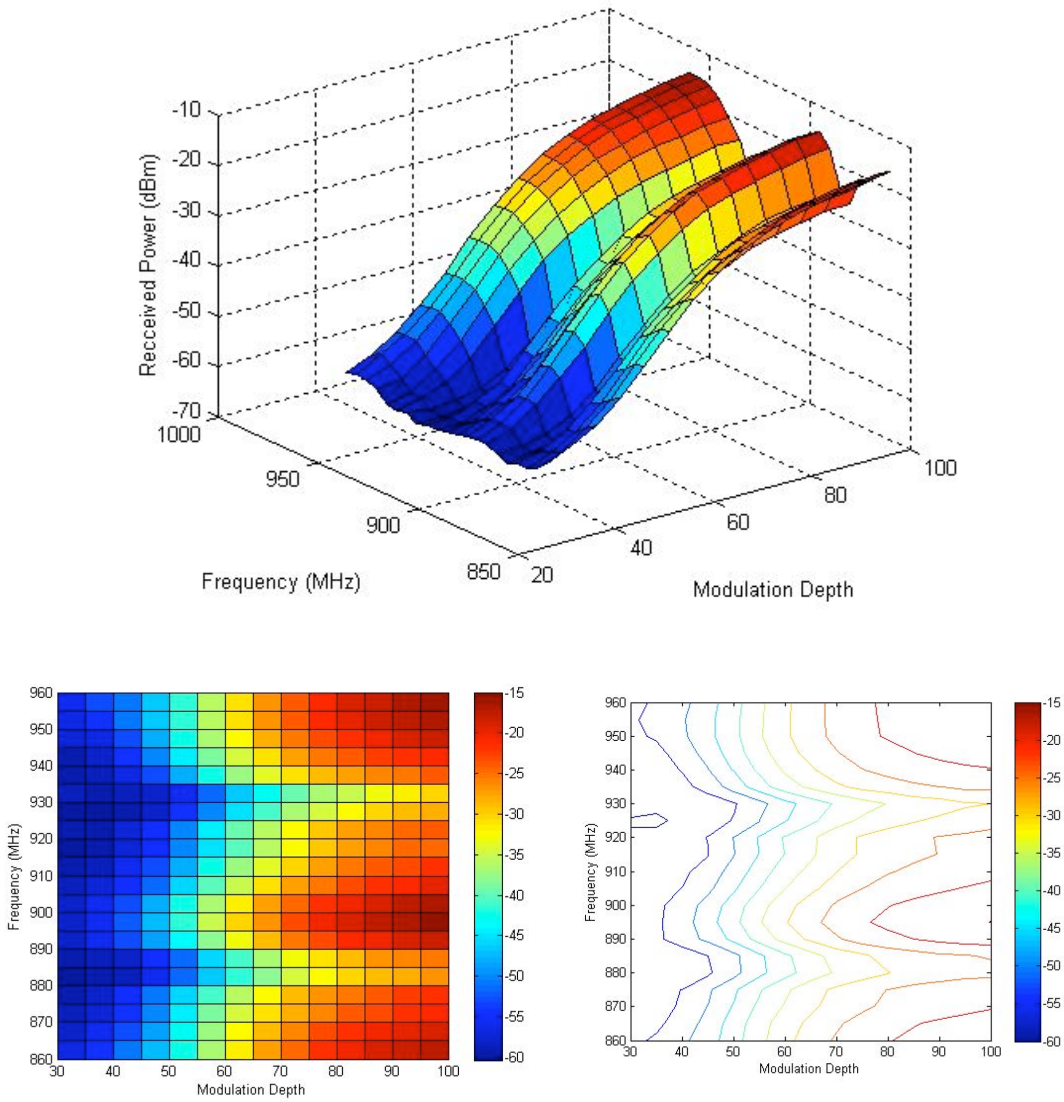


Figure 9.8. Tripod Tag at Tari = 12.5μsec in the Lab NH 131.

