Performance and reliability of Radio Frequency Identification (RFID)

Theoretical evaluation and practical testing in relation to requirement from use in Abu Dhabi Sewerage Directorate

By

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Abstract

The primary objective of this research is to investigate the performance and reliability of using RFID technology. There are some factors that can have an effect on RFID performance. Reading distance and material's magnetic penetration are issues discussed in this master thesis.

RFID is a technology with bright future. Many companies and organizations are trying now to implement RFID in their infrastructure, but the implementation progress is very slow because of the security, privacy and cost problems.

Abu Dhabi Municipality & Town Planning in United Arab Emirates is a local government organization that serves more than one million people in one of the most modern city in the world. The Sewerage Directorate in Abu Dhabi wants to find a technology solution that solves their problems such as manhole identifying. RFID technology is very good candidate to solve these problems.

In this research, the Sewerage Directorate's facilities and environments will be first analysed. Then, this analysis will be used to define the characteristics of the RFID system that could be implemented.

The selected RFID equipment was used as testing system under this research. PocketPC software was developed to display and manage data when components get communicate. The conducted test scenarios were based on the requirements of the actual environments. Finally, the results will be evaluated and compared to the theoretical ones, including recommendations and suggestions for further work.

This work was done in parallel with another master thesis on possible use of Radio Frequency Identification (RFID) in Abu Dhabi Sewerage Directorate using Contextual Design methodology.

Preface

This thesis was written for Agder University College (Høskolen I Agder) with collaboration with Abu Dhabi Higher Colleges of Technology (HCT) and Sewerage Directorate of Abu Dhabi Municipality. This research assignment is a part of the Master degree in Information and Communication Technology (ICT) at Agder University College, Faculty of Engineering and Science in Grimstad Norway.

The work has been done in Norway and United Arab of Emirates between January and June 2004.

I would like to thank my supervisors Dr. Lars Line (Agder University College) and Dr. R. Anand Kumar (Abu Dhabi Higher College of Technology) for their continuous guidance and positive attitude throughout this research. I would also like to thank Mustafa Abdulla Almusawa (Head of Automation & IT Division, Sewerage Directorate in Abu Dhabi Municipality) for his willingness to share his time and knowledge.

Special thanks also for the staff in Abu Dhabi Higher Colleges of Technology and, Sewerage Directorate of Abu Dhabi Municipality for their time, cooperation, patience and work support.

At last but not least, I would like to express a special thank to my friends and colleagues Bjørnar Landheim and Vidar Bekken for their cooperativeness, knowledge, and for spending amazing and enjoyable time in Abu Dhabi.

Grimstad, June 2004

Hussain Al-Mousawi

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Abbreviations

ADM	Abu Dhabi Municipality (Department)
AIMS	Asset Information Management System
ASK	Amplitude Shift Keying
CDMA	Code Domain Multiple Access
EAS	Electronic Article Surveillance
EEPROM	Electrically Erasable Programmable Read-Only Memory
EPC	Electronic Product Code
FDMA	Frequency Domain Multiple Access
FDX	Full Duplex
FRAM	Ferromagnetic Random Access Memory
FSK	Frequency Shift Keying
GIS	Geographic Information System
HDX	Half Duplex
HF	High Frequency
IEC	International Electrotechnical Commission
IFF	Identify: Friend or Foe
ISO	International Organization for Standards
JTC1	Joint Technical Committee
LF	Low Frequency
MACE	Mechanical and Civil Engineering
OEM	Original Equipment Manufacturers
PSK	Phase Shift Keying
PVC	Polyvinyl chloride
RFID	Radio Frequency Identification
SCADA	Supervisory Control And Data Acquisition
SDMA	Space Division Multiple Access
SEQ	Sequential Systems
SRAM	Static Random Access Memory
TDMA	Time Domain Multiple Access
TPD	Town Planning (Department)
UCC	Uniform Code Council
UHF	Ultra High Frequency
VDC	Venture Development Corp.

1. INTRODUCTION

1.1. Background

Radio Frequency Identification (RFID) is a wireless technology for tagging and identification of materials and components. RFID is a relatively new technology and the experience from use in different environments is limited.

All RFID systems consist basically of a reader and a transponder. The transponder is the data carrier part of the RFID system. RFID reader's tasks are to power, read, write and handle the communication to/from the transponder. Briefly, the reader's antenna sends out radio signals to communicate with transponders. These signals make a magnetic/electromagnetic field which represents the interrogation zone of the reader. When a transponder, which does not usually possess its own voltage supply (battery), enters the interrogation zone of the reader, it will be activated by receiving the required power and time pulse. Then the transponder will be ready to communicate and exchange data with the reader.

The Sewerage Directorate of Abu Dhabi Municipality and Town planning face some problems of identifying manholes and locating their accurately.

RFID is reliable, easy and fast technology that improves profitability by reducing labour, paperwork and time. The main disadvantage of this technology is that it still costly project for many organizations and companies.

During the entire working period for this thesis, there has been a co-operative work with Vidar Bekken and Bjørnar Landheim, co-students who are writing a thesis on possible use of Radio Frequency Identification Technology (RFID) in supporting a work processes for the Sewerage Directorate using Contextual Design methodology.

1.2. Thesis definition

The master thesis description was presented in January in this way:

Title:

Performance and reliability of Radio Frequency Identification (RFID)

Theoretical evaluation and practical testing in relation to requirement from use in Abu Dhabi Sewerage Directorate

Description:
Radio Frequency Identification (RFID) is a wireless technology for tagging and identification of materials and components. RFID is a relatively new technology and the experience from use in different environments is limited.

This thesis runs in parallel with a thesis that focuses on possible use of RFID in Abu Dhabi Sewerage Directorate. Based on the requirements established by the parallel work, this thesis will focus on performance and reliability of RFID technology.
The work will both comprise a theoretical evaluation and practical testing of selected RFID technology.

1.3. The case

After collecting enough information about Abu Dhabi Sewerage Directorate, this thesis will discuss RFID performance and reliability in case of using and implementation with directorate's facilities.

The case is divided into two parts: theoretical and practical part. In the theoretical part of RFID, reading range and magnetic penetration issues will be discussed. This part will give understanding of RFID technology's expectations and limitations. The second part of this case will take care of the practical testing of RFID system based on the properties of Sewerage Directorate's environments.

1.4. Project progress

Some steps were important to run through to reach the case of this project and solve its approaches. The project progress is divided into 3 phases as shown in Figure 1.1:

- **Phase 1**

This phase is concerned with the collection of information about RFID technology and makes a review of it. The review will provide a good understanding of RFID technology's frequencies, readers, transponders, security, privacy, uses, etc. The work was done in Norway with four other students (Totally 5 students; 3 groups) in January 2004.

- **Phase 2**

At this phase, information about Sewerage Directorate in Abu Dhabi were collected and sorted to make it possible to make the limits and requirements for the RFID products that will be purchased. This phase was accomplished in Abu Dhabi with to other students (Totally 3 students; 2 groups) in March and at the beginning of April.

- **Phase 3**

Theoretical and practical part was the last phase of this project. RFID technology's properties and limitations such as reading distance, reading speed and permeability were used for study cases. This phase was accomplished in Abu Dhabi from April to the end of May.

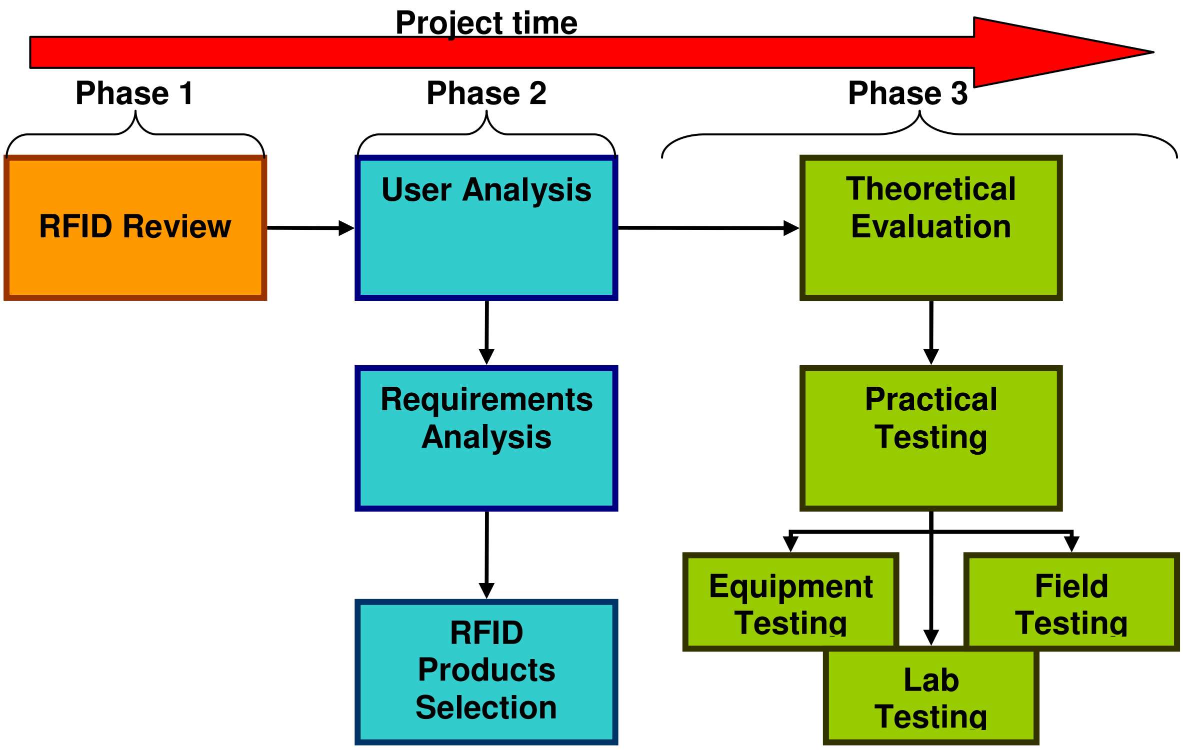

Figure 1.1 – Project phases' overview

1.5. Literature review

Basically, most of the technical information about RFID is brought from an exciting and a well written book entitled RFID Handbook - Fundamentals and Applications in Contactless Smart Cards and Identification - Second Edition - by Klaus Finkenzeller [3].

This book is intended for students and engineers who could be confronted with RFID technology for the first time. The book's basic chapters describe the functionality and the physical and IT-related principles of RFID technology.

Another good resource for this thesis was from RFID organizations and manufacturers Websites. Not all the information on the internet should be trusted, therefore only a few websites were used as resources. These websites are owned and managed by people and companies with huge RFID expertise and qualifications.

Aim Global [2], RFID journal [26], and Texas Instruments [27] Websites were mostly used. These sites consist of useful collection of RFID news, articles, case studies, vendors, products, etc.

Magnetic field information such as permeability and material penetration was brought from NDE/NTD Resource Center [23], Tampere University of Technology [24], and University of Texas at Austin [25]. Information found in these Websites were informative and easy to understand.

1.6. Report outline

The remaining parts of this report will be as follows:

Chapter 2: RFID Technology review

This chapter provides a theoretical overview of the technology discussed in this thesis. The technology is explained in the detailed level needed for this thesis.

Chapter 3: User analysis

User analysis describes the user of the chosen RFID components, such as facilities and environments.

Chapter 4: Requirement analysis

Chapter 4 lists the requirements and limitations that should be considered before choosing RFID equipment based on the user analysis.

Chapter 5: Product selection

This chapter concentrates on listing, evaluating and choosing of relevant RFID readers and tags.

Chapter 6: Theoretical evaluation

This chapter provides a theoretical and mathematical background of the reading range and magnetic penetration issues. The technology is explained in the detailed level needed for this thesis.

Chapter 7: System practical testing

Test cases conducted are clearly described with images.

Chapter 8: Test results

The results of the tests conducted are presented in this chapter.

Chapter 9, 10: Discussion and Conclusion

These two chapters will discuss, evaluate and conclude the test results compared to the theoretical part. It also includes recommendations and suggestions on the solutions.

2. RFID TECHNOLOGY VIEW

2.1. Overview

This chapter introduces and explains the RFID technology as known today. The information in this chapter gives enough background to understand RFID. The principles described in this chapter are related to the goals of this master thesis.

This chapter will mainly describe the functionality of RFID technology. At the beginning, a small introduction on RFID will be presented and the history behind. Furthermore, RFID system's components, communication and characteristics will be introduced in different sections. Finally, summary of RFID technology benefits, uses and prospective challenges will be outlined.

2.2. What is RFID?

Radio frequency identification (RFID) is an automatic identification technology with ability to wireless communication (read and write data without direct contact) and without the necessity for line-of-sight.

RFID is not a new technology as most people think. The first use of RFID system was in the 1940's for distinguishing friendly aircraft from the enemy one. Large powered RFID tags were placed on friendly aircraft. These tags would give response to identify the carrying aircraft as 'friendly' when interrogated by a radar signal. The system was called IFF (*I*dentify: *F*riend or *F*oe) and present day aviation traffic control is still based on its concepts. [1]

After that, the wheels of RFID development were turning. The 1950s were an era of exploration of RFID techniques following technical developments in radio and radar in the 1930s and 1940s. Work such as F. L. Vernon's "Application of the microwave homodyne" and D.B. Harris' "Radio transmission systems with modulatable passive responder" were important for development of RFID. [2]

The 1960s were the prelude to the RFID explosion of the 1970s. Commercial activities were beginning in the 1960s. Sensormatic and Checkpoint were founded in the late 1960s. These companies, with others such as Knogo, developed electronic article surveillance (EAS) equipment to counter theft. EAS is arguably the first and most widespread commercial use of RFID. [2]

In the 1970s developers, inventors, companies, academic institutions, and government laboratories were actively working on RFID.

The 1980s became the decade for full implementation of RFID technology, though interests developed somewhat differently in various parts of the world. The greatest interests in the United States were for transportation, personnel access, and to a lesser extent, for animals. In Europe, the greatest interests were for short-range systems for animals, industrial and business applications, though toll roads in Italy, France, Spain, Portugal, and Norway were equipped with RFID. [2]

The 1990's were a significant decade for RFID since it saw the wide scale deployment of electronic toll collection in the United States. The world's first open highway electronic tolling system opened in Oklahoma in 1991, where vehicles could pass toll collection points at highway speeds, unimpeded by a toll plaza or barriers and with video cameras for enforcement. The world's first combined toll collection and traffic management system was installed in the Houston area by the Harris County Toll Road Authority in 1992. Interest was also keen for RFID applications in Europe during the 1990s. Both Microwave and inductive technologies were finding use for toll collection, access control and a wide variety of other applications in commerce. [2]

Below, Table 2.1 summarizes the RFID development history.

Decade	Event
1940 - 1950	Radar refined and used. Major World War II development effort. RFID invented in 1948.
1950 - 1960	Early explorations of RFID technology, laboratory experiments.
1960 - 1970	Development of the theory of RFID. Start of applications field trials.
1970 - 1980	Explosion of RFID development. Tests of RFID accelerate. Very early adopter implementations of RFID.
1980 - 1990	Commercial applications of RFID enter mainstream.
1990 - 2000	Emergence of standards. RFID widely deployed. RFID becomes a part of everyday life.

Table 2.1 - The decades of RFID

For more information about RFID refer to Appendix A, RFID History Line.

2.3. RFID System's Components

RFID systems exist in countless variants, produced by many different manufacturers, but RFID system is mainly consists of the following components:

1. **Reader (transceiver):** This device is used to read and/or write data to RFID tags. Antenna could be build inside the reader. The antenna is the channel between the tag and the transceiver, which control the systems data access and communication.
2. **Tag (transponder):** A device that transmits data to reader which is located on the object to be identified.

These components communicate via radio signals that carry data either uni-directionally or bi-directionally (Figure 2.1).

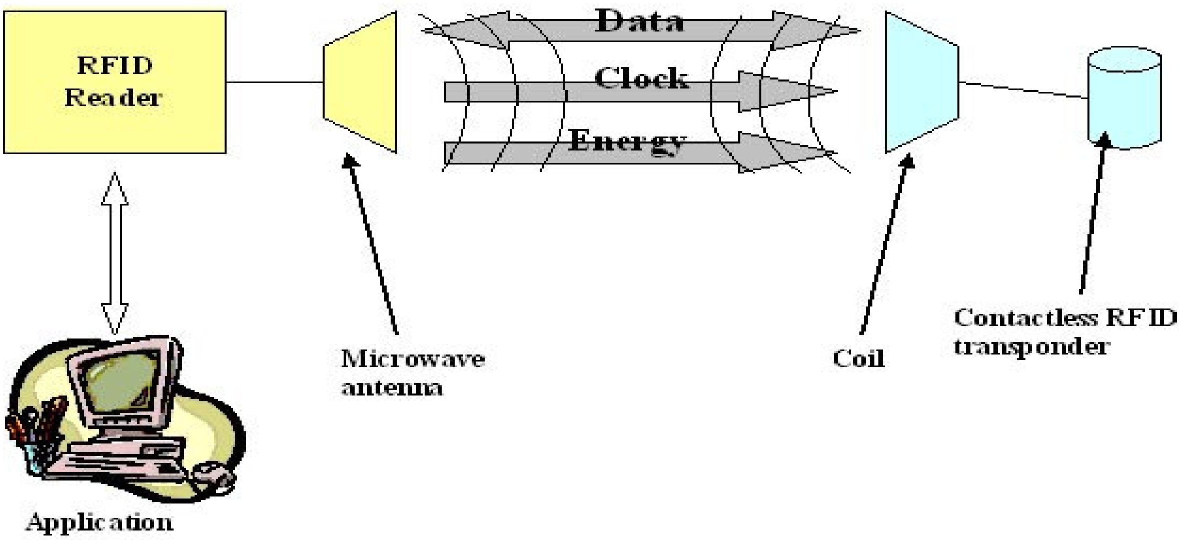

Figure 2.1 – RFID System components

2.4. System communication

Typical communication procedure between the transponder and the reader can be highlighted as follows:

- **Handshake:**

1. The interrogator sends a command to start communication with transponder in the interrogator field and also to power it (passive transponders).
2. Once the tag has received sufficient energy and command from the reader, it replys with its ID for acknowledgment.
3. The reader now knows which tag is in the field and sends a command to the identified tag for instructions either for processing (read or write) or Sleep.

- **Data exchange:**

4. If the tag receives processing and reading commands, it transmits a specified block data and waits for the next command.
5. If the tag receives processing and writing commands along with block data, it writes the block data into the specified memory block, and transmits the written block data for verification.

- **Termination:**

6. After the processing, the interrogator sends an End command to send the tag into the Sleep (“silent”) mode.
7. If the device receives an End command after processing, it sends an acknowledgement (8-bit preamble) and stays in Sleep mode. During the Sleep mode, the device remains in non-modulating (detuned) condition as long as it remains in the power-up.

2.5. RFID Transponder

A transponder is a small electronic device that will transmit information upon request from the reader. Transponders are the data carrier in the RFID system. There are more than 100 suppliers of RFID tags, ranging from large semiconductor companies like TI, Motorola, and Philips down to one-man entrepreneurial businesses.

2.5.1. Transponder components

Basically, RFID transponders (tags) consist of an integrated circuit (IC) or a chip attached to an antenna (Figure 2.2). Information about the physical object of the tag is stored on the IC/chip, while antenna is responsible for receiving and transmitting data and recharging the transponder (passive tags). Typically, these components are printed or encased on a thin plastic sheet.

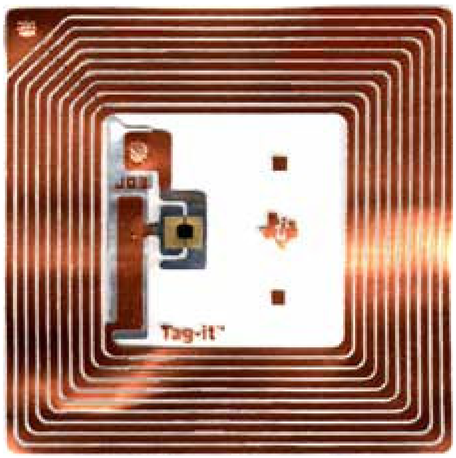

Figure 2.2 – RFID Transponder

2.5.2. Shapes and sizes

RFID transponder comes in different construction formats, such as label-type, card-type, coin-type, stick-type etc., depending upon the application and environment that will be used on. It can be as small as the head of a pin and as flat as a sheet of paper.

2.5.3. Power supply

Powering the RFID transponders is important to any RFID system. There are to types of transponders which can be summarized as follows:

2.5.3.1. Active transponders

These kinds of transponder have no need to be powered by the reader. Active transponders have an integrated battery which supplies all or part of the needed power. When the communication between the reader and the transponder starts, signals from the reader will put the transponder in “wake up” mode. After completing the transaction with the reader, the transponder will then return to the power saving “sleep” or “stand-by” mode.

