ABSTRACT

LOCATION ESTIMATION IN A 3D ENVIRONMENT USING RADIO FREQUENCY IDENTIFICATION TAGS

by
Adwitiya Akash Jain

RFID tag location estimation in a 3D environment is investigated. The location of the tag with unknown coordinates can be estimated with certain accuracy. However, accuracy can be improved using the knowledge based on measurement of additional reference tags with known location. This thesis studies the mathematical formulation and practical realization of location sensing using RFID tags.

Deviating from the standard use of RFID technology which employs one tag reader to identify the presence of tag, here multiple tag readers with known location are used to estimate the physical location of an individual tag, with/without the help of few reference tags with known locations.

Mathematical model of this concept has been developed based on distance variations in terms of signal strength. Experimental approach with limited range passive tags has been carried out. Since the range of the RFID system was limited only to a few inches, signal strength variations were insignificant. Instead, time domain measurements with the help of an external antenna were conducted. The composite signal width including of the wake up signal of the interrogator, travel time between the interrogator and tag, and the tag's response was measured and quantified. It was observed that the width of the signal was proportional to the distance between the tag reader and the tag. It was noticed that the use of four RFID tag readers yielded fairly accurate results to identify the location the tag based on the mathematical formulation developed here.

Additionally, concept of trilateration has also been extended for tracking the tag of unknown location without the use of reference tags. Archival data set corresponding to all tag location due to four different tag readers was compiled. The unknown tag was probed with four tag readers and matching the data to the archival data set yielded unique and accurate results for its unknown location. It was demonstrated that both approaches were proved to be cost-effective techniques and estimation of the location of a specific tag has been achieved with sufficient accuracy.

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by
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APPROVAL PAGE

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Dedicated to my aunts

Alka , Seema and Deepa

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CHAPTER 1

INTRODUCTION

The universe is becoming more mobile with each day and as a result, knowledge of location plays an important role in daily lives. Mobile computers and communication devices are establishing themselves as pervasive features of today. This development is linked to tremendous growth in the number and sophistication of mobile and mobile-aware software applications. Increasingly, such applications need access to information about their own and other objects' physical locations, a requirement known as location-awareness [1]. Emerging convergence among mobile computing devices and embedded technology sparks the development and deployment of "context-aware" applications, where location becomes the most essential parameter [2].

Utilization of Radio Frequency IDentification (RFID) for location estimation is a relatively new technology. Traditionally, RFID system is used to identify the presence of physical object equipped with a tag, e.g., identify and process tag ID for toll collection. In the past, researchers have utilized the properties of the RFID technology for location sensing; SpotOn [3] was based on hardware and embedded system and Landmarc [2] was based on reference tags in a two-dimensional environment.

The objective of this research is to examine an indoor location-sensing system for various mobile commerce applications. The goal is to implement prototype indoor location-sensing system using radio frequency identification so that one can estimate the location of a specific object within a given space with sufficient accuracy.

A mathematical model of the theoretical concept based on the reference tags approach has been developed. This model utilized the distance as a variable. Various experiments were performed to get the best model that helped to estimate the location of any specific object. It was observed that there was not much variation in the intensity in the limited range of RFID tags that were chosen for the experiments. However, it was possible to measure the composite time domain signal comprising of the wake up signal generated by the tag reader and the tag's response. In the limited range, due to proximity of the tag reader and the tag, these messages overlapped and it was possible to observe the width of combined interval corresponding to wake up signal and response messages including the travel time between the tag reader and the tag. It was established that the width of the composite signal is proportional to the distance between the tag reader and the tag, using multiple readers; measurements obtained due to unknown tag were used in the formulation developed in this thesis to estimate the location of this unknown tag.

Further, measured data based on the principle of trilateration has been extended to estimate the location of tracked object with the help of reference graphs, stored in the archival data of the system, eliminating the need of reference tags.

The thesis is divided into five chapters. Chapter 1 introduces the objective of proposed research work. Chapter 2 describes the generic RFID system, its components, operating frequencies, advantages, limitations, applications and privacy issues. Chapter 3 includes the concept of location sensing, various techniques used, different location sensing systems and finally the location sensing using RFID and its related research performed in the past. Chapter 4 describes the proposed mathematical model and experimental investigation. Chapter 5 summarizes conclusions and future suggestions.

CHAPTER 2

RADIO FREQUENCY IDENTIFICATION

The British pioneered RFID technology during World War II to identify its own aircrafts returning from sorties over occupied Europe. Early radars system could spot an incoming aircraft but was not able determine its type. But the transponder in RAF (Royal Air Force) planes, based on RFID technology, could differentiate Allied aircrafts from enemy aircraft. In fact, this is essentially the same kind of friend-or-foe (FoF) identification system still being in use today.

In the late 1960s, the US government began using RFID to tag and monitor nuclear and other hazardous materials. In 1972, the same year as the first deployment of Universal Product Code (UPC), Schlage Electronics (now Westinghouse) developed an RFID card for access control. In 1977, Los Alamos Scientific Laboratories transferred its technology to the public sector, which encouraged a number of companies to explore new uses of RFID technology [4].

RFID systems have gained popularity, and notoriety, in recent years, especially in toll collection (E-ZPass), and incident detection [5]. The TRANSMIT system based on RFID technology now presents collection of real time traffic data on unimaginable scale compared to other data collection methods. Currently 2.5 millions vehicles equipped with E-ZPass tags are in everyday traffic in NY/NJ/Connecticut metropolitan area.

"Radio Frequency Identification Device", refers to systems that allow a device to read information contained in a wireless device that is commonly called a tag, and provides a method to transmit and receive data from one point to another without making any physical contact [6].

RFID tags contain silicon chips and antennas to enable them to receive and respond to radio-frequency queries from an RFID tag reader/Interrogator.

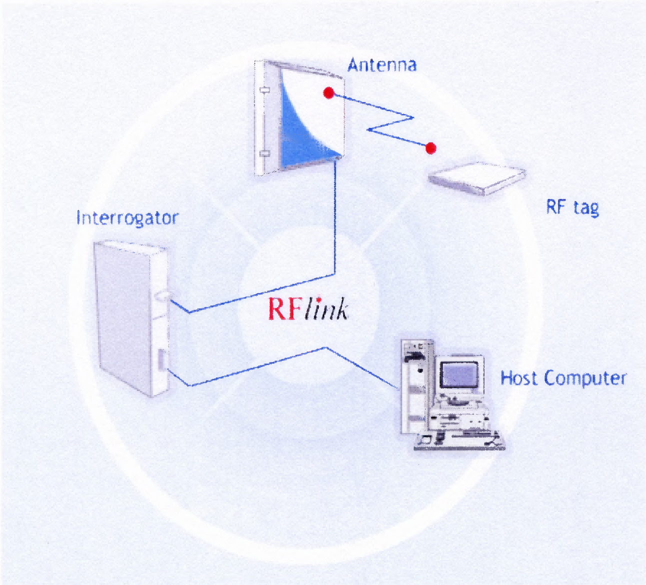


Figure 2.1 Generic RFID system [7].

2.1 Components of RFID

An RFID system is collection of various components that implement an RFID solution. The most vital parts of an RFID system as shown in Figure 2.1 have been described below:

2.1.1 RFID Tags

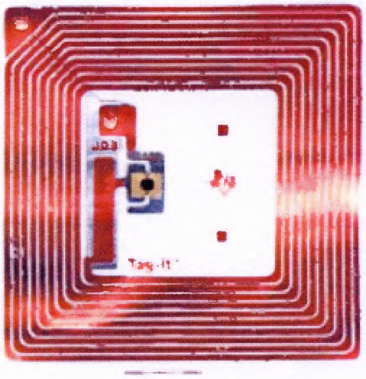
An RFID tag is a device that can store and transmit data to a reader in a contactless manner using radio waves [8]. RFID tags can be broadly classified into two main categories, based on whether the tag contains an on-board power supply and provides support for specialized task (active), or do not posses any power source, being energized by the power of interrogation signal (passive).

Passive Tags

This type of RFID tag doesn't have an on-board power source (for example, a battery), and instead uses the RF power emitted from the reader to energize itself and transmit its stored data to the reader. The minute electrical current induced in the antenna by the incoming radio frequency signal provides just enough power for the CMOS integrated circuit (IC) in the tag to power up and transmit a response. The response of a passive RFID tag as shown in Figure 2.2 is not just an ID number; the tag chip can contain nonvolatile EEPROM (Electrically Erasable Programmable Read-Only Memory) for storing data, as seen in Figure 2.3.

A passive tag is simple in its construction and has no moving parts. As of 2006, the smallest such devices measured 0.15 mm × 0.15 mm, and are thinner than a sheet of paper (7.5 micrometers). Conclusively, such a tag has long life and is generally resistant to harsh environmental conditions. For example, some passive tags can withstand corrosive chemicals such as acid, temperatures of 400^0 F, and more.

A passive tag is typically smaller than an active or semi-active tag. It has a variety of read ranges starting with less than 1 inch to about 30 feet (9 meters approx). Since passive tags are cheaper to manufacture and have no battery, the majority of RFID tags in existence are of the passive variety. As of 2005, the lowest cost EPC Gen 2 tags available on the market are as low as 7.2 cents each in volumes of 10 million units or more. Current demand for RFID integrated circuit chips is expected to grow rapidly based on such low prices [8]. A contactless smart card is a special type of passive tags that is widely used today in various areas (for example, as ID badges in security and loyalty cards in retail). The data on this card is read when it is in close proximity to a reader.



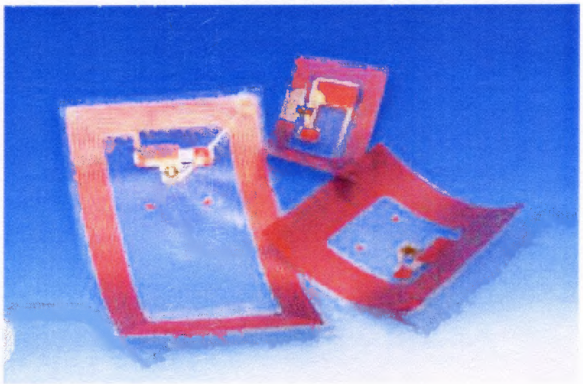


Figure 2.2 Passive tags [9].

A passive tag consists of following main components [8]:

- Microchip
- Antenna

Microchip

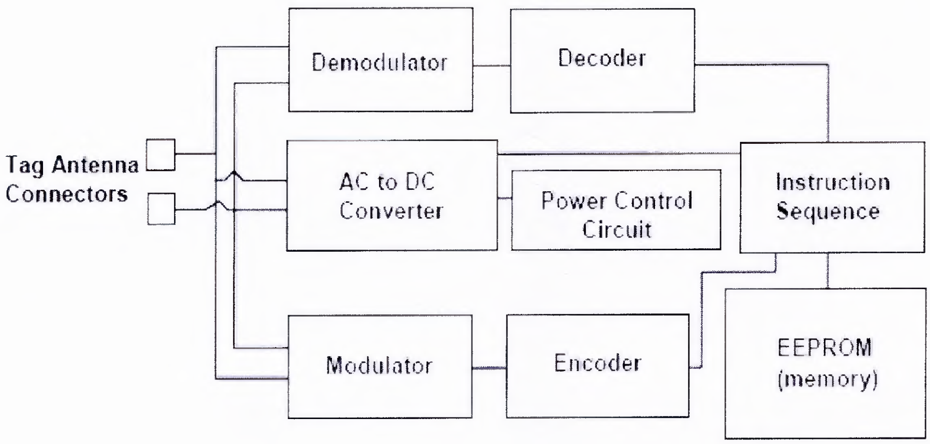


Figure 2.3 Block diagram of a microchip in a passive tag.

Power control circuit supplies power to other components of the microchip. Rectifier converts RF power to DC. Modulator modulates the received reader signal. Memory is for storing data. Instruction sequence is responsible for implementing the communication protocol between the tag and the reader.

Antenna

A passive tag's antenna is used for collecting energy from the tag reader's signal to energize the tag and for sending and receiving the data from the reader. This antenna is physically attached to the microchip. The antenna's dimensions are directly proportional to the tag's operating wavelength [8].

The advantages of a passive tag are:

- The tag is typically much less expensive to manufacture,
- The tag functions without a battery; these tags have a useful life of twenty years or more,
- The tag is much smaller (some tags are the size of a grain of rice). These tags have almost unlimited applications in consumer goods and other areas.

The disadvantages of a passive tag are:

- The tag can be read only at very short distances, typically a few feet at most. This greatly limits the device for certain applications,
- It may not be possible to include sensors that can use electricity for power,
- The tag remains readable for a very long time, even after the product to which the tag is attached has been sold and is no longer being tracked [10].

Semi-Active (Semi-Passive) Tags

Semi-active tags have an on-board power supply (for example, a battery) and electronics for performing specialized tasks. The on-board supply provides energy to the tag for its operation. However, for transmitting its data, a semi-active tag uses the reader's emitted power. It is also known as battery-assisted tag. Reading range can be 100 feet under ideal conditions using UHF and microwave [8]. Applications are supermarket barcode replacement, airline bags, factory automation, and box tracking.

Active tags

Active RFID tags have an on-board power source (for example, a battery; other sources of power, such as solar, are also possible) and electronics for performing specialized tasks. An active tag uses its on-board power supply to transmit its data to reader. It doesn't need the reader's emitted power for data transmission. The on-board power supplied electronics can contain microprocessor, sensors, and input/output ports powered by the on-board power source. Therefore, for example, these components can measure the surrounding temperature and generate the average temperature data. The components then can use this data to determine parameters such as expiration date of the attached item and transmit to a reader (along with its unique identifier). At present, the smallest active tags are about the size of a coin. Reading distance of an active tag can be upto 100 feet (30.5 meter approximately) or more with active transmitter of such a tag as shown in Figure 2.4.

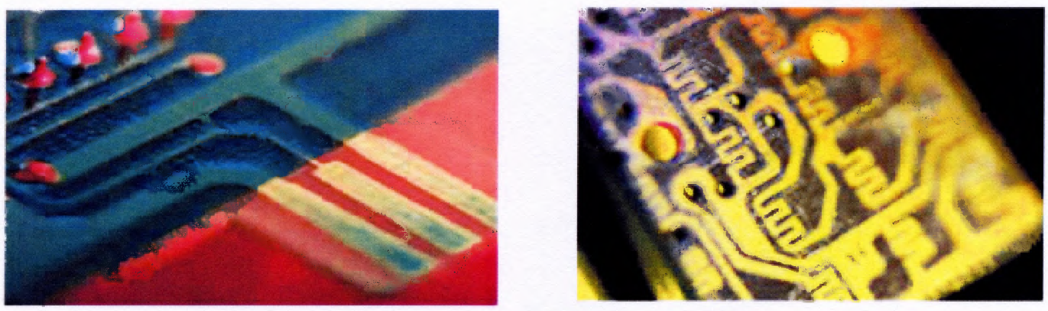


Figure 2.4 Active tags on-board power source's circuit.

In tag-to-reader communication for this type of tag, a tag always communicates first, followed by the reader. Because the presence of reader is not necessary for data transmission, an active tag can broadcast its data to its surrounding even in the absence of a reader.

Few application of active tags are tracking of cargo, proof of tamper evidence on containers, long range asset tracking, peer to peer networks for sensing, real time location of assets and people and remote identification in difficult environments [8].

An active tag consists of following main components.

- Microchip: the microprocessor size and capabilities are generally greater than the microchip found in passive tags,
- Antenna: this can be in the form of an RFID module that can transmit the tag's signals and receive reader's signal in response,
- On-board power supply,
- On-board electronics.

The major advantages of an active RFID tag are:

- It can be read at distances of one hundred feet or more, greatly improving the utility of the device,
- It may have other sensors that can use electricity for power.

The disadvantages of an active RFID tag are:

- The tag cannot function without battery power,
- The tag is typically more expensive, often costing $20 or more,
- The tag is physically larger, which may limit applications [10].

2.1.2 Tag Readers

An RFID tag reader, also called an interrogator, is a device that can read from and write data to compatible RFID tags. Thus, a reader also doubles up as a writer. The act of writing the tag data by a reader is called creating a tag. The process of creating a tag and uniquely associating it with an object is called commissioning the tag. The time during which a reader can emit RF energy to read tags is called the duty cycle of the reader.

The reader is the key component of the entire RFID hardware system-establishing communication with and control of this component is the most important task of any entity which seeks any integration with this hardware [8].

A reader has the following main components as shown in Figure 2.5:

- Transmitter: The reader's antenna is used to radiate RF power to the tags in its read zone. This is a part of the transceiver unit, the component responsible for sending the reader's signal to the surroundings environment and the receiving tag responses back via the reader antenna(s).
- Receiver: This component is also part of transceiver module. It receives analog signal from the tag via the reader antenna. It then sends these signals to the reader's microprocessor, where it is converted to its equivalent digital form.
- Microprocessor: Responsible for implementing the reader protocols to communicate with compatible tags. It performs decoding and error checking for the analog signal from the receiver.
- Memory: Used for storing data such as reader configuration parameters and a list of tag reads.
- Input/output channels for external sensors, actuators and annunciators: Provides a mechanism for turning reader on and off depending on the external events. A sensor of some sort, such as a motion or light sensor, detect the presence of tagged object in the reader's read zone. This sensor can then set the reader on to read this tag.
- Controller: A controller is an entity that allows an external entity, either a human or a computer program, to communicate with and control a reader's function, and to control annunciators and actuators associated with this reader.
- Communication interface: The communication interface components provides the communication instructions to a reader that allow it to interact with external entities, via a controller, to transfer its stored data and to accept commands and send back the corresponding response.
- Power: Supplies power to the reader components.

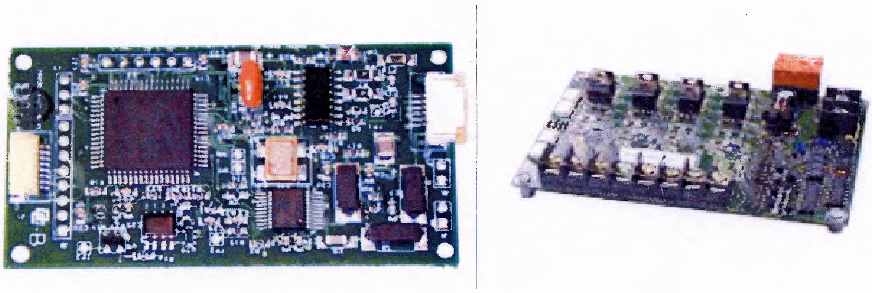


Figure 2.5 Reader's circuit.

2.1.3 Tag Reader's Antenna

A tag reader communicates to a tag through its antenna, a separate device that is physically attached to a reader, at one of its antenna ports, by means of a cable (6 to 25 feet). A reader's antenna as shown in Figure 2.6 is also called the reader's coupling element because it creates an electromagnetic field to couple with the tag. An antenna broadcasts the reader transmitter's RF signal into its surroundings and receives tag responses on the reader's behalf. Therefore, proper positioning of the antennas, not the readers, is essential for good read accuracy. Some stationary readers might have an in-built antenna [8].

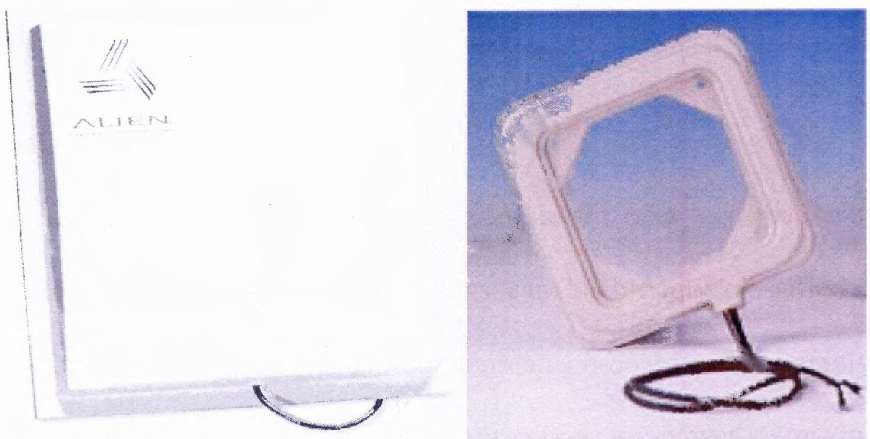


Figure 2.6 Examples of reader's antenna.

2.1.4 Host and Software System

The host and software system is an all-encompassing term for the hardware and software component that is separate from the RFID hardware; the system is composed of following four main components as shown in Figure 2.7 [8]:

- Edge interface/system: Integrates the entire host and software systems with the RFID hardware.
- Middleware: can be broadly defined as everything that lies between the edge interface and the enterprise back-end interface.
- Enterprise back-end interface: used to integrate the middleware components with the enterprise back-end component.
- Enterprise back end: encompasses the complete suite of applications and IT systems of an enterprise.

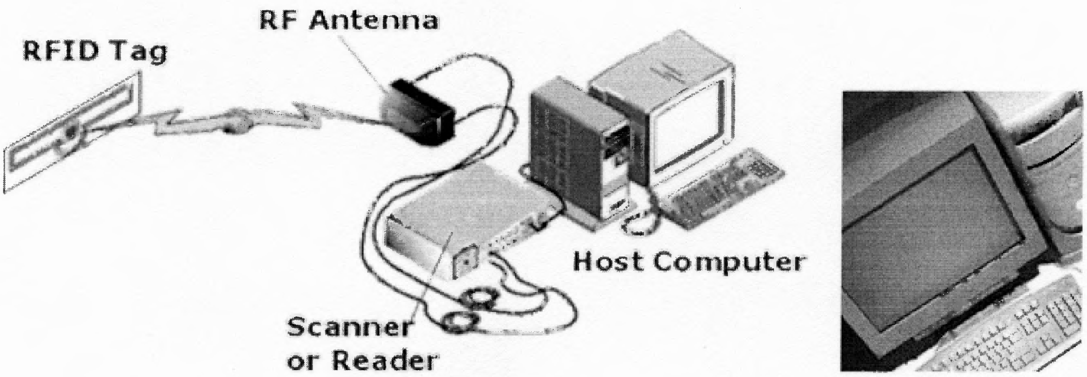


Figure 2.7 Hosts and software systems.

2.1.5 Communication Infrastructure

This component provides connectivity and enables security and systems management functionalities for different components of RFID system, and is therefore an integral part of the system. It includes the wired and wireless network, and serial connections between readers, controllers, and computers. The wireless network type can range from a personal area network (PAN, provided by Bluetooth), to a LAN offered by 802.11x technology, to a WAN provided by 2.5G/3G. Satellite communication network, for example, using geosynchronous L-band satellites are also becoming an increasing reality for RFID systems that need to work in a very wide geographical area where existence of a pervasive reader infrastructure isn't guaranteed [8].

2.2 Frequency Spectrum for RFID systems

There are various frequency bands in which RFID systems operate, as described below [8]:

Low Frequency (LF) Band

Frequencies between 30 kHz and 300 kHz are considered low. RFID systems commonly use the 125 kHZ to 134 kHz frequency range. RFID systems operating at LF band generally use passive tags, have low data-transfer rate from the tag to the reader, and are especially good if the operating environment contains metals, liquid, dirt, snow, or mud. Because of the maturity of this type of tag, LF tag systems probably have the largest installed base and the LF range is accepted worldwide.

High Frequency (HF) Band

HF ranges from 3 MHz to 30 MHz, with 13.56 MHz being the typical frequency used for HF RFID system. A typical HF RFID system uses passive tags, has a slow data-transfer rate from the tag to reader, and offers fair performance in the presence of metal and liquids. HF systems are also widely used, especially in hospitals (where it does not interfere with the existing equipment). The HF frequency range is accepted worldwide.

The next frequency band is called Very High Frequency (VHF) band and lies between 30 and 300 MHz. Unfortunately, none of the current RFID systems operate in this range.

Ultra High Frequency (UHF) Band

UHF ranges from 300 MHz to 1 GHz. A typical UHF RFID system operates at 915 MHz in the United States and at 868 MHz in Europe. A typical active UHF RFID system operates at 315 MHz and 433 MHz. A UHF system can therefore use both active and passive tags and has a fast data-transfer rate between the tag and the reader, but performs poorly in the presence of metals and liquid (not true for 315 MHz and 433 MHz). UHF range isn't accepted worldwide. E-ZPass auto identification system for toll collection operates at 915 MHz.

Microwave Frequency Band

Microwave frequency range includes frequencies upward from 1 GHz, a typical microwave RFID system operates either at 2.45 GHz or 5.8 GHz, although the former is more common, can use both semi-active and passive tags, has the fastest data-transfer rate between the tag and the reader, and performs very poorly in the presence of metals and liquid. The 2.4 GHz frequency range is called Industrial, Scientific and Medical (ISM) band and is accepted worldwide.

2.3 Advantages of RFID

Each particular advantage is examined from different perspectives to provide an in-depth understanding of RFID systems [8].

Contactless

An RFID tag doesn't need to establish physical contact with the tag reader to transmit its data, which proves advantageous from the following perspective:

- No wear and tear,
- No slowing down of operation,
- Automatic reading of several tags in a short period of time.

In summary, RFID instantly offers several benefits just by being contactless. In addition, this is clearly a current advantage of this technology.

Writable data

Rewritable RFID tags that are currently available can be rewritten from 10,000 to 100,000 times or more! Although writable data tags might seem like an advantage, they are not widely used today because of the following reasons:

- Business justification of tag recycling,
- Security issues,
- Necessity of dynamic writes,
- Slower operating speeds.

However, it is certain possible that some RFID applications exist for which using rewritable tags makes good business as well as technical sense for example, monitoring the production quality control of bottling operation for a medical drug.

Absence of line of sight

It is probably the most distinguished feature of RFID. An RFID reader can read a tag through obstructing materials that are RF-transparent for the frequency used. This property proves useful for inspecting the content of a container without opening it. There are some privacy concerns with this feature that we would discuss later. However, in some situations we require LoS to help configure the tag read distance, reader energy, and reader antenna to counter the environmental impact, for example, UHF tags and the presence of large amount of RF-reflecting material like metals.