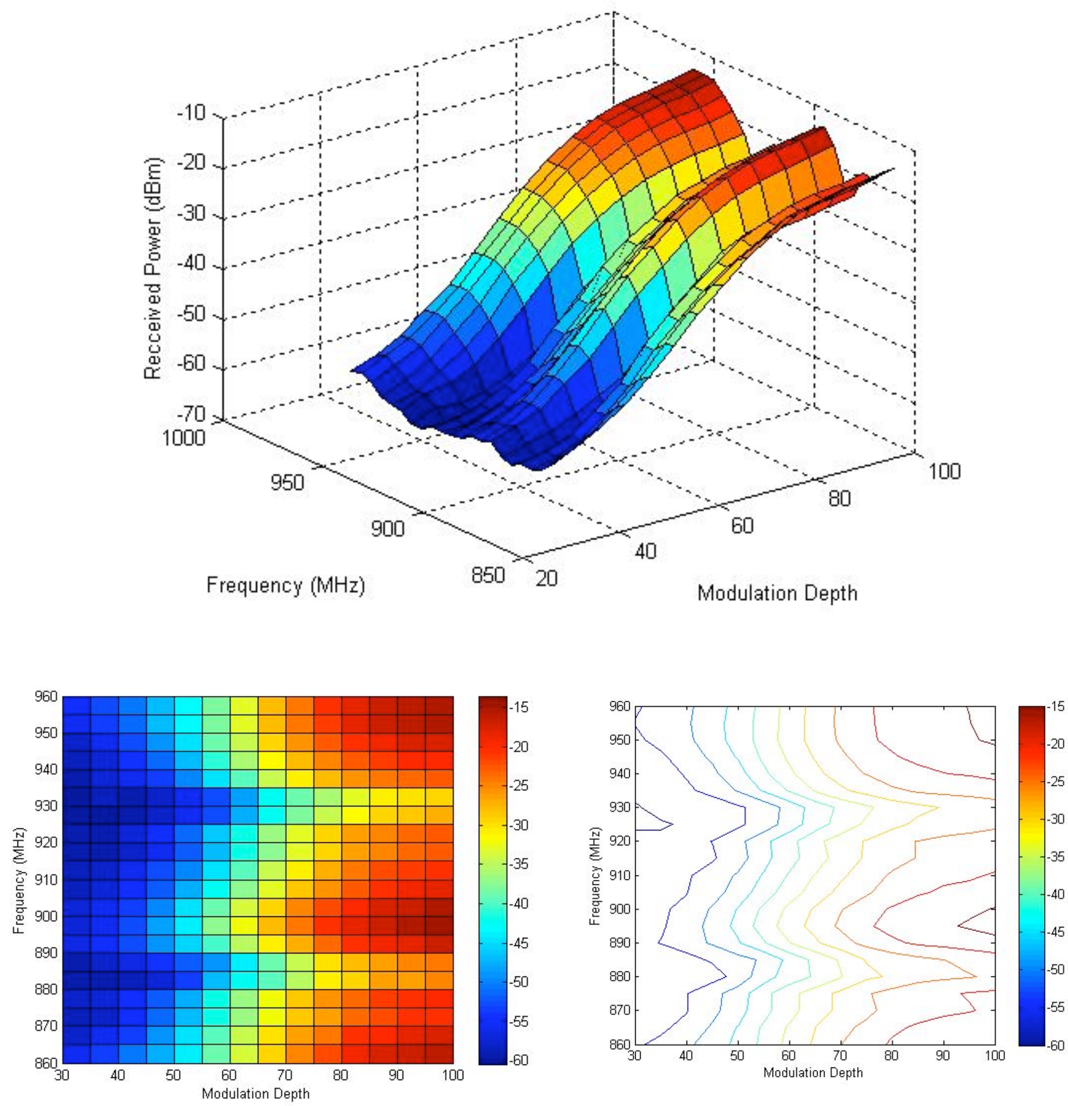


Figure 9.9. Tripod Tag at Tari = 25μsec in the Lab NH 131.

