AUTOMATIC STUDENT ATTENDANCE REGISTRATION USING RADIO FREQUENCY IDENTIFICATION (RFID)

by

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DECLARATION OF INDEPENDENT WORK

I, RENGITH BABY KURIAKOSE, hereby declare that this research project, submitted for the degree Magister Technologiae: Engineering: Electrical, is my own independent work and has not been submitted before to any institution by me or anyone else as part of any qualification.

09-03-2010

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Student's signature Date

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ABSTRACT

The main aim of this research was to automate student attendance registration, thereby reducing human involvement in the whole process. This was made possible using Radio Frequency Identification (RFID) technology.

The Central University of Technology uses student cards that are compatible for use with RFID technology. As a result, no initial investment (except for the existing personal computer's and the constructed RFID reader) in infrastructure was required for this project.

The basic working of the project was as follows. The students belonging to a specific class had their vital educational data (Student number, Name) entered into a database table at the time of registration. A student card containing a serial number, with reference to the data contained in the database table, was given to the students after registration.

The students walk into their respective classes and scan their student cards with the RFID reader. The serial number stored in the student card is transferred to the reader and from there wirelessly to the main server using ZigBee technology. In the main server, using Java programming language, the card serial number is sent to the Integrated Development Environment (IDE). In this project the Netbeans IDE (Java platform) was used.

The Netbeans IDE is connected to the Apache Derby database using Java Database Connector (JDBC), so the serial number (which is referenced to the educational data of the students) from the student card is automatically compared with the original database created at the time of

registration. Once a match is confirmed between the two entries, the data is entered into a separate database table which serves as the basic attendance sheet for a specific day.

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LIST OF ABBREVIATIONS

ASK	-	Amplitude Shift Keying
CAP	-	Contention Access Period
CRC	-	Cyclic Redundancy Check
CSMA	-	Carrier Sense Multiple Access
CSMA-CA	-	Carrier Sense Multiple Access with Collision Avoidance
DCE	-	Data Communication Equipment
DTE	-	Data Terminal Equipment
EAN	-	European Article Number
EEPROM	-	Electrically Erasable Programmable Read-only Memory
FDMA	-	Frequency Division Multiple Access
FSK	-	Frequency Shift Keying
GTS	-	Guaranteed Time Slot
ICASA	-	Independent Communication Authority of South Africa
IDE	-	Integrated Development Environment
ISM	-	Industrial, Scientific and Medical band
JDBC	-	Java Data Base Connectivity
LRC	-	Longitudinal Redundancy Check
MAC	-	Media Access Control
NRZ	-	Non-Return to Zero (Data coding technique)
PAN	-	Personal Area Network
PSK	-	Phase Shift Keying
RAM	-	Random Access Memory
RFID	-	Radio Frequency Identification
ROM	-	Rea- Only Memory
SDMA	-	Space Division Multiple Access
TDMA	-	Time Division Multiple Access
UART	-	Universal Asynchronous Receiver Transmitter
VRC	-	Vertical Redundancy Check (Parity checking method)
WLAN	-	Wireless Local Area Network

PART 1

CHAPTER 1 INTRODUCTION

The monitoring and registration of attendance in any educational institution is an important but often neglected procedure. Distribution of attendance sheets, getting them filled in by the students, safekeeping of the sheets and finally entering the information into a central database system is an essential but painstaking process. The abovementioned factors, coupled with the main responsibility of the lecturers, namely lecturing and evaluating answer scripts, can undermine the important role that attendance registration plays in any educational institution.

The use of technology in attendance registration has evolved at a slower pace than the corresponding growth in other areas of educational institutions, such as the use of projectors and e-education [1], to name only a few.

The tight schedules of lecturers and the need to reduce the paperwork involved in manual attendance registration require an innovative solution to improve the monitoring of student participation in an educational institution. The use of Radio Frequency Identification (RFID) technology to automate attendance registration is presented in this thesis as a possible solution to the challenge posed here.

However, the consideration and adoption of RFID technology as a possible solution has been slow. This is due to various factors, notably the sophistication of the technology itself. However, an important criticism of RFID technology is the question of the cost of developing an efficient solution.

The objections mentioned in the paragraph above have been overcome to a small extent by a number of salient developments in the field of RFID technology in the recent past. The use of RFID technology in access control [2] and the retail shopping sector [3] have considerably decreased the costs of major elements of RFID technology [4]. These developments have also helped to give much-needed exposure to RFID technology.

RFID is a technology that is capable of transferring data from one end of the communication link to the other with minimal human intervention [5, p.10]. This aspect of RFID technology is perceived as a critical element that will assist in finding a solution.

1.1 Scope of the Research

In this research, the Central University of Technology, Free State, was used as a basis for defining the problem and finding a solution. A solution is given at the end of this thesis which extended as solution to other educational institutions facing similar challenges.

1.2 Research Objectives

The main objective of this research is the automating of the student attendance register using RFID technology. The thesis guides the reader through the step-by-step procedure that was used to arrive at a cost-effective solution to automate the student attendance register.

1.2.1 Hypothesis

The hypothesis of this research is that RFID technology is a growing trend worldwide which allows the transfer of data from one end to the other with the minimum of human

intervention, and that this same technology can be used to automate a student attendance register.

1.2.2 Corollary

How the hypothesis mentioned in Section 1.2.1 can be practically implemented forms the basis of the corollary. A step-by-step explanation is given in Section 3 which details how the challenge was addressed and overcome.

1.3 Structure of the Thesis

This thesis is divided into four parts comprising five chapters. Part 1 contains Chapter 1 - *Introduction*. This part of the thesis gives a general overview of the problem and a possible solution to the challenges posed by RFID technology.

Part 2 consists of Chapter 2 - *Literature Survey.* This part of the thesis examines the various elements that require further study in order to understand the different challenges mentioned in Chapter 1 (Section 2.1). This Chapter also examines the different technologies available to solve the problem (Section 2.3). It then goes on to discuss RFID technology in detail (Section 2.5). It will become clear that RFID technology alone cannot solve the problem on hand. As a result, wireless technologies such as ZigBee technology (Section 2.8) and data manipulation techniques are discussed in this chapter (Section 2.9).

Part 3 comprises Chapters 3. Chapter 3 - *Research Structure* is divided into three sections: the Hardware section (Section 3.1), the Wireless section (Section 3.2) and the Software

section (Section 3.3). This is the main part of the thesis as it presents the solution to the problem explained in Section 2.1.

Part 4 comprises of Chapter 4 and Chapter 5

Chapter 4 – *Results*. This section looks at the different tests that were done during the course of the project and their results. This chapter holds up the bulk of research that was mention in Chapter's 2 and 3.

Chapter 5 *Conclusion and Future work.* Concludes the thesis by examining some of the challenges that arose during the research for the solution. This part also investigates certain areas which were outside the scope of this research but nevertheless are worth further research by other people with access to this thesis.

PART 2

CHAPTER 2 LITERATURE SURVEY

This part describes the background study that was done prior to starting the practical work on the project.

2.1 Current Procedure for Attendance Registration

During class hours in an educational institution, the lecturer in charge of the class distributes an attendance list to the students. The attendance list contains the names and student numbers of the students. Each student signs against his/her name on the attendance list.

At the end of the lecture period, the lecturer takes the attendance list from the students and enters the details into his/her computer. This process is repeated by the lecturer for every class taken during the academic term.

At the end of the academic term the lecturer tabulates the attendance of each student. This is done by dividing the number of classes attended by a student by the total number of working days in the academic year. This process is repeated for every class the lecturer is in charge of.

2.2 Challenges Facing the Current System

The current system discussed in Section 2.1 poses some challenges which are discussed in detail in the following sections.

2.2.1 Tedious Procedure

The main aim of the project, as discussed in the introduction in Chapter 1, is to relieve the teaching and non-teaching staff of avoidable and often tedious paperwork. With the current system, the lecturers first have to manually enter the attendance of each class daily. Next, the tabulation involves a lot of attendance calculations for the lecturer. This is not the only work for which the lecturer has a deadline - s/he must also set examination papers, mark answer sheets, etc.

2.2.2 Errors on the Part of Students and Lecturers

When the attendance list is passed around the classroom, some of the students forget to sign or sign for another student. The lecturer may also forget to bring the attendance list. These may be minor problems on the scale of things, but they complicate the current procedure.

2.2.3 Not Foolproof

One of the major drawbacks of the current system is that it can easily be cheated. The students may sign as proxy for their friends who are not present in the classroom when the attendance list is being filled in. This may not be noticed by the lecturer who is busy giving a lecture.

A manual head count and comparison with the attendance list is a way around this problem, but more often than not this is not practical. Even if this is possible, it makes the entire process more tedious.

2.2.4 Loss of Data

There is an immense amount of material on paper in any lecturer's office at any given time, and it is very easy to loose track of the attendance lists. The problems will be compounded if the information has not been entered into a computer. With the current method used for attendance registration, it is easy to misplace an attendance list.

2.2.5 Neglect

The current system is monotonous and tedious as mentioned in Section 2.2.1. In time this may lead to neglect on the part of the lecturer. An important responsibility thus gets neglected. Neglect of the attendance registration procedure will undermine its importance.

2.3 Automatic Student Attendance Registration Systems

This section examines some of the technologies available for meeting the challenges mentioned in Section 2.2. These are the following:

- Barcode systems
- Biometric systems
- Smart card systems
- RFID systems.

2.3.1 Barcode Systems

Barcode technology is widely used in the retail shopping sector [6, p.6]. It is a very cheap and simple technology. It is a binary code comprising fields of bars and gaps arranged in a parallel configuration. The bars and gaps are arranged in a predetermined pattern and represent a symbol.

Despite appearing identical, there are considerable differences between each barcode. This is the result of the different coding techniques used in the design. The European Article Number (EAN) is the most common type of coding used for designing barcodes [7, p.2]. A barcode has a data density of 100 bytes.

Barcodes are usually read with optical scanners. The different reflections of a laser beam from the black bars and the white gaps assist in interpreting the bars and graphs on a barcode numerically and alphanumerically. The optical scanner has to be placed very close (10-50 cm) and in the line of sight of the barcode for data to be read from it.

A barcode system could have been an ideal replacement for the current manual system because barcode systems are cheap and easy to operate. However, these advantages are negated by the fact that they are affected by dirt, highly susceptible to wear and tear, and fail completely if the barcode is blocked from the direct view of the optical scanner. Barcode systems are therefore not suitable for attendance registration.

2.3.2 Biometric Scanning (Dactyloscopy)

Biometrics is the study of methods of uniquely recognising persons based upon one or more intrinsic physical characteristic. There are various biometric techniques, but in keeping with the context of this project, dactyloscopy [7, p.3] or fingerprint scanning will be examined in some detail.

Fingerprint scanning was first used, and is still being used, by criminologists [7, p.4]. Criminal offenders are fingerprinted when they are charged with a crime. If there is a match

between a fingerprint found at a crime scene and one stored in the criminal database, this is regarded as conclusive evidence against the criminal, as fingerprints differ in every person.

Fingerprint readers are used in dactyloscopy. Users must first register their fingerprints in the central database. This is done by placing the fingertip on the reader. The reader system calculates a data record from the fingerprint pattern and stores it in the memory.

Once the fingerprints of the users have been registered in the database, the fingerprint reader can be used to register the attendance of the users. Every time the users enter a classroom their fingers are scanned. A match between the scanned images and those already stored in the database will prove that the users belong in the classroom and thus confirm their attendance.

The advantages of the biometric scanning system are that it is very accurate, compact and resistant to data tampering. However, the high cost and complexity of the system make it less attractive compared to the other technologies available for automating attendance registration.

2.3.3 Smart Card Systems

Smart card systems are mainly used for electronic data storage. Their applications range from prepaid telephone cards to the SIM cards used in GSM mobile phones [8, p.5]. Smart cards are equipped with galvanic contacts. The smart card is provided with the necessary voltage and pulse from the smart card reader when the two come into contact with each other.

There are two types of smart cards, namely memory cards and microprocessor cards. Memory cards [8, p.11] have an Electrically Erasable Programmable Read-Only Memory (EEPROM). The end application that needs to be run using the memory card is stored in the EEPROM. The security algorithms used in the card are also stored in the EEPROM. The advantage of the memory card is that it is very cheap to manufacture. However, low data storage capacity and susceptibility to wear and tear have resulted in memory cards slowly being phased out of the market.

Microprocessor cards, on the other hand, have different sectors, namely a Read-Only Memory (ROM), a Random Access Memory (RAM) and an EEPROM. As a result microprocessor cards can store many more applications. This advantage of the microprocessor card is negated by its cost.

2.3.4 Radio Frequency Identification Systems

RFID systems are similar to smart cards except that they do not have to be physically in contact with the RFID reader. Data stored in an RFID card are transferred via radio waves to the RFID reader.

RFID systems comprise of an RFID transponder, an RFID reader and RFID middleware [9, p.6]. RFID transponders have a very high data density. RFID transponders are small microchips that can store data. RFID systems are not influenced by dirt or by obscuring the tags.

RFID readers have a range of up to 5 m without the transponder being in the line of sight of the RFID reader. The advantages mentioned in this section have prompted the use of RFID in automating the student attendance register. RFID technology will be discussed in detail in Section 2.5.