Variety of read ranges

A LF passive RFID tag has a read distance of few inches; for a HF passive tag, distance is about 3 feet; the reading distance of an UHF passive tag is about 30 feet, a UHF active tag in extreme cases can be read at a distance of 300 feet. This wide array of reading distance makes it possible to apply RFID to a wide variety of application. Today, the tags for every frequency type are commercially available. In addition, the location of an active or passive tag can be associated with a reader that reads this tag.

Wide data-capacity range

A typical passive tag can contain a few bits to hundreds of bits for data storage. Rewritable miniature tag from Maxwell operating in the 13.56 MHz range can carry up to 4K bytes of data within 2.5 mm $\times$ 2.5 mm space. An active tag has not theoretically data-storage limit because the physical dimensions and capabilities of an active tag are not limited, provided the tag is deployable.

Support for multiple tag reads

Using what is called an anti-collision algorithm, an RFID reader can automatically read several tags in its read range in a short period of time. This benefit allows the data from a collection of tagged objects, whether stationary or moving, to be read by a reader, thus preventing any need to read one tag at a time. This can be accomplished by controlling a variable phase delay in the tag's response.

Rugged

A passive tag has few moving parts and can therefore withstand environmental conditions such as heat (-40^0 F to 400^0 F), humidity, corrosive chemicals, mechanical vibrations, and shock to a fair degree. On the other hand, an active/semi-active tag that has on-board electronics with a battery is generally more susceptible to damage.

Perform smart tasks

The on-board electronics on active tags can be used to perform specialized tasks such as monitoring its surrounding environment (for example, detecting motion, temperature, humidity etc). For example, suppose an active tag is attached to high-value item for theft detection, if somebody moves, it will detect the motion and start broadcast this event to surroundings.

Read accuracy

In the media, the read accuracy of RFID is mentioned variously as "very accurate", "100 percent accurate" etc, but no objective study show how accurate RFID reads really are. Factors on which read accuracy depend are tag type, tagged object, operating environment and consistency.

2.4 Limitations of RFID

RFID technology is not without its limitations. Some of the limitations that exist today have good potential to be improved as technology advancement takes place. Therefore, one can look at these limitations as opportunities for creative solutions [8].

Poor performance with RF-opaque and RF-absorbent objects

This is frequency dependent behavior. If high UHF and microwave are used, and the tagged object is made up of RF-opaque material such as metal or some other type of RF-absorbent material such as water, an RFID reader might partially or completely fail to read the tag data. It is expected that improvements in the tag technology will over come several of the current issues related to RF-opaque and RF-absorbent objects.

Limitation on the actual read tag reads

The number of tags that a reader can identify uniquely per unit time is limited. For example, today, a reader on average can uniquely identify a few to several tags per second. To achieve this number, a reader has to read tag's response which could be varied by additional time delay.

Impacted by hardware interference

RFID reader can exhibit reader collision, if improperly installed. A reader collision happens when the coverage area of two readers overlap and the signal of one reader interfere with other in this common coverage area. This issue has been attempted to be solved by assigning various time delays in response for the tags placed in a nearby region.

Limited penetrating power of the RF energy

The penetrating power of RF energy finally depends on the transmitter power of the reader and duty cycle. A reader might fail to read some cases on a pallet if they are stacked too deep. This number will also vary from country to country, depending on the restriction of the reading power and duty cycle.

Immature technology

It is a practical issue facing RFID technologies today, an RFID solution can only be as good as the hardware currently available from the vendors. The vendors are doing their best to develop improved products, but maturity might not be available for some time to come. Same tags from different vendors might perform differently.

Readers have come a long way in past two years, gradually transmitting from a single interrogator to a well-defined network device with built-in intelligence to support several functions needed for the RFID application. Stabilization of the technology in terms of the product and globally acceptable standard will eradicate this issue, but a prediction of the timeline for that is difficult to make.

Impacted by Environmental factors

If the operations environment has large amount of metals, liquid, and so on, those might affect the read accuracy of tags, depending upon the frequency. The reflection of reader antenna signals on RF-opaque objects causes what is known as multipath. In addition, the existence of almost any type of wireless network within the operating environment can interfere with the reader operation.

2.5 Applications of RFID

The potential application of RFID technology is limited only to one's imagination. Although a popular belief holds that RFID is best suited to supply-chain management or consumer packaged good industries, the range of current RFID applications goes far beyond these areas as depicted in Figure 2.8 [8].

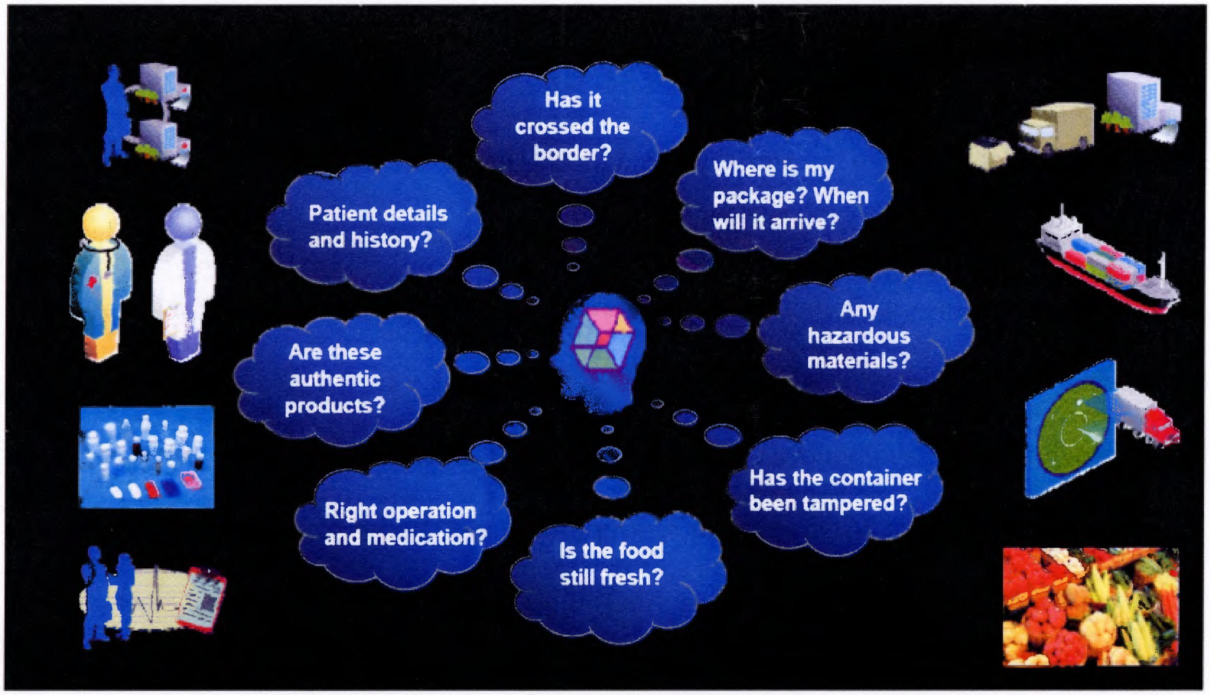


Figure 2.8 Questions in which RFID can help.

Currently found in applications from work tracking and waste management, to vehicle security and highway toll systems, radio frequency identification (RFID) technology is increasingly becoming a familiar part of our lives, both at work and at home. RFID, which creates a dynamic link between people, objects and processes, has established itself as a primary player in the future of data collection, identification and analysis systems.

The uses for RFID technology are limitless. More flexible and easier to use than bar coding or other forms of data collection, RFID is a multi-purpose technology as can be seen from Figure 2.9. While this presentation will discuss the capabilities of RFID and site some specific examples, keep in mind that the full potential of RFID technology has only just started to be realized -- perhaps some of the greatest applications and unique solutions based on RFID have yet to come to market.

Figure 2.9 Application of RFID and some of the daily use RFID equipments.

RFID is a technology that enables wireless data capture and transaction processing. There are two main areas of application, defined broadly as proximity (short range) and vicinity (long range). Short range or proximity applications are typically access control applications. Long range or vicinity applications can generally be described as track and trace applications, but the technology provides additional functionality and benefits for product authentication [11].

Pharmaceutical industry

The e-pedigree is a hot topic in the pharmaceutical industry. The origin of pharmaceuticals has to be verified on the item-level. There is also need for anti-counterfeiting procedures. The utilization of RFID empowers safe and secure supply and proper administration of pharmaceuticals.

Supply chain management

Supermarkets are tagging pallets, cases and other returnable transit items, such as plastic crates used for fresh foods. Tagging the crates gives total asset visibility and allows better management of the asset pool. The ability to write to the tag also allows the addition of information such as the contents of the crate, sell-by date and manufacturer. Linking this type of information to the store's inventory management systems can ensure that goods are moved to the shelves in strict rotation and reduce spoilage and out-of-stocks.

Library and media management

RFID is used in many libraries to automate the issue and return of books, videos and CDs and to give real-time visibility for library inventory. Until recently, books and CDs have been identified using bar coded labels, each of which had to be read individually with a bar code reader. With RFID, books and CDs can be checked in and out automatically and inventory control can be automated using scanners on shelves or with their hand-held counterparts. The result is a reduction in the need for personnel and a much higher degree of accuracy in inventory management.

Garment tags

Incorporating RFID tags into garment labels or even into the garment itself can be a valuable tool for brand owners. A tag inserted at the garment manufacturing plant can identify its source. By using the tag's unique identification number, the garment can be certified as authentic, which enables the identification and control of counterfeits. The tags enable inventory visibility throughout the supply chain, reducing shrinkage and out-of-stocks.

Baggage tagging

Many airlines have run RFID trials over the past few years to prove the efficacy of the systems employed in the air transport environment. Tests have shown first-read rates of over 99% with RF tags compared to less than 90% for bar code-only tags. Similarly, RFID is already being used to track passenger progress through airports, reducing the number of passengers arriving late at the gate and in so doing ensuring that planes leave on time.

Toll collection

E-ZPass system is an example of effective toll collection, currently over 2.5 millions tags are in use in NY/NJ/Connecticut metropolitan area. Asides from toll collection, TRANSMIT system [5] has the capability to collect real time traffic data and identify incidents.

Credit cards

American Express has introduced RFID tag based credit card in 2005. It allows transaction to take place without exchanging the card between vendor and the customer.

Next-Generation RFID

- RFID tag promises to reduce the number of surgery errors -- which apparently kills several thousand people every year. A radio frequency tag that patients can affix like a bandage to ensure doctors perform the right surgery on the right person has already won government approval.

- Hoping to prevent the loss of a child through kidnapping or more innocent circumstances, a few schools have begun monitoring student arrivals and departures using technology similar to that used to track livestock and pallets of retail shipments.

- RFID chips for animals are extremely small devices injected via syringe under skin. Under a government initiative to control rabies, all Portuguese dogs must be RFID tagged by 2007. When scanned the tag can provide information relevant to the dog's history and its owner's information.

- RFID technology can provide independent, non-stop systems for security, parking, and access control. RFID tags can be affixed to automobiles for activating hands-free access to communities and parking lots. The RFID reader can also trigger surveillance cameras or video recorders whenever a vehicle enters or exits the controlled area [12].

- Rental car companies can use RFID on the glass of the vehicle for identification.

2.6 Privacy Concerns

In a global context, "privacy" is understood in different ways by different individuals, across many cultures and sectors. Privacy has traditionally been discussed along the two issues.

- As a fundamental human right, including the right to be free from unreasonable search and seizure or intrusion.

- As protection of personal information [4].

The use of RFID technology has engendered considerable controversy and even product boycotts by consumer privacy advocates such as Katherine Albrecht and Liz McIntyre of CASPIAN who refer to RFID tags as "spychips".

The four main privacy concerns regarding RFID are:

- The purchaser of an item will not necessarily be aware of the presence of the tag or be able to remove it.
- The tag can be read at a distance without the knowledge of the individual.
- If a tagged item is paid for by credit card or in conjunction with use of a loyalty card, then it would be possible to tie the unique ID of that item to the identity of the purchaser.
- The EPC global system of tags create, or are proposed to create, globally unique serial numbers for all products, even though this creates privacy problems and is completely unnecessary for most applications [13].

Most concerns revolve around the fact that RFID tags affixed to products remain functional even after the products have been purchased and taken home, and thus can be used for surveillance and other harmful purposes.

A number of countries have begun to embed RFID devices in new biometric passports, to facilitate efficient machine reading of personal data. The RFID-enabled passport uniquely identifies its holder, and in the proposal currently under consideration, will also include a variety of other personal information. This could greatly simplify some of the abuses of RFID technology, and expand them to include abuses based on machine reading of data such as a person's nationality. For example, a mugger operating near an airport could target victims who have arrived from wealthy countries, or a terrorist could design a bomb which functioned when approached by persons from a particular country [13].

There might be potential health risks to customers and staff from the hundreds of RFID tag readers in a supermarket full of "intelligent shelves" constantly transmitting, as they read each unique RFID tag in sequence.

CHAPTER 3

LOCATION SENSING

3.1 Location Sensing Techniques

Emerging mobile computing applications often need to know where things are physically located. To meet this need, many different location systems and technologies have been developed. Triangulation, scene analysis, and proximity are the three principal techniques for automatic location-sensing. Location systems may employ them individually or in combination. These are described below [14]:

Triangulation

The triangulation location-sensing technique uses the geometric properties of triangles to compute object locations. Triangulation is divisible into the subcategories of lateration, using distance measurements, and angulation, using primarily angles as variables.

Lateration

Lateration computes the position of an object by measuring its distance from multiple reference positions. Calculating an object's position in two dimensions requires distance measurements from three non-collinear points as shown in Figure 3.1. In three dimensions, distance measurements from four non-coplanar points are required. Domain-specific knowledge may reduce the number of required distance measurements.

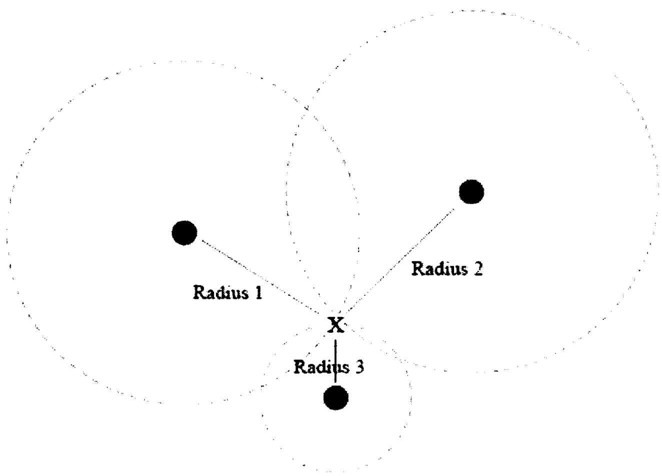


Figure 3.1 Determining 2D position using lateration requires distance measurements between the object 'X' and 3 non-collinear points.

There are three general approaches to measuring the distances required by this technique:

- **Direct:** Direct measurement of distance uses a physical action or movement. For example, a robot can extend a probe until it touches something solid or take measurements with a tape measure. Direct distance measurements are simple to understand but difficult to obtain automatically due to the complexities involved in coordinating autonomous physical movement.

- **Time-of-Flight:** Measuring distance from an object to some point P using time-of-flight means measuring the time it takes to travel between the object and point P at a known velocity.

- **Attenuation:** The intensity of an emitted signal decreases as the distance from the emission source increases. The decrease relative to the original intensity is the attenuation. A free space radio signal emitted by an object will be attenuated by a factor proportional to $1/r^2$ when it reaches point P at distance r from the object.

Angulation

Angulation is similar to lateration except, instead of distances, angles are used for determining the position of an object. In general, two dimensional angulations requires two angle measurements and one length measurement such as the distance between the reference points as shown in Figure 3.2. In three dimensions, one length measurement, one azimuth measurement, and two angle measurements are needed to specify a precise position.

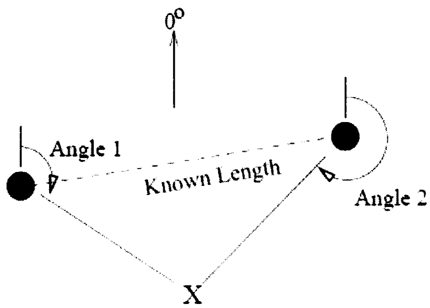


Figure 3.2 Example of 2D angulation illustrates locating object 'X' using angles relative to a 0° reference vector and the distance between two reference points. 2D angulation always requires at least two angles and one distance measurement to unambiguously locate an object.

Scene Analysis

The scene analysis location-sensing technique uses features of a scene observed from a particular vantage point to draw conclusions about the location of the observer or of objects in the scene. In static scene analysis, observed features are looked up in a predefined dataset that maps them to object locations. In contrast, differential scene analysis tracks the difference between successive scenes to estimate location. Differences in the scenes will correspond to movements of the observer and if features in the scenes are known to be at specific positions, the observer can compute its own position relative to them.

Proximity

A proximity location-sensing technique entails determining when an object is “near" a known location. The object's presence is sensed using a physical phenomenon with limited range. There are three general approaches to sensing proximity:

1. *Detecting physical contact*: Detecting physical contact with an object is the most basic sort of proximity sensing. Technologies for sensing physical contact include pressure sensors, touch sensors, and capacitive field detectors.

2. *Monitoring wireless cellular access points*: Monitoring when a mobile device is in range of one or more access points in a wireless cellular network.

3. *Observing automatic ID systems*: A third implementation of the proximity location-sensing technique uses automatic identification systems such as credit card point-of-sale terminals, computer login histories, landline telephone records, electronic card lock logs, and identification tags such as electronic highway E-Toll systems, UPC product codes, and injectable livestock identification capsules.

3.2 Location Sensing Systems

Active Badge (Infrared)

A solution to the problem of automatically determining the location of an individual has been to design a tag in the form of an 'Active Badge' that emits a unique code for approximately a tenth of a second every 15 seconds (a beacon). These periodic signals are picked up by a network of sensors placed around the host building. A master station, also connected to the network, polls the sensors for badge 'sightings', processes the data, and then makes it available to clients that may display it in a useful visual form. The badge was designed in a package roughly 55mm x 55mm x 7mm and weighs a comfortable 40g. As with any diffuse infrared system, Active Badges as shown in Figure 3.3 have difficulty in locations with fluorescent lighting or direct sunlight because of the spurious infrared emissions these light sources generate. Diffuse infrared has an effective range of several meters, which limits cell sizes to small- or medium-sized rooms. In larger rooms, the system can use multiple infrared beacons. They can operate up to a range of 6 m [15].

Figure 3.3 Active Badge System.

Active Bat

It uses an ultrasound time-of-flight lateration technique to provide more accurate physical positioning than Active Badges. Users and objects carry Active Bat tags as shown in Figure 3.4. In response to a request the controller sends via short-range radio, a Bat emits an ultrasonic pulse to a grid of ceiling-mounted receivers. At the same time the controller sends the radio frequency request packet, it also sends a synchronized reset signal to the ceiling sensors using a wired serial network. Each ceiling sensor measures the time interval from reset to ultrasonic pulse arrival and computes its distance from the Bat. The local controller then forwards the distance measurements to a central controller, which performs the lateration computation. Statistical pruning eliminates erroneous sensor measurements caused by a ceiling sensor hearing a reflected ultrasound pulse instead of one that traveled along the direct path from the Bat to the sensor [14].

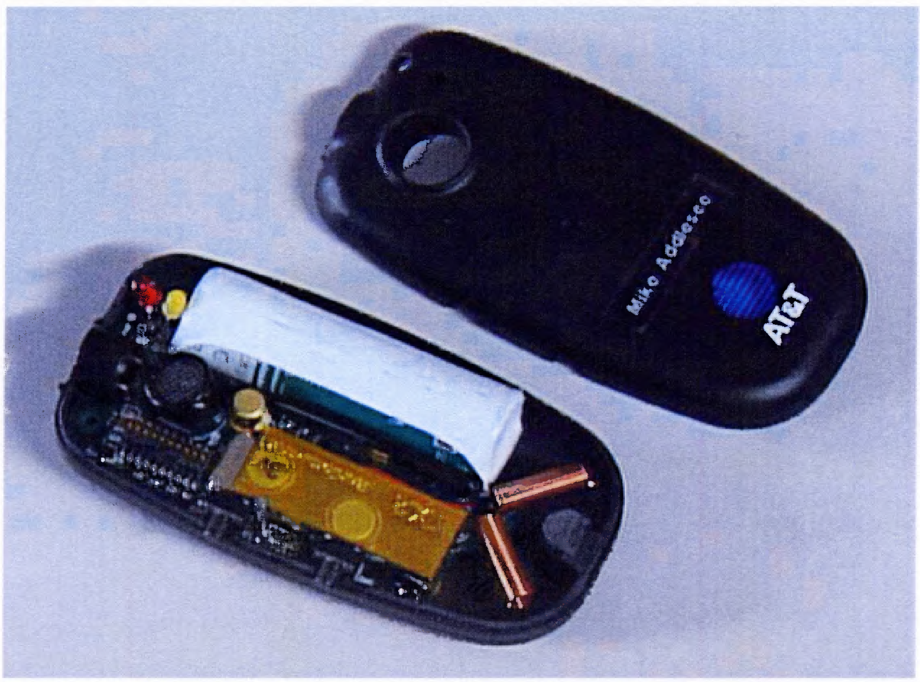


Figure 3.4 Active Bat Equipment.

Cricket

Complementing the Active Bat system, the Cricket Location Support System shown in Figure 3.5 uses ultrasound emitters to create the infrastructure and embeds receivers in the object being located. Cricket uses the radio frequency signal not only for synchronization of the time measurement, but also to delineate the time region during which the receiver should consider the sounds it receives. Cricket implements both the lateration and proximity techniques. Receiving multiple beacons let receivers triangulate their position [14].

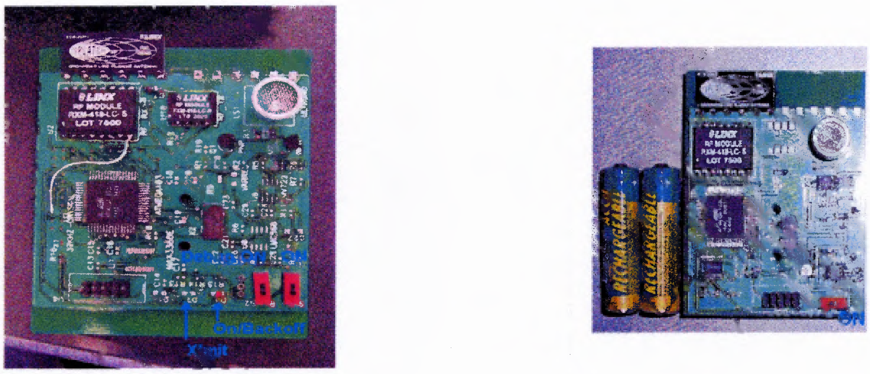


Figure 3.5 Cricket's Beacon and Cricket's Listener.

Radar

A Microsoft Research group has developed RADAR, a building-wide tracking system based on the IEEE 802.11 WaveLAN wireless networking technology. RADAR measures, at the base station, the signal strength and signal-to-noise ratio of signals that wireless devices send, then it uses this data to compute the 2D position within a building. It requires only a few base stations, and it uses the same infrastructure that provides the building's general purpose wireless networking [14].

Smart Floor

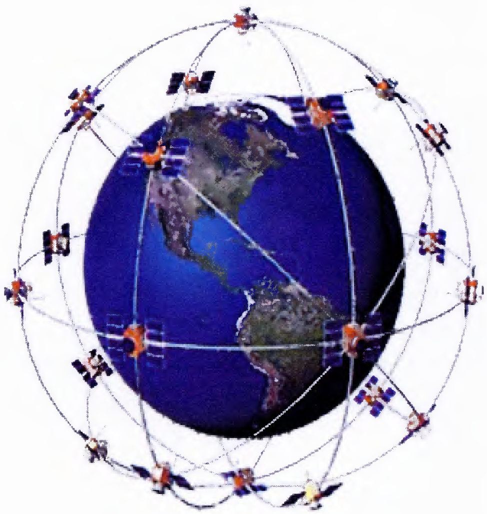
Smart Floor proximity location system embedded pressure sensors capture footfalls, and the system uses the data for position tracking and pedestrian recognition. This unobtrusive direct physical contact system does not require people to carry a device or wear a tag. However, the system has the disadvantages of poor scalability and high incremental cost because the floor of each building in which Smart Floor is deployed must be physically altered to install the pressure sensor grids [16].

GPS (Global Positioning System)

Our ancestors had to go to pretty extreme measures to keep from getting lost. They erected monumental landmarks, laboriously drafted detailed maps and learned to read the stars in the night sky. Things are much, much easier today. For less than $100, you can get a pocket-sized gadget that will tell you exactly where you are on Earth at any moment. As long as you have a GPS receiver and a clear view of the sky, you'll never be lost again.

The Global Positioning System (GPS) as shown in Figure 3.6 is actually a constellation of 27 Earth-orbiting satellites (24 in operation and three extras in case one fails). United States Department of Defense developed the system, officially named NAVSTAR GPS (Navigation Signal Timing and Ranging GPS), and the satellite constellation is managed by the 50th Space Wing at Schriever Air Force Base [17]. Although the cost of maintaining the system is approximately US$400 million per year, including the replacement of aging satellites, GPS is available for free use in civilian applications as a public good.

Each of these 3,000 to 4,000-pound solar-powered satellites circle the globe at about 12,000 miles (19,300 km), making two complete revolutions every day. The orbits are arranged so that at any time, anywhere on Earth, there are at least four satellites "visible" in the sky. A GPS receiver's job is to locate four or more of these satellites, figure out the distance to each, and use this information to deduce its own location. This operation is based on a simple mathematical principle called **trilateration.**



(a)

(b)

(c)

Figure 3.6 GPS Technology (a) Satellites covering Earth (b) Coverage area of a satellite (c) GPS instrument.