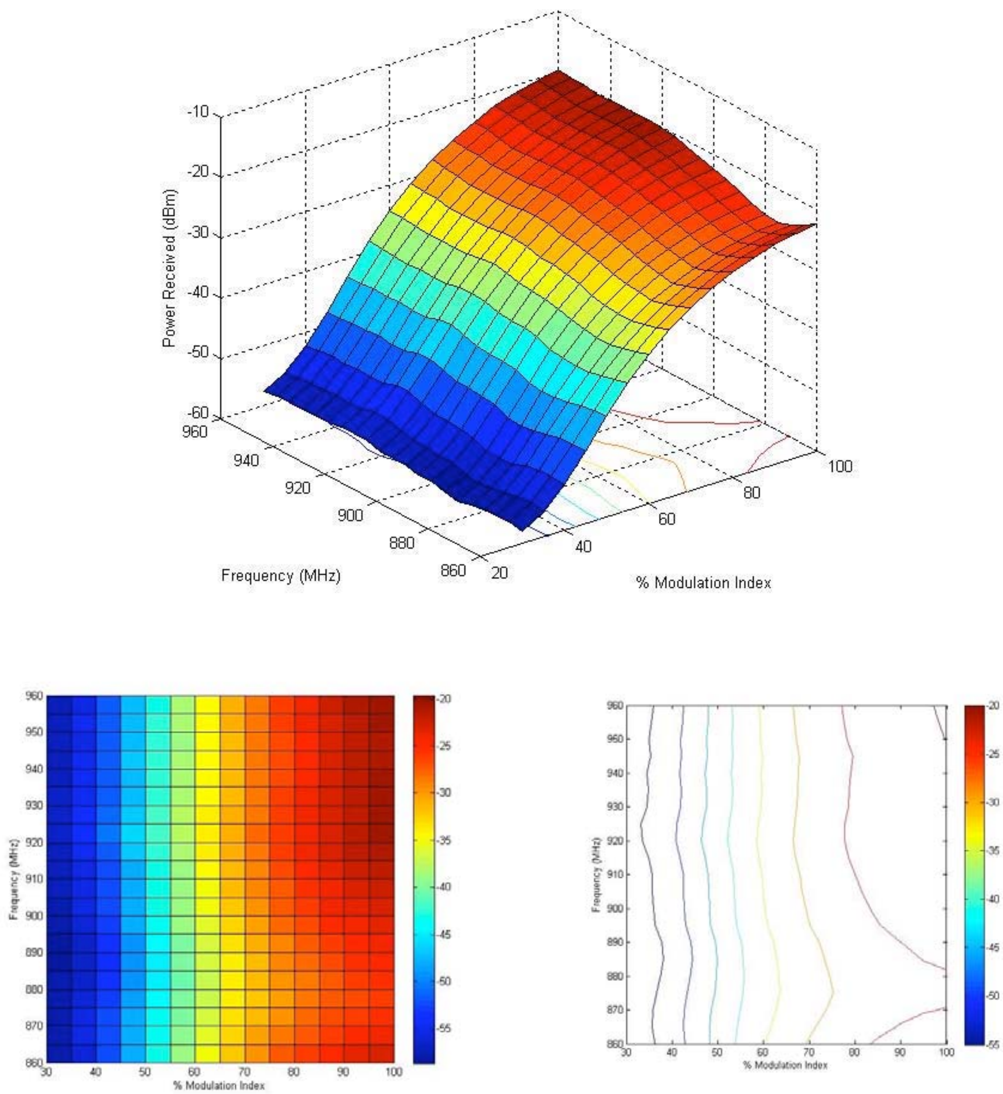


Figure 9.10. Tripod Tag at Tari = 6.25μsec in the Anechoic Chamber.

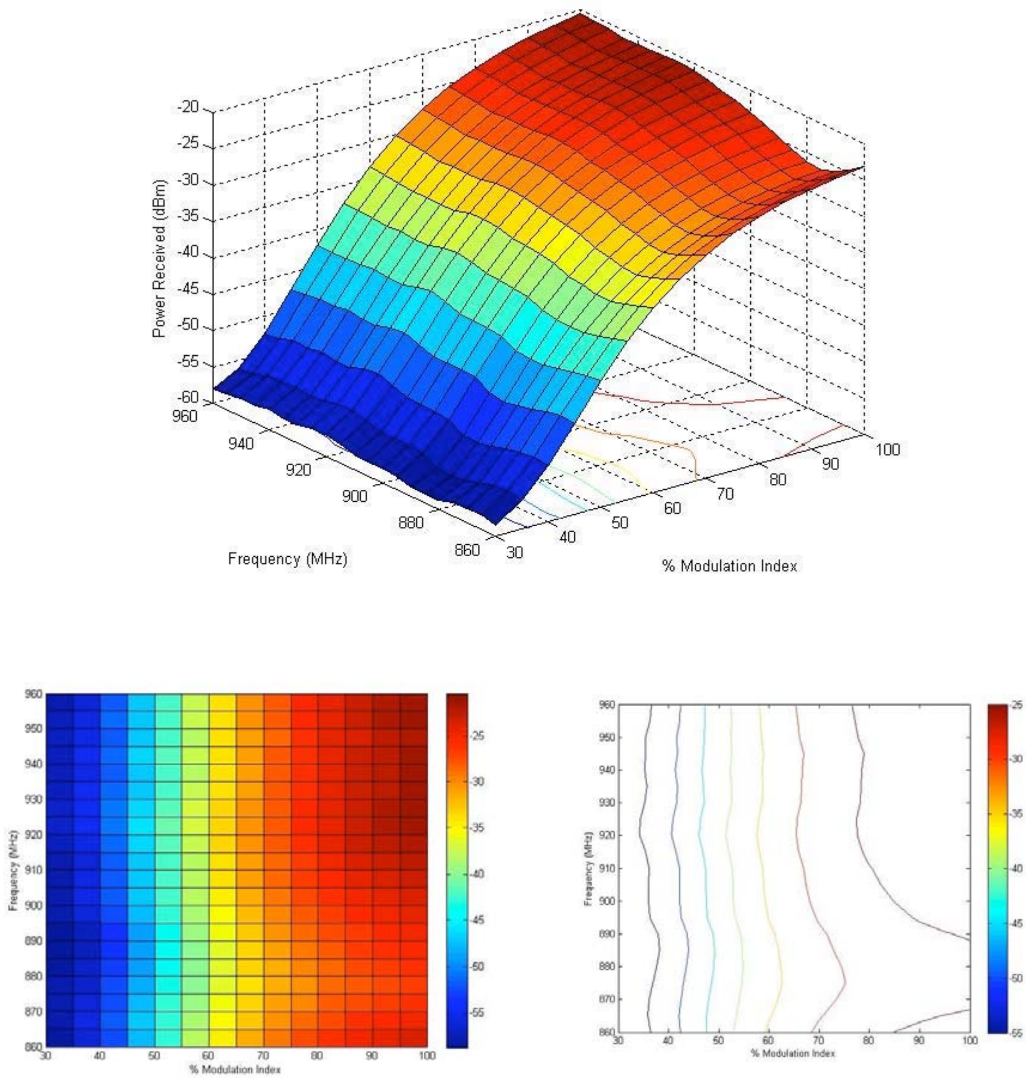


Figure 9.11. Tripod Tag at Tari = 12.5μsec in the Anechoic Chamber.