2.4 Comparison between Various Automatic Identification Systems

In Section 2.3 the different technologies available for automating the student attendance register were discussed. This section will examine the pros and cons of each of these technologies, bearing in mind the objective of this project. The aim of this section is to narrow down the technology that can be used for automating the student attendance register. A comparison is made of the technologies with respect to some of the vital parameters concerned with automating the student attendance register (see Table 2.1).

Table 2.1: Comparison between different automatic identification systems

Parameters	Barcode system	Biometric system (Dactyloscopy)	Smart card system	RFID systems
Data density (bytes)	Low data density 100 bytes	High data density	Very high data density -16-64 kb	Very high data density
Influence of dirt	Very high	No influence	High if contacts come in contact with dirt	No influence
Influence of covering the data carrier	Total failure of system	Total failure as system works on contact	Total failure as system works on contact with the smart card	No influence
Influence of direction between reader and data carrier	Failure - if no line-of-sight communication	Not applicable as direct contact is needed	Not applicable as direct contact is needed	No influence as data are transferred via radio waves
Wear and tear of data carrier	Limited - if not tampered with intentionally	Not applicable	Possible with extended use	No influence
Purchasing cost	Low	High	Low	Low
Operating cost	Low	High	Low	None
Reading speed in seconds	Low - up to 4 seconds	Very low - 5-10 seconds	Low – 4 seconds	Very fast - 0.5 to 1 second
Distance between reader and data carrier in centimetres	0-50 cm	Direct contact	Direct contact	0-6 m depending on the frequencies used

2.5 Introduction to Radio Frequency Identification (RFID) Technology

The comparison in Section 2.4 shows that RFID technology is an ideal solution for automating the attendance register. Section 2.3.4 briefly introduced RFID technology. This section aims to elaborate on that discussion. First, the components of an RFID system are

examined in detail. Secondly, anti-collision in RFID technology is studied. Thirdly, the security issues concerning RFID technology are elaborated on.

An RFID system consists of three main components, namely the RFID tag, the RFID reader and RFID middleware.

2.5.1 RFID Tags

RFID tags (hereafter referred to as tags) are also called transponders. The tag is placed on the object that needs to be identified. It contains an internal antenna and a microchip [6, p.22]. The microchip stores the data which define and distinguish each tag.

There are three types of tags in use: active tags, passive tags and semi-passive tags.

Active tags incorporate a battery along with the antenna and the microchip. The battery affects the cost and size of active tags. As a result active tags [7, p.13] are not very commonly used.

Passive tags do not have a built-in battery. The power requirements of a passive tag are generated from the electric or magnetic fields generated by the RFID reader. How the power requirements are met is explained in Section 2.5.5.3. Passive tags [9, p.66] are very cheap and smaller than active tags. As a result they are used in the project on attendance registration.

Semi-passive tags have an onboard power source and may have onboard sensors. The onboard power source provides a continuous power source for the sensors. This enables the

semi-passive tags to transfer data even in the absence of an RFID reader. The semi-passive also has an increased read range. The cost of semi-passive tags lies between the costs of active and passive tags [10, p.3].

2.5.1.1 Types of tag constructions

The type of tag construction depends on various factors such as the type of tag used (active, passive or semi-passive), the desired read range, and the end-user application. Some of the different types of tag construction are discussed briefly in this section.

Glass tube tags: These types of tags are used in animal identification [7, p.13]. They have a nominal read range and are very small in size. The glass tubes contain a microchip, which processes the data, as well as the antenna for data transmission. Figure 2.1 shows the physical layout of a glass tube tag.

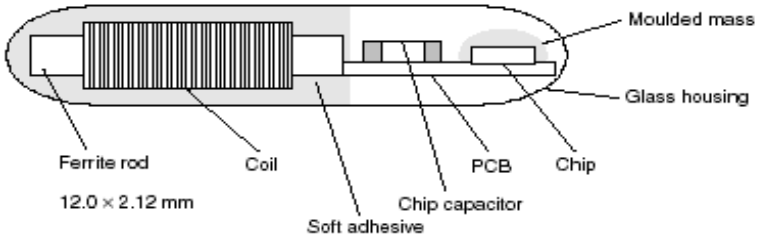


Figure 2.1: Physical layout of a glass tube transponder

(From: RFID Handbook, K. Finkenzeller)

Key format construction: This format incorporates the transponder circuitry in a key shape. The key is used in *keyless* start functions of many modern vehicles [11] or as automatic access control to rooms.

Identification card formats: These types of tags come in standard credit card size (85.72 mm × 54.03 mm × 0.76 mm). They have coil antennas attached to the microchip circuitry [7, p.18] which is laminated between two sheets of polyvinyl chloride (PVC) foil. These are then baked at high temperature to seal the bond. These types of tags are used in this project.

Smart labels: These types of transponders are very thin and flexible. They resemble stickers or labels [10, p.112], and are manufactured by screen-printing and etching techniques. They are about 0.1 mm thick. These types of tags are stuck onto the asset which has to be tracked or identified. Figure 2.2 shows a picture of a smart label.

Figure 2.2 Smart label next to a pen top to show its size

2.5.2 RFID Reader

It was established in Section 2.5.1 that all RFID tags contain a microchip which stores data that distinguish each tag. The data contained in each tag must be transmitted. The transmission midpoint of an RFID system is referred to as the RFID reader (referred to as a reader from now on). The reader reads the data in the tag and sends the data to the RFID middleware.

This section examines the physical components of the reader and the different types of readers available. There are three components to the reader: the antenna, the controller and the network interface. See the block diagram in Figure 2.3.

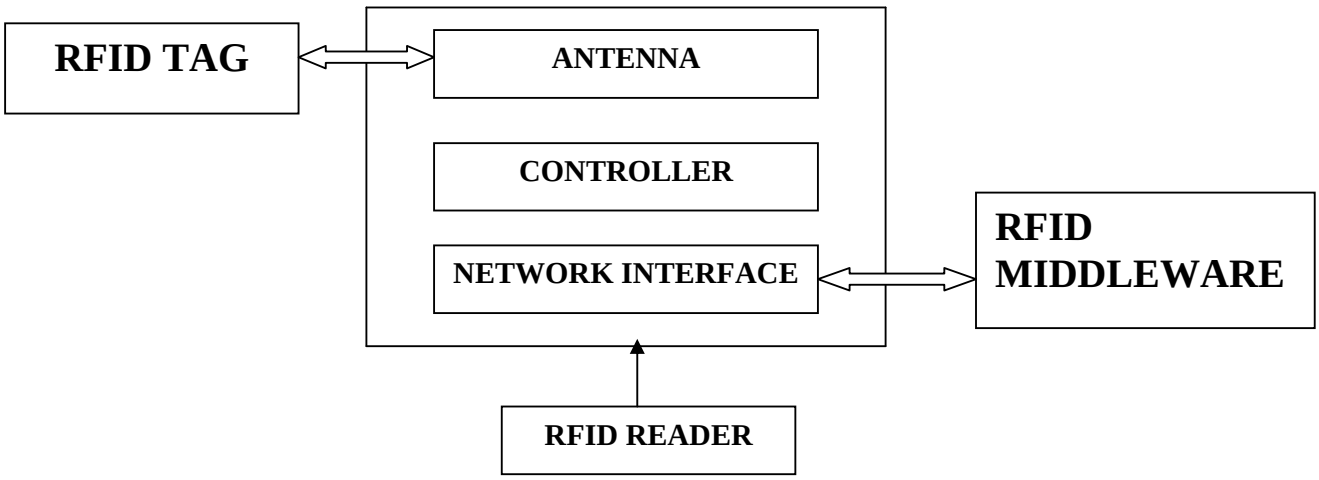


Figure 2.3: Physical components of an RFID reader

Antenna subsystem: All RFID readers need an antenna as the tag communicates with the reader using radio frequency (RF). The antenna acts as a receptor of the RF waves. This makes the antenna the most important component of an RFID reader.

The antenna is designed such that the radio frequency waves it receives are optimised for the centre frequency ranges. This is high-precision work which requires considerable attention during the antenna design stage and fine tuning of the design properties (the design procedures for the antenna in this project are described in Section 3.2).

The types of antenna used in readers vary. Most readers use a single antenna, which energises the passive tag once it comes within the range of the antenna [7, p.125]. Some readers use

two antennas. In this instance, one antenna acts as a transmitter and the other as a receiver. In this type of arrangement the transmitter antenna energises the tag when it comes within its read range. The receiver antenna collects data from the energised tag [12].

The two designs are illustrated in Figures 2.4 and 2.5.

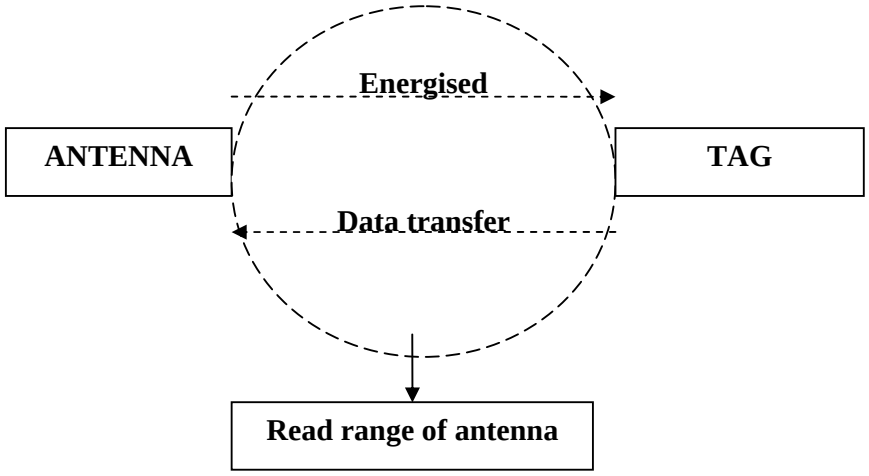


Figure 2.4: The antenna energises a tag when it comes within read range and the tag transmits its data

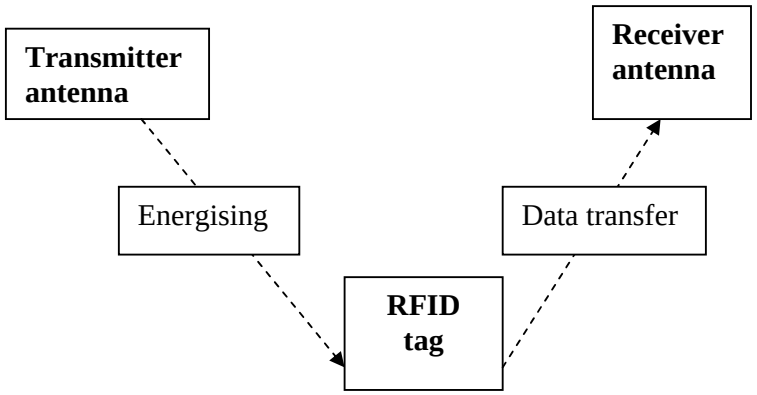


Figure 2.5: RFID reader operating with two antennas

Controller: All readers need a controller to run the different processes involved in reading RFID tags. The complexity of the reader varies. A reader can be equipped with only a single embedded chip which can function as a simple-state machine, or it can run an entire operating system with substantial hard disk space and RAM.

Network interface: The data read from the tags by the reader must be transferred to a device which recognises and manipulates the data. This is where a network interface is needed. Most RFID readers have either an RS232, an RS485 interface or, as in this project, a wireless ZigBee interface.

2.5.2.1 Types of RFID readers

Readers differ in size, shape and protocol depending on their end-user applications. This section examines the different types of readers available on the market.

RFID portals: These types of readers are placed in passageways [13, p.113] and are designed to monitor devices moving in and out of the passageway. They are used mainly in industrial warehouses where the movements of tagged items can be tracked. Figure 2.6 shows an RFID portal.

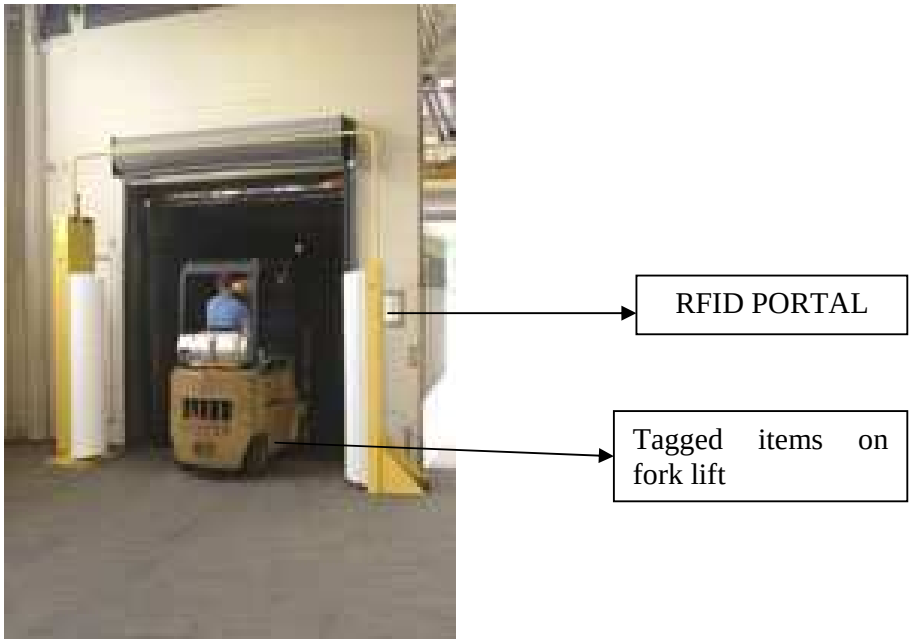


Figure 2.6: Forklift carrying RFID-tagged items though an RFID portal

(Picture taken from www.industrialit.com.au)

RFID tunnels: An enclosure that houses an RFID reader is referred to as a tunnel. These types of readers are used in airports [13, p.114]. The difference between RFID portals and RFID tunnel readers is that tunnel readers have an RF shield. The RFID shield prevents misdirected RF waves from interfering with other readers in the vicinity. Figure 2.7 illustrates an RFID tunnel type reader.