Limitations of the systems being used:

Infrared (Active Badge):

- Line-of-sight requirement,
- Short-range signal transmission.

Ultrasonic (Active Bat and Cricket):

- Use of ultrasonic requires a great deal of infrastructure in order to be highly efficient and accurate; the cost is extremely high that makes it inaccessible to most of the users.

Radar:

- Overall accuracy is not as optimal as desired. For example, Radar's implementation can place object to within about 3 meters of their actual position with 50 percent probability,
- Requires more time.

Smart floor:

- Poor scalability, high incremental cost.

GPS:

- GPS suffers from various factors such as clock errors, Ephemeris errors, receiver errors, atmospheric errors which collectively decreases the performance of the system,
- Not useful for indoor location sensing.

3.3 Location Sensing System Using RFID

Researchers have been working on the technology of RFID for creating an indoor location sensing system. SpotOn and Landmarc are two of the location sensing systems using RFID and are briefly explained below:

SpotOn

It uses an aggregation algorithm for three dimensional location sensing based on radio signal strength analysis. Researchers have focused mostly on the hardware and embedded systems aspect. In this approach, objects are located by homogenous sensor nodes without central control. SpotOn tags use received radio signal strength information as a sensor measurement for estimating inter-tag distance. However, a complete system has not been made available as of now [3].

Landmarc

Landmarc [2] is a location sensing prototype system that uses Radio Frequency Identification (RFID) technology for locating objects inside buildings by utilizing the concept of reference tags. It proposed a new idea of finding the location of tracking tag with the help of RFID active tags. The initial idea was taken from this paper, but there were many differences between the system setup of work being performed here and the one reported in Landmarc. Basic differences between Landmarc and the proposed system are:

- Landmarc uses active tags and proposed system consists of passive tags,
- Landmarc reading range is 150 feet but here it is around 6 inches (0.5 feet),

- RFID readers operate at the frequency of 308 MHz (UHF) in Landmarc, proposed system has 13.56 MHz (HF) as an operating frequency,

- The tag readers Landmarc uses is provided with the digital control of read range via a software and API with 8 incremental read ranges.

- Landmarc proposed the idea of locating a tag in a two-dimensional environment, but the idea that is proposed here extends the location estimation to three dimensions.

Concept of Landmarc:

Since readers are quite expensive, proposed system employed extra fixed location reference tags instead, which acted as additional reference points in the system. This system doesn't require large number of readers and gives better accuracy. Placement of readers and reference tags is very important though in achieving higher accuracy. .

System is based upon the signal strength information re-transmitted from each tag back to the reader. Consider "n" RF readers, "m" reference tags and a tracking tag and let the signal strength vector of a tracking tag is defined as $S = (S_1, S_2, \ldots, S_n)$, where S_i denotes the signal strength of the tracking tag received at reader "*i*", where $i \in (1, n)$. For the reference tags, denote the corresponding signal strength vector read by a particular reader as $\Theta = (\Theta_1, \Theta_2, \ldots \Theta n)$ where Θ_i denotes the signal strength of the reference tag read by reader "i".

Defining $E_j = \sqrt{\sum_{i=1}^{n} (\theta_i - S_i)^2}$ where $j \in (1, m)$ as Euclidian distance in signal strength between a tracking tag and a reference tag "j". Let *E* denotes the location relationship between the reference tags and the tracking tag, i.e., the nearer reference tag to the tracking tag is supposed to have a smaller *E* value. When there are *m* reference tags, a tracking tag has its *E* vector as $E = (E_1, E_2, \ldots, E_m)$.

There are numerous issues regarding the success of the proposed ideas, one of them is where to place the reference tags in the vicinity of tracking tag, by performing various theoretical experiments, better locations were found out for such placement of reference tags. Another issue is to determine the optimum number of reference tags placed in the system to achieve the minimum error. The reference tag with the smallest value of E will be the nearest reference tag to the tracking tag. Or one could desire to get two nearest reference tags to the tracking tag. If one uses k-nearest reference tags, it will be called as k-nearest neighbor algorithm. The unknown tracking tag's co-ordinate can be found by:

$$(x, y) = \sum_{i=1}^{k} w_i (x_i, y_i)$$

where w_i is the weighting factor to the i^{th} neighboring reference tag. Now the choice of these weighting factors is another design parameter. Intuitively, w_i should depend on the E value of each reference tag in the cell, i.e., w_i is a function of the E values of k-nearest neighbors. In approach followed, weight is assigned by:

$$w_j = \frac{1/E_i^2}{\sum_{i=1}^{k} 1/E_i^2}$$

This approach provides the least error in most of the experiments, which means the reference tag with the smallest E value has the largest weight.

Location estimation error, e, is defined as the linear distance between the tracking tag's real coordinates (x_0, y_0) and the computed coordinates (x, y), given by

$$e = \sqrt{(x-x_o)^2 + (y-y_o)^2}$$

CHAPTER 4

PROPOSED WORK

4.1 Mathematical Model

Landmarc [2], as a system is based on location determination in a 2D environment. Here, extension of the concept of Landmarc from 2D environment to 3D environment is being suggested. Study of a 3D environment is essential because the world is three dimensional, if one has to track any particular object in a 3D space, one has to include the estimation of all three coordinates. Thus, the current research work initiated the extension of the theoretical formulation given in the Landmarc paper to 3D environment.

A cube is considered as a 3D space, the aim is to estimate the location of a particular object within that cube with the help of the tag readers and reference tags with known locations. Assuming that the tag readers are going to be fixed on the top plane of 3D space, a model of subdivided cube is proposed. Three fixed location readers, four reference tags (with known locations), and a single tracking tag are used for the initial phase. A $4'' \times 4'' \times 4''$ cube is being considered which is further divided into 1 inch subdivisions. Initially, distances between the tag readers and tags are mapped in terms of relative signal strengths. To demonstrate the effectiveness of RFID technology in estimation of the location, few cases have been taken into account and corresponding results are presented below based on the mathematical formulation.

Case 1: Place three tag readers on the top plane as shown in Figure 4.1 and situate four reference tags and a tracking tag on the lowest plane ($z = 0$). For fixed locations of tag readers and reference tags, the position of the tracking tag was varied; different errors have been observed for different selected positions of the tracking tag.

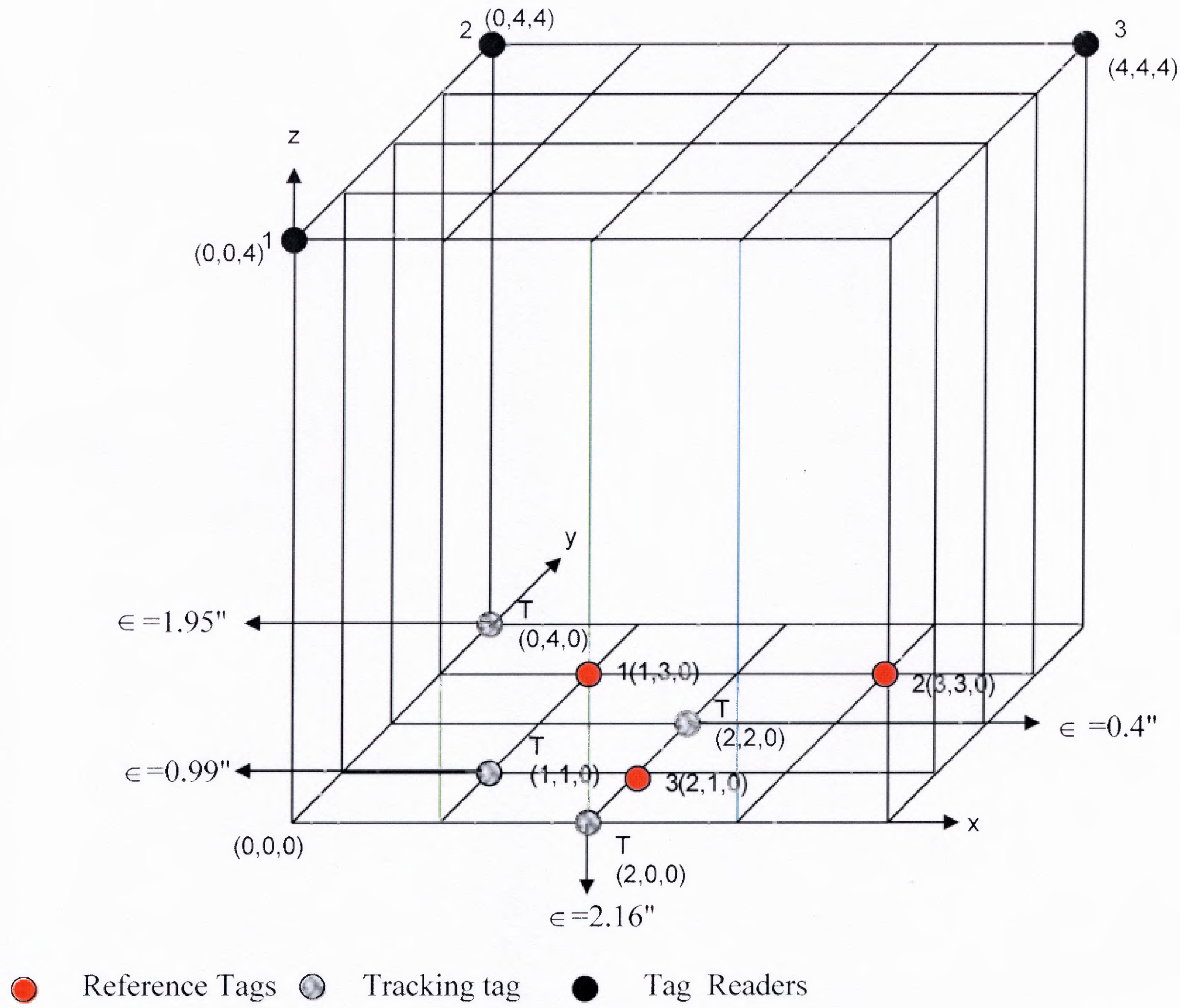


Figure 4.1 Cube with three tag readers on the top plane ($z = 4$), reference tags and tracking tag on the bottom plane ($z = 0$). Error rates are shown for selected co-ordinates.

It was observed that the denser the reference tags are with respect to tracking tag, the lesser the error rate (in inches) is. Error rates increased as the tracking tag moved further than the corresponding group of reference tags.

Error rate is estimated through the formulation given in the landmark paper by transforming the system from two dimensional to three dimensional. Error rate of 0.4 inches defines that the estimated tracked tag location is within the region of the radius of 0.4 inches centered at the actual coordinates. Using the formula

$$(x, y, z) = \sum_{i=1}^{k} w_i (x_i, y_i, z_i)$$

where w_i represents the weigh of a particular reference tag, one can estimate the coordinate of the tracking tag. Error rate is defined as a linear distance between the tracking tag's actual coordinates (x_o, y_o, z_o) and the estimated coordinate (x,y,z),

$$\in = \sqrt{(x-x_o)^2 + (y-y_o)^2 + (z-z_o)^2}$$

Case 2: The reference tags as well as the tracking tag are now placed on elevated plane ($z = 1$), keeping tag readers are on the top plane as shown in Figure 4.2. Error rates are shown for different selected positions of tracking tag and appear to decrease.

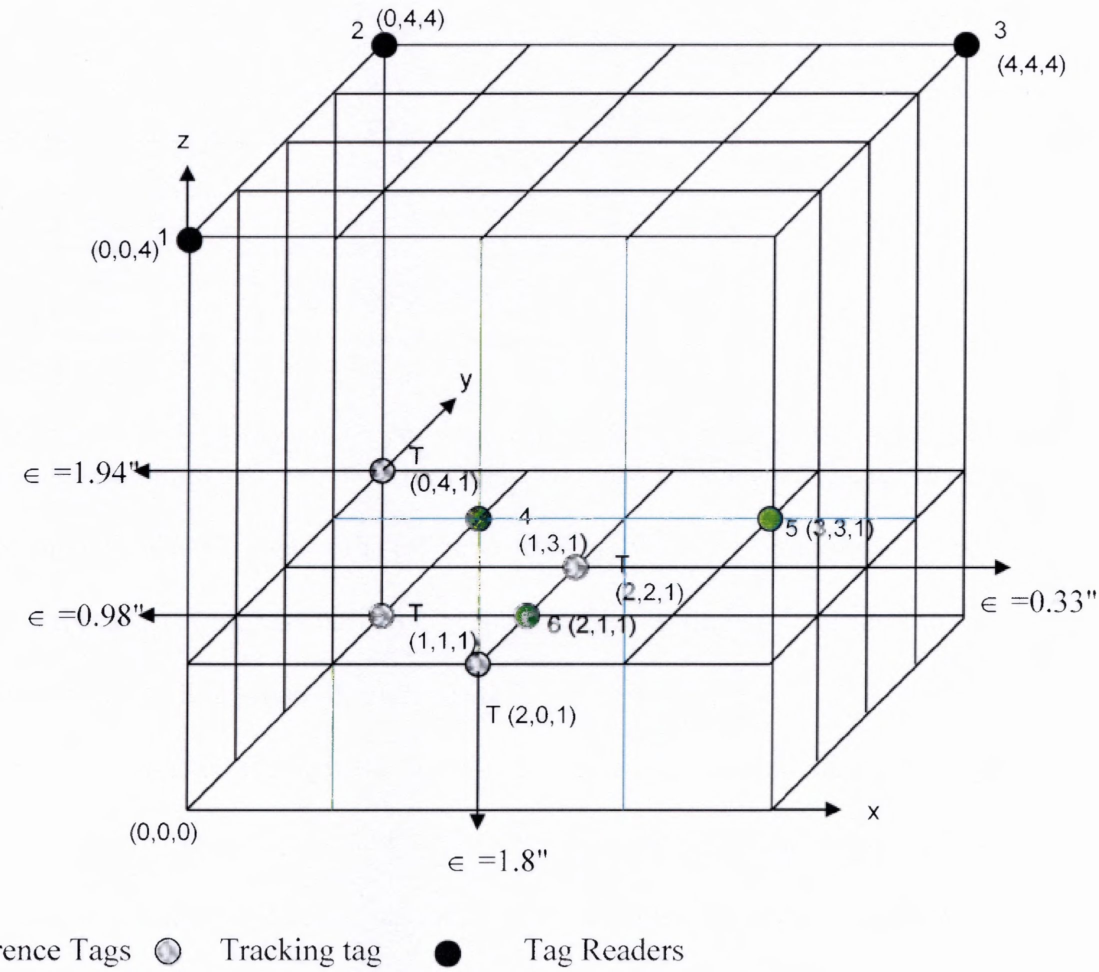


Figure 4.2 Cube with three tag readers on top plane, reference tags and tracking tag on the elevated plane ($z = 1$). Error rates are shown for selected co-ordinates.

It is observed that error rate has increased as the tracking tag is moved beyond the corresponding group of reference tags. Error rates were reduced compared to the previous experiment as the distance between the tag readers and the whole system inclusive of tracking and reference tags have now been decreased.

Case 3: In this experiment, plane of reference tags and tracking tag has been elevated again by one unit ($z = 2$) as shown in Figure 4.3.

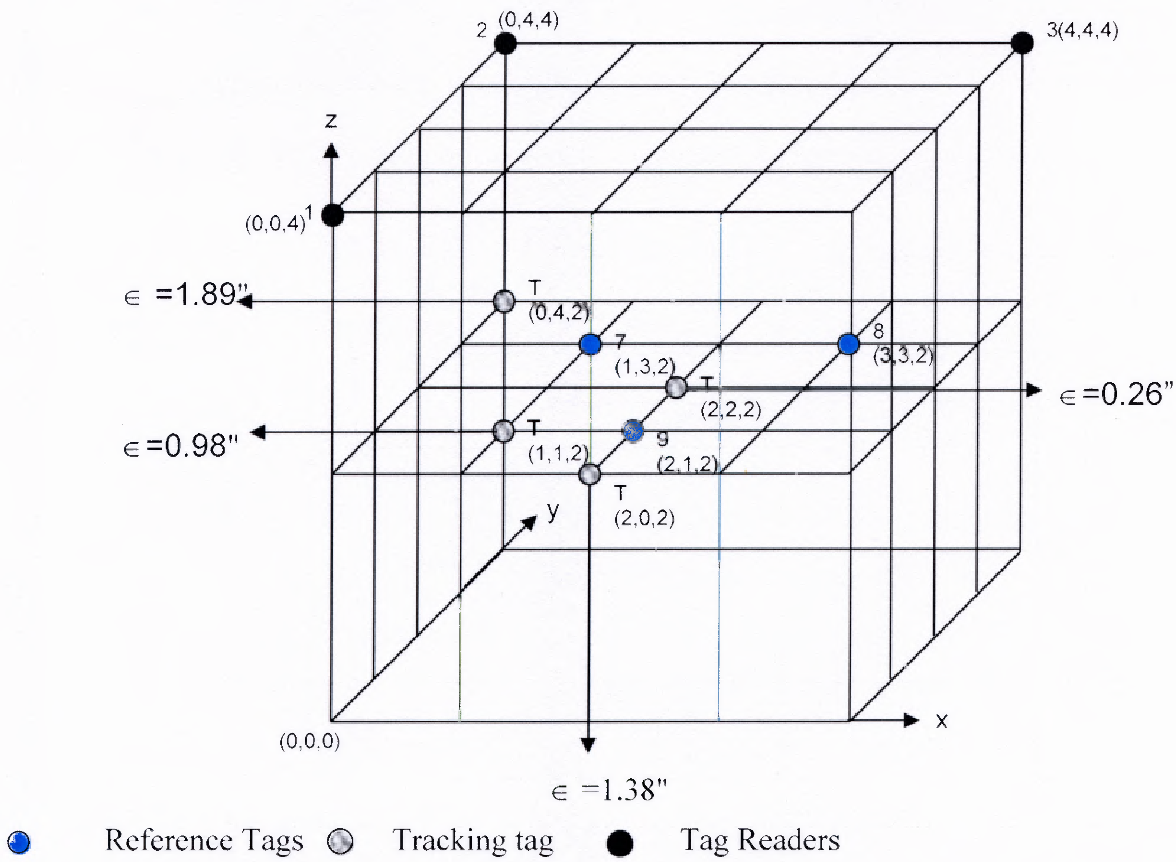


Figure 4.3 Cube with three tag readers on top plane, reference tags and tracking tag are on the middle plane ($z = 2$). Error rates are shown for selected co-ordinates.

Note that by decreasing the distance between the reference tags and the tracking tag with respect to tag readers, the overall error rates decreased. Several variations were tried to minimize the error. In the following model, after placing the tag readers on the top plane, as shown in Figure 4.4, and by placing sixteen reference tags all over the cube, numerical data was complied.

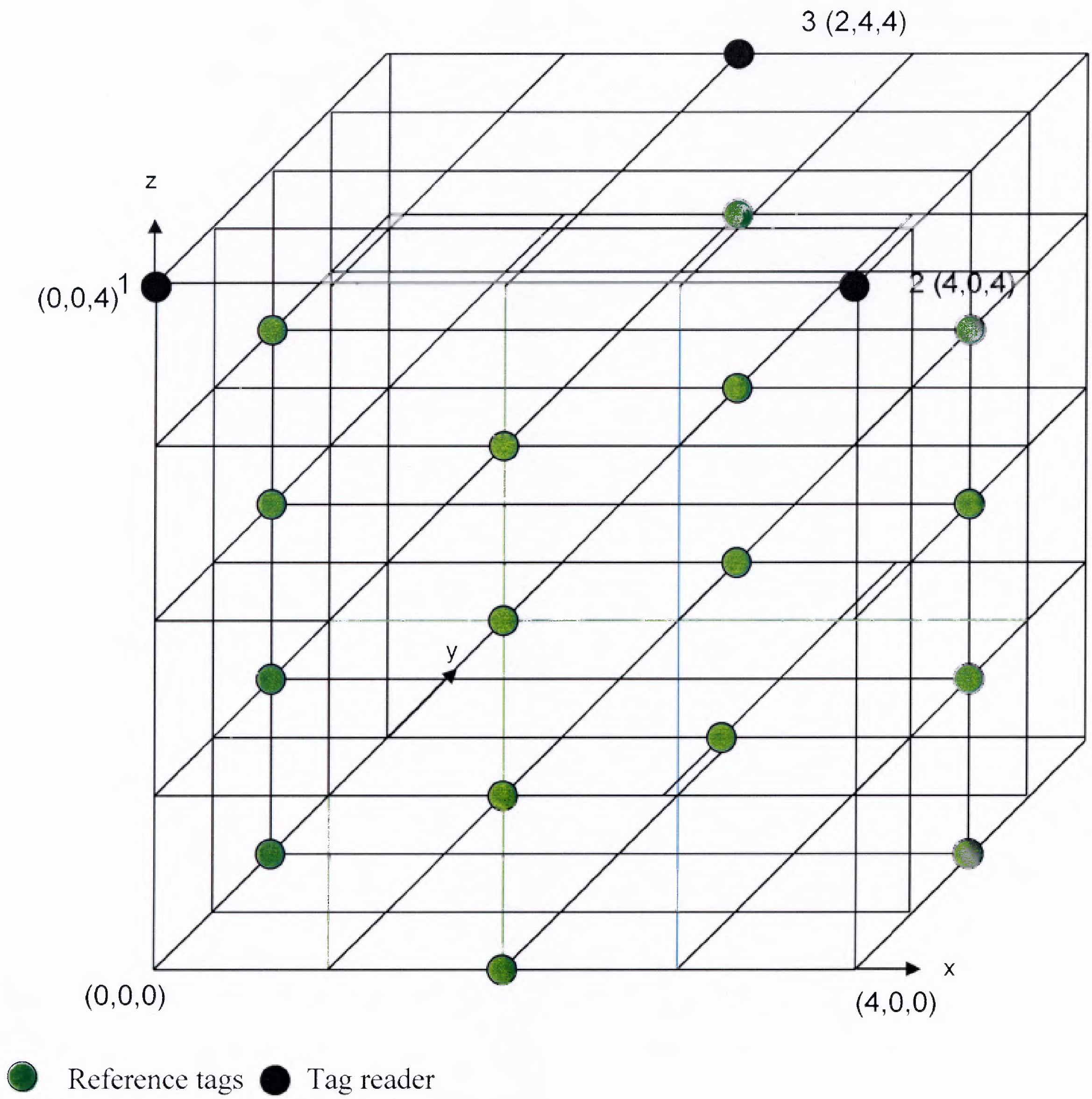


Figure 4.4 A 4" × 4" × 4"cube, with three readers on the top plane and sixteen reference tags at the middle position of each four vertical planes.

In any plane of a cube, one can place a tracking tag at 25 different points since a square plane is divided into 16 grids, and each corner of an individual grid is considered as a potential point where the tag can be placed. A cube contains five planes including the upper most one which implies that one can have 125 different positions where one can place the unknown tracking tag.

Error rate variation as a function of position has been plotted in Figure 4.5. The horizontal axis is labeled in terms of tag positions (0-25 implies that tracking tag is placed on the bottom plane with (0,0,0) as point '1' and (4,4,0) as '25'). Elevated planes are repeated in the same manner.

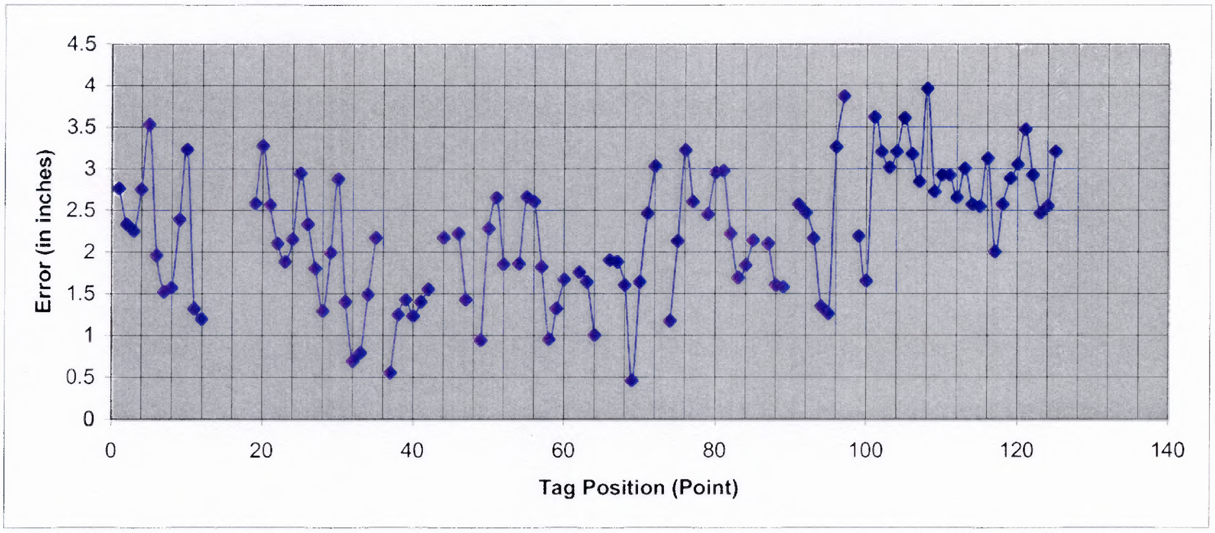


Figure 4.5 Variation in error rate versus the position of a tracking tag for configuration as Figure 4.4.

The overall error variation in Figure 4.5 is observed to be in the range of 0.5-4", however error reduction has been observed in the range of 0.5-2.75". The lowest error range corresponds to reduced physical distance variations, as well as reference tag positions which are in close proximity of the tracked tag.

Figure 4.6 represents another model where readers are again on the top plane. However, by just placing only twelve reference tags but in a diagonal manner all over the cube, improved results were observed. Again, by placing tracking tag at all 125 different positions, resulting error rates were plotted in a graph of Figure 4.7.