2.5.3.2. Passive transponders

Passive transponders do not have any integrated power source and therefore are totally dependent on reader's (magnetic/electrical) field to get the needed power supply. The transponder collects part of the energizing field via its antenna. Typically, passive transponders are smaller and lighter than active ones, and less expensive. They are maintenance free and will last almost indefinitely.

2.5.3.3 Active vs. passive transponders

Table 2.2 shows the main differences between the active and passive RFID transponders.

	Active	Passive
Power	Battery powered	Powered by electromagnetic signals
Reading distance	Long	Short
Size	Large device	Small device
Life time	Limited	Unlimited
Cost	Expensive	Inexpensive
Working environment	Sensitive to harsh environment	Withstands harsh environment
Weight	Heavy	Light

Table 2.2 - Differences between active and passive RFID transponders.

2.5.4. Operation type

RFID systems operate according to one of two basic procedures, Full Duplex (FDX)\Half Duplex (HDX) systems or sequential systems (SEQ).

In full\half duplex systems the transponder's response is broadcast when the reader's radio frequency field is switched on. The transponder's signal to the reader can be extremely weak compared to the signal from the reader itself. Because of that transmission procedures must be employed to differentiate the transponder's signal from the reader. That means in practice that data exchange from transponder to reader using load modulation, but also Subharmonics technique may be used for the reader's transmission frequency.

Sequential systems employ a system whereby the field from the reader is switched off briefly at regular intervals. These gaps are recognized by the transponder and used for sending data to the reader. The disadvantage of using this procedure is the power loss to the transponder during the transmission break, which must be smoothed out by the provision of sufficient auxiliary capacitors or batteries.

2.5.5. Data quantity

The normal range for the data capacity of RFID transponders vary from few bytes to several kilobytes. The only exception is so-called 1-bit transponders. 1-bit of data is enough to describe the situation for the reader: “transponder in the field” or “no transponder in the field”. These kinds of transponder are very cheap because of no need for electronic chip and for this reason enormous number are used in Electronic Article Surveillance (EAS) to protect goods in shops and businesses.

2.5.6. Data carrier’s memory access

According to memory accessibility, there are two types of transponders:

2.5.6.1. Read-Only transponders

Read-only transponders are programmed only one time by the manufacturer. The information in the memory (transponder ID) cannot be changed by any command once it has been written. This kind of transponders has small memory and is not expensive.

2.5.6.2. Read/write transponders

On the other hand, Read/write transponders can be reprogrammed by reader’s commands. These transponders have large memory and more expensive than the Read-Only transponders. Read/write transponders have three main procedures for storing and managing the data:

- **EEPROM** (Electrically Erasable Programmable Read-Only Memory)

This procedure is dominant in many RFID systems. However, this has the disadvantages of high power consumption during the writing operation and a limited number of write cycles.

- **FRAM** (Ferromagnetic Random Access Memory)

FRAM are more used in isolated cases. FRAM’s read power consumption is lower than the EEPROM by a factor of 100 and the writing time is 1000 times lower. Manufacturing problems have hindered its widespread introduction onto the market.

- **SRAM** (Static Random Access Memory)

SRAM are used for data storage in microwave system which facilitate very fast write cycles. The disadvantage of this procedure is that the data requires an uninterruptible power supply from an auxiliary battery (active transponder).

2.6. RFID Reader

RFID reader has the responsibility to read, write and retransmit data to RFID transponders (tags) without direct contact and in some cases powering when the transponders are passive. Reading and writing operations to tags are based on master-slave principle. Reader's role could be master or slave, which depends on whom the reader are communicating with. As showed in Figure 2.3, the application software (end-user) is controlling and activating the reader by sending write or read commands. In this case the reader is slave for the application program. On the other side, the reader starts the communication, which is originally an order from the application software, with RFID transponder in the interrogation zone. The RFID reader here takes the master role.

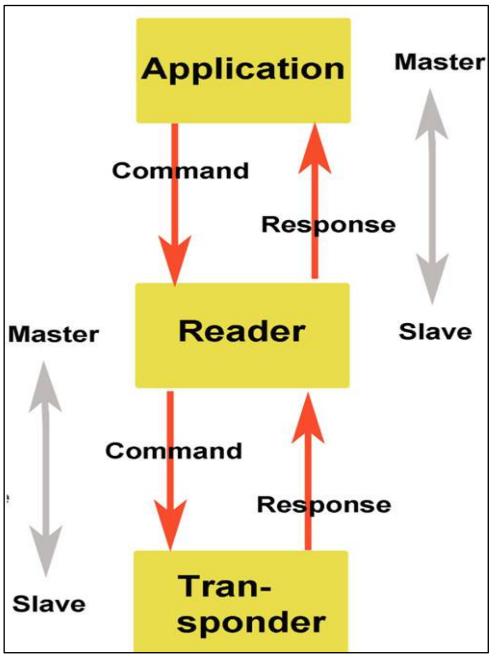

Figure 2.3 – RFID reader's master-slave role

2.6.1. Reader's components

Generally, readers in all systems consist of two fundamental functional blocks as shown in Figure 2.4:

2.6.1.1. HF interface

The master part of the reader which has these functions:

- Supplying RFID transponders with power by generating high frequency power.
- Modulation of the signal to the transponder
- Reception and demodulation of signals from the transponders.

2.6.1.2. Control unit

The slave part of the reader performs the following functionalities:

- Communication and executing the application software's commands
- Signal coding and decoding
- Communication control with a transponder

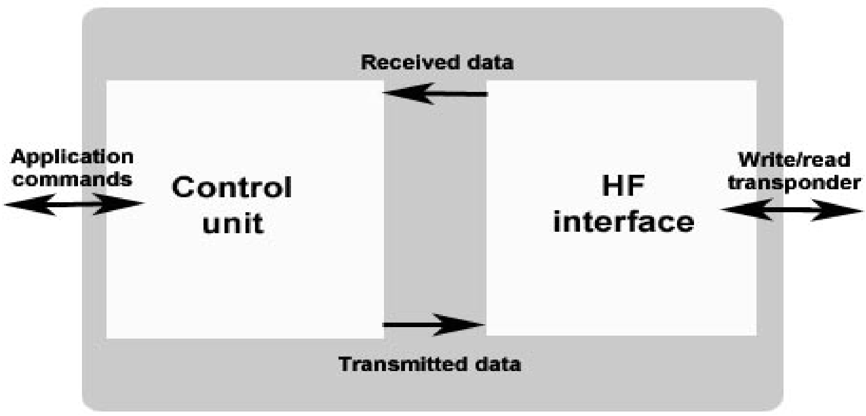

Figure 2.4 – RFID reader components

Other RFID system operates with addition functions like anti-collision algorithm, encryption and decryption of transferred data, and transponder-reader authentication.

2.6.2. Data transfer to transponder

2.6.2.1. Amplitude Shift Keying (ASK)

In amplitude modulation, high envelope is a ‘1’ and a low is a ‘0’. Amplitude modulation can provide a high data rate but with low noise immunity.

2.6.2.2. Frequency Shift Keying (FSK)

This form of modulation uses two different frequencies for data transfer. FSK allows for a simple reader design, provides very strong noise immunity, but suffers from a lower data rate than some other forms of data modulation.

2.6.2.3. Phase Shift Keying (PSK)

This method of data modulation is similar to FSK except that only one frequency can be used, and the shift between 1’s and 0’s is accomplished by shifting the phase of the backscatter clock by 180 degrees. PSK provides fairly good noise immunity, a moderately simple reader design, and a faster data rate than FSK.

Because of the simplicity of demodulation, the majority of RFID systems use ASK modulation.

2.6.3. Readers’ types

Different applications have different requirements from each other, which results to different designs of readers. Generally, readers are classified into the following three types:

2.6.3.1. OEM readers

OEM (Original Equipment Manufacturers) readers are mostly used for data capture systems, access control systems, robots, etc.

2.6.3.2. Industrial use readers

Industrial readers are used in assembly and manufacturing plant.

2.6.3.3. Portable readers

These readers are more mobile than the other readers which are supported with a LCD display and keypad. Animal identification, device control and asset management are some of uses for this kind of readers.

2.7. RFID Carrier Frequencies

RFID operates in several frequency bands. The RFID frequency for each country is controlled by The Radio Regularity (Post- og teletilsynet in Norway and Ministry of Communication in UAE). Most of the RFID frequencies that are used now are frequencies that have been served specifically for industrial, scientific or medical application known as ISM frequency ranges. RFID frequencies can be divided into the following three basic ranges:

2.7.1. Low Frequency

The range of the low frequency RFID fluctuates a lot from a product to other because the RFID producers do not have a standard. The range will find a place between 30 and 500 kHz. 134.2 kHz is the most ordinary used frequency that has been used for the low frequency tags and readers.

Low frequency systems have short reading ranges and lower system costs. The vast majority of the low frequency systems operate without the need of integrated battery in their tags. They are most commonly used in security access, asset tracking and animal identification applications. They are not too sensitive to metal, water and electrical noise.

2.7.2. High Frequency

High frequency systems operate between 10 – 15 MHz, but a range of high frequency RFID tags and readers operating mostly at 13.56 MHz (ISM frequency). High frequency systems have longer read ranges and higher reading speeds than the low frequency systems. The cost of this system is inexpensive, but higher than the low frequency system. These systems are used in access control and smart cards.

2.7.3. Ultra High Frequency

An ultra high frequency system operates between 400 MHz to 1000 MHz and 2.4 GHz to 2.5 GHz. This technology is very expensive compared to the systems above. This frequency range has a very long read range and a high reading speed. Unlike the other systems, line of sight is required for the communication between RFID readers and transponders. Ultra high frequency systems are used for such applications as railroad car tracking and automated toll collection.

2.7.4. Frequency comparison

It will be much easier to understand the RFID frequencies properties by comparing each other. Table 2.3 shows the differences between RFID frequency categories and their applications.

Frequency Band	Reading Range	System Characteristics	Typical Use
Low 100 – 500 kHz	3 cm – 10 Feet	- Short read range - Inexpensive - High reading speed	-Access control - Animal id
High 10 – 15 MHz	3 inches – 20 Feet	- Medium read range - Medium reading speed	- Access control - Smart cards
Ultra High 850 – 950 MHz 2.4 – 5.0 GHz	Average of 100 Feet	- Long read range - High reading speed - Expensive - LoS Required	- Vehicle id. - Toll collection systems

Table 2.3 - RFID frequency bands

Finally, it is important to ensure that RFID systems do not interfere with or jam radio and television, mobile radio services, marine and aeronautical radio services and mobile telephones.

2.8. RFID standards

The lack of official RFID standards has delayed the widespread adoption of this technology like the early bar coding days. Without global standardization, real growth of the RFID industry will be limited.

There are two organizations that are working on globalization of RFID standards:

2.8.1. EPCglobal

EPCglobal is collaboration project between the Uniform Code Council (UCC) and EAN International. This organization, witch is entrusted by the industry, will establish and develop the Electronic Product Code (EPC) standard and network.

EPC is an open standard and was first developed by the Auto-ID Center, which is currently founded by a number of large companies such as Coca Cola, Intel, Wal-Mart and Philips Semiconductors. The goal of Auto-ID Center is to bring the cost of the hardware down to a level where RFID can be used to track individual items. EPC is a unique number that identifies a specific item which is stored on a RFID tag.

EPC is built up as a series up numbers; a header, and three sets of data. The header (8 bits) identifies the EPC's version number, thereby allowing for different lengths or types of EPC later on. Auto-ID Center has proposed EPCs of 64 and 96 bits, but there could be more. The 96-bit number provides unique identifiers for 268 million companies. Each of these companies can have 16 million object classes (often used to identify a specific product), and 68 billion (109) serial numbers in each class, which should be sufficient for years to come.

Many companies like Gillette, Wal-Mart, Hewlett-Packard and Johnson & Johnson are in the administrative board of EPCglobal.

2.8.2. ISO

The International Organization for Standards (ISO) has three technical committees working on RFID. RC104 is focused on freight containers, TC204 on road informatics, and TC122 on packaging. ISO has also formed a Joint Technical Committee (JTC1) with the International Electrotechnical Commission (IEC), an international body that publishes standards for all electrical, electronic and related technologies. This committee has many subcommittees; SC31 deals with automatic data capture technology; and have four work groups; WG4 deals with RFID.

WG4 has a number of subgroups. Of these, subgroup 3 is focused on using RFID for automatic identification and item management. (Tracking items in the supply chain). Subgroup 3 is responsible for a proposed standard called ISO 18000, which is expected to be published as international standards by April 2004. The goal of ISO 18000 standard for RFID asset tracking is to allow any ISO 18000 chip to talk to any ISO 18000 reader at a given frequency.

2.9. RFID Benefits

The primary benefits of RFID are:

- **Quality**. Remove of clerical errors in recording data
- **Reliable**. Operates in harsh environments (e.g. wet, dusty, dirty conditions; corrosive environments; or applications where vibrations and shocks are possible)
- **Faster** data collection, Non-contact operation.
- **Easy**. Freedom from line-of-sight constraints (transponders can be read irrespective of orientation; through paint, even through non-ferrous solids)
- **Effective**. Reduction in labour and paperwork that required to process data.

There are many advantages when RFID technology is implemented in a company like:

- Realize major gains in labour efficiency and productivity;
- Automate many manufacturing, assembly and quality control processes;
- Reduce waste and keep inventory levels at a minimum;
- Increase customer satisfaction;
- Improve profitability.

2.10. RFID Disadvantages

There are also a number of possible disadvantages related to the use of RFID technology and these are summarized as follows:

- **Privacy**. Several people and organizations have expressed vocal concerns over the possible misuse of RFID tags for identification of customers. This represents a public relation problem that has to be overcome before widespread use of RFID can be a reality. A website that has become the gathering point for many of these opponents is www.nocards.org.

- **Security**. When a tag is read, there is a possibility that someone with malicious intent may overhear the data being sent. Therefore, it is not recommended to store excessive amounts of data on the tag.

- **Cost**. Both the tags and the reader cost money. In addition, there may be substantial redesign required in the infrastructure. This has to be weighed against the possible savings when implementing RFID.

- **Implementation** of RFID in applications is a relatively new, so it may be said that it hasn't been thoroughly tested yet. This may make someone hesitant about implementing it, but RFID has proved itself in every test so far.

- **Standards**. RFID is also plagued with competing standards (esp. ISO/EPC), so a company may decide to wait till this has been resolved. However, if the company is going to implement a closed-loop solution, this is not a problem.

2.11. RFID Applications

Comparing to barcodes, RFID have no need for line-of-sight communication, can store and manage data, and have the ability to read more than one tag at once (Cluster reading). Because of these features, RFID can be implemented and determined in every industry, commerce and service where data needs to be collected such as transportation, distribution, manufacturing and security. Following selected examples of RFID applications:

2.11.1. Access Control

Authorization of individuals and premises concerns many people and companies today. RFID have been used in this kind of application to increase the security. Before designing any access application, there are two different access control systems:

- **Online systems:** This kind of system requires that all the terminals are connected to a central system which runs a database. The terminals have to check with the database every time to authorise and give access to users. Online systems are used where access authorization of a large number of users with inefficient access processing.

- **Offline systems:** In offline status, each terminal stores a list of identification keys. The terminal read the information from the data carrier (Transponder) and compares it with the stored identification keys. Access will be given if the compared data match. Offline systems are used where there are few people and many iseperate rooms.

2.11.2. Animal identification

The time showed that using RFID to identify and locate animal is a successful system. A huge kind of animals can be identified, from cows to birds. There are four basic procedures for attaching the transponder to the animal:

- **Collar transponders:** This kind of transponder is tied up like the animal bell. It is easy to remove and transfer from one animal to another.

- **Ear tags:** These tags are very small transponders that compete with ear barcodes. Ear barcodes can not give a totally automated system because of the reading distance and Line-of-Sight requirement.

- **Injectible transponders:** This transponder will be placed under the animal's skin by using a special tool and can be removed only by an operation. Injecting the animal has existed for around 10 years ago.

- **Bolus transponders:** This is a transponder mounted in an acid resistant housing. Bolus is placed in the rumen via the gullet using a sensor. Under normal circumstances the bolus remains in the stomach for the animal's entire life. Removing the bolus transponders is easier than removing the injectible transponder from the animal.

2.12. The future of RFID

According to Venture Development Corp. (VDC) the global RFID industry reached 663 M€ in 2000 growing approximately 25 % annually as shown in Figure 2.5. Frost and Sullivan estimated the worldwide RFID market at 1.6 billion dollars in 2001 and that the market will reach 3.6 billion dollars by 2006. [5]

The involvement of large company of developing RFID technology (Auto-ID Center) indicates that this technology does have the potential of becoming a very prominent technology.

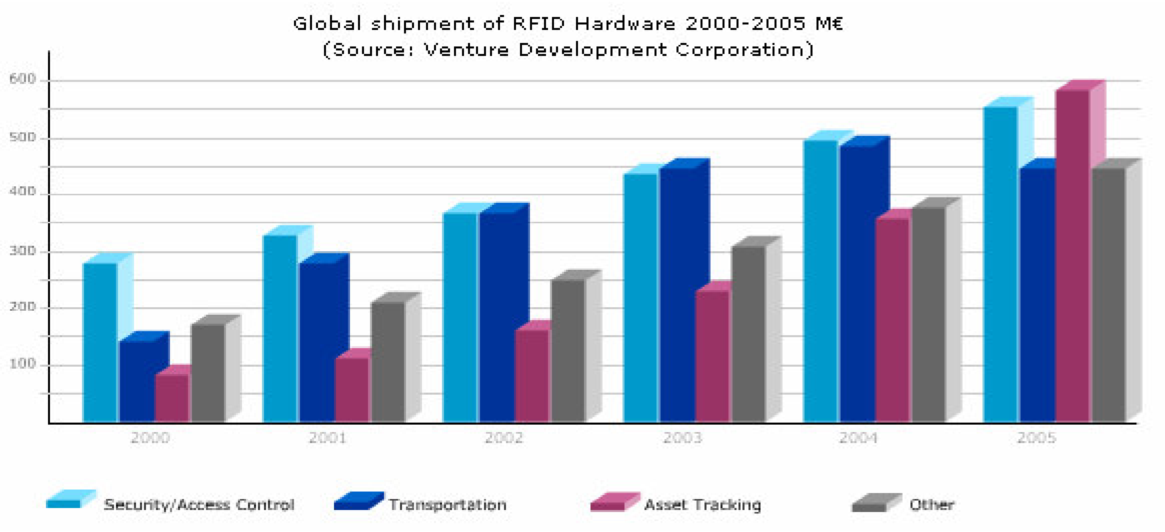

Figure 2.5 – Global RFID market growth according to RFID applications [5]

But there are some important obstacles that should be solved to make the RFID more progressive and acceptable:

2.12.1. Standardization

Lessons and experience from previous technology such as barcodes showed that the lack of official standard has delayed the adoption of these technologies. The standardization of RFID technology is divided into to areas:

- **RF spectrum:** This area is very difficult to standardize and accomplish because each country owns and controls its own radio spectrum. Each of these countries individually has to consider the allocation of the spectrum based on their particular needs.

- **RFID Standards:** The manufacturers of RFID systems has created and developed many standards, for communication between the reader and the transponder, because of the market and the hard competition.

2.12.2. Cost

The adoption of RFID by small and large businesses will become ubiquitous if the cost of RFID system components is low enough. Today, implementing RFID tags on cheap items is far from reality. Replacing barcodes with RFID tags will be a matter of time if the Auto-ID Center reaches its goal of a 5 cent RFID tags.

2.12.3. Privacy

This is one of the main RFID obstacles that concern groups who fears for the holiness of their private life. There have always been debates about implementing RFID tags inside the human body, storing all the information about the person who carries it. This will make identifying individuals easy, which means destroying the privacy of these individuals.

3. USER ANALYSIS

3.1. Overview

The collected data and information from the user of chosen RFID system will be analysed in this chapter.

The chapter starts with answering the following questions:

- Why writing this analysis?
- How has the analysis been done?
- And who is “exactly” the user of the next system?

The second part of this chapter will focus on listing all user facilities and working environments.

The rest of this chapter will summarize and analyse the user problems, needs and expectation of the new system.

3.2. Introduction

3.2.1. Purpose

The user analysis provides a good understanding of the user for the approved system. Collecting and filtering user’s information and needs will play some role in the product’s use and selection and the decision of product idea (whole system). The collected information can be used later on the design process.

