

CONVERT UHF RFID TAG FROM PASSIVE TO SEMI-PASSIVE TAG USING  
EXTERNAL POWER SOURCES

by

TANVI MEHTA

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To my parents, brother and  
all my friends !!!!

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## ABSTRACT

### CONVERT UHF RFID TAG FROM PASSIVE TO SEMI-PASSIVE TAG USING EXTERNAL POWER SOURCES

TANVI MEHTA, M.S.

The University of Texas at Arlington, 2010

Supervising Professor: Daniel W. Engels

In this thesis, I present novel circuit designs that convert a Ultra High Frequency (UHF) passive Radio Frequency Identification (RFID) tag into a semi-passive RFID tag. Passive RFID tags are relatively inexpensive to purchase and to integrate into objects and devices. However, in some environments and on some objects the performance of the pure passive tags is not sufficient for the intended applications.

A semi-passive tag, in comparison to a pure passive tag, has significantly greater communication range since the semi-passive tag derives its operational power from an on-tag power source instead of just from an interrogator's communication signal.

As a result, semi-passive tags have greater usability in a broad range of applications. My novel circuit designs act as an additional on-tag power source and are intended to be low-cost additions to an existing passive tag operating in the UHF (Ultra-High Frequency) frequency range.

Thus, currently deployed tags may be retrofitted in the field as their intended applications change and demand greater communication range. Prototype implemen-

tations of my designs were able to increase the read range of a passive UHF RFID tag by up to 39%.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

In general, Radio Frequency Identification (RFID) is a way of identifying a person or object using a radio frequency transmission. This technology identify, track, sort or detect a wide variety of objects [41]. Identification of objects by machines enables the operation of global supply chain management, makes it more efficient and reduces the cost. Apart from RFID, various other technologies such as bar codes, smart cards, voice recognition and biometric technologies fall under the same category knew as Auto-ID systems or Automatic Identification and Data Capture (AIDC) systems for identifying objects automatically.

Ever since the first scan in 1974, low cost and contact less reading ability have made bar code systems the most popular and the most widely used AIDC systems in the world [75]. However, certain limitations such as line of sight reading requirement and limited storage capacity confines their use as identification systems in several applications. On the other hand, RFID offers various compelling advantages over bar-codes, including non-line-of-sight operation, minimizing human interference and faster identification. Other advantages of RFID over bar codes are discussed in next chapter. Many large retailers like Wal-Mart [41] and agencies such as US department of Defense (DOD) have started using RFID extensively and with the use of a single integrated circuit microchip, adoption of passive RFID technology has tremendously increased as an automated identification system due to the improved performance and reduced size, cost and power requirements of the RFID tags [87]. The combination

of high performance and low cost of RFID tags provide an economical path for the adoption of this technology in increasing number of applications [48]. This thesis puts forward different possible designs which when connected to the passive tag enhances the tag-reader read range significantly by reducing the harvested power required to operate the tag functionality.

## 1.2 Motivation

A basic RFID system consists of RF tags, RF tag readers or interrogators, and a Information System. A tag stores a number, such as a Electronic Product Code (EPC), on its microchip for the identification purposes. This microchip is connected to an antenna and packaged in either a label or some other encapsulation. The entire structure is called an RFID tag. The reader reads the data on the tag using radio wave communication. Thus, the stored number on the tag forms the basis of identification. This stored number is attached to the back end information system which does the required processing on the data attached to the identification number.

As discussed earlier, with the introduction of the microchip the design of passive RFID tags has reduced the cost, size and power requirements of the tag. Consequently, the number of industries that can use RFID system in a variety of applications also increased. RFID tags can further be classified into three categories; Passive, Semi-passive, Active and Semi-Active tags. Semi-passive tags have on tag power source to run the processing logic of the tag and have backscatter mechanism for tag to reader communication. Semi-passive tags have better readability, higher functionality and read range performance unlike pure passive tags. This makes them highly usable in applications such as post management, dangerous cargo investigation and cold chain logistics [95][18]. Also, as Semi-passive tags do not use the method of power amplification to transmit signals, cheap thin film batteries with small power

capacity can be employed to make them commercially competitive in price[1]. We discuss more about different tags categories in Chapter 2. As a result of low cost, at present passive tags are extensively used in diverse applications. But, if we directly activate the passive tag's chip by external energy source entire energy incident on it from RFID reader can be used to backscatter the stored information and hence increase the communication range among the two.

### 1.3 Passive Tag

A passive tag does not require a local battery, and hence has a longer lifespan than a semi passive or an active tag. On the flip side, as it depends on the power of incident radio waves, the strength of the tag power source varies significantly in different environments. Owing to the path loss, the maximum distance between a UHF RFID passive tag and the reader with 1-W effective isotropic radiated power (EIRP) is typically limited to 3 meters[80]. Multi path fading also causes received power of a tag to fall below its minimum power requirement which is typically -10 dBm [37]. The multi path fading in a passive RFID system can effect the read range of a tag in the reader-to-tag link and the tag to reader link. Based on the information stated in [37] and [65], the link budget in the forward link is the main factor which determines the tag read range.

So, it is a tough challenge to extend the forward-link-limited range in an energy harvesting passive ultra-high-frequency (UHF) RFID system without either improving the tag efficiency or reducing the harvesting power consumed by the tag. Basically, there are two proposed major approaches to overcome the range limit in the forward link, one possible approach is to reduce the minimal power requirement of a passive tag, for which there have been some progresses in reducing the tag IC power consumption [56]. But range limit issue has not yet been completely solved. Another possible

approach is to increase the received power of a passive tag. But health considerations and regulation constraints also put a limit to this approach.

#### **1.4 Passive to Semi-Passive**

According to the above discussions, passive tags are the cheapest and most readily available tags in the market. But these tags are mostly used in the areas which require less read range. In this thesis, prototypes of three different designs with various power sources have been implemented which allows the tag IC to get activated directly and hence to extend the forward-link-limited range of a passive UHF RFID tag. As this semi-passive turned passive tag requires less power from an incident radio wave, the read range is much longer than that of a regular UHF passive tag with the same reader transmission power. Due to this, the popularity of passive tags can be increased in the market as low power; low in cost passive tags would no longer be limited to the small scale applications. If the external source is turned off, these passive tags can behave normally. With this, one tag can either be used as a passive or semi-passive by operating the external power source attached to it.

#### **1.5 Summary of Contributions**

In this thesis, we have determined an optimum frequency for transferring power to the passive tag externally and hence significantly improve the tag-reader communication range which also validates the theory. The frequency for continuous wave emitter should not be chosen near the frequency of operation of the tag to avoid interference with RFID communication.

New circuit has been designed to power up the chip and also built the prototypes of three different designs. According to the efficiency performance Design 2 proved to

be the best to use with passive tag as it increases its range by 50% and make it perform as a semi-passive tag when required. During the course of experiments, it was also observed that center frequency of tag shifts from its original value when connected with an external energy source. Solar energy and piezoelectric vibration source proved as viable power sources for the external circuitry. Also, wireless continuous wave increases the tag-reader read range by 40%.

Chapter 2 presents the basics of RFID system. We also discuss the history of RFID system and their classification based on operating frequency and type of communication. Advantages of RFID over bar codes are also been discussed.

Chapter 3 presents the contributions from various researchers to improve the passive tag performance by external energy sources and their advantages and disadvantages which highlight the open areas of research.

Chapter 4 deals with the design and implementation of RFID tags. It also gives a detailed explanation of tag properties and its behavior in near or far field communication.

Chapter 5 presents the design parameters required for continuous wave emitter (CWE). Three constraints are discussed in detail for optimum frequency selection. Experimental method for optimum power level selection is also presented briefly.

Chapter 6 explains about three different power sources which were used to supply power to the Continuous Wave Emitter.

Chapter 7 briefly explains about designing of power assisted passive tag inexpensively. Newly built designs are categorized as modules: Module A with Design 1,2, and 3 and Module B. They are individually evaluated with two different power sources. This chapter deals with Module A Design 1.

Chapter 8 discusses the Module A Design 2.

Chapter 9 discusses the Module A Design 3, which was further categorized based on continuous wave emitter sources used in them. Later, all the designs in Module A are compared based on few selected parameters.

Chapter 10 discusses the Module B with piezoelectric vibration sensor and its performance.

Chapter 11 analyzes the performance of various implementations in terms of efficiency, least cost and transmitted power. The implementation shows that present significantly increases the passive tag-reader communication distance.

Chapter 12 summarizes the contributions and presents the future work which can be potential open areas of research. Thus, significant increase in read range of passive UHF RFID tag can be achieved by connecting an external energy source to it.



## CHAPTER 2

### RFID SYSTEMS BASICS

#### 2.1 Introduction

In an RFID system, a radio frequency transmission is used to identify a person or an object. It is one of several technologies jointly known as Auto-ID systems; systems for identifying objects automatically. RFID can also be used to track, sort or detect a wide variety of objects[41].

Identification can be performed using several methods, but the most common is to store an identifier, such as a Electronic Product Code (EPC), that identifies a person or object and perhaps other information. The EPC number is stored on an RFID tag. With the use of radio waves an RFID reader gathers the stored information on a tag and hence the stored identifier on tag forms the basis of identification technology.

#### 2.2 History of RFID System

The roots of RFID technology can be traced back to World War II [19]. The Germans, Americans and British were all using radars, invented in 1935 to warn of approaching planes while they were still miles away. The issue was that there was no way to identify which planes belong with the enemy and which were a country's own pilot returning from mission. This problem led to sometimes shooting down own planes and thus Germans discovered that if pilots rolled their planes as they returned to base, it would change the radio signal reflected back. This technique alerted the radar crew on the ground that these were German planes and not allied aircraft. The

British at the same time developed the first active identify friend or foe (IFF) system [19]. They put a transmitter on each British plane. When it received signals from radar stations on the ground, it began broadcasting a signal back that identified the aircraft as friendly.

RFID works on this same basic concept. A signal is sent to a transponder, which either reflects back a signal or broadcasts a signal. Low cost RFID technologies began their adoption within the retail and pharmaceutical supply chains in 2003 when Wal-Mart, the world's largest retailer, began deploying passive UHF (Ultra High Frequency) RFID systems within its warehouse and the back room of its retail stores. Since then, the U.S Department of Defense (DoD) and a significant number of additional retailers, including Target, Tesco, and Metro have adapted passive RFID technologies within their supply chains. Consequently, the demand for RFID tagged items that can be automatically identified without human intervention at all points within the supply chain has increased.

### **2.3 RFID Tags and Barcodes**

Before going deep into the RFID tags, whole RFID system and its performance let's have a look at the basic differences among RFID tags and long term market beloved Barcodes. Table 2.1 shows the basic comparisons among RFID tags and barcodes with respect to listed parameters.

A typical RFID system consists of three main components: Tags, Readers, and Information Systems[88], as shown in Figure 2.1. Tags and reader are the most important components in an RFID system. The tags are affixed to objects that are to be automatically identified. Readers may be either at a fixed location such as cellular telephone tower, or they may be mobile, allowing them to be brought to the tags. Readers read the data that are stored on the tags and then communicate their

Table 2.1. Comparison between RFID Tags and Bar-Codes

Parameters	RFID Tags	Barcodes
Data size	Kbytes	1-100 Bits
Memory	Read, WORM, R/W	Read
Dirt influence	No effect	High
Sight Obstruction	No effect	Failure
Wear and Tear	None	Susceptible
Unauthorized Copying	Prevented	Susceptible
Read Speed	Few milliseconds	more than seconds
Reading Distance	More	Less
Data format standards	Few	Many
Cost	More	Pennies or even less

captured data to the information system. The information system utilizes the data obtained from the tags for a defined set of applications.

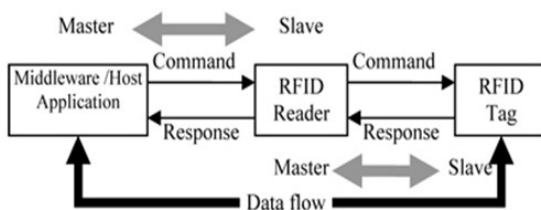


Figure 2.1. RFID System.

## 2.4 Classification of RFID Systems

RFID systems can be classified in several ways. The term RFID infers a broad class of identification devices. All RFID systems have readers and tags. As mentioned earlier readers capture the data or information stored by the tag which is attached on the object. As the tags are attached to objects, they suffer the most stringent

specifications related to performance, size, and cost. The various classification of RFID systems are based around these specifications. One broad classification is of chip versus chip less tags. Chip tags have an integrated circuit chip, whereas chip less tags do not.

Another classification, which is a subset of chip tags, is that of passive, semi-passive or active tags. Passive tags have no on-tag power source and no active transmitter, semi-passive tags have an on tag-power source, but no active transmitter, and active tags have both an on-tag power source and an active transmitter.

Nest category is on read only or read-write tags. Read-only tags have either read-only, or write once read many memory. Read-write tags allow writing and re-writing of information.

RFID systems are also classified as LF, HF, UHF or radioactive systems, based on its operating frequency range. Table 2.2 shows the categories into which RFID systems can be classified easily. Further to analyze properly RFID technology, both for gaining an understanding of its functional characteristics, and for making improvements in design, we must evaluate its function by specifications. These include cost, size and performance.

Table 2.2. Classification of RFID systems

<b>Operating Frequency Range</b>	<b>Type of communication</b>	<b>Power source for communication</b>	<b>Tag Type</b>
LF(9-135 KHz)	Passive	Passive tags	Inbuilt Chip
HF(13.56 MHz)	Active	Semi-Passive tags	Chip less
UHF(860-960 MHz)		Semi-Active tags	
Microwave(2.4-6GHz)		Active tags	

### 2.4.1 Operating Frequencies

The frequency is one of the important parameters which decide the type of RFID systems. Typically radiation from the RFID devices can interfere with other frequency devices; therefore it is necessary to allocate specific bands for their use [82]. The power level and the bandwidth of operation are regulated by FCC in the United States, ETSI in Europe and MPT'S radio law in Japan.

Usually Low Frequency (LF) and High Frequency (HF) RFID systems are near field operated in the near field range. In the near field, electromagnetic fields are reactive and quasi-static in nature. The information is transferred by either capacitive or inductive coupled systems. In practice, the Low Frequency Systems (less than 135 kHz) and the High Frequency Systems (13.56MHz) use inductive coupling [30]. Such systems usually have the antenna with typical read range from a few centimeters to a meter.

LF RFID is widely used by the automotive industry. Currently, most car immobilizers use a LF transponder embedded into a car key with a reader mounted in the ignition. However, UHF systems are far field operated systems where data is transferred using transmission, propagation and reception of electromagnetic waves. Some of major applications of the HF systems are contactless smart cards, credit cards, passports and access control systems. Nowadays HF RFID is widely used in security as well [79].

The RF Surface Acoustic Wave (SAW) systems fall under the category of chip-less tag system. As we have already seen that, chip-less tag do not contain an integrated chip, but they encode unique patterns on the surfaces of materials. These patterns constitute the data that is reflected back to the readers [64]. These systems are known to have the highest read range with high reading speeds as well. Table 2.3 shows the RFID system properties at different operating frequencies [42].

Table 2.3. RFID Properties at Different Frequencies

<b>Properties</b>	<b>LF RFID Tags (9-135 KHz)</b>	<b>HF (13.56 MHz)</b>	<b>UHF (860-960 MHz)</b>
Read Range	Low	Moderate	High
Data Transfer rate	Slow	Moderate	Fast
Read-Write Data carriers	Yes	Yes	Yes
Directional Readers	No	No	Yes
Read through glass, clothes, woods, etc	Yes	Yes	Yes
Dirt Resistance	Good	Good	Good
Few Applications	Animal Identification Automobile Key	Smart cards Container tracking	Item Management Supply Chain management

### 2.4.2 Chipless Vs Chip

As our focus is on extremely low cost tags that provide the minimum of functionality that means a simple read only device with a permanent unique identification number that is chip less tags would be optimal. One can easily avoid the silicon costs and the intricate manufacturing process required for integrated circuitry. For two reasons chip tags are chosen over chip less tags[38]. First is the tag must hold enough memory to hold an identification number from a scheme designed to identify uniquely massive numbers of objects. And secondly, the reader must be able to read multiple tags in its field.

To uniquely identify all manufactured items, a numbering scheme should allow for enough unique codes. Most chip less tags at present allow up to 24 bits or less, some may allow 64 bits but at the cost of higher price[50]. Due to an ever increasing number of objects, ever decreasing in size, will be tagged, it is necessary

that a reader be able to read multiple tags within its range and in close to one another. And at present the best way to accomplish this is through some intelligence on the tag itself. In later chapters we see how this was achieved in our research work. Even though chip less tags show tremendous promise in achieving larger memories and improved anti-collision functions, and in the future, circuits may be printed directly onto non-silicon substrates, chip tags offer the most near-term promise in fulfilling the demands of most object tracking and identification applications.

### **2.4.3 Power and Communication**

Available tags in the market can be divided into four categories depending on the type of powered communication between tag and the reader and they are Passive, Semi-Passive, Active and Semi-Active tags.

#### **2.4.3.1 Passive Tags**

Passive tags have no on-tag power source and no on-tag transmitter. These tags are very inexpensive; can cost as little as 20 cents per piece, also new technologies are constantly making efforts to reduce their prices even further to integrate them into common materials and products. As passive tags are inexpensive, they will likely be the basis of most of the growth in RFID implementations and that is the reason I chose Passive tag for my research. Along with their low cost, passive tags can also be quite small. Recent antenna technology limits the smallest useful passive tag to about the size equivalent to a quarter. The larger the tag, the larger the read range[94].

A passive RFID system operates in the following way. RFID reader transmits a modulated RF signal to the RFID tag which consists of an antenna and an integrated circuit chip. The chip receives power from the antenna and responds by varying its input impedance and thus modulating the backscattered signal. Amplitude shift

keying is often used in RFID where the chip impedance switches among two states; one is matched to the antenna and another one is strongly mismatched[66]. The passive UHF RFID with EPC class 1 Gen 2 standard has been widely accepted for applications in track, trace assets or people.

#### **2.4.3.2 Semi-Passive Tags**

Semi-Passive Tags are the tags that communicate passively with the reader but it has its own tag power supply, which is used to run the logic on the chip and activate sensors if any available. These tags have better range than passive tags, and the read range goes may be up to several hundred meters. These tags are usually used for tracking high value goods that needs to be scanned over long ranges.

#### **2.4.3.3 Active Tags**

Active tags use on board power supply for powering the logic as well as to communicate with the reader. Because they have their own power source, active tags transmit a stronger signal, and readers can access them from farther away. The on board power source makes them larger and more expensive, so active RFID systems typically work best on large items tracked over long distances. Active tags can remain dormant until they come in range of a receiver or can constantly broadcast a signal[94].

#### **2.4.3.4 Semi-Active Tags**

A semi-active tag is an RFID tag that uses a battery to communicate but remains dormant until an RFID reader sends an energizing signal. The tag then uses its battery to communicate with the reader. Semi-active tags have a longer range than passive tags and a longer battery life than active tags. Battery assisted semi-active RFID tags have been recently focused because of its robust and long distance



communication[72]. According to the present stand of RFID tags in market, the semi-active RFID technology will create new application areas such as disposable RFID sensor systems for sensor networks, and sophisticated multifunctional devices for value added service[57]. But the major drawback of battery assisted tags is limited operating time as tags cannot be used once the battery has died. In conclusion, when the tag receives commands from readers but the rf power is not sufficient, the tag operates in the semi-active mode. Table 2.4 shows the basic comparisons between RFID Active, Semi-Passive and Passive tags.

Table 2.4. Comparison between RFID Tags

<b>Parameters</b>	<b>Active Tags</b>	<b>Semi Passive</b>	<b>Passive</b>
Power Source	Battery on tag	Battery for chip operation. Radio wave energy from reader for communication	Radio wave energy from reader for operation and communication
Tag Signal Availability	From several hundred meters to kilometers	Only within field of reader	From several tens of meters
Signal Strength Tag	High	Low	Very Low
Required signal strength from reader to read the tag	Very low	Low	Very High
Typical Application	Used for tracking high value goods, that needs to be scanned over long ranges	Used for tracking high value goods, that needs to be scanned over long ranges	Useful for high volume goods, where items can be read from short ranges

## 2.5 Performance and Durability Comparison

Performance and cost of RFID tags are directly proportional to one another, whereas life span of an individual tag is indirectly proportional to its complexity. Following the brief performance evaluation of RFID tags based on its read range and cost.

### 2.5.1 Read Range

The read range is the distance among the reader and tag that a reader can recognize a tag's existence. In assessing the RFID system performance, read range is one of the key parameters. It can be classified into two parts, one is the forward link read range from reader to tag and the other is reverse link read range from tag to reader. And the smaller of two is considered to be the read range[45]. The forward link read range is defined by the distance the reader signal can wake up the tag. Whereas, the reverse link read range is defined by the distance the reader can detects the backscattered signal of tag. The previous one can be generally improved by reducing the power consumption in tag chip and the latter one can be achieved by better reader's sensitivity[45]. And according to the theory [60], the read range when compared from passive to semi-passive to active ,it increases and in fact read range of semi-passive tags are almost double than that of passive tags. Figure 2.2 shows the graphical representation of read range of RFID tags.

Since a distance of reader to tag is short in passive RFID system, Friis's free space propagation formula can be used for computing the read range of passive RFID system[45].

$$P_{RX,tag} = P_{tx,reader}G_{reader}G_{tag}\left(\frac{\lambda}{4\pi r}\right)^2T_b \quad (2.1)$$

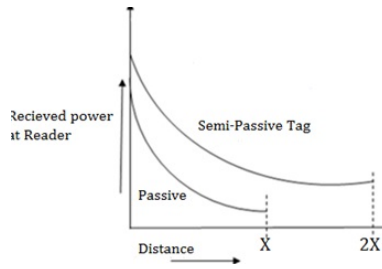


Figure 2.2. Read Range of RFID Tags.

$$P_{RX,reader} = P_{tx,reader}(G_{reader})^2(G_{tag})^2\left(\frac{\lambda}{4\pi r}\right)^4 T_b \quad (2.2)$$

Where  $P_{RX,tag}$ ,  $P_{TX,reader}$ ,  $G_{reader}$ ,  $G_{tag}$ ,  $T_b$ ,  $\lambda$ , and  $P_{RX,reader}$  represent the received power at tag, the transmitted power from reader, the transmitted antenna gain of reader, the Rx antenna gain of tag, backscattered transmission loss, wavelength, and the received power in reader respectively[45]. The forward link received power at tag is proportional to  $(1/r^2)$ , as shown in equation 2.1. The reverse-link received power at reader, which is transmitted from tag to reader, is proportional to  $(1/r^4)$ .

This shows that the improvement in forward link is less effective than that in reverse link. In the forward link, a tag generates DC supply voltage with the transmitted power from reader because the passive tag has no on tag battery. And the transmitted power strength at tag should be large enough to generate DC power supply to tag (wake up). Forward link read range is determined by the threshold power. Usually, the forward link read range is known as the minimum threshold power required from tag.

In this thesis research, we are improving the forward link read range of a passive RFID tag by giving an external energy source to the tag's chip so that entire energy coming from the reader is used to backscatter the stored information on the chip

unless passive tags in market which consumes part of the energy from the reader to get its chip activated and rest of the incident energy for backscattering the stored data on it.

### 2.5.2 Cost and Complexity

After discussing the read range of RFID tags, let us consider their Cost vs complexity trade-off. Active and Semi-Passive tags use internal batteries to power their circuits. An active tag also uses its battery to broadcast radio waves to a reader, whereas a semi-passive tag relies on the reader to supply its power for broadcasting. As these tags contain more hardware than passive RFID tags, they are more expensive. On the other hand passive tags have lower production costs, meaning they can be applied to less expensive merchandise. Also, more complex the tag is more would be difficult to stay active longer. Thus life span also decreases when we compare from passive to semi-passive to active tag. Figure 2.3 shows the bar graph that compares the complexity and cost of various RFID tags.

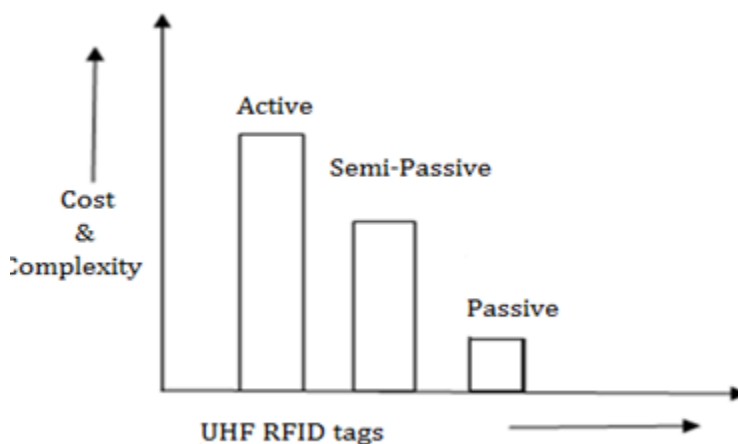


Figure 2.3. Cost and Complexity Variation of UHF RFID Tags.

## 2.6 RFID Tags

To understand the fundamentals of tag design, it is important to delve into the physics behind RFID tags. Irrespective of the application, the accuracy of tag reads is an unavoidable requirement. This can be achieved with optimal tag designs. Thus, basic knowledge on tag designs is priceless since it enables the right choice of tags for the right application. Most UHF tags use dipole antennas[76] since UHF frequencies are electric in nature while most LF and HF tags are coiled antennas due to their frequencies being magnetic in nature. RFID transponders consist of a microchip (the tag IC) and a coupling element (the tag antenna). Figure 2.4 shows a picture of an Alien Squiggle Tag [35].



Figure 2.4. Picture of an Alien Squiggle Tag.

### 2.6.1 Microchip

The tag IC is strapped to the tag antenna which acts as a coupling element. Antenna design considerations are provided in [85]. A substrate which is commonly a plastic film holds the tag IC and the tag antenna together [24]. The IC inside the tag has a memory which stores the data that uniquely identifies the tag. This data is the serialized EPC code which is programmed in the tag during the tag manufacturing process. Most passive tags can store up to 96 bits of data. The minimum threshold power required to read the EPC data is approximately -10 dBm. Depending on the chip design the tag is a read only or a read -write tag. The tag IC receives power from the tag antenna as an altering current at the reader frequency. Now this current

must be down-converted and rectified by circuitry tuned to a specific frequency. The efficiency of the power circuitry of the tag IC is dependant on the matching of the individual components of the tag IC.