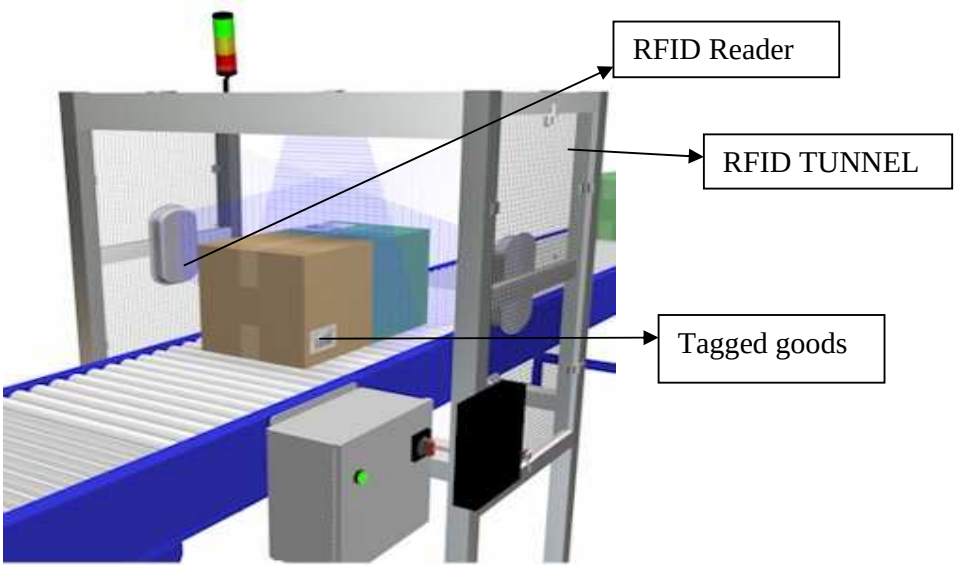


Figure 2.7: RFID tunnel with tagged goods on a conveyor belt

(Picture taken from www.rfidsupplychain.com/BBconveyorportal.jpg)

Handheld readers: These types of readers are used in applications where the tag is immobile or inconvenient to move about. As the name suggests they are hand held. They have a built-in antenna, reader and network interface [13, p.115]. They have a smaller read range compared to RFID portals and RFID tunnel type readers.

Figure 2.8 shows a handheld reader used in a shop to read tagged DVDs.

Figure 2.8: Handheld RFID reader

(Picture taken from www.yourdictionary.com/RFIDRD3.jpg)

Stationary readers: These types of readers are used for scanning smart card-type RFID tags (discussed in Section 2.5.1.1). They are similar to the ones used in this project. Stationary readers [13, p.117] have a built-in antenna, a controller and a network interface much like the handheld readers on the same unit. They are used in applications where the reader is placed strategically at a point so as to register entry into a room or allow access to a building. Stationary readers have a small range to avoid picking up stray signals. Figure 2.9 shows a photograph of the stationary reader used in this project to explain these types of readers.

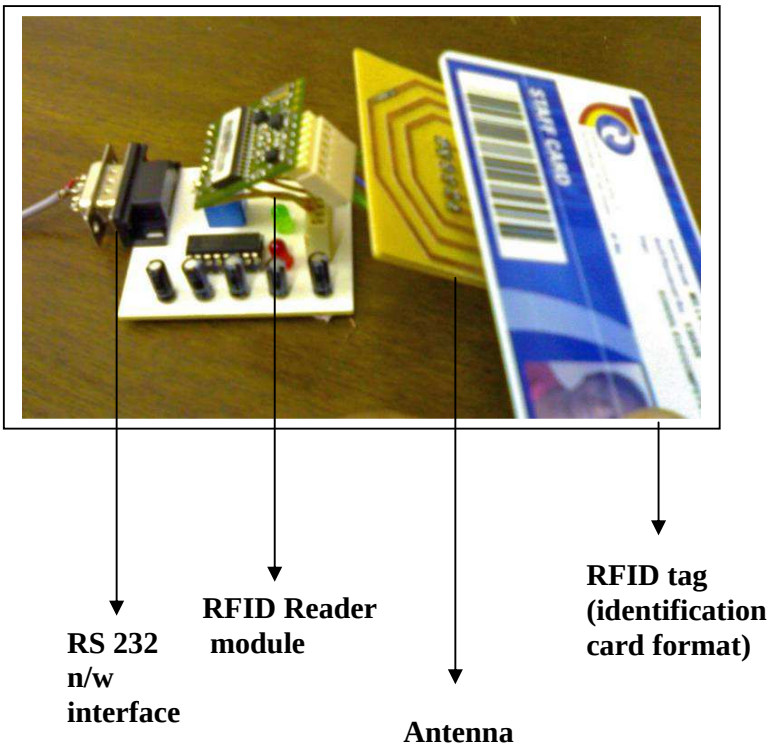


Figure 2.9: Stationary RFID reader and a tag

2.5.3 RFID Middleware

The data obtained from the tag by the reader must be given significance. The only way is if the data drives an output or if it is stored for future reference as in this project.

RFID middleware [13, p.238] serves three main purposes: to capture data from the network interface of the reader and input it to an end-user application; to process the data from the reader so as to allow the end-user application to see only the necessary data, and to provide an application level interface for managing the reader.

Based on this, basic RFID middleware should consist of three principal components: the reader adapter, the event management unit and the application level interface. A block diagram illustrating these three components is given in Figure 2.10.

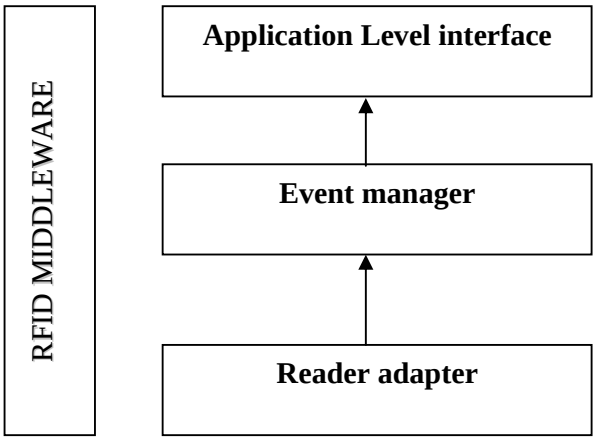


Figure 2.10: Components of RFID middleware

Reader adapter: A number of readers are available on the market. It is not possible for the end user to be familiar with all these readers and specifically the network interfaces of these modules. The first and main component of RFID middleware is that it should contain a reader

adapter [13, p.116] which will spare the end user the need to learn about the network interface capabilities of each individual RFID reader.

Event management: The data that a reader captures from the tag is said to be “raw” data. This means that the reader reads many data, which may not be necessary for the end-user application.

The RFID readers used today can handle suitable data, but they are not intelligent enough to adjust to a specific end-user application. The event manager [13, p.144] in the middleware makes up for this deficiency on the reader side with a high-level filter. As a result only the necessary data reach the end-user application.

Sometimes certain types of data need to be added to the data from the tags, which the reader cannot do. The event manager can add these data. This aspect is a problem encountered in this project.

The data contained in the tag is a unique 8-character numeral. The code differs from the student number, which identifies each student. The RFID reader cannot read the student number from a tag; it can only read the unique code. The specific reader used in this project cannot output the date and time once the tag has been scanned, which is necessary for registering the attendance.

The event manager in the RFID middleware can be programmed to input the corresponding student number for a unique code as well as a time stamp when a tag is scanned. Section 3.3 explains this example in detail, and there is further discussion on the example.

Application-level interface: This is the top layer of the RFID middleware. The primary objective of this component is to provide a standard output that allows an application to receive filtered data from the RFID reader. In addition, the application-level interface [13, p.141] should enable the end user to manage and improvise the data from the reader so as to provide multi-functionality, i.e. there should be room for development if and when the end user deems it necessary.

Figure 2.11 summarises the function of the middleware, which is in essence to reduce the complexity of the raw data from the reader and maximise the functionality of the application.

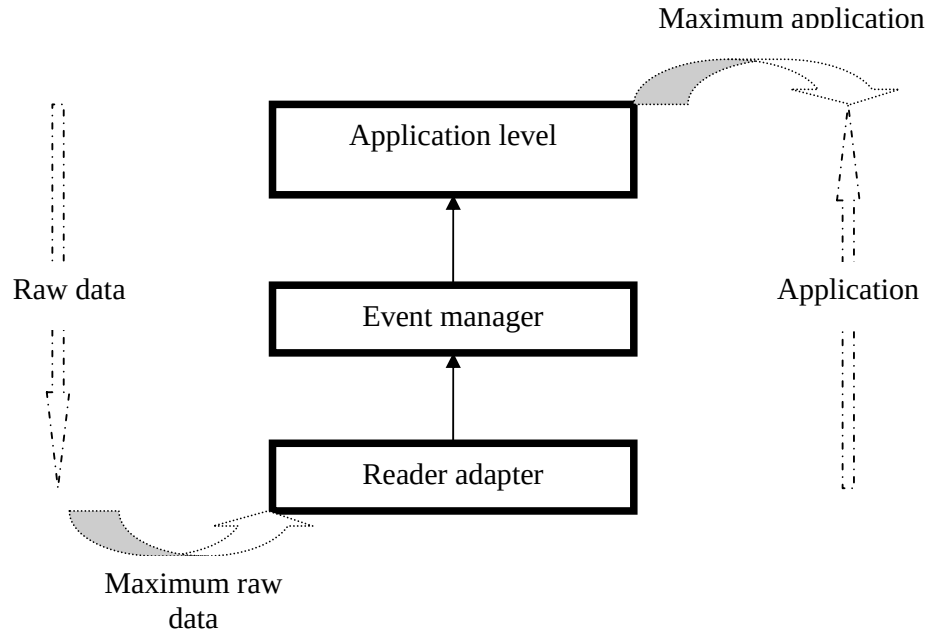


Figure 2.11: Raw data and application relevance at different levels of RFID middleware

2.5.4 Physics behind RFID

The last three sections introduced the basic components of an RFID system. This section aims to shed some light on the physics behind the actual working of the various RFID components, especially the RFID tags and the readers. Radio waves are the main component used in the functioning of an RFID system.

Data transfer in RFID is done mainly through magnetic principles. The derivations done in this section go a long way towards the design of major components of the RFID reader discussed in detail in Section 3.

2.5.4.1 Magnetic field strength

When current passes through a circuit a magnetic field is created. The magnitude of the magnetic field created is known as the magnetic field strength [7, p.61]. It is denoted by H. Mathematically it is written as [7, p.61]:

$$\sum I = \oint \mathrm{H}.\delta s \qquad (2\text{-}1)$$

i.e. “the closed integral of the magnetic field strength along a closed curve is equal to the sum of current strengths with the curve [7, p.61]”

Where:

H = Magnetic field strength (ampere/metre)

I = Current through the circuit (ampere).

This function can be used to derive the magnetic field strength along a straight conductor. From Figure 2.12, an expression for the magnetic field strength along a straight-line conductor can be derived.

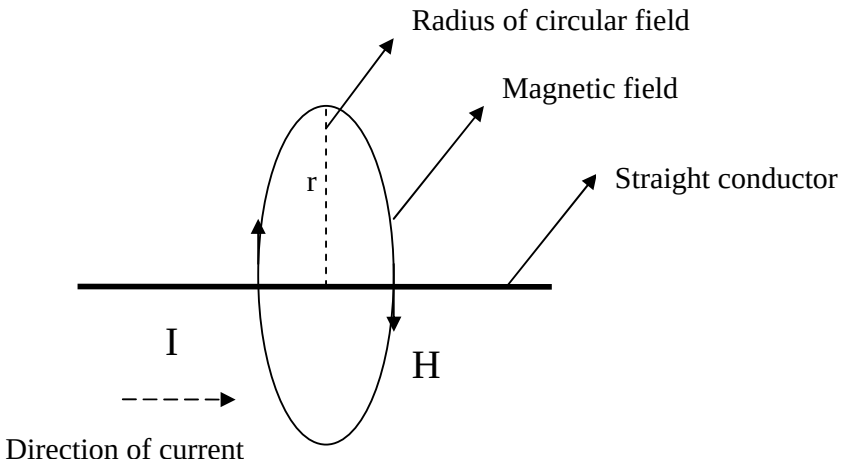


Figure 2.12: Current I flowing through a straight conductor creating a magnetic field with strength H

The radius of the magnetic field is r. Then the magnetic field strength H is equal to [7, p.61]:

$$H = \frac{I}{2\Pi r} \tag{2-2}$$

2.5.4.2 Path of field strength h(x) in a conductor loop

The RFID antenna is a cylindrical coil that generates magnetic fields similar to those in Figure 2.12. In this section we aim to find the relationship between the field strength [7, p.62] and the distance from the centre of the antenna.