3.2.2. Analysis execution

Since the stakeholders drive the project and facilities, it is important that they are involved from the inception of the project. Meetings with the Sewerage Directorate’s staff in person or using phone conversations are a very important part in the process. In addition, email is great for confirming and verifying details, however with personal contact the task is best accomplished. This analysis is based on the following procedures:

1. Conversations with:

- **Mustafa Abdulla Almusawa** [6], for all relevant aspects around the Sewerage Directorate.
- **Jacek Mierzejewski** [7], for the Asset Information Management System (AIMS).
- **Hassan Ahmed Al Kurbi** [14], for the AIMS and the pipe network.

- **Aminol Kaibia** [15], for the Close Circuit TeleVision (CCTV) pipe surveys.

- **Jerzy Augustyniak** [16], for the SCADA system, a remote control and alarm system for pumping stations.

- **Ghassan Koujan** [9], for arranging field trips and pipe network.

- **Ken Vaheesan** [8], for Mechanical and civil Engineering Contractor (MACE).

- **Frank Mueller** [10], for supervising previous RFID project at the Sewerage Directorate.

All conversation was done personally with the persons involve and at their office. Some of the conversations were supplemented with demonstrations in the field, on computers or with billboards to get a complete and a clear picture.

2. Field visits with guides to:

- Mafraq Treatment Plant.
- Irrigation reservoirs.
- Different types and size pumping stations.
- Regular manholes, during maintenance work.
- Different types and forms of manholes and champers.

Speaking with contractors or regular employees in the Sewerage Directorate provided valuable information about the general operations.

To ensure quality and correctness, the registered data was written down and sent to Mustafa Abdulla Almusawa for verification and corrections. This made the basis for the reminding sections of this chapter.

All conversations and field trips were carried out in February 2004. The research was done in co-operation with Vidar Bekken and Bjørnar Landheim, who will do the extended version of this analysis.

3.2.3. Scope

Abu Dhabi Municipality and Town planning was established in 1966. At that time Abu Dhabi Emirate (as shown in Figure 3.1) was a pure desert with a small population. After more than 30 years of hard work, Abu Dhabi now is one of the most modern cities in the world. Abu Dhabi Municipality and Town Planning is serving more than one million people (The Island and Mainland population). There are about 40,000 employees taking care of all services that a modern society must have.

Figure 3.1 – United Arab Emirates (UAE) map [13]

Abu Dhabi Municipality & Town Planning is consisting of two main vertical departments: Abu Dhabi Municipality (ADM) Department and Town Planning (TPD) Department. TPD contains a number of directorates that are working with building permissions, Land Dividing, Geographic Information System (GIS) and other similar tasks. ADM Department is also divided into many directorates like Sewerage, Roads, Transportation, Traffic, Health, Agriculture directorates, etc. [6]

The project will be carried out for the Sewerage directorate, which will be the potential user of the approved RFID system.

3.3. User's Environment

3.3.1. Utility network

There are three utility networks that the Sewerage Directorate operates:

- **Sewage network:**
  This network covers the transport of sewage from homes, buildings, shops, factories to the pump station, which direct it to the treatment plant. The network pipe is about 2440 km in length.

- **Storm and surface drainage network:**
  This network transports the collected water from the storm and surface and transfers it directly to the sea. The network pipe is about 416 Km in length.

- **Irrigation network:**
  The treated effluent from the treatment plant will be transported back to city in the irrigation network and used for irrigation of plantations and greening. The network pipe is 244 km in length.

3.3.2. Manholes and champers

Approximately, there are more than 96880 manholes and champers operating in Abu Dhabi Municipality. There are many kinds of manholes and champers coming with different shapes and functionalities. Unlike Europe, there is a manhole on every 60 m of small pipes and on every 200 on big pipes and of course on every pipe node. Manholes are more than 2.5 m in depth and less than this depth are inspection and collecting champers.

3.3.3. Pumping Stations

At present approximately 175 pump stations are operating under the Abu Dhabi Municipality. These stations are distributed all over Abu Dhabi Island and Abu Dhabi Emirate except Al Ain. Each station operating with one to six pumps. The pump stations' tasks are to collect and distribute or redirected the flow. Pumping stations can be classified according to the following subheadings [9]:

- **Flow:** Including irrigation pumping stations, surface water pumping stations, and waste water pumping stations

- **Structure:** Including drywell pumping stations and submersible pumping stations

- **Pumping methods:** Including lifting station and pumping station

- **Pump types:** Including centrifugal pumping stations, screw pumping stations, and vacuum pumping stations

3.3.4. Mafraq Treatment Plant

The Mafraq Treatment Plant is located 40 km from Abu Dhabi Island and serves the whole of the greater Abu Dhabi area. All sewage flows to Mafraq TM is pumped from three main pump stations. Sewage treatment comprises a number of physical, biological and chemical processes to ensure the required standard of effluent quality is achieved. The processes are linked together to treat the wastewater. The treated effluent is re-used all over Abu Dhabi as part of the irrigation and greening program. The solids are processed to Class A fertilizer by the Mussafah composting facility. The result of composting is an environmentally safe and odor free product that can be sold to farmers or in the market place. [11]

3.3.5. MACE

As part of the privatization process in the UAE, the Abu Dhabi Sewerage Projects Committee has assigned private companies for the operation and maintenance of the sewerage, drainage and irrigation networks in Abu Dhabi Island. The Municipality has 12 main contractors now. Each of these contractors has a specific task to do for the municipality's facilities. MACE (Mechanical And Civil Engineering) is one of the main contractors for Abu Dhabi Municipality. MACE comprises the operation and maintenance of all sewerage, storm water drainage and irrigation Networks in Abu Dhabi Island under the control of the Operational and Maintenance Section. [8]

3.3.6. AIMS

AIMS stands for Asset Information Management System. AIMS is an enterprise computer system being developed for SD of Abu Dhabi Municipality, consisting of a suite of integrated applications designed to:

- Provide an easy access to documents.
- Provide an easy access to up-to-date information on location, condition and technical characteristics of sewerage, storm water and irrigation assets.
- Assist in operating and maintaining these assets. [7]

3.4. How these facilities work together?

- **Sewage Network:**
  The sewage from end-users (houses, shops, etc) will be transported to the nearest pumping station using gravity. Small pump stations carry forward sewage and pump it to the main pump stations. From the main pumping station the sewage will be transferred to Mafraq Treatment Plant.

- **Irrigation Network:**
  After treating the sewage in Mafraq Treatment Plant, the treated water will be pumped to the city for plantation and greening.

- **Waste- and rainwater Network:**
  Underground- and rainwater are not treated in Abu Dhabi Municipality and will end in the sea.

3.5. User's Staff

Generally, the directorate's staff varies in educational level and type. The leadership is well educated, and qualified in civil, mechanical, chemical and electrical engineering. While the rest of the staff have lower education like diploma and down to secondary school graduated.

3.6. User problems

- Thousands of manholes are spread all over Abu Dhabi with little or no record.

- Location accuracy and attribute precision of the field assets (manholes, pipes …) in the as built drawings is poor, hence it becomes very difficult to locate and identify the field assets.

- The Hydraulic capacity in Abu Dhabi Island is very limited with a challenge to pump out against gravity. This makes the business mission critical and highly public and environmental sensitive especially during emergencies such as break of power, raining and measure shutdowns of main sewers or pumping stations.

- There are many pump stations in Abu Dhabi Municipality and more are planned in the future.
- The sewage, storm water and irrigation network are very long and running in parallel.
- The Mafraq Treatment Plant is a very large plant with many facilities such as pipes, trapdoors, gates, buildings, etc.

RFID could be used to properly identify these problems.

3.7. Old RFID projects

Actually, there was a RFID project going in the directorate five years ago. The directorate and a local company called STS, in collaboration with a German company, tried to implement a RFID system in the sewage network by tagging the manholes covers. They succeeded to apply some of these tags in the network, but the work stopped because of the user's requirements and changing layouts. One of the most important requirements that caused this stoppage was the tags storage capacity. The user demanded that the tag should store many type of information about manholes, something that was not possible at that time. The storage of each tag was 64 bits. [10]

Now, five years later, RFID tags are smaller, lighter, cheaper and with bigger storage capacity. Storage problem will not be an obstacle for the next implementation. Figure 3.2 shows the reader and antenna prototype of the old RFID system

Figure 3.2 – The reader and antenna of the old RFID system

3.8. User's expectation

The coming RFID solution must consider the user's claims. Without focusing on these claims, the selected solution will be waste and not approved by the user. The user defines some properties for the RFID solution:

- **Sewerage Directorate's mission:** "Provide quality service to **public** with maximum protection of **environment** and with **cost effective** operation". The directorates' staff will put all their efforts to satisfy the public, and at the same time respect the environment and operations' cost. RFID should be cost effective and environmentally friendly.

- **Identifying the assets:** This is a very important case for the directorate. The reason is that the manholes are becoming more difficult to identify. Based on previous experiences, the maintenance crew and contractors should be certain that the manhole they are working on is the right one. RFID should give an easy access to get the static and dynamic attributes.

- **Locating the assets:** Sometimes some of directorates' assets are hard to find as they may be covered by sand, dust or rubbish. Locating these assets is one of the central issues that the directorate wants to solve using RFID technology.

- **Usability:** The coming system should be easy to use and to implement by the Sewerage Directorate's crew and contractors.

- **Reliability and performance:** RFID system must operate correctly without any problems or errors such as writing and reading data to the data carrier.

3.9. User Analysis summary

RFID technology could be very helpful for the sewerage directorate. Many places need to be identified and some needs to be located. Below is a list about possible RFID scenarios:

- Tagging all kind of manholes for identifying and locating. It will also make it easy to store other information like maintenance date, GPS location, etc.

- Labeling all pipelines, rising mains and tagging valve chambers.

- Tagging pumping stations (inlet sump and wet sump), lifting pump stations

- Marking pipes, trapdoors, gates, buildings, etc with RFID tags in Treatment plant

Choosing the coming RFID system and equipment should be based on:

- User's environment
- User's staff educational level
- User's old RFID projects failure factors
- User's needs

4. REQUIREMENTS ANALYSIS

4.1. Overview

Based on user's needs and environments, this chapter lists and presents a detailed description of all requirements and assumptions that an approved RFID system needs. This chapter will highlight relevant points regarding to collected information of the user analysis.

These requirements are divided into four sections which will characterize the approved RFID system.

4.2. Introduction

The meaning of requirement analysis is to specify system behavioural requirements and to experience the design that the system should have. This system is proven to comply with the requirements. As mentioned earlier, the Sewerage Directorate will be the user and the custodian of the approved RFID system.

4.3. System Characteristics

The approved RFID system should have characteristics that fit in the implementation environments. Additional requirements that the new system should have will be driven by the user.

4.3.1. Working Environment

The approved system has to work in a harsh environment. Middle East has one of the roughest and hottest environments in the world. The challenges will be:

- **High temperature:** Between 0 and up to +60 ºC
- **High Humidity level:** This is caused by the sea and the sewage
- **Hard Material:** The RFID tags will be attached on materials like metal, concrete, plastic and other similar substances.
- **Tag placing:** The tags might be planted underneath the manholes covers, which mean that it will be subjected to sand, metal, concrete and even plastic layer. Tags (Labels) will also be attached to plastic or metal pipelines. Tag placing will be discussed and tested later.

4.3.2. Tags

- **Passive Tags:** The system should include passive tags. These tags are cheaper, lighter, maintenance free and have unlimited life. It required choosing passive labels (for pipe tagging) and capsulated tags (for network tagging).

- **Rewritable Tags:** Some of the stored data will be overwritten by the reader like maintenance date, assets information, etc. Because of that tags have to be rewritable.

- **Tags Storage Capacity:** The tags have to store some information about the assets/objects. 128 bits – 2 Kbits will be a reasonable choice.

- **Small and light tags:** This will make it easy to place the tags on any assets/objects.

- **Tags range:** A range between 50 and 100 cm will be quite enough for the approved system (100 cm is the maximum reading range for high frequency tags).

4.3.3. Readers

- **Reading environment:** The reader should read tags under sand, concrete, plastic and metal.

- **Portable Reader:** This will make it easy to move and be free to identify many assets.

- **Reader’s Standard Support:** There is no need for a complex RFID reader that supports more than one standard.

- **Reader’s Interface:** The reader should have host interface connection options like RS-232 and USB.

- **Reader’s size and weight:** The main goal is to have a widely portable reader, meaning that less size and weight is an advance.

4.3.4. RFID System

- **Mid-long Reading Range:** It required that the reading range should be between one to three meters. The reason for that is some of these tags will be underground, so it will be much easier if the reading range is longer than one meter.

- **No Line-of-Sight:** This means that it should not be a problem for the reader reading the tags if there is type of object that intercept them.

- **13.56 MHz High Frequency:** Because of the range and no Line-of-Sight request, so the frequency should be 13.56 MHz or higher. Higher frequency requires Line-of-Sight. The Ministry of Communication in Abu Dhabi will not give permission to use frequencies between 860 and 930 MHz. They did not give any reason to jutisfy that but the use of other frequency bands are permitted.

- **Reading speed:** This will not be a big issue for the approved system because all the assets and objects, which will be tagged, are stand still or stationary.

- **RFID Standard:** The reader and tags must have the same standard, otherwise communication will be difficult. The standard type is not a big issue.

- **Transmission Power:** There is be no problem in choosing European (0.5 W) or American (2 W) transmission power.

4.3 System budget

The budget for this project is funded by Agder University College (HiA). The ordered RFID equipment must not increase 20000 Norwegian Krones (about 2300 Euros). The RFID system must contain all the necessary RFID equipment to make a full RFID system.

5. RFID PRODUCTS SELECTION

5.1. Overview

This chapter investigates and lists all RFID products that could fit in the user's environments based on the requirement analysis. In order to decide and select the components for the future RFID system, products will be evaluated and compared to each other.

5.2. Products selection process

5.2.1. Searching techniques

There are many RFID products on the market today. These products are so different from each other that might not fit in any application. Searching the internet was the only way to find the product with the requested properties from the previous chapter (requirement analysis). It started first to search all the producers and manufacturers that have anything to do with RFID, and then sort them according to the operating frequency of their products. RFID components from 13.56 MHz producers were studied and evaluated with respect for the functionality and cost. Companies with classified products were contacted by email to get more info about delivery time, maximal reading range, price, etc. Next stage was to contact the companies with top rated product by phone to make deals, get more product description and know payment method.

5.2.2. Problems under product searching

Finding RFID products on the internet was not an easy task. This job took much longer time that it expected. The reason was insufficient product info on the Websites. There were a few well arranged websites that had full information about their products. Many Websites had also good information about their products, but they lack other information that expected to be published.

A difficulty in reaching the produces or the distributors was the second problem. Many of these whom sell the RFID products did not replied to our e-mails, which was the fastest way to get contact with them. Then we tried to directly call those who might have the required product to save some time.

5.3. System Characteristics

Choosing the right RFID equipment and frequency for the system is very important and not easy task. By choosing improper equipment and frequency band will cause financial and technical damages for the company or organization that implemented the RFID system.

This section discusses the motivations for choosing passive transponders and 13.56 MHz high RFID frequency.

5.3.1 Why Passive transponders?

There are some financial and technical explanations for choosing the passive RFID transponders:

- **Maintenance free**

Active transponders supplied with power by an integrated battery. Battery's life is limited depending on transponders activity. A new battery must be replaced when the old one is flat, or replace the whole transponder with a new one. Checking the battery level and replacing it with a new one is a process that takes very long time and labour work. Passive transponders get their power from the signals of a reader. For this reason there is no need to change or replace any implemented transponders.

- **Cheaper**

Passive RFID transponders are very cheap compared with active transponders. The reason is that the passive ones have small memory size, no battery integrated and easier to produce.

- **Withstand harsh environment**

Unlike the active transponders, the passive transponders can work on very difficult and harsh environments.

5.3.2 Why High Frequency RFID?

There are two major reasons for choosing 13.56 MHz radio frequency for the coming RFID system:

- **No Line-of-Sight Query**

Communication between the reader and the tag will be without the requirement for line-of-sight, which allows communication between the reader and the tag even with the existence of an obstacle object. Higher frequency means more requirement of line-of-sight. Ultra High Frequency (UHF) requires line-of-sight. The best frequencies are the Low Frequency (LF) and High Frequency (HF). The LF signals penetrate metal; concrete, plastic, etc, while HF has problems with metallic objects.

- **Long Reading Range Query**

Higher frequency means longer reading range. UHF has the longest reading range (up to 100 m), HF has a medium reading range (up to 1 m) and LF has the shortest range (up to 10 cm).

The summery of the information above is simple. Using UHF solution is not possible because of the line-of-sight matter, and using LF reading range will not satisfy our application's requirements. The solution will definitely be the HF RFID.

5.4. Product Comparison & Evaluations

The approved RFID system should be appropriate to the systems' environments and requirements that will be implemented on.

5.4.1 Vendors

Founded tags were produced by Philips, Microchip, Texas Instruments and Escort Memory System which has a good reputation and long history on semiconductors industry. Unlike the tags manufacturers, the producers of reader solutions are smaller and relatively unknown.

5.4.2 Tags

Searching the Internet provided many products, but only few were suitable for the proposed system. Eight RFID tags were found. The task will be to find the one that are most attractive and compatible of these tags.

All of the eight tags are rewritable/programmable passive tags that operate in 13.56 MHz high frequency band.

- **Tag 1 - SL1ICS3001 & SL1ICS3101; I-CODE1 Label IC - Philips**
    - **Application:** I-CODE1 label IC is a chip for logistics, retails and identification.
    - **Reading distance:** I-CODE1 is designed for long range applications with a range of up to 1.5 meter.
    - **Memory:** Good memory size of 512 bits
    - **Temperature:** Operates on temperatures up to +70 °C

- **Tag 2 - 211 13.56MHz Passive Tag - Microchip**
    - **Application:** 211 tags are used for item-level tagging.
    - **Reading distance:** Can carry up to 1 meter range.
    - **Memory:** The tag has large storage capacity of 1K bits
    - **Temperature:** Operates on temperatures up to +60 °C

- **Tag 3 - Sample RFID Transponder KIT - Philips**
  - **Application:** These tags are used for identification and asset management.
  - **Reading distance:** Information is not available.
  - **Memory:** The storage capacity is from 384 and up to 1024 bit
  - **Temperature:** From -20 to +70 °C depends on tags type
- **Tag 4 - 13.56MHz Encapsulated Transponder – Texas Instruments**
  - **Application:** Encapsulated transponder can be used in harsh environments such as laundry tracking.
  - **Reading distance:** Not available. Could not be found.
  - **Memory:** Very large storage capacity of 2k bit
  - **Temperature:** Working in very high temperature, up to +90 °C.
- **Tag 5 - Tag-it HF-I Transponder Inlays – Texas Instruments**
  - **Application:** product authentication, ticketing, library management, and supply chain management applications.
  - **Reading distance:** Not available. Could not be found.
  - **Memory:** Very large memory of 2k bit
  - **Temperature:** Working in high temperature, up to +70 °C.
- **Tag 6 - Tag-it Inlays – Texas Instruments**
  - **Application:** Identification such as airline baggage identification.
  - **Reading distance:** Not available. Could not be found.
  - **Memory:** Very small memory of 256 bits.
  - **Temperature:** Working in high temperature, up to +70 °C.
- **Tag 7 - LRP125HT-FLX RFID Tag – Escort**
  - **Application:** For industrial environments.
  - **Reading distance:** Short reading range of 0.203 meter.
  - **Memory:** The storage capacity is 384 bits (48 Bytes).
  - **Temperature:** Working in very high temperature, up to +93 °C.
- **Tag 8 - LRP125 (HT) / LRP250 (HT) Passive Read/Write RFID Tags - Escort**
  - **Application:** For industrial environments.
  - **Reading distance:** Short reading range of 0.216 meter.
  - **Memory:** The storage capacity is 384 bits (48 Bytes).
  - **Temperature:** Working in very high temperature, up to +93 °C.

More detail information with product datasheets about the RFID tags and its vendors/sellers in **Appendix B**.

5.4.3 Tag comparing

Table 5.1 summarizes tags information that mentioned above. Red cells represent that there were no information available, while green cells represent the best cells.

Tag Number	Application	Memory (bit)	Reading Distance (m)	Temperature (°C)	Price (£)
Tag 1	FIT	512	**1.5**	-25 to +70	1.17
Tag 2	FIT	1024	1.0	-10 to +60	1.10
Tag 3	FIT	384-1024	**No Info**	-20 to +70	**0.84**
Tag 4	FIT	**2048**	**No Info**	-25 to +90	**?**
Tag 5	FIT	**2048**	**No Info**	-25 to +70	**?**
Tag 6	FIT	256	**No Info**	-25 to +70	**?**
Tag 7	FIT	384	0.203	**-40 to +93**	**?**
Tag 8	FIT	384	0.216	**-40 to +93**	**?**

Table 5.1 - Tag comparison

All the listed tags operate on very high temperature environments and also have no problem fitting in the approved RFID system. Tag 4 and 5 from Texas Instrument has the biggest storage capacity, but sadly some information about reading distance and price is missing. Tag 7 and 8 from Escort has the lowest and the highest temperature levels, however these tags has the shortest reading range (around 0.2 meter).