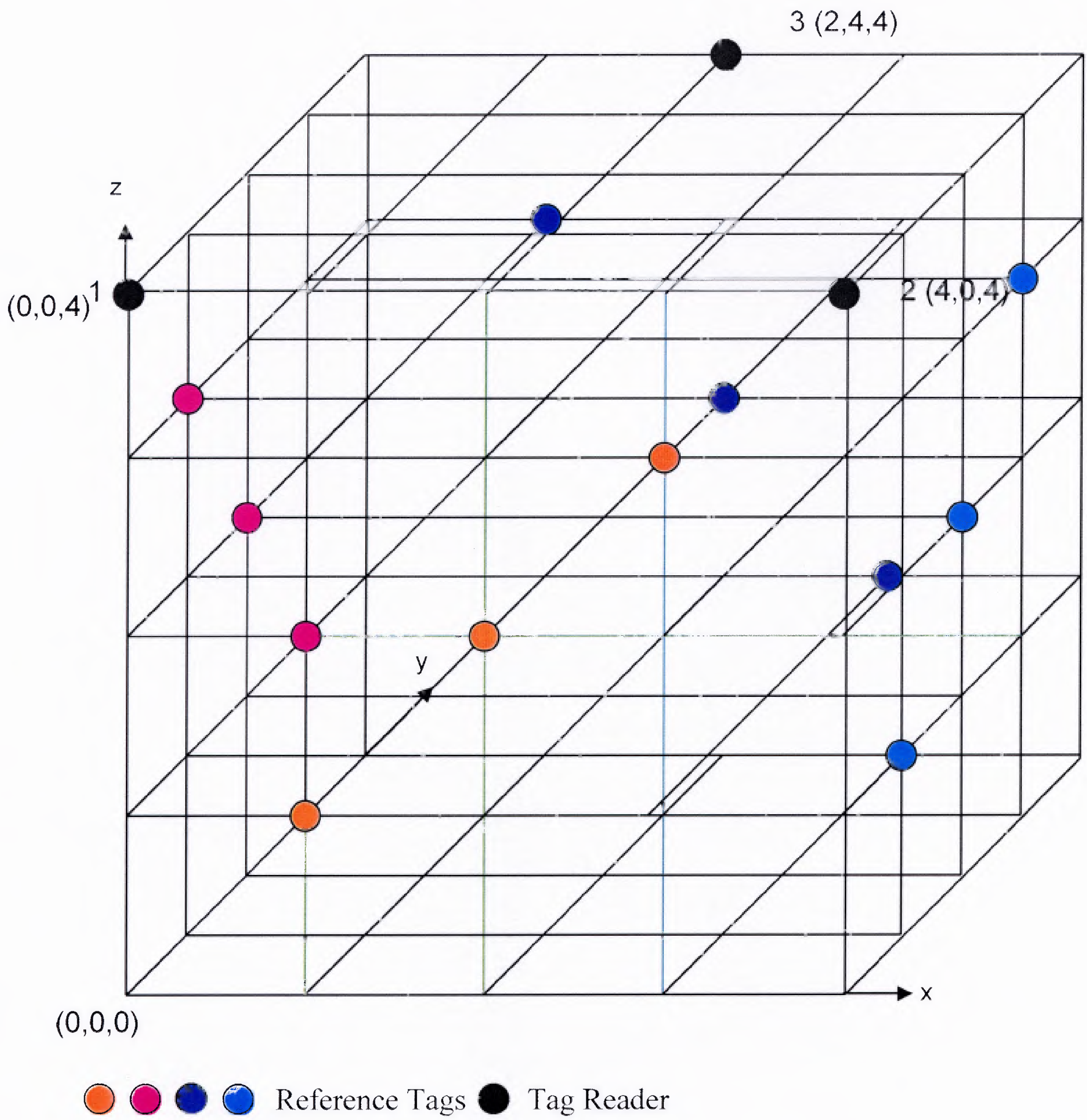


Figure 4.6 A 4" × 4" × 4" cube, with three readers on the top-plane and twelve reference tags diagonally placed on each four vertical planes.

The overall error varied in the range of 0-3" which is less than the error of previous models even less number of reference tags were used. But there is a common fact, that the 2nd, 3rd, and 4th plane has the lowest errors, due to higher density of the reference tags in the vicinity.

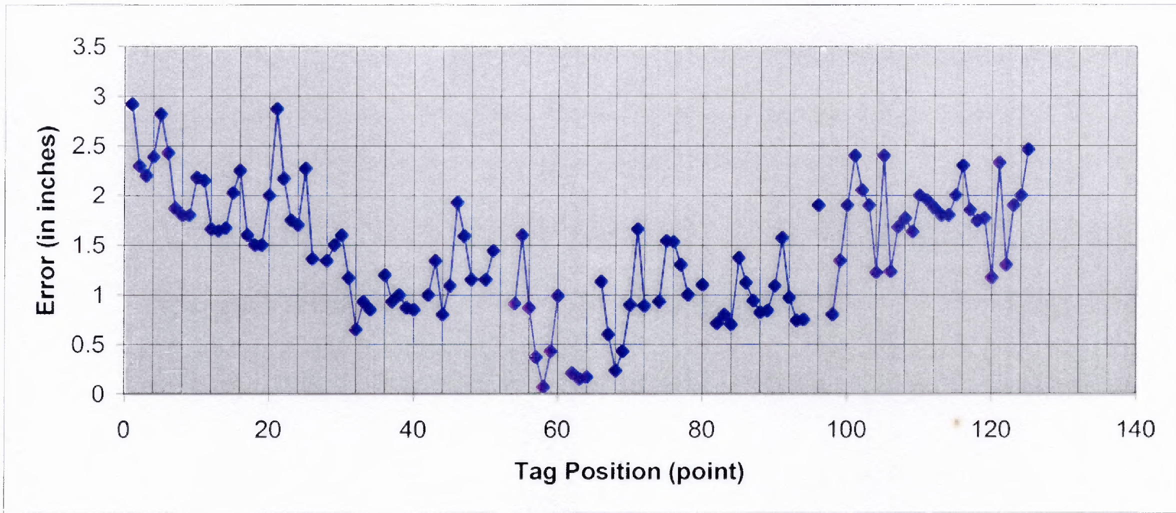


Figure 4.7 Variation in error rates versus the position of a tracking tag for the configuration as shown in Figure 4.6.

4.2 Experimental Verification

Even though the theoretical formulation in 3D presented here was developed based on Landmarc model (2D environment), the theoretical variables chosen based on distance (signal strength) have to be remapped into time domain due to experimental observations. During experimental investigation, it was observed that the signal strength variation within the measurement zone was insignificant. Rather, time width comprising of the interrogation pulse, travel time and the tag's response was kept as a variable to quantify the distance between the tag reader and the tag.

4.2.1 Experimental System Setup

Tag Readers: Tag-it™ Reader System RI-R00-320A by Texas Instruments [18].

It comprises of a reader, an antenna, an antenna matching board, and various tags. The Tag-it™ Reader Module (see Figure 4.8) handles all RF and digital functions required in order to read Tag-it™ tags. The Tag-it™ RS232 Interface Board provides signal level conversion and serial interface for the reader. The Tag-it™ Reader Module 320A consists of a transmitter, receiver and digital control module, which communicates with individual tags. The reader is designed to be integrated into and controlled by an existing host systems such as a PC, a larger computer, or other intelligent device. The basic system diagram is shown in Figure 4.9

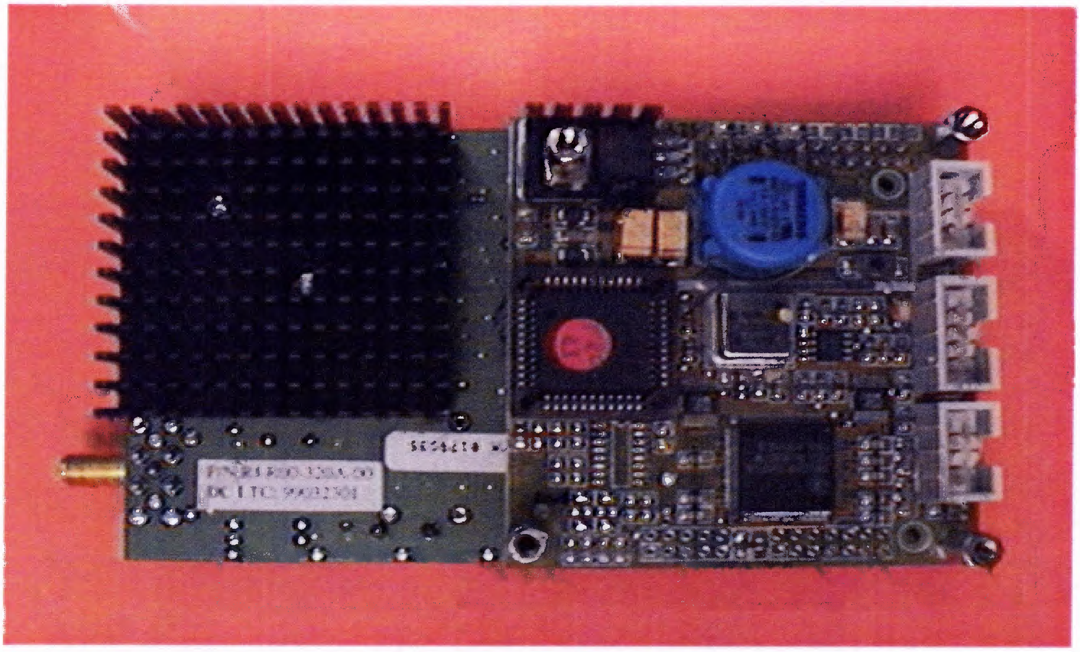


Figure 4.8 Tag-it™ reader module (RI-R00-320A).

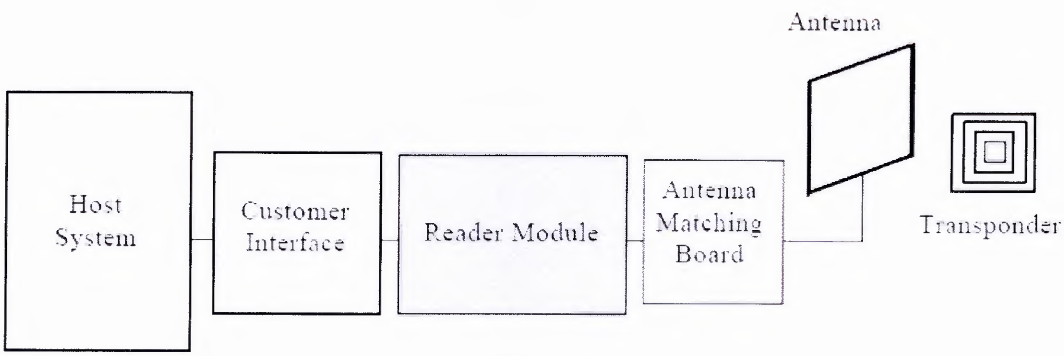


Figure 4.9 Basic system overview (RI-R00-320A).

12V power supply and RS232 cable (1:1 connection) female/female connectors were required before proceeding further. The power supply has to have a low voltage connector as shown in Figure 4.10.

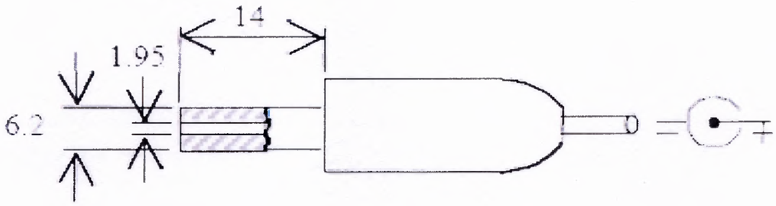
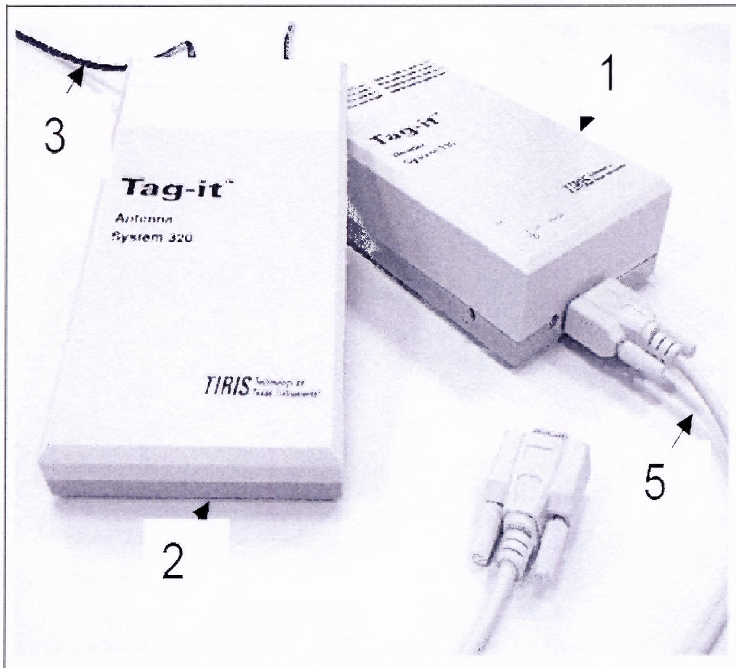


Figure 4.10 Low voltage connector (dimensions in mm).



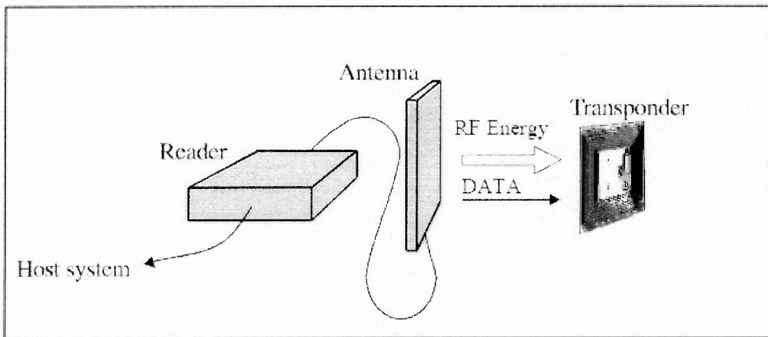
The Tag-it Reader / Antenna Set consists of:

1 Reader
2 Antenna
3 Antenna cable
4 Navigator software (RI-S00-NAV1 or RI-S00-NAV2) not shown
5 RS232 interface cable (not included)

In order to meet PTT regulations, the reader and the antenna are inseparably connected by antenna cable.

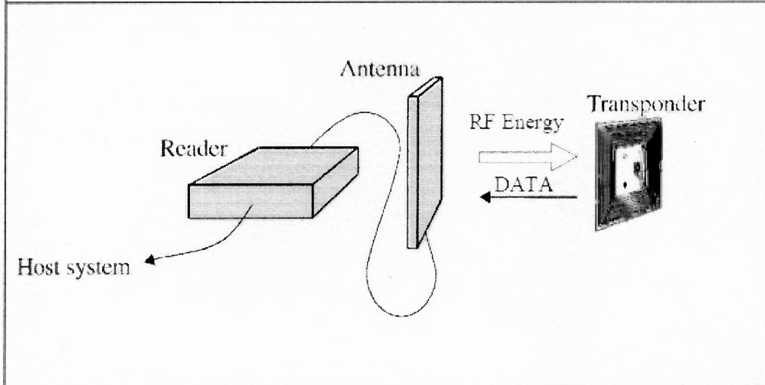
Figure 4.11 Tag-it™ reader / antenna set [19].

Figure 4.11 describes Tag-it™ reader / antenna set, while Figure 4.12 schematically describes the communication link between reader-to-tag and tag-to-reader.



Communication Reader-to-Tag

The frequency transmitted by the antenna is used to supply the tag with operating energy and to transmit data from Reader to Tag.



Communication Tag-to-Reader

The tag derives the operating energy from the transmitted frequency to respond to the reader and return requested data.

The antenna receives the coded signal from the tag and the reader starts communication with the host system.

Figure 4.12 Communication modes of an RFID system.

The Tag-it™ Navigator is a Windows® program (WIN 3.1, WIN95) capable of communicating with Tag-it™ Reader via a standard serial interface [19]. Upon turning on the system power supply switch and PC, the system becomes functional:

- As Tag-it™ tags are brought into the area around the antenna box, the retrieved ID numbers are displayed on the PC screen,
- Similarly, data can be written onto the tag by entering it on the PC under the appropriate write option.

The distance in which the tag can be read or written depends on the relative orientation of the tag with respect to the antenna. Best performance is achieved with the tag oriented parallel to the antenna housing and directly above or below the center of the antenna. The operating frequency of the system is 13.56 MHz.

Tags

Five tags by Texas instruments were used in the experiment. The reading range was found to be upto 5 to 7 inches.

Antenna

An additional antenna (Figure 4.13) was required to capture the RFID signals transfer from reader-to-tag as well as from tag-to-reader. Loop antenna was built by using a simple shielded 70" loop. The loop is made using coaxial cable (CATV). The outer shield must be broken at the exact center. C_1 is a 25-pf variable capacitor, and is connected in parallel with a 33-pf mica padder capacitor, C_3. C_1 must be tuned to the desired frequency while the loop is connected to the oscilloscope. C_2 is a small differential capacitor used to provide electrical symmetry [20].

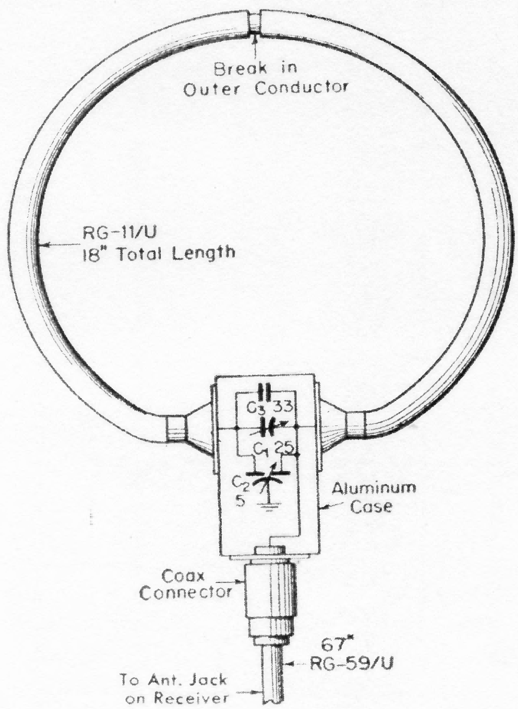


Figure 4.13 Sketch showing constructional details of W9PYG's transmitter-hunt loop. The outer braid of the coax loop is broken at the center of the loop [20].

During the experiments, it was observed that the reading range of the tags were very short, confined to distance less than 6". Changes have been made to the theoretical formulation which was presented in the initial phase. Landmarc, the system upon which the formulation is based, used signal strengths of the tags; their reader provided digital control of read range via providing configuration software and API with eight incremental read ranges. RFID reader has 8 different power levels. Based on the signal strength received by the RFID reader, the reader will report or ignore the received ID, where power level 1 has the shortest range and level 8 was corresponding to the longest range [2]. In the experiments performed here, observed signal strengths variations were insignificant.

Therefore, instead of signal strengths, basis for analyzing the experimental data became the width of the signal corresponding to the transaction between the tag reader and the tag. Distance is proportional to the travel time. However, since the distances involved were relatively short, the travel time itself was difficult to isolate. Instead the time interval of the interrogation signal, travel time and the tag response time intervals were observed and measured in a combined form. The duration of such a composite signal observed to be shorter when the relative distance between the tag and the tag reader was short. The duration extended with increase in the relative distance, therefore, the experimental observations were based on the duration of such a composite signals chosen as an independent variable.

For observing the transaction between the tag reader and the tag, an external antenna designed for 13.56 MHz was used. The Tektronix 11802 Digital Sampling

Oscilloscope was used as a receiver and signals observed during the transaction were captured and analyzed.

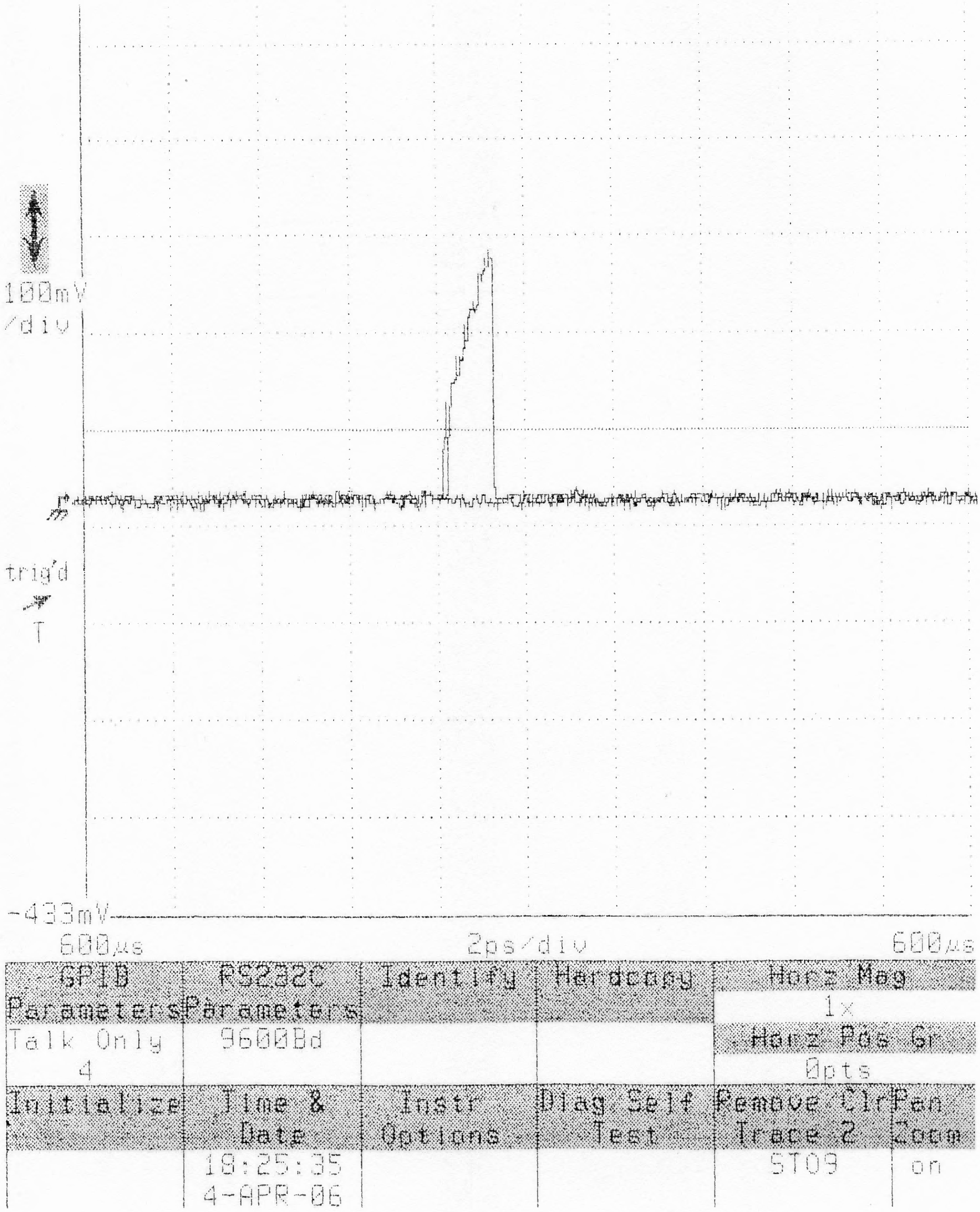


Figure 4.14 An interrogation signal sent by the tag reader detected by an external antenna. Note that the signal width is 1.7 picoseconds.

Initially, the interrogation signal sent by the tag reader in the absence of any tags is captured as shown in Figure 4.14.

Figure 4.15 depicts the combined signal composing of interrogation signal and the tag (placed at a distance of 0.1 inches) response including the travel time involved between the tag and tag reader.

Figure 4.16 presents another merged signal consisting of interrogation signal and the tag (placed at a distance of 6.5 inches) response including the travel time involved between the tag and the tag reader.

As one can observe from Figures 4.15 and 4.16, the composite signal width can be mapped proportionally to an equivalent distance. Measurements were performed for various distances between the tag reader's antenna and the tag varying from 0 inches to 6.5 inches. Even though the formulation based on Landmarc [2] was in the terms of signal strength, the measurement did not show significant variation in amplitude within the finite range, instead variations in time intervals comprising of composite signal due to interrogation signal of the reader, travel time between the tag reader and the tag and the tag's response signal were used as mentioned earlier. It was difficult to isolate the segment corresponding to travel time between the tag reader and the tag since it was mixed up in the composite signal. The response of the tag may begin before the interrogator's initiative signal ends.

Since the whole objective is to differentiate between various distances, this was achieved with the help of the composite signal width rather than the signal strength, with the tag closer to reader's antenna having less width and farther one having larger width in time.