### **2.6.2 Tag Antenna**

For passive RFID tags, antenna inside it plays a very important role, as it absorbs the energy from the RF field from the reader and powers the tag IC to communicate data back to the reader. The amount of power which is transferred from the reader's electromagnetic field to the antenna and from antenna to the tag's microchip depends on the coupling efficiency of the tag antenna. The impedance matching between the chip and the tag antenna is very important, as power delivery to the chip depends on the matching circuitry. Reflection cross section (RCS) signifies the efficiency with which electromagnetic waves are reflected by the tag antenna. Tag antenna which is tuned at a particular frequency has a larger reflection cross section at that particular frequency. The amount of power absorbed and scattered by antennas is explained in detail in [74]. The reflected wave is modulated by varying the reflection cross section i.e. the impedance of the antenna. RCS of the tag antenna has a direct dependence on its size. This phenomena is very critical to the performance of the tag as it determines the maximum read range of the RFID system.

## **2.7 RFID Reader at a Glance**

Reader is a transceiver which sends the RF signal to activate and establish communication with the tag and also receives the data from the tag to be sent to the information systems.

### 2.7.1 Basic Units

An RFID reader typically contains a module (transmitter and receiver), a control unit, and a coupling element (antenna) [41] [49]. The amount of power transmitted by the reader operating within the United States is restricted by the regulations. The control unit within the reader modulates the frequency and amplitude of the wave that is generated by the reader. The antenna inside the reader sends out the modulated data-carrying RF signal to interrogate the tag. And as a receiver reader receives the modulated data from the tag, it sends that to the information system via middleware for processing.

### 2.7.2 Antenna Characteristics

As antenna of the reader communicates with the RFID chip; high directivity and gain are its desired characteristics. Directivity is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity in all the direction [41]. It is important to have a 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. This would prevent ghost reads and reader collision problems to a certain extent.

Apart from high directivity[21], high gain is also an important parameter which measures the efficiency of an antenna as well as its directional capabilities. The ratio of the power delivered to the antenna to the power that is actually radiated by the antenna gives the efficiency of the antenna. The reader antennas must be able to power the tag for it to respond for transmission and must also be able to receive and detect the feeble backscatter of the tag for reception.

Polarization is another important concept in RFID readers. The polarization of the reader antenna must match that of the tags for efficient communication be-

tween the reader and tag. Other antenna parameters such as radiation efficiency and impedance matching are also of significance in the design of reader antennas.

### **2.7.3 Frequency Constraints**

For RFID communication, there are various restrictions, like a radio device that operates in the ISM band (902 - 928 MHz UHF RFID band in the United States) is required to frequency hop every 0.4 sec, which restrict the RFID reader performance and limits its maximum operating range, back scatter power and strength [46] [73]. The European Regulations provide a specific set of power levels and frequency spectrum (865- 868 MHz) for RFID reader operation. The ETSI (European Telecommunications Standards Institute) specifically requires RFID readers to listen for any communication in the desired frequency level before transmitting on it. And this is popularly known as Listen Before Talk (LBT). Reader requirements vary depending on the type of task and application. The reader that we are using in our experiment is SIRIT reader as shown in Figure 2.5. Various types of reader systems are available in market such as Handheld readers that act like a handheld bar code scanner, Readers embedded into mobile data collection devices and Fixed readers, which are mounted to read tags automatically as items pass by or near them.

## **2.8 Middleware and Information Systems**

The middleware and information system play very important role in whole RFID system. All the data which is being read by the reader or interrogator is processed at the information system.





Figure 2.5. Sirit Reader[10].

### 2.8.1 Information System

Information System makes the data on the tag to actual information. Numerous application specific programs run on the Information system, which integrate the reader data and trigger application specific events. Middleware is another system block between the reader and the information system. This subsystem supports efficient collection of data obtained by the reader and reduces the data redundancy in the information system.

### 2.8.2 Middleware

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 need to be routed to multiple or same applications. Data management, done by the Middleware is very critical requirement, if not done it will increase the data traffic at the information

system. Middleware should filter out redundant and undesirable data and must also route the data to appropriate destinations. Figure 2.6 shows the basic RFID network with middleware and Information systems. Various implementations of RFID middleware are: Application Level Events (ALE) by EPCglobal, which provide specific standard interface to obtain filtered EPC data from RFID readers and other data sources. Also, the ALE specification provides exile mechanisms to alter and group raw RFID data. This altering and grouping capability provides a means to isolate and focus specific and desired applications.

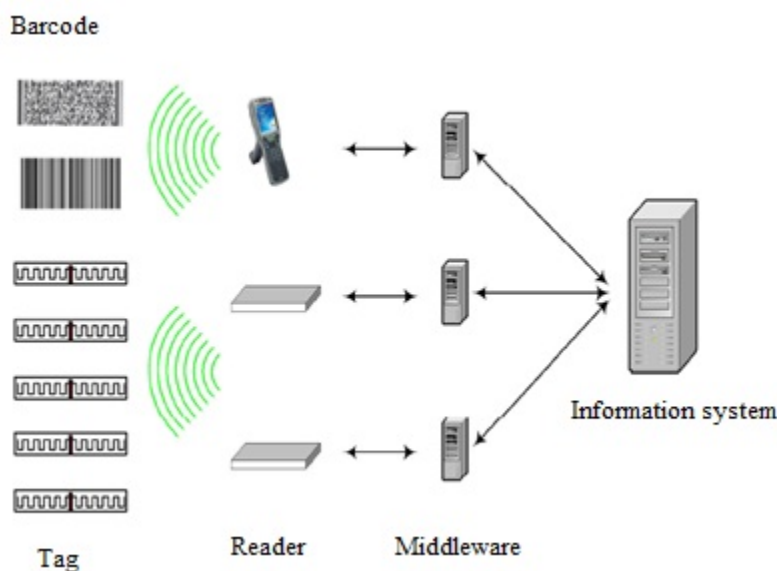


Figure 2.6. Middleware and Information System.

## 2.9 Summary

RFID systems are moving to become the most popular and the most widely implemented AIDC systems in the world. As tags and readers become less expensive, economic adoption of this technology will be faster. A brief overview of the basic

components and the working of an RFID system were provided in this chapter. Tags can be read at a very high rate and without line of sight requirement. The stored information identifies uniquely the object to which it is affixed. Due to this automated identification, human intervention can be reduced tremendously and this leads to overall reduction in the operating cost of a system. Passive tags are the cheapest and most readily available tags in the market. But these tags are used in the areas which require less read range. Forward-link-limited range of a passive UHF RFID tag can be extended, if the tag IC is activated directly. As this semi-passive turned passive tag requires less power from an incident radio wave, the read range is much longer than that of a regular UHF passive tag with the same reader transmission power. Thus, the popularity of passive tags can be increased in the market as low power, low in cost passive tags would no longer be limited to the small scale applications.

## CHAPTER 3

### RELATED WORK

#### 3.1 Introduction

The key guidelines in the successful implementation of an RFID system are the appropriate choices of readers, tags, tag location, reader antenna configuration, and analysis of objects to be tagged and last but not the least characterization of the environment. Also there are several parameters such as tag sensitivity, backscatter signal strength, communication range, and reflection efficiency of the tag, reader sensitivity, IC design and antenna design that effect the performance of tags in different environments and on different objects to be tagged. It is the complex interaction of all these parameters that determine RFID system performance; therefore, each parameter will affect the performance of additional power source applied to a tag designed for pure passive use. In this chapter, we discuss the work that has been accomplished in the past on the analysis of various RFID system parameters that impact the performance of tags. And also about the previous work on converting passive to semi-passive tag.

#### 3.2 Previous Work

RFID passive tag's antenna harvests power by the incident radio waves, which is converted into the DC power to supply the power demand of the tag IC [37]. The Control unit is the heart of the tag IC which decodes the reader commands and correspondingly decides the response using the air interface protocol [52]. The tag then backscatters its Modulated Backscattered Signal (MBS) using the un-modulated continuous wave (CW) from the reader as its carrier. Memory stores the tag ID and

other information. Figure 3.1 shows architecture of a typical class1 Gen2 RFID tag.

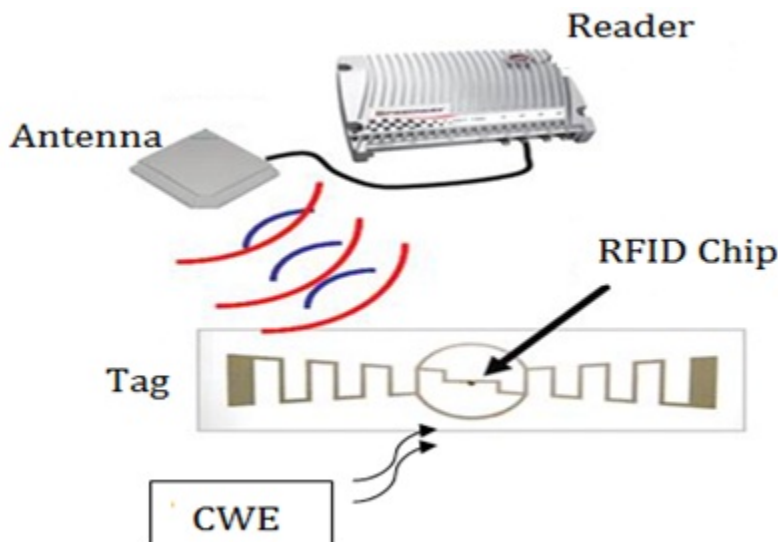


Figure 3.1. Architecture of Typical Class1 Gen2 RFID Tag.

As discussed in [60], the accessible range of Gen2 tags can effectively be increased by a multi-carrier UHF passive RFID system. The fundamental reader system in a multi-carrier UHF passive RFID system is composed by two parts: one set of isolated continuous wave emitters (CWE) and a transceiver.

The CWE is an isolated entity which can power up the tags lying in the field of the CWE source as shown in figure 3.2. And transceiver is mainly used to transmit R-T commands and receive T-R responses used[60]. Now, as the power received from the reader by the passive tag is fully utilized to send the data back, the read range is anticipated to increase significantly. But Due to the use of an additional frequency besides the reader signal the isolated CWE source can prove to be spectrum insufficient. [62] proposed a new design of an enhanced passive tag(EPT) that can

extend the read range of an EPCglobal Class-1 Gen2 tag by attaching a battery assisted circuit(BAC) to the tag integrated circuit unlike [60].

In [62], the proposed system utilizes multiple un-modulated Continuous Waves (CWs) with different frequencies to illuminate a passive tag simultaneously as shown in figure 3.2.

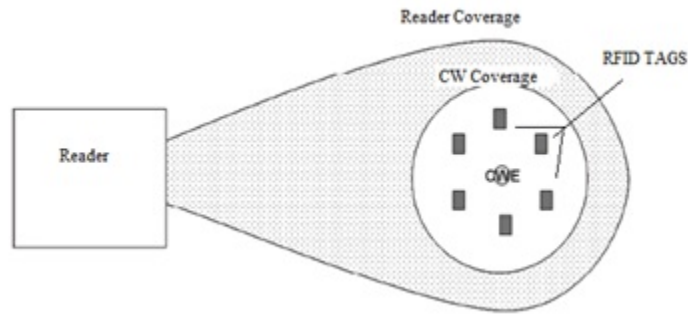


Figure 3.2. Passive UHF RFID System[60].

With the proposed design of EPT the issues related to the spectrum insufficiency could be handled. The design constrains of the BAC included careful selection of the RF frequency and power so as to acquire maximum harvested power and minimum radiation into space, and negligible interference in the Reader - Tag communication. The frequency value of 800MHz at -11.94 dBm was used as CWE.

All the research work that has been done so far only proposed a CWE with randomly selected frequency and power values keeping into consideration above mentioned constraints. Thus, this thesis aims to fill this void and achieve a cumulative and comprehensive analysis for selection of optimum frequency and power values for CWE. This thesis also aims in implementing prototypes and designing circuits based on the calculated parameters. In the following chapters we discuss about the effect

on center frequency of tag by connecting an external energy source and also we would examine the effect of wired or wireless medium transferring energy to tag externally.

### **3.3 Summary**

In this chapter, we have discussed the work that has been accomplished in the past on increasing the passive tag-reader communication range. Initially we saw work done by [60] which proves that the accessible range of Gen2 tags can effectively be increased by a multi-carrier UHF passive RFID system. Later we saw a new proposed design by [62] of an enhanced passive tag(EPT) that can extend the read range of an EPCglobal Class-1 Gen2 tag by attaching a battery assisted circuit(BAC) to the tag integrated circuit. In my thesis, I propose to increase the passive reader-tag communication distance significantly by carefully selecting an optimum frequency and power values for CWE and implementing them in a novel circuit design for charging tag externally.

## CHAPTER 4

### DESIGN AND IMPLEMENTATION OF RFID TAGS

#### 4.1 Introduction

Before designing an external power source for passive UHF RFID tag, we should understand about the basic design and implementation of tags. In this chapter, we have a brief discussion on tag properties such as its data holding capacity, mutability, and methodology for data transfer and the basic protocols used for data transfer among tag and reader. We would also discuss the near and far field communication which then be followed by tag power management. Figure 4.1 give examples of RFID inlays of passive UHF RFID tags. Tags operating at HF (13.56MHz) frequency often utilize coiled antenna and at UHF frequency (860-960 MHz) the dipole antennas.

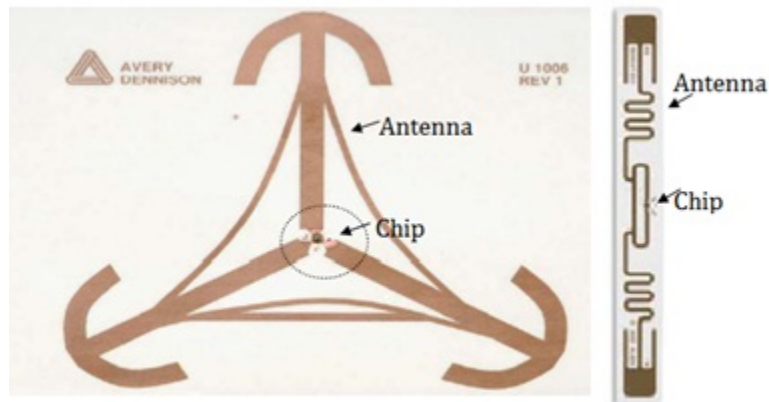


Figure 4.1. Inlays of UHF (860-960 MHz) RFID Tags [86].



## 4.2 Tag Properties

RFID tags available in the market are distinguished based on their various characteristics and features. Depending on the application's necessity a particular tag is being chosen. Below are the categories in which tag's properties can be classified easily.

### 4.2.1 Data Quantity

A RFID tag can normally store data quantity ranging from few bits to several kilobytes. Tag containing one bit data is sufficient to signal two states of the reader for instance information consisting of purchase or not purchase of product. Tag containing tens of bits allows a unique identification number to be associated with it as tag consisting of thousands of bits allows object specific data to be stored on it. Amount of data stored on the tag's chip affects the workable frequencies at which an RFID system can operate. Tags storing more number of bits of data usually require more than a second to communicate all the stored information bits at low frequencies. This becomes impractical sometimes to wait for longer period for tag-reader communication, thus high data quantity tags are used mainly in Ultra-High Frequency (UHF) systems, where all of the data on a tag may be read in few milliseconds.

### 4.2.2 Data Flexibility

Other than categorizing tags into active, passive, semi passive and semi-active, they can also be categorized based on the flexibility of data stored on it. According to the data mutability, we have below listed categories

#### 4.2.2.1 Read-Only Tags

Read -Only Tags, are produced with an n-bit unique serial number for identification. Central databases are used to link the information to the objects to which they are attached. These passive read only tags are designed for a broad range of applications. They include a transponder and antenna circuit in an application specific enclosure. N-bit permanent serial number is stored on them during the manufacturing process. This serial number can never be changed and is used for tracking, routing and identifying vehicles, objects, animals or people[97]. As they do not require a battery, they have an unlimited lifetime and can be completely embedded in any non-metallic material.

#### 4.2.2.2 WORM Tags

Second category of tags are Write once-read many(WORM tags) which allow a one-time, unchangeable coding of the information on the tag that can be read effectively any number of times. After the data is read from any type of transponder, it can be sent to a host computer, or stored on a reader to be later uploaded to a computer. On the other hand, Read/Write Tags have individual, writable memory areas and allow the user to set and reset its data content.

#### 4.2.2.3 Data flexibility Vs Cost

The ability to write data on a tag provides significant flexibility to the RFID system. Reference data handling instructions or process data can be stored and encoded. In addition, read/write tags may be written several thousands of times letting them to be reused, considerably reducing their per use cost while maintaining current, accurate data on the tagged object [86].

Tag cost, size, memory capabilities vary. Tag information can be limited to a unique code, or include detailed information such as manufacturer, storage conditions etc. Price of a tag increases with the amount of information that can be stored on a tag. Current prices are between 50 cents to \$50 depending on the memory, type (active/passive, RO, R/W or WORM) and operating frequency. Data security is achieved in RFID tags with an optional password mode, which requires a password to enable read and write functions. Data in a tag can be locked by the user to prevent future modification[20].

### **4.2.3 Data Transfer Protocol**

When the RFID tag starts communicating with the reader, it either adopts the simultaneous data transfer method to the reader or it sends data only for a limited period of time depending on the application demand. In Full/Half Duplex data transfer, reader starts emitting the RF field, tags start communicating either in half or in full duplex data transfer mode.

#### **4.2.3.1 Half Duplex**

Half duplex systems serialize the data transfers between tag and the reader. At a time either the data can be sending to the tag or can be received from the tag by the reader. These systems may communicate on a single channel or frequency. In this method, the reader sends magnetic charge pulses followed by a silent period. The charge is stored in a capacitor within the tag to supply enough power to return the unique ID when the pulse goes off. The power requirements for half duplex readers are lower due to the pulsed charge method. The charge and listen periods can be adjusted to slow the scan rate to lower power requirements even further. Half duplex antenna can be much larger than ones for full duplex readers[47].

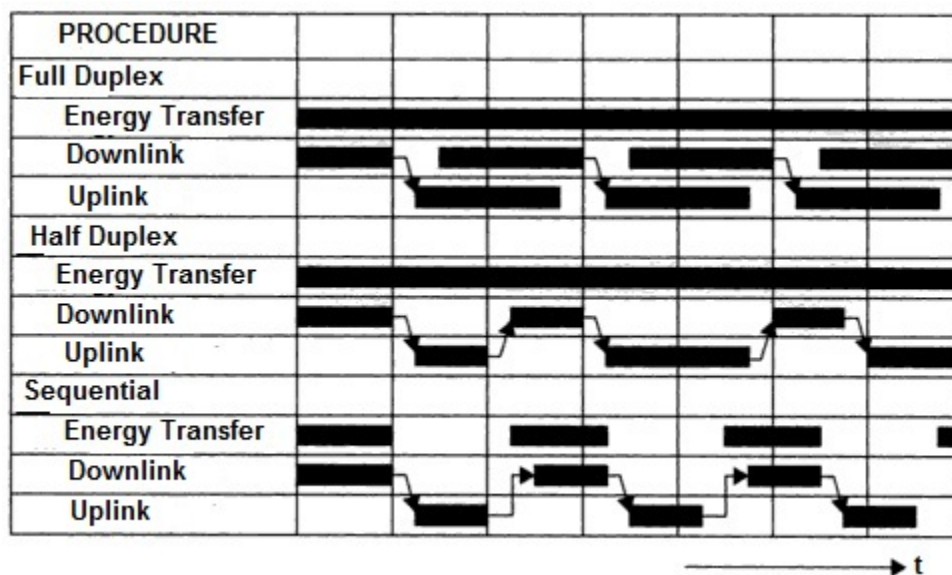


Figure 4.2. Full/Half Duplex and Sequential Systems over Time[41].

#### 4.2.3.2 Full Duplex

In full duplex data transfer mode, data can be transferred from the reader to the tag and vice versa simultaneously. And full duplex communication requires the use of either multiple channels or multiple frequencies. Full duplex tags can be read at a faster rate than half duplex[23]. Sizes of full duplex tags are much smaller compared to the half-duplex tags. And is preferred in applications where small tags are required. In both the procedures (Half and Full Duplex), the transfer of energy from the reader to the transponder is continuous that is it is independent of the direction of data flow. In sequential systems (SEQ), on the other hand, the transfer of energy from the transponder to the reader takes place for the limited period of time only (pulse operation-Pulse system).

Data transfer from the transponder to the reader takes place in the pauses between the power supplies to the transponder. Figure 4.2 shows the representation of Full duplex, half duplex and sequential systems. The main or significant difference

between the half-duplex or sequential data transfer mode is that the half-duplex protocol continuously sends power to the tag while the sequential protocol periodically terminates power to the tag. The loss of power to the tag in half duplex must be compensated by the provision of sufficient supporting capacitors or batteries located on the tags[41].

#### **4.2.4 Data Transfer Method**

When the tag comes under the vicinity of the reader's radiation, transfer of data occurs between tag and the reader. There are three different ways in which the data can be exchanged between the two.

##### **4.2.4.1 Backscatter Modulation**

According to the RADAR technology, electromagnetic waves are reflected by the objects whose dimensions are greater than around half the wavelength of the wave during backscattered mode of data transfer. Reflection Cross Section (RCS) of an object outlines the efficiency with which it reflects the incident electromagnetic waves. RCS varies according to the coupling devices which are in resonance with the wave front hitting them. A tag with a high reflection cross section for a given frequency reflects an electromagnetic wave at that frequency.

The reflected wave from the tag has small amount of incident radio waves from the reader. Coupling device at the reader detects the reflected wave traveling in the backward direction to the wave emitted by the reader [39].

##### **4.2.4.2 Load Modulation**

The second method for data transfer between tag and the reader is modulating the magnetic or electric field incident on the tag from the interrogator and is called

as Load Modulation. When the tag gains its energy from the magnetic field, it inductively couples to the reader whereas when it gains its energy from the electric field it is magnetically coupled to the reader. Due to coupling, the amount of energy received by the tag gets reduced and hence the power transfer efficiency drops. Inductively coupled tags are mostly operated passively. For this reason the reader's antenna coil generates a strong, high frequency electromagnetic field which penetrates the cross section of the coil area and the area around the coil.

Amount of power transfer between inductively coupled reader and tag is directly proportional to the interrogation frequency, the number of coil windings, the angle of the two coils relative to one another and the distance between reader and the tag. Size of the electrodes and area enclosed by the tag's coupling device affects the energy transfer in capacitive coupled tags.

As inductively coupled systems depends upon transformer type coupling between the primary and the secondary coil in the reader and transponder respectively, distance between them plays an important role. The distance between the coils does not exceed  $0.16\lambda$ , so that the tag is located in the near field of the transmitter antenna [39].

#### 4.2.4.3 (Sub) Harmonic Generation

As we have seen that the load modulation causes reduction in the output voltage from the interrogator and hence reduced communication signal between the two. For instance, in HF (13.56 MHz)RFID communication system reader voltage of 100V can expect a communication signal load modulation of 10mV[40]. To detect the occurrence of this small voltage modulation, another frequency can be used for the communication from the tag to the reader. And this frequency could be harmonic or sub harmonic of the reader's interrogation frequency and this is known as data

transfer between tag and reader with the help of (Sub) Harmonic generation. Figure 4.3 shows the Load modulation data transfer method in Low frequency RFID passive tags.

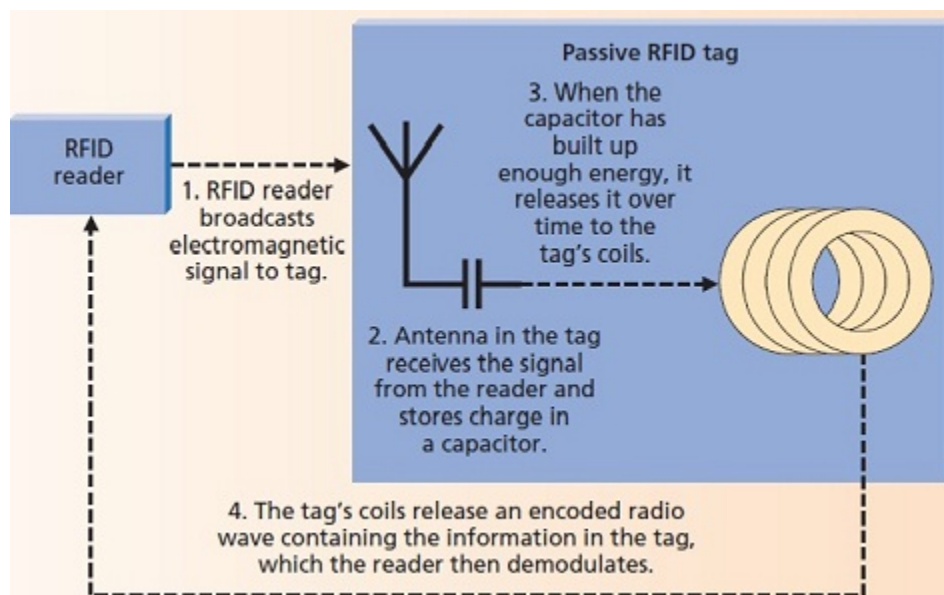


Figure 4.3. Data Transfer in LF Passive RFID Tag[94].

### 4.3 Tag Power Supply

Power source at the tag is used to store and transmit its stored data to the reader. There is no power source available on the passive tags. They use part of the incident energy from the reader to get activated and then rest of the energy is being used to send the data back to the reader. Typically, in today's market low-power tag circuits use between 10uW and 50uW of power, drawing between 5uA and 500uA of current at a minimum voltage of 1.8V[40]. Passive tags typically obtain their power from the reader's signal either through load modulation (near field communi-

cation): inductive coupling & capacitive coupling or backscatter communication (far field energy harvesting).

#### 4.4 Near Field Communication

In the low-frequency (HF) range with short read distances, the tag is in the near field of the reader antenna. The power and the signals are transferred with the help of magnetic coupling using inductors. And hence in the HF range, the tag antenna comprises a coil (inductive loops), to which the chip is attached.