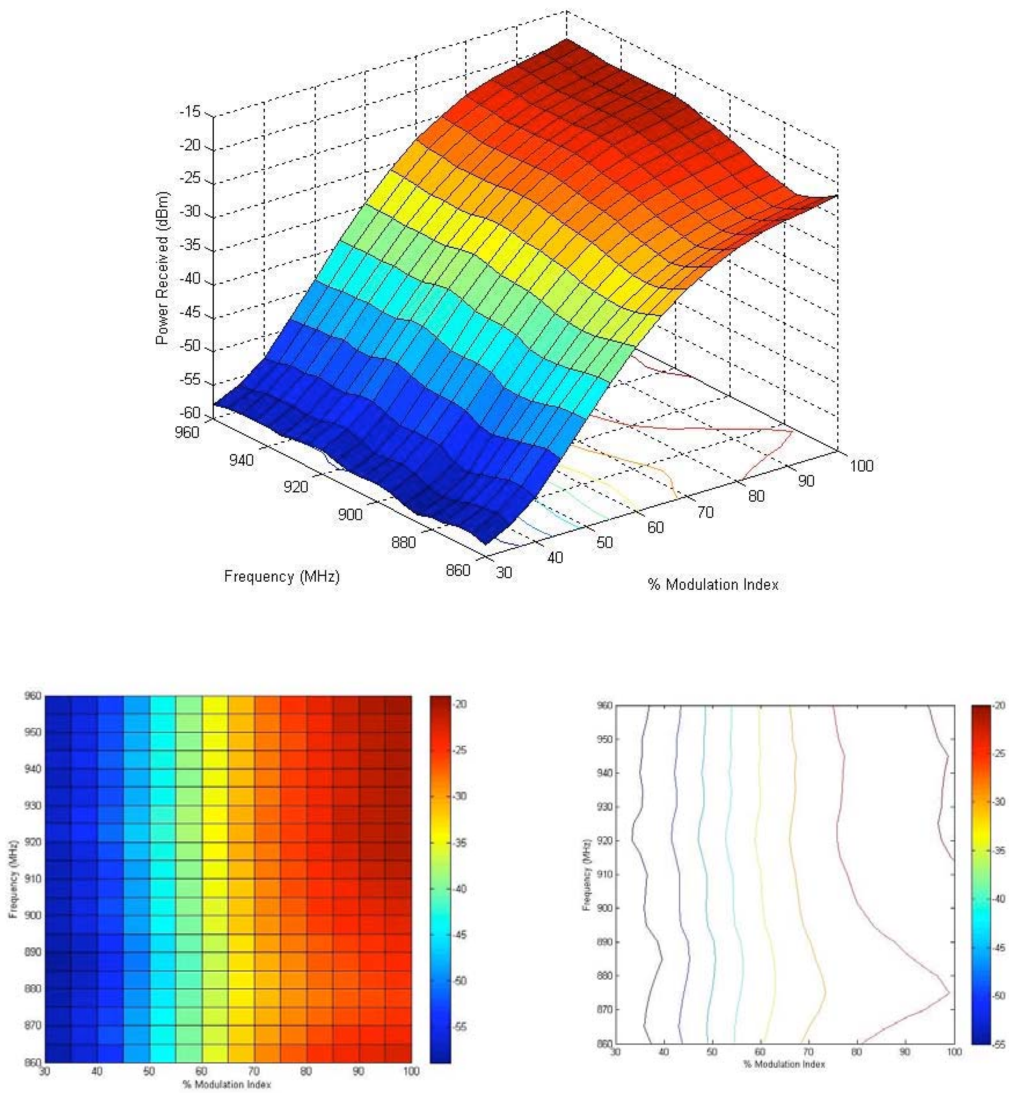


Figure 9.12. Tripod Tag at Tari = 25μsec in the Anechoic Chamber.