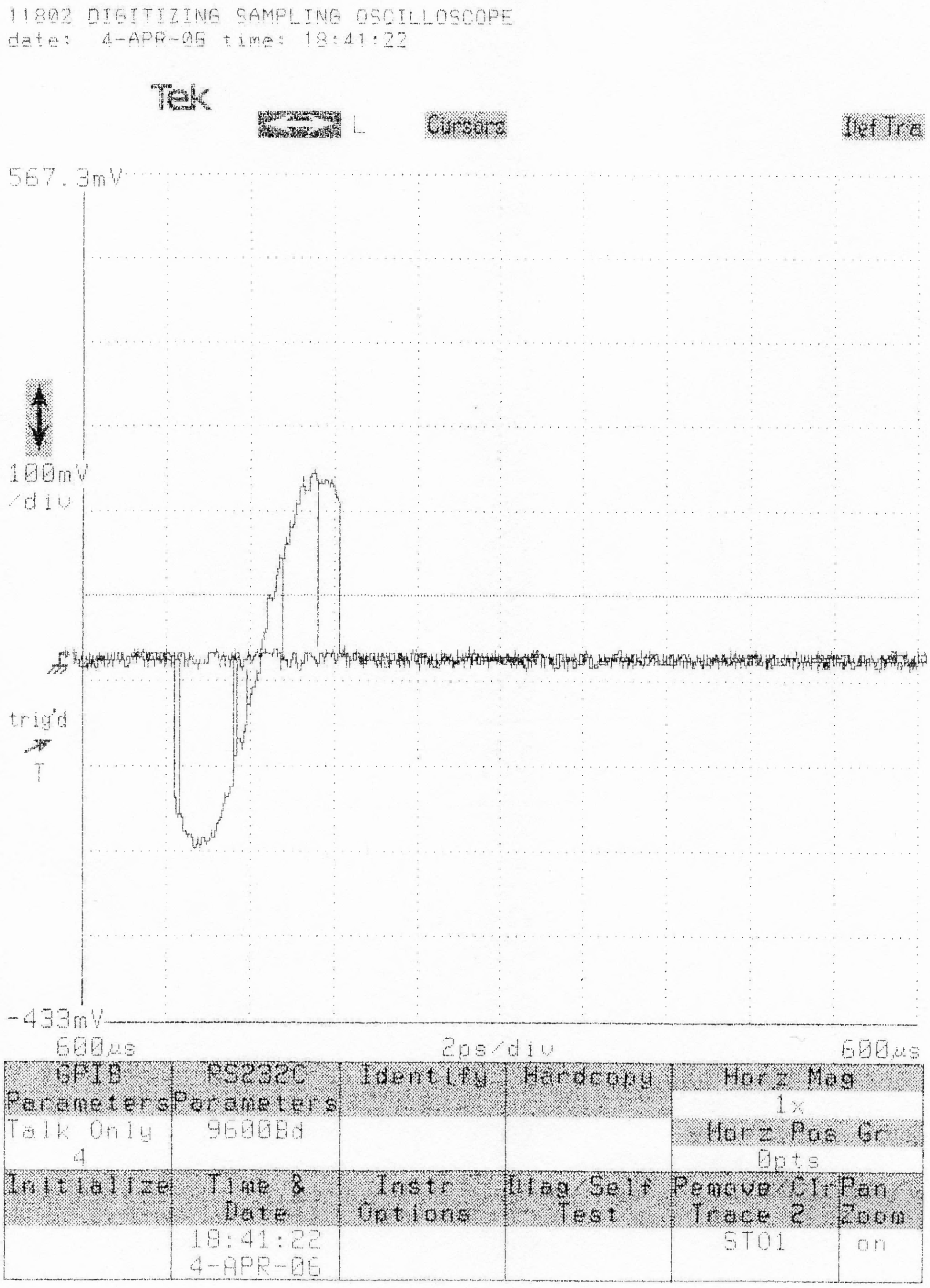


Figure.4.15 A composite signal detected by an external antenna when a tag is placed at 0.1 inches from the reader's antenna (Signal width is 3.9 picoseconds).

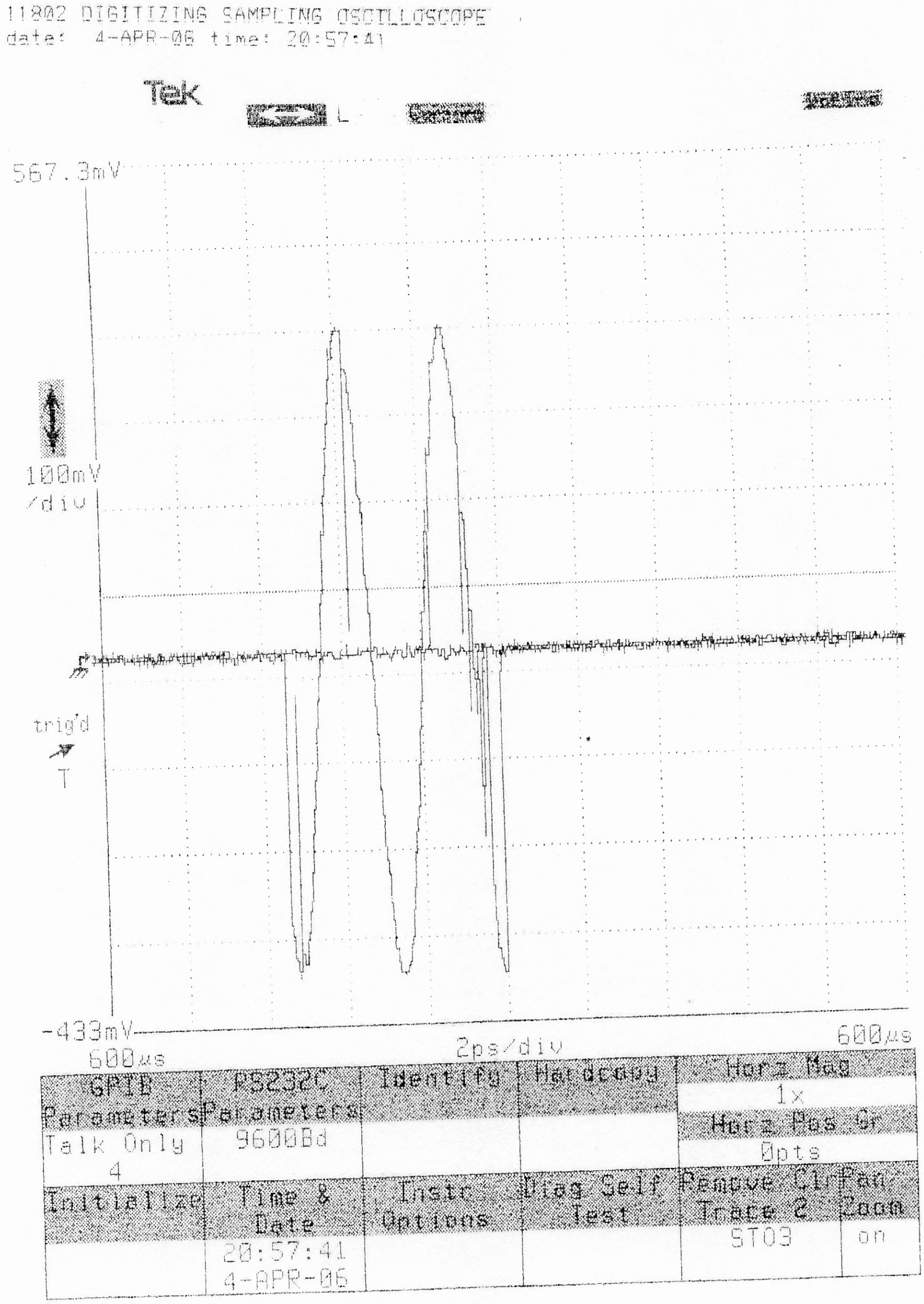


Figure.4.16 A composite signal detected by an external antenna when a tag is placed at 6.5 inches from the reader's antenna (Signal width is 5.7 picoseconds).

The experimental data is processed based on th formulation developed earlier. Following results with four tag readers, four reference tags and a tracking tag were obtained as shown in Figure 4.17.

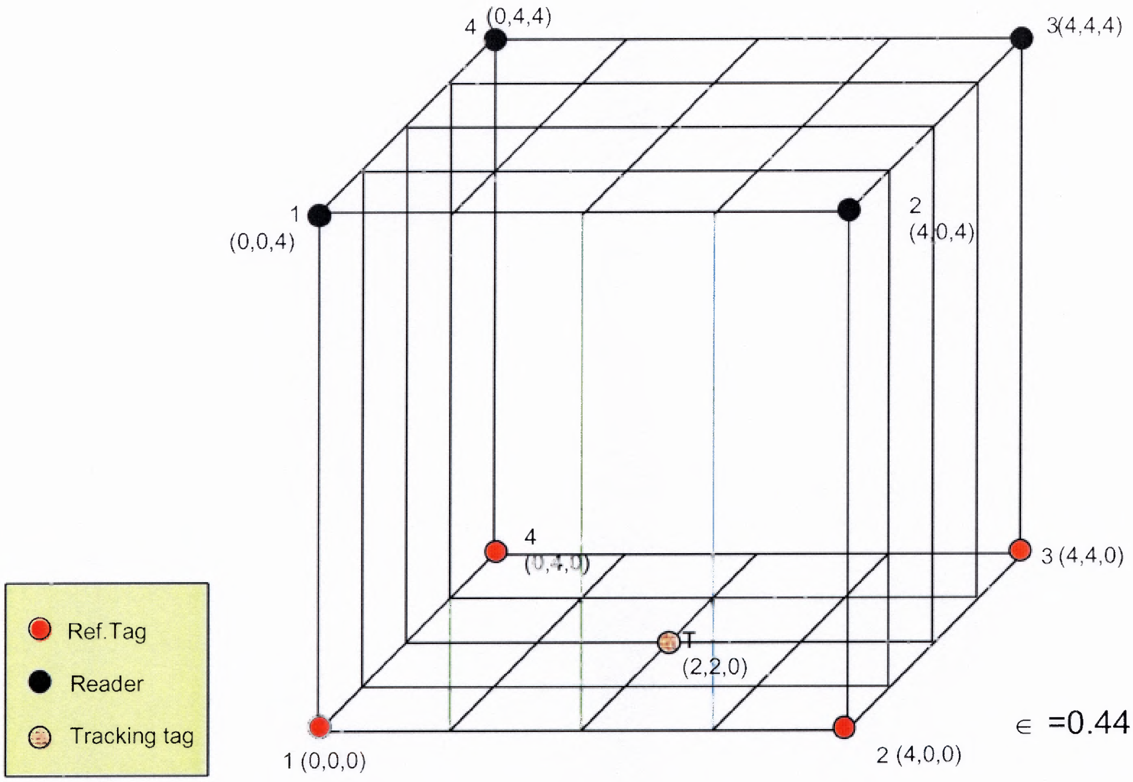


Figure 4.17 Four tag readers, four reference tags and a tracking tag placed in a $4'' \times 4'' \times 4''$ cube. The experimental error rate was found to be 0.44 inches.

Figure 4.17 represents a model where four tag readers are placed on the top-plane, four reference tags and a tracking tag are kept on the bottom plane ($z = 0$). The overall error is shown for the whole system. Error of $\in = 0.44$ inches implies that the estimated coordinate lies within the radius of 0.44 inches of the actual co-ordinate. Figure 4.18 shows similar model but different placements of the reference tags. This time, reference tags are placed closer to the tracking tag, which resulted in the less error as compared to the previous model (Figure 4.17). Error was reduced to $\in = 0.11$ inches.

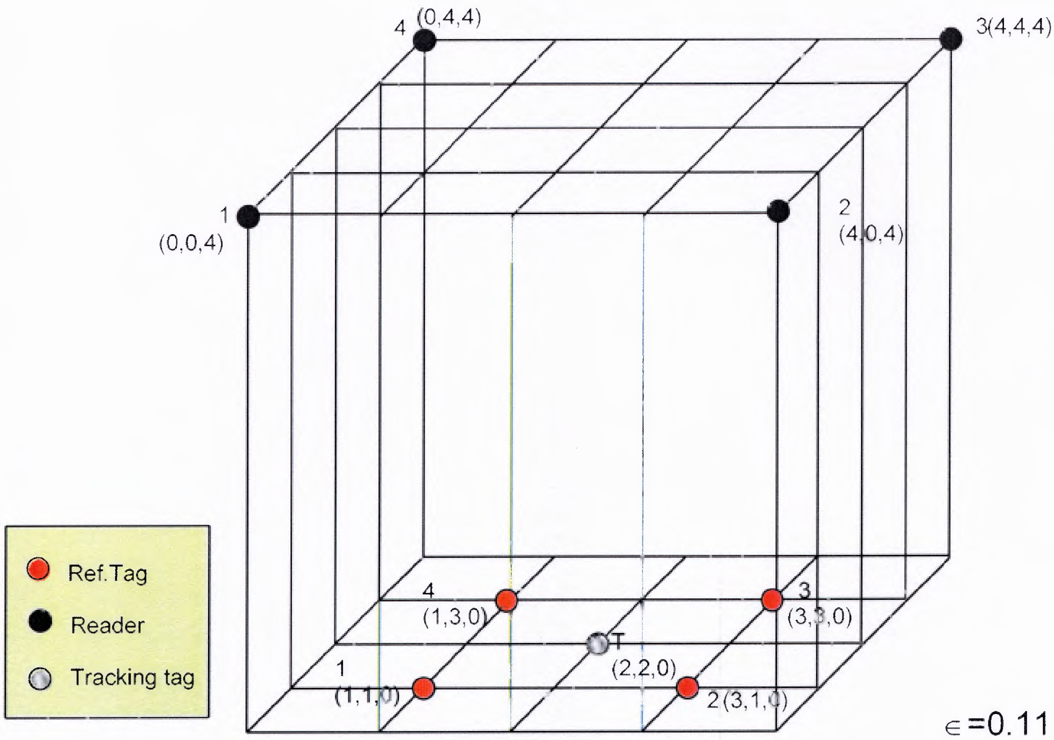


Figure 4.18 Alternative positions of reference tags, error rate has reduced to ∈=0.11 inches.

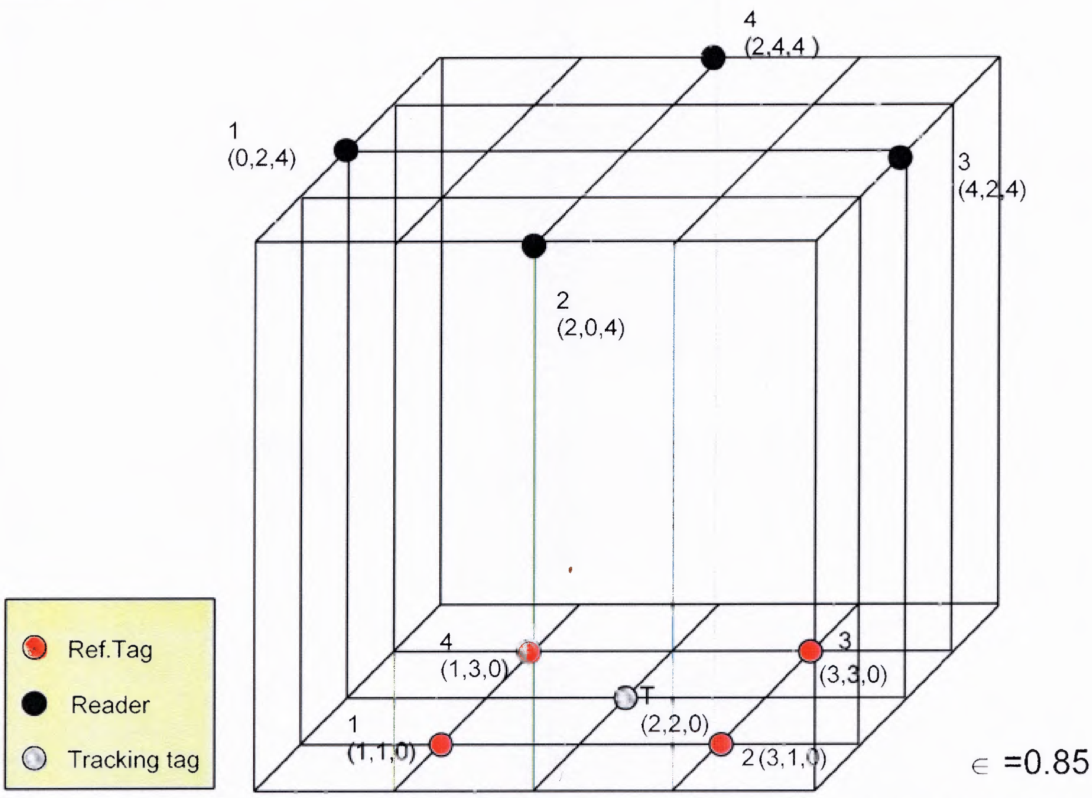


Figure 4.19 Another alternative positions of tag readers caused error rate to increase to ∈=0.85 inches.

Figure 4.19 describes a model in which the positions of reference tags and tracking tag are same as in Figure 4.18, but the position of tag readers have been changed, which gave worse results $\in$=0.85. Thus, optimized orientation of tag readers with respect to the system of tags becomes significant.

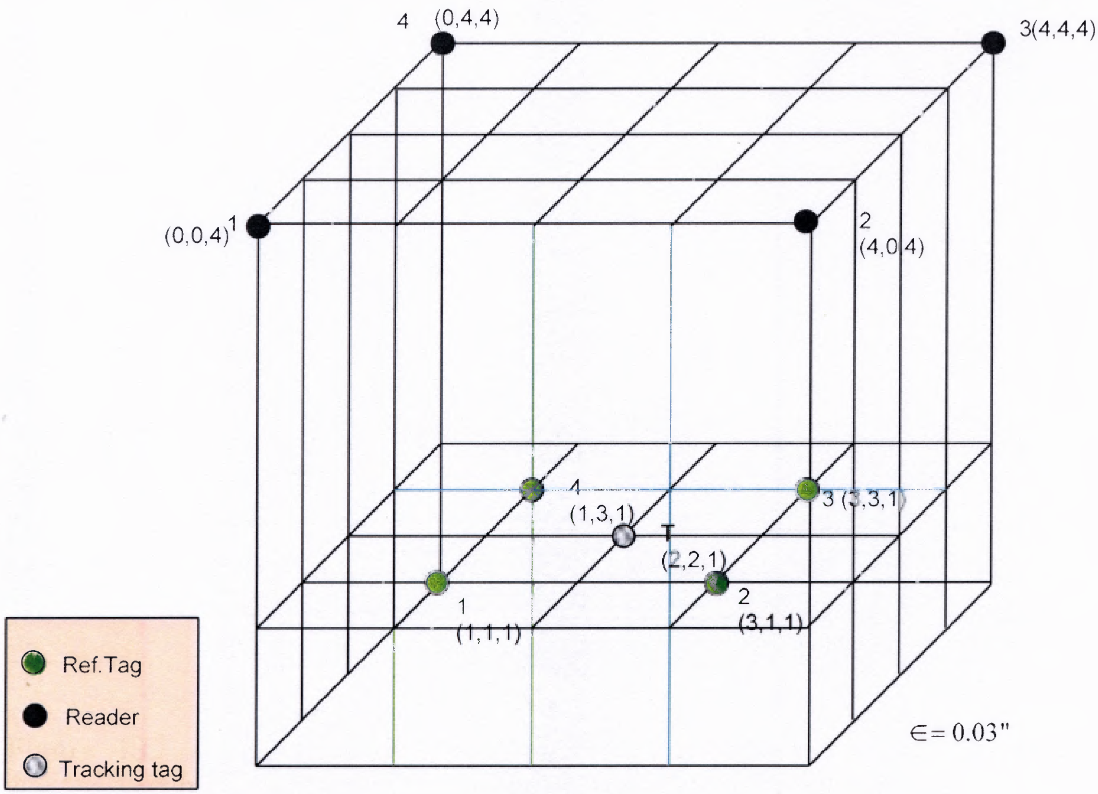


Figure 4.20 Error decreases effectively as the distance between the system consisting of reference tags and tracking tag with respect to readers decrease as proved theoretically in Figure 4.2.

Figure 4.20 represents a similar model to Figure 4.18 but the system of reference tags and a tracking tag are now on the elevated plane ($z = 1$). As discussed earlier in the theoretical formulation, error now has decreased, as the distance between system consisting of reference tags and tracking tags is decreased (Figure 4.2 and Figure 4.3).

experimental verification of the same configuration has been proven to correlate the theory.

Step based on a mathematical formulation have been shown to explain how the error of $\in = 0.03"$ of Figure 4.20 was attained.

Tag Reader's location: **1.** (0,0,4) ; **2.** (4,0,4) ; **3.** (4,4,4) ; **4.** (0,4,4)

Reference tag's location: **1.** (1,1,1); **2.** (3,1,1) ; **3.** (3,3,1) ; **4.** (1,3,1)

Unknown tracking tag's location: (2,2.1)

Data evaluation based on distance parameters was suggested in the theoretical formulation. Here, mapping to the relative width of the composite signal is discussed, data related to overall experimental measurements are shown in Appendix A.

Table 4.1 Data for Error Evaluation of Figure 4.20

	Signal Width (in ps)	Signal Width (in ps)	Signal Width (in ps)	Signal Width (in ps)
$W^0_{1,j}$	2.16	2.28	2.425	2.28
W j	2.21	2.21	2.21	2.21
$W^0_{2,j}$	2.28	2.16	2.28	2.425
W j	2.21	2.21	2.21	2.21
$W^0_{3,j}$	2.425	2.28	2.16	2.28
W j	2.21	2.21	2.21	2.21
$W^0_{4,j}$	2.28	2.425	2.28	2.16
W j	2.21	2.21	2.21	2.21

Here, $W^0_{i,j}$ is the width of the composite signal due to the tag reader "j", at the reference tag "i". W_j is the width of the composite signal due to the tag reader "j" at the tacked tag.

After mapping the composite width data to corresponding distances, the relative distances between the tag readers and the tracked tag are given below:

$$E_1 = \sqrt{(\theta_1 - S_1)^2 + (\theta_2 - S_2)^2 + (\theta_3 - S_3)^2 + (\theta_4 - S_4)^2} = 0.38$$

$$E_2 = \sqrt{(\theta_1 - S_1)^2 + (\theta_2 - S_2)^2 + (\theta_3 - S_3)^2 + (\theta_4 - S_4)^2} = 0.38$$

$$E_3 = \sqrt{(\theta_1 - S_1)^2 + (\theta_2 - S_2)^2 + (\theta_3 - S_3)^2 + (\theta_4 - S_4)^2} = 0.38$$

$$E_4 = \sqrt{(\theta_1 - S_1)^2 + (\theta_2 - S_2)^2 + (\theta_3 - S_3)^2 + (\theta_4 - S_4)^2} = 0.38$$

The normalized factors are

$1/E_1^2 = 1/E_2^2 = 1/E_3^2 = 1/E_4^2 = 6.85$

$\Sigma\, 1/E_i^2 = 27.4$

Weighing factor is calculated as:

$w_1 = (1/E_1^2) / \Sigma\, 1/E_i^2 = 0.248$

$w_2 = (1/E_2^2) / \Sigma\, 1/E_i^2 = 0.248$

$w_3 = (1/E_3^2) / \Sigma\, 1/E_i^2 = 0.248$

$w_4 = (1/E_4^2) / \Sigma\, 1/E_i^2 = 0.248$

which were used to estimate the unknown coordinates of the tracked tag.

The unknown tracking tag is found using the given formula:

$$(x,y,z) = w_1 (x_1, y_1, z_1) + w_2 (x_2, y_2, z_2) + w_3 (x_3, y_3, z_3) + w_4 (x_4, y_4, z_4)$$

$$= 0.248\,(1,1,1) + 0.248\,(3,1,1) + 0.248\,(3,3,1) + 0.248\,(1,3,1)$$

$$(x,y,z) = (1.98, 1.98, 0.99)$$

However, the actual coordinates of the unknown tracked tag are (2,2,1). Hence, the estimation error is given by and can be mapped back to inches.

$$\in = \sqrt{(2-1.98)^2 + (2-1.98)^2 + (1-0.99)^2} = 0.03$$

which can be mapped back to 0.03 inches.

Following the same principles, one can estimate the location of a tracking tag with the help of reference tags whose positions are already known. Although, one should have a prior knowledge of where to place the tag readers and reference tags for better estimation. Following points should be kept in mind before setting up the systems (assuming readers are fixed on the top plane):

1. Reference tags should be densely located in a uniform manner around the tracking tag,

2. The best results come out if the system of reference tags and tracking tag are placed in the middle or one plane above or below it,

3. If the system (reference tags and tracking tag) is placed on the ground or top plane then it might give inefficient results,

4. Readers as well as reference tags may interfere with each other, so when taking the readings for the multiple tag, outputs might be different when observed with a single tag,

5. The difference between the signals widths in experiments performed here are very small, thus one has to take approximations into account when dealing with tags placed very close to each other,

6. The tag reader and reference tags should be placed in similar patterns.

Estimation of the coordinates of the tag can also be done using the concept based upon trilateration, the principle on which GPS is based [21]. **Trilateration** is a method of determining the relative positions of objects using the geometry of triangles. It uses the known locations of two or more reference points, and the measured distance between the object and each reference point. To accurately and uniquely determine the relative location of a point on a 2D plane using trilateration alone, generally at least 3 reference points are needed. If 3D environment is used, four reference points are needed to produce better estimates based on equivalent spheres.

There are 125 points where one can place a tracking tag in the model that was developed in this thesis. In a cube of four units with five planes, and on a single plane, one can place the tag at 25 fixed locations. Fixing the tag reader and moving the tracking tag at all 25 locations, readings were recorded. Same procedure was repeated for each plane. Hence, with respect to a particular tag reader, 25 data points on each plane were graphed. Five different curves with each curve corresponding to one plane were generated. The process was repeated for each tag reader and the complete data is presented in Appendix A.

After acquiring all the graphs, a tag was placed at a random position; readings were taken from all four different tag readers. Then search process was initiated to match the data corresponding to an unknown location of the tag to pre-determined values that lie within the specified range. Numerical example to illustrate this process is given below:

Figure 4.21 shows the system consisting of four tag readers and a tracking tag whose pre-determined position is to be estimated. Place the tracking tag at any random location, i.e., (2,4,3); x=2, y=4 and z=3.