It can be noted from the table above that tag 1 and 2 are the most relative candidates for the coming RFID system. Philips' I-Code1 labels have the longest reading range of all the tags and also a great operating temperature range. On the other hand, Microchip's passive transponders have a great memory size and price too.

In practise, product specifications were not the only factor to decide and choose one of these tags. The sellers' co-operation played also very big role in this stage. As mentioned before, many of the sellers' websites were not good enough to get full product description. Requesting the missing details by email was the first step. Quick replies from companies were appreciated and gave them more credits on their products.

Unlike Copytag (Tag 1 seller), Avonwood (Tag 2 seller) was more supportive and ready to use some time on this project. Conversations with Avonwood were very successful and the response was very fast and helpful. Copytag took very long to reply and most of their datasheets links were unapproachable.

Philips' I-Code1 labels are very good RFID tags with great reading range, otherwise there was no big support from the selling company. Avonwood's tag, with a great storage, good range and company's support, will be definitively the one that are chosen for the coming RFID system.

5.4.4 Readers

After searching the internet and classifying all the founded readers, six readers are picked up and only most suitable one will be chosen.

All the readers listed below operate on 13.56 MHz high RFID frequency and support ISO 15693 standard. These readers have the ability to energize, read and write to the transponders.

- **Reader 1 - Sentinel-sense MPR-1530 - AWID**

This portable reader reads transponders at the range of 5-8 inches. The reader has only RS232 interface, and the reader's size is 20.3 X 9.25 X 4.0 cm and weight 680 g.

- **Reader 2 - Memor2000 RFID/HT - Minec**

Also portable reader reads and writes to Tag-it and I-CODE smart labels. It has a range of up to 70 mm, weight is 235 g and the size is 186 X 52 X 27 mm. Connections are available in infrared and RS232. The datasheet doesn't say anything about the standards support or the environment, but it will probably be ISO 15693 because of Tag-it and I-Code smart labels.

- **Reader 3 - 211 13.56MHz ISO Single Point Reader - Avonwood**

This reader provides interfaces like USB, RS232 and isolated RS485/RS422 as standards. Avonwood's reader supports long range ISO-15693 and ISO-18000. Size is 300 X 200 X 80 mm.

- **Reader 4 - Ridel5000 - Softrónica**

Ridel5000 supports interfaces like RS232 and RS485 and standards like ISO14449 and ISO-15693. The reader can support a range of up to 1.2 meter, dependent of the antenna. Softrónica says the reader is the world smallest and most advanced for 13.56 MHz. The size is 120 X 120 X 38 mm.

- **Reader 5 - CT-MR100-A DEVELOPMENT KIT - Copytag**

CT-MR100-A development kit is based on a CT-MR100-A reader, a CT-ANT340/240 pad antenna, 12 VDC power supply, a RS232 cable and power socket cable, and a software development kit (SDK) 5 sample tags. It supports I-CODE, Tag-it and ISO15693. Interface is RS232 or optional TCP/IP. The size is 145 X 85 X 31 mm, and the weight is 1.5 Kg. The reading and writing range is 30 cm at max.

- **Reader 6 - CT-LR200 -A DEVELOPMENT KIT - Copytag**

CT-LR200-A development kit is based on copy tag SL 13.56 MHz, an antenna, and a CT_LR200-A long range reader. This kit will read/write to ISO15693 I-Code and Tag-it transponders at 40 cm. There are no datasheets available for this product.

More detail information with product datasheets about the RFID reader and its vendors/sellers in **Appendix C**.

5.4.5 Readers comparing

Table 5.2 shows a comparison for the readers mentioned above. Red cells represent that there were no information available, while green cells represent best cells.

Reader Number	Application	Reading Distance (m)	Size (mm)	Weight (kg)	Interface RS232
Reader 1	FIT	0.203	203 X 92.5 X 40	0.680	✓
Reader 2	FIT	0.07	**186 X 52 X 27**	**0.235**	✓
Reader 3	FIT	1.0	300 X 200 X 80	No Info	✓
Reader 4	FIT	**1.2**	120 X 120 X 38	No Info	✓
Reader 5	FIT	0.3	145 X 85 X 31	1.500	✓
Reader 6	FIT	0.4	No Info	No Info	✓

Table 5.2 - Reader comparison

All the readers are qualified and suitable for the new RFID system with the opportunity of connecting it to a host system (PC, PocketPC, etc.) via RS 232 interface.

Getting a portable system is the basis of choosing RFID reader. Size and weight should be as small as possible to make the system more mobile and easy to handle. Reader 1 and 2 are the smallest and lightest with integrated display and keys. But on the other hand, these readers have very short reading range.
Softrónica reader (reader 4) from EHag is the one with the longest reading distance using extra antennas. Reader's weight information was missing. Reader 3 from Avonwood was the next longest reading range up to 1 meter using extra antennas.

The main concern here is: Can any reader communicate and exchange information with tags? This depends on many factors such as communication standard, protocol, encoding and decoding. Buying reader and transponder from different producer is very risky, so it will not be an alternative.

Based on tag selection, reader's reading distance, seller's confirms and support, the reader from Avonwood is the alternative that we going for. Vidar Bekken and Bjørnar Landheim will make this solution more portable and accessible with PocketPC interface.

5.3 The selected products

As mentioned above, the selected RFID equipment, called Eureka, will be purchased from a company named Avonwood Developments Ltd. Avonwood are based in the UK and was established in 1987 to provide innovative electrical solutions for its industrial based partners.

The company could promise a product within the criteria's, and were co-operative to help and support. The offered products are a 13.56 MHz passive smart label tags, and a 13.56 MHZ ISO long range reader. The products are listed below:

- The Eureka 13.56 MHZ passive tag: The frequency is 13.56 MHz. It's passive and rewritable. The Storage memory is 1kbit, and the reading range is up to 1 meter.

- The Eureka 211 industrial decoder: Standard interfaces are USB, RS232, RS485 and RS422. The size is 300 X 200 X 80 and it supports ISO15693.

In addition, it has two to antennas to make it possible to reach the mentioned reading distance.

Product Acquisition with contact information, cost and payment information, and shipping information such as carrier, shipping cost, and receiver will be found in **Appendix D.**

5.3.1 Selected RFID Products specifications

For official documentation regarding the reader and the tag, refer to the following Appendixes:

- **Appendix H:** Datasheets Eureka 211 – 13.56MHz Tags (two pages).
- **Appendix I:** Datasheets Eureka 211 – 13.56MHz Readers (two pages).
- **Appendix J:** Installation & Operation Manual (sixteen pages).
- **Appendix K:** 211 Decoder Firmware (22/3138) Manual (twenty-six pages).
- **Appendix L:** Smart Label ISO IC (sixteen pages).

5.4 The received equipment

The equipment has been received on the 17th of May. These equipment were not similar with the ordered one. Here are the major differences between these two:

5.4.1 Tag type

The received tags were Phillips I-Code tags, which are of another brand than ordered (Microchip). Phillips I-Code tag is one of the best tags and has indeed better properties than Microchip tag. Instead of ordered 30 tags, 50 were delivered.

5.4.2 Antenna's reading range

Avonwood promised that the reader can detect a tag at a range up to 100 cm from the antenna's centre. According to open environment testing, the range could not reach further than 35 centimetres.

6. THEORETICAL EVALUATION

6.1. Overview

This chapter discuss performance and reliability of RFID technology. Definitions and general relations about magnetic material will be discussed. First part starts discussing the reading distance issue and what factors that could affect its performance. Finally, permeability of different materials will be then discussed.

The theory and equations in this chapter will in Chapter 10 be compared later with the practical results in Chapter 9.

MATLAB 6.5 has been used to write mathematical equation and simulate the results in graphs. The source code files will be found in Appendix M – MATLAB RFID Equation Source Code inside the CD-ROM.

6.2. Reading distance

The definition of reading distance is the distance between a RFID reader and tag, where the tag has received essential signals to power it self and send signals that could be sensed by the reader.

Reading distance is dependent on two factors: How strong is the magnetic field generated from the antenna and how much power a transponder needs to be activated and to start transmitting. The following sections will discuss these factors and other additional that could affect the reading range:

6.2.1 Antenna's magnetic field

Magnetic field will be generated from the antenna of the RFID reader. The strength of this field, called *H,* is variable and can be calculated for around antenna by using this equation:

$$\mathrm{H} = \frac{\mathrm{I} \times \mathrm{N} \times R^2}{2 \times \sqrt{\left(R^2 + x^2\right)^3}} \qquad (1)$$

Where

I: Electric current
N: The number of windings
R: The radius of the circle coil antenna

While the magnetic field strength path of a rectangular antenna can be calculated by using this equation:

$$H = \frac{I \times N \times a \times b}{4\pi \times \sqrt{\left(\frac{a}{2}\right)^2 + \left(\frac{b}{2}\right)^2 + x^2}} \times \left(\frac{1}{\left(\frac{a}{2}\right)^2 + x^2} + \frac{1}{\left(\frac{b}{2}\right)^2 + x^2} \right) \quad (2)$$

Where

I: Electric current
N: The number of windings
a: The first side length of rectangular coil
b: The second side length of rectangular coil
x: The distance from the centre of the coil

From equation (1) and (2), can we see that antenna's current, size, and windings number variables are very central and important. Magnetic field strength H will weaken when moving away from the antenna. Increasing antenna's size will lead to more stable magnetic field, not stronger. The two graphs in Figure 6.1 show that increasing antenna's side will not amplify the magnetic field strength. Instead the magnetic field will survive longer than the one with smaller antenna size.

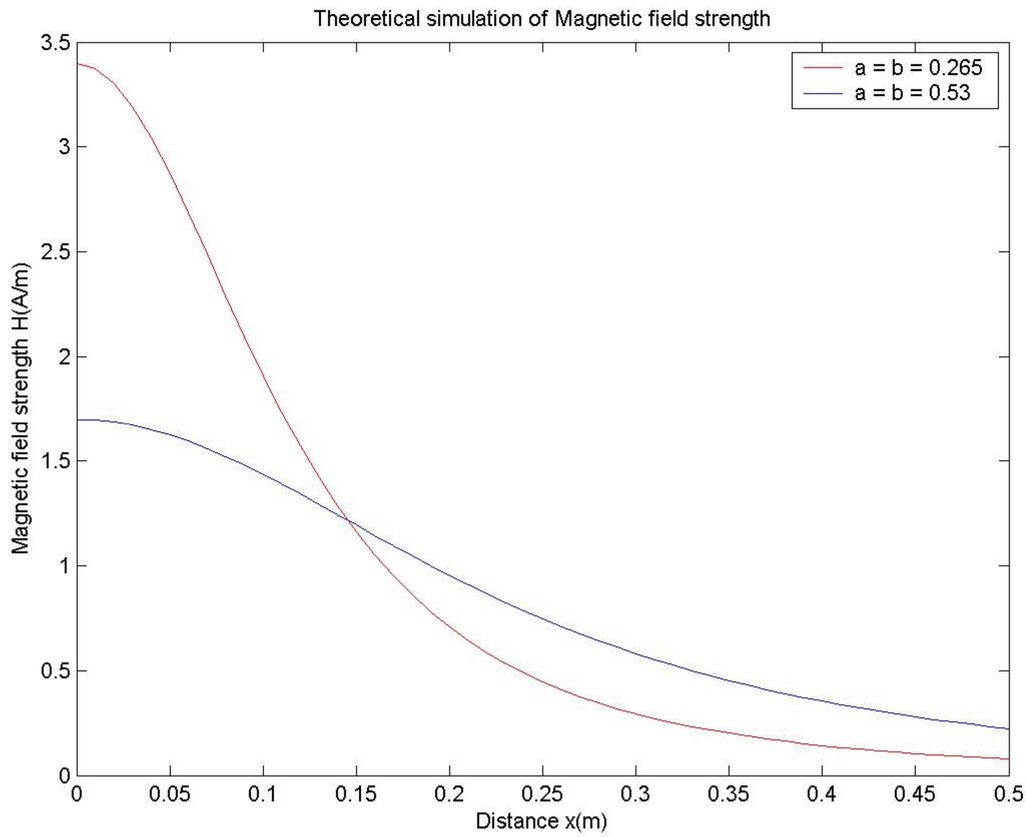

Figure 6.1 – Theoretical simulation of magnetic field strength H for a rectangular antenna in proportion to distance x where current I = 1 and winding number N = 1.

6.2.2 Interrogation field strength H_{min}

H_{min} is the minimum field strength, at a maximum distance x between the reader and transponder, that supply enough voltage for the operation of the transponder. This value can be computed by using the equation below:

$$H_{min} = \frac{u_2 \times \sqrt{\omega^2 \left(\frac{L_2}{R_L} + \frac{R_2}{\omega_0^2 L_2} \right)^2 + \left(\frac{\omega_0^2 - \omega^2}{\omega_0^2} + \frac{R_2}{R_L} \right)^2}}{\omega \times \mu_0 \times A \times N} \quad (3)$$

Where

u_2: High Frequency input voltage
μ_0: Permeability constant
ω: The angular frequency of the magnetic field (reader transmission frequency)
ω_0: The resonant frequency of the transponder
L_2: Transponder coil inductance
R_2: Transponder input resistance
R_L: Transponder load resistor
N: Number of windings of the transponder coil
A: The cross-sectional area of the transponder coil

Large H_{min} means that the transponder needs a lot of power to start proceeding. Improving H_{min} can be feasible by increasing transponder's area and windings and by decreasing transponder's input and load resistance and transponder coil inductance.

Most part of RFID transponders are operating on 3V or 5V (u_2). A voltage regulator inside the tag regulates u_2 and holds it constant.

Figure 6.2 shows that transponder resonant frequency divergence from the reader's transmission frequency will affect harmful on reading range. The values used to generate this graph are: N = 4, A = 0.05*0.08 m², u_2 = 5V, L_2 = 3.5µH, R_2 = 5Ω, R_L = 1.5kΩ and ω = 13.56 MHz.

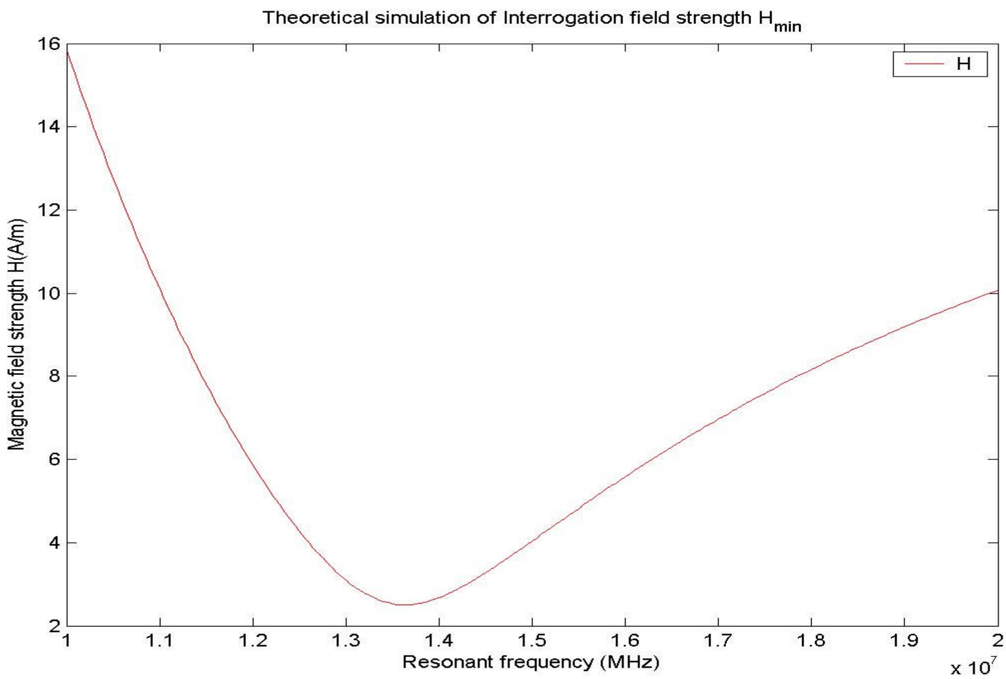

Figure 6.2 – Interrogation sensitivity of a transponder

6.2.3 Energy range

After distinguishing H_{min}, the energy range for a certain reader can be assessed. The formula below will be used for that purpose:

$$x = \sqrt{\sqrt[3]{\left(\frac{I \times N_1 \times R^2}{2 \times \mathrm{H}_{min}}\right)} - R^2} \quad (4)$$

Where

I: Electric current
N_1: The number of windings of the transmitter antenna
R: The radius of the circle coil antenna
H_{min}: The interrogation field strength of a transponder

Distance x is the maximum readable distance between the transponder and the antenna.

6.2.4 Interrogation zone

Interrogation zone is an area where communication between tags and reader is possible. As exposed in Figure 6.3, this zone changes formation when transponders change orientation. The figure to the left shows the interrogation zone when the transponder and the antenna are parallel, while the figure to the right shows the interrogation zone when the transponder is 90 degrees in proportion to the antenna.

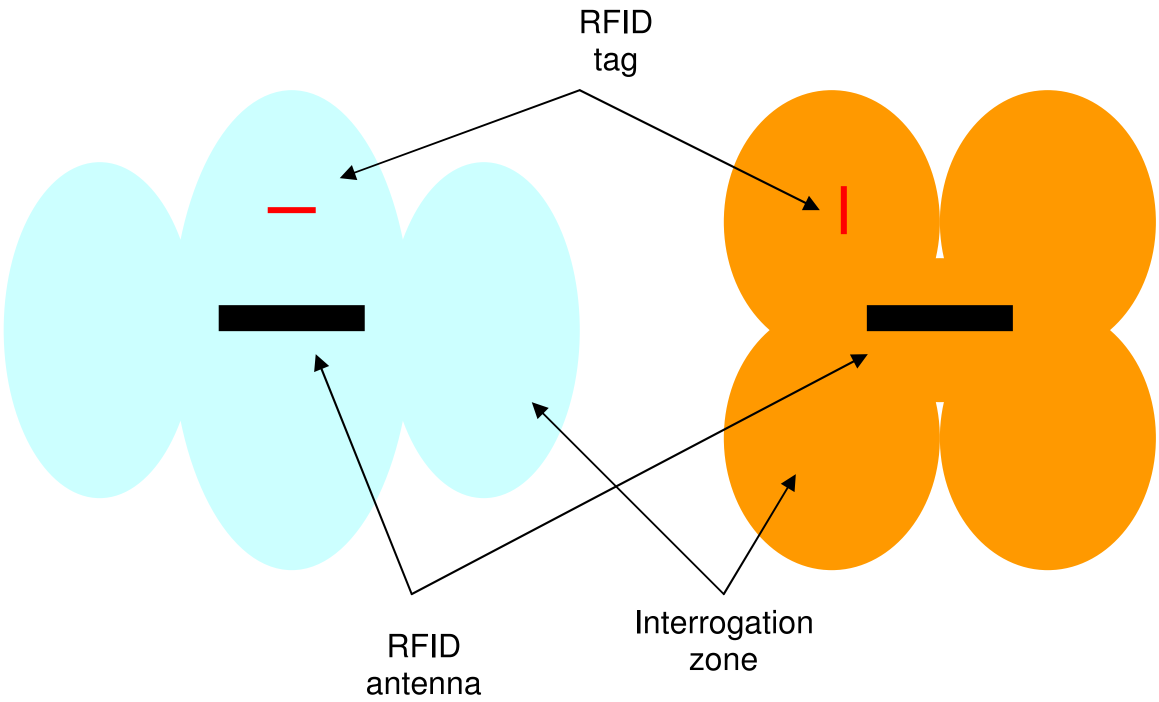

Figure 6.3 – Interrogation zone for an antenna at different transponder orientations

6.3 Materials susceptibility and permeability

6.3.1 Material properties

Materials are classified by their response to the magnetic field. These magnetic responses differ greatly in strength. Each magnetic material belongs one of the following three groups:

- **Diamagnetic materials**
  This type of materials has a very low permeability, but it can decrease the magnetic field (see Figure 6.4).