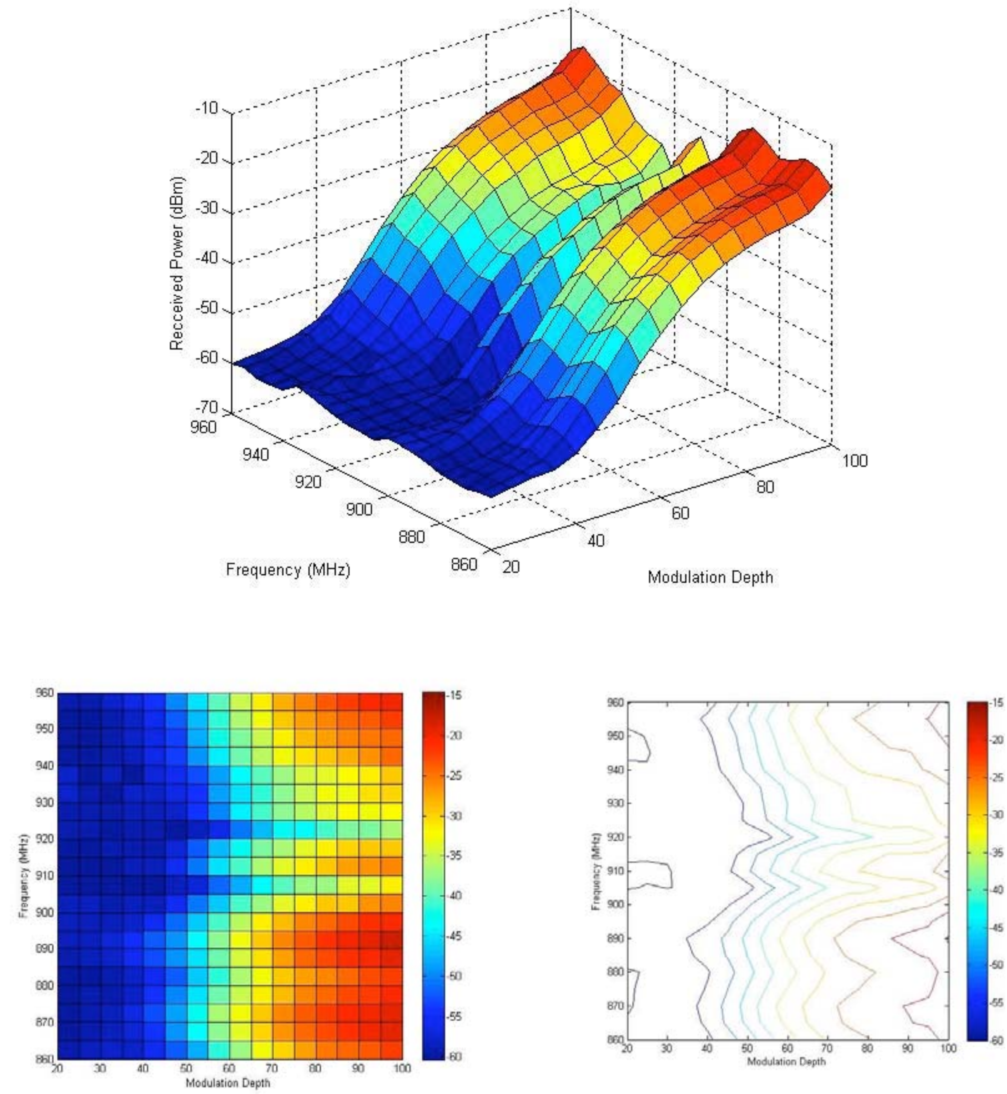


Figure 9.13. TI Tag at Tari = 6.25μsec in the Lab NH 131.