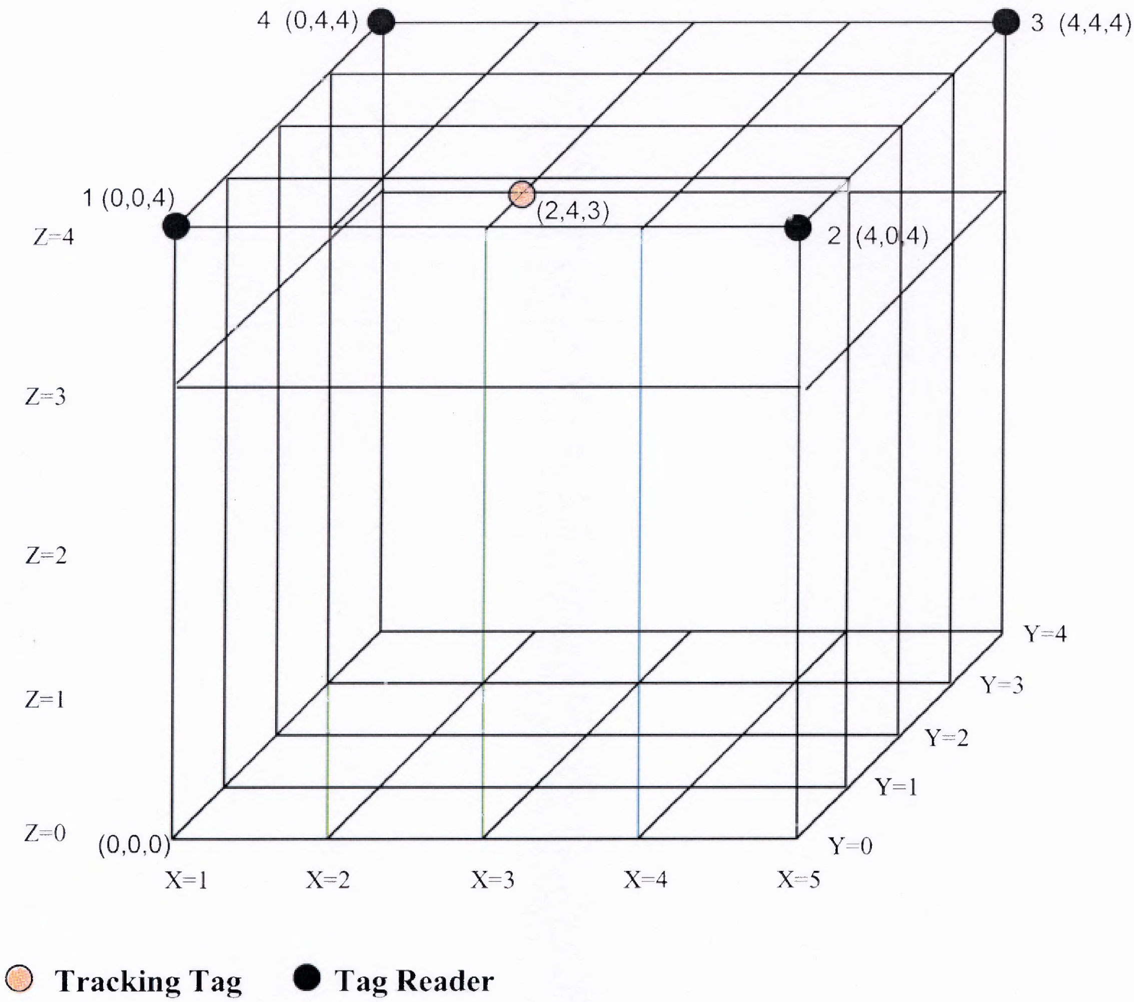


Figure 4.21 Example showing how to estimate location of tracking tag with the help of reference graphs.

Figure 4.21 shows all the four readers and one tracking tag at location (2,4,3). When all the four readers would read the tracking tag, they will yield different readings. Corresponding readings have already been plotted in the graphs and shown in the system database. For this particular location, Reader 1 yielded reading (width of the composite signal on the oscilloscope) as 2.18 ps, Reader 2 yielded reading as 2.26 ps, and Reader 3 yielded 2.12 ps and Reader 4 yielded 2.07 ps. Upon these measurements, search is initiated on a previously collected data to obtain relevant match.

Reader 1: After matching all the five graphs of the first readers, the following coordinates were approximately chosen that yielded an approximate 2.18 ps width.

x=2, y=1, z=0; x=1, y=3, z=1; **x=2, y=4, z=3**

Reader 2: following co-ordinates were approximately determined to match 2.26 ps width.

x=2, y=1, z=0; x=4, y=3, z=0; x=1, y=1, z=1;

x=5, y=4, z=1; **x=2, y=4, z=3**; x=3, y=4, z=4

Reader 3: following co-ordinates were approximately determined to match 2.12 ps width.

x=4, y=4, z=1; **x=2, y=4, z=3**; x=2, y=3, z=4

Reader 4: following co-ordinates were approximately obtained to match 2.12 ps width.

x=1, y=3, z=3; x=1, y=4, z=3; x=3, y=4, z=4; **x=2, y=4, z=3**

The search for the common coordinate in the above data lead to identify the location of the tag to be as (2,4,3). The procedure was applied to other possible candidate points and conclusions were always similar.

CHAPTER 5

CONCLUSIONS AND FUTURE EXTENSIONS

5.1 Conclusions

This thesis has presented a prototype indoor location-sensing system using RFID in a 3D environment. Generally, passive tags are not designed for accurate indoor location sensing, since their reading ranges are relatively low, conclusively it does not provide needed accuracy for many practical applications. Here, the proposed two methods have proved that it is possible to estimate the location of a tracking tag with sufficient accuracy.

Two different concepts were proposed and their experimental validations were carried out. One was based on the Landmarc [2], but due to unavailability of ideal equipment, many modification has to be implemented. Composite time width was measured by an external antenna to include the interrogator wake up signal, propagation delay and the tag's response time. This was inevitable in the system used, since the interrogator's signal and the tag response overlapped. Due to nature of close proximity between the tag reader and the tag, it was not practical to isolate the travel time between the tag reader and the tag. Also, it was observed that the tag responded before the interrogation signal terminated. Under these circumstances, including the shortness of the travel time, sub nanoseconds required to treat the entire captured signal as a composite signal.

Results came out successfully in a 3D environment with the formulation developed in this thesis based on the by Landmarc for 2D. Estimation of the location of tracking tag with the help of reference tags took place and satisfactory results were obtained. If the reference tags and tracking tag are placed in a proper manner as discussed, location of tracking tag can be estimated with insignificant error.

Another concept that was suggested and validated experimentally was based on the trilateration. Graphs were plotted for all four tag readers by placing tracking tag at all the 125 possible positions in a $4" \times 4" \times 4"$ cube. An example is presented to determine the location of a tracking tag with the help of those graphs.

Results were successful; location of the tracked tag was estimated uniquely based on four tag readers, without any additional help of reference tags.

The proof of the concept to determine the location of a tag in a 3D environment was based on a specific system developed by Texas Instrument^{TM}, which was limited in range. Hence, the developed concept in this thesis has flexibility and can be adapted to specific requirements of any RFID system.

5.2 Future Extensions

Even if RFID system with passive tags can be a cost-effective contender for location sensing, there are few problems that have to surpass in order to be viable in this competitive market. Though the signal strength measurements seem like a viable solution, in densely packed environment they may not have adequate resolution. Measurements based on time delay or pulse widths, such as the one suggested here could represent a better alternative.

Enhanced systems such as one developed my MICRON, has embedded variable time delay in a tag response, which may further help to increase the resolution and reduce interference due to signal collision.

Passive tags are useful for many applications as they are cheaper, but for the location sensing, they are not that effective when compared to active tags because of their short-range. Another problem faced was the variation in the characteristics of the reader. Even if they were from same vendor and same model, the corresponding readings varied.

The future RFID system specific to tag location estimation has to address all the features discussed here for increased accuracy and reliability.

APPENDIX A

CUBICAL 3D MODELS AND THEIR CORRESPONDING GRAPHS

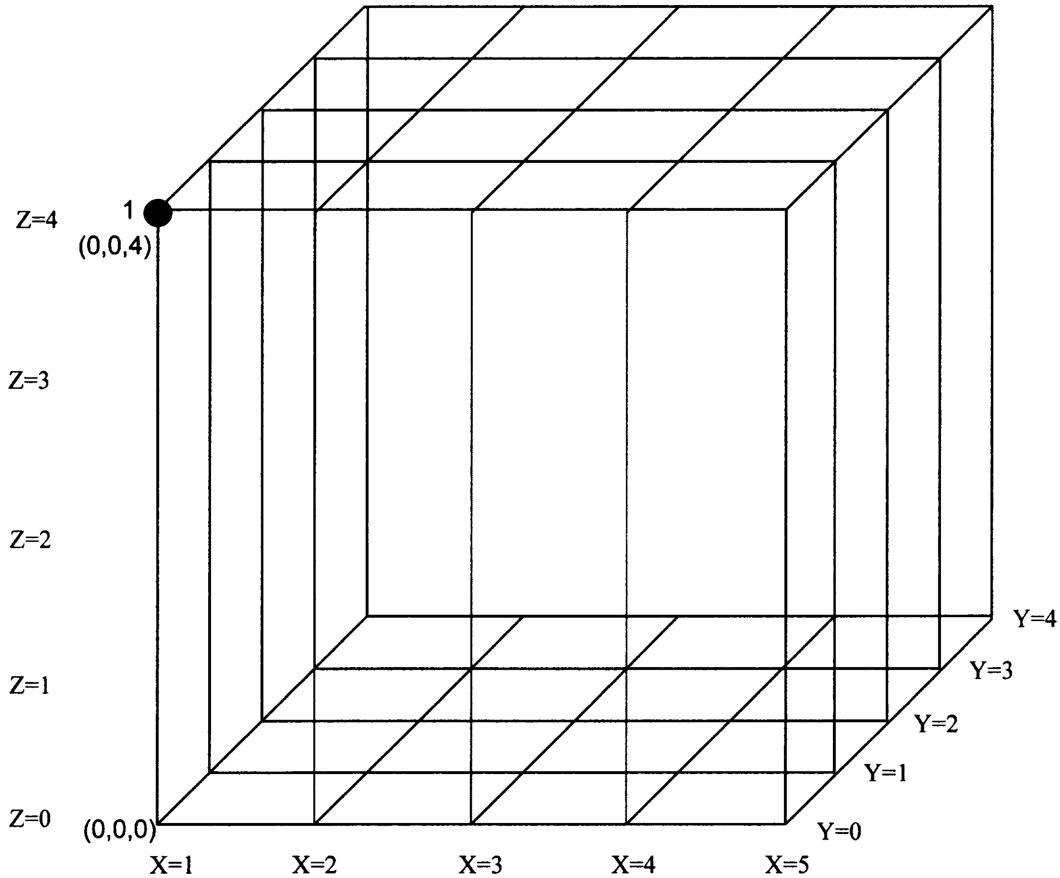


Figure A.1 Reader 1 at (0,0,4).

Z-axis is shown separately on every graph. On x-axis, 1 represents the extreme left corner and 5 represents extreme right corner, i.e., 1 is (0,0,0) for y=0, (0,1,0) for y=1. This process is being repeated for increasing values of y. Once, the data points on the lowest plane are mapped, the process itself repeats itself for elevated planes.

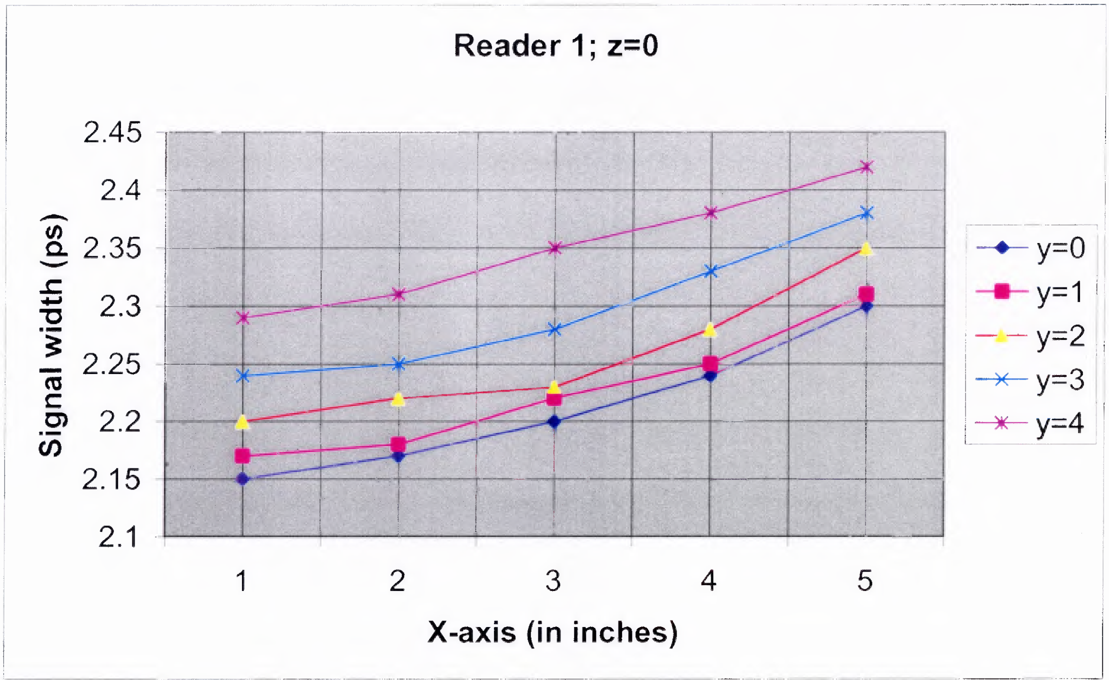


Figure A.2 Signal width for reader 1 located at (0,0,4). Tracking tag is on the lowest plane ($z = 0$). Observations were obtained for five points for each y-axis on the grid of the plane.

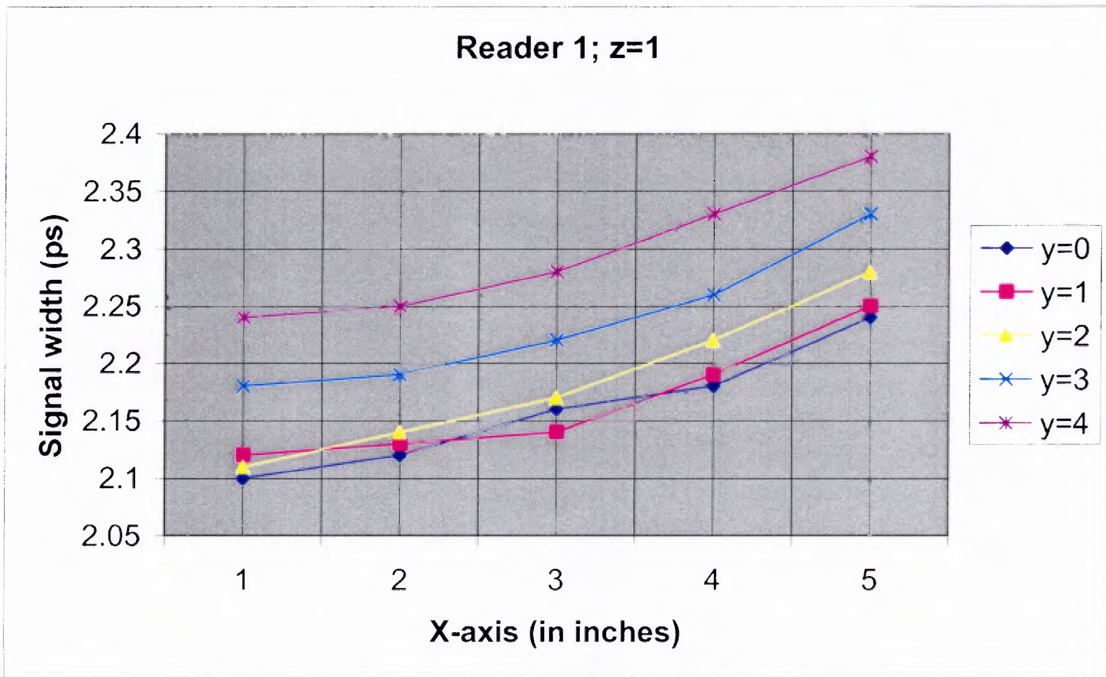


Figure A.3 Signal width for reader 1 located at (0,0,4). Tracking tag is on the elevated plane ($z = 1$). Observations were obtained for five points for each y-axis on the grid of the plane.

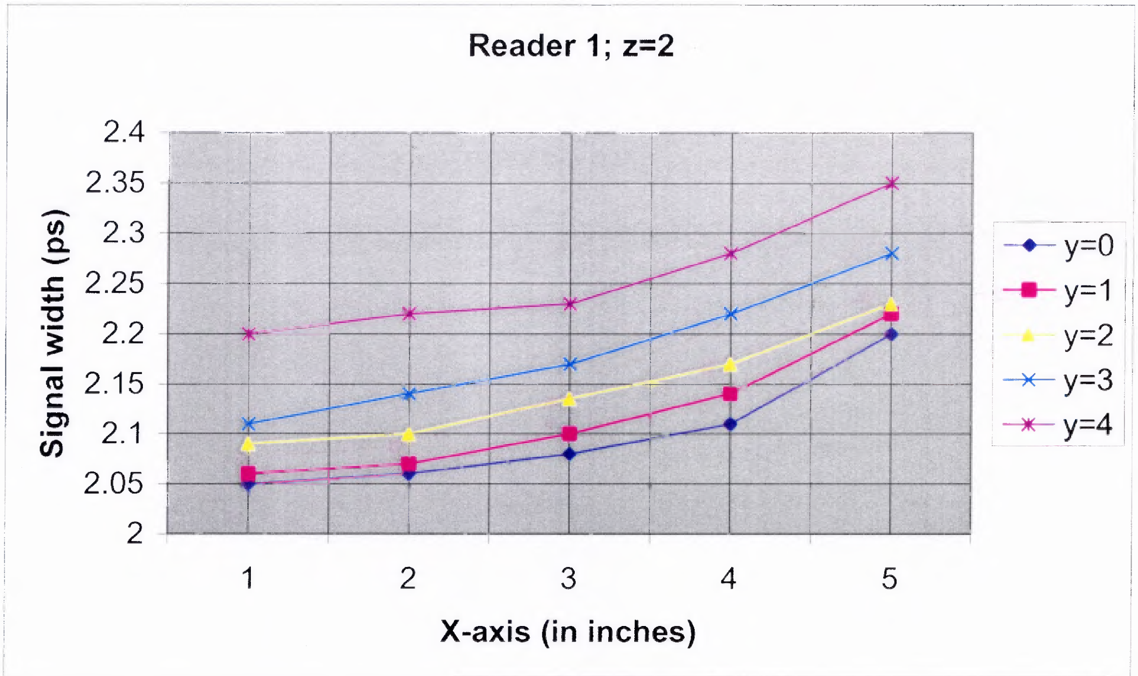


Figure A.4 Signal width for reader 1 located at (0,0,4). Tracking tag is on the elevated plane ($z = 2$). Observations were obtained for five points for each y-axis on the grid of the plane.

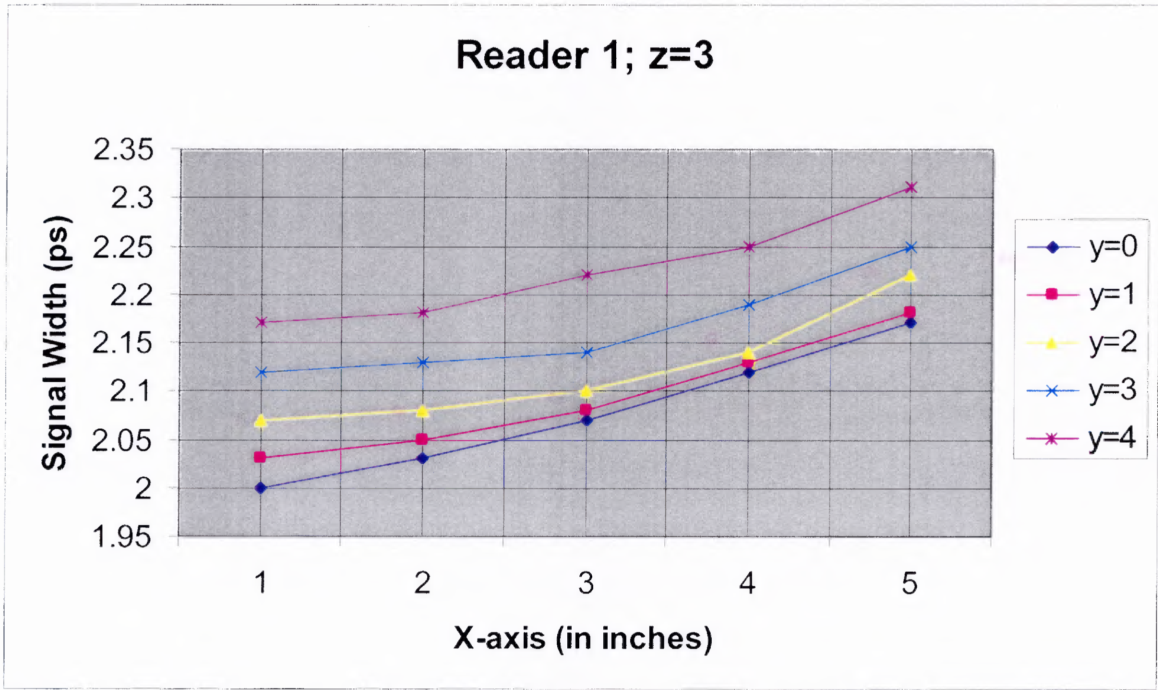


Figure A.5 Signal width for reader 1 located at (0,0,4). Tracking tag is on the elevated plane ($z = 3$). Observations were obtained for five points for each y-axis on the grid of the plane.

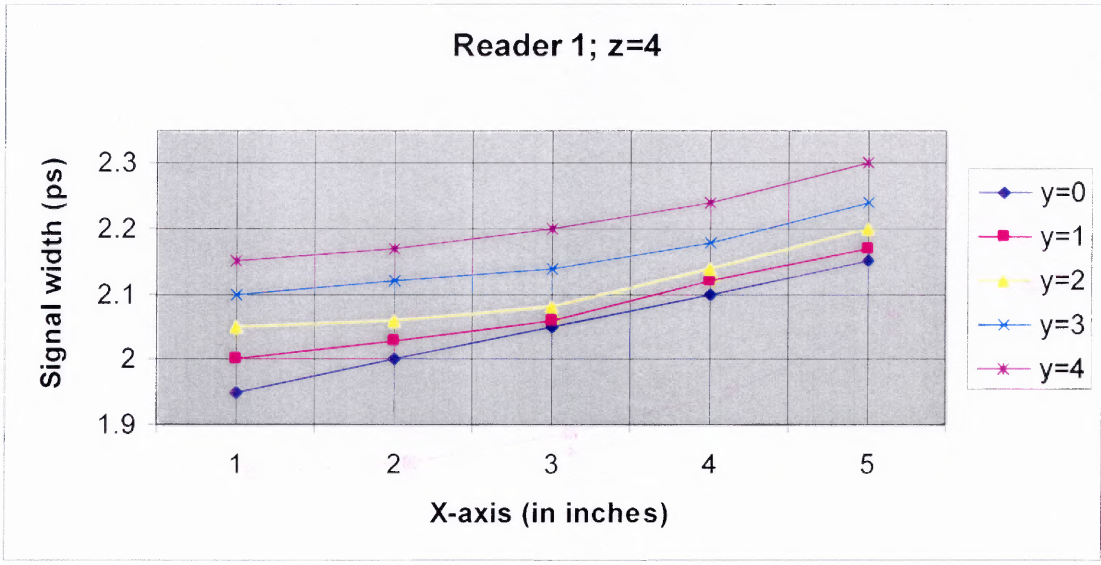


Figure A.6 Signal width for reader 1 located at (0,0,4). Tracking tag is on the elevated plane ($z = 4$). Observations were obtained for five points for each y-axis on the grid of the plane.

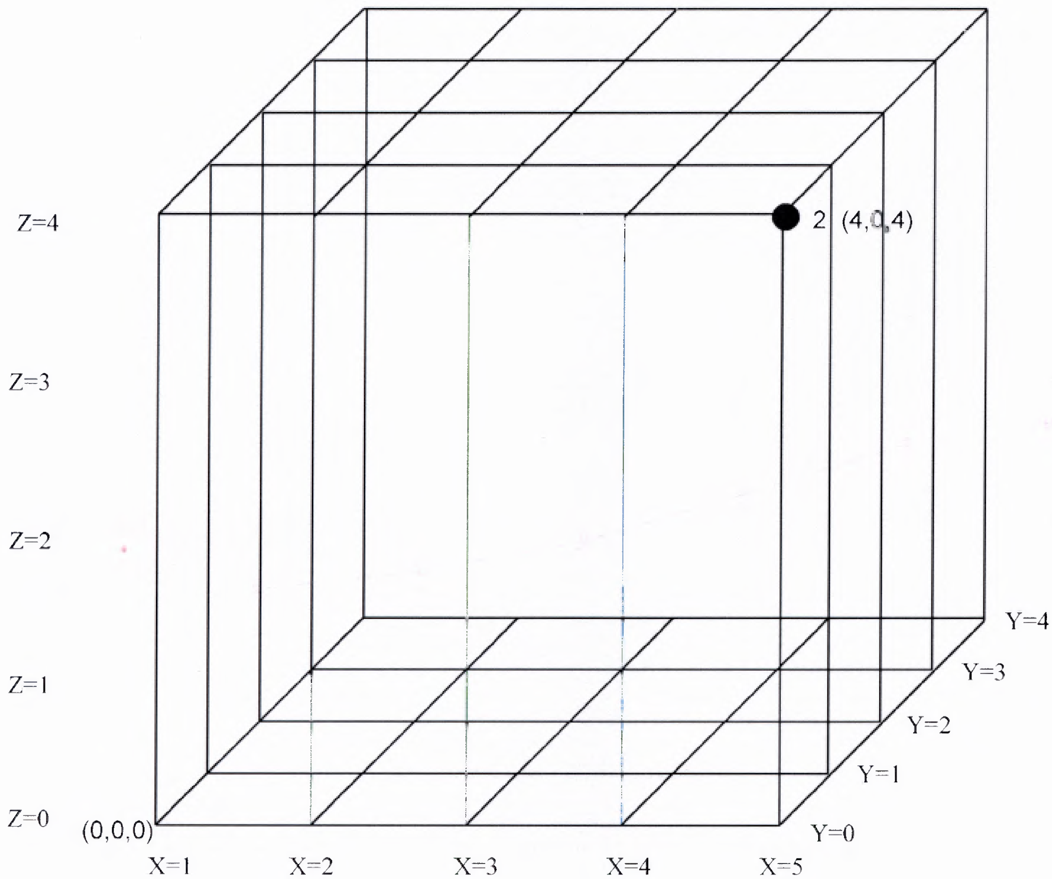


Figure A.7 Reader 2 at (4,0,4).