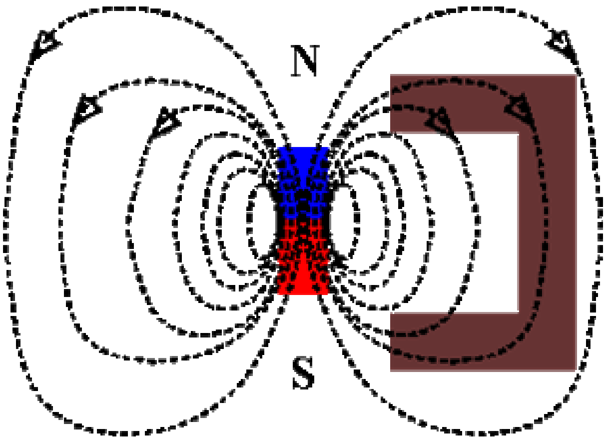

Figure 6.4 – Magnetic field in Diamagnetic and Paramagnetic materials [24]

- **Paramagnetic materials**

  Paramagnetic materials are stronger than diamagnetic ones. These materials produce magnetization in the direction of the applied field and proportional to the applied field. The permeability of paramagnetic materials is very close to vacuum permeability (see Figure 6.4).

- **Ferromagnetic materials**

  Ferromagnetic effects are very large (see Figure 6.5). This type of materials has a big permeability and because of that it is hard to magnetize/saturate. The permeability value is much larger than in diamagnetic or paramagnetic materials.

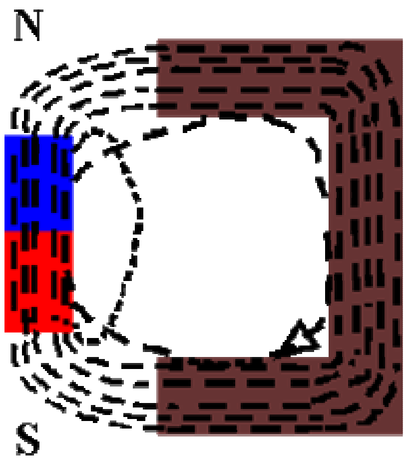

Figure 6.5 – Magnetic field in Ferromagnetic materials [24]

6.3.2 Permeability of diamagnetic and paramagnetic materials

For the first two types of materials, there exists an approximately linear relationship between the magnetic dipole moment (*magnetization*) **M** and magnetic intensity **H**. If the material is isotropic then

$$M = x_m \times H \quad (5)$$

Where

x_m: The magnetic susceptibility.

The magnetic susceptibility describes the response of a material to a magnetic field. If x_m is positive the material is called *paramagnetic*, and the magnetic field is strengthened by the presence of the material. If x_m is negative then the material is *diamagnetic* and the magnetic field is weakened in the presence of the material. The magnetic susceptibilities of paramagnetic and diamagnetic materials are generally extremely small. A few sample values are given in Table 6.1.

Material	x_m
Aluminium (Al)	2.3×10^{-5}
Copper (Cu)	-0.98×10^{-5}
Diamond (C)	-2.2×10^{-5}
Tungsten	6.8×10^{-5}
Hydrogen (H)	-0.21×10^{-8}
Oxygen (O)	209.0×10^{-8}
Nitrogen (N)	-0.50×10^{-8}

Table 6.1 - Magnetic susceptibilities of some paramagnetic and diamagnetic materials at room temperature

A linear relationship between **M** and **H** also implies a linear relationship between Magnetic flux density **B** and Magnetic field strength **H**. This leads to Maxwell equation:

$$B = \mu \times H \qquad (6)$$

Where

$$\mu = \mu_0 (1 + x_m) \qquad (7)$$

μ is the relative magnetic permeability of a material , while μ_0 (= 4π · 10^{-7} Vs/Am) is the permeability of free space. It is clear from Table 6.1 that the permeability of common diamagnetic and paramagnetic materials does not differ substantially from that of free space. In fact, to all intents and purposes the magnetic properties of such materials can be safely neglected *i.e.* $\mu = \mu_0$

6.3.3 Permeability of ferromagnetic materials

This is the third class of magnetic materials. Ferromagnetic materials do not exhibit a linear dependence between M and H or B and H. For that reason equations (5) and (6) with could not be employed here. The permeability of a ferromagnetic material, as defined by equation (5), can vary through the entire range of possible values from zero to infinity, and may be either positive or negative.

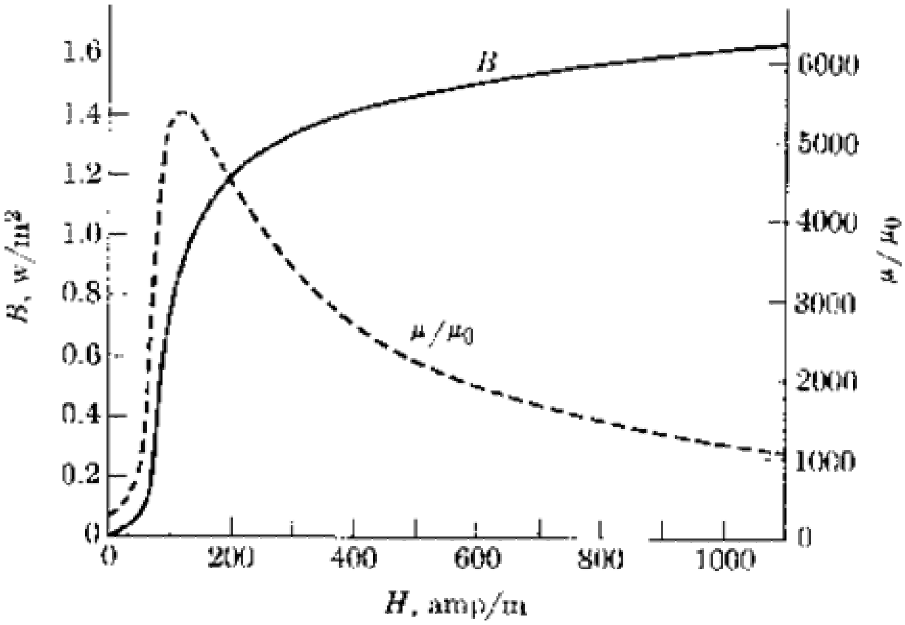

Figure 6.6 – Magnetization curve and relative permeability of commercial iron [25]

The magnetization curve showed in Figure 6.6 make it clear that the permeability μ (where $\mu = B / H$) are always positive, has a wide range of values, and could be as large as $\mu_0 .10^5$ at maximum in some materials. The reason for the knee in the curve is that the material reached its maximum value of magnetization **M** called the saturation magnetization. Equation (8) describes Figure 6.6.

$$B = \mu_0 \times (H + M) \qquad (8)$$

Ferromagnetic materials are used either to channel magnetic flux or as sources of magnetic field.

6.3.4 Depth of penetration

The depth of penetration of eddy currents decreases with increasing frequency, increasing electrical conductivity and increasing magnetic permeability [23]. These three variables are used to calculate the standard depth of penetration of eddy currents δ in the following equation:

$$\delta = \frac{1}{\sqrt{\pi \times f \times \mu \times \sigma}} \tag{9}$$

Where

f: Test Frequency
μ: Magnetic Permeability
σ: Electrical Conductivity

7 Test Application

7.3 Overview

This chapter provides information about testing system and software used in this research.

7.4 System solution

The final testing system is shown in Figure 7.1. The system consists of the following components:

- RFID Reader
- RFID Antenna
- HP 5555 PocketPC
- Rechargeable 12 V DC battery
- RS-232 Cable

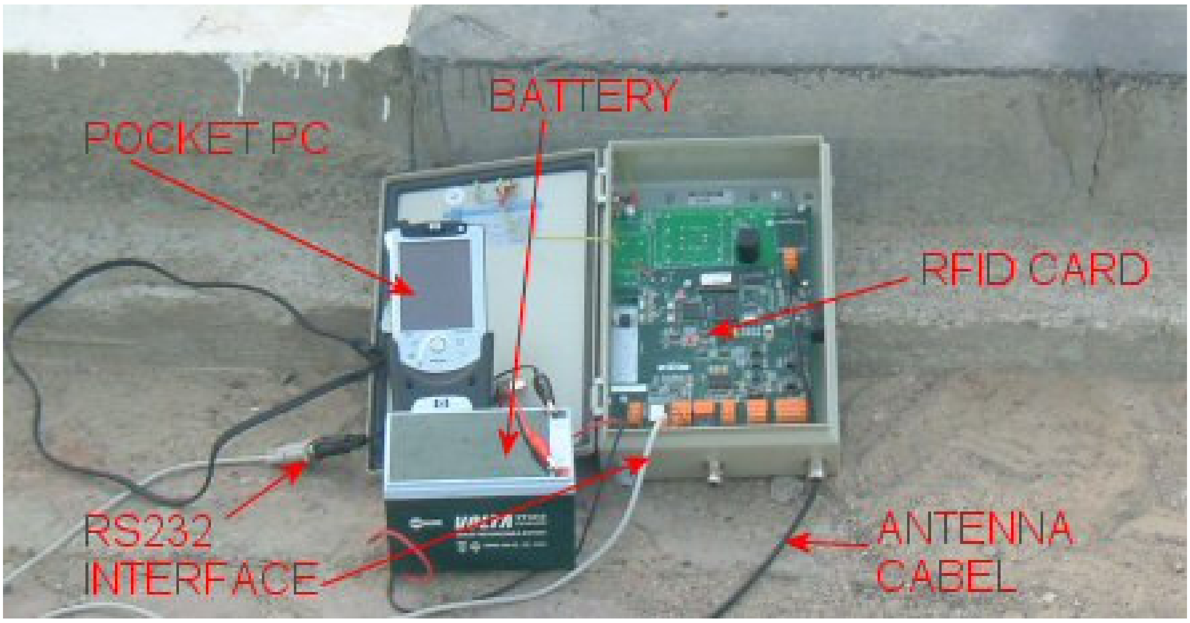

Figure 7.1 – Final RFID testing system

The final system is not as mobile as required, but was sufficient for the test cases. The RFID reader's case and the 12 V DC battery ware quite heavy. Reducing the weight of these two and designing a good prototype will help to make this system more portable.

7.5 Test software

The developed software is specially designed for this RFID system using RS-232 connection. Figure 7.2 shows the RFID software. The user of this program has to set upa connection to the RFID. When the communication is achieved, the user has the following options:

- Search for tags.
- Stop the application in searching, and keep the tag it found.
- Select the tag.
- Read the tag; All, GPS, Asset ID, Description, Main Date or Comments.
- Write to the tag; GPS, Asset ID, Description, Main Date or Comments.

For more details on using this software, refer to Appendix F which is the user manual of this software. Appendix G is the source code of the developed software. Both Appendix F and Appendix G will be found in the CD that follows with this rapport.

Figure 7.2 – Overview of RFID PocketPC software

In order to be able to develop software on the Pocket PC to communicate with the RFID reader, the following software was installed on the work laptop with the following sequence:

- **Visual Studio 6.0 [21]**
  This huge development software will make it easy to create a software using Visual Basic as programming language.

- **Microsoft Active Sync 3.7 [19]**
  Communication between work Laptop and the Pocket PC will be enabled using ActiveSync.

- **AppForge Crossfire [20]**
  This software will let the user run mobile VB programs at the Pocket PC

8 SYSTEM PRACTICAL TESTING

8.3 Overview

This chapter gives a detailed description of the various tests conducted. The description includes objective of the test, assumptions, limitations and a testing description.

Unfortunately, not all RFID products operate as their manufacturers claim. The tests below are designed to determine product durability, reliability, and performance under a variety of conditions.

8.4 Test materials

Some materials were made and used to make testing in the laboratory to gain realistic results. Concrete, metal and plastic represent the environment materials of the manholes.

8.2.1 Concrete

Four 600 mm x 600 mm concrete blocks were made for test scenarios. Concrete blocks were of thickens of 50 mm, 100 mm, and 200 mm. Materials used to make concrete blocks were:

- 20 mm crushed stone 720 kg/m^3.
- 10 mm crushed stone 390 kg/m^3.
- 5 mm aggregate 950 kg/m^3.
- Cement 350 kg/m^3.
- Water 210 kg/m^3.

Strength of concrete blocks was found to be 35 Pascal after 10 days. 6 mm reinforced steel 550 long 8 nos. at 180 apart and plastic spacer 20 mm 6 nos. to give uniform cover

8.2.2 Metal

Two 600 mm x 600 mm mild steel plates were used under testing. The plates' thickness was 10 mm and 30 mm.

8.2.3 Plastic

One 600 mm x 600 mm PVC plastic sheet of thickens of 10 mm was included for some testing.

8.2.4 Tag protection

RFID tags were protected by using transparent acre line or transparent plastic container. Acre line protection (90 mm x 50 mm x 3 mm) surrounds RFID tags without any air gap, while the plastic container protection (125 mm x 90 mm x 10 mm) was used to get more air gap.

8.5 Field strength testing

To analyse the strength of the electromagnetic field of the reader, some steps and measurements must be taken. The first step will be to measure RFID reader's output voltage using oscilloscope (Figure 8.1). This step is necessary because it will prevent the high voltage (high power) from damaging the spectre analyser. Spectre analyser is the measuring equipment for the second step. This equipment measures the transmission power of the RFID reader as shown in Figure 8.2.

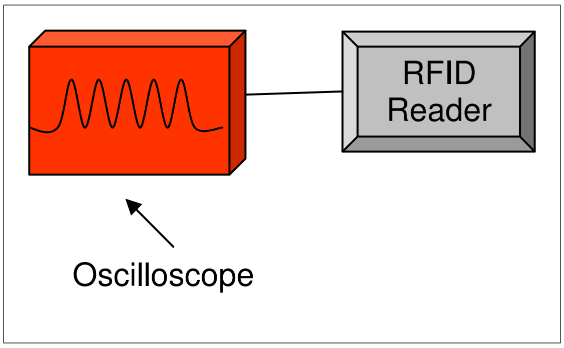

Figure 8.1 – First step: RFID reader connected to oscilloscope

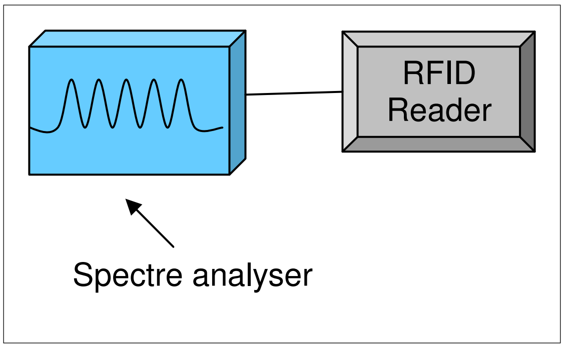

Figure 8.2 – Second step: RFID reader connected to spectre analyser

Then, the third step deals with measuring the input and output current of the RFID reader by using an advanced power supply (as shown in Figure 8.3). The advanced power supply has a display that shows the input current. Output current will be measured using multi meter measurement equipment.

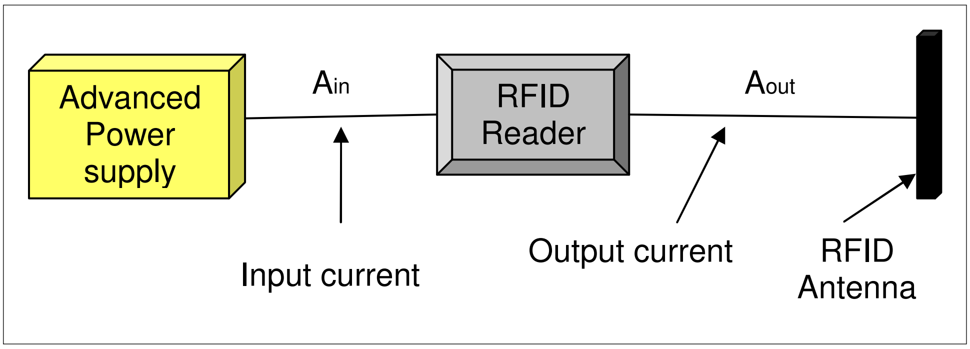

Figure 8.3 – Third step: Measurements of input and output current of the RFID reader

8.6 Reading angle testing

The objective of this test is to find out the best reading angle between RFID tag and antenna. The reader gets its power from a 12 V DC battery as shown in Figure 8.4. There are 4 variables:

- x is the vertical distance between the centre of both tag and antenna.
- h is the horizontal distance between the centre of both tag and antenna.
- p is the maximum readable distance between the tag and antenna, p = x when θ = 0°.
- θ is the angle for the maximum readable distance p.

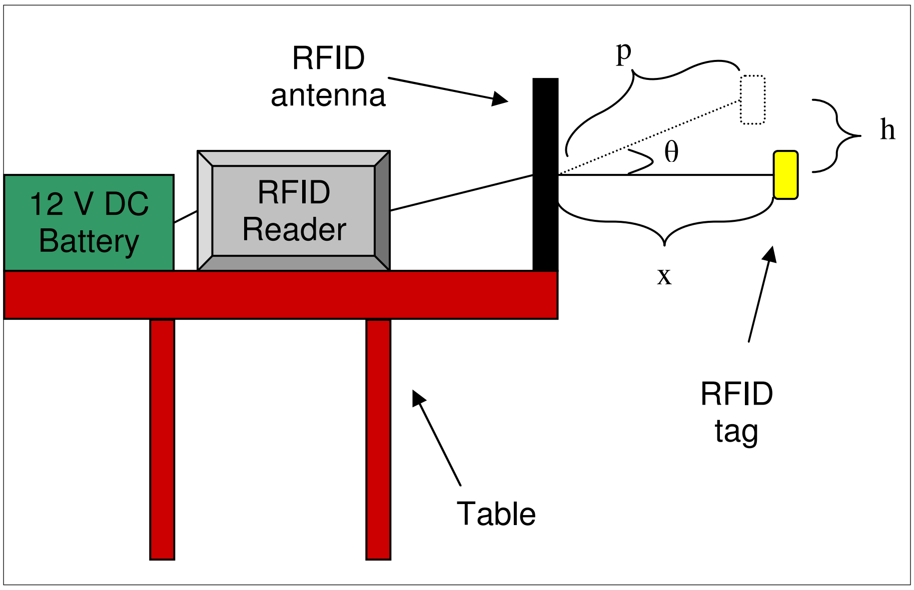

Figure 8.4 – Measuring reading angle of the RFID antenna

The test will be done as follow:

- First, the centre of both tag and the antenna must be placed parallel, facing each other.
- The tag should now be moved vertically to find out the maximum readable distance between the antenna and the tag p = *x* when θ = 0°.
- Then the tag will be moved horizontally, measure the height h and x from antenna where the tag is sensed by the antenna.
- p and θ can be calculated by using the trigonometric functions (sinus, cosines, and tangent) and Pythagorean theorem.

8.7 Tag endurance

The goal of this test is to find out tags real perseverance against concrete. As shown in Figure 8.5, unprotected tag will be placed inside a new-made concrete block. The tag will then be tested the day after to realize if it will be detected by the RFID antenna or not.

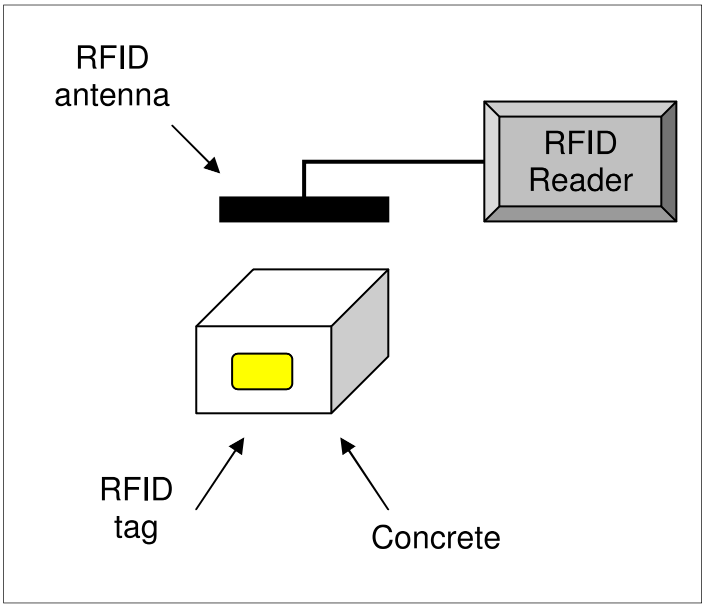

Figure 8.5 – Unprotected RFID tag inside a new-made concrete block

8.8 Plastic permeability testing

The major idea behind this test is to understand if the plastic sheet will affect the RFID interrogation field.

One RFID tag will be placed behind a 10 mm thick plastic sheet. In the front of this plastic sheet will be the RFID antenna (see Figure 8.6). The antenna will be moved horizontally trying to detect the RFID tag. Maximum detecting range *x* will be measured, and then maximum reading and writing ranges will be noted using PocketPC.