Figure 2.13 shows an antenna similar to that used in RFID systems and the magnetic field surrounding it.

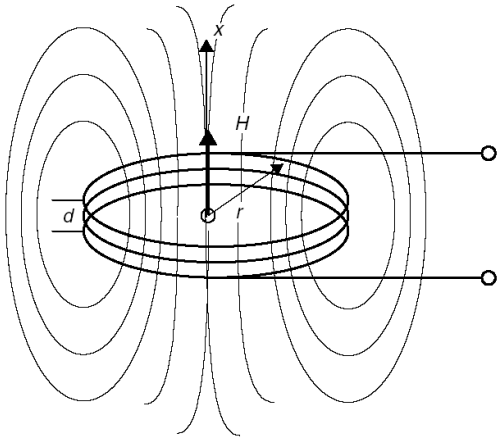


Figure 2.13: RFID antenna and magnetic field

(From: RFID Handbook, K. Finkenzeller)

In Figure 2.12:

N = Number of coil turns

R = Radius of the circle created by the magnetic field

x = Distance from the centre of the coil.

d = Diameter of the wire coil.

Then the equation can be re-written as [7, p.62]:

$$H = \frac{I N R^2}{2\sqrt{(R^2 + x^2)^3}} \quad (2\text{-}3)$$

The field strength at the centre of the antenna (where x = 0) is:

$$H = \frac{I \cdot N}{2R} \quad (2\text{-}4)$$

2.5.4.3 Magnetic flux (Φ)

Magnetic flux [7, p.66] is denoted by Φ. It is the total number of magnetic field lines passing through a current-carrying coil. It can be written mathematically as [7, p.66]:

$$\Phi = B. A \quad (2\text{-}5)$$

Where;

B = Magnetic flux density, which is the magnetic flux per unit area of the section perpendicular to the direction of flux. Magnetic flux density can be expressed in terms of magnetic field strength as follows [7, p.66]:

$$B = \mu_0 \mu_r H = \mu H \quad (2\text{-}6)$$

Where;

μ_0 = permeability of free space

μ_r = permeability of the medium

μ_0 μ_r = μ = permeability.

2.5.4.4 Inductance

Magnetic flux is generated in a current-carrying conductor as explained in Section 2.5.4.3. If the current-carrying conductor has N loops, then a magnetic flux will be generated in every loop. Therefore the total flux ψ can be expressed mathematically as follows [7, p.66]:

$$\Psi = \sum \Phi N = N.\ \Phi = N.\ \mu.\ H.\ A \tag{2-7}$$

Where;

N = Number of turns in the current-carrying coil

Φ = Magnetic flux

H = Magnetic field strength.

Now inductance [7, p.66] is defined as the total flux ψ that arises in an area 'A' enclosed by the current 'I'. It can be mathematically defined as follows [7, p.66]:

$$L = \frac{\Psi}{I} = \frac{N.\Phi}{I} = \frac{N.\ \mu.\ H.\ A}{I} \tag{2-8}$$

Where;

L = Inductance

Ψ = Total flux in an enclosed area

Φ = Magnetic flux

N = Number of coil windings

I = Current flowing through the conductor coil

H = Magnetic field strength

A = Area

μ = permeability of the medium.

Figure 2.14 illustrates the concept of inductance.

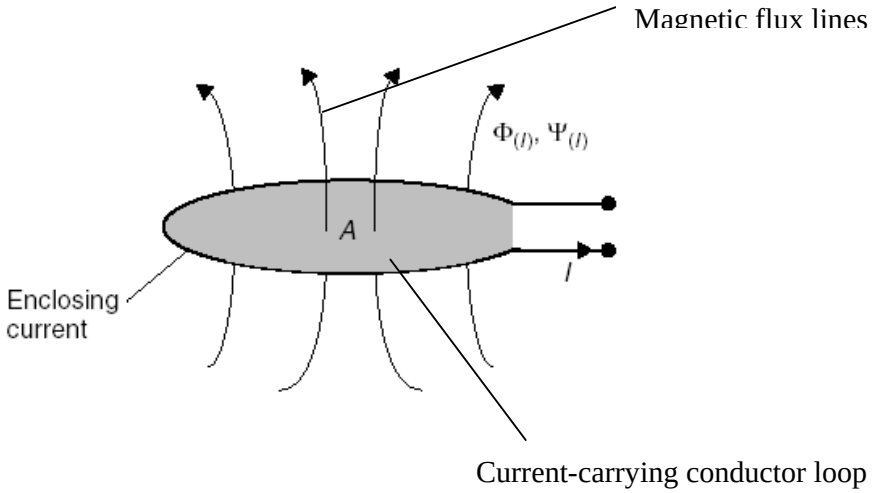


Figure 2.14: Inductance in a current-carrying metal conductor

(From: RFID Handbook, K. Finkenzeller)

2.5.4.5 Mutual inductance (M)

Section 2.5.4.4 explained the phenomenon of inductance in a single conductor with area A. Now suppose a second conductor loop (loop 2) with area A_2 and current I_2 flowing through

it enters the magnetic field created by the first conductor loop (loop 1) with Area A_1 and current I_1. Loop 2 will then be subjected to a portion of the magnetic flux generated in loop 1. This is called a coupling flux.

The coupling flux, ψ_{21}, like the total flux, depends on the area of the loops, the current flowing through the circuits, the permeability of the material used in the conductor loops and the field strength.

The voltage induced on loop 2 as a result of the partial flux changes, ψ_{21}, in loop 1 is called mutual inductance, M_{21}. The mathematical expression for M_{21} can be written as follows [7, p.68]:

$$M_{21} = \frac{\Psi_{21}(I_1)}{I_1} = \oint_{A2} \frac{B_2(I_1)}{I_1} . d\ A_2 \qquad (2\text{-}9)$$

Where

ψ_{21} = Partial flux on conductor loop 2 due to current I_1 on loop 1

I_1 = Current flowing through loop 1

B_2 = Flux density induced in loop 2

A_2 = Area of loop 2.

There will also be an equal inductance on loop 1 as a result of current I_2 flowing through loop 2. This inductance is referred to as mutual inductance [7, p.68] M_{12}. This creates a

coupling flux ψ_{12}. The mutual inductance M_{12} is the same as M_{21}. They can thus be written as:

$$M_{12} = M_{21} = M.$$

The mutual inductance phenomenon is shown in Figure 2.15.

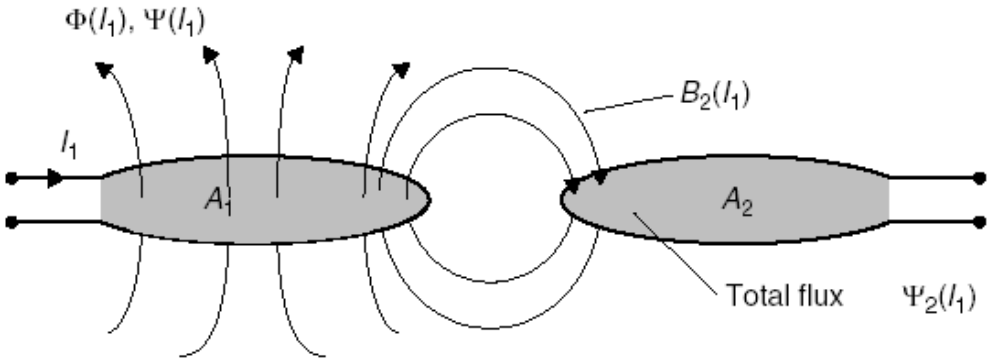


Figure 2.15: Mutual inductance M_{21}

(From: RFID Handbook, K. Finkenzeller)

Mutual inductance is an important phenomenon as far as RFID is concerned. It forms the basis for inductive coupling (explained in Section 2.5.5.4) in the RFID system.

Equation 2-9 can be re-written as [7, p.68]

$$M_{12} = \frac{B_2(I_1).N_2.A_2}{I_1} = \frac{\mu_0 H(I_1).N_2.A_2}{I_1} \qquad (2\text{-}10)$$

Where;

$H(I_1)$ = Magnetic field strength H due to current I_1. (It is the same as H.)

Substituting for H in Equation 2-10 with Equation 2-3, a new expression for M_{12} is obtained. This is expressed as Equation 2-11.

$$M_{12} = \frac{\mu_0 . N_1 . R_1^2 . N_2 . R_2^2 . \Pi}{2\sqrt{(R_1^2 + x^2)^3}} \qquad (2\text{-}11)$$

Where;

M_{12} = Mutual inductance

μ_0 = permeability

H (I_1) = Magnetic field strength due to current I1

R_1 = Radius of circular loop 1

R_2 = Radius of circular loop 2

N_1 = Number of coil turns in loop 1

N_2 = Number of coil turns in loop 2

x = distance from the centre of the coil

Π = constant (3.14).

This formula is used to calculate the mutual inductance.

2.5.4.6 Faraday's law

This law states that a change in the magnetic flux φ will result in an electric field E being generated. The electric field generated depends on the magnetic properties of the medium. For a conductor with N windings, Faraday's law can be written as follows [14, p.231]:

$$E_i = N . \delta\varphi/\delta t \qquad (2\text{-}12)$$

Where;

E_i = Electric field induced as a result of change in flux

N = Number of windings on the conductor coil

$\delta\varphi/\delta t$ = Change in flux with respect to time.

Faraday's law is important in the study of RFID, as Faraday's law applied to metallic surface results in the creation of a back electromotive force called eddy current. Eddy currents increase with an increase in the alternating flux. As a result, in the design of RFID systems (tags or readers) it is vital to avoid construction or installation on or near metallic surfaces. This is shown in Figure 2.16

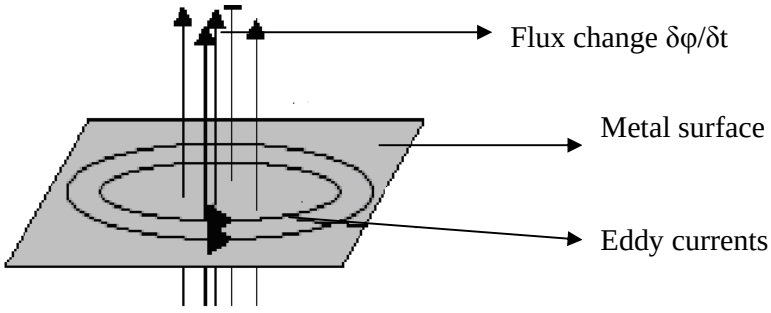


Figure 2.16: Faraday's law applied to a metal conductor

(From: RFID Handbook, K. Finkenzeller)

The concepts discussed thus far in this chapter can be used to enhance the understanding of inductively coupled RFID systems. An equivalent circuit for an RFID system comprising a reader and a tag is shown in Figure 2.17. Both the reader and the tag are shown as inductors.

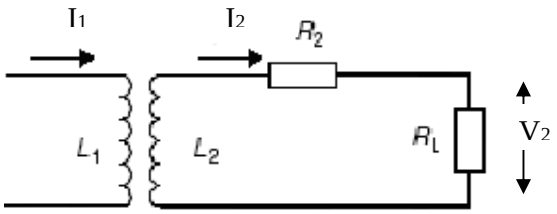


Figure 2.17: Equivalent circuit for a reader and a tag

Where;

L_1 = Reader antenna

L_2 = Tag antenna

R_2 = Coil resistance of L_2

R_L = Load resistance of L_2

I_1 = Current flowing through L_1

I_2 = Current flowing through L_2

V_2 = Voltage across R_L.

A time-varying current I_1 through L_1 results in a voltage V_{21} induced in L_2 due to mutual inductance. V_{21} flows through R_2 creating a voltage V_2 which can be measured across the load resistor R_L. The current I_2 flowing through L_2 results in a slight back e.m.f due to eddy currents. The total voltage across R_L in L_2 can be calculated as shown in equation 2-13 [14, p.231]:

$$V_2 = M\,\delta I_1/\delta t - L_2\,\delta I_2/\delta t - I_2 R_2 \qquad (2\text{-}13)$$

Where;

M = Mutual inductance on L_2 as a result of voltage induced in L_1 ($M_{12} = M_{21} = M$)

$\delta I_1/\delta t$ = Change in current I_1 with respect to time

L_2 = Inductance representing tag antenna

$\delta I_2/\delta t$ = Change in current I_2 with respect to time

I_2 = Current flowing through L_2

R_2 = Coil resistance of L_2.

Equation 2-13 can be put into words as follows: “the voltage induced as a result of mutual inductance less the voltage drops created by the back emf and the drop across the resistor R_2”.