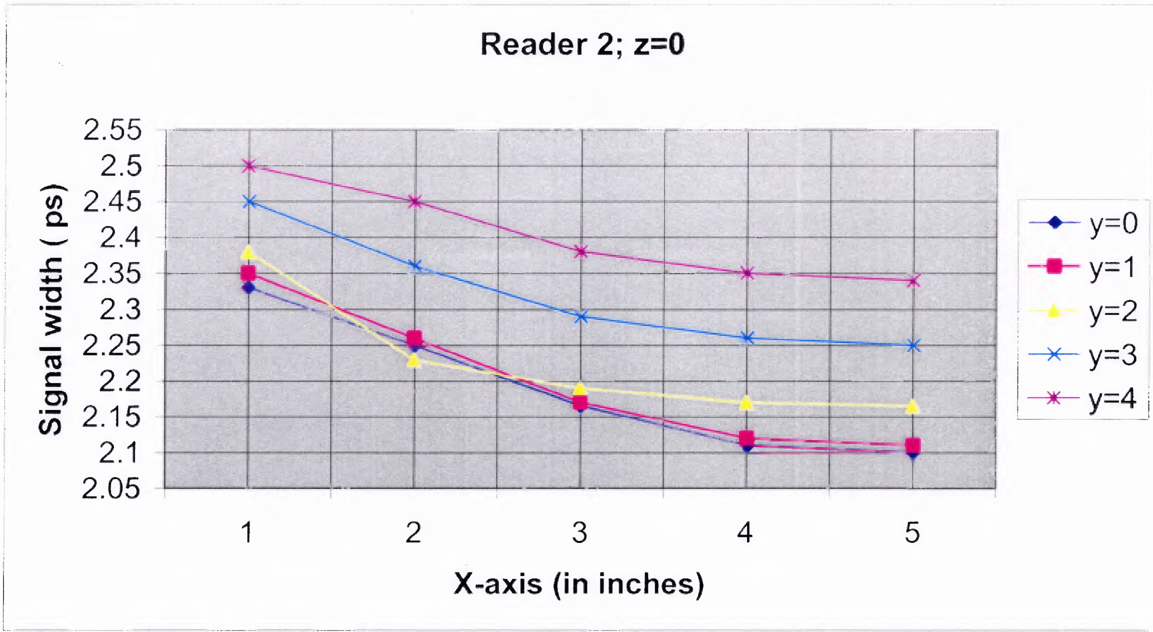


Figure A.8 Signal width for Reader 2 located at (4,0,4). Tracking tag is on the lowest plane ($z = 0$). Observations were obtained for five points for each y-axis on the grid of the plane.

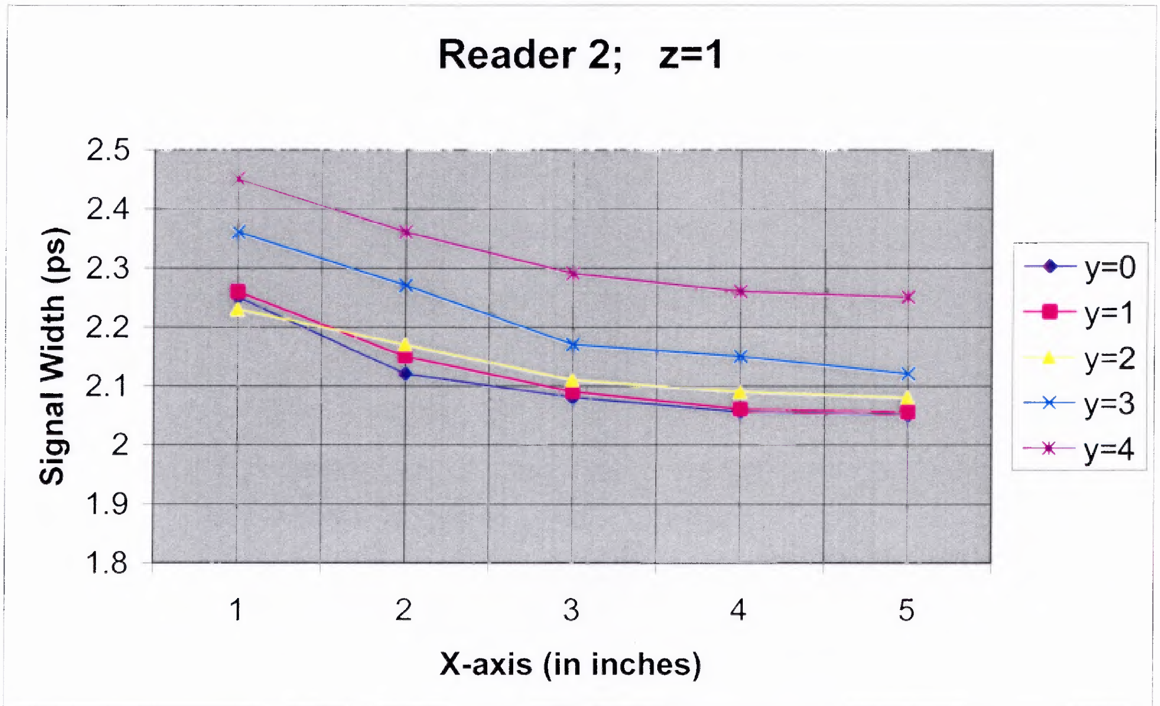


Figure A.9 Signal width for Reader 2 located at (4,0,4). Tracking tag is on the elevated plane ($z = 1$). Observations were obtained for five points for each y-axis on the grid of the plane.

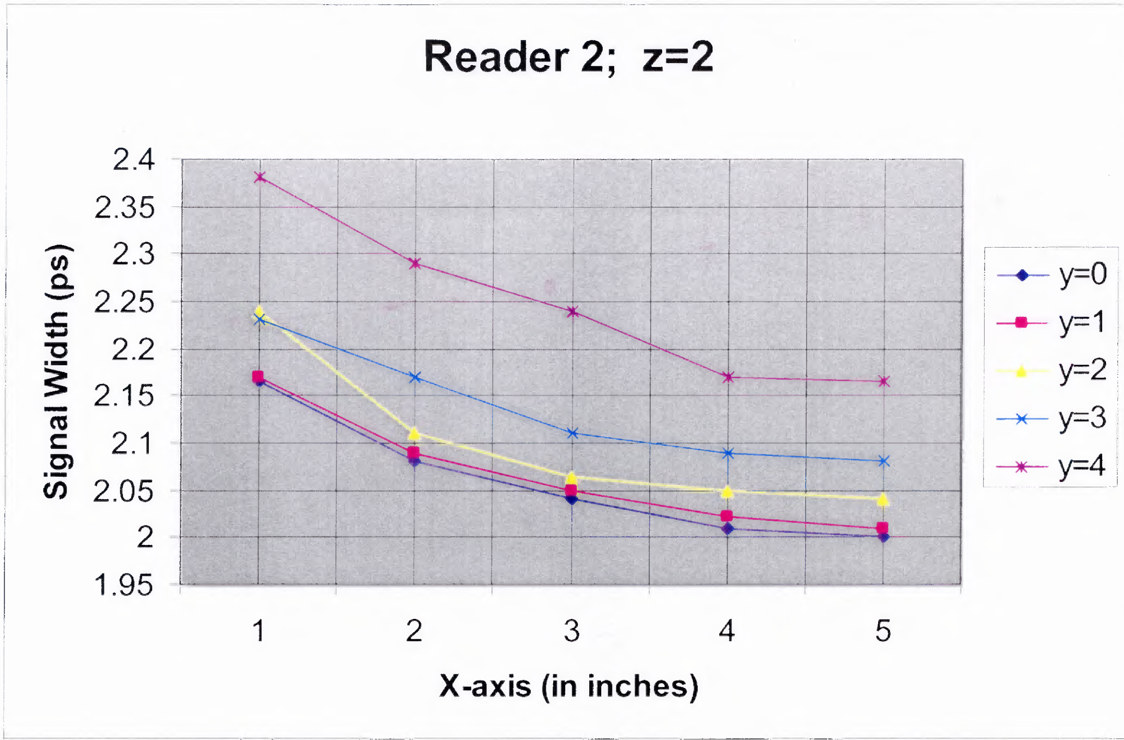


Figure A.10 Signal width for Reader 2 located at (4,0,4). Tracking tag is on the elevated plane ($z = 2$). Observations were obtained for five points for each y-axis on the grid of the plane.

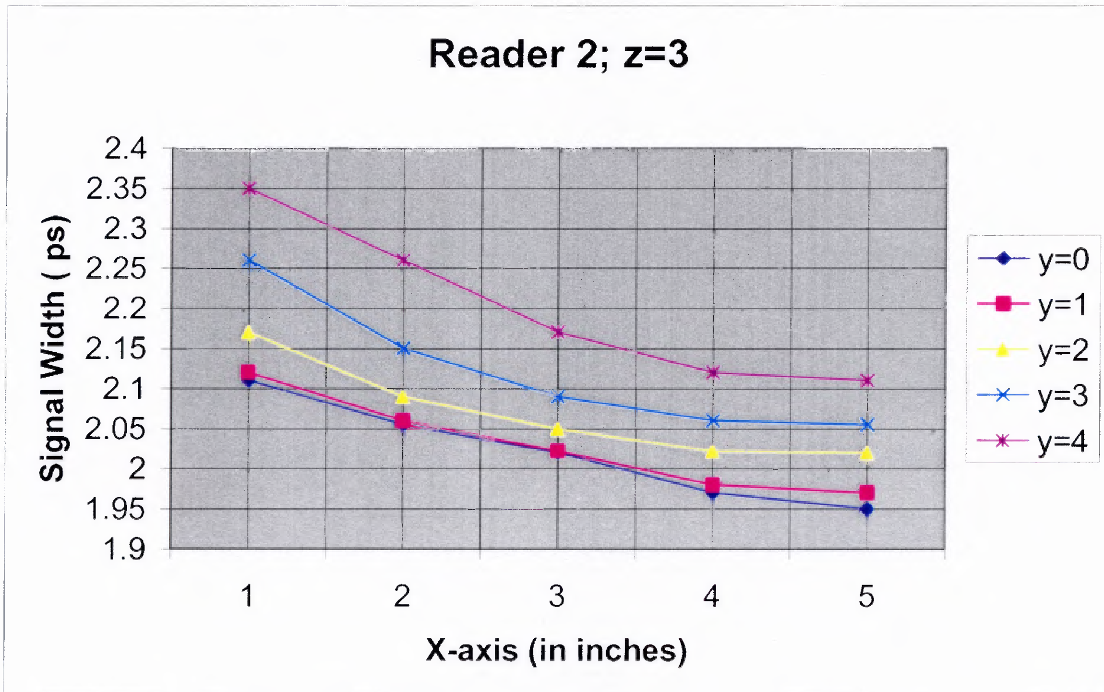


Figure A.11 Signal width for Reader 2 located at (4,0,4). Tracking tag is on the elevated plane ($z = 3$). Observations were obtained for five points for each y-axis on the grid of the plane.

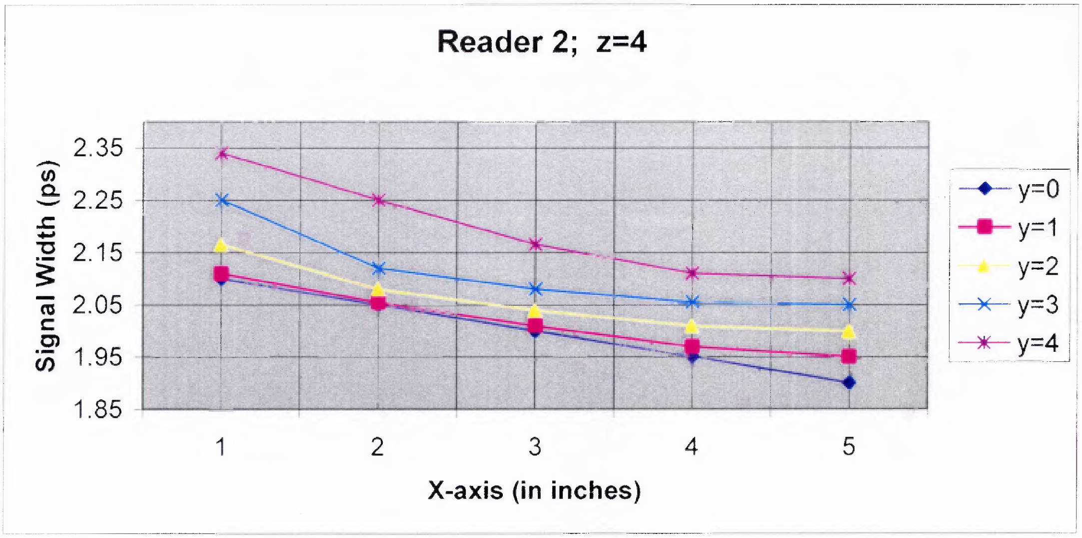


Figure A.12 Signal width for Reader 2 located at (4,0,4). Tracking tag is on the elevated plane ($z = 4$). Observations were obtained for five points for each y-axis on the grid of the plane.

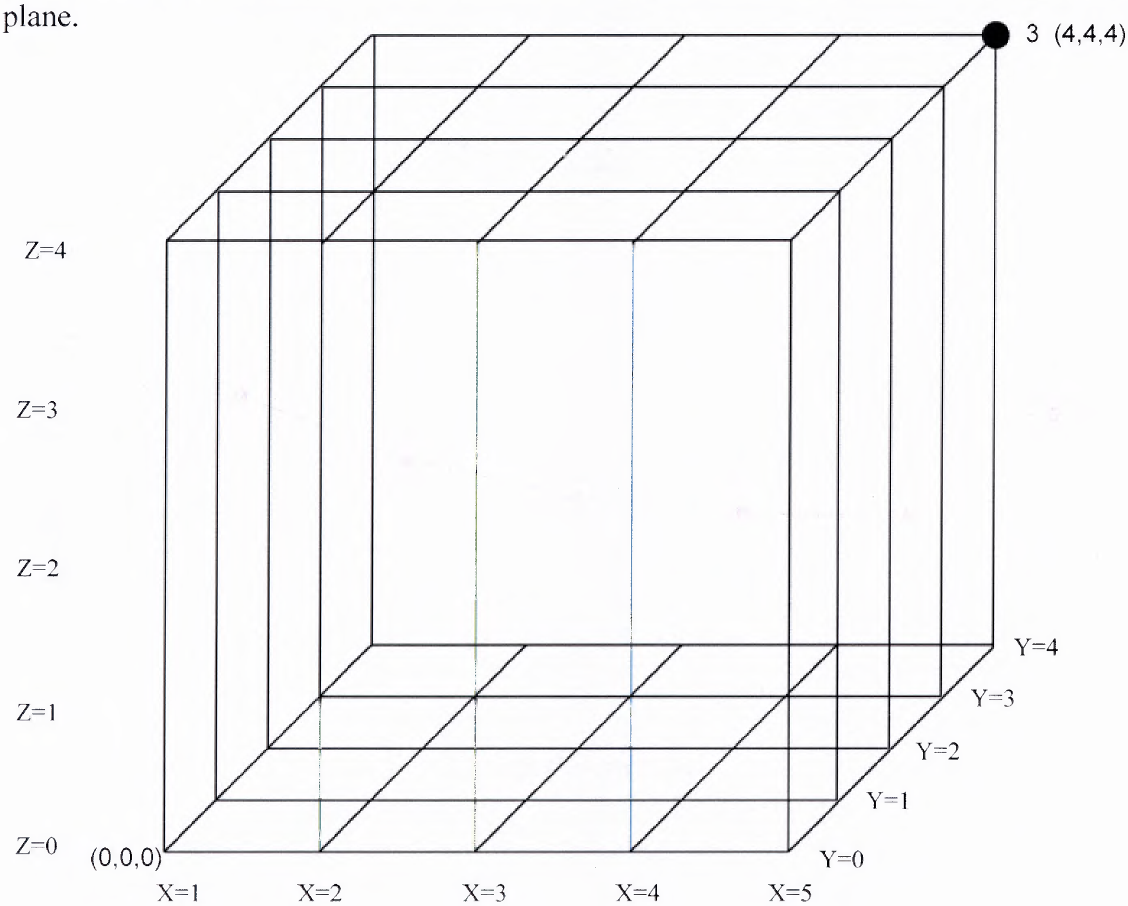


Figure A.13 Reader 3 at (4,4,4).

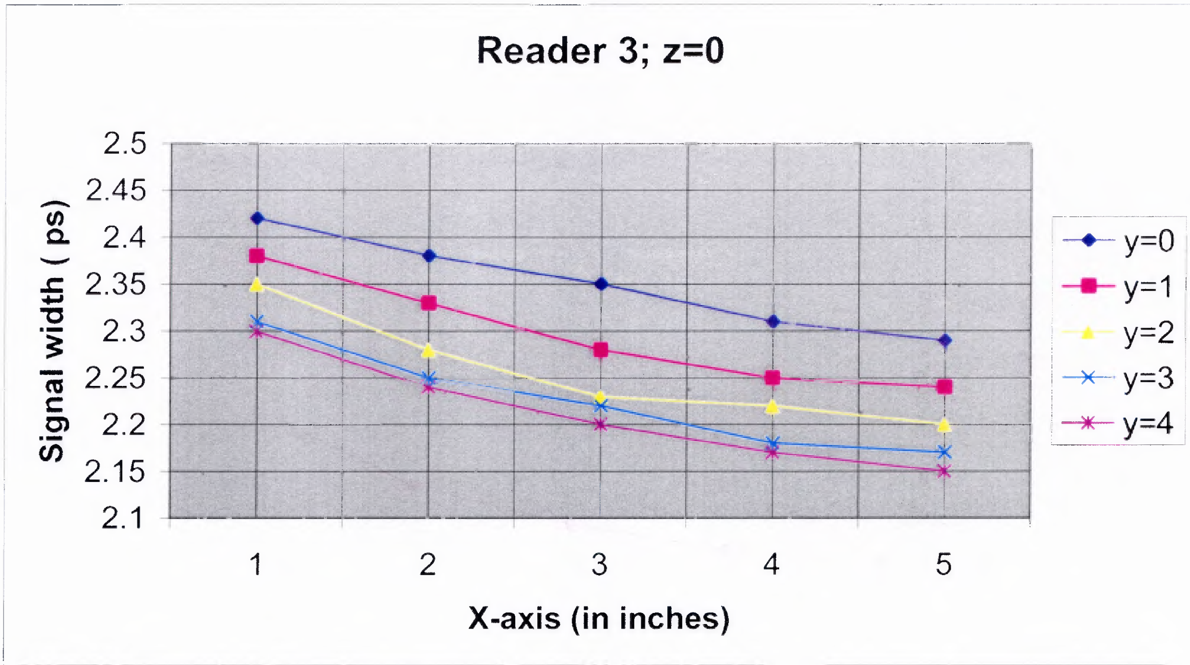


Figure A.14 Signal width for Reader 3 located at (4,4,4). Tracking tag is on the lowest plane ($z = 0$). Observations were obtained for five points for each y-axis on the grid of the plane.

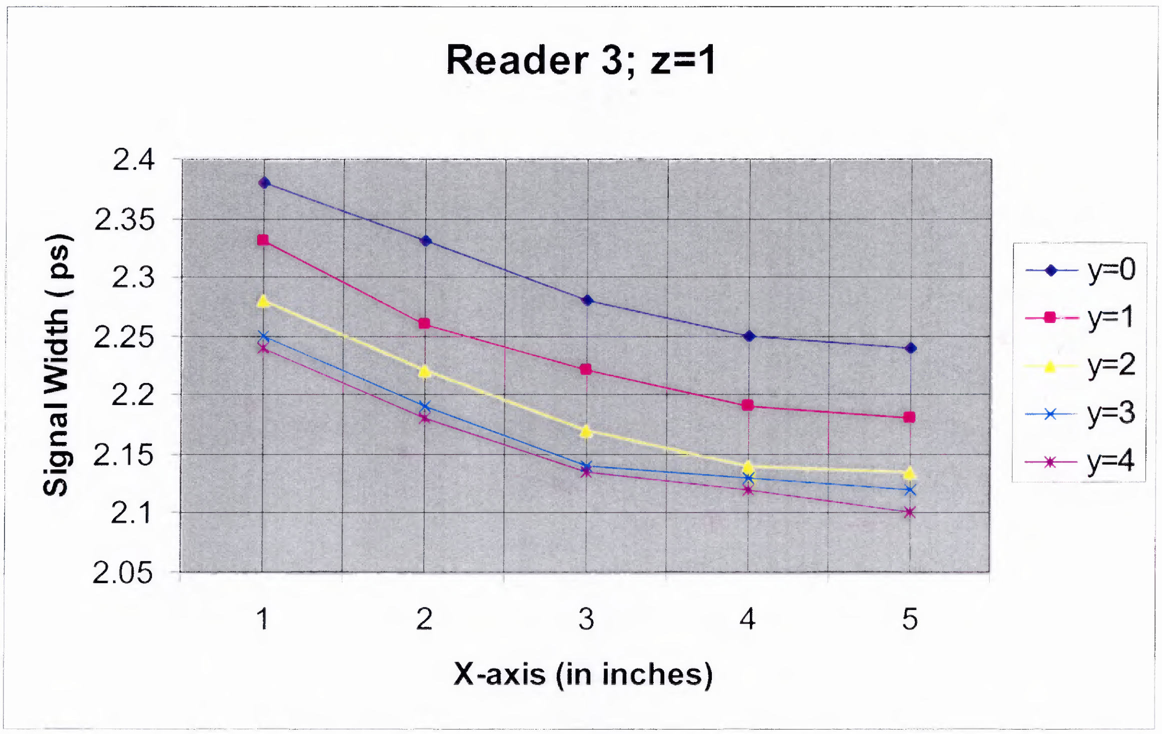


Figure A.15 Signal width for Reader 3 located at (4,4,4). Tracking tag is on the elevated plane ($z = 1$). Observations were obtained for five points for each y-axis on the grid of the plane.

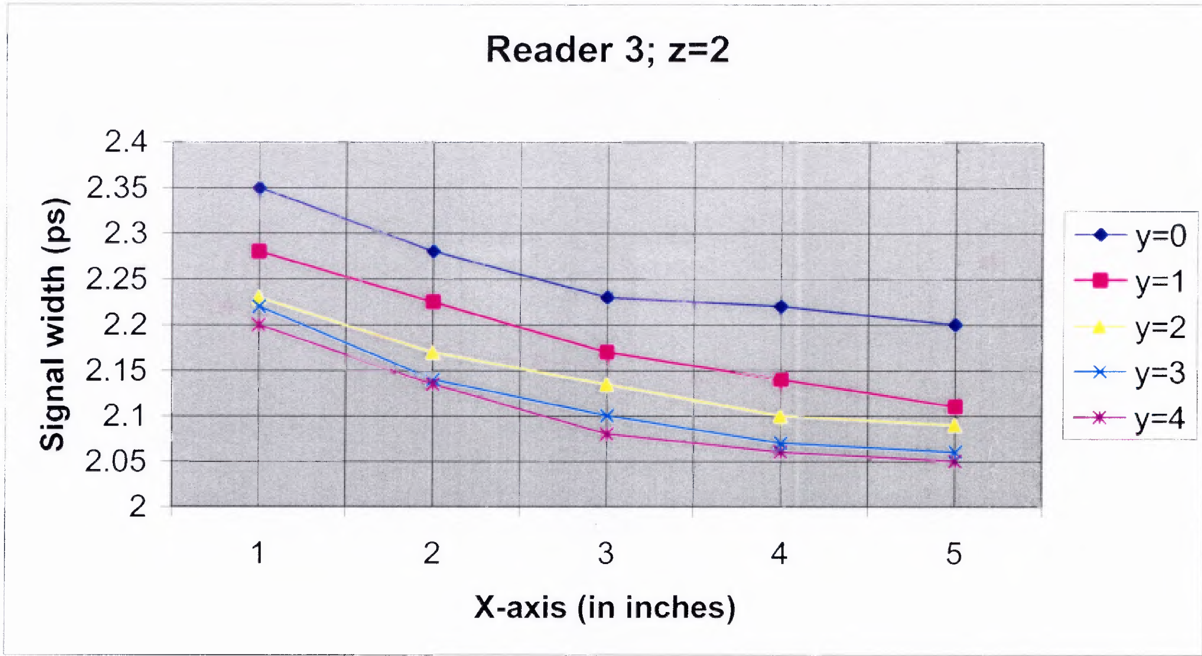


Figure A.16 Signal width for Reader 3 located at (4,4,4). Tracking tag is on the elevated plane ($z = 2$). Observations were obtained for five points for each y-axis on the grid of the plane.