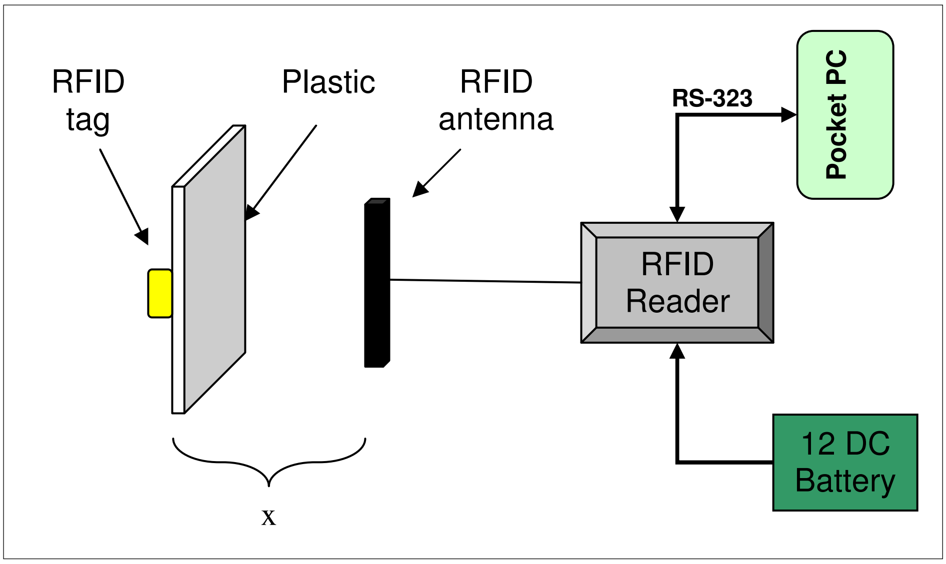

Figure 8.6 – RFID antenna sensing a tag behind a 10 mm plastic sheet

8.9 *Concrete permeability testing*

In this test three concrete blocks with different thickness were used (50 mm, 100 mm, and 200 mm). As shown in Figure 8.7, the tag was located behind every centre of the concrete block and RFID antenna was positioned in the front side of the concrete block. Next step is to measure the maximum detecting range of the RFID antenna, which is the sum of *x* and *z*. Also measuring the maximum reading and writing ranges.

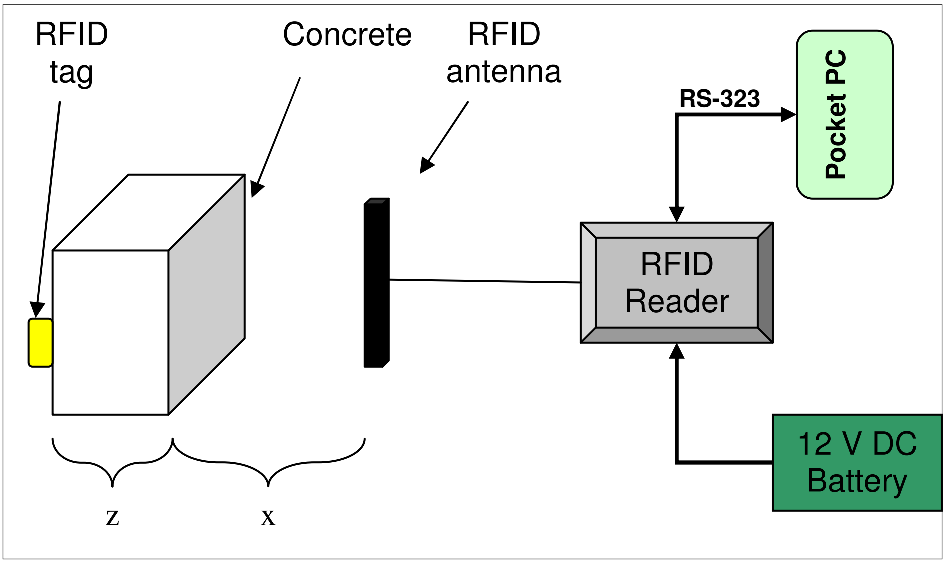

Figure 8.7 – RFID antenna sensing a tag behind 50mm, 100mm and 200mm concrete block

Next round of this test is to place a tag inside a concrete block. For embodying the tags we had to drill and chip to three holes in two different concrete blocks. The depth of these holes is different, one at 25 mm and two at 70 mm in depth. The hole was filled with concrete after placing the tags inside it (see Figure 8.8).

All the tags that have been used in these tests are protected with acre line sheets. Only one tag has been protected with a plastic container, which is not as narrow as the acre line protection (with air gap). The tag with plastic container protection was placed in a 70 mm deep concrete hole.

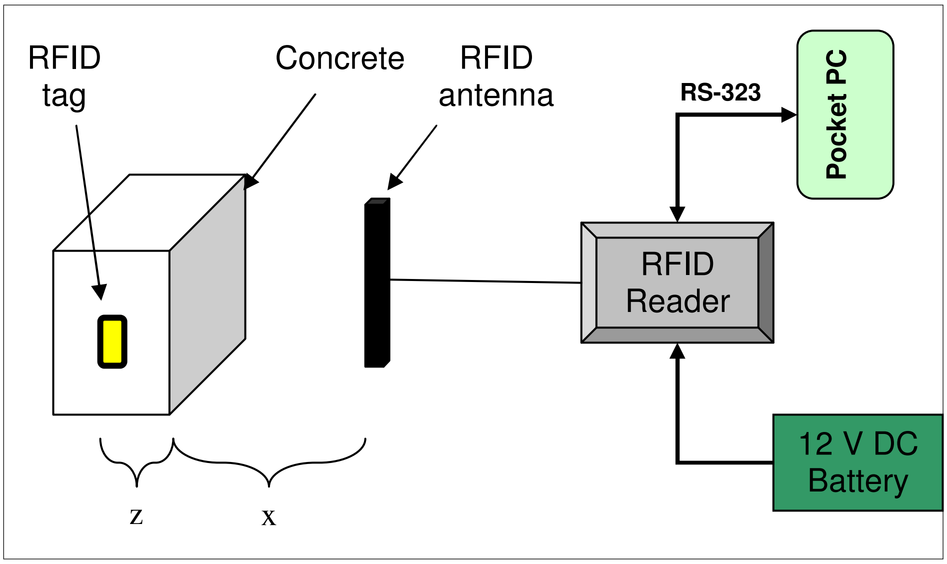

Figure 8.8 – RFID antenna sensing tag inside the concrete block

8.10 Metal permeability testing

High frequency field are very sensitive to ferromagnetic materials. This test finds out if the tag is readable when it is under, above or around the metal plate. Two metal plates have been used under this test (see Figure 8.9). The test tags were not protected.

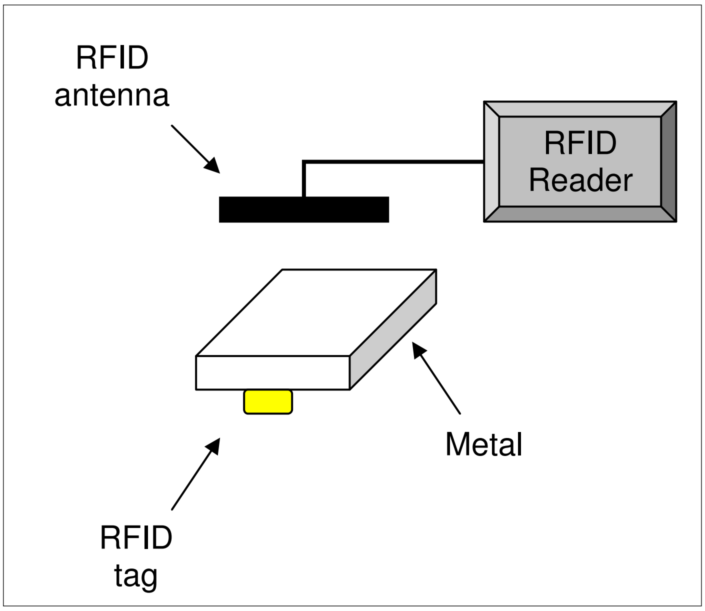

Figure 8.9 – RFID antenna trying to sense tag under a metal plate

8.11 Field testing

The main objective here is to find out if other outdoor factors such as humility and temperature will affect the reading distance of the whole RFID system. The system looks like as shown in Figure 8.10. The RFID tag her was not implemented under the manhole concrete. Sewerage Directorate's workers were afraid to damage the concrete frame around the manhole. Instead, 50 mm concrete layer was placed on the tag's top.

After that, maximum sensing distance, maximum reading and writing distance will be measured by PocketPC. The tag used under this test was protected with acre line sheet.

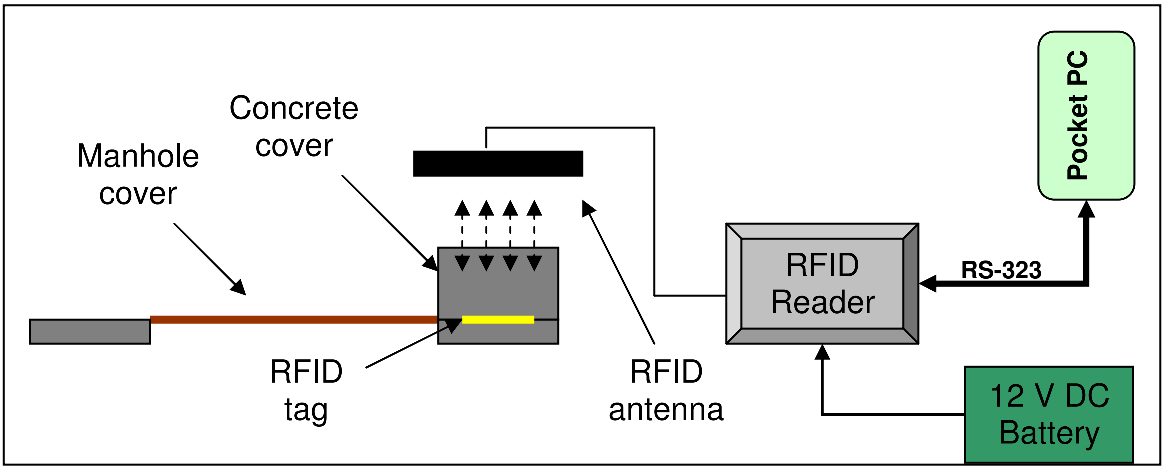

Figure 8.10 – Complete RFID system in field testing

9 TEST RESULTS

9.3 Overview

The results from the tests conducted in the previous chapter are presented below. The results are presented in form of tables and images in the same sequence as the test: field strength, reading angle, tag endurance, plastic permeability, concrete permeability, metal permeability, and field testing.

Appendix E describes in more details how these tests have been executed, step by step, including summary and final results.

9.4 Magnetic field strength results

9.4.1 Oscilloscope results

The oscilloscope used under this test showed that the RFID reader will not damage the spectre analyser measurement equipment. Measurements showed that the output voltage of the RFID reader was not high, which means it will be safe to connect the spectre analyser with the reader. The maximum output voltage was around 245 mV. For more details about this test refer to Appendix E, Test 1.

9.4.2 Spectre analyser results

Figure 9.1 shows the results from the screen of the spectre analyser. The big wave in the middle of this figure is the reader signals at 13.56 MHz frequency. Transmission power of the RFID reader is -35.30 dBm. For more details about this test refer to Appendix E, Test 2.

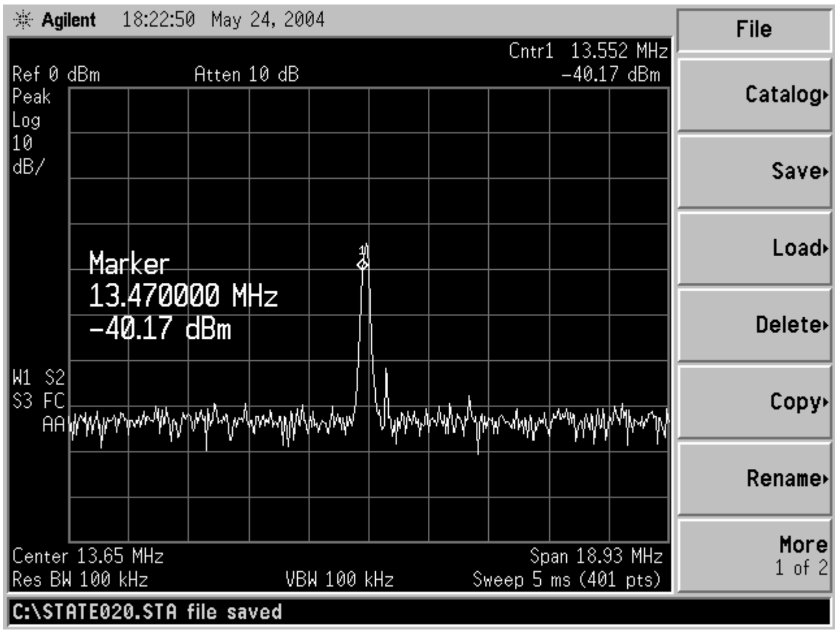

Figure 9.1 – Transmission power measurement, image from spectre analyser

9.4.3 Current measurements results

The display of advanced power supply showed that the maximum value for input current could not exceed 0.2 A. While the output current was much lower that expected. After many measurements using multi meter, the output current reached 0.1 mA as maximum value. For more details about this test refer to Appendix E, Test 3.

9.5 Reading angle results

The result of this test is listed in Table 9.1. The table shows the reading distance in proportion to reading angle

Reading Angle θ (°)	Reading Distance (mm)
0°	350
32°	320
42°	320
55°	300
60°	270
74°	320
90°	350

Table 9.1 – Reading distance vs. reading angle

For more details about this test refer to Appendix E, Test 4.

9.6 Tag endurance results

RFID tag inside the concrete block was not detectable at all.
For more details about this test refer to Appendix E, Test 5.

9.7 Plastic permeability results

A tag behind a 10 mm plastic sheet can be detected from a distance of about 280 mm (including plastic sheet thickness). The tag is readable and writable at distance of 270 mm.

For more details about this test refer to Appendix E, Test 6.

9.8 Concrete permeability results

9.8.1 RFID tag outside concrete

Table 9.2 shows different type of maximum distances when RFID tag is located behind 50 mm, 100 mm or 200 mm thick concrete block. All the presented distances values are included with concrete thickness.

Concrete block thickness (mm)	Max Distance (mm)	Max Read Distance (mm)	Max write Distance (mm)	Write speed (ms)
50 mm	230	185	185	65 – 114
100 mm	220	205	205*	64 – 124
200 mm	200	X	X	X

Table 9.2 – Maximum distances for the RFID tag behind concrete block with different thicknesses

For more details about this test refer to Appendix E, Test 7.

9.8.2 RFID tag inside concrete

Table 9.3 shows different type of maximum distances when RFID tag is located 25 mm or 70 mm inside concrete block. All the presented distances values are included with the concrete thickness.

Tag alignment inside the concrete (mm)	Max Distance (mm)	Max Read Distance (mm)	Max write Distance (mm)	Write speed (ms)
25 mm	205	165	165	65 – 100
70 mm without air gap	85	X	X	X
70 mm with air gap	280	235	235	64 - 112

Table 9.3 - Maximum distances for the RFID tag inside concrete block with different depths

For more details about this test refer to Appendix E, Test 8.

9.9 Metal permeability results

This test shows that RFID tag was not readable or even detectable when it placed on or under the metal plate. The reader senses the tag when it lies beside the metal plate.

For more details about this test refer to Appendix E, Test 9.

9.10 Field testing results

A tag inside a 50 mm concrete layer can be detected from a distance of about 200 mm (including layer height). The tag is readable and writable at distance of 170 mm.

For more details about this test refer to Appendix E, Test 10.

10 DISCUSSION

10.3 Overview

This chapter will discuss and compare the tests conducted with the theoretical part of this thesis.

10.4 The final RFID system

10.4.1 RFID tag

Phillips I-Code RFID label was not the ordered tag type. But this type of labels has a good range and operates perfectly. One of the major disadvantages is that tag was not protected and could easily be damaged. Any pressure on the tag will cause shorter reading range or total communication block.

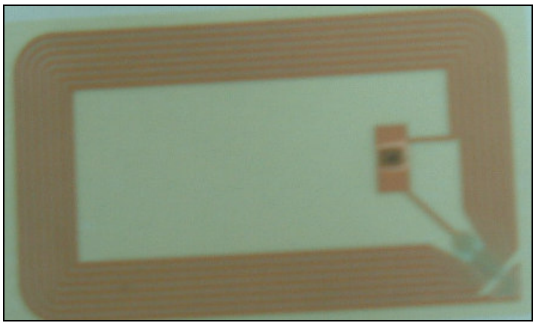

Figure 10.1 – Phillips I-Code RFID label

10.4.2 RFID reader

Avonwood's Eureka RFID reader operated very well under this research time. The reader lies in a metal case and does not have any display integrated (see Figure 10.2). When a tag is in interrogation field of the reader, red lights will be activated. Eureka RFID reader does not give the option to change values such as frequency, current or transmission power. This reader should send power to antenna to make it read a tag from a distance of 100 cm. The tests showed that detecting range did not reach over 35 cm at maximum.

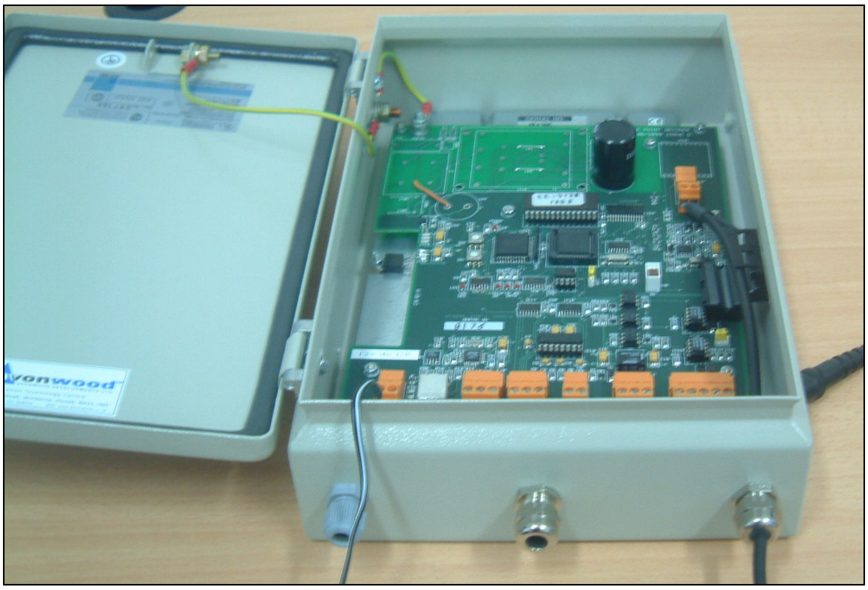

Figure 10.2 – Avonwood's Eureka RFID reader

10.4.3 RFID antenna

Avonwood's Eureka RFID antenna size was exactly the same as described. As shown in Figure 10.3, the antenna is rectangular (30 cm x 30 cm) and thin. The maximum reading range of this antenna is 35 cm, which was not what Avonwood promised.

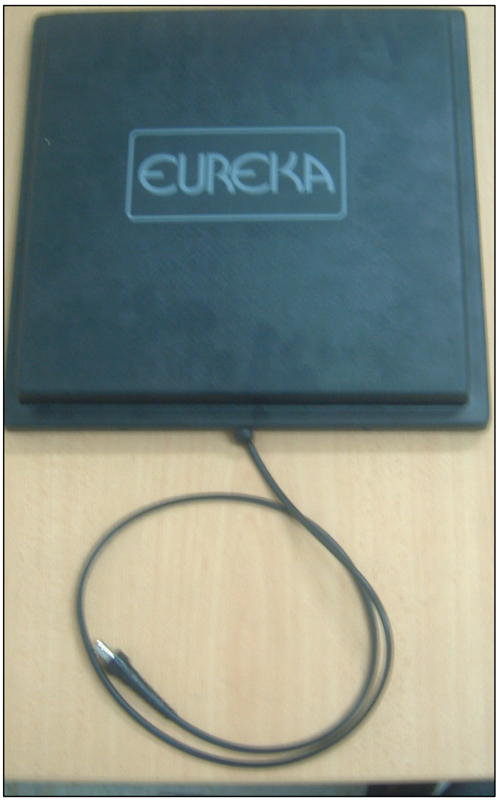

Figure 10.3 – Avonwood's Eureka RFID antenna

10.4.4 Portability

As shown in Figure 7.1, the final RFID system under this research was not quite portable. Good design of prototype will make it possible to move it easily from a place to other. Reader's protecting case is quite heavy and should be replaced with a light and strong case. The 12 V DC batteries were also very heavy. Lighter rechargeable batteries could be found easily on the market.