Equation 2-13 can be written using complex notations as the currents are sinusoidal in nature as shown in Equation 2-14 [14, p.231].

$$V_2 = j\omega M I_1 - j\omega L_2 I_2 - I_2 R_2 \quad (2\text{-}14)$$

Now $I_2 = V_2 / R_L$, substituting for I_1 in equation 2-14:

$$V_2 = j\omega M I_1 - j\omega L_2 (V_2 / R_L) - (V_2 / R_L) R_2 \quad (2\text{-}15)$$

Solving for V_2,

$$V_2 = \frac{j\omega M I_1}{1 + \frac{j\omega L_2 + R_2}{R_L}} \quad (2\text{-}16)$$

This is the magnitude of the voltage used to power the microchip in an RFID transponder.

2.5.4.7 Resonance

The circuit in Figure 2.15 can be modified to significantly improve the efficiency of the RFID tag. The modification is the addition of a capacitor, C_2, in parallel to the inductor, L_2, in Figure 2.15. This will result in the creation of a parallel resonant circuit operating at the resonant frequency of the RFID system. In this project the RFID system operates at 13.56 MHz.

The equivalent circuit diagram is shown in Figure 2.18.

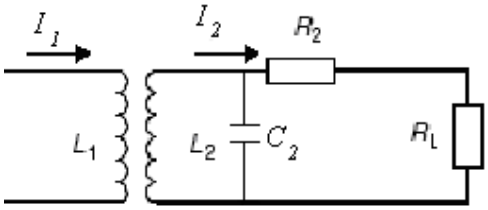


Figure 2.18: Equivalent circuit for an RFID tag circuitry

The equation for finding the resonant frequency is [14, p.231]:

$$f = \frac{1}{2\Pi\sqrt{L_2 C_2}} \tag{2-17}$$

In practice, C_2 is made up of parallel capacitor C_{2p} and a parasitic capacitance C_p. The value for the parallel capacitor C_{2p} can be found with the same formula used in Equation 2-17, but subtracting the parasitic capacitance.

$$C_{2p} = \frac{1}{(2\Pi f)^2 L_2} \tag{2-18}$$

The parallel capacitor C_2 is now added to the circuit as shown in Figure 2.19, the equation for the equivalent voltage also tends to change from equation 2-16 and it becomes:

$$V_2 = \frac{j\omega M I_1}{1 + (j\omega L_2 + R_2)(1/R_L + j\omega C_2)} \quad (2\text{-}19)$$

Where;

$C_2 = C_{2p} + C_p.$

Therefore Equation 2-19 represents the actual value of the output voltage across the load resistor of the RFID transponder. Figure 2.19 gives the equivalent circuit diagram of the magnetically coupled conductor loops of an RFID system.

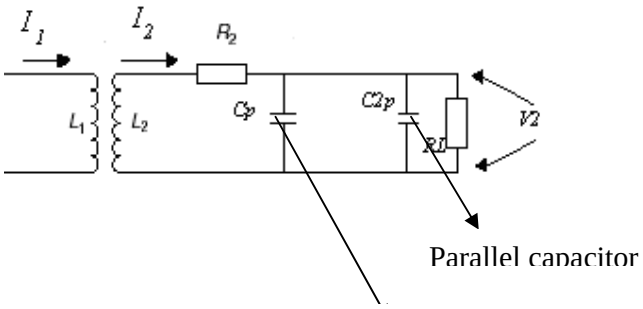


Figure 2.19: Effective circuit diagram of an inductively coupled RFID system with the addition of parallel and parasitic capacitors

2.5.4.8 Interrogation field strength H_{MIN}

The results from the study of resonance in Section 2.5.3.6 can be used to find the minimum field strength H_{min} at which the voltage V_2 (voltage at the terminal L_2 in Figure 2.17 (of last resonance) is just high enough for the operation of the data carrier.

An expression for mutual inductance can be written using Equation 2-10 as follows:

$$M = \frac{\mu_0 H (I_1) N.A}{I_1} \tag{2-20}$$

Where;

$H (I_1)$ = Magnetic field strength due to current I_1. $H (I_1)$ can be replaced with H_{eff} which is the effective field strength of a sinusoidal magnetic field

μ_0 = permeability of free space

N = number of coil windings

A = cross-sectional area of the coil

I_1 = Current through the coil.

Since $H (I_1) = H_{eff}$, Equation 2-20 can be re-written as follows:

$$M = \frac{\mu_0 H_{eff.} N.A}{I_1} \tag{2-21}$$

Now replacing M in $j\omega.M\ I_1$ (Equation 2-19) with Equation 2-21, a new expression for the voltage V_2 is obtained, which is written as follows:

$$V_2 = \frac{j\omega.\ \mu_0.\ H_{eff.}\ A.\ N}{1 + (j\omega\ L_2 + R_2)\ (1/R_L + j\omega C_2)}$$

(2-22)

When multiplying the denominator the expression in equation 2-22 becomes:

$$V_2 = \frac{j\omega.\ \mu_0.\ H_{eff.}\ A.\ N}{j\omega\ (L_2/R_L + R_2C_2) + (1 - \omega^2\ L_2C_2 + R_2/R_L)}$$

(2-23)

Solving Equation 2-23, an expression for H_{eff} can be obtained which is expressed in complex form. The general case for this expression gives H_{MIN}. This is given in Equation 2-24:

$$H_{MIN} = \frac{V_2 \sqrt{\left(\frac{\omega L_2}{R_L} + \omega R_2 C_2\right)^2 + \left(1 - \omega^2 L_2 C_2 + \frac{R_2}{R_L}\right)}}{\omega.\mu_0.\ A.N}$$

(2.24)

From Equation 2-24 the following inferences can be made about the minimum field strength:

H_{MIN} depends on the frequency ($\omega = 2\Pi f$) of the operation of the RFID system, the area of the coil (antenna) A, the number of coil windings, N, the minimum input voltage V_2 and input resistance R_2.

For optimum functioning of the antenna, the resonant frequency of the tag should match that of the reader. This is not always possible as the tolerance factor in the manufacture of the tags tends to make them deviate from the resonant frequency. Also to account for anti-collision, (Section 2.5.6) the resonant frequency is always placed higher.

2.5.4.9 Energy range of transponder systems

This is the distance of a tag from the reader antenna at which there is just enough energy to operate the tag. This phenomenon can be determined by using Equation 3 and solving for x, where x is the distance from the centre of the reader antenna. For this calculation minimum field strength H_{min} is used.

The solved equation for x is given by Equation 2-25 [14, p.231].

$$x = \sqrt{\sqrt[3]{\left[\frac{I.N.R^2}{2.H_{MIN}}\right]^2} - R^2} \qquad (2\text{-}25)$$

2.5.4.10 Interrogation zone of readers

The interrogation zone of an RFID reader [7, p.80] refers to the area in which the reader has the ability to pick up the signals of an RFID tag. Up to this section all the calculations were made assuming that the tag is parallel to the antenna of the reader. This section examines the effects of tilting the angle of the transponder antenna with respect to the central axis of the coil.

Consider that V_O is the voltage induced on the coil and is perpendicular to the magnetic field. Then the voltage when the coil is at an angle θ will be $V_{O\theta}$, which is given by; [7, p.80]:

$$V_{O\theta} = V_O .\cos(\theta) \qquad (2\text{-}26)$$

Where;

θ = 90°, cos 90° = 0 and therefore $V_{O\theta} = 0$.

The antenna radiation patterns with the angle of the tag at $\theta = 0$ and θ = 90° is shown in Figure 2.20.

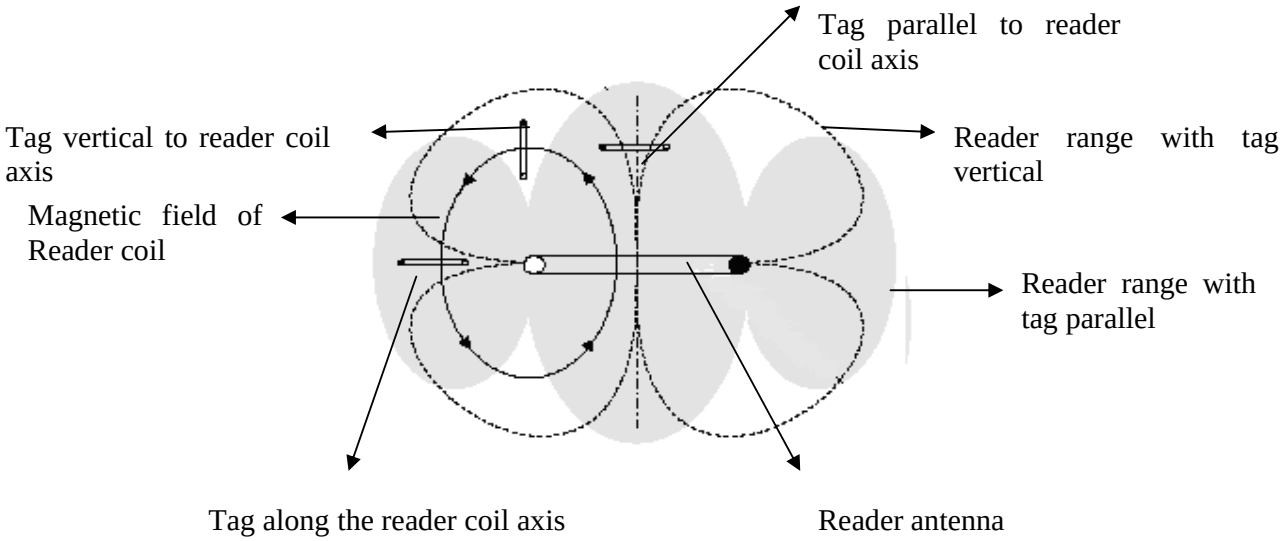


Figure 2.20: Reader range for different tag positions

(From: RFID Handbook, K. Finkenzeller)

2.5.5 Operation of RFID

The last section introduced the physics behind the operation of RFID systems. This section investigates the modes of communication between a tag and the reader, the types of modulation used in RFID data transfer, the types of encoding, and the different ways of sending and receiving information.

2.5.5.1 Communication modes in RFID

There are mainly three ways in which a tag and reader can communicate. These are the full duplex, half duplex and sequential modes of communication.

Full duplex communication: In this mode data transfer between the reader and the tag occurs at virtually the same time [13, p.55]. The RFID reader provides an uninterrupted power

supply to the tag. The data transfer from the tag to the reader can either be sub-harmonic or enharmonic.

Sub-harmonic data transmission occurs when the tag transfers data at a fraction of the frequency of the reader frequency. An example of this is when the reader transmits at 128 kHz and the tag chooses to transfer data at 64 kHz (which is half the reader frequency) [7, p.41].

Enharmonic data transmission occurs when data transmission between the tag and the reader does not depend on a particular frequency and can occur virtually at any time as long as power is supplied to the tag by the reader [7, p.41].

The functioning of a full duplex system is given in the block diagram in Figure 2.21.

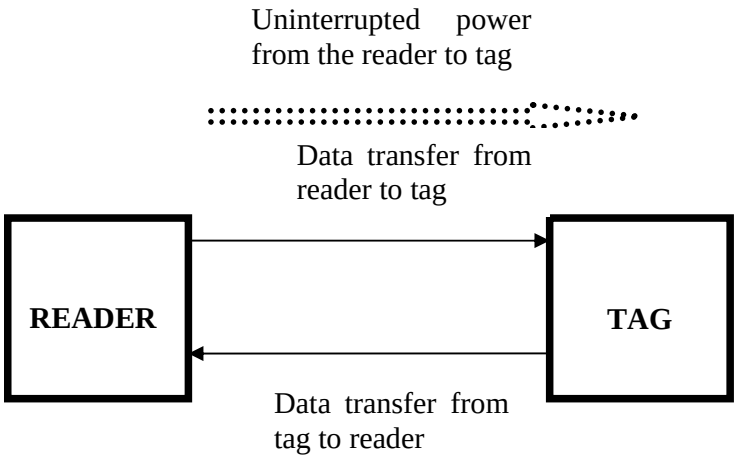


Figure 2.21: Full duplex system

Half duplex communication: In this mode either the reader or the tag transfers data at a given time [13, p.56]. The power supply from the reader is uninterrupted as in the case of full duplex systems. The transmission is such that the reader transmits a packet of data first, and then during the interval between the end of the first packet of data and the start of the second packet of data, the tag responds to the first packet of data. The half duplex mode of data transmission is shown in Figure 2.22.