The current induced in the coupling element powers the tag. Thus inductively coupled systems act like a loosely coupled transformers with tuned LC circuits and hence used to maximize the coupling between the reader and the tag. Subsequently, inductive coupling works only in the near field of the interrogation signal. And the near field for an inductively coupled system is given as

$$\leq \lambda/2\pi \tag{4.1}$$

where  $\lambda$  = wavelength of the communication frequency.

Like inductive coupling, capacitive coupling works only in the near field of the interrogation signal. This coupling method uses the electric field generated by the interrogation signal to induce the voltage differential between the electrodes in its coupling element. And this voltage differential supplies the power for the tag, allowing it to transmit its data to the reader. Since, capacitive coupling requires two electrodes for the reader and two electrodes for the tag; sometimes it becomes difficult to specify the range of the tag [17].



## 4.5 Far Field Communication

Unlike near field communication, far field energy harvesting uses the energy from the reader signal's far field wave to power the tag. The voltage is induced at the input terminals of the tag when reader's signal is incident on it. When this very voltage is detected by the RF front-end circuitry of the tag, it is then used to charge a capacitor that provides the necessary bias for the tag processing circuitry. Figure 4.4 shows the front end of the tag which consists of the antenna and internal circuitry of the chip. The figure explains the backscatter communication and far field energy harvesting by the tag.

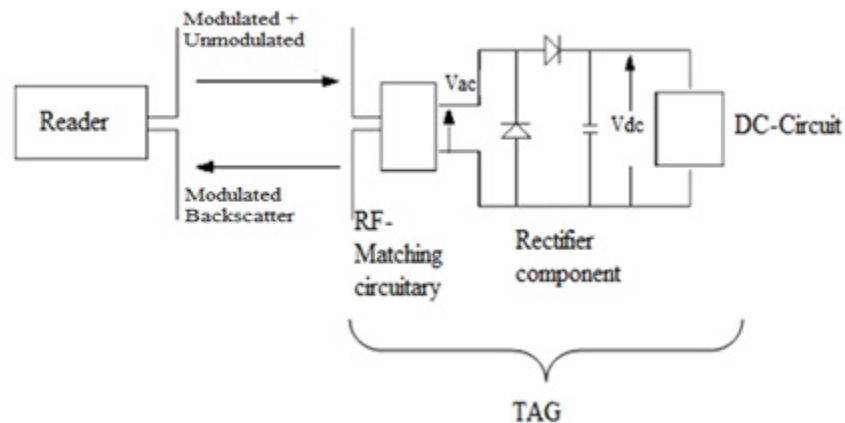


Figure 4.4. Backscatter Communication.

## 4.6 Power Management

The next generation of UHF RFID tags known as higher class UHF RFID tags provides extended functionality in terms of independent sensing and monitoring, high communication range and large memory areas. This requires continue operation of

the tag itself- even though they are not powered by the reader which is in pure passive UHF RFID systems.

Thus, an on board energy supply is required which renames the passive UHF RFID technology to semi-passive and active technology. The main difference between the semi-passive and active technology is the tag to reader communication. Semi-passive UHF RFID tags provide added functionality as discussed earlier but the communication is entirely based on semi-passive method as passive UHF RFID tags simply reflects and modulates the reader signal. The operating range of such tags type is much higher, as the reader signal is entirely used for communication between reader and tag but not for powering up the tag as in passive RFID systems[89].

#### **4.7 Near field Vs Far Field**

RFID systems usually employ either near or far field coupling techniques for power and data transmission. As discussed in the previous section, Inductive coupling occurs when reader-tag communication takes place in near field applications whereas, in far field applications communication between reader and tag is performed through transmission, propagation, and reception of electromagnetic waves[89]. The near field RFID systems mainly operate at relatively low frequencies i.e., LF and HF bands, with the reading distance within the radian sphere defined by  $\lambda/(2\pi)$ . The far field RFID operates at higher frequencies with a higher read range as compared to the near field systems.

#### **4.8 Far Field RFID System**

In this thesis we are designing the power generating circuit for far field RFID applications operating at the UHF band. Figure 4.5 shows the block diagram of a

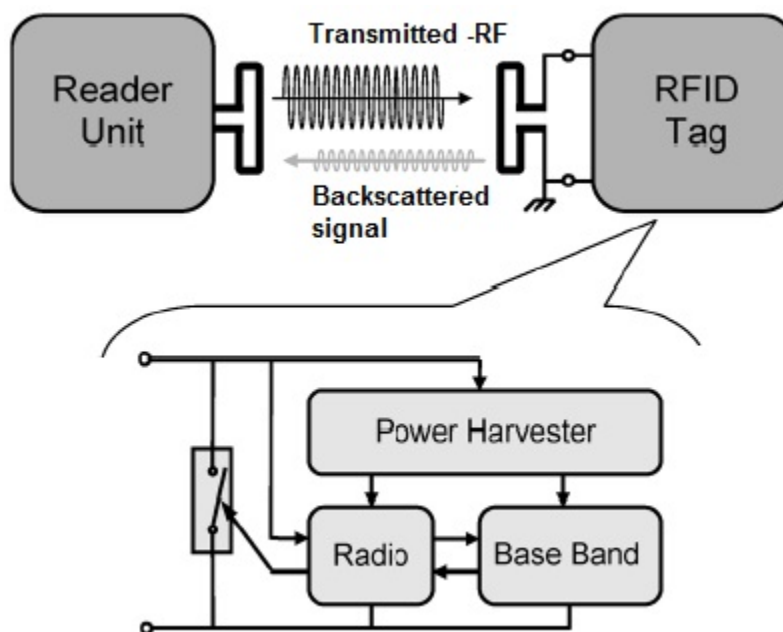


Figure 4.5. Far Field RFID System[89].

far field RFID system, where the passive tag consists of a power harvester unit, radio unit and processor unit.

Power harvester unit rectifies the received signal and generates the supply voltage. Due to the power limitation of the reader, multistage rectifier is required at the front-end of the tag for voltage rectification and enhancement purposes. Radio unit consisting of an envelope detector and a comparator in order to receive the data transmitted from the reader.

At the end the received data is processed at the processing unit and the tag responds to the reader by changing its input impedance, that can be sensed at the reader side [90]. The antenna load is a controlled resistance, demonstrated as a transistor that changes the impedance of the dipole, hence enabling the backscattering.

Multistage rectifier converts induced voltage which is in form of small amplitude AC to a certain DC voltage level which power the microchip. As the front end of the

chip is consisting of a rectifier circuitry, it becomes necessary to give an AC signal so that the capacitor at the front gets charged up and hence power up the chip as also shown in Figure 4.6. Thus, the first task before supplying an AC signal to the chip is to choose the certain types of waveform and frequencies.

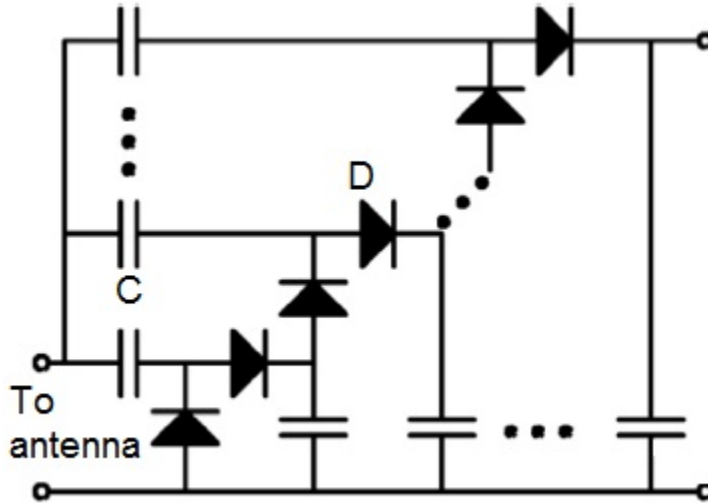


Figure 4.6. Multistage Rectifier.

To supply enough power, theoretically any voltage waveform with AC components will be good for example square wave, sine wave which can be easily generated. Whereas, as given in [39][40][59], the information exchange occurs in certain frequency band.

As if the power signal introduces abundant harmonics inside the system, quality of communication would be affected by the unwanted components. Thus, accurate AC signal is required with appropriate power so that the chip inside the tag gets activated at the point where it harvests the maximum power so that it starts replying back to the reader in very less time.

#### 4.9 Thesis Motivation

According to the discussions in Chapters one and three, passive tags are the cheapest and most readily available tags in the market. But these tags are mostly used in the areas which require less read ranges. However, they are continuously being used in applications requiring greater and greater read range. Thus, if we directly activate the passive tag's chip by attaching an external energy source to it through two leads as shown in Figure 4.7, the passive tag can be converted into a semi-passive tag.

Due to this, the popularity of passive tags can be increased in the market as low power; low in cost passive tags would no longer be limited to the small scale applications. If the external source is turned off, these passive tags can behave normally. With this, one tag can either be used as passive or semi-passive by operating the external power source attached to it.

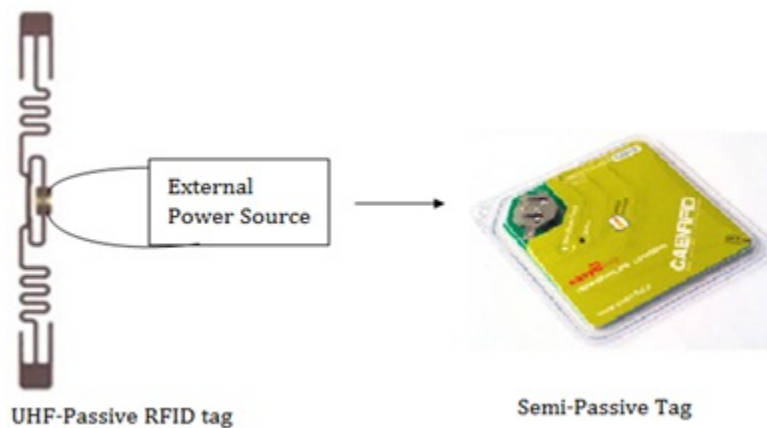


Figure 4.7. Proposed Passive to Semi-Passive UHF RFID Tag.

## 4.10 Summary

In this chapter, we have reviewed some of the fundamental concepts associated with design and implementation of a remotely powered addressable UHF RFID transponder. We discussed the inlays of UHF tags. Later we saw some of the characteristics of the passive UHF RFID tags and the power management. We saw that rectifier circuit is required at the front end of the passive tag as when it receives the RF radiations from the reader it converts that to dc value which is required to charge the chip.

After looking deep into the tag architecture and energy requirements it can be concluded that if a direct external energy is given to the tag's chip at chip-antenna interface, passive tags can show significant increase in read ranges. The frequency and the power level at which the external energy should be given to the tag is our next step now. Thus, in next chapter we see how the specific frequency and power level can be chosen for external energy source so that the chip gets activated in minimum time and backscatters the information to the reader.

## CHAPTER 5

### DESIGN PARAMETERS FOR CONTINUOUS WAVE EMITTER

#### 5.1 Introduction

As discussed in the Chapter 1, a semi-passive tag consists of batteries which power-up the chip and hence improves the read range as compared to the passive UHF tag. Also a passive UHF tag can be powered-up externally through a continuous wave emitter source. When the external power is on, tag would act as a semi-passive tag, whereas when the external power is off, it would behave as a normal passive tag showing significant change in the read ranges.

Choosing the right frequency with associated power for the CWE might be quite a task for increasing the communication range significantly. However, it is very important to perform various tests on the absorbing and reflecting capability of the tag and analyze the results to gain an insight into the impact of the continuous wave of various frequencies and power level on the tag themselves. In this chapter, we provide a step-by -step procedure for selecting accurate design parameters for Continuous Wave Emitter (CWE).

#### 5.2 Multi-Carrier UHF Passive System

In an ordinary Gen2 RFID system, reader not only sends continuous waves(CW) to provide energy and the backscatter carrier to tags, but also transmits the pulse interval encoding(PIE) reader-to tag(R-T) commands to tags and receives tag-reader(T-R) responses.

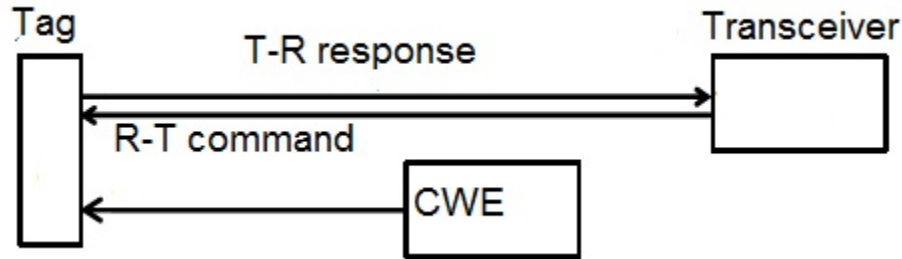


Figure 5.1. UHF Passive RFID System with Isolated CWE.

Whereas, on the other hand the fundamental reader system in a multi-carrier UHF passive RFID system consists of two parts; A set of isolated CW Emitters (CWE) and a transceiver. The CWE can either be wired or wireless source near to tags, that emits CW at a certain frequency illuminating nearby tags as shown in Figure 5.1. As soon as the CWE turns on, it provides energy and MBS carrier to tag continuously. And transceiver transmits and receives R-T commands and T-R responses respectively.

CWE illuminates the nearby tags at a certain frequency; therefore when there are many CWEs occupying the same frequency in the system, they are wisely arranged so that destructive co-channel interference (CCI) is diminished. It should be noted that RF signal from transceiver can to some extent provide essential energy and the MBS carrier to tag as well.

An integrated reader sends no less than 1.5 milliseconds ( $T_s$ , setting time) CW to provide power to passive tags before issuing an R-T command [61], so that the tag ICs have sufficient operation power and are ready for the R-T command.

Similarly, passive tags must be charged and ready to listen for an R-T command before it is supplied by the transceiver in the proposed system. Because passive tags obtain full or limited power from nearby CWEs, CWEs must start to emit CW



before the transceiver sends an R-T command. Thus, the frequency of operation for CWE and the power to which the continuous waves are transmitted are topics of big discussion now.

### **5.3 RF in RFID**

Chip tags are usually made to work at a particular frequency range which is license free. And they are Low frequency (less than 135 KHz), High Frequency (13.56 MHz), Ultra High Frequency (UHF- 860 to 960 MHz), Microwave (2.45 GHz and 5.8 GHz). All have various advantages and disadvantages, and affect not only the performance and size of the tag but also the price of the tags and the readers. Also the tolerated power levels and regulations for these vary from country to country. Lower frequencies have low energy that means they transmit data more slowly and range is limited.

However even though they have smaller range than higher frequencies they are more tolerant of obstacles. High frequencies have more energy and thus can be used for long range applications. Power drops off as the cube of distance for low frequency but only as the square of distance at high frequency.

However, these high frequencies give problems with reflections, irradiation of humans, inability to see round corners and difficulties with blocking of the beam by few materials or matter the human eye can see through. High frequencies having more energy have faster data transfer[37].

### **5.4 Far-Field Operation Frequencies**

Let us review limitations on far field operation frequencies, by choosing few set of frequencies. At UHF and microwave frequencies, limits are usually specified in

terms of radiated power (ERP or EIRP). Limits may also be expressed in terms of transmitter output power and antenna gain. And from these quantities EIRP and ERP can easily be calculated. In the 900 MHz region, 2.45 GHz and 5.8 GHz bands, spread spectrum operation including frequency hopping and/or direct sequence may be permitted.

#### **5.4.1 433.92 MHz**

The band 433.050 -434.790 MHz is not a worldwide ISM band. This band is allocated in 10 European countries according to (RR S5.280) and in region 1 according to (RR S.138)[36]. This is heavily used by various short range and ISM devices and lies within an amateur radio band. In Europe, CEPT/ETSI has allocated this band for non-specific short range devices[81]. Power is limited to 10mW ERP and devices must have a duty cycle less than 10%.

#### **5.4.2 862-870 MHz**

The 868-870 MHz band is not an ISM band, but has been allocated by CEPT for non-specific short range devices. Neighboring bands includes cordless, cellular phones and other devices which are sensitive to interference. At present 868-870 MHz band is divided into five sub-bands 868-868.6, 868.7-869.2, 869.3-869.4, 869.4-869.65 and 869.7-870 MHz. Out of these sub-bands, 869.4-869.65 MHz band allows the highest power level, 500 mW ERP and thus is suitable for RFID. Bandwidth is 250 KHz and devices must have a duty cycle of less than 10%. Outside these mentioned band, power should not exceed 250 nW ERP[81].

As the current limits are lower than those allowed in United States, a proposal has been made to open the 865-868 MHz band to nonspecific SRDs. It has also been proposed that RFID devices operating within this band either with a fixed frequency

or with frequency hopping in fifteen 200 KHz channels. To avoid interference with the neighboring channels, it is suggested that power levels should be lower at edges of the band.

Figure 5.2 shows the summary of proposed bandwidth and radiated power levels of frequency band between 865 to 868 MHz under CEPR/ETSI regulations.

<b>Frequency</b>	<b>Power(ERP)</b>	<b>Power(EIRP)</b>	<b>Detector</b>
865-865.6 MHz	100 mW	164 mW	Quasi-peak
865.6-867.6 MHz	2 W	3.28 W	Quasi-peak
867.6-868 MHz	500 mW	820 mW	Quasi-peak
865-868 MHz	250 nW	410 nW	Quasi-peak

Figure 5.2. Proposed BW and Radiated Power Limit.

### 5.4.3 915 MHz

The 902- 928 MHz band is recognized as an ISM band in region 2. There is neither a similar allocation in Europe nor Japan. However countries like Canada, Australia, New Zealand, and much of Latin America allow operation in or around this band. This band is used by number of devices including motion sensors and cordless phones. In the United States, there are three modes under which devices may operate within this band. One is limited to field disturbance sensors, another to either frequency hopping or direct sequence spread spectrum operation and the third is limited to general narrow band operation.

In the 902-928 MHz band, channels may occupy a 20 dB bandwidth of up to 250 kHz or between 250 kHz and 500 kHz. Systems using channels with up to 250 kHz bandwidth must use at least 50 hopping frequencies and maintain an average time per frequency of 0.4 seconds in 20 seconds. Whereas systems using channels with between

250 kHz and 500 kHz of bandwidth, must use at least 25 hopping frequencies and maintain an average time per frequency of 0.4 seconds in 10 seconds.

Other devices may also operate in the 902-928 MHz band in accordance with FCC 15.249 without frequency hopping. The fundamental must not exceed 500 microvolt per meter at 3 meters [70]. Outside of the band, the emissions should not exceed the 15.209 general limit of 500microvolt per meter at 3 meters. Figure 5.3 shows the bandwidth and power limits for narrow band use at 902-928 MHz under FCC regulations.

Frequency	Electric Field Strength	~Power (EIRP)	Detector
902 – 928 MHz (fund)	50 mV/m at 3 m	750 $\mu$ W	Quasi-peak
902 – 928 MHz (harm)	500 $\mu$ V/m at 3m	75 nW	Quasi-peak
902 – 928 MHz $\rightarrow$	500 $\mu$ V/m at 3m	75 nW	Average

Figure 5.3. Bandwidth and Power Limit-Under FCC[70].

## 5.5 Selection of Operating Frequency for CWE

The frequency at which the continuous wave is given to the passive tag should be chosen carefully. To decide the same, we performed various experiments taking into consideration the below mentioned constrains, harvested power, radiated power and interference with RFID communication. Continuous wave emitter hardware in our experiment is National Instruments PXI RF platform which included RFSG (RF Signal Generator ) and RFSA (RF Signal Analyzer), controlled by Lab View [85].

Signal Tone generator from the NI Lab View files was used to generate sinusoidal wave of varying frequency and power levels. Frequency range used for calculation is 400MHz to 2 GHz with power ranging from (-20 dBm) to (+17 dBm), as the allowable maximum power value by the system was constrained to +17 dBm. The test tag in

all our experiments was UHF Alien 9640 Squiggle white wet inlay henceforth referred to as squiggle tag [2].



Figure 5.4. Front Panel of the PXI Rack with RFSG and RFSA.

### 5.5.1 Constraint- Harvested Power

Most passive RFID tags simply reflect back the incident waves from the reader. Energy harvesting is a technique, which allows the tag to gather all the energy coming from the reader, storing momentarily and then later transmitting back at a different frequency level. RFID is fundamentally based on wireless communication that makes use of radio waves which form part of the electromagnetic spectrum (i.e. frequencies from 300 kHz to 3 GHz). RFID operates in unlicensed spectrum space, which is also referred as ISM (Industrial, scientific and Medical) but the exact frequencies which constitutes ISM may vary depending on the regulations in different countries.

The harvested power calculation is performed to find the frequencies at which the RF inputs of tag can successfully extract the signal power. Figure 5.5 shows the setup used for the calculation. The Alien squiggle tag was placed 1.75 feet away from the patch antenna transmitting the CW of various frequencies. The power harvested

by the tag was noticed via the leads connected to the tag using the Rohde and Schwarz spectrum analyzer.

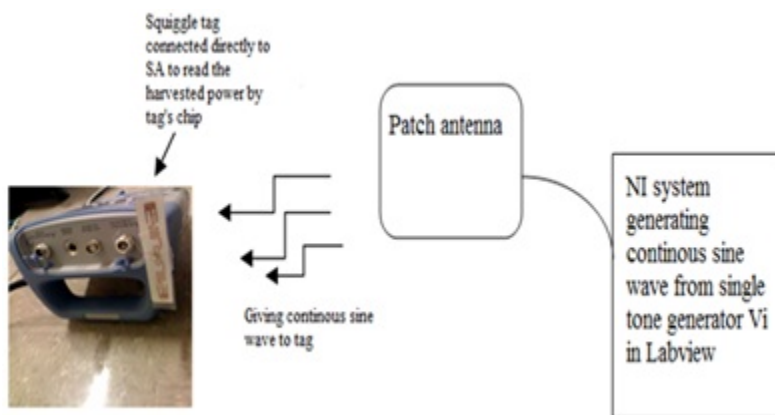


Figure 5.5. Set-up for Harvested Power Calculations.

Initially, harvested power values by the tag at various frequencies and power levels were tabulated. Figure 5.6 shows power harvested by Tag at various frequencies, it can be concluded that the frequency band of 600 MHz to 940 MHz shows more harvested power compared to other frequency bands.

### 5.5.2 Constraint: Radiated Power

This calculation is performed to find the radiated power at various frequencies. This power is desired to be as small as possible so as to avoid the electromagnetic interference and power loss. Figure 5.7 shows the setup for the radiated power calculation. Wired CW from NI system was given to the tag's input leads. The power radiated at various frequencies was calculated using the Spectrum Analyzer placed at a distance of 1.75 feet.

When at a given frequency range, more power is harvested and less is radiated by the tag, it performs better in that particular range. Figure 5.8 shows the radiated

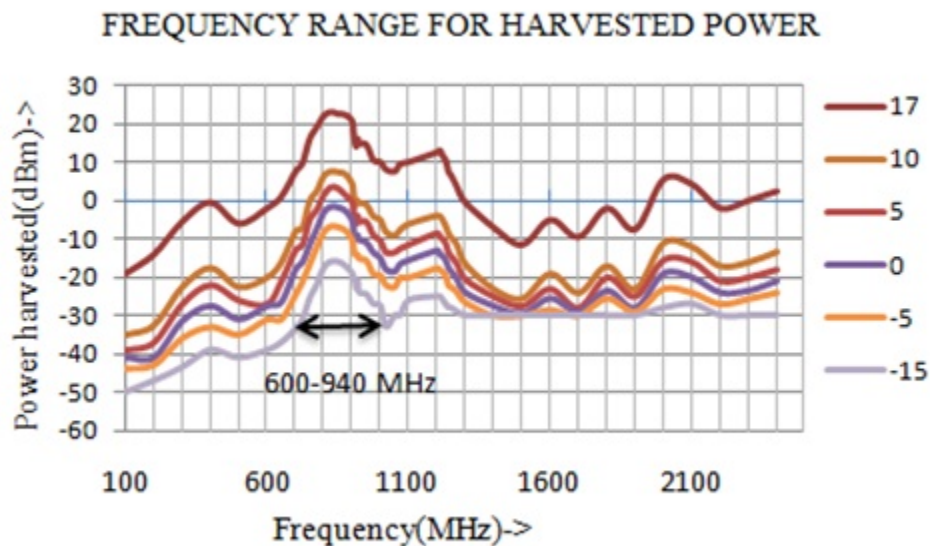


Figure 5.6. Power Harvested by Tag's Chip at Various Frequencies.

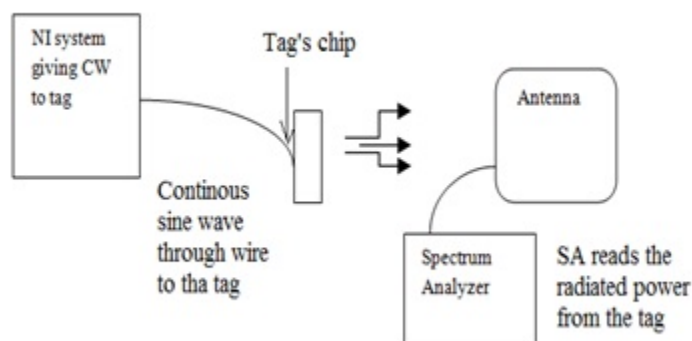


Figure 5.7. Set-up for Radiated Power Calculations.

power by the tag at different frequencies. It is observed that 600MHz to 750 MHz have poor radiating power ability and the same is true for the frequency range from 810 MHz to 930 MHz. The radiated power increases much for the frequencies between 750MHz to 810 MHz.