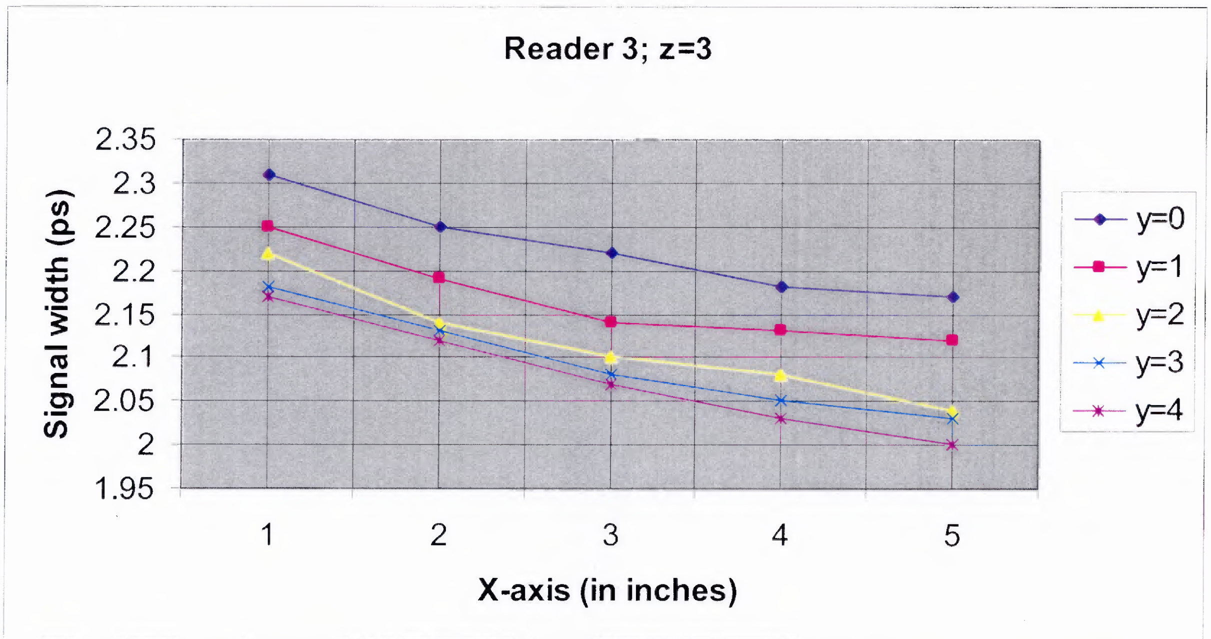


Figure A.17 Signal width for Reader 3 located at (4,4,4). Tracking tag is on the elevated plane ($z = 3$). Observations were obtained for five points for each y-axis on the grid of the plane.

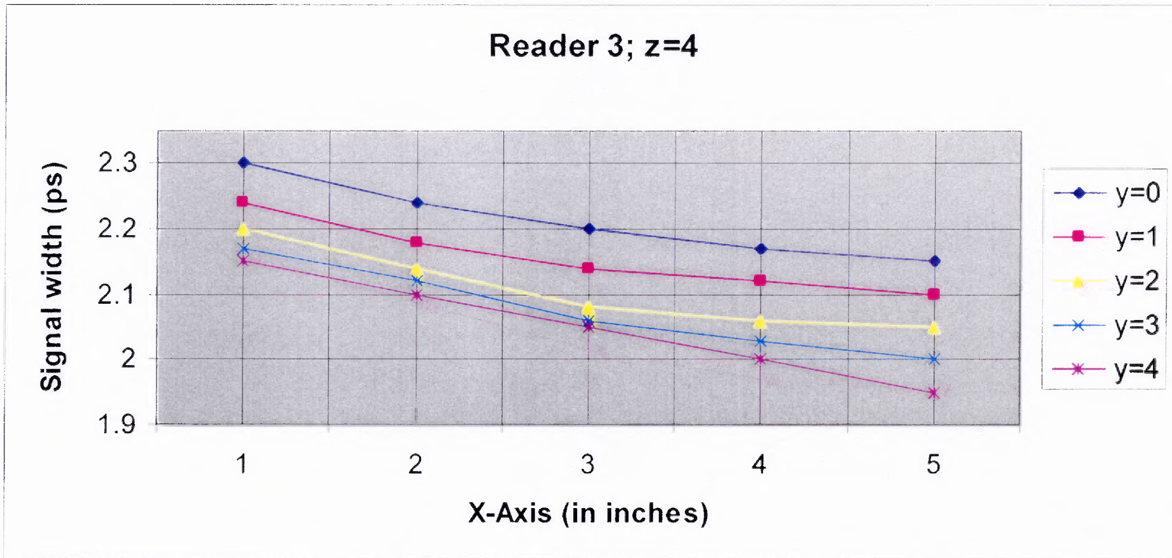


Figure A.18 Signal width for Reader 3 located at (4,4,4). Tracking tag is on the elevated plane ($z = 4$). Observations were obtained for five points for each y-axis on the grid of the plane.

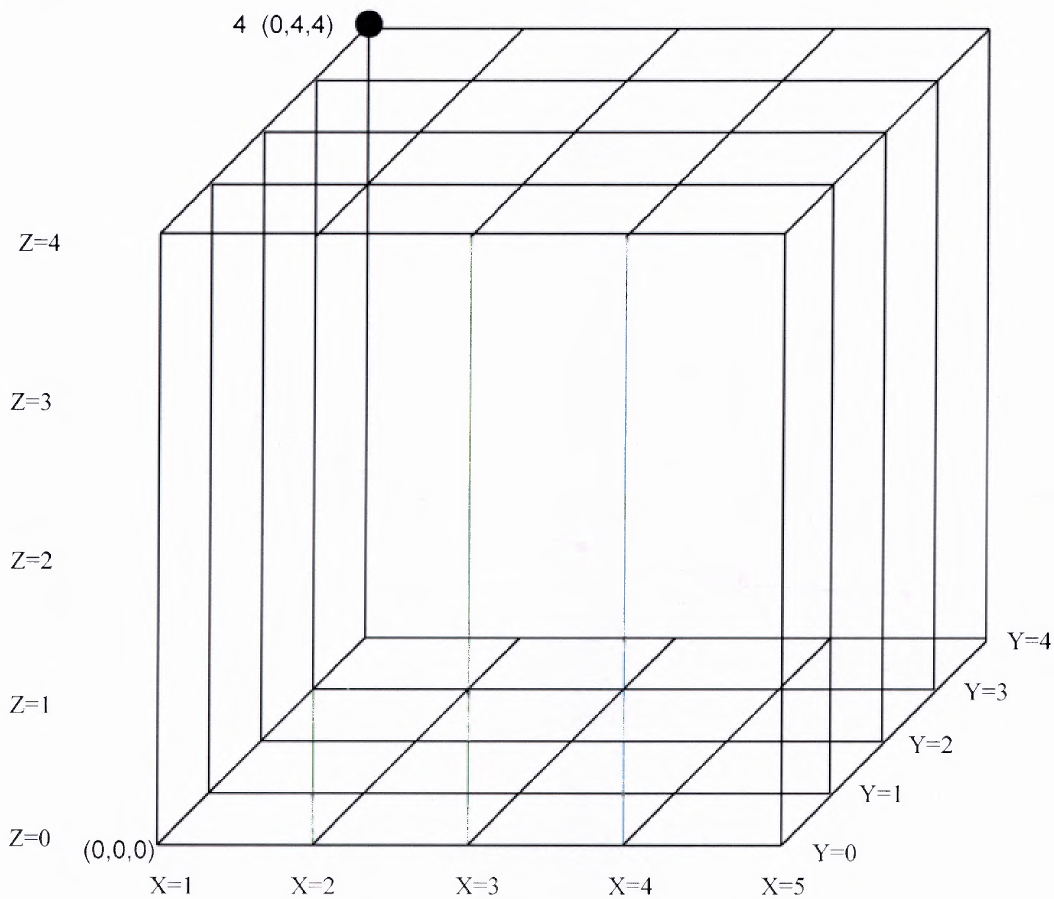


Figure A.19 Reader 4 at (0,4,4).

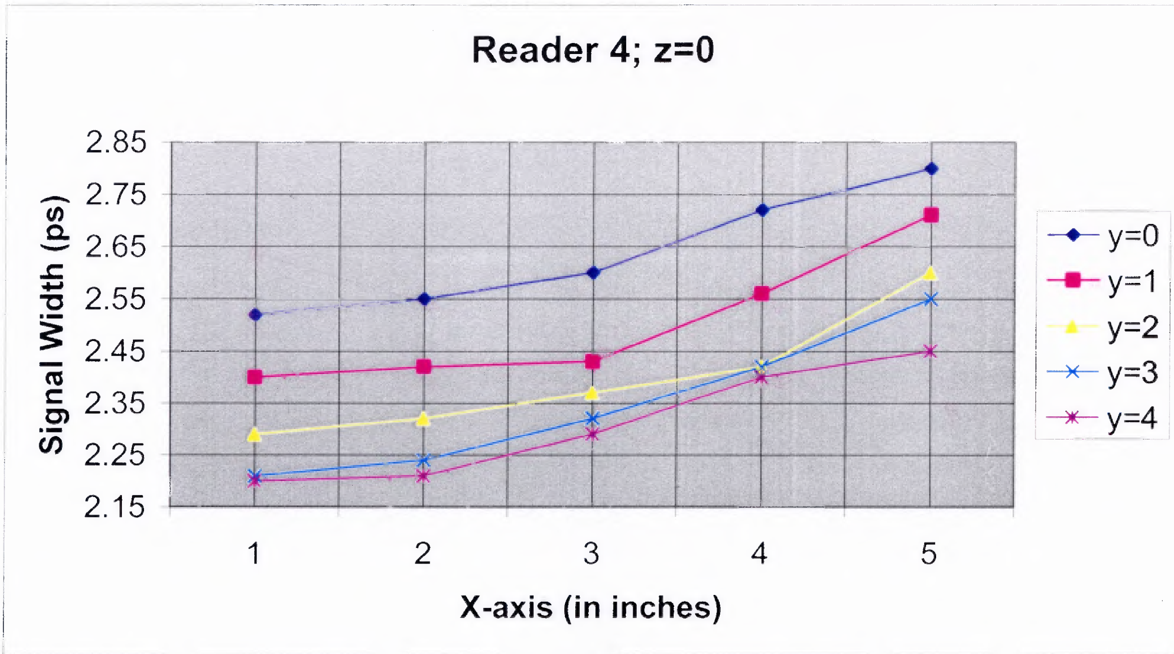


Figure A.20 Signal width for Reader 4 located at (0,4,4). Tracking tag is on the lowest plane ($z=0$). Observations were obtained for five points for each y-axis on the grid of the plane.

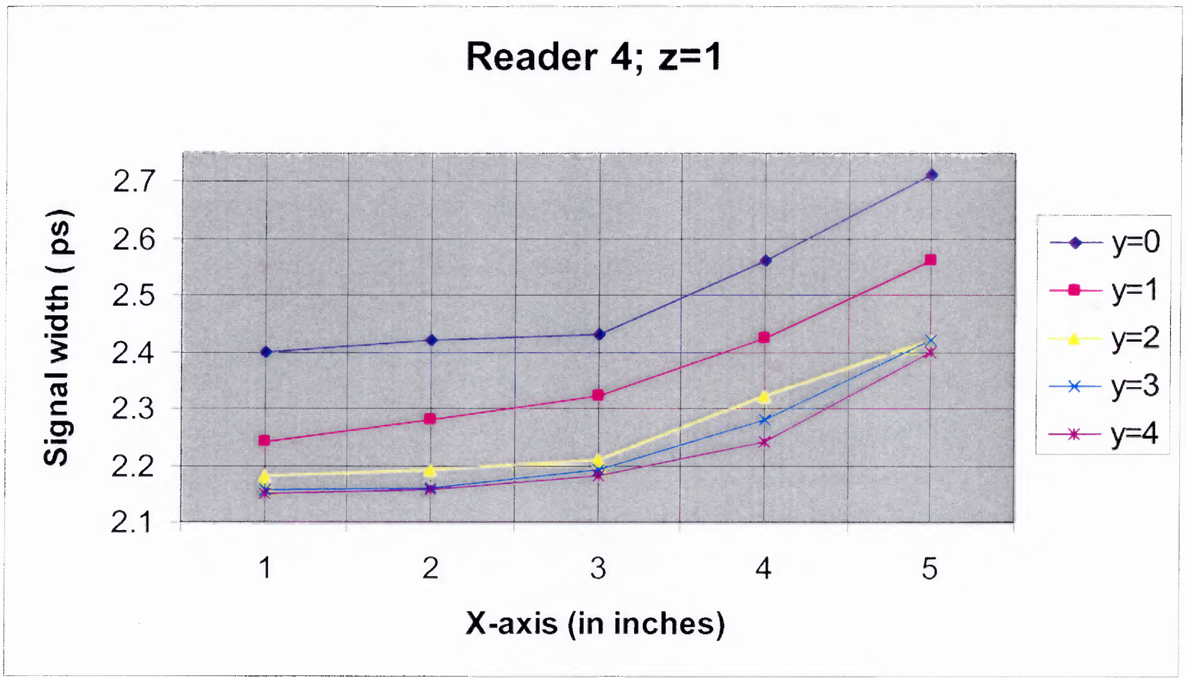


Figure A.21 Signal width for Reader 4 located at (0,4,4). Tracking tag is on the elevated plane ($z=1$). Observations were obtained for five points for each y-axis on the grid of the plane.

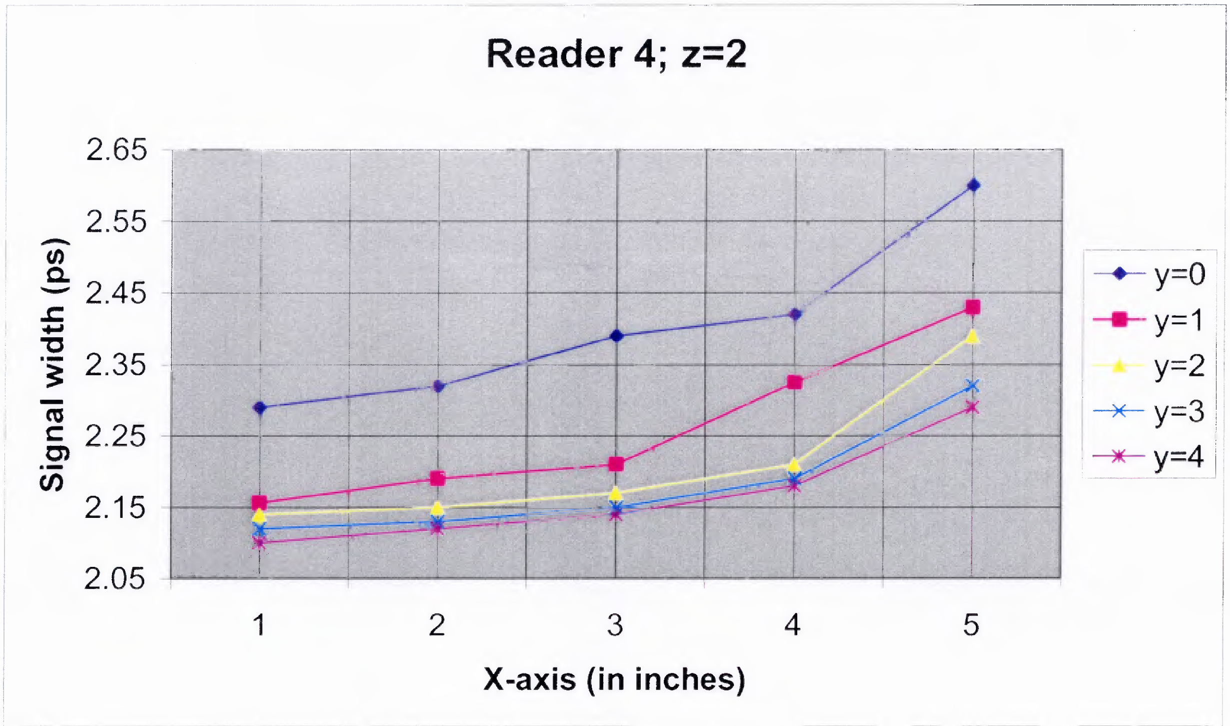


Figure A.22 Signal width for Reader 4 located at (0,4,4). Tracking tag is on the elevated plane ($z = 2$). Observations were obtained for five points for each y-axis on the grid of the plane.

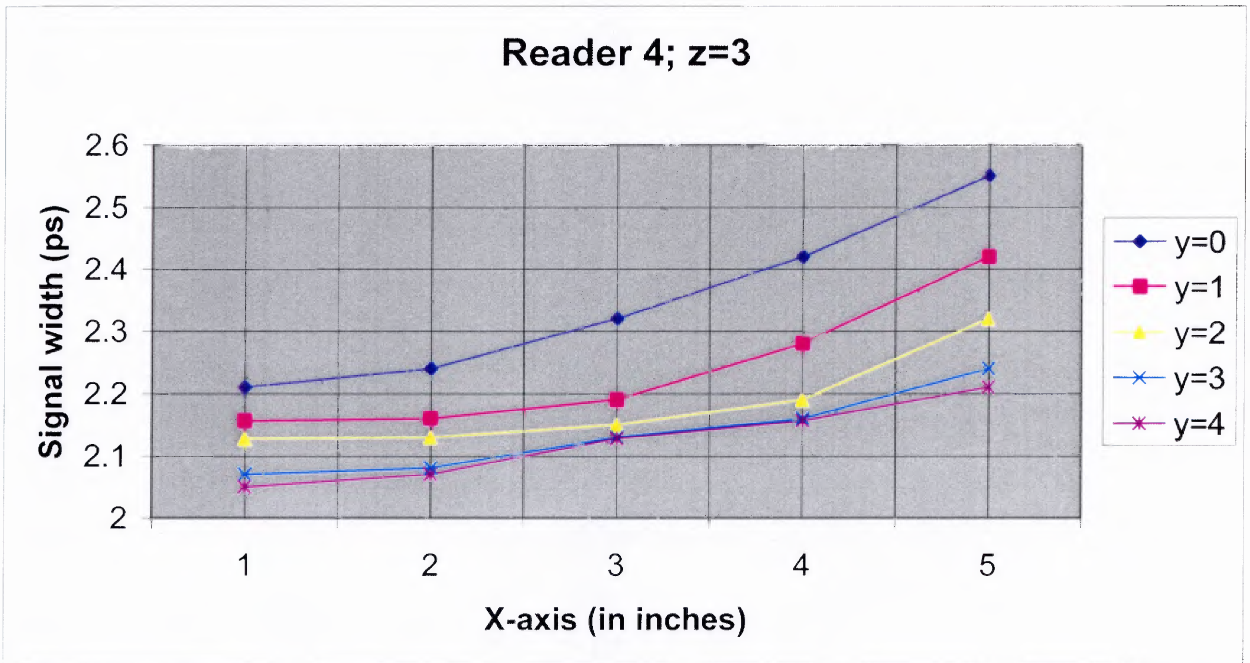


Figure A.23 Signal width for Reader 4 located at (0,4,4). Tracking tag is on the elevated plane ($z = 3$). Observations were obtained for five points for each y-axis on the grid of the plane.

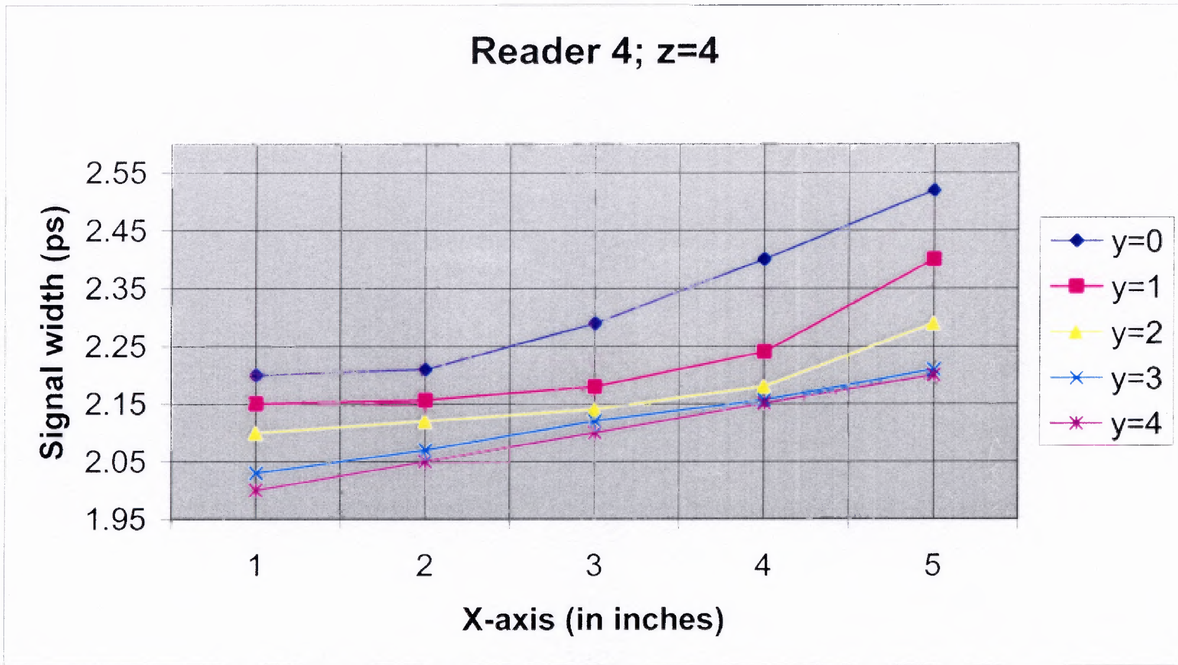


Figure A.24 Signal width for Reader 4 located at (0,4,4). Tracking tag is on the elevated plane ($z = 4$). Observations were obtained for five points for each y-axis on the grid of the plane.

APPENDIX B

RFID PROGRAM

```
// RFID.cpp program will find the error in estimating the location of a tracking tag

# include <iostream.h>
# include <math.h>

void main()
{

  int rd,rf,tt=1,
  xrd[10],yrd[10],zrd[10],
  xrf[20],yrf[20],zrf[20],
  xtt[10],ytt[10],ztt[10];
 double s[30],th[60],E[60],w[30],nxtt[20],nytt[20],nztt[20],
  x=0.0,y=0.0,z=0.0,sumw,Error;

 cout<<"\nREADERS\n";
   cout<<"\nEnter the No. of Readers : ";
   cin>>rd;

   for(int i=0;i<rd;i++)
   {
      cout<<"\nEnter the value of x co-ordinate : ";
      cin>>xrd[i];
      cout<<"Enter the value of y co-ordinate : ";
      cin>>yrd[i];
      cout<<"Enter the value of z co-ordinate : ";
      cin>>zrd[i];
   }

   cout<<"\nREFERENCE TAGS\n";
   cout<<"\nEnter the No. of Reference Tags : ";
   cin>>rf;

   for(i=0;i<rf;i++)
   {
      cout<<"\nEnter the value of x co-ordinate : ";
      cin>>xrf[i];
      cout<<"Enter the value of y co-ordinate : ";
      cin>>yrf[i];
      cout<<"Enter the value of z co-ordinate : ";
```

```
        cin>>zrf[i];
    }
          cout<<"\nTRACKING TAG\n";
          cout<<"\n\nEnter the co-ordinates of tracking tag: ";

    for(i=0;i<tt;i++)
    {
        cout<<"\nEnter the value of x co-ordinate : ";
        cin>>xtt[i];
        cout<<"Enter the value of y co-ordinate : ";
        cin>>ytt[i];
        cout<<"Enter the value of z co-ordinate : ";
        cin>>ztt[i];
    }

  //cout<<"\n\nThe co-ordinates of the readers entered are: \n\n";

    for(i=0;i<rd;i++)
    {
  //      cout<<xrd[i]<<" "<<yrd[i]<<" "<<zrd[i]<<"\n\n\n";
    }

    int count = 0;
    for(i=0;i<tt;i++)
    {
        for(int j=0;j<rd;j++)
            {

            s[count]=sqrt((xtt[i]-xrd[j])*(xtt[i]-xrd[j])+(ytt[i]-yrd[j])*(ytt[i]-yrd[j])+(ztt[i]-
zrd[j])*(ztt[i]-zrd[j]));
            count++;
            }

    }

 // cout<<"Values of s are\n\n";

    for(i=0;i<tt*rd;i++)
    {
     //  cout<<s[i]<<"\n";
    }

    count=0;

    //cout<<"\n\nValues of thetas are : \n";
```

```
    for(i=0;i<rf;i++)
    {
        for(int j=0;j<rd;j++)
            {

            th[count]=sqrt((xrf[i]-xrd[j])*(xrf[i]-xrd[j])+(yrf[i]-yrd[j])*(yrf[i]-
yrd[j])+(zrf[i]-zrd[j])*(zrf[i]-zrd[j]));
            count++;
            }

    }


    for(i=0;i<rf*rd;i++)
    {
   //     cout<<th[i]<<"\n";
    }


    count=0;
    for(i=0;i<tt;i++)
    {
        for(int j=0;j<rf*rd;j=j+3)
            {

            E[count]=sqrt((th[j]-s[i])*(th[j]-s[i])+(th[j+1]-s[i+1])*(th[j+1]-s[i+1])+(th[j+2]-
s[i+2])*(th[j+2]-s[i+2]));
            count++;
            }

    }

    //cout<<"\nvalues of Es\n";

    for(i=0;i<tt*rf;i++)
    {
   //     cout<<E[i]<<"\n";
  }

 sumw=0.0;

 //cout<<"\n\n1/E*E\n" ;

  for(i=0;i<tt*rf;i++)
  {
   w[i]=1.0/(E[i]*E[i]);
```

```
 //cout<<w[i]<<"\n";
 sumw+=w[i];
 }

 //cout<<"\n\nweighs are: \n";
 for(i=0;i<tt*rf;i++)
 {
 w[i]=w[i]/sumw;
 // cout<<w[i]<<"\n";
 }


 for (i=0;i<rf;i++)
 {
 nxtt[i]=xrf[i]*w[i];
 nytt[i]=yrf[i]*w[i];
 nztt[i]=zrf[i]*w[i];
 }


 for (i=0;i<rf;i++)
 {
 x+=nxtt[i];
 y+=nytt[i];
 z+=nztt[i];
 }

/* for (i=0;i<rf;i++)
 {
 cout<<nxtt[i]<<" "<<nytt[i]<<" "<<nztt[i]<<"\n";
 }*/
cout<<"\n\nThe co-orninates of the tracking tag found out to be : \n";
cout<<x<<" "<<y<<" "<<z<<"\n";

 Error= sqrt((x-xtt[0])*(x-xtt[0])+(y-ytt[0])*(y-ytt[0])+(z-ztt[0])*(z-ztt[0]));
 cout<<"\n\nError is : ";
 cout<<Error<<"\n";

// cout<<"\n\nThanks for running the program";

// END OF PROGRAM
}
```

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