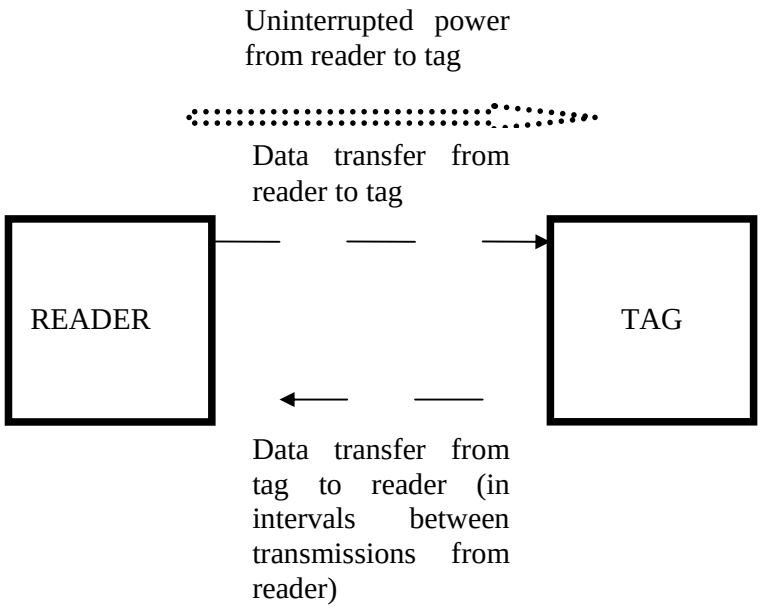


Figure 2.22: Half duplex operation. Note the data transmission interval between the tag and the reader

Sequential mode of communication: This is a mode of communication in which the power supply from the reader to the tag is pulsed or interrupted [13, p.57]. The reader transmits data

to the tag at the same time as power is transmitted to the tag. The tag has circuitry with a capacitor, which retains the power from the reader and uses it for data transmission once the reader has transmitted its data. The sequential mode of communication is shown in Figure 2.23.

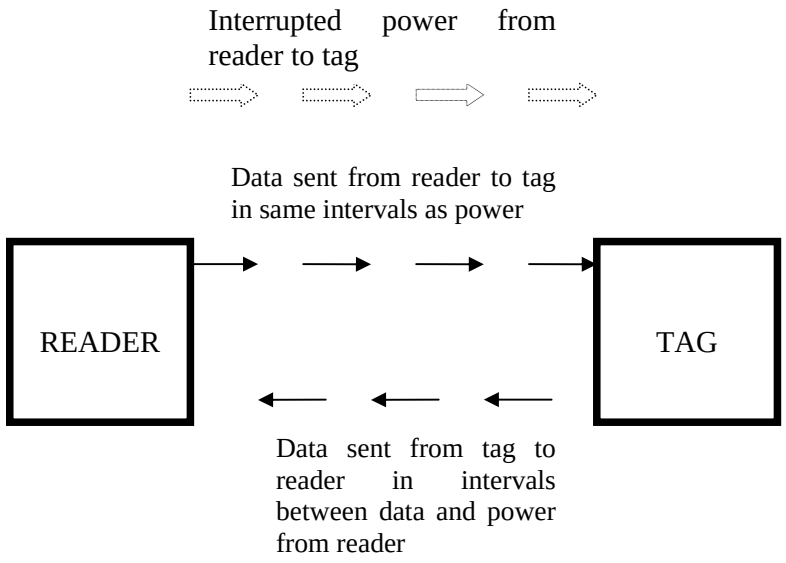


Figure 2.23: Sequential mode of communication

2.5.5.2 Types of modulation used in RFID

The antenna in an RFID system radiates energy into the surrounding area in the form of radio waves. A data signal can be modulated by influencing the amplitude, frequency or phase of the data signal. The process is referred to as modulation or keying.

Three types of modulation are used in RFID systems, namely Amplitude Shift Keying (ASK), Phase Shift Keying (PSK) and Frequency Shift Keying (FSK). This section examines these three types of modulation or keying.

Amplitude Shift Keying (ASK): This is a type of keying in which the amplitude of the data signal is varied [42] (keeping frequency and phase constant) to produce a modulated signal.
An ASK signal is generated by multiplying the data signal by a carrier signal using a mixer. Figure 2.23 shows exactly how this is done. A mathematical explanation [15, p.180] is given in 2.27 and 2.28

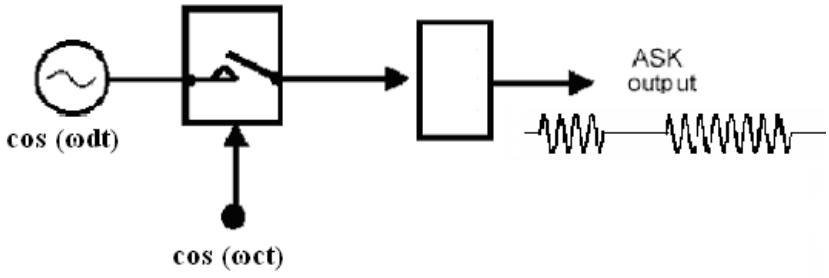


Figure 2.24: ASK mixer

(From: RFID Handbook, K. Finkenzeller)

In Figure 2.24:

The data signal = cos (ωdt)

The carries signal = cos (ωct).

When the two signals are mixed, the following result is obtained as per the trigonometric product to Sum formula:

$$\cos A.\cos B = \tfrac{1}{2}\cos(A-B) + \tfrac{1}{2}\cos(A+B). \quad (2\text{-}27)$$

Applying this to the ASK mixer, the following result is obtained:

$$\cos(\omega dt).\cos(\omega ct) = \tfrac{1}{2}\cos(\omega d-\omega c)t + \tfrac{1}{2}\cos(\omega d+\omega c)t. \quad (2\text{-}28)$$

The terms $(\omega d-\omega c)$ and $(\omega d+\omega c)$ represent the lower and upper sidebands of the ASK wave, respectively. The mathematical analysis is done to show that the bandwidth obtained by a modulated ASK signal is twice that of the original data signal.

Frequency Shift Keying (FSK): This form of modulation changes the frequency parameters (keeping voltages and phase constant) [15, p.181-186] of the data signal by multiplying them by a carrier wave with a different frequency.

There are two methods of generating FSK signals. The first and obvious method is by switching between two different frequency sources using a mixer. The disadvantage of this method is that it results in a phase discontinuity.

The second method overcomes the disadvantage of the first method. A Voltage Controlled Oscillator (VCO) is used. The VCO gives a frequency change that is linearly proportional to the applied voltage. Therefore when a data signal is multiplied by an output from a VCO, the output will be a continuous waveform.

Phase Shift Keying (PSK): A PSK output is generated by varying the phase of the data signal [15, p.187]. This is done by switching the data signal with an in-phase (0°) and out-of-phase (180°) signal.

2.5.5.3 Data coding in RFID

After modulating, the data signal has to be encoded. Encoding [13, p.67] is done mainly for security reasons. The RFID reader and the tag have to agree on a similar coding technique so that the transmitted data will only be decoded by a specific reader that knows the encoding technique used by the tag.

Some of the different coding techniques used in RFID are discussed in this section, followed by a graphical representation of each code with respect to a data signal and a clock.

Non-Return to Zero (NRZ) coding: In this method a binary 1 is represented as one significant condition (logic level high) and a binary 0 is represented by a logic level zero [9, p.101].

Manchester encoding: This method is self-clocking. The level changes always occur in the middle of a clock cycle. A binary 0 is translated into a low-to-high transition (0 to 1) and a 1 is translated into a high-to-low transition (1 to 0). This type of coding is also called split-phase coding [9, p.101].

Miller coding: In this method a binary 1 is represented by a transition. The transition can either be low-to-high or high-to-low and occurs in the middle of a clock cycle [7, p.185]. A binary 0 is represented by a continuation of the 1 over the next clock cycle. This type of coding is also known as Miller sub-carrier encoding.

FMO coding: In this coding a transition occurs at the beginning of each clock cycle. A binary 1 is represented by no transition in the middle of the clock cycle. A binary 0 is represented by an additional transition in the middle of the clock cycle [16, p.41]. The FMO coding is also called bi-phase space encoding.

Uni-polar RZ coding: A binary 1 is represented by a high logic level during the first half of the clock cycle and a binary 0 is represented by a low logic level for the duration of the clock cycle[9, p.102].

Differential coding: A binary 1 changes the logic level and a binary 0 causes no change in the logic level [7, p.185].

The data coding techniques explained in this section are shown diagrammatically in Figure 2.25.

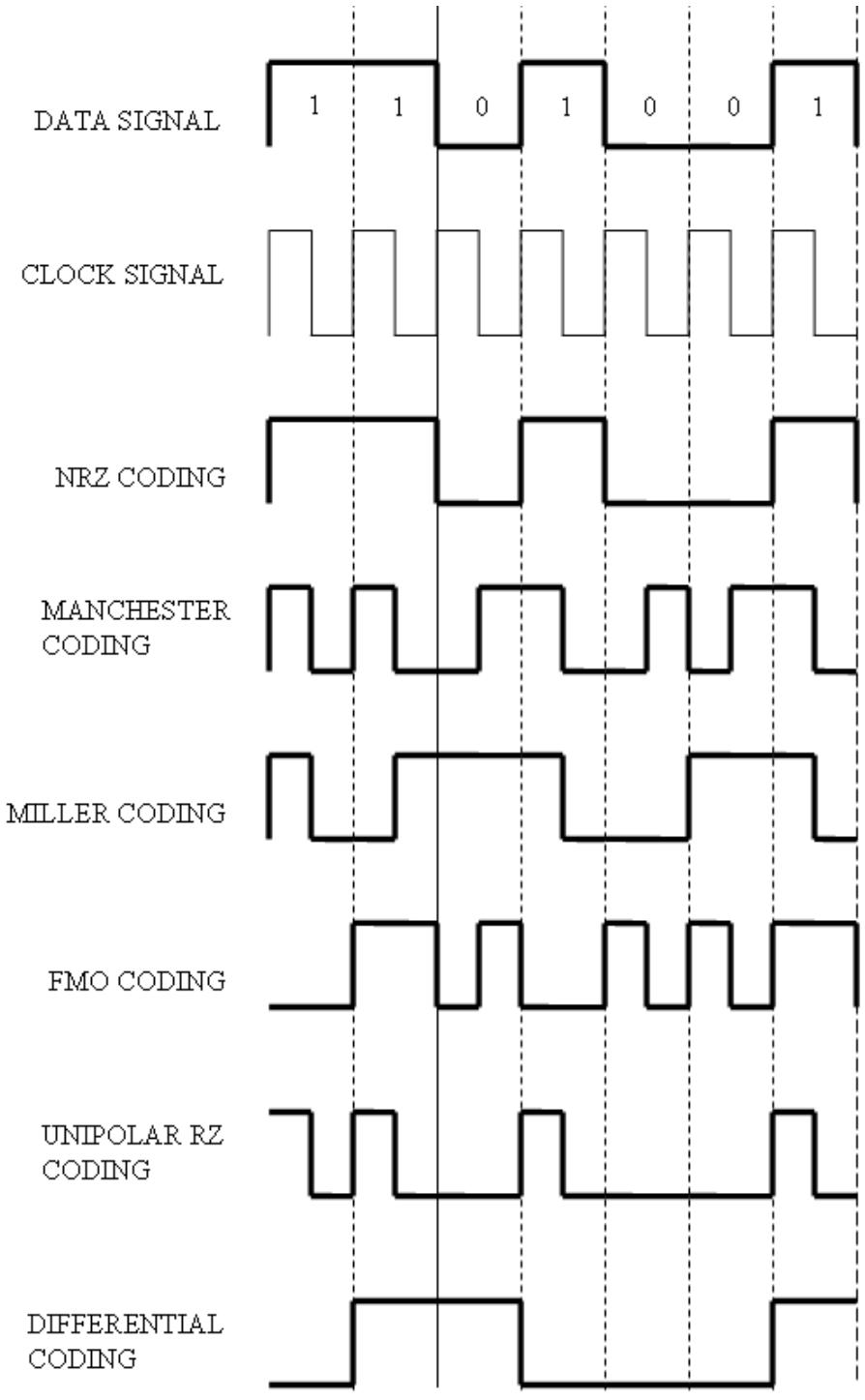


Figure 2.25: Digital coding techniques

2.5.5.4 Coupling mechanisms in RFID

The coupling mechanism used by an RFID tag determines the way a circuit on the tag and the RFID reader influence each other to send and receive information. Based on the read range created between the reader and a tag, there are three types of coupling: vicinity coupling, close coupling and long-range coupling.

In close coupling [7, p.49] the read range between the tag and the reader is within 10 mm. Examples of close coupling are capacitive and magnetic coupling.

In vicinity coupling [7, p.57] the read range is between 10 mm and 1000 mm. This type of coupling is also called remote coupling. Inductive coupling is an example of vicinity coupling.

Long-range coupling [6, p.240] offers the highest range of all the coupling methods. The range extends beyond 1 000 mm. Backscatter coupling is an example of long-range coupling.

Magnetic coupling: In this close coupling method [7, p.49] the reader and the tag are very close to each other. If the tag is placed within the alternating field of an RFID reader, the tag draws energy from the magnetic field which powers the tag.

A load resistor placed at the tag can be switched on or off in the tag, which will result in a fluctuation in the magnetic field generated by the reader. This will result in voltage changes in the reader antenna.

This voltage change effectively works as amplitude modulation. If the timing of the load resistor is controlled by the data present in the tag, then data can be transferred from the tag to the reader. This type of data transfer is referred to as load modulation.

Capacitive coupling: This is the second type of close coupling [7, p.49]. For the operation of this type of coupling the tag has to be inserted into the reader. A property of an RFID system that functions using capacitive coupling is that antennas are replaced by electrodes.
When the tag is inserted into the reader slot, the electrodes of the reader and the tag come very close together, forming a capacitor. As with magnetic coupling, data can be transferred using load modulation in capacitive coupling.