10.4.5 Developed application

Communication with the RFID was possible by using self-made developed software running in PocketPC platforms. The purpose of this software is to make it easy to connect to the RFID and to read and write to RFID tags. Therefore, the application has not very advanced functions or methods.

10.5 Test results

10.5.1 Introduction

Measurements equipment and methods that were used to measure the RFID reader values are not the best. Therefore, the result will present these values with some fault rate and will not reflect the real, whole picture but only an approximation of it. This was one of the important obstacles under.

10.5.2 Field strength

Measurements showed that the RFID reader has a small transmission power and output current. These two values are very important to increase the reading range. According to equation (1) and (2), increasing current will also increase the magnetic field strength.

It was not possible to increase the output current for this reader. The only way to increase this current is to redesign the reader board. The reader was designed to read tags in distance of 35 cm at maximum.

10.5.3 Reading angle

The results from Table 9.1 are illustrated in Figure 10.4. The results shows that the reading range of the RFID antenna is not circular, but consisting of two different ellipse shaped fields.

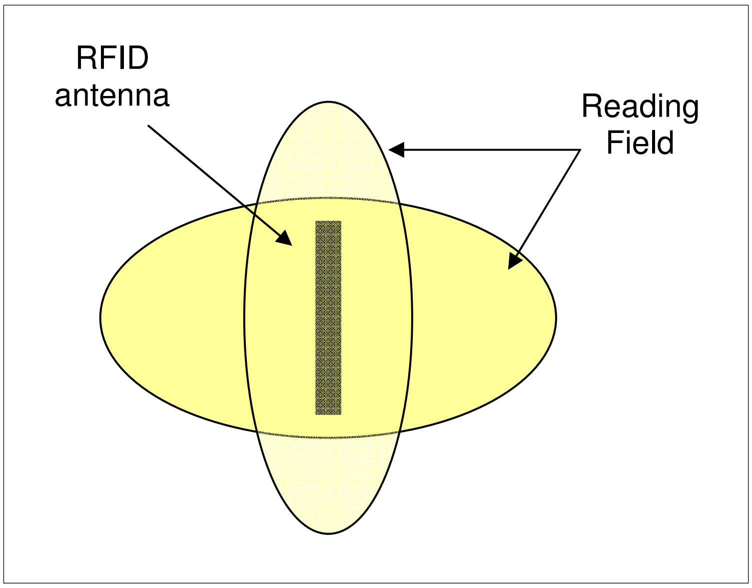

Figure 10.4 – Approximate reading field from test results

Comparing Figure 10.4 with the left image in Figure 6.3 shows that these two are quite similar. Reading range in theory consists of many magnetic fields, so as the practical results.

10.5.4 Tag endurance

This test concludes that unprotected tag inside a concrete block is waste. The concrete mix includes materials that penetrate inside the tag and damage its antenna and the date carrier. Communication then will be impossible.

10.5.5 Plastic permeability

Results showed that the plastic sheet had reduced the reading range, but the effect was very small. The plastic sheet used was Polyvinyl chloride (PVC). This type of plastic allows most part of magnetic field to penetrate [28]. The results of this test confirm the theoretical part of it.

10.5.6 Concrete permeability

Tags were detectable up to 200 mm behind a concrete block. But writing and reading operation could only be executed around range of 100 mm. This is because these operations needs more power.

Tests showed also that tag with acre line plastic sheet had a shorter range than the one with plastic container protection with air gap. Air gap has enhanced the readability in the RFID system. The only explanation is that tags are more pressed in acre line sheets protection. Pressure on tag decreases its ability to receive and send signals which mean also shorter communication range.

The permeability of concrete depends on blocks water content [29] and integrated reinforcement steel. Test blocks were made a week before testing, which means that the water content is very high. Water content in concrete becomes stable after 3 weeks. Steel is conductor and will damage the reading range. More information on metal permeability in next section.

10.5.7 Metal permeability

The generated results from this test shows that the RFID tag could not be detected when it lies under or above the metal plate. The reason is that metal is a conductor and the conductivity influences the permittivity. In other words, the permittivity for metal is huge. Metal can be magnetised so its permeability depends on whether it can be magnetised or not.

The next task in this test was to find the minimum operating distance when tag is located around the plate. Tests showed that the tag is detectable, readable and writable when it lies right beside the metal plate. The metal plate will not disturb the tag to get enough magnetic field to energize itself.

10.5.8 Field testing

Tag was not implemented inside the concrete frame of the manhole to avoid damaging it. Instead, the tag was placed under a concrete layer made especially for this test.

In testing day, the temperature and humidity was very high. High humidity and temperature will decrease the functionality of RFID system. Humidity decreases the reading range up to 20 %.

It is not known if the humidity and temperature are really the major factor behind the decrementing range. The test was done two days after implementing the tag inside the concrete. The concrete water content will probably be very high, which will also make the reading range shorter.

10.6 Problems

Any project will face some difficulties and problems. This will give the taste of the real working environment and life experience. Here are the major problems that cause this research delay and inexactness:

10.6.1 RFID products order

Choose the right equipment was on one of the difficulties in this thesis. Manufacturers and sellers were unable to reach. Enough information about the products was not published. This caused time delay and more confusion on product selecting. There has been also some delay after the order was purchased.

10.6.2 Products differentiation

The received products were not quite similar the ones ordered. Tag type was different and reading range was shorter.

10.6.3 Product specification

The detail specifications of the received products were not available. It took to long time to receive the wanted ones.

10.6.4 Measurement equipment

Measurement equipment used under this research were simple. Gathering correct results means also using advanced equipment. Some necessary equipment and kits were not available such as magnetic field and penetration measurement equipment.

10.7 *Future work*

This thesis could be start of further work. Here are some subjects for future work that could improve and be based on this research:

10.7.1 Anti-collision and data accuracy

One of the important procedures in RFID is the Anti-collision procedure. The procedure prevents collision and data loss when there is more than one transponder in the interrogation zone. Testing the performance and reliability of this procedure will be very interesting subject.

10.7.2 Solution on metal surfaces

As mentioned in this research, high frequency RFID tag could not operate on metal surfaces. Finding a solution for this problem might be a good research case.

10.7.3 Tag planting methods

The methods used under this research are difficult and take long time. In addition, the concrete frame around the manhole could be damaged. New prototype design of RFID tag will improve labour work and time.

10.7.4 PocketPC application

PocketPC software developed under this research is very simple and does not use the storage in RFID labels effectively. Programming interface between PocketPC and reader will be a challenge.

10.7.5 System portability and mobility

The testing RFID system operates good but difficult to move it from a place to other. The approached system will be used by workers who need their equipment as portable as possible. Design new prototype will be a good case.

11 CONCLUSION

Radio Frequency Identification (RFID) is a wireless technology for identification and location of materials and components. RFID is an old technology with relatively new tasks and the experience from use in different environments is limited.

This thesis has presented and evaluated Abu Dhabi Sewerage Directorate, which are the user of the approved RFID system. User's facilities and environments were listed and evaluated to make it easy to choose the right equipment for the RFID system.

RFID system equipments were ordered from a company called Avonwood. Unfortunately, not all the received equipment was as described. The received RFID system was the testing equipment. These equipment have been used in test cases to find out RFID reading distance and penetration.

The results showed that the equipment operate very well but have very short reading range. The primary tests indicated that the maximum detecting range for this system is 35 cm in free space. This range is much shorter than what was promised.

The tests on metal surfaces showed that the system has difficulties with sensing the data carrier. High frequency RFID should not be used in places where materials are ferromagnetic (metallic).

Penetration of plastic was very little in relations with concrete. Concrete's permeability was decided by the water content and reinforcement steel inside the concrete block.

Protection with air gap gave better performance and reading range. RFID tag must not be pressed. This will decrease tag operation's performance.

Some work should be done on designing prototype for the RFID tag and for the whole system to make more portable.

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Appendixes

Appendix A – RFID Timeline
A figure that shows the history and the progress of RFID technology

Appendix B – RFID Tags
Eight tables that lists all the founded information about RFID tags such as manufactures, sellers, price, delivery time, etc.

Appendix C – RFID Readers
Six tables that lists all the founded information about RFID readers such as manufactures, sellers, price, delivery time, etc.

Appendix D – Products acquisition
Screenshot of the billing information including product's names, code, quantity and price.

Appendix E – Testing steps
Ten tables that shows how the tests in Chapter 7 were executed step by step.

Appendix F – Software User Manual (CD-ROM)
User manual for the application developed under this research

Appendix G – PocketPC application Source Code (CD-ROM)
Whole the source code created in Visual Studio 6.0 using Visual Basic as programming language

Appendix H – Datasheets Eureka 211 – 13.56MHz Tags (CD-ROM)
Avanwood's information on Eureka 211 tags

Appendix I – Datasheets Eureka 211 – 13.56MHz Readers (CD-ROM)
Avanwood's information on Eureka 211 readers

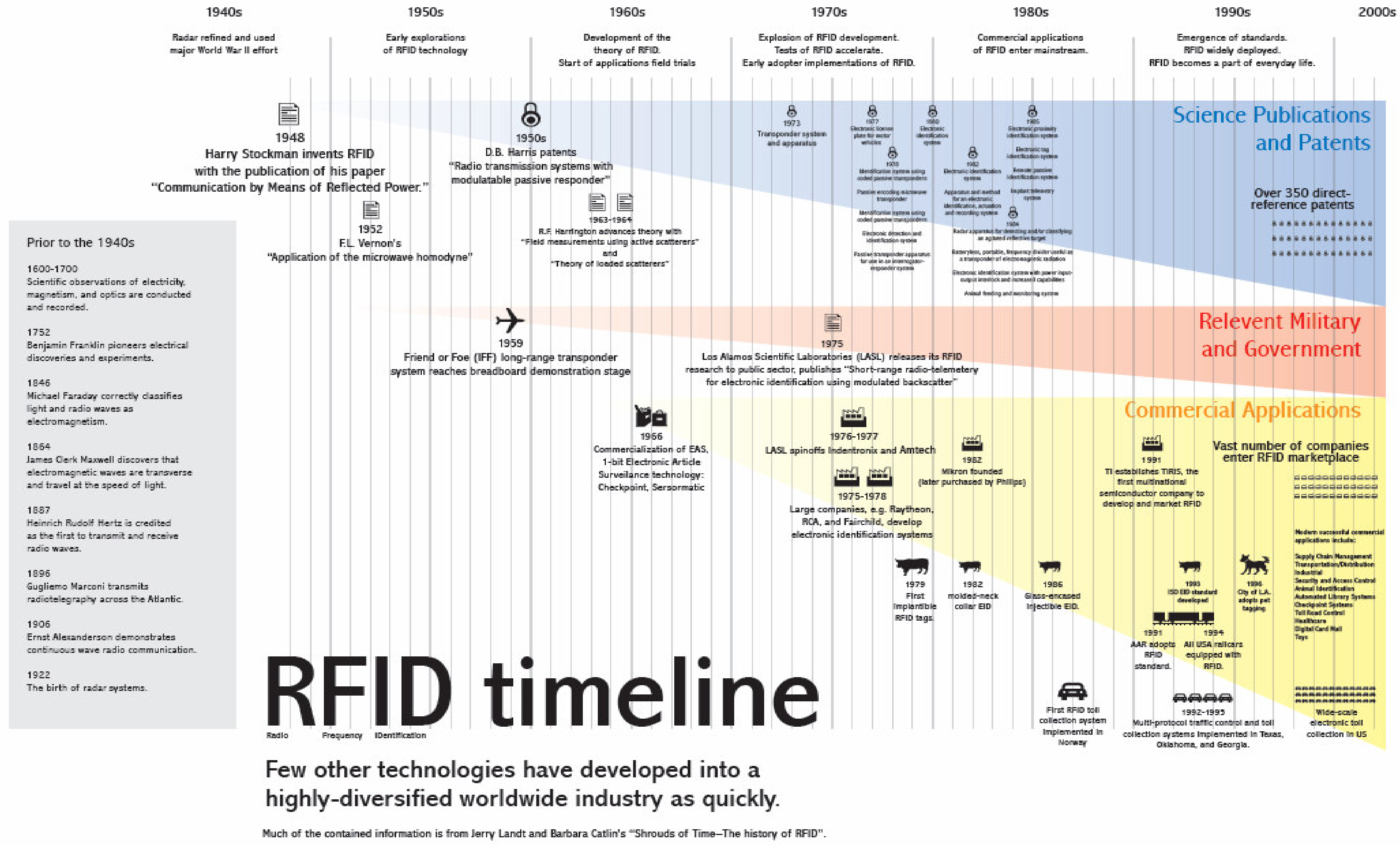
Appendix J – Installation & Operation Manual (CD-ROM)
Avanwood's installation and operation manual for Eureka 211 readers

Appendix K – Decoder Firmware (22/3138) Manual
Avanwood's document on using Eureka 211 reader's commands

Appendix L – Smart Label ISO IC
Phillips datasheet for I-Code RFID labels

Appendix M – MATLAB RFID Equation Source Code
The source code of three MATLAB files that simulate and calculate RFID equations

Appendix A – RFID Timeline



Appendix B – RFID TAGS

Tag 1

	**SL1ICS3001 & SL1ICS3101; I-CODE1 Label IC** The I-CODE1 label IC is a dedicated chip for intelligent label applications for logistics and retail (including EAS) and for baggage and parcel identification in airline business and mail services. The I-CODE system offers the possibility of operating labels simultaneously in the field of the reader antenna (anticollision). It is designed for long range applications. Whenever connected to a very simple and cheap type of antenna (due to the 13.56 MHz carrier frequency) made out of a few windings printed, wound, etched or punched coil, the SL1ICS3001 operates without line of sight up to a distance of 1.5 m (gate width).
Producer	Philips
Product link	http://www.semiconductors.philips.com/pip/SL1ICS3001W_N4D.html
Data Sheet	http://www.semiconductors.philips.com/acrobat/datasheets/SL1ICS3001_2.pdf
Application	Identifying
Seller	http://www.copytag.com
Price	9.99 £ (Excluding: VAT at 17.5%) for 10 labels
Delivering time	14 – 21 days

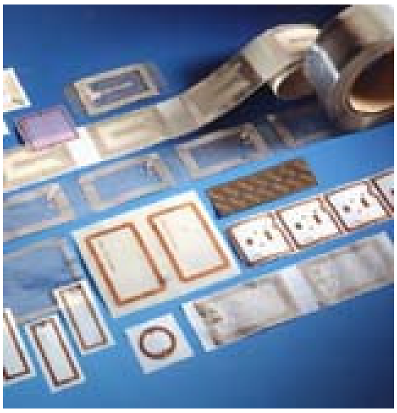
Tag Specifications	
Memory size	512 bits
Operating Temperature	from -25 to +70 °C
Reading range	Up to 1.5 m
Standard	ISO 15693

Tag Evaluation	
+ Long Reading range	−
+ Operates on very warm environments	−

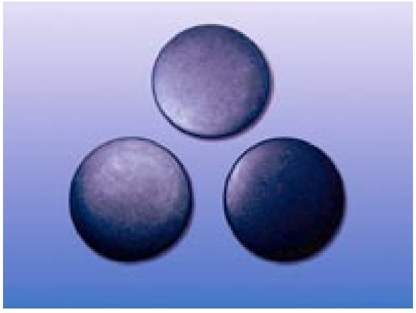
Tag 2

	211 13.56MHz Passive Tag
	Low cost high performance tags for item-level tagging, combining security with inventory, retail, video stores, airline baggage, parcel tracking, anti-counterfeiting and document management are just some of the applications requiring a reliable and low cost alternative to bar coding. · High performance · Read/write · Large memory · Low power consumption · High data rate · Up to 1m read range · Customer specific packaging
Producer	http://www.microchip.com/
Product link	http://www.avonwood.com/products/product_details.asp?id=2#8
Data Sheet	http://www.avonwood.com/pdf/web243044B13.56MHztags.pdf http://ww1.microchip.com/downloads/en/DeviceDoc/40232h.pdf
Application	Identifying
Seller	http://www.avonwood.com
Price	1.1 £
Delivering time	From 2 to 7 days (with DHL)
Tag Specifications	
Memory size	1 Kbit
Operating Temperature	From -10 to +60 °C
Reading range	Up to 1 m
Standard	ISO 15693 & 18000
Tag Evaluation	
+ Large memory	−
+ Long reading range	−
+ Operates on high temperatures	−

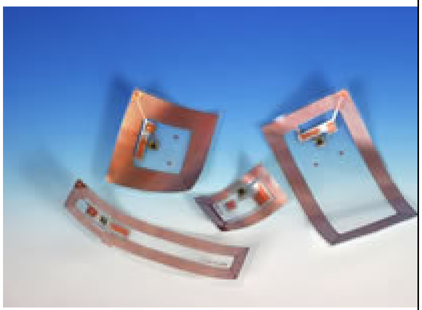
Tag 3

	SAMPLE RFID TRANSPONDER KIT
	A selection of RFID Smart Label Transponders working on a frequency of 13.56 MHz. Technical sheets and fitting guide included where applicable. 10 off 49 x 82 x 0.3 mm ICode 1. 10 off 49 x 82 x 0.3 mm ICode SLI. 10 off 55 x 55 x 0.3 mm ICode SLI. 10 off 43 x 43 x 0.3 mm ICode SLI. 10 off 60 x 20 x 0.3 mm ICode 1. 10 off 36/17 x 0.3 mm CD/DVD Round ICode 1. 10 off 18 x 36 x 0.3 mm ICode SLI. 10 off 58 x 105 x 0.3 mm I-Code SLI In-mould transponder (IMT)
Producer	Philips
Product link	http://www.copytag.com/acatalog/Sample_RFID_Transponders.html
Data Sheet	http://www.copytag.com/acatalog/sampletags.pdf
Application	Identifying
Seller	http://www.copytag.com
Price	£67.20 (Excluding: VAT at 17.5%)
Delivering time	14 – 21 days
Tag Specifications	
Memory size	384 – 1024 bit (depends on tags type)
Operating Temperature	From -20 to +70 °C Depends on tags type
Reading range	Not Available
Standard	ISO 15693
Tag Evaluation	
+ Good package, with different tag types	− Some tags are not suitable
+ Good price	−

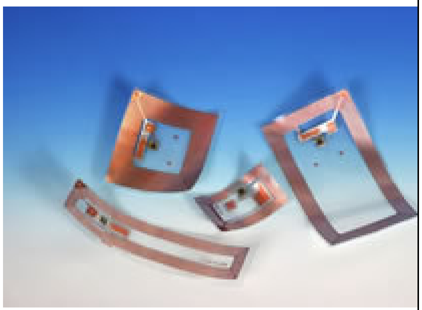
Tag 4

	**13.56MHz Encapsulated Transponder** The 13.56MHz Encapsulated Transponder from Texas Instruments is compliant with the ISO/IEC 15693 standard, a global open standard that allows interoperability of products from multiple manufacturers. With a user memory of 2k bits, organized in 64 blocks, the rugged 13.56MHz Encapsulated Transponder allows for advanced solutions in demanding supply chain management applications such as laundry tracking. It is especially designed and tested for applications that require a ruggedized transponder that can withstand harsh environments.
Producer	Texas Instruments
Product link	http://www.ti.com/tiris/docs/products/transponders/1356mhz-encapsulated.shtml
Data Sheet	http://www.ti.com/tiris/docs/manuals/pdfSpecs/1356mhz-encapsulated.pdf
Application	Chain management
Seller	Not Available
Price	Not Available
Delivering time	Not Available
Tag Specifications	
Memory size	2k bits
Operating Temperature	From -25°C to +90°C
Reading range	Not Available
Standard	ISO 15693
Tag Evaluation	
✚ Designed for harsh environments	−
✚ Large memory	−

Tag 5

	**Tag-it HF-I Transponder Inlays** The Tag-it HF-I Transponder Inlay family is compliant with the ISO/IEC 15693 standard, a global open standard for contactless integrated circuits cards (vicinity cards) operating as 13.56MHz which provides also the basis for consumable smart labels. With a user memory of 2k bits, organized in 64 block, the Tag-it HF-I Transponder Inlays offer advanced solutions for product authentication, ticketing, library management and supply chain management applications. To cover the specific requirements of different applications, the thin and flexible Tag-it HF-I Transponder Inlays are offered in different antenna shapes and can be easily converted into paper or plastic labels.
Producer	Texas Instruments
Product link	http://www.ti.com/tiris/docs/products/transponders/RI-I02-112A.shtml
Product Bulletin	http://www.ti.com/tiris/docs/manuals/pdfSpecs/TagitHF-IProdBulletin.pdf
Data Sheet	http://www.ti.com/tiris/docs/manuals/pdfSpecs/RI-I02-112A.pdf
Application	Authentication, ticketing and managment
Seller	Not Available
Price	Not Available
Delivering time	Not Available
Tag Specifications	
Memory size	2k bits
Operating Temperature	From -25°C to +70°C
Reading range	Not Available
Standard	ISO 15693
Tag Evaluation	
+ Large memory	– Missing information about reading range and price