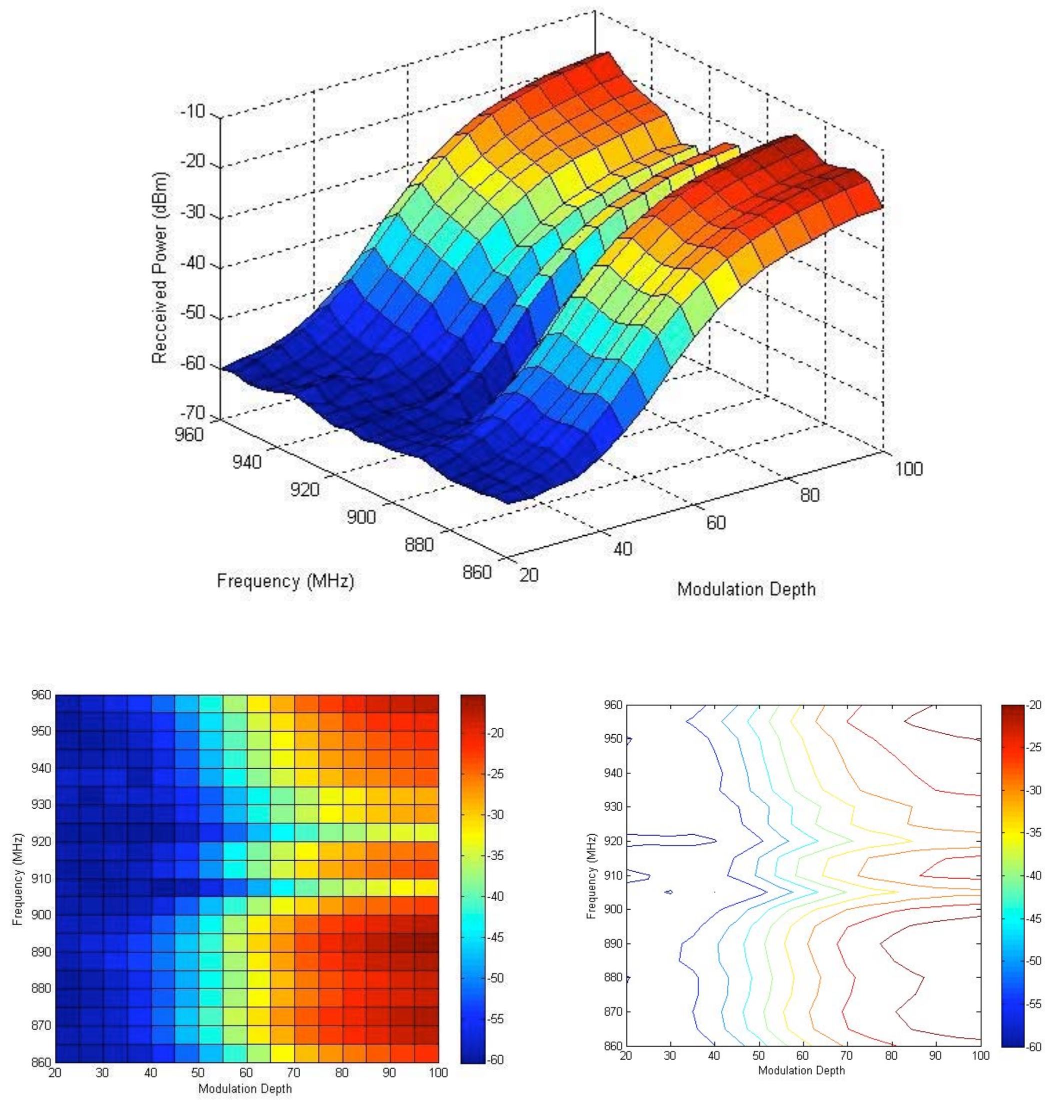


Figure 9.14. TI Tag at Tari = 12.5μsec in the Lab NH 131.

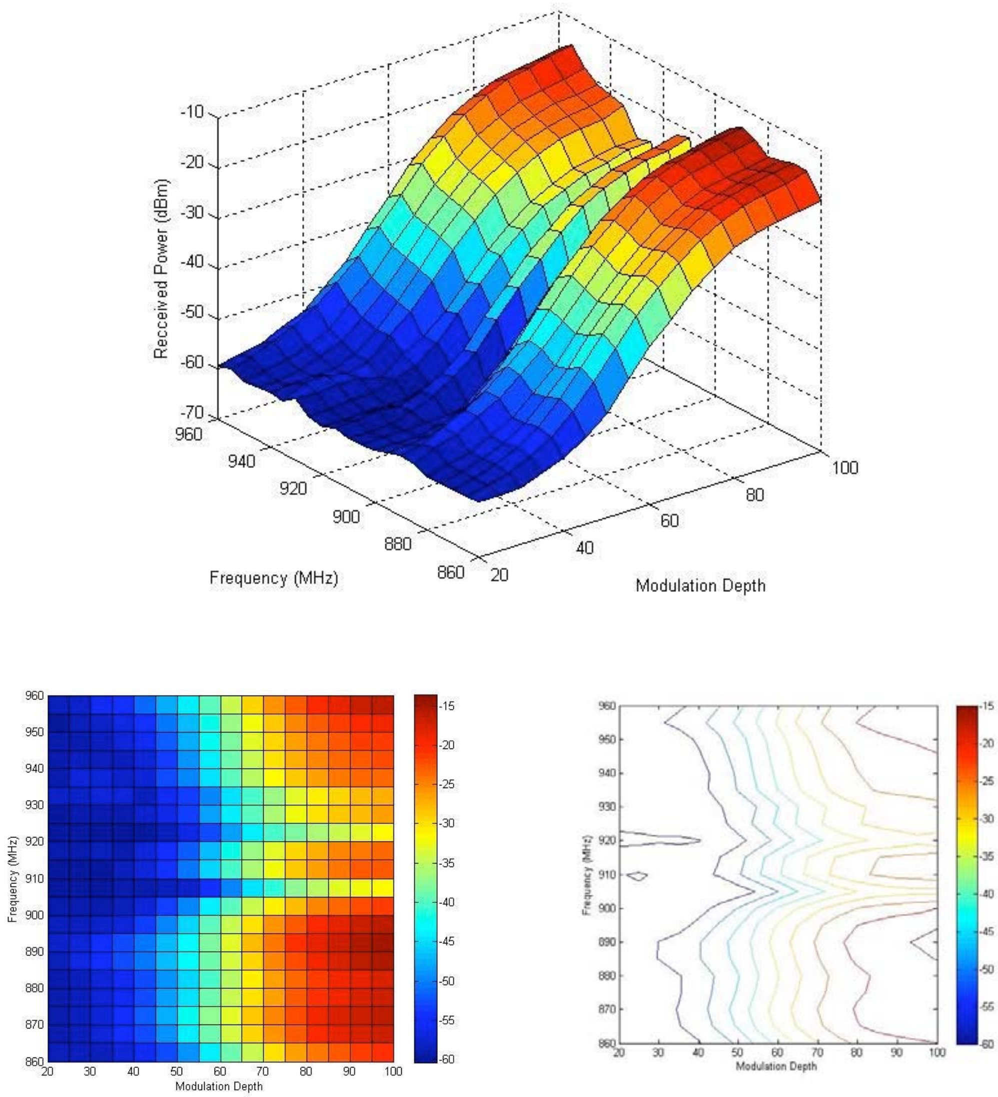
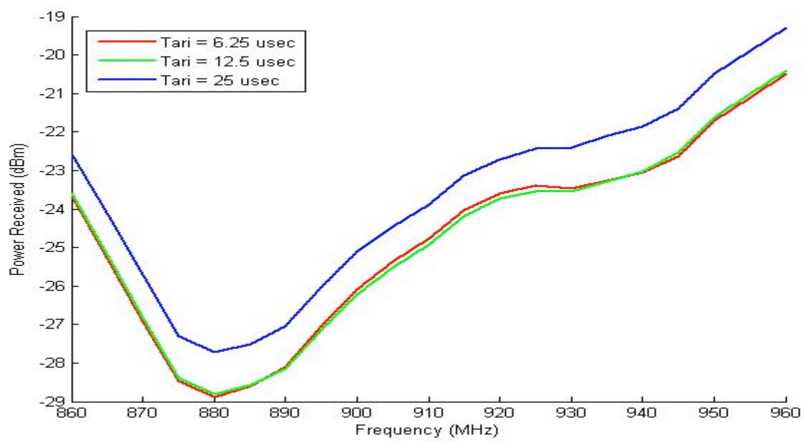