Inductive coupling: This coupling is used in the RFID system for this project. The tag is powered in the same manner as in magnetic coupling. The tag comes into the magnetic field of the reader, and by induction transfers power to the microchip in the tag. Inductive coupling is also referred to as transformer coupling [9, p.96] [7, p.41].

Data transfer is carried out by using load modulation but with some differences. Inductive coupling uses three main methods to transfer data from the tag to the reader. The first of these methods is called the sub-carrier method [7, p.42]. In this method the tag rapidly switches its load resistor on and off. This results in two different frequencies being generated, which are different from the operating frequency of the reader.

These two frequencies generated by the reader are called sub-carrier frequencies. Data are transferred by modulation with either of the sub-carrier frequencies.

The second method of data transfer is called the sub-harmonic method [7, p.36]. The tag splits the operating frequency of the reader by an integral value and transmits data back to the reader at this frequency.

The third method of data transfer in an inductive system is called sequential data transfer [7, p.41]. Here the power from the reader to the tag is not continuous, so the tag contains a capacitor circuit which stores the power from the reader when it comes within the magnetic field generated by the reader.

The tag also contains an oscillator circuit to create its own magnetic field. Since the reader is powered down at this stage, it is able to detect the field generated by the tag and transfer data. In this method Frequency Shift Keying is used for transferring data.

The first two methods of data transfer in inductive coupling are full duplex methods while the last is a sequential method. These methods were discussed in Section 2.5.5.1.

Backscatter coupling method: In this type of coupling the tags contain a photovoltaic cell, which is powered by the energy (field generated from the magnetic field) of the RFID reader. The power generated in this manner gives backscatter coupling the longest range [9, p 101] of all three couplings discussed in this section.

The tag also contains a load resistor at its output as explained previously in the discussion on coupling methods. The tag communicates back to the reader using the same frequency by switching the load resistor on or off.

The tag is continuously powered by the reader, but the communication between the tag and the reader is in intervals. The reader sends a request and the tag replies once the data from the reader have been sent. This makes backscatter coupling the best example for half duplex communication (Section 2.5.5.1) in RFID. An interesting fact about backscatter coupling is that it uses the same frequency to power the circuitry as well as transfer data, unlike in close and vicinity coupling.

2.5.6 Collision and Anti-Collision Procedures in RFID

Collision in an RFID system [17, p.139] can be best explained with an example. The example used is a possible scenario in an RFID application where the read range exceeds 15 cm. RFID systems having read range less than 10 cm are not affected by anti-collision as only one user can be scanned at time.

Suppose a reader is placed in a classroom to register attendance of students entering a class. If a group of students pass the reader with their student cards (tags) at the same time, the RFID reader may be confused as to which card to read first. It would be even worse if one of the tags were not read. This undesirable situation is referred to as collision in RFID.

The seriousness of this problem is such that anti-collision procedures have been put in place to counter and thereby reduce collision. This section examines some of these procedures and explains how collision is minimised in an RFID system.

There are two types of anti-collision procedures in use:

- Reader anti-collision algorithm
- Tag anti-collision algorithm.

2.5.6.1 Reader anti-collision algorithm

To counter collision, the reader has to communicate with all tags that come within the read range within a short space of time. This type of communication is referred to as multi-access. Multi-access is diagrammatically represented in Figure 2.26. Some multi-access procedures that are used in RFID systems are described in this section. They are:

- Space Division Multiple Access (SDMA)
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)

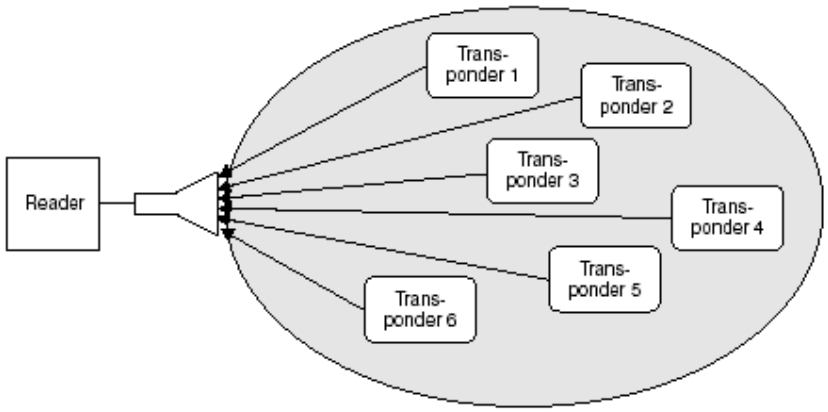


Figure 2.26: Multi-access procedures in RFID systems

(From: RFID Handbook, K. Finkenzeller)

Space Division Multiple Access (SDMA): This multi-access procedure is implemented in RFID by re-using the channel capacity [7, p.202] of the readers that are separated by distance.

This is implied in a real-life RFID system by combining several readers and aligning them in such a way that the net read range is vastly increased. Therefore the tags communicating with the reader will be differentiated based on their angular frequency.

A practical implementation of SDMA is to use a reader with an electronically controlled directional antenna. This is shown in Figure 2.27.

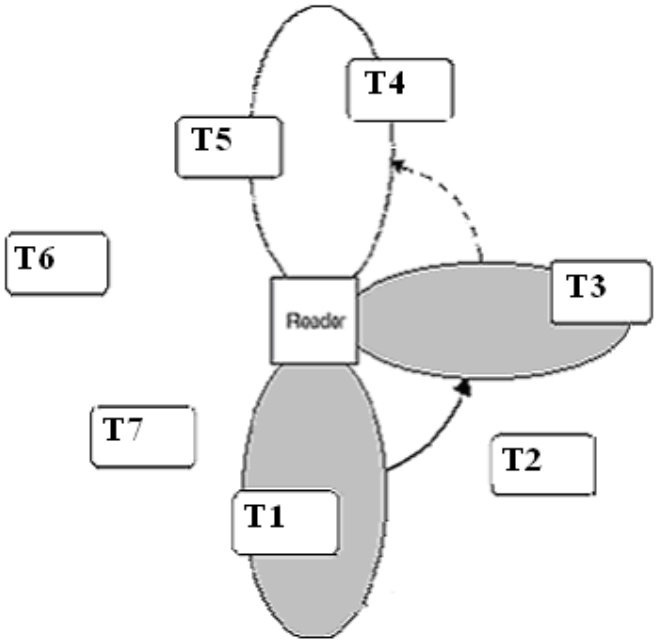


Figure 2.27: Reader with electronically controlled directional antenna

(From: RFID Handbook, K. Finkenzeller)

(The beam of the antenna shifts position so as to accommodate as many tags as possible).

SDMA is rarely used in RFID systems due to the complexity of the system and the high implementation cost.

Frequency Division Multiple Access (FDMA): This is another multi-access procedure that allows a certain number of tags to communicate with the reader using several channels [7, p.204] on various carrier frequencies.

In an RFID system this is achieved by constructing a reader with a dedicated receiver for every channel. This is shown in Figure 2.28.

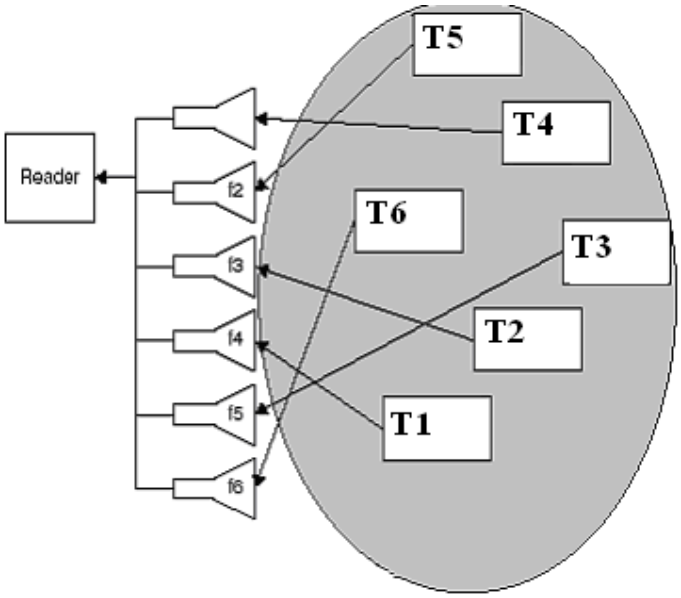


Figure 2.28: FDMA procedure

(From: RFID Handbook, K. Finkenzeller)

The available RF bandwidth is split into different frequencies. The RFID reader is split into receivers, each of which is suited for a certain frequency. The RFID tags will also be allocated corresponding transmission frequencies. Once the tag comes within the range of the reader, it can respond on any of the available frequency channels in the frequency range.

The cost of producing such readers is very high, and therefore the FDMA technique is very seldom used in RFID anti-collision procedures.

Time Division Multiple Access: This technique is the most widely used (including in this project). The available RF channel for data transfer is split by the reader into unique time slots [7, p.205]. The time slot is allocated to each tag present in the channel. This process is better explained under the heading “tag anti-collision procedures”.

2.5.6.2 Tag anti-collision algorithms

The tag, like the reader, also has anti-collision algorithms which prevent collisions with other tags and allow effective communication with the reader. There are many variations of tag anti-collision procedures in use, but in the context of this project, only two types of algorithms are explained:

- ALOHA procedure
- Tree linking procedure.

ALOHA procedure: The ALOHA procedure is divided into two parts, Simple ALOHA (or ALOHA as it is called) [13, p.87] and the Slotted ALOHA procedure [7, p.200]. Slotted ALOHA is a modification made to improve the ALOHA procedure.

Simple ALOHA anti-collision algorithm: In this procedure, a tag starts transmitting data as soon as it is in the read range of the reader. If another tag transmits at the same time, an overlap of data occurs. This results in either a complete or partial collision. When a collision occurs, each tag is given a waiting time. After the waiting period has expired the tags re-send

the data once again. The procedure continues until all tags have successfully transmitted their respective data

This method is quite convenient if there are only a few tags. But if the number of tags in the field increases, the chance of collision increases. Furthermore, the waiting period for retransmission then also increases. Overall the efficiency of the Simple ALOHA procedure is heavily compromised as a result of the waiting period. A flow chart of the functioning of the Simple ALOHA procedure is shown in Figure 2.29.

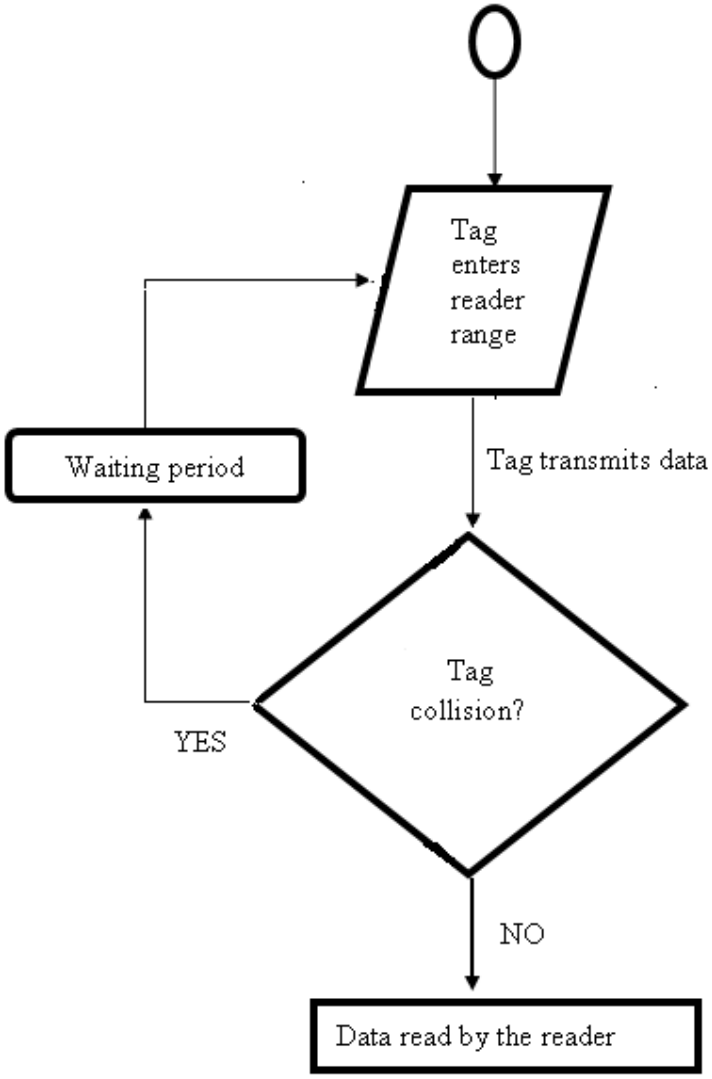


Figure 2.29: Flowchart of the simple ALOHA procedure

The diagram in Figure 2.30 shows the functioning of the simple ALOHA procedure.