As the power retained by the tag for its use is the difference of power harvested and the power radiated, using the above results we can conclude that the retained

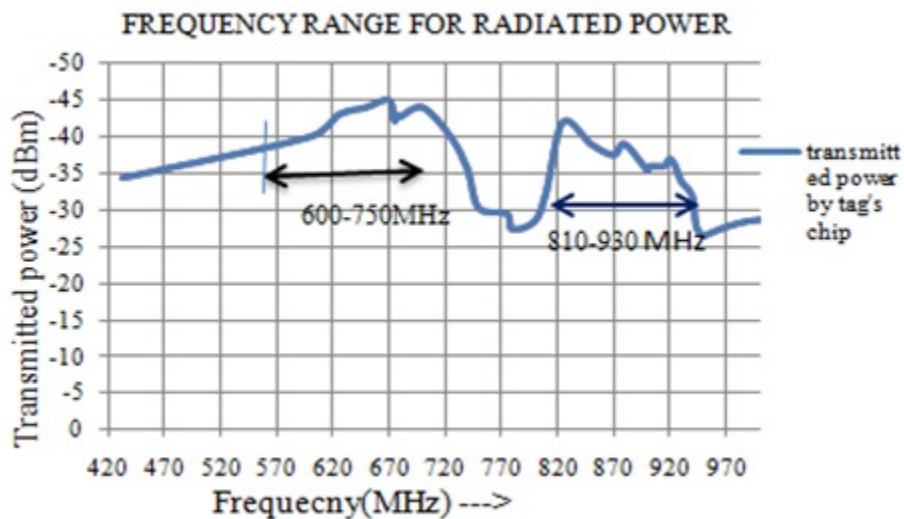


Figure 5.8. Radiated Power by Chip at Various Frequencies.

power by the tag is more in the frequency ranging from 600 MHz to 750 MHz and from 810 MHz to 930 MHz.

### 5.5.3 Constraint: Interference with RFID Communication

The UHF frequency range used for communication with the passive RFID tag allowed by FCC is 860 MHz to 960MHz, and specifically 902 MHz to 928 MHz for USA. The following experiments were performed to see the effect of using the CWE frequency in the communication range band.

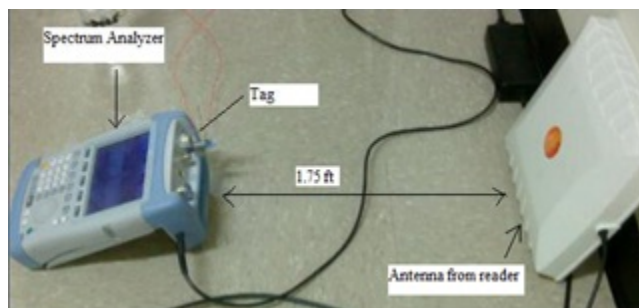


Figure 5.9. Set-up for Communication Range Experiments.



The setup for the following experiments is as shown in figure 5.9. The Tag was powered up using wired Sinusoidal wave form from the NI system at 900MHz at different power levels. Then, frequency sweep from 860 MHz till 960 MHz was performed using the Sirit Infinity 510 Reader [10].

It was observed that the CW at a frequency inside the communication range causes interference deteriorating the tags performance. In figure 5.10 horizontal axis shows the frequency at which the sweep was performed and vertical axis shows the transmitted power by the reader. Looking at this graph, we can conclude that, there is an occurrence of peak at 900 MHz, which is due to the interference of the CW frequency and the communication range. Similar experiments were carried for frequencies from 800 MHz to 1 GHz. It was observed that after 840 MHz the interference due to the CW source starts dominating.

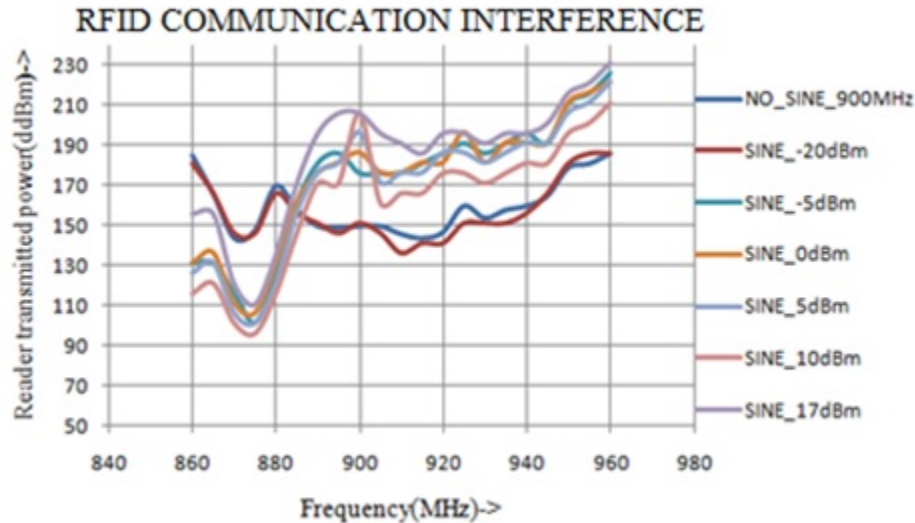


Figure 5.10. Frequency Sweep by SIRIT Reader.

Thus, it is concluded that frequency for CW should not be chosen near to the frequency of operation of the tag. Therefore the frequency band 810 MHz to 930 MHz was excluded.

### 5.5.3.1 Optimum Frequency Selection

After the exclusion of the frequency band from 810 MHz to 930 MHz we are left with 600 MHz to 750 MHz band. To select the exact frequency value of operation, first the frequency sweep from SIRIT reader to read the tag without any continuous wave was performed. It was observed that the minimum power required to read tag without any CW was 13.1 dBm. Later, the sweep was performed with the same set-up with external CW at different frequencies. For this experiment we chose a single power level and gave that power to all the sine waves of different frequencies.

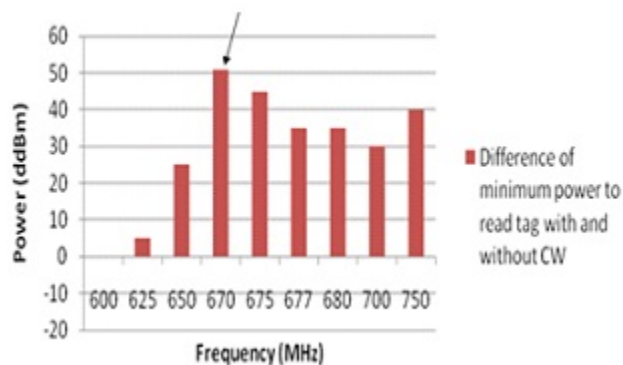


Figure 5.11. Reading Passive Tag.

Figure 5.11 shows the difference in the minimum power required by the reader to read the tag with and without CW source. It was observed that at 670MHz CW minimum power at which the tag was read by the reader was 5.1 dBm. Thus, the tag

with 670MHz CW was read at 5.1 dBm lower power as compared to the standalone tag and this gives us the optimum frequency level for Continuous Wave Emitter (CWE).

## **5.6 Integrated Circuit Power Consumption**

An understanding of the power consumption characteristics of the tag is important not only from the standpoint of integrated circuit design, but also from the standpoint of communications protocol design. Coding, modulation and command routines can and should be designed to take the power consumption characteristics into account. Minimization of power consumption can have a direct positive effect on range. In an RFID tag IC, there are analog as well as digital circuits.

### **5.6.1 Power Consumption:Analog Circuitry**

Even though a tag will contain more digital than analog circuitry, analog circuitry power consumption may be disproportionately higher. For this very reason, analog circuitry must be carefully designed and optimized for low power[29]. Antenna matching, RF front end and power supply circuitry should be designed for maximum power transfer efficiencies.

### **5.6.2 Power Consumption:Digital Circuitry**

Digital CMOS power consumption characteristics are comparably much better, yet contribute significantly to the overall power consumption of the chip. Digital CMOS power consumption can be broken into two classes: static and dynamic. Static power consumption is the power consumed when a device is idle, ideally it should be zero.

Dynamic power consumption on the other hand is not. Dynamic power consumption consists of two components: short circuit and capacitive consumption.

Short circuit power consumption is due to a momentary direct current from the supply to ground during the switching of a gate. It has been shown that it is typically less than 10% of the capacitive consumption, so it is often neglected [51].

Capacitive power consumption is that resulting from the charging and discharging of the parasitic capacitances throughout the integrated circuit. The energy in the capacitances is related to the driving voltage, and the total power consumption is related to the activity and frequency of the switching. As the dynamic power consumption is neglected, the equation for dynamic power consumption is given as

$$P_{dynamic} = \alpha \cdot f \cdot C \cdot V^2 \quad (5.1)$$

Where  $\alpha$  is the activity factor,  $f$  is the data rate,  $C$  is the total capacitance and  $V$  is the supply voltage. The activity factor represents the number of zero to 1 transition per data cycle. The average data rate represents the clock frequency in synchronous systems.

The dynamic power consumption is essentially affected by three main variables: the switching activity, capacitance and the square of the supply voltage. Because of its quadratic relationship, reduction of the supply voltage can bring the greatest reduction in power consumption. In addition, as it is globally applied, its reduction has a significant effect.

The main problem is that, it can cause the overall performance to suffer through increased delays. Because of the quadratic relationship, it may often make sense to reduce voltage at the cost of increased capacitance and switching activity [77]. Capacitance is present in both devices and interconnects, it can be reduced by decreasing size of line width and components, and distances between them. But the side effect of this is the decreased current drive and this can slow the performance and possibly

require an increase in supply voltage. Thus, we saw few of the characteristics of tag's chip power consumption and the variables which affect the overall power consumption of the tag.

### 5.7 Selection of Optimum Power For CWE

The power value for CW is also an important factor that determines the performance of the tag. As discussed earlier, the main purpose of the external continuous wave emitter is to provide an additional power source to the tag's chip, so that the tag has a longer range and is less affected by multi path fading effects. We performed numerous experiments and found out that the optimum frequency for the CW to enhance the performance of the passive tag is 670 MHz.

To select the optimum power value at 670 MHz we performed frequency sweep using Sirit Reader with Power values Ranging from -10 dBm to +17 dBm. Comparing the performance of the tag for varied power levels, we could conclude that more power given to the tag gives more read range. Figure 5.12 shows that best performance of the tag was at 17 dBm. But according to the FCC part 15, the field strength from 470 MHz - 668 MHz is

$$E = 200mV/m^2 \quad (5.2)$$

$$P_t \times G_t = 0.3 \times E^2 \quad (5.3)$$

Putting the value of E in equation (5.3) and assuming

$$G_t = 0dB \quad (5.4)$$

we get maximum allowable transmitted power from an intentional radiator by FCC Part 15 as 10.2 dBm [26].

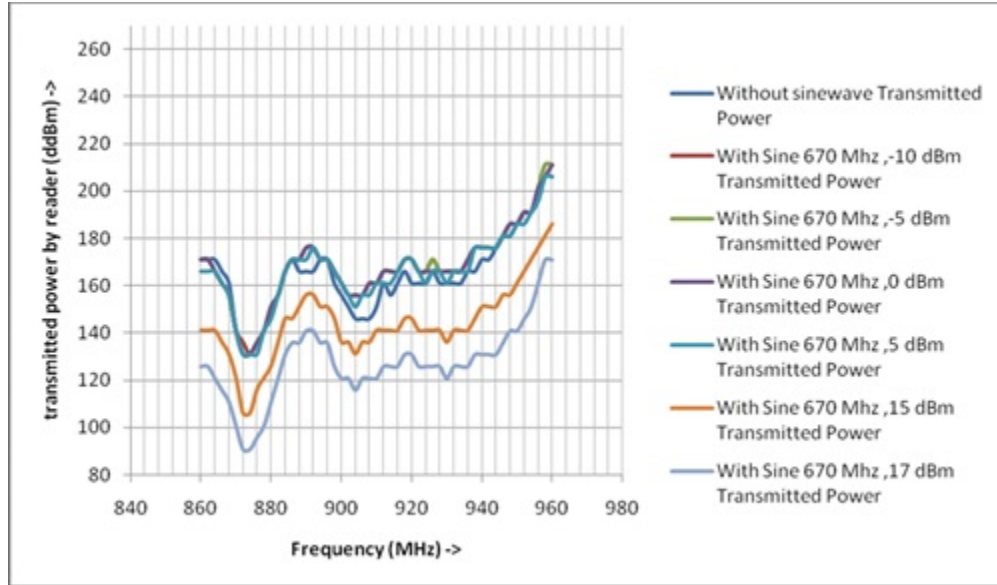


Figure 5.12. Frequency Sweep at 670 MHz with Various Power Levels.

## 5.8 Selection of Optimum location for CWE

As discussed earlier, fundamental reader system in a multi-carrier UHF passive RFID system consists of two parts: A set of isolated CW Emitters (CWE) and a transceiver. Consider the distance between transceiver and tag as  $d_2$  and between CWE and tag as  $d_1$  as shown in Figure 5.13 .

According to Friis equation [71],

$$P_{tag} = P_{cw} \times \left(\frac{\lambda_{cw}}{4\pi \times d_1}\right)^2 \times G_{cwe} \times G_{tag} \quad (5.5)$$

and

$$P_{rx} = P_{tag} \times \left(\frac{\lambda}{4\pi \times d_2}\right)^2 \times G_{rx} \times G_{tag} \quad (5.6)$$

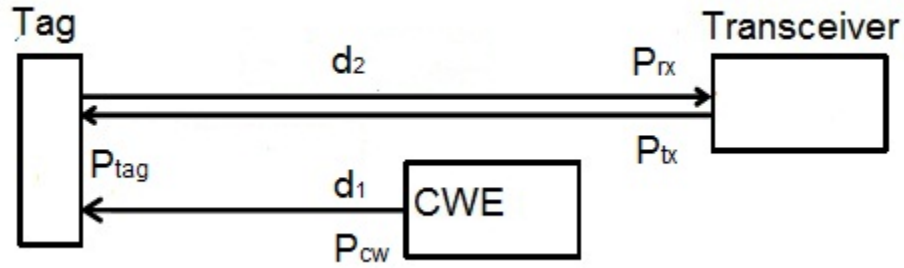


Figure 5.13. UHF RFID Passive System with Isolated CWE.

where  $P_{tag}$ =received power of the tag,

$P_{rx}$ = power received at the reader

$P_{cw}$ =power emitted by CWE

$\lambda_{cw}$ =wavelength of the CW

$G_{rx}, G_{cwe}$  and  $G_{tag}$ = Power gain of receiver, CWE and tag antennas respectively.

In an ordinary system, where reader acts both as CWE and transceiver, we have power gain of CWE,tag and rx equal i.e.

$$G_{rx} = G_{cwe} = G_{tag} \quad (5.7)$$

but  $f$  and  $P$  of CWE in ordinary and diverse frequency systems are same i.e

$$\lambda_{cw} = \lambda \text{ and } P_{cw} = P \quad (5.8)$$

Thus we get,

$$\frac{P_{rx}}{P_{rx1}} = \frac{(d_0)^4}{(d_1)^2 \times (d_2)^2} \quad (5.9)$$

Figure 5.14 shows ordinary UHF passive RFID system.

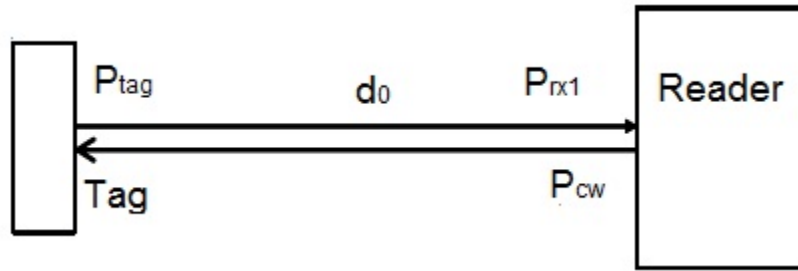


Figure 5.14. Ordinary UHF Passive RFID System.

When  $d_1 < d_0$  and  $P_{rx} = P_{rx1}$  then  $d_2 > d_0$

Or we can also conclude that, distance between CWE and tag is inversely proportional to distance between tag and transceiver[60]. Thus, closer we place CWE from tag, longer the read range is achieved. In our experiments we took the distance between CWE and tag as 1.75 feet.

## 5.9 Summary

This chapter explains about the methodology for designing continuous wave emitter. We increase the read performance of passive RFID tag by applying an external continuous wave emitter source to it. The RF frequencies ranging from 400 MHz to 2 GHz and corresponding power from -10 dBm to + 17 dBm were investigated and 670 MHz with 10.2 dBm power levels for intentional radiators is proposed to be the optimum design values for the CWE source.

Further chapters explain that how these calculated values of frequency and power for CWE is used to form various designs which convert passive tag to semi-passive tag inexpensively.



## CHAPTER 6

### POWER SOURCES

#### 6.1 Introduction

In previous chapter, the operation frequency for the external continuous wave emitter with the associated power was calculated. Before explaining about design and operation of built designs for CWE based on calculated parameters, we study about power sources. Three different power sources were used to charge the external continuous wave emitter which is explained one by one in this chapter. The power sources considered here are battery, Photovoltaic cells and piezoelectric vibration sensor.

#### 6.2 Battery

Batteries consist of one or more electrochemical cells that convert chemical energy directly to electrical energy. There are many types of batteries and the two basic in use are Primary and Secondary consisting of primary and secondary type of cells respectively.

##### 6.2.1 Primary Cells

Primary cells are the one in which electrochemical reaction is not reversible, that implies the chemical reactants cannot be restored to their initial position and capacity. In a primary cell, for instant a dry cell, zinc is used as the negative electrode and a carbon rod is used as the positive electrode and they are dipped in a solution called electrolyte made up of manganese dioxide and ammonium chloride.

Positive electrode is termed as cathode where chemical reduction occurs whereas anode accepts electrons from the electrolyte causing chemical oxidation. Current can be drawn from primary cell until the zinc chloride is completely drained off.

### 6.2.2 Secondary Cells

Secondary cell produces electricity from chemical reactions in the cell. When direct current is fed through the cell, the chemical reactions are reversed and the cell can be reused. Most commonly used secondary cell is a lead-acid cell, the positive electrode is lead oxide and the negative is lead which is dipped in the diluted sulphuric acid solution known as electrolyte.

This cell gives an e.m.f of 2.2V when it is fully charged but when it is in use it falls to 2V. The cell is discharged at 1.8V and has to be recharged before its second use.

### 6.2.3 Primary Vs Secondary

Rechargeable batteries are advisable to use when their initial high cost and cost of a charging system can be spread out over many use cycles for instance in hand held equipment like T.V remote, mobile phones etc., as it would be very costly to replace a high capacity primary battery pack every few hours of use. On the other hand, primary batteries have lower self-discharge rate unlike rechargeable ones and they are used where long period of storage is required.

As our main aim is to give the external energy source to the tag when the reading is required so we opted for primary battery, the battery remains disconnected when it is not in use with the help of switch and whenever the power is required the switch turns on. Also it made the source low in cost. We used two PCB mounting coin cell batteries. Figure 6.1 shows the battery used for Designs 1, 2 and 3.



Figure 6.1. Batteries used as Power Source for CWE.

### 6.3 Photovoltaic Cell

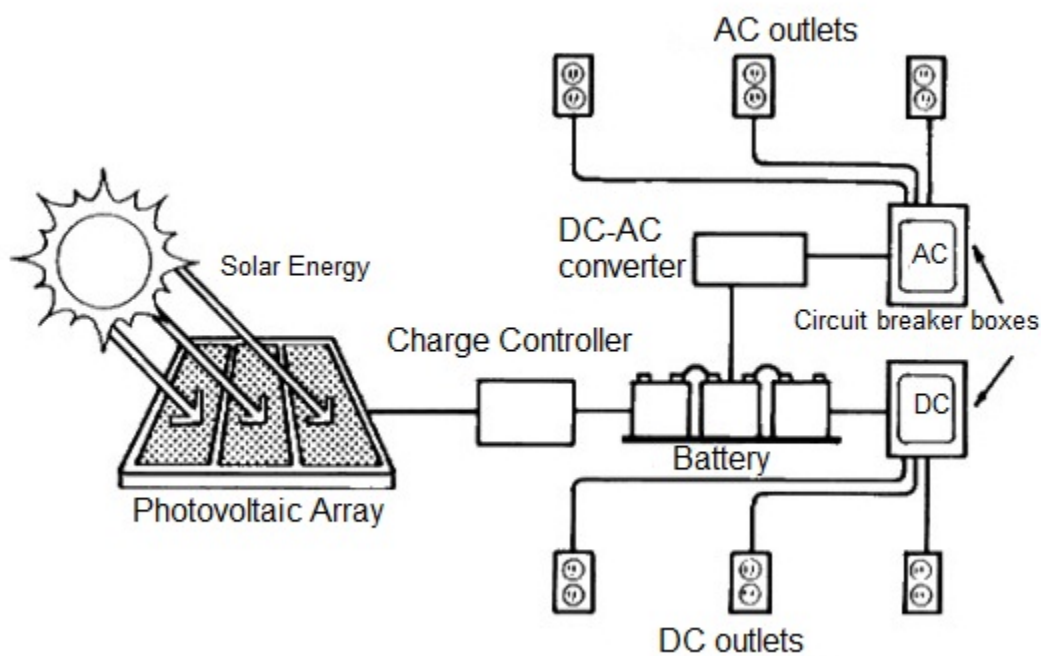


Figure 6.2. Solar to Electrical Energy[83].

Another form of power source we are using is the solar energy. Solar energy is the most abundant source of energy available to mankind.

#### 6.3.1 Introduction

Photovoltaic [83] are arrays of cells which convert solar light photons into electricity. These cells fulfill main two functions: Photo generation of charge carriers

that is electrons and holes in a light-absorbing material, and separation of the charge carriers to a conductive contact that will transmit the electricity.

Solar cells are usually used in remote locations where cost effective access to local power grids are not possible. Materials presently used for photovoltaic include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride and copper indium selenide[53]. Figure 6.2 shows the major blocks and steps involved to provide electricity using solar energy.

### 6.3.2 Principle of Operation



Figure 6.3. Solar Panel (12V).

When the photovoltaic cell gets exposed to light, the generated electrons are transferred from the valence bands to conduction bands within the material, resulting in the buildup of a voltage between two electrodes[12]. In p-n junction solar cells,

illumination of the material results in the creation of an electric current as excited electrons and the remaining holes are swept in different directions by the built-in electric field of the depletion region[13].

As the technology is developing day by day manufacturing has increased and the cost of photo voltaic has declined steadily since the first solar panel came into the market [83]. Figure 6.3 shows the solar panel that we will be using as our second source of power for external circuitry.

For design 1 we have used 12V solar panel consisting of 36 cells with dimension as 115 X 85 X 3 mm, output power of 1.5W and made of polycrystalline material. Whereas for circuit 2 we have used 5V solar panel measuring 2.4 X 3.0 inches, output power of 0.5W and made of crystalline material.

Table 6.1. Advantages and Disadvantages of Photovoltaic Cell

<b>Advantages</b>	<b>Disadvantages</b>
It is pollution free with the highest power density among all renewable energies	Costly to install
Solar energy is unlimited, once connected to CWE & the board is in use under sun it can provide energy at no cost for years	Solar electricity not produced at night & is much reduced in cloudy conditions
It produces DC, so can be connected to the main board of all the designs directly	

#### 6.4 Piezoelectric Vibration Sensor

A piezoelectric sensor is a device that uses the piezoelectric effect to measure pressure, acceleration, strain or force by converting them into an electric force.

### 6.4.1 Introduction

A piezoelectric transducer has very high DC output impedance and can be modeled as a proportional voltage source and filter network. The voltage  $V$  at the source is directly proportional to the applied force or pressure. The output signal is directly proportional to this mechanical force.

Figure 6.4 shows the schematic symbol of a piezoelectric sensor.  $L_m$  is due to the seismic mass and inertia of sensor.  $C_e$  is inversely proportional to mechanical elasticity of the sensor.  $C_0$  represent the static capacitance of the transducer, which results from an inertial mass of infinite size[27].  $R_i$  is the insulation leakage resistance of the transducer element.

Piezoelectric film is an enabling transducer technology with unique set of qualities. Piezo film produces voltage in proportion to compressive or tensile mechanical stress or strain, making it an ideal dynamic strain gauge. It makes a highly reliable, low-cost vibration sensor, accelerometer or may be a dynamic switch element.

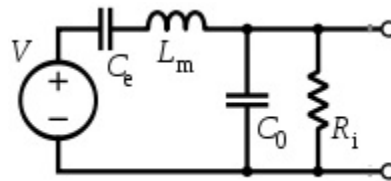


Figure 6.4. Schematic Symbol of a Piezoelectric Sensor.

### 6.4.2 Principle of Operation

There are three modes of operation for piezoelectric material depending on how they are cut. The modes are Transverse effect: When the charges are generated along the (x) direction which is perpendicular to the (y) direction where force is applied then

piezoelectric element operates in transverse mode. Total amount of charge produced is directly proportional to the geometrical dimensions of the piezoelectric element [28]. Charges produced in x directions can be written as shown in Equation 6.1

$$C_x = d_{xy}F_y b/a \quad (6.1)$$

Where a is the dimension of the line where force is applied, b is the line with charge generating axis and d is the corresponding piezoelectric coefficient.

In longitudinal effect, amount of charge produced is directly proportional to the force applied and is independent of the size and shape of piezoelectric element. Charge produced is given as

$$C_x = d_{xx}F_x n \quad (6.2)$$

Where  $F_x$  is the applied force in x direction, n is the number of stacked elements and  $d_{xx}$  is the piezoelectric coefficient for a charge released by forces  $F_x$ .

Whereas in shear effect, amount of charge produced is directly proportional to the force applied and is independent of the size and shape of piezoelectric element. For number of elements which are mechanically in series whereas electrically in parallel the induced charge is

$$C_x = 2d_{xx}F_x n \quad (6.3)$$

### 6.4.3 Properties

For manufacturing piezoelectric sensors either piezoelectric ceramics or single crystal materials can be used. Piezoelectric ceramics are physically strong and chemically inert and inexpensive to manufacture. Ceramics manufactured by formulations

of lead zirconate /lead titanate exhibit higher sensitivity and more operating temperatures and PZT material is presently in great demand in the market.

Materials used for single crystal piezoelectric element are Quartz, Lead Magnesium niobate /lead titanate(PMN-PT), lithium niobate etc [28].

In next chapter we discuss about the laminated piezoelectric element with small mass on its surface and its performance in our experiments. Table 6.2 shows the main advantages and disadvantages of a piezoelectric sensor.

Table 6.2. Advantages and Disadvantages of Piezoelectric Sensor

<b>Advantages</b>	<b>Disadvantages</b>
High modulus of elasticity	Cannot be used for truly static measurements
High natural frequency & excellent linearity over a wide amplitude range	High temperature causes drop in internal resistance and sensitivity
Insensitive to electromagnetic & radiation	

## 6.5 Summary

In this chapter, we discussed in detail about various power sources which we have used for powering up our built designs. First category of power source is battery consisting of electrochemical cells which convert chemical energy directly into an electrical energy. As our main aim is to have least cost design with less complexity we selected primary battery with primary electrochemical cells. Another type of power source we used was photovoltaic cells.