Figure 9.15. TI Tag at Tari = 25μsec in the Lab NH 131.



(A)

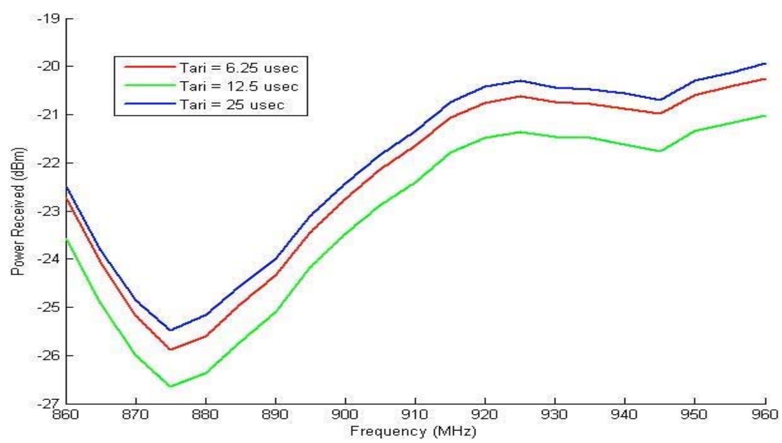
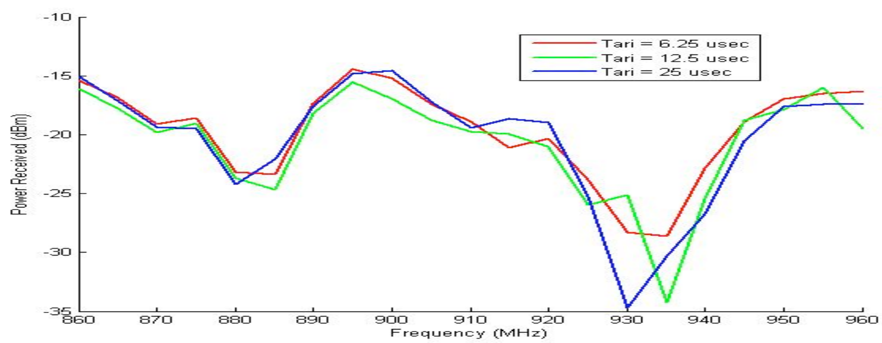
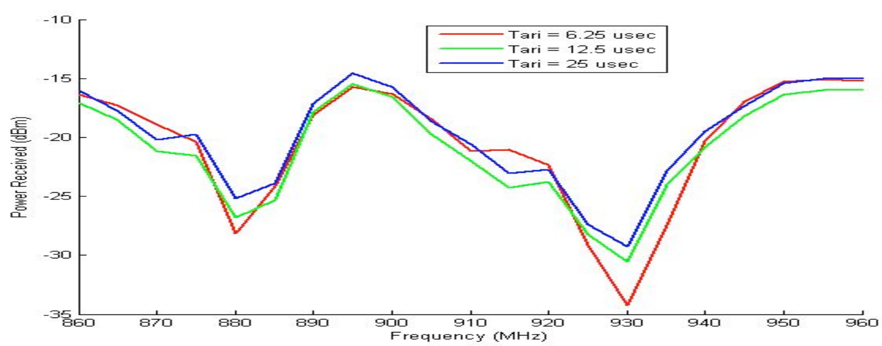


Figure 9.16. Power received from (A) Bow-Tie and (B) Tripod Tag.