Tag 6

	**Tag-it Inlays** The Tag-it inlay, a new generation of TI-RFid transponders, is the basis for the first consumable smart label for industries needing quick and accurate identification of items such as express parcels and airline baggage. Ultra-thin and batteryless, this general purpose read/write transponder is placed on a polymer tape substrate and delivered in reels. It fits between layers of laminated paper or plastic to create inexpensive stickers, labels, tickets and badges. Tag-it inlays can be embedded into products and items, and can include magnetic stripes, barcodes or other printed information. User data is read and stored in a 256-bit non-volatile user memory that is organized in eight blocks. Each block is user programmable and can be locked to protect data from modification. Tag-it inlays are available in four sizes for standard labelling requirements.
Producer	Texas Instruments
Product link	http://www.ti.com/tiris/docs/products/transponders/RI-I02-112A.shtml
Product Bulletin	http://www.ti.com/tiris/docs/manuals/pdfSpecs/TagitHF-IProdBulletin.pdf
Data Sheet	http://www.ti.com/tiris/docs/manuals/pdfSpecs/RI-I02-112A.pdf
Application	Industrial environments
Seller	Not Available
Price	Not Available
Delivering time	Not Available
Tag Specifications	
Memory size	256 bits
Operating Temperature	From -25°C to +70 °C
Reading range	Not Available
Standard	Not Available
Tag Evaluation	
+	− Missing information
+	− Small memory

Tag 7

	**LRP125HT-FLX RFID Tag** The FastTrack™ family of RFID Tags/Labels/ PCBs use Philips Semiconductor I-CODE Reader/Writer chips, but most important, use EMS' unique, patented design and manufacturing technology to create the most advanced industrial RFID Tags. EMS' reusable (or disposable) FastTrack™ Series Passive Read/Write RFID Tag, LRP125HT-FLX, is specifically designed for demanding manufacturing environments. The Tag is available in a compact .88in diameter. This FastTrack Tag also features high temperature surviving capabilities, Long-Range Read and Write distances and Multiple-Tag-In-Field Read/Write. The LRP125HT-FLX is compatible with EMS's LRP-Series Reader/Writers.
Producer	http://www.ems-rfid.com/
Product link	http://www.ems-rfid.com/support/lrp125ht-flxsup.html
Data Sheet	http://www.ems-rfid.com/support/dsheets/lrp125ht-flx.pdf
Application	For industrial environments.
Seller	http://www.ems-rfid.com/
Price	Not Available
Delivering time	Not Available

Tag Specifications	
Memory size	384 bits (48 Bytes)
Operating Temperature	From -40 to +93 °C
Reading range	UP to 0.203 m
Standard	ISO 15693

Tag Evaluation	
+ Tolerate high temperature	– Short reading range
+	– Small memory

Tag 8

	LRP125 (HT) / LRP250 (HT) Passive Read/Write RFID Tags
	Escort Memory Systems FastTrack line of RFID Tags and Reader/Writers (or Antennas) provides outstanding RFID solutions for demanding industrial environments. From scorching paint ovens to post office parcel tracking applications in which 99 Tags must be read and written at the same time, the FastTrack family of RFID tags and Reader/Writers will be your complete RFID solution. The Tags use I-CODE chips, but most important, use Escort Memory Systems unique patented design and manufacturing technology to create the most advanced industrial Tags.
Producer	http://www.ems-rfid.com/
Product link	http://www.ems-rfid.com/support/lrp125-250htsup.html
Data Sheet	http://www.ems-rfid.com/support/dsheets/FastTrack_Tags.pdf
Application	http://www.ems-rfid.com/support/appnotes/Ryton.pdf
Seller	http://www.ems-rfid.com/
Price	Not Available
Delivering time	Not Available

Tag Specifications	
Memory size	384 bits (48 Bytes)
Operating Temperature	From-40° to 93 °C
Reading range	Up to 0,216 m
Standard	ISO 15693

Tag Evaluation	
+ Tolerate high temperature	− Short reading range
+	− Small memory

Appendix C – RFID Readers

Reader 1

	**Sentinel-Sense™ MPR-1530** ▪ 5-8 inches read range with smart tags ▪ Multi-Protocol: I-Code™, MicroID™, Performa™, Tag-It™ and ISO-15693. ▪ License-Free ISM (Industrial, Scientific and Medical) band ▪ Dual Technology Design: Bar code (optional) and 13.56 MHz RFID ▪ Read, Write and Search RFID tags, and read bar code labels ▪ Palm OS Operating System and Industry-standard RS-232 output ▪ Capability to adapt and accept other PDA families
Producer	http://www.awid.com/
Product link	http://www.awid.com/product/mpr-1530/mpr-1530.htm
Data Sheet	Not Available
Application	Tracking and asset management
Seller	Not Available
Price	Not Available
Delivering time	Not Available
Reader Specifications	
Reading range	12.7-20.3 cm (5-8 inches)
I/O Control	RS-232
Standard	ISO-15693
Reader Evaluation	
✚ Support many types of tag	▬ Missing information
✚ Hand held with Palm OS	▬ Short reading distance

Reader 2

	**Memor2000 RFID/HF** The Memor2000RFID hand-held terminal reads and writes to Tag-it (Texas Instruments) and I-Code (Philips Semiconductors) smart labels. Smart labels employ radio frequency identification (RFID) technology. Each printable and flexible label is a transponder with an integrated circuit and an antenna. The label does not require a battery as it receives energy together with information from the Memor2000 read/write module at distances of up to 70 mm. Smart labels can be programmed with production information such as date and place of manufacture, distribution history and guarantee details, which ensures traceability from production line to point of sale. Contact Minec if your company is considering the introduction of a smart label identification system. We have the hand-held terminals, software and know-how to set up smoothly running smart label systems.
Producer	http://www.minec.com/
Product link	http://www.minec.com/products/m2000/tagit.html
Data Sheet	http://www.minec.com/products/m2000/rfid_high2.pdf
Application	Inventory control, Genuine Brand identification
Seller	http://www.minec.com/
Price	1400 € (exclusive works)
Delivering time	Not Available

Reader Specifications	
Reading range	Up to 70 mm
I/O Control	Infrared link, RS-232
Standard	ISO 15693

Reader Evaluation	
✚ Support many types of tag	− Short reading distance
✚ Hand held	−

Reader 3

	**211 13.56MHz ISO Single Point Reader** Conforming to the current and emerging ISO standards, ISO 15693 and ISO 18000, the Eureka 211 13.56MHz single point readers are available in industrial and commercial versions. · Configurable USB, RS232 and isolated RS485/RS422 interfaces as standard · Standard operating modes and features · Optimised for speed, range and anti-collision
Producer	http://www.avonwood.com
Product link	http://www.avonwood.com/products/product_details.asp?id=2
Data Sheet	http://www.avonwood.com/pdf/211/web%20243388A%20211%20industrial%20decoder%20copy.pdf
Application	Supporting a wide variety of applications
Seller	http://www.avonwood.com
Price	680 £ plus 620 for external antennas
Delivering time	2 to 7 days (DHL)
Reader Specifications	
Reading range	Up to 1 meter
I/O Control	USB, RS232 and isolated RS485/RS422
Standard	ISO 15693 and ISO 18000
Reader Evaluation	
✚ Good reading range	▬ High price
✚ Supports many interfaces	▬

Reader 4

 	**RIDEL 5000** - Radio-Frequency Identification module (RFID) for contactless reading and encoding of labels or cards with ISO 14449 and ISO 15693-Protocol I-CODE, Tag-it, PicoTac, Mifare etc. - Compact size, smallest 8W Reader/Encoder available. - Anti-theft (EAS) bit activation/deactivation. - 4-channel I/O port. - Long range reading/encoding with the anticollision feature a large number of tags or labels can be treated simultaneously, reading and/or encoding one, several or every label in the working field. - RS232 or RS485 communication up to 115200 baud. - Wysiwyg calibration with fine tuning for critical environment.
Producer	Softrónica
Product link	http://www.ehag.ch/prod/rfid/sof/ridel5000.htm
Data Sheet	http://www.ehag.ch/prod/rfid/sof/pdf/RIDEL5000%20Manual/120001110-RIDEL-Manual°.pdf
Application	Any application requiring long-range reading
Seller	http://www.ehag.ch/
Price	€ 1 673.00
Delivering time	Not Available
Reader Specifications	
Reading range	1.2 meter with antenna
I/O Control	RS232 and RS485
Standard	ISO 15693
Reader Evaluation	
+ Good reading range	– Not portable

Reader 5

	**CT-MR100-A DEVELOPMENT KIT** 1 x CT-MR100-A reader, 1 x CT-ANT340/240 Pad antenna, 1 x 12 VDC Power supply (UK or EU Only) 1 x RS232 Cable and power socket cable, 1 x Software development kit (SDK) 5 Sample tags
Producer	http://www.copytag.com/
Product link	http://www.copytag.com/acatalog/actinic.html
Data Sheet	http://www.copytag.com/acatalog/ct-mr100-a-dev-kit.pdf
Application	Application retail, EAS, Logistics and warehouse management.
Seller	http://www.copytag.com/
Price	£377.99 (Excluding: VAT at 17.5%)
Delivering time	14 to 21 days
Reader Specifications	
Reading range	Up to 30 cm
I/O Control	RS232, or optional TCP/IP
Standard	ISO 15693
Reader Evaluation	
+ Cheap solution	− Short reading distance

Reader 6

	**CT-LR200 -A DEVELOPMENT KIT** CopyTag SL 13.56 MHz ISO 15693 compatible CT-LR200-A long range reader and the 300/300 mm external antenna that will read/write to ISO 15693, I-code and Tag-It tags at 40CM . Including power supply and industrial case. Sample tags and SDK software Included.
Producer	http://www.copytag.com/
Product link	http://www.copytag.com/acatalog/Evaluation_Kits.html
Data Sheet	Not Available
Application	Not Available
Seller	http://www.copytag.com/
Price	£1,667.93 (Excluding: VAT at 17.5%)
Delivering time	14 to 21 days
Reader Specifications	
Reading range	40 cm
I/O Control	Not Available
Standard	ISO 15693
Reader Evaluation	
+	− Short reading distance
+	− Expensive solution
+	− Missing information

Appendix D – Product Acquisition

AVONWOOD DEVELOPMENTS LTD.

Eureka Radio Frequency Identification Systems
KNOLL TECHNOLOGY CENTRE, STAPEHILL ROAD, WIMBORNE, DORSET, BH21 7ND
TEL: +44 (0)1202 868000 FAX: +44 (0)1202 868001
Website: www.avonwood.co.uk email: sales@avonwood.co.uk

PROFORMA INVOICE No. 00101

CONTRACT No. E 02962

INVOICE DATE 25/03/2004

REF. GM

PAGE 1

ORDER No.

DATE 25/03/2004

CONSIGN TO:

NAME AND ADDRESS

Mostafa Almusawa
PO Box 70799
Abu Dhabi
United Arab Emirates

CARRIAGE: DHL

CUST. VAT No.

PART No.	QTY	DESCRIPTION	UNIT PRICE £ STERLING	NET PRICE £ STERLING
EUR211D3308	1	211 Single Point Decoder 24v DC	680.00	680.00
EUR211T3713	30	13.56MHz Labels 82mmx47mm (R14 Adhesive)	1.10	33.00
EUR211A3581	1	211 Antenna 0.3m x 0.3m Industrial	340.00	340.00
ADL	1	211 Parasitic Antenna 0.3x0.3	280.00	280.00
PP	1	Export Carriage/Packing/Insurance DHL Courier (2 days depending on Custom's clearance)	116.75	116.75
		NOTES Payment of Pro Forma before goods are despatched. Telegraphic Transfer Payments to be paid by customer. Payment to be made to: Lloyds TSB Bank plc, 84 Victoria Road, Ferndown, Dorset BH22 9JB, UK Sort Code 30 93 25 Account No 01576426 Order Acceptance upon receipt of payment. Please supply a full delivery address for Courier delivery.		
			Net	£ 1449.75
			Vat	£
			Total	£ **1449.75**

Credit transfer payments to: Lloyds TSB Bank plc, 84 Victoria Road, Ferndown, Dorset, BH22 9JB
Sort Code: 30 93 25 Account No: 01576426

VAT No. UK 579 9365 63

Appendix E – Testing steps

Test 1

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.2.1**
Test Objectives:	**Measure reader's voltage in the oscilloscope using 1A/12 V battery**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**24.05.2004 Test Time: 14.45 Time Taken: 15 min**
Test Case nr.	**1**

Step nr.	Step description	Expected result	Actual result
1	Connecting the reader to the oscilloscope	Show waves on the monitor of the oscilloscope	Waves on the monitor of the oscilloscope
2	Read the reader's voltage	Show the voltage value of the reader on the oscilloscope monitor	The oscilloscope shows Peak-to-Peak voltage at 245 mV

Summary	**This test is taken to make sure that the reader has not very high voltage. Very high voltage means very high power. High power will cause damage for the spectre analyser (measurements equipment used under test nr. 2).**
Result	**The test shows that the RFID reader has a peak-to-peak voltage at 245 mV, which mean it will not damage the spectre analyser.**

Test 2

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.2.2**
Test Objectives:	**Measurement of reader transmission power**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**24.05.2004 Test Time: 18.00 Time Taken: 1 hour**
Test Case nr.	**2**

Step nr.	Step description	Expected result	Actual result
1	Connect the reader to the spectre analyser	Will create connection	Connection successful
2	Set the center frequency at 13.56 MHz	Some changes will be showed on the monitor of the spectre analyser	One big wave in the middle of the monitor
3	Put the marker on the top of the big wave	The symbol ◊ will move to the top of the big wave	The symbol ◇ on the top of the big wave
4	Measure the transmission power	A value will be showed on the monitor	The transmission power was around -35.30 dBm

Summary	**The purpose of this test is to measure the transmission power of the RFID reader**
Result	**The transmission power of the reader was about -35.30 dBm**

Test 3

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.2.3.**
Test Objectives:	**Measure the input and output current for RFID reader**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**25.05.2004 Test Time: 13.00 Time Taken: 1 hour**
Test Case nr.	**3**

Step nr.	Step description	Expected result	Actual result
1	Connect RFID reader to the advanced power supply, and set the voltage value to 12 V	RFID reader will work normally	RFID reader works normally
2	Note the input current shown on the power supply display	Power supply display will show a value under 1.0 A	The maximum input current value noted is 0.2 A
3	Connect RFID reader to the multi meter and set it to measure the output current	multi meter display will show a value under 1.0 A	The maximum output current value noted is 0.1 mA

Summary	**This test is done to measure the input and the output current values for the RFID reader. The value will help to understand readers interrogation field properties**
Result	**Input current = 0.2 A --- Output current = 0.1 mA**

Test 4

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reading angle**
Document Reference:	**9.3.**
Test Objectives:	**Measure the reading distance and reading angle**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**27.05.2004** **Test Time:** **12.00** **Time Taken:** **3 hours**
Test Case nr.	**4**

Step nr.	Step description	Expected result	Actual result
1	Set up equipment as shown in Figure 8.4, and then measure the maximum readable distance between the tag and the reader	The distance should be around 30 cm	35 cm was the maximum range between the reader and the tag when $\theta = 0°$
2	Move the tag vertically and then horizontally. Measure the height h and horizontal distance x	It should be no problem measuring h and x	h and x was measured successfully
3	Use trigonometry to calculate θ, and then use Pythagoras theorem to calculate the maximum readable distance p	$\theta = \tan^{-1} h/x$ ---------- $p = \sqrt{(h^2 + x^2)}$	
4	Do step 2 again to calculate new θ and p		

Summary	**Calculation of θ and p can be done if the height h and the distance x is measured**
Result	$\theta = \tan^{-1} h/x$ ---------- $p = \sqrt{(h^2 + x^2)}$

Test 5

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Tag endurance**
Document Reference:	**9.4.**
Test Objectives:	**Discover tag endurance without protection**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**30.05.2004 Test Time: 20.00 Time Taken: 20 hours**
Test Case nr.	**5**

Step nr.	Step description	Expected result	Actual result
1	Make new concrete block and implement RFID tag inside it. Wait until the block is dry	Dry concrete next morning	The concrete block was dry enough
2	Move the RFID antenna around the concrete block to sense the tag	tag should be detected	No tag was detected

Summary	**RFID tag was damaged because of concrete.**
Result	**The tag should be protected**

Test 6

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.5.**
Test Objectives:	**Permeability of plastic sheet**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**31.05.2004 Test Time: 15.00 Time Taken: 30 min**
Test Case nr.	**6**

Step nr.	Step description	Expected result	Actual result
1	Set up equipment as shown in Figure 8.6		
2	Measure the longest distance between the tag and the antenna	The distance could be around 300 mm	280 mm was the longest registed distance
3	Measure the longest read and write distance between the tag and the antenna	The distance could be around 280 mm	270 mm was the longest distance for both reading and writing

Summary	**The plastic sheet did affect the reading range for the RFID antenna**
Result	**Maximum detecting range was 280 mm, while the maximum distance for reading and writing was 270 mm**

Test 7

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.6.1.**
Test Objectives:	**Permeability of concrete block - Tags outside concrete**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**30.05.2004 Test Time: 15.00 Time Taken: 2 hours**
Test Case nr.	**7**

Step nr.	Step description	Expected result	Actual result
1	Set up equipment as shown in Figure 8.7		
2	Measure the longest distance between the tag and the antenna when the thickness of the concrete blocks is different	All the tags in these test should be detectable	The result are listed in Table 9.2
3	Measure the longest reading and writing distance between the tag and the antenna when the thickness varies	All the tags in these test should be readable and detectable	The result are listed in Table 9.2
4	Measure the writing speed	writing speed should be very fast	The result are listed in Table 9.2

Summary	**The tests showed that thicker concrete block means less power for the RFID tag**
Result	**The result are listed in Table 9.2**

Test 8

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.6.2.**
Test Objectives:	**Permeability of concrete block - Tags inside**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**30.05.2004 Test Time: 20.00 Time Taken: 19 hours**
Test Case nr.	**8**

Step nr.	Step description	Expected result	Actual result
1	Set up equipment as shown in Figure 8.8		
2	Measure the longest distance between protected tags and the antenna when the depth varies	All the tags in these test should be detectable	The result are listed in Table 9.3
3	Measure the longest reading and writing distance between the tag and the antenna when the depth varies	writing speed should be very fast	The result are listed in Table 9.3
4	Measure the writing speed	writing speed should be very fast	The result are listed in Table 9.3

Summary	**The tag with plastic container protection operates much better than the one with acre line sheet protection**
Result	**The result are listed in Table 9.3**

Test 9

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.7.**
Test Objectives:	**Permeability of metal plate**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**31.05.2004 Test Time: 16.00 Time Taken: 1 hour**
Test Case nr.	**9**

Step nr.	Step description	Expected result	Actual result
1	Set up equipment as shown in Figure 8.9		
2	Put the RFID tag under the metal plate and try to detect it with the antenna	The tag should be detected	The tag could not be detected
3	Put the RFID tag above the metal plate and try to detect it with the antenna	The tag should be detected	The tag could not be detected
4	Put the RFID tag straight beside the metal plate and try to detect it with the antenna	The tag should be detected	The tag was detected

Summary	**This test was done to see if high frequency RFID could work on metal surfaces. The tests showed that the metal plate absorbed/block the magnetic waves that energize the tag**
Result	**High frequency RFID is not working on metal surfaces**

Test10

Project name:	**Performance and reliability of Radio Frequency Identification (RFID)**
Module:	**Reader testing**
Document Reference:	**9.8.**
Test Objectives:	**Field testing**
Prepared by:	**Hussain Al-Mousawi**
Test Date:	**21.05.2004 Test Time: 17.30 Time Taken: 1 hours**
Test Case nr.	**10**

Step nr.	Step description	Expected result	Actual result
1	Set up equipment as shown in Figure 8.10		
2	Measure the longest distance between the tag and the antenna	Expecting around 230 mm	200 mm (including the 50 mm of the concrete layer)
3	Measure the longest read and write distance between the tag and the antenna	Expecting around 185 mm	170 mm (including the 50 mm of the concrete layer)

Summary	**This test was done to make sure that the outside factors such as temperature and humidity will not affect the performance of the RFID system**
Result	**RFID can be used in outdoor applications, the range of detecting has decreased**