This power source was chosen as it is pollution free with the highest power density between all renewable energies. Solar energy is unlimited, once connected to CWE and the board is in use under sun it can provide energy at no cost for years.



The third category in power sources for our implemented designs includes piezoelectric vibration sensors. It has the high natural frequency and excellent linearity over a wide amplitude range.

## CHAPTER 7

### DESIGNING POWER ASSISTED PASSIVE TAG-I

#### 7.1 Introduction

Electromagnetic radiation is being incident on the passive tag, part of which is used for charging the tag and remaining to back scatter the stored information on its chip. As the energy received from reader is used for both the purposes; the read performance of the tag reduces [65]. If we charge the chip externally and let the entire energy coming from reader to be used by the tag just to backscatter its stored information, the read range would improve and hence resulting in better tag read performance.

In Chapter 5 we saw that the operation frequency of 670 MHz for the external continuous wave emitter with the associated power 10.2 dBm yields the best performance improvement. This and the next chapter deals with the designing of Continuous Wave Emitter, powered by suitable source whose effect on the tag read performance is appreciable.

There were various ways we could supply the same, but our main objective was the whole design should be inexpensively efficient [56]. As discussed in Chapter 6, three different power sources were used to charge the external continuous wave emitter.

Also all the implemented designs were modeled and tested under lab conditions and at the end of the chapter we present the best design with the appropriate power source effecting the read performance of the tag maximum. The designs are categorized into two modules. Module A consists of three different designs viz. Design 1,2,

and 3 with battery and photovoltaic cells as their power sources. Module B consists of piezoelectric vibration sensor. In this chapter we will have a brief look at the Module A Design 1 . In Chapter 8,9 and 10 we will study about Module A Design 2 and 3 and Module B piezoelectric vibration sensor.

## 7.2 Module A Design 1

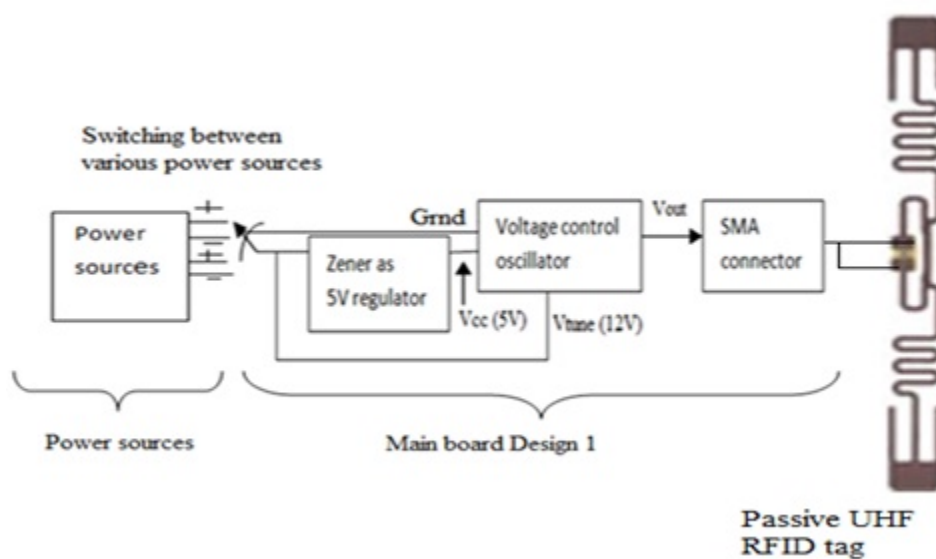


Figure 7.1. Design 1: Basic Architecture.

The main objective behind this design was to emit continuous wave at 670 MHz at power level of 10.2 dBm. There are many ways to achieve the same, but for gaining accuracy with minimum possible components at Ultra High Frequency was a big challenge. To fulfill the requirements, components used in this design are Voltage controlled oscillator(VCO), SMA connector, Switch and a Zener diode (IN5231 5.1v 0.5W) as regulator. Continuous wave is emitted by VCO, tuned to operate at 670 MHz.

Its inputs are  $V_{cc}$  and  $V_{tune}$ .  $V_{cc}$  and  $V_{tune}$  is being given by various power sources (solar and battery) and VCO output is fed to the tag's chip via SMA connector. Solar and battery sources are giving 12 V at their output being fed directly as  $V_{tune}$  for VCO and further which is when given to ZENER diode (5V IN5231 5.1v 0.5W ) gives 5V constant to  $V_{cc}$  of VCO. Figure 7.1 shows the basic architectural design idea of Design 1.

### 7.3 Voltage Controlled Oscillator(VCO)

VCO is an electronic circuit that produces a repetitive signal whose oscillation frequency is controlled by the input DC voltage. The internal circuitry consists of one or two transistors, an LC tank circuit and a buffering amplifier. The amplifier provides the adequate gain and a resonant circuit that feeds back the signal to the input. When the positive gain occurs at the loop, circuit starts oscillating at the resonant frequency. LC tank circuit for RF oscillators consists of the voltage controlled capacitor (varactor diode) and hence the frequency varies according to the applied voltage to it. This can be modeled simply as shown in Figure 7.2.

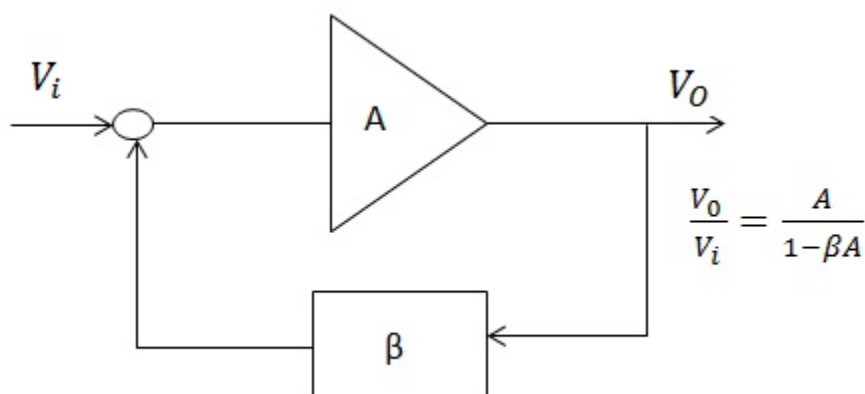


Figure 7.2. Basic VCO Operation Principle.

$$\alpha\beta = 1 \quad (7.1)$$

### 7.3.1 Operational Principle

VCO is the combination of an amplifier and a feedback circuit.  $\alpha$  = Amplifier's element gain in circuit.  $\beta$  = Transfer function of feedback path. and  $\alpha\beta$  = loop gain around the feedback of circuit. And steady state oscillation occurs if  $\alpha\beta = 1$  is satisfied. At the frequency of oscillation, the total phase shift around the loop should be 360 degrees and the magnitude of the open loop gain must be unity.

A tuned circuit once excited will oscillate continuously if there is no resistive element present to dissipate the energy. It is the function of amplifier to generate the negative resistance or maintain oscillation by supplying an amount of energy equal to that dissipated. If the circuit is used with feedback from collector to base, the feedback circuit must provide additional 180 degrees phase shift. If a common base circuit is used, there is no phase shift between the emitter and collector signals, and the feedback circuit must provide either 0 degree or full 360 degree phase shift.

Even though, Figure 7.2 is usually used to analyze and determine the necessary and sufficient conditions for oscillation, but it is always much easier to use Figure 7.3 where the analysis is performed in terms of a negative resistance concept. This concept is based on the principle that a resonator such as an inductor- capacitor tuned circuit once excited, will oscillate continuously if no resistive element is present to dissipate the energy.

It is the function of the amplifier to generate the negative resistance and maintain oscillation by supplying an amount of energy equal to that dissipated. The selection of the circuit topology is decided by the parameters such as Oscillation frequency, tuning range, choice of transistor and resonator type[15].

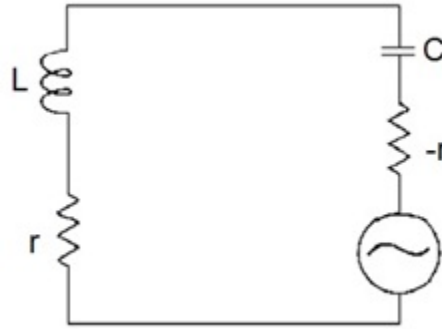


Figure 7.3. Oscillator:Negative Resistance Concept.

### 7.3.2 Oscillator Design Examples

A bipolar transistor with capacitances between the base and emitter, and the emitter and ground, can be used to generate a negative resistance. An inductive resonator may be used in parallel resonant oscillator circuit. The signal is generated at the frequency where the inductor resonates with the load capacitance.

Circuits shown in Figure 7.4 are usually preferred for high stability oscillator circuits because of the ease with which the resonator may be isolated from the load, which is in the collector circuit. In a Voltage Controlled Oscillator, the variable capacitance is implemented using a varactor diode. The Clapp circuit has an advantage of better constancy of feedback as the ratio of  $C_1$  to  $C_2$  does not vary over the tuning range.

### 7.3.3 Tuning Sensitivity Characteristics

There are basically two types of varactors: abrupt and hyper abrupt. The abrupt tuning diodes have very high Quality factor ( $Q$ ) and will operate over a very high tuning voltage range (0V to 60V). Due to high  $Q$  factor, abrupt tuning diode provides the best phase noise performance.

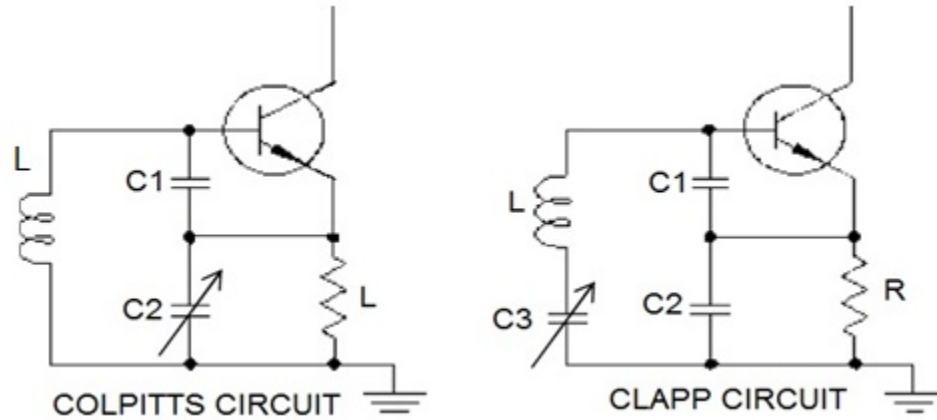


Figure 7.4. Two forms of Oscillator Circuit[92].

On the other hand, hyper abrupt tuning diodes with capacitance inversely proportional to the square of the voltage provides much more linear tuning characteristic than the abrupt diodes. And hence, these diodes are the best choice for wide band tuning VCOs. But the drawback is that they have much lower Q, and thus provide a phase noise characteristic higher than that provided by the abrupt diodes [15]. For a varactor diode, we have

$$C = \frac{A}{(V_r + \phi)^n} \quad (7.2)$$

Here A is constant,  $V_r$  is applied reverse bias voltage and  $\phi$  is the built in potential which is 0.7V for silicon diodes and 1.2V for gallium arsenide diodes. For the following analysis, we can write

$$C = \frac{A}{V^n} \quad (7.3)$$

Where A is the capacitance of the diode when V is one volt and n is a number between 0.3 and 0.6 but could reach up to 2 for a hyper abrupt junction.

In a typical VCO, tank circuit has a parallel tuned circuit consisting of an inductance  $L$ , a fixed capacitance  $C_f$ , and a varactor diode  $C$ . Now the frequency of oscillation can be given as

$$\frac{1}{\omega^2} = L(C_f + AV^{-n}) \quad (7.4)$$

Consider  $\omega_0$  be the angular frequency of the un modulated carrier, and let  $V_0, C_0$  be the corresponding values of  $V$  and  $C$ . Then from 7.4 we have

$$L = \frac{1}{\omega_0^2(C_f + C_0)} \quad (7.5)$$

If  $V_0$  is modulated by a small voltage  $\Delta V$ , the carrier will be deviated by a small frequency difference  $\Delta\omega$

$$(\omega_0 + \delta\omega)^{-2} = L[C_f + A(V_0 + \Delta V)^{-n}] \quad (7.6)$$

Now, if we substitute for  $L$  and rearrange the equations we get

$$\left(1 + \frac{\delta\omega}{\omega_0}\right)^{-2} = \frac{C_f + C_0\left(1 + \frac{\Delta V}{V_0}\right)^{-n}}{C_f + C_0} \quad (7.7)$$

Thus, oscillator tuning sensitivity  $K_1$  can therefore be written as shown in Equation 7.8 and unit of  $K_1$  are radian/second/volt

$$K_1 = \frac{d\omega}{dV} = \frac{n\omega_0}{2V_0} \left(\frac{C_0}{C_f + C_0}\right) \quad (7.8)$$

### 7.3.4 Selection of VCO

We have learn about few basic concepts for understanding VCO. At this stage, before moving further let's consider the key terms related to VCO and how we chose ROS -850w-119+ VCO [16]from mini-circuits for all our new designs which later would



act as an external energy source to a passive UHF RFID tag. The features of the chosen surface mount VCO are low phase noise, low frequency pushing, high output power and operating at wide frequency band ranging from 400 MHz to 850 MHz. These features are discussed one by one in detail below.

#### **7.3.4.1 Tuning of a VCO**

Tuning slope or tuning sensitivity for a VCO defines a slope of the frequency to voltage tuning characteristic at any given point. The slope could be positive or negative. For a positive slope, the output frequency increases as the tuning voltage increases. Similarly for a negative slope, the output frequency decreases as the tuning voltage increases. Figure 7.5 shows the frequency and tuning sensitivity of ROS - 850w-119+, which shows that its tuning sensitivity is typically 18-32 MHz/V.

Monotonic tuning of a VCO refers to the characteristic which means that the frequency is single valued at a given voltage and vice-versa. And the tuning slope has the same sign across the tuning range. VCO in all our circuits have a monotonic tuning characteristic with a positive slope and its tuning voltage ranges from minimum 1V to maximum 25V.

#### **7.3.4.2 Modulation Bandwidth**

Modulation bandwidth of a VCO is the modulating frequency at which the frequency deviation decreases to 0.707 of its DC value. Driving sources' impedance that tunes the VCO is usually resistive and the tuning port of VCO is mainly capacitive. This combination acts as a low pass filter. Increase in modulation frequency results in reduction of amplitude at the port of this filter.

Consequently, the frequency deviation of the VCO reduces. On the other hand modulation bandwidth can be increased by reducing the time constant associated

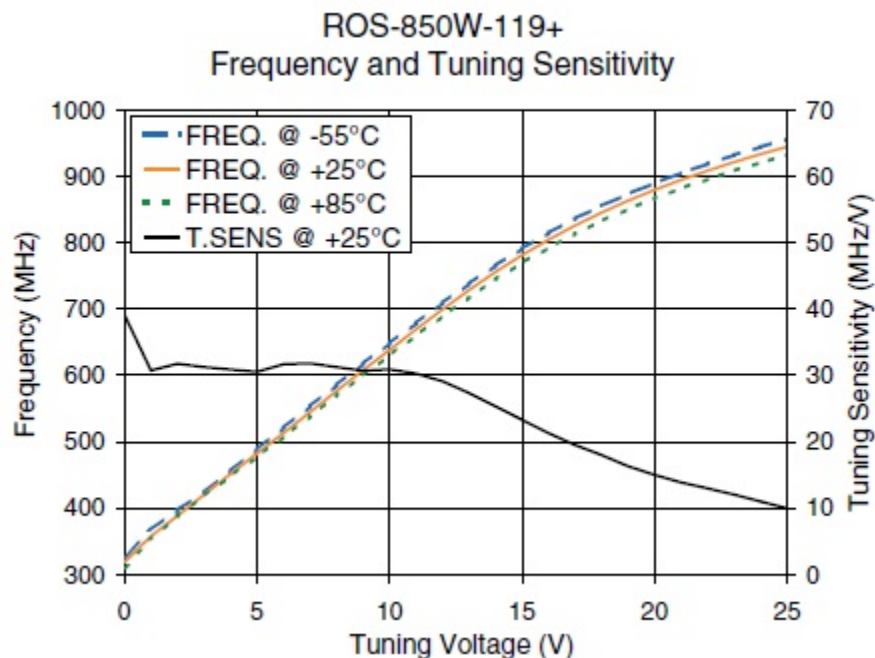


Figure 7.5. Frequency and Tuning Sensitivity [16].

with the tuning port of the VCO. For a fast tuning VCOs, high modulation/tuning bandwidth is required. Minicircuit's ROS -850w-119+ VCO has a typical value of 13 MHz as 3dB modulation bandwidth[16].

### 7.3.4.3 Frequency Pulling and Pushing

In a VCO when at a fixed tuning voltage output frequency changes corresponding to the given change in supply voltage frequency pushing occurs which is expressed in MHz per volt. Whereas when the frequency changes due to the change in impedance of the output load frequency pushing takes place occurs. Pushing is usually specified at a load return loss of 12dB and all possible phases and is expressed in MHz peak to peak[4]. Frequency pulling and pushing for ROS -850w-119+ VCO is defined as typically 0.3MHz/V and 4MHz pk-pk at 12 dB respectively[16].

To define harmonic content or harmonic suppression for a VCO, harmonic levels are measured relative to the fundamental signal (the carrier) and expressed in dB referenced to the carrier (dBc). Spurious spectral components of a VCO are unwanted and non-harmonically related signals which are present at its output and are usually expressed in dBc. ROS -850w-119+ has typical value of -22 dBc and maximum of -12 dBc as its harmonics whereas it has typical value of -90 dBc as non-harmonic spurious content[16].

#### **7.3.4.4 Phase Noise**

FM noise or phase noise of a VCO is defined by the short term random frequency fluctuations of a signal whereas on the other hand frequency stability is a measure of the degree to which an oscillator maintains the same value of frequency over a given time. Single side band(SSB) phase noise in 1 Hz bandwidth is measured relative to the carrier power at a given offset from the carrier frequency and is expressed as dBc/Hz. Phase noise Vs Tuning voltage graph for -850w-119+ VCO is shown in Figure 7.6. It can be seen from graph and above data that VCO ROS -850w-119+ has low phase noise and low pushing.

#### **7.3.4.5 Output Power**

Another important feature of VCO is its output power that is defined as the fundamental sinusoidal frequency output of the oscillator measured into a 50 ohm load and is expressed in dBm. And the maximum to minimum power variation observed over a specified frequency range in a 50 ohm system at a given temperature is defined as variation in output power. Output power also varies with respect to the temperature and Figure 7.7 shows the variation of output power with respect to tuning voltage at various temperatures for ROS -850w-119+.

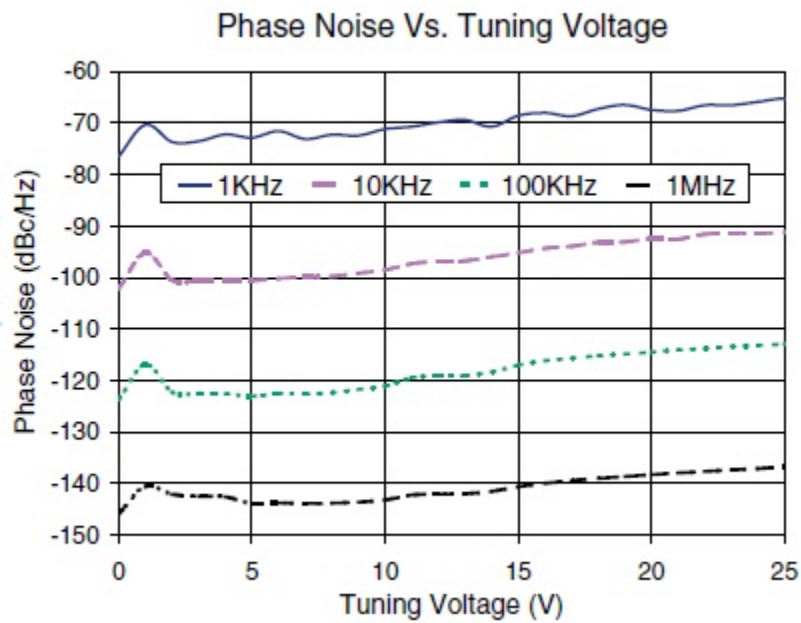


Figure 7.6. Phase Noise Vs Tuning Voltage[16].

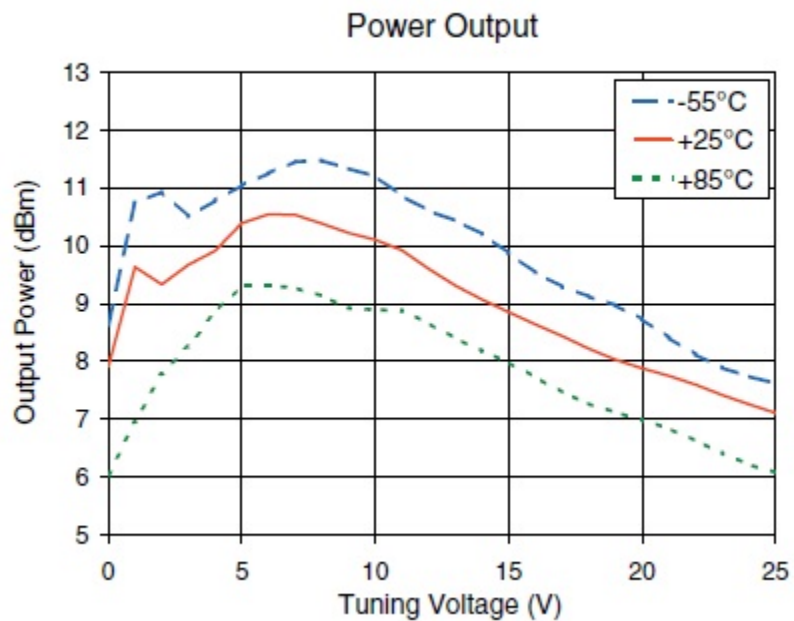


Figure 7.7. Output Power Vs Tuning Voltage[16].

## 7.4 SMA Connector

SMA is an acronym for Sub miniature version A and was developed in 1960s. They are the most commonly used RF/microwave connectors. 50 ohm SMA connectors are semi precision, sub miniature units that provide excellent electrical performance from DC to 18 GHz. These high-performance connectors are compact in size and mechanically have high durability.

They are intended for use on semi-rigid cables and in components which are connected infrequently. These coaxial RF connectors take the cable dielectric directly to the interface without air gaps with a screw type coupling mechanism. They are available in male and female versions which refer exclusively to the inner pin or socket of the connectors. Thus, to prevent the power loss; we used SMA connector to give continuous waves to the RFID passive tag. The SMA Connector that we used is female, right angled, gold plated 50 ohm manufactured by Amphenol that costs \$2 [8].

## 7.5 Switch

In electronics field, switch is an electrical component that can break an electrical circuit, by interrupting or diverting the current from one conductor to another[11]. From all the switches available in the market, the most popular are the electromechanical devices consisting of one or more number of electrical contacts. Contacts can be in two states: open: when contacts are separated and non-conducting or closed: when contacts are conducting and allow the current flow in circuit.

Switches are classified according to the arrangement of their contacts in electronics. One of the ways to define their contacts is by using pole and throws terms. Pole defines the number of separate circuits which are controlled by a switch whereas

throw defines the number of separate positions that the switch can adopt. For instance a double throw switch has a contact that can be connected to either of two other contacts, a triple throw can be connected to one of three other contacts and so on[9].

Thus switches which are used in electronics are abbreviated as Single pole Single Throw (SPST), Single Pole Double Throw (SPDT) etc. We also used the switch mechanism to select the two different power sources for design one. We used Double Pole Double Throw (DPDT) switch worth \$0.5 whose symbol is as given in Figure 7.8. In this two changeover switches are there and accordingly any connection can be achieved. For instance, A can be connected to C or D; also B can be connected to E or F.

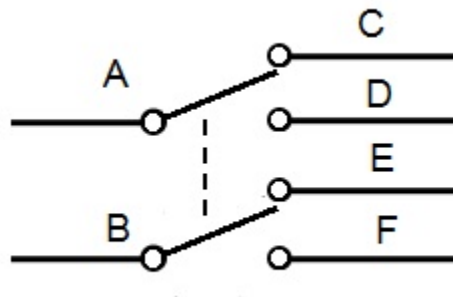


Figure 7.8. DPDT Switch Symbol.

## 7.6 Zener diode

A Zener diode with cut-off voltage as 5.1V is used to give the regulated output to Vcc input of the VCO. A reversed biased Zener diode will exhibit a controlled breakdown and allow the current to keep the voltage across the zener diode at the zener voltage. When the input variable voltage is connected in parallel with the

zener diode, it is in reverse biased condition and conducts when the voltage reaches the diode's reverse breakdown voltage.

And thus, from that point on, the relatively low impedance of the diode keeps the voltage across it at that value. We used 5.1 V zener diode, so that when the 12V from battery and solar source is given as its input, it delivers constant 5V for  $V_{cc}$  of VCO. Figure 7.9 shows the basic zener diode operation. Zener diode that we used costs \$0.2

Advantages of zener diode over other regulator ICs are many. Firstly, it is the simplest of the parallel-shunt type of voltage regulator and that is its greatest advantage. Secondly, It consists of only a series resistor and a zener diode. Whereas on the other hand, its disadvantage is firstly they can regulate at high current levels and they have low efficiency. Secondly zener diodes can only regulate voltages that are lower than the source voltage.

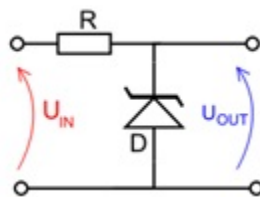


Figure 7.9. Stable  $V_{out}$  from Variable  $V_{in}$  by Zener Diode.

## 7.7 Conclusions

There are many ways to give power to the design. And for module A Design 1, we have used battery and photovoltaic cell as its power sources. There are pros and cons of each power source. When the switch is in position B, and the tag is placed in sunlight it will get CW with solar source as the power source element. The

photovoltaic cell used in this design is of efficiency 12V. Thus, it is directly connected to the VCO for its  $V_{tune}$  and via zener it goes to  $V_{cc}$  of VCO so that 5V can also be delivered by photovoltaic cell. Table 7.1 shows the estimated cost for using different power sources with Module A Design1.