(A)



(B)

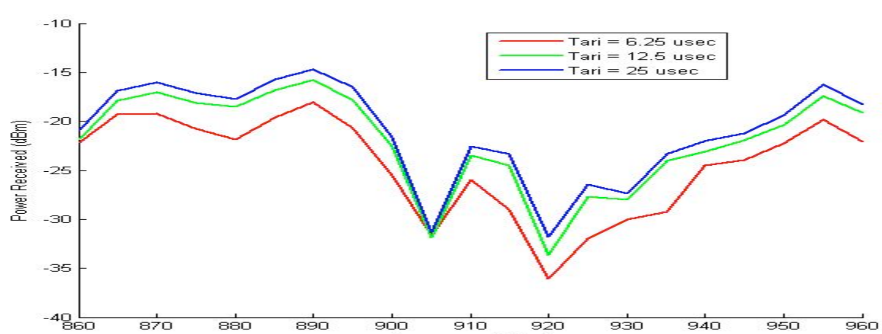


Figure 9.17. Power received from (A) Bow-Tie and (B) Tripod (C) TI Tag.

CHAPTER 10

SUMMARY AND CONCLUSION

10.1 Introduction

In this chapter we will summarize the research and the conclusion drawn from the data collected. Along with the what the future direction of the research and how this research can support the industry. This research focuses on the core fundamentals of the UHF RFID fundamentals and ISO 180006-C Class 1 Generation 2 protocol.This document explains the physics behind the RFID and summarizes the ISO 180006-C Class 1 Generation 2 protocol. The research conducted requires the highly precise reader. For this research the reader was developed on National Instruments PXI RF Hardware and IF-RIO FPGA module, using LabVIEW v.8.5.1 as the main software architecture and NI-VISN RFID FPGA Toolkit.

10.2 Conclusions

In this research several test have been conducted in conform the ISO 180006-C Class 1 Generation 2 protocol and in process the tag IC and its design. In the experiment 1 we tested the effect of Tari on the response time T1 of the tag at different frequency. Which concludes that Alien Squiggle tag follows the ideal tag timings the closest, whereas for the TI tag, the dip in the timings was very early hence they are faster at Tari $21\pm1\mu$sec. For the Avery Dennison Tags both Bow-Tie and Tripod they are exactly identical in their behavior and does not match with the ideal tag timings above 15μsec.

In the experiment 2, we tested the effect of the power received by the tag at the different value of Tari, as we have proved that the power received from the tag is independent of the value of Tari, but in all the tags viz. Alien Squiggle, Avery Dennison's Bow-Tie and Tripod, and Texas Instruments tag shows a common behavior at the Tari = 15±3μsec, where is there is a dip in the power received which does not follow the specification and the theory. Hence we can conclude that the reader working at the Tari = in the range 15±3μsec should transmit higher power in order to have the same performance.

In the experiment 3, we tested the effect of the pulse width of Tari and the power received at different frequency, from the experiment we conclude that the best value for the pulse width is 0.5±0.1 for all type of tags viz. Alien Squiggle, Avery Dennison's Bow-Tie and Tripod, and Texas Instruments tag as they have the same behavior. Also we have conducted this experiment at three different values of Tari viz. 6.25μsec, 12.5μsec and 25μsec. From the result we conclude that the best Tari for the ideal pulse width i.e. 0.5 is 12.5μsec.

In the experiment 4, we tested the effect of the modulation depth of the message signal on the carrier on with respect to power received at different frequency. We can conclude that the all the tags used in the experiment responded at the modulation depth of 70% whereas the protocol recommends it to be 80%. Hence the commercial tags available can work sufficiently well in the noisy environment. Also the frequency form 880±10 MHz has power dip hence need more power the equivalent performance, also for the Tari = 25μsec both in noisy and noise free environment.

10.3 Future Research Work

In the commercial world RFID is still infant and needs to reach amazing heights. This research creates a staring point to opening all the possibilities that are still missing in the field of RFID. The research performed and the conclusions made in this research were based on three types of tags which have different silicon used in them.

This research can be extended on to the other various tags and can be used to design the metric based with different tag silicon and various protocol parameters not only ISO 180006-C Class 1 Generation 2, but HF and other UHF protocols. This research can be extend finding the power limits of the tags based on different aspects of power instead of frequency.

The reader developed for this research can be used for identifying tag collision, based on the received power and the IQ data and some signal processing collision can be pre-detected and the collided slots can be made a read slots which can lead to a better RFID protocol, which works efficiently in dense tag environment.

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