In this section we have discussed about Module A Design 1 architecture. All the architectural components were studied in detail. Battery and photovoltaic cell were chosen as two different power sources, and it was concluded that Design 1 with battery source is small and requires less initial cost. Design 1 with photovoltaic cell is bulky and demands high initial cost. Figure 7.10 and Figure 7.11 show the picture of Design 1.

Table 7.1. Comparing different Power Sources for Module A Design 1

<b>Power</b>	<b>Advantages</b>	<b>Disadvantages</b>	<b>Estimated cost</b>
Battery	Target of 670 MHz CW and 0.2 dBm power is achieved	High i/p supply required (12V)	Battery(\$2)+ other components(\$22.7)=\$24.7
	Less components	Zener diode-non efficient regulator	
		High Cost	
Photovoltaic Cell	Renewable power source	high initial cost	Solar panel(12V):\$7+ other component(\$22.7)=\$29.7
	Free power source in light	No use without light	
	Pollution free energy source	bulky	



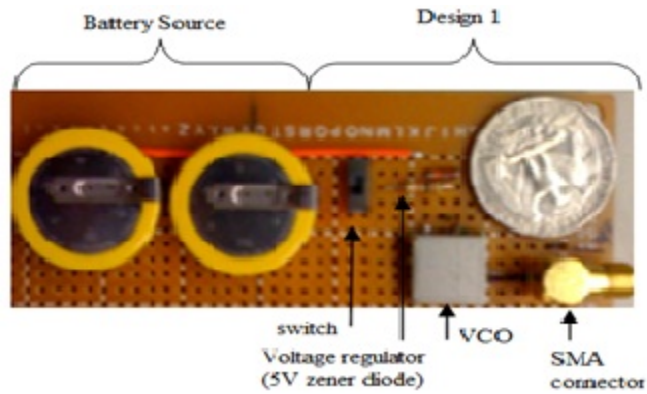


Figure 7.10. Implemented Design 1 with Battery Power Source.

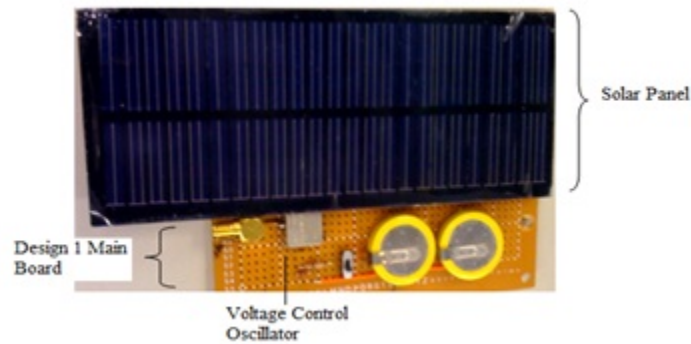


Figure 7.11. Implemented Design 1 with Photovoltaic cell.

## 7.8 Summary

In this chapter, we divided our designs into two modules: Module A and Module B. Module A Design 1 was implemented using components such as Voltage Controlled Oscillator (VCO), SMA connector, switch and zener diode (as regulator). The Design was powered by both battery and photovoltaic cell. We had a brief study on each of the building blocks of Module A Design 1. In next chapter, we discuss the architecture and operational principle of Design 2 basic units.

## CHAPTER 8

### DESIGNING POWER ASSISTED PASSIVE TAG-II

#### 8.1 Introduction

As discussed in previous chapter, we have designed and implemented the prototypes of three different designs which transfer power to the passive tag externally. The designs are categorized into two modules. Module A consists Design 1, Design 2, and Design 3 with battery and photovoltaic cells as their power sources. Module B consists of piezoelectric vibration sensor. We have already discussed and had a brief look at the Module A Design 1 . In this Chapter, we would be looking at Module A Design 2.

#### 8.2 Module A Design 2

The main objective of the design is to emit continuous wave at 670 MHz with power 10.2dBm. But after looking at the drawbacks of the design 1, design 2 was implemented with efforts to overcome the same. Components used for Design 2 are VCO, Voltage Regulator, Voltage Booster and a switch. Figure 8.1 shows the basic idea behind this design with different power sources.

#### 8.3 Voltage Regulator

A voltage regulator provides the constant DC output voltage, regardless of the changes in load current or input voltage. Basic elements of the voltage regulator are stable reference voltage, voltage sampling element, voltage comparator, power dissipating control device.

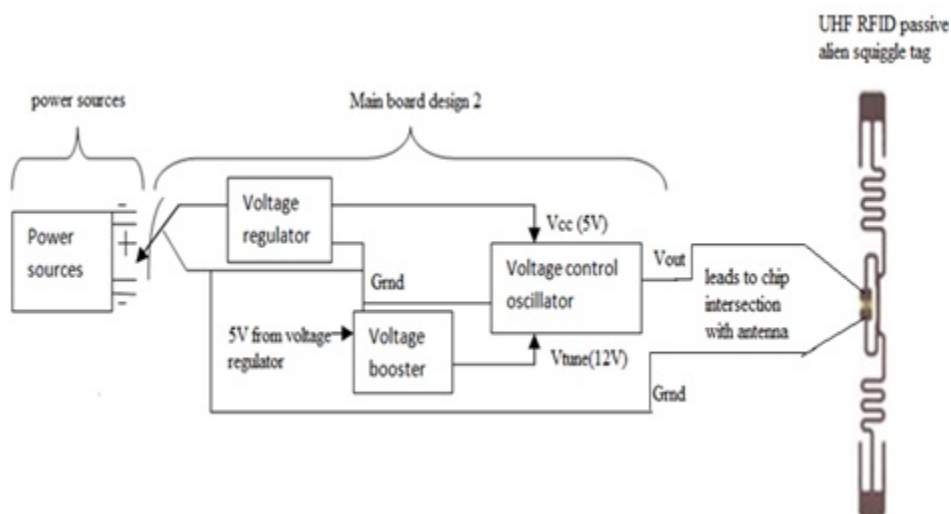


Figure 8.1. Design 2 Basic Architecture.

### 8.3.1 Operational principle

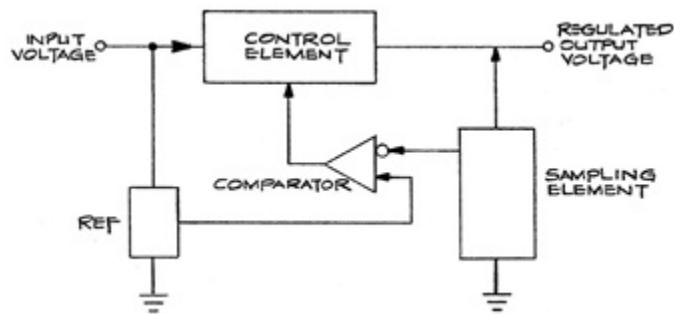


Figure 8.2. Voltage Regulator.

Figure 8.2 shows the basic regulator design. In this the voltage sampling element translates the output voltage down to a level that would be equal to the reference voltage for a particular output voltage. Then, as the output voltage varies, the sampled voltage changes to a value more or less than the reference voltage. The voltage difference is sensed by the comparator element which generates an error signal.

This signal is then amplified and directs the power dissipating control element to perform the desired regulation function.

### 8.3.2 Selection of Voltage Regulator

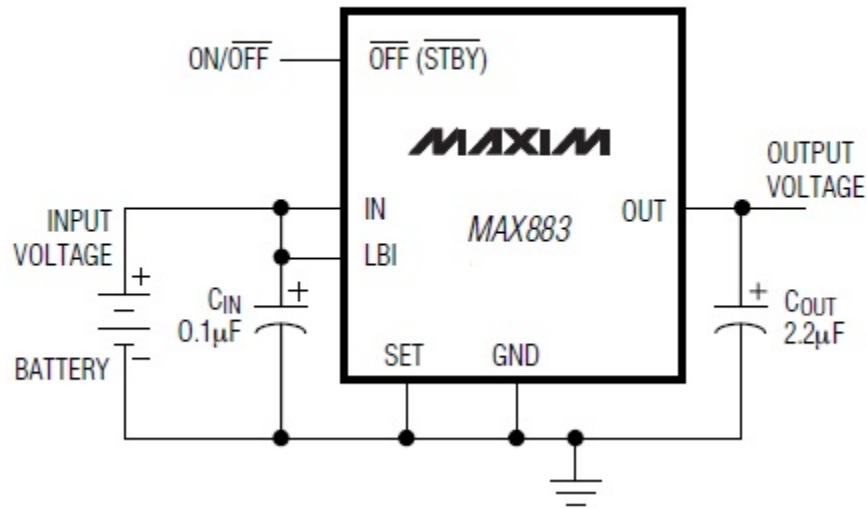


Figure 8.3. Typical Operating Circuit:MAX883 [6].

We have used MAX883 as a linear regulator for Design 2. This regulator maximizes the battery life by combining ultra-low supply currents and low drop out voltages. MAX883 uses a p-channel MOSFET pass transistor to maintain a low 11 micro Ampere (15 microAmpere maximum) supply current from no-load to the full 200 milliampere output. The main advantage of this type of regulator is that, there are no PNP base current loses that increases with output current. In dropout, the MOSFET does not suffer from excessive base currents that usually occurs when PNP transistors goes into saturation. Typically it has drop out voltage as 220 mV at 5V and 200mA, or 320mV at 3.3V and 200mA. It also has a unique feature of a shut-

down or OFF mode that turns off all circuitry, reducing supply current to less than 1microAmpere [6].

Figure 8.3 shows the typical operating circuitry for MAX883. In design 2 MAX883 gets its input DC source from power sources. The regulator is connected so as the constant 5V is being delivered to the VCO and to the voltage booster which might get damaged if given more than 5.5V as its input. Series voltage regulator in design 2 over zener voltage regulator circuit used in design 1: Series voltage regulator regulates the voltage by absorbing any change in voltage between the unregulated source voltage and the regulated load voltage across themselves. Series voltage regulators are a bit more efficient than any shunt regulator. They are simple but not as simple as zener diode regulator. However, their maximum power is typically more than the zener diode type. The cost of the regulator is &1.

#### 8.4 Voltage Booster

The major drawback of design 1 was, it required 12V from the power supply to tune VCO for 670 MHz and practically it is not possible to provide so much power to the CWE as it makes the cost and size of the CWE high and impractical. Thus, to overcome this problem we used voltage booster in design 2. As even after giving 5V input from the external power supply, we could manage to deliver 12V Vtune for VCO to tune it at 670 MHz. A powerful converter is called as a step-up or boost converter when its output DC voltage is greater than the input DC voltage. Step up converters belong to the class of switching mode power supply (SMPS) which consists of minimum two semiconductor switches (a diode and a transistor) and at least one storage element. Filters consisting of capacitors or capacitor inductor combination are usually added to the output to minimize the output voltage ripple.

### 8.4.1 Operational Principle

Figure 8.4 shows the basic diagram for a boost converter. The key principle lies in the tendency of the inductor  $L$  that resists the changes in current. When the inductor is charged during the close state (switch is closed), it acts like a load and absorbs energy. But when it is in open state (switch is open), it transfers' it's accumulated energy during the on state to the diode and load and acts as an energy source (as a battery). Voltage it produces during the discharge phase is related to the rate of change of current and not to the original charging voltage, and hence allowing different input and output voltage.

The whole operation can be described in two small steps, on state and off state. In On state, the switch  $S$  is closed hence resulting in increase in inductor current. On the other hand during off state, the switch is open and the only path offered to inductor current is via fly back diode  $D$ , load and capacitor connected parallel to the load. Hence, transfers the accumulated energy during the on-state into the capacitor. If we consider the two states of switch as  $u=1$  and  $u=0$ . Then

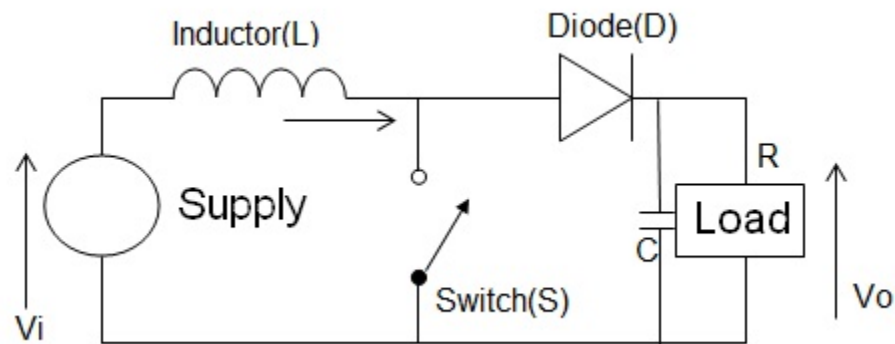


Figure 8.4. Boost Converter Schematic.

under ideal conditions: ideal switch, ideal inductor and an ideal capacitor, this boost

converter can be described using ordinary differential equation as given in equations 8.1 and 8.2 [3].

$$C \frac{dV_c}{dT} = (1 - u)i_L - v_c/R - i_o \quad (8.1)$$

$$L \frac{di_L}{dT} = v_{in} - (1 - u)v_c \quad (8.2)$$

#### 8.4.2 Selection of Voltage Booster

In design 2 we used PTN04050C by Texas instruments which is a four pin boost-voltage regulator [7]. It shows markable thermal characteristics with its case-less, double sided packaging. Operating over 2.95V to 5.5V input range, the PTN04050C provides high efficiency, step-up voltage conversion for loads of up to 12W. The output voltage is set using a single external register. The PTN04050C can be set to any value with in the range from 5V to 15V. The output voltage of the PTN04050C can be as little as 0.5V higher than the input, allowing an output voltage of 5V, with an input voltage of 4.5V. We chose PTN04050C booster as it was the one with least required external circuitry and most accurate with less cost among the available booster ICs. Figure 8.5 shows the pin connections of the booster used in design 2. To set the output voltage to 12V, the value of R is calculated as 2Kohm from the datasheet [7]. The cost of the booster is \$3.

#### 8.5 Conclusions

Same as Module A Design 1, we have used battery and photovoltaic cell as the power sources for Design 2. There are pros and cons of each power source. To use photovoltaic cell as its power source, a 6V panel is connected to the voltage regulator

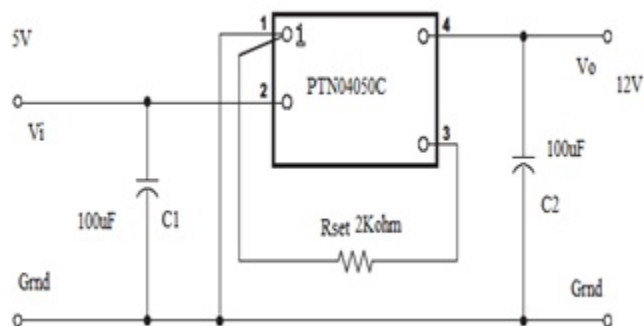


Figure 8.5. Voltage Booster used in Design 2.

of the main board. One part of 5V output from regulator goes to the booster to achieve desired 12V VCO Vtune whereas the other part is directly delivered to the VCO as its Vcc. In this Design regulator plays a significant role, by regulating the output from 6V solar panel. Table 8.1 shows the estimated cost for using different power sources with Module A Design2. Figure 8.6 shows the implemented Design.

Table 8.1. Comparing different Power Sources to Module A Design 2

Power	Advantages	Disadvantages	Estimated cost
Battery	Less i/p supply required(5V)	Bulky	Battery(\$2)+ other components(\$24.5)=\$26.5
	Stable and efficient Voltage regulator	High Cost	
Photovoltaic Cell	Renewable power source	high initial cost	Solar panel(6V):\$4 +other component (\$24.5)=\$28.5
	Free power source in light	No use without light	
	Small compared to Design 1 Photovoltaic cell	Bulky compared to Design 2 Battery source	
	Pollution free source		



Design 2 is being powered by battery and photovoltaic cell. When Design 2 is being compared with Design 1, the major advantage it shows is the size and reliability. Table 8.2 shows the major differences between Design 1 and Design 2 with respect to few listed parameters.

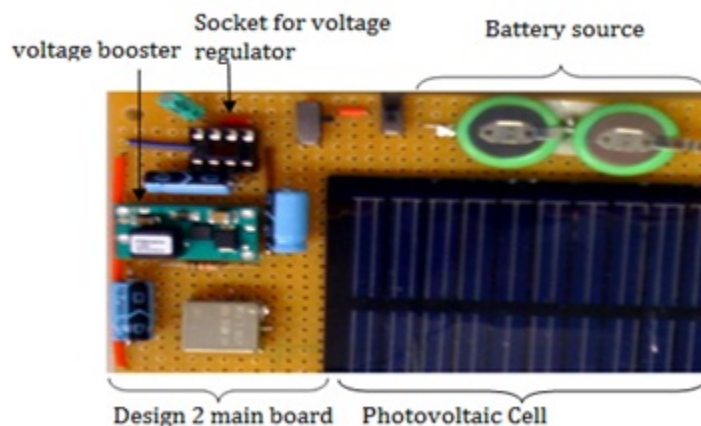


Figure 8.6. Design 2 Power Sources.

Table 8.2. Comparison of Module A; Design 1 and Design 2

Parameters	Design 1	Design 2
Cost	\$ 24.7(Battery) \$ 29.7 (Photovoltaic)	\$ 26.5(Battery) \$ 28.5(Photovoltaic)
Components	Less	More
Input Supply	12V	5V
Size	Large	Small
Disadvantage	High Cost High input supply Zener diode-non efficient regulator	Higher initial total cost

## 8.6 Summary

In this chapter, we discussed Design 2 in detail. The Design was implemented using components such as Voltage Controlled Oscillator, SMA connector, switch, voltage regulator and voltage booster. When Design 1 and Design 2 were compared with respect to performance under sunlight, Design 2 with voltage regulator proved to be more efficient than Design 1 with zener diode as voltage regulator. Also, Design 2 requires less input supply of 5V unlike Design 1 which makes Design 2 as compatible. In next chapter we would explore more on Module A Design 3.

## CHAPTER 9

### DESIGNING POWER ASSISTED PASSIVE TAG-III

#### 9.1 Introduction

This chapter will discuss in detail about third design in Module A. Discussion would include a detailed study on its introduction, components, performance and comparison with respect to Design 1 and Design 2.

#### 9.2 Module A Design 3

After implementing perfect designs for emitting 670 MHz with 10.2 dBm power associated with it, we determined that cost was very high, also design was too bulky comparing the size of the tag. Thus, new idea for next design was required with minimum possible components and minimum cost. We tried to make the design as small as possible and which could efficiently affect the read range of the tag even though the external continuous wave was not given at 670 MHz and demanded power level. Looking into these requirements, we figured out various methods used to deliver continuous wave.

#### 9.3 IC 555 timer

The 555Timer is a very cheap, popular and useful precision timing device that can act as either a simple timer to generate single pulses or long time delays or also as a relaxation oscillator producing stabilized waveforms of varying duty cycles from 50 to 100%. The chip of a 555Timer is very robust and stable 8 pin device which can be operated either as a monostable, bistable or astable multivibrator to produce

a variety of applications. The single 555 timer chip is a bipolar 8-pin mini dual-in-line (DIP) device which consists of around 25 transistors, 2 diodes and nearly about 16 resistors which are nicely arranged to form two comparators; a flip flop and a high current output stage as given in Figure 9.1[14].

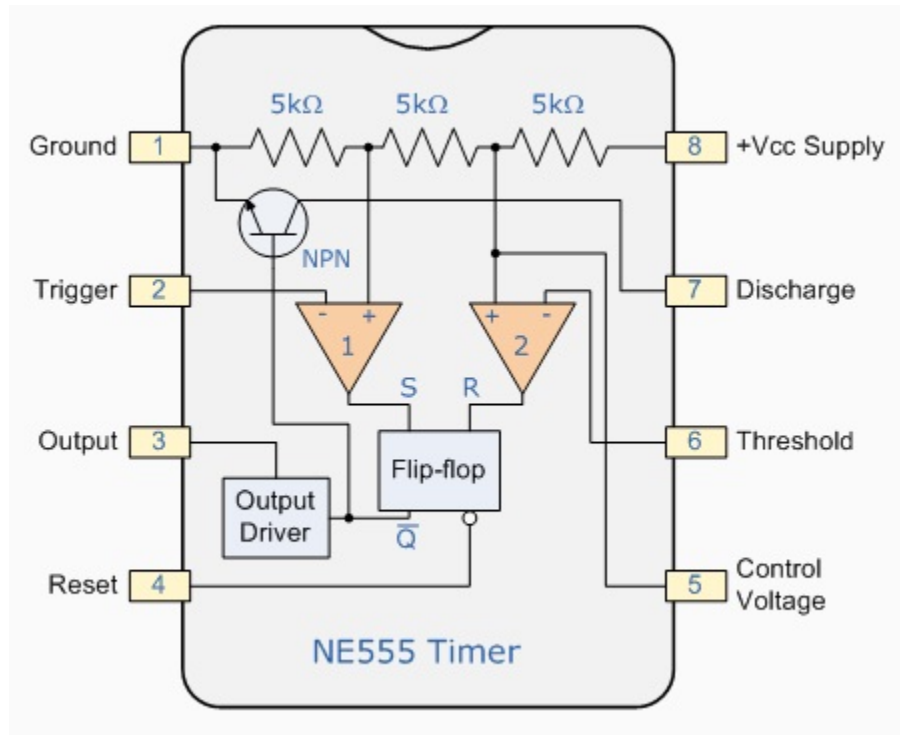


Figure 9.1. IC555Timer Oscillator Block Diagram [14].

### 9.3.1 Operational Principle

A negative pulse on pin 2 sets the internal flip-flop when the voltage drops below  $1/3 V_{cc}$  causing the output to switch from low to high state. As pin 2 is the trigger, the negative input to comparator No. 1. Pin 4: Reset, It is used to reset the internal flip flop controlling the state of the output at pin 3. This is an active low input and is usually connected to logic 1 level when not used to prevent any unwanted resetting

of the output. Threshold pin is used to reset the flip-flop when the applied voltage grows beyond the  $2/3 V_{cc}$  and causes output to switch from high to low. And the discharge pin is directly connected to the collector of an internal NPN transistor that is used to discharge the timing capacitor to ground when the output switches to low.

The voltage across the resistive network holds the positive input of comparator two at a value of  $2/3 V_{cc}$  and the positive input at value equals  $1/3V_{cc}$ . Both the comparators produce the output voltage dependent upon the voltage difference at their inputs which in turn is determined by the charging and discharging action of the externally connected RC circuit. At this stage, output from both the comparators are connected to the two inputs of flip flop that in turn generates either a high or low level output at Q' based on its input's state. Finally the output from the flip-flop is used to control a high current output switching stage to drive the connected load producing either a high or low voltage level at the output pin.

### 9.3.2 Designing

IC555 can be used as an oscillator when operating in astable mode[14]. Figure 9.2 shows the connections for IC555 which makes it work as an oscillator producing continuous square wave at 1Mhz at its output. The circuit is being simulated in multisim. Threshold and trigger pins are connected together so that the circuit can retrigger itself on each and every cycle that makes IC555 continue to run as a running oscillator. During each cycle capacitor C charges up through both the timing registers R1 and R2 but discharges itself only through R2 as the other side of R2 is connected to the Discharge terminal. Then the capacitor C charges up to  $2/3V_{cc}$  which is determined by  $0.693(R1+R2)C$  and discharges itself down to  $1/3V_{cc}$  determined by  $0.693 R2C$ . This results in a waveform whose output on and off time periods are

determined by capacitor and resistors values. Frequency depending on R and C values is given in equation (9.1)

$$f = 1.44 / (R_1 + 2 \times R_2) \times C \quad (9.1)$$

Thus we can choose the values for Resistor and capacitor so that the required frequency of operation can be achieved.

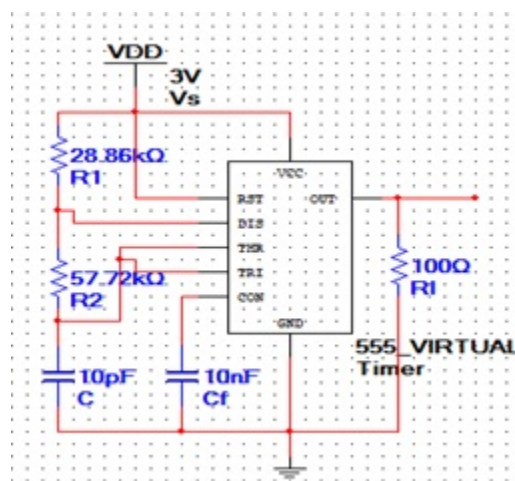


Figure 9.2. IC 555 timer as CWE.

### 9.3.3 Results

Thus, after making IC 555 timer work with the various power sources the effect on the tag reader read range was calculated. Figure 9.3 shows the basic architecture of the main board with IC555 powered by various power sources to make it work and tag connected to its output. The module generates square wave of maximum 1 MHz with the externally connected resistors and capacitors. Estimated Cost is as follows

1. Batteries: \$2

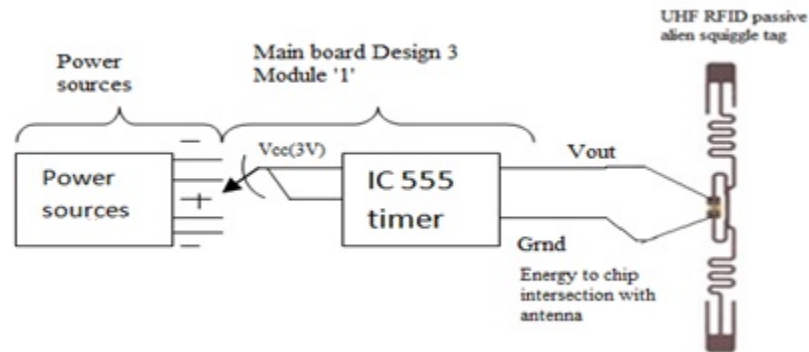


Figure 9.3. Basic Architecture of Design 3 with IC555 Timer.

2. IC555 timer : \$0.11
3. 2 Resistors and 3 Capacitors: \$0.1 Total cost for design 3 module '1' with battery source: \$2.22

Table 9.1. Pros and Cons compared to Design 1 and 2

Advantages	Disadvantages
Low input supply required (3-12V) Picture shown in Figure 9.4	Continuous square wave output.
Light in weight, small and handy	Maximum frequency attained is 1 MHz
Low Cost	

#### 9.4 Operational Amplifier(OPAMP)

Another idea for generating continuous wave is from readily available and very useful Operational Amplifiers(OPAMPS). They are DC coupled high gain electronic voltage amplifiers with a differential input and usually a single ended output. They give output which is usually much larger than the voltage difference between its input terminals.

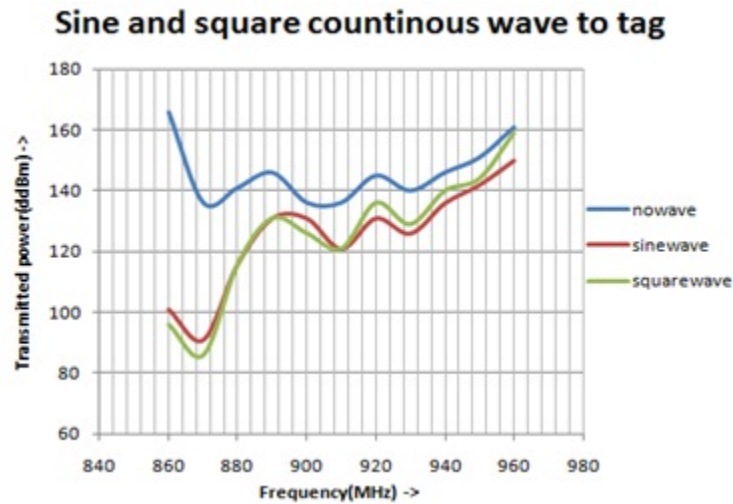


Figure 9.4. Performance Check-CWE with Tag.

#### 9.4.1 Operational Principle

Figure 9.5 shows the basic circuit diagram which can be used to generate the continuous sine wave of the desired frequency. The circuit generates a sine wave by first generating the square wave, at the required frequency with the first amplifier (a1) whose frequency is determined by C1 and R1. Amplifier 2 (a2) acts as a two pole low pass sallen keys filter with the cut-off frequency equivalent to square wave frequency from A1 which filters the harmonic component of square wave and as a result fundamental frequency remains at the output of A2. Change in supply voltage will change the peak values of the sine wave and square waves. The circuit is simulated and tested in multisim keeping the values of R2, R3 and R4 as

$$1K\Omega \quad (9.2)$$



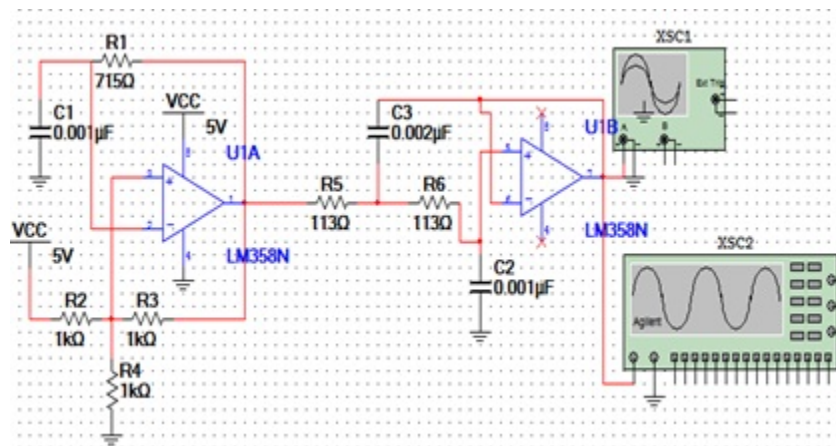


Figure 9.5. Sine Wave from dual OPAMP Circuitry.

#### 9.4.2 Designing

The characteristics of the amplifier selected affect the range of component values selected. To minimize the effect of input bias current for high-speed amplifier (we chose LMH 6622) we selected low resistors values (below about 15 KW) whereas when low-speed, low less bandwidth amplifier was used (we chose LM 358N) wider range of resistor values were available as it has low input bias current. But as given in [83], bandwidth of the amplifier should be at least 10 times the frequency of oscillation. Formula used are equations 9.3 and 9.4.

$$f = 1.386R_1C_1 \text{ where } C_2 = 0.5C_3 = C_1 \quad (9.3)$$

And the other equation is

$$f = 8.886R_5C_1 \text{ where } R_6 = R_5 \quad (9.4)$$

### 9.4.3 Results

Thus, using an OPAMP IC and external 6 resistors and 3 capacitors with connected various power sources, we can generate continuous sine wave of varying frequency depending on the quality of OPAMP used. Figure 9.6 shows the basic architecture of main board for design 3 module '2' when connected to power inputs and tag at its output. Estimated Cost

1. Batteries: \$2
2. OPAMP IC : \$0.25
3. 6 Resistors and 3 Capacitors: \$0.6 Total cost for design 3 module '2' with battery source: \$2.85

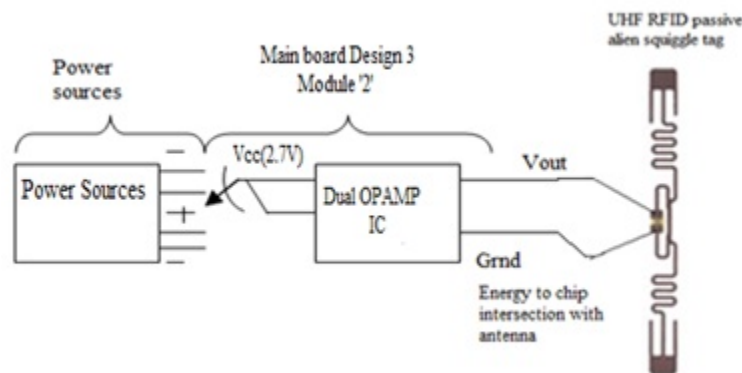


Figure 9.6. Basic Architecture of Design 3 OPAMP.

## 9.5 Logic Gates

Another idea to improve further and reduce the bulkiness of the board we came out with the concept of using Logic gates. It performs a logical operation on one or more logic inputs and gives the single logic output. Logic normally performed is

Table 9.2. Pros and Cons of Design 3,Module 2

Advantages	Disadvantages
Low input voltage (3-12)	Costly compared to design 3 module '1'
Light in weight, small and handy	
Low cost but high compared to module'1'	
High frequency range and amplitude compared to module '1'	

Boolean logic and is commonly found in digital circuits. In electronics, a logic level is represented by a voltage or current. And each logic gate requires power so that it can source and sink currents to achieve the correct output voltage level. Truth table is used to describe the behavior of a logic gate or its combination. Logic gates are AND, NAND, OR, NOR, NOT, XOR and XNOR. The cheapest gate available is the NAND gate. We used 7400N with single Resistor Capacitor combination to get the continuous wave at its output. 7400 consists of 4 two input NAND gates and we are using 2 from them. It doesn't generate the sine wave, but as we have seen in Figure 9.7 various waves' geometries doesn't make much difference in tag read range. Formula used:

$$Pulserate = 1/1.4RC \quad (9.5)$$

### 9.5.1 Operational Principle

Figure 9.7 shows the basic connection simulated and tested in multisim to generate continuous wave at required frequency. The circuit works on the basic RC charging and discharging characteristics. When the high input is given to gate one its output is low and thus output of gate two is high and forms the capacitor charge through series R whereas when the input voltage is low Capacitor at gate two's output discharges and thus forms the continuous wave as its output.

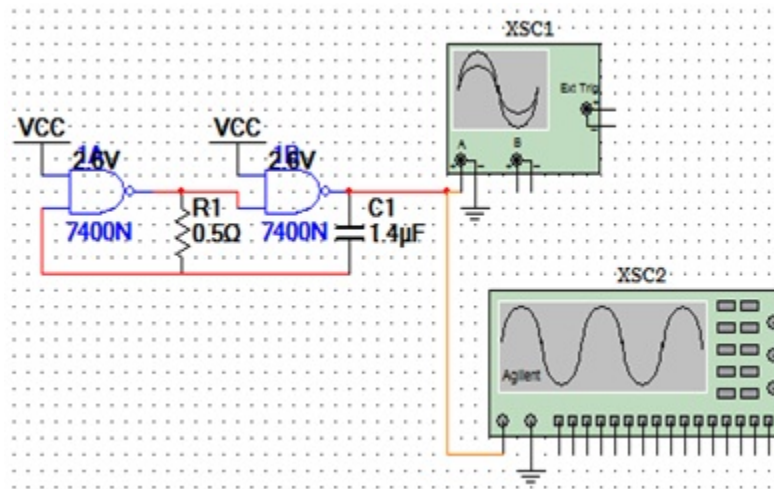


Figure 9.7. Continuous Wave from NAND Gates.

### 9.5.2 Designing

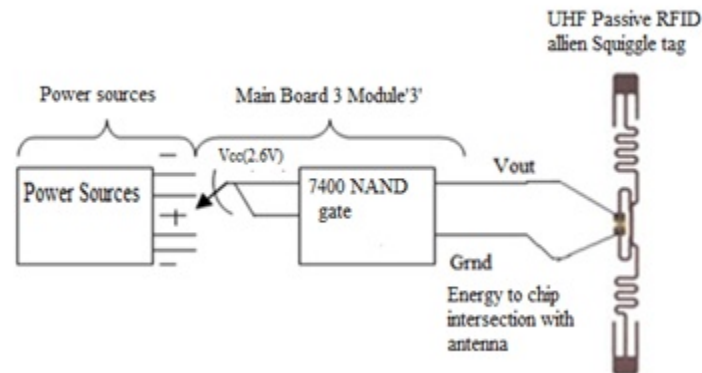


Figure 9.8. Basic Architecture of Design 3 with NAND Gates.

Thus 7400 NAND gate IC and external RC circuit when connected with various power sources, can generate continuous wave of varying frequency depending on the R and C values. Figure 9.8 shows the basic architecture of main board for design 3 module '2' when connected to power inputs and tag at its output.

### 9.5.3 Results

Estimated Cost:

1. Batteries: \$2
2. 7400 (two input NAND gates): \$0.24
3. 1 Resistors and 1 Capacitors: \$0.04

Total cost for design 3 Module '3' with battery source: \$2.28. Figure 9.9 shows the implemented prototype of the design 3 with NAND gate IC.

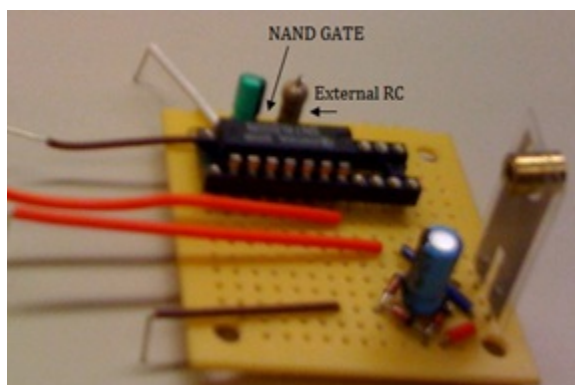


Figure 9.9. Implemented Design 3 with NAND gate IC.

### 9.6 Conclusion

Design 3 with IC555, OPAMP and NAND Gate ICs require very less power source to get activated. Thus, all the modules under this design can be implemented by using one small photovoltaic cell of efficiency 3V. The solar panel that we used is of \$2 for 3V efficiency. Therefore, the total costs for all the options become

1. Module 1 + solar panel=  $0.22 + 2 = \$2.22$
2. Module 2 + solar panel=  $0.85 + 2 = \$2.85$
3. Module 3 + solar panel=  $0.28 + 2 = \$2.28$

Table 9.3 presents the advantages and disadvantages of Module A:Design 3 and Table 9.4 summarizes the above discussion on Design 3 built using three different CWE options.

Table 9.3. Pros and Cons of Design 3 -Module 3

<b>Advantages</b>	<b>Disadvantages</b>
Very low input supply (2.7V onwards)	Arbitrary waveform as its output
Light in weight, small and handy	
Least in cost and components	

Table 9.4. Design 3 with various CWE sources

<b>Parameters</b>	<b>IC555 Timer</b>	<b>OPAMP</b>	<b>Logic Gates</b>
Cost	\$2.22 (Battery) \$ 2.22(Photovoltaic)	\$2.85(Battery) \$2.8(Photovoltaic)	\$2.3(Battery) \$ 2.3(Photovoltaic)
Components	Less	More	Least
Input Supply	3-12V	3-12V	from 2.7V
Disadvantages	Maximum frequency 1MHz	Frequency varies w.r.t OPAMP	Arbitrary waveform-less frequency

## 9.7 Summary

This chapter was in continuation of previous two chapters where we discussed about Module A Design 1 and Design 2. Here, we discussed about Module A Design 3. The main purpose of the design was to use minimum components and minimum cost. IC555 timer, OPAMP, and NAND gates were used as three different choices for generating CW in this Design. Design 3 showed significant results, even after being less in cost and components compared to Design 1 and Design 2.

## CHAPTER 10

### DESIGNING POWER ASSISTED PASSIVE TAG-IV

#### 10.1 Introduction

In previous three chapters we saw the use of battery and photovoltaic cell for powering up the external continuous wave emitter for passive tag. Now we discuss about the third way to power up continuous wave emitter. In this chapter, we will be discussing Module B in detail which consists of piezoelectric vibration sensor.

#### 10.2 Module B Piezoelectric Vibration Sensor

After implementing the above mentioned two designs with battery and solar as their power source, we came with an idea which directly can affect the read range of the tag when it is immediately connected to it. In this case no particular frequency with associated power was taken into consideration. The main objective for this design was to increase the communication range of tag significantly by applying vibrational energy to it. The components used in this design were Piezoelectric Vibrational Sensor, Diodes for rectifier circuitry and Charge capacitor.

##### 10.2.1 Introduction

In Chapter 6, we had a brief discussion on piezoelectric vibration sensors, its main principle and various forms of sensors available in the market. Accordingly for our Module B we chose piezoelectric element as LDT0-028K. Here L in LDT stands for laminated sensor. Typically 125 micro millimeter polyester layer is laminated to a 28 micrometer or 52 micrometer piezo film element[5].

### 10.2.2 Operational Principle

When this piezo element is used in bending mode, laminated film elements develop much higher voltage output when flexed than non-laminated sensors. Its capacitance is directly proportional to the area and inversely proportional to the thickness of the element. To significantly increase the sensitivity of the piezo element small mass  $M$  of 0.72 grams is attached on the element and sensor is now called as LDTM-028K (M-Mass). As according to theory and our experiments LDT element with mass exhibited more sensitivity to the pressure applied, we used LDTM in our Model. LDTM-028K is shown in Figure 10.1. Piezoelement has pair of solder tabs which can easily be soldered directly to our board but with a reasonable amount of care and as quickly as possible as they cannot withstand the temperature above 80 degree C[5].

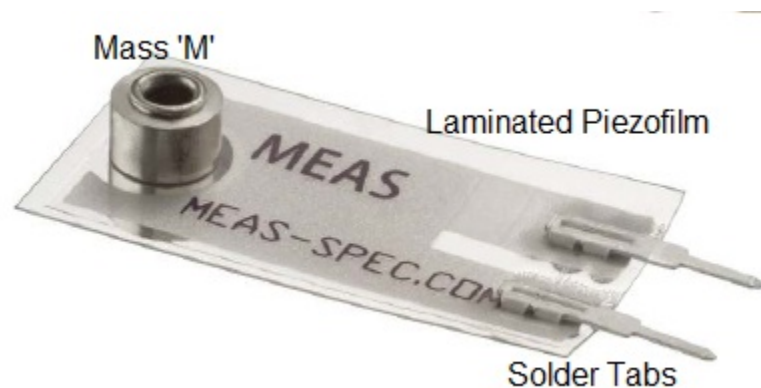


Figure 10.1. LDTM-028K[5].

The presence of heat sink at the interface area between the film and the crimps will take the heat away from the film. Figure 10.2 shows the top view of the piezoelement with all the dimensions specified. Thus the main features of LDT piezoelements are they have solder tab, added mass increases the sensitivity and it can withstand



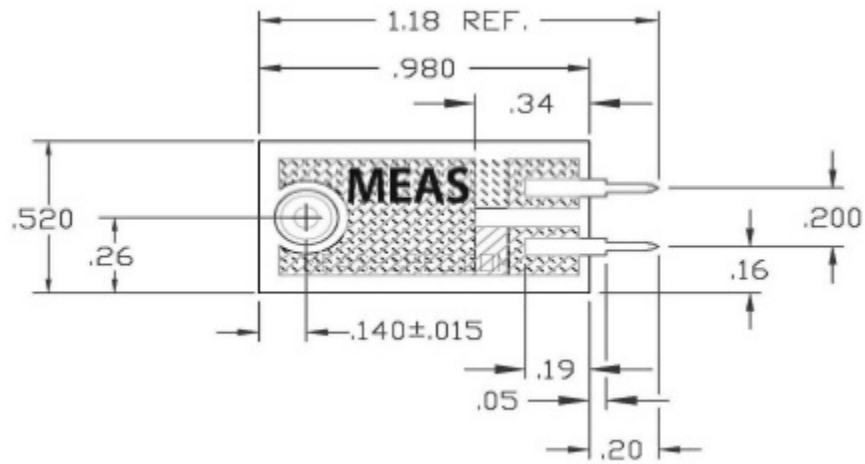


Figure 10.2. Dimensions:LDTM-028K[5].

high impacts and can operate at the temperature ranging from 0 degree Celsius to 85 degree Celsius.

### 10.2.3 Results

When this piezofilm is displaced from its mechanical neutral axis, bending creates very high strain within the piezopolymer and thus high voltages are generated. Figure 10.3 shows the basic architecture of piezoelectric vibration sensor connection with the tag. And Figure 10.4 shows the implemented module B-vibration sensing circuitry.

As the resonant frequency of the source used is 100 Hz, we used small vibrating motor found in toys, Gillette razors to vibrate the sensor. Figure 10.5 shows that how vibration effects the read range of tag from the reader. We also saw the effect of vibration at different frequencies. As shown in Figure 10.6, the vibration improves the tag's performance at every frequency level. Figure 10.7 shows the power conditioning circuit schematic, which itself explains how the tag chip is activated by the vibrations

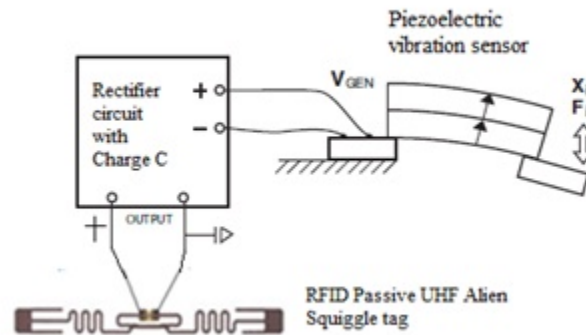


Figure 10.3. Piezoelectric Vibration Sensor with Tag.

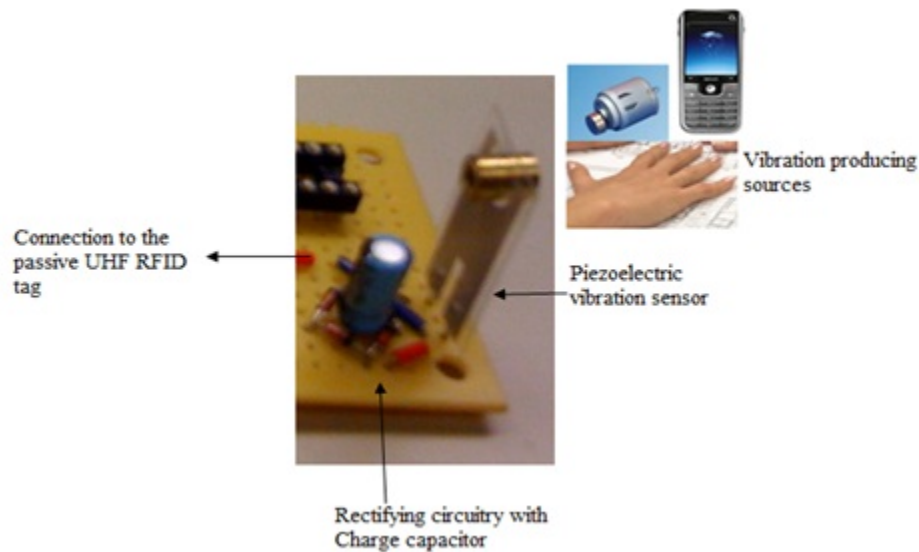


Figure 10.4. Implemented Module B-Vibration Sensing Circuitry..

generated by tapping or toy vibration motors. Here the rectifier circuit is connected after the sensor as it rectifies and delivers smooth output which then charges the capacitor. And later the charge stored on the capacitor is used to energize the tag's chip [68]. Total estimated Cost for Module B is \$2.6 as piezoelectric sensor is of \$1.8 and Diodes plus Capacitors are \$0.8. Table 10.1 shows the advantages and disadvantages of Module B compared to battery and photovoltaic power sources.

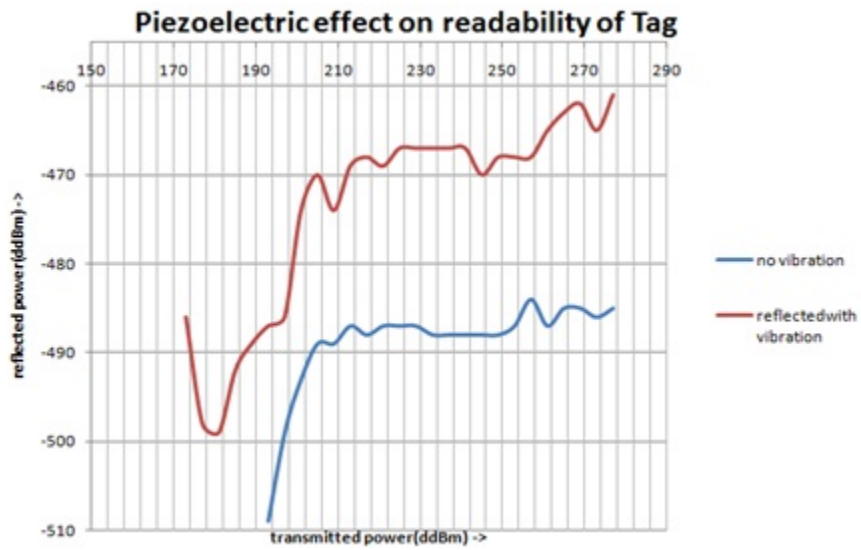


Figure 10.5. Piezoelectric Effect on Readability of Tag.

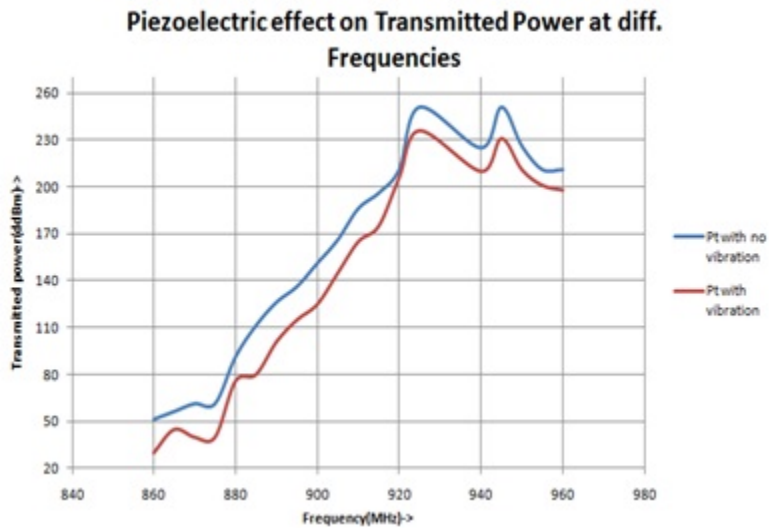


Figure 10.6. Piezoelectric Effect on Transmitted Power.

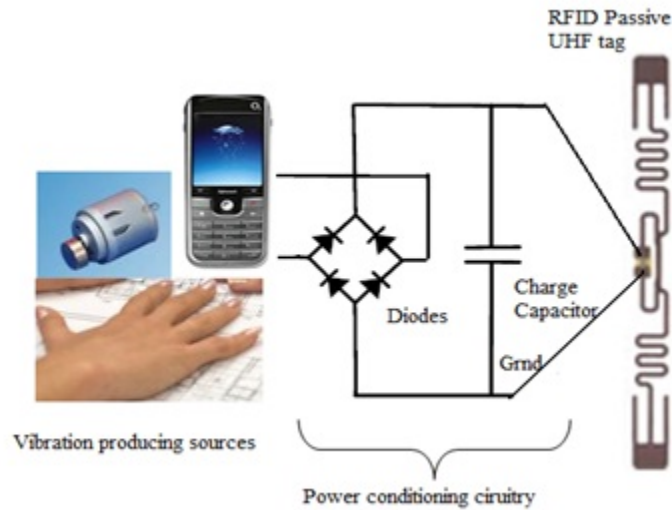


Figure 10.7. Power Conditioning Circuit Schematic.

Table 10.1. Module B compared to Other Power Sources

Advantages	Disadvantages
Low in cost	Outputs high impedance signal that requires conditioning prior to analyze
Virtually inexhaustible	Irregularity in output
Simple and easy to operate	

### 10.3 Summary

This chapter was in continuation of previous three chapters where we discussed Module A Design 1, Design 2 and Design 3. Module B was implemented with components such as piezoelectric vibration sensor, diodes and charge capacitor. By designing these modules, we also proved that external energy source increases the read range. With the use of solar and piezoelectric vibrational sources as the power sources to our designs, it also shows that choosing one of the above mentioned sources are now a viable option.

## CHAPTER 11

### PERFORMANCE ANALYSIS

#### 11.1 Introduction

As discussed in previous chapters, one major advantages of RFID systems is RF tags can be read through obstacles and does not required line of sight for their operation. In this thesis we have considered passive UHF RFID tags that do not have on-tag power supply; hence, the overall communication range of the system is limited by the amount of power that is available for the tag IC and the amount of power it backscatters to the reader. Long read ranges by a passive UHF tag are possible when an externally connected continuous wave emitter is attached directly to the tag antenna. In this chapter, we analyze the performance of UHF passive tags when they are connected to our three different novel energy source prototypes. The tag's performance is evaluated because of its read range efficiency, required transmitted power from the reader, and design cost.

#### 11.2 Performance

The main performance specifications include: range, speed, integrity and compatibility. Exact specifications require knowledge of the exact application and configuration in which RFID systems are to be used. Though the broad application is low cost consumable item tagging, this can be subdivided into numerous applications and each with multiple configurations. Applications such as item checkout at stores are in much demand these days. Readers and tags have to cope with interference from other readers in the vicinity, and reflections or influences from metal and people

in the environment. Large number of random distributions of items may need to be identified accurately and quickly. Maximum required read range will likely need to be comparable to meters. And no doubt for the end user, cost should be minimized. Every aspect of the RFID system must be optimized first for low cost and second for performance. Before moving forward for the performance analysis, let's review what we have seen in Chapter 3 about tag-reader communication.

### 11.3 Modules- Performance Check

The success behind the UHF is mainly attributed to the EPCglobal standard where physical and logical requirements are briefly specified in the frequency range of 860-960 MHz. With respect to the HF and the first generation of the UHF systems, EPCglobal has significantly contributed to the growth of overall system performance as also discussed in previous Chapters. Particularly, rules have been provided aiming at the coexisting of more readers in a given location volume, avoiding collisions among various simultaneous responses from multiple tags and interference among readers. Higher data rate of UHF systems as compared to the LF and HF systems shows that in the same time interval, more tags can be interrogated and more information per tag can be transferred to the reader. Further, UHF systems allow obtaining wider read ranges that implies the volumes in which a given read rate can be guaranteed.

We have four designs from module A and B which were designed according to the calculated values of required frequency and power levels for efficient CWE. To evaluate the design's performance when attached to the passive tag, each are compared with respect to its effect on communication range between reader and tag, transmitted power required by the reader to read the tag in its vicinity and the overall cost.

### 11.3.1 Analysis-Efficiency

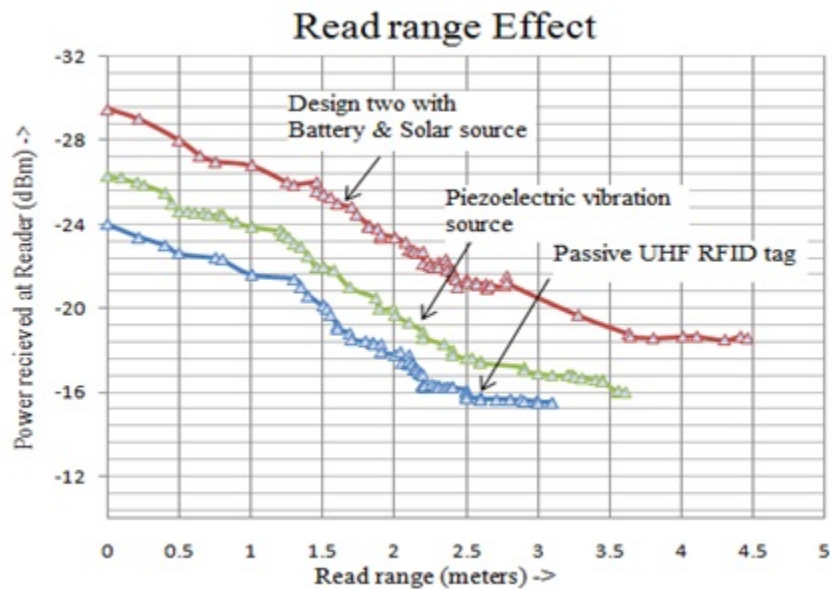


Figure 11.1. Best Efficiency Design: Design 2.

The sensitivity of a tag can be measured by determining into the minimum signal strength required at the tag to charge it. As discussed, signal strength depends on chip threshold power sensitivity, tag antenna gain and match between tag antenna and chip's high impedance. According to the experiments with UHF passive RFID squiggle tag, the maximum range up to which it can be read by the reader was noted as 3.1 meters. To see the effect of externally connected CWE source few range experiments were performed. Under the same experimental setup used to calculate the parameters for CWE, passive tag is now connected to all three different designs one by one and readings were noted down to evaluate its read range. Fig. 6.2 shows that when passive tag was connected to a piezoelectric vibration source, the read range increases by 0.6 meters. And also the range depends on the intensity of the vibrations produced by different sources as given in chapter 5.

When Design 2 or Design 1 was connected to the tag, it shows same effect on read range when working on battery power source. But when switched to photovoltaic cell as its power source, Design 1 performance varies as it doesn't have reliable voltage regulator. Also Design 1 requires 12V as its input supply which is many times impractical to provide. Thus, after looking into all the above results and from Figure 11.1 we can conclude that read range is increased by 1.5 times which is a significant increase in communication range between a passive tag and a RFID reader with Design 2 as our new CWE.

### 11.3.2 Analysis-Least Cost

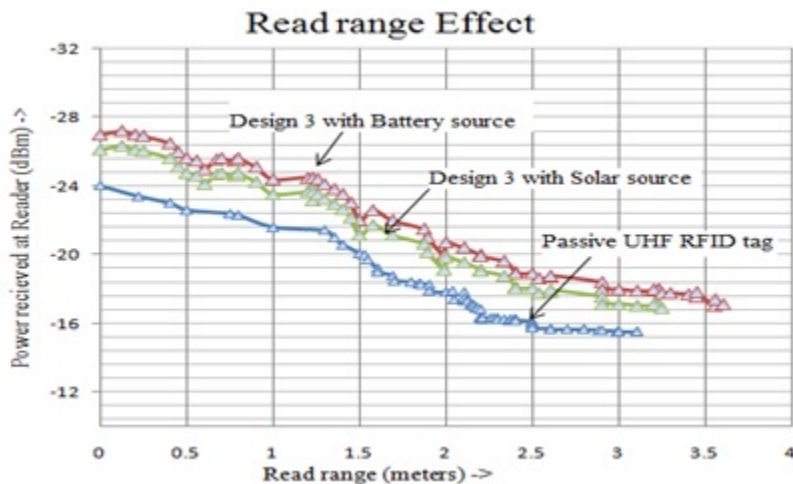


Figure 11.2. Best Cost Design-Design 3 with Battery.

Presently, RFID technology is expensive and the price of RFID tags has traditionally been a significant obstacle to its widespread deployment in supply chain management. An Accenture survey found cost to be one of the two primary barriers to the implementation of RFID [63]. Reports on the current cost of RFID tags vary, whereas they all find common ground in noting that the current cost of tags is too



high to justify tagging all the items available in the market. This is the reason, most companies mandating the use of RFID are focusing on tagging pallets and cases, in comparison to item level tracking, which is still years away[63]. The recent popularity of Passive UHF RFID technology is attributed to the low cost RF tags and the lack of on-tag power supply [84].

Thus, if we want to use our external CWE for increasing passive tag read range then we have to look into its overall cost. Cost of design 1 and 2 are in the range of dollar twenties and cost of design 3 is approximately \$2. Same is true with piezoelectric vibration source. Therefore, we carried out the experiment to compare the designs with respect to their cost and performance. Figure 11.2 shows the effect on read range when best cost design is attached to the passive squiggle tag. It shows that when design 3 was powered by photovoltaic cell then range is increased by 0.3 meters whereas when powered by battery source range increases by 0.6 meters. Thus, keeping into consideration the cost of the design and effect on read range of passive RFID tag we chose design 3 powered by battery or photovoltaic source depending upon the application requirement to be the best option.

### 11.3.3 Analysis-Transmitted Power

Once the passive tag is powered up, it modulates and backscatters the reader's signal. Transmitted power by the reader is one of the major factors affecting the received power from a tag. As discussed, with passive tags we know that part of incident RF waves from reader is used to activate the chip and rest used to backscatter the stored data. Whereas, when the chip is activated using CWE other than reader, whole incident energy from the reader is just used to backscatter the stored data and hence tag can be read with less transmitted energy from the reader up to greater distance.

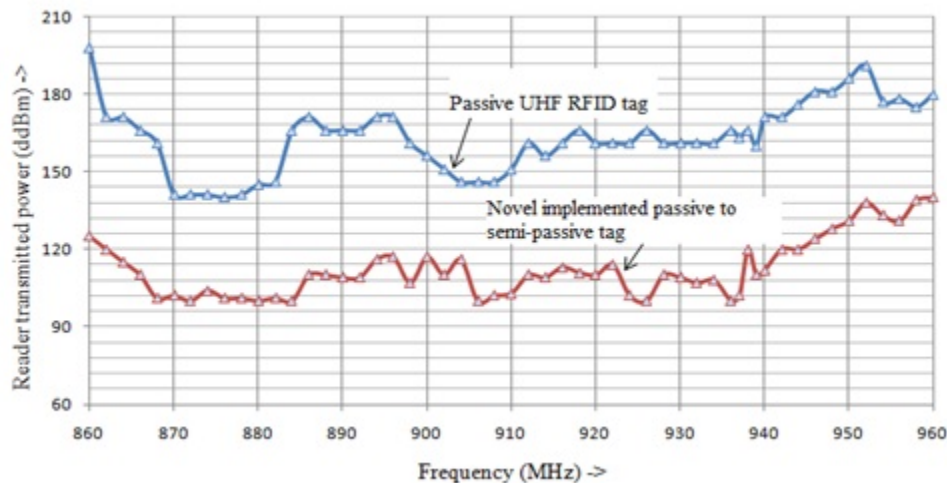


Figure 11.3. Reader Transmitted Power Vs Frequency.

Figure 11.3 shows that how reader transmitted power is affected when passive tag is being charged externally with our new derived frequency and power values for CWE. The figure 11.3 clearly shows that when the passive UHF RFID squiggle tag was connected with the CWE designed at 670 MHz and with power at 10.2 dBm, reader requires much less power to read the tag and thus increasing the read range effectively.

#### 11.3.4 Summary

With passive UHF RFID systems becoming very ubiquitous recently, it is very important that RFID tags should perform at their best with minimum possible cost and maximum performance. We have seen the effect of connecting three different novel energy source prototypes with passive UHF RFID tags. The performance was evaluated keeping into consideration three important parameters which are read range efficiency, required transmitted power from reader, and design cost. Efficiency was being measured to check the effect on communication between reader and the tag.

And after a series of experiments Design 2 proved to be best efficiency design. To find the best low cost design was one of the major concerns because of the recent popularity of passive UHF RFID technology. And comparing the design total costs and their effect on passive tags, Design 3 with battery source proved to be the best least cost design. Finally, transmitted power to read the passive UHF RFID tag by a reader was compared when it was reading the tag with or without externally connected CWE (@ 670 MHz and 10.2 dBm). Table 11.1 shows the preferred design according to the application requirements.

Table 11.1. Suitable Design according to Application

<b>Performance Parameter</b>	<b>Best Design</b>
Efficiency	Design 2
Least Cost	Design 3 with battery source

#### 11.4 Shift in Center Frequency

Center frequency is the measure of frequency between the upper and lower cut-off frequencies. In U.S.A operating frequency range in UHF RFID frequency band is 902-928MHz. The tag used in all our experiments is Alien Squiggle passive UHF RFID tags. As stated in its features, operating frequency range of this tag with HiggsTM-3 IC is 840-960 MHz with center frequency of 902 MHz. We now know that appropriate powering up the tag's microchip is essential in functioning of passive UHF RFID systems. Power transfer maximization is directly related to impedance matching of the tag's antenna and the microchip. According to the requirements, RFID tags are built and antenna designs are chosen because of their structure and impedance properties. For all our experiments, to directly charge the tag's microchip

we have connected one conductive copper lead on each interface surface between chip-antenna.

Thus, when we connect an external leads to the antenna-chip interface we are changing the already defined impedance matching between the two. As we have changed the impedance matching, the center frequency also gets affected. To see this experimentally, readings were taken for reading a wet inlay Squiggle passive tag and squiggle tag with leads connected at its antenna-chip interfaces. Figure 11.4 shows the change in center frequency between the two tags in test.

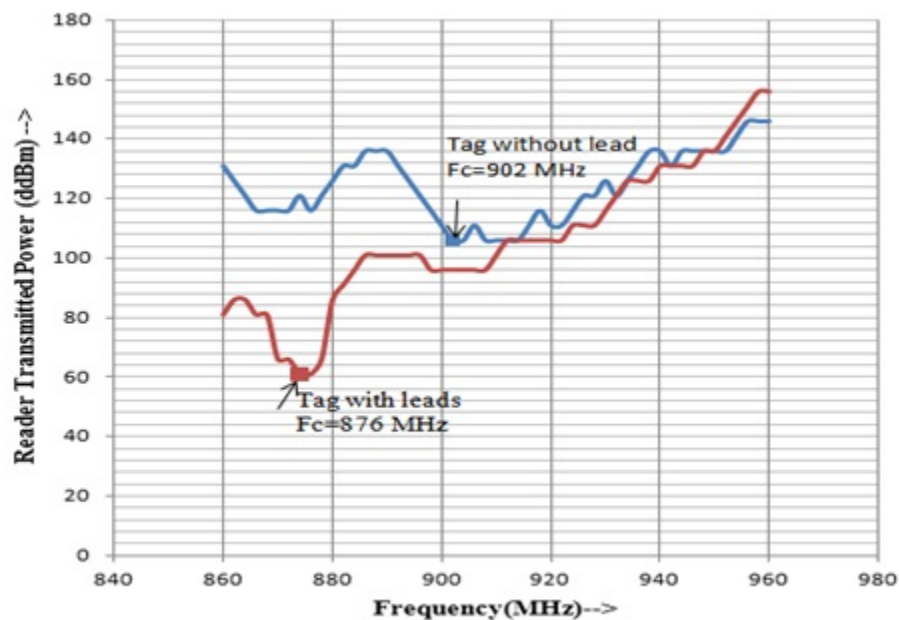


Figure 11.4. Effect on Passive Tag Center Frequency.

### 11.5 External CWE with Varying Wave Geometries

In Chapter 4 we have already seen that for charging passive tag's microchip directly, it should be given a continuous AC signal so that the tag front end recognizes the incident waves. In all our experiments we have used a continuous sine wave as

our external energy source. Further, to see the effect of giving continuous waves of various geometries such as square, ramp or randomly generated wave we performed an experiment where the SIRIT reader reads a tag when it is not given any continuous wave externally and when it is getting charged by signal of various shapes from waveform generator. Figure 11.5 shows tag performance analysis while reader

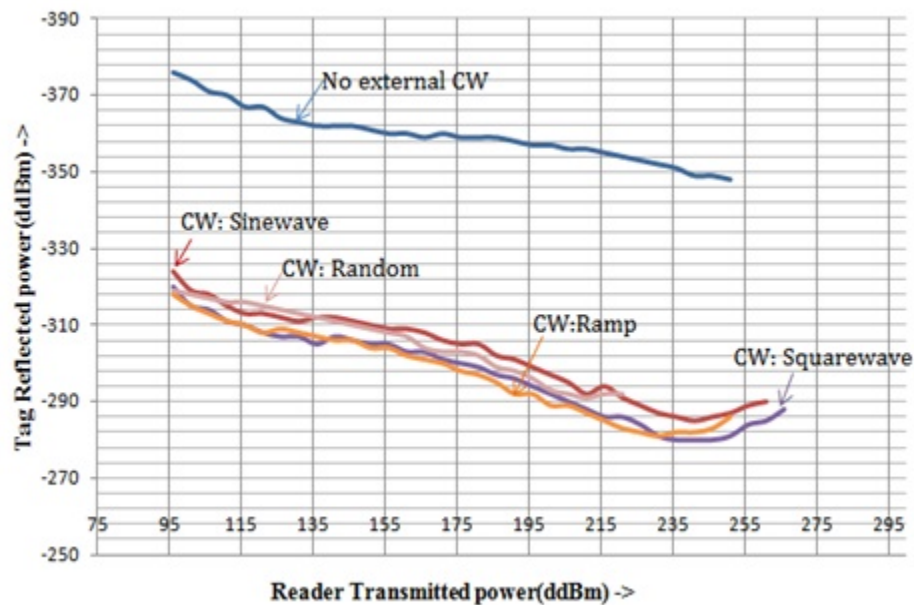


Figure 11.5. Passive Tag and various External CWE .

reading the tag with or without any externally given continuous waves of various geometries.

## 11.6 Summary

In this chapter we have analyzed the performance of tag when it is being charged externally with our newly built three designs. According to the efficiency performance Design 2 is the best to use with passive tag as it increases its range by 50% and make

it perform as a semi-passive tag when required. Secondly as per the cost, Design 3 is suitable to use with low cost passive RFID tags which increase the read range by 20% at a very low price. We have also seen how the reader's transmitted power gets reduced when it is reading our novel implemented semi- passive tag. Further, shift in center frequency value was also observed as connecting leads directly to the chip-antenna intersection, interfere with the already well matched impedance between the two. At the end, to examine various geometric of continuous waves, tag was tested after being connected with the waveform generator. And we saw that, continuous waves of any form and shape produce the same affect on reader tag communication.

## CHAPTER 12

### CONCLUSIONS AND FUTURE WORK

#### 12.1 Introduction

In this chapter we summarize the research and conclusion drew from various experiments and implemented designs. Along with that, we will also have a look at the future direction of this research and how this can be of great support to the industry. This research focuses on determining an optimum frequency and power level for energizing the passive tag externally which would significantly improve the tag-reader communication range. New circuit has also been designed to power up the chip besides building the prototypes of three different designs. Solar energy and piezoelectric vibration source proved as viable power sources for the external circuitry.

#### 12.2 Conclusions

In this thesis, initially detailed study behind history of RFID system was performed and we listed many major advantages of RFID tags over Barcodes. Then at the next stage, we studied major contributions from various researchers who tried to improve the passive tag performance by external energy sources and their advantages/disadvantages which highlights the open areas of my research. RFID tags can be categorized into many categories according to their data storage capacity, communication with readers, and operating frequency ranges. One whole chapter was dedicated to study about the design and implementation of RFID tags; with brief explanation of tag properties and its behavior in near or far field communication. In passive RFID systems, when the transmitted radio waves from reader incident on the

tag; part of the energy is being used by the tag's chip to get energized and remaining energy is used to backscatter the stored information(data) on the tag. If the passive tag is energized separately, entire incident radio waves from reader on the tag can be used to backscatter the stored data on passive tag, hence increase the read range between tag and the reader.

### 12.2.1 Parameters Selection

Passive tags get charged through Continuous wave emitter (CWE). The major part of thesis was dedicated to calculate appropriate parameters for designing CWE. Three major constraints were taken into account to finalize the frequency for CWE. First, tag should be able to harvest the maximum power at the operating frequency of CWE. After this constraint, we got the frequency range from 600-940 MHz. Secondly, the radiation from the tag's chip should be minimum at the selected frequency. With the help of experiments the outcome frequency range after this was from 600-750 MHz and 810 to 930 MHz. Last but not the least, passive tag with CWE should not interfere the normal occurring UHF communication. And looking at the experimental graphs we excluded the frequency range from 810 to 930 MHz.

At this stage to select the optimum frequency from 600-750 MHz, we plotted a graph of difference in minimum power required by the reader to read the tag with and without CW source. And it was observed that the tag with 670 MHz CW was read at 5.1 dBm lower as compared to the standalone tag and this gives us the optimum frequency level for Continuous Wave Emitter(CWE). Later for optimum power selection, at 670 MHz we performed frequency sweep with power values ranging from -10 dBm to +17 dBm. Comparing the performance of the tag for varied power levels, we could conclude that more power gave to the tag gives more read range.



But according to FCC part 15, the maximum allowable transmitted power from an intentional radiator at 670 MHz is 10.2 dBm.

### 12.2.2 Designing

After choosing the CWE's parameters, we designed inexpensive power assisted passive tags, which now can be called as semi-passive tags. To differentiate our designs properly, we categorized them into modules (Module A and B) and each module was powered with the help of battery or solar source. Module B was entirely for piezoelectric vibration sensor element, which was also able to increase the read range significantly. All the designs were built, keeping in mind, the desired output from the same. Each building component/element for the design was studied and selected carefully. After the successful implementation of three different designs as CWE for a passive UHF RFID tag, they were examined and rated according to their performance in efficiency, transmitted power and overall cost. When the performance graph was

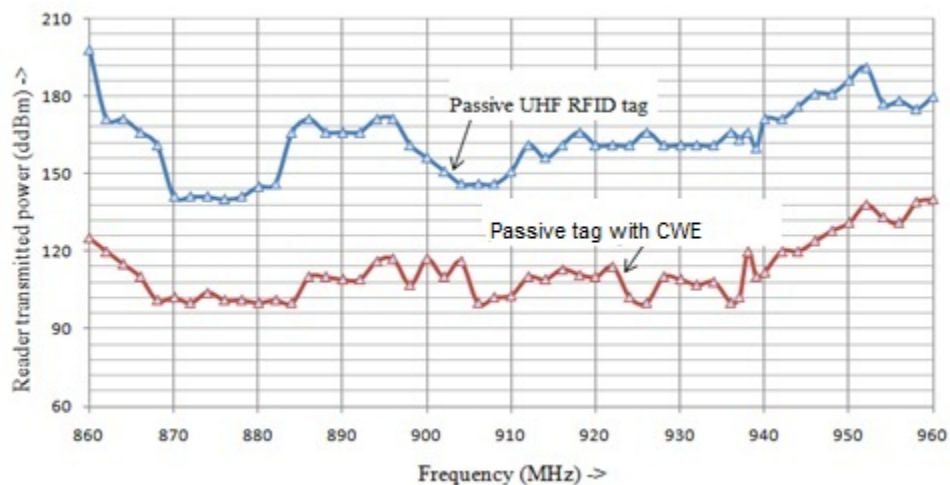


Figure 12.1. CWE with Passive Tag.

compared with the original efficiency of passive tag, we could see that the read range between a Passive UHF RFID tag and a reader can be increased significantly by connecting an external energy source to the tag as shown in Figure 12.1. Adding to the same, these three novel designs which are proposed in this thesis can be used as the basis for commercialization of this concept. Figure 12.2 shows the comparison

PARAMETER	Module A : Design 1		Module A: Design 2		Module A: Design 3		Module B: Peizo
	BATTERY	SOLAR	BATTERY	SOLAR	BATTERY	SOLAR	
<b>COST</b>	\$24.70	\$29.70	\$26.50	\$28.50	\$2.22	\$2.22	\$2.60
<b>READ RANGE</b>	4.3 m	3.7 m	4.5 m	4.5 m	3.5 m	3.2 m	3.6 m

Figure 12.2. Results:Module A and Module B.

between Module A and B with respect to its cost and effect on read range. It should be noted that the read range of test tag was 3 meters.

### 12.2.3 Summary

Thus, it is concluded that frequency for CW should not be chosen near the frequency of operation of the tag. In the latter half of thesis, after performing many significant experiments it was also shown that if the external continuous wave emitter is connected through wired medium to the tag, the increase in read range is more when compared with wireless medium. Whereas looking at the cost of our novel built designs, Design 1 and Design 2, it can also be concluded that using discrete components are not feasible for low cost RFID applications. We also analyzed and chose the best design suitable for passive to semi-passive conversion with respect to cost, effective read range increase, and reader transmitted power. Figure 12.3 shows that if the system requires high efficiency, i.e., more read range and not bothering

about system cost, then Design 2 is the best choice. If the system allows compromise in efficiency, Design 3 or piezoelectric vibration sources can be used at very low cost for passive to semi-passive tag conversion.

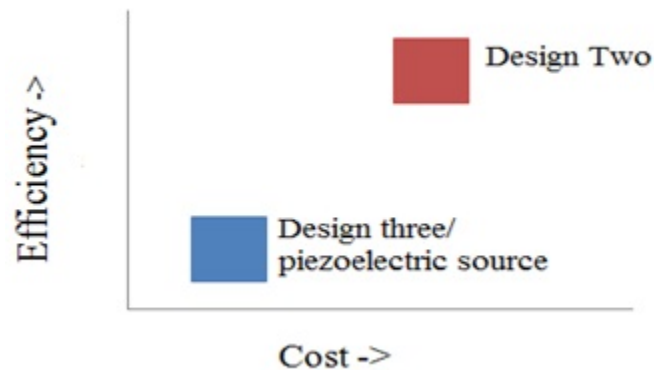


Figure 12.3. Efficiency Vs. Cost.

### 12.3 Future Work

In studying, experimenting and designing new models for continuous wave emitters (CWE) for passive tag, several areas deserving of future work emerge. I briefly discuss few of those areas here one by one.

Impedance matching is important at high frequency applications. When high frequency signals are carried on transmission lines of any significant length, care must be taken that the transmission medium is matched to its terminations. To minimize the signal reflections, source and load impedance should be equal to the characteristic impedance of the transmission line. The presence of impedance discontinuities or mismatches will degrade the amplitude and phase accuracy. Although we have seen remarkable improvement on passive tag's performance after connecting my three novel built designs, further work on impedance matching can improve its performance.

After connecting two copper leads directly to the tag's chip, proper experimentation should be followed to study impedance matching between the tag antenna and the microchip interference.

In the area of electromagnetic, Equivalent Isotropic Radiated Power (EIRP) measurements play an important role. We know that the effective isotropic radiated power is the measure of power that a theoretical isotropic antenna would emit to produce the peak power density observed in the direction of maximum antenna gain. Thus, performing EIRP measurements on all the three implemented designs in my thesis would take into account the losses in transmission line and connectors.

Finally, additional functions and new applications should provide several interesting and compelling areas of research. Integration of CWE either through MEMS devices[93], or simpler material structures, would be useful to a several current and likely new applications. Implementation of such designs in robotics or automation should be studied[58]. Presently, converting a passive UHF RFID tag a semi passive tag using an external power source is the major topic of discussion in RFID market.

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## BIOGRAPHICAL STATEMENT

Tanvi Mehta was born in Panipat, India in 1986. She completed her Bachelor's in Electronics and Telecommunication Engineering from Mumbai University, India in 2007. Tanvi then worked as a System Engineer at Polaris Software Labs Ltd., India for 6 months. She then joined University of Texas at Arlington, Texas for her Masters in Electrical Engineering. Tanvi was working as a Supplement Instructor for Mathematics and Physics in SOAR department of UTA. She then also worked as graduate teaching assistant for the digital design course. She submitted 1 paper in peer reviewed conferences at the time of her graduation. Her research interests lies in different aspects of RFID including antenna design, tag reader communication, performance of tags and in various applications of RFID tags in real world. She is also interested in circuit design, implementation and verification and has a good knowledge in Matlab. She maintained 3.7 GPA with thesis in her 2 years of Masters.