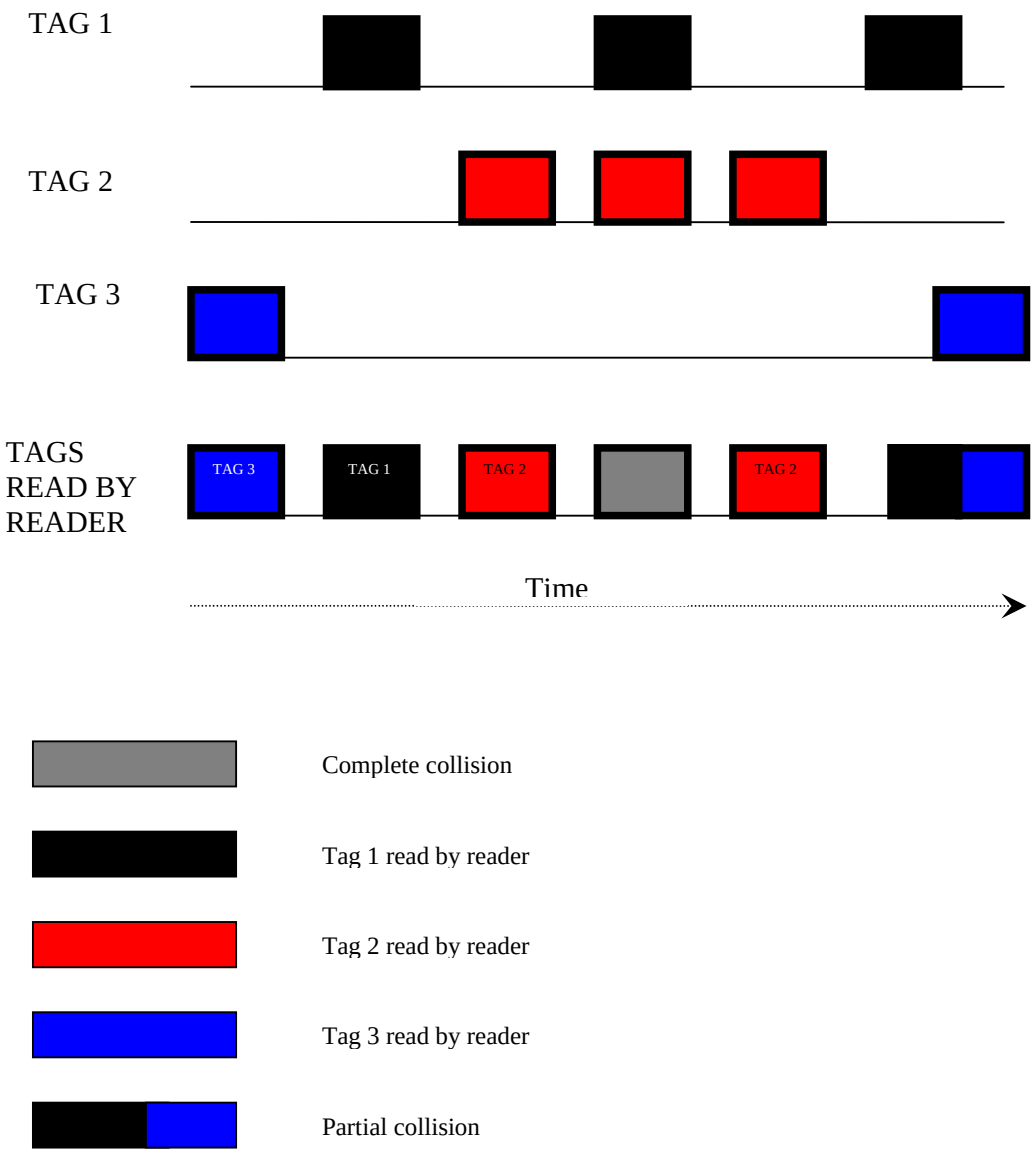


Figure 2.30: Functioning of the simple ALOHA procedure

Slotted ALOHA procedure: This method is used to overcome the disadvantages of the Simple ALOHA procedure. It uses three commands to sort tags, REQUEST, SELECT and READ.

The REQUEST command provides different time slots for all the tags within the read range to communicate with the reader. Based on availability, each tag selects an offered time slot. The tags then transmit their unique ID during the selected time slot.

Upon receiving the ID and making sure there are no collisions at this time, the reader issues the SELECT command for a specific ID using a pseudo-random code generated within the reader. This command basically selects a tag to transmit its data.

Once the tag has been selected, the reader issues a READ command. The READ command instructs the tag to transfer the data it contains. The tag complies with this instruction. After the data are transmitted, the reader discontinues the communication with this specific tag.

The procedure is repeated for all the tags in the field. The main advantage of the slotted ALOHA procedure is that it completely avoids partial collisions that occur in the simple ALOHA procedure. The slotted ALOHA procedure overcomes the disadvantages of the simple ALOHA technique.

The slotted ALOHA procedure is also adaptive, i.e. if there are fewer tags it uses fewer time slots (faster data transfer), and if there are many tags it uses a greater number of slots (fewer collisions). This increases the overall efficiency of the algorithm. Figure 2.31 shows the flow chart used for the slotted ALOHA procedure.

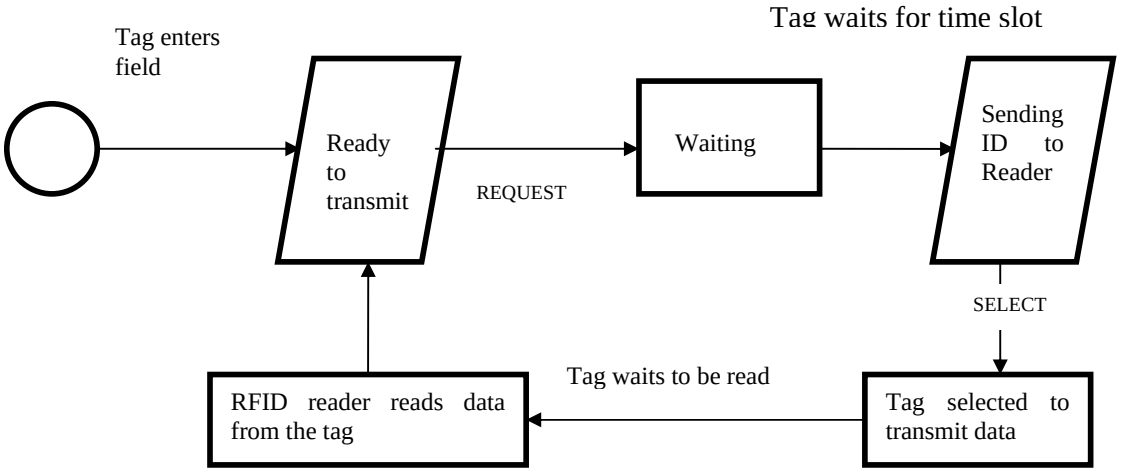


Figure 2.31: Flow chart of the slotted ALOHA procedure

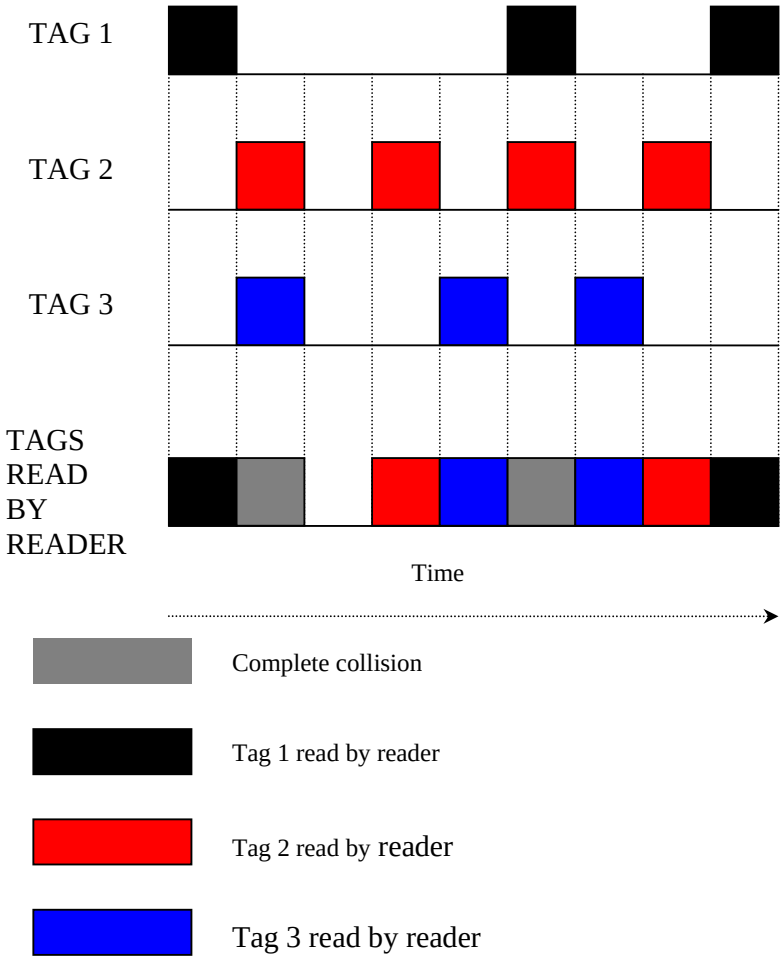


Figure 2.32: Functioning of the slotted ALOHA procedure

Tree walking procedure: The ALOHA procedure is used in high-frequency systems typically operating at 13.56 MHz. For ultra-high-frequency applications, typically between 860 and 915 MHz, the tree walking [6, p.437] procedure is used. (The various frequencies used in RFID are discussed in Section 2.5.7.)

This is a more deterministic scheme which uses a process called ‘singulation’. ‘Singulation’ [13, p.87] is the means whereby an RFID reader identifies a tag with a specific serial number (tag ID) from a number of tags in the read range of the reader.

Depending on the number of bits in the ID number of the tag, a tree can be drawn. The tree will contain as many branches as the number of bits in the tag ID. If a tag ID has 4 bits, then the tree will have four branches.

The RFID reader searches the entire length of the tree to identify the tag with the specific ID number, starting at the top and proceeding to the bottom depending on where the tag is. Once the tag has been located, data are transferred from the tag to the reader. This is shown in Figure 2.33. Here the tag contains 5 bits. Suppose the tag ID that needs to be searched is 10110. The red dots indicate the path followed in the binary search to reach tag 10110.

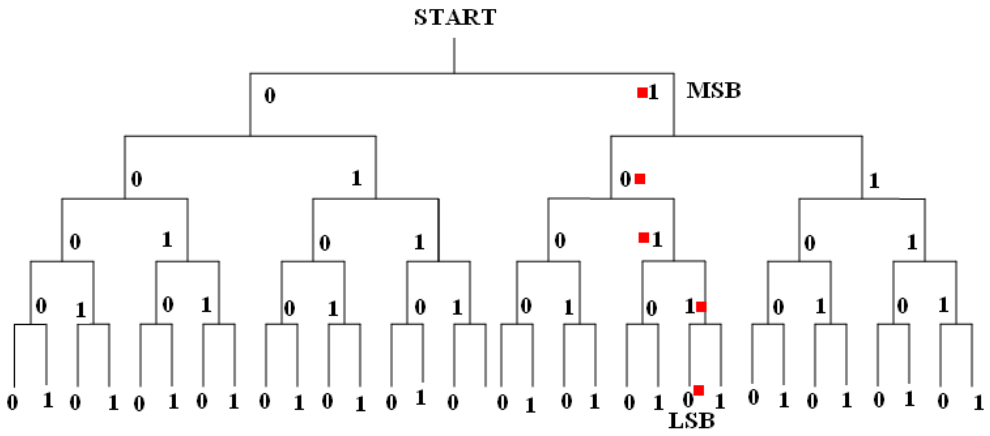


Figure 2.33: Binary search algorithm for a tag with 5-bit ID

The major disadvantage of this method is that the querying approach makes data highly susceptible to eavesdropping (discussed in Section 2.5.8: Data Security in RFID), i.e. any system can access the data from this system.

2.5.7 Frequency Ranges used in RFID

The discussion thus far has made clear the importance of radio waves in the functioning of an RFID system. This section analyses the electromagnetic spectrum with respect to RFID in more detail.

There are mainly four frequency ranges [6, p.437] used by RFID. They are low frequency (LF), high frequency (HF), ultra-high frequency (UHF) and microwave frequency. Not all frequencies in these ranges are used in RFID, as some have already been allocated for other purposes. The frequency used in RFID is in the Industrial, Scientific and Medical (ISM) band.

The applications of an RFID reader also vary with operating frequency. Table 2.2 shows the frequency ranges used in RFID. It also shows the applications at the various frequencies.

Table 2.2: Frequency ranges used in RFID

Frequency Range	Common frequencies used in RFID	Typical application	Max. read range (theoretical)
LF - low frequency (30 to300 kHz)	30 kHz 125 kHz 135 kHz 300 kHz	Access control Animal identification Lot identification Chemical distribution	500 mm
HF - high frequency (3 to 30 MHz)	3.0 MHz 13.56 MHz 30.0 MHz	Warehouse management Tracking and monitoring Baggage checking Library management Parcel tracking Security	Up to 100 mm

		applications	
UHF – ultra-high frequency (300 MHz to 1 GHz)	300 MHz 433 MHz 866 MHz (Europe) 915 MHz (USA)	Retail vendors Toll roads Warehouse logistics Long-range applications	4 metres
Microwave frequency > 3 GHz	2.45 GHz 3.0 GHz	Long-range applications Freight tracking	6-10 metres

2.5.7.1 Standardisation in RFID

Standardisation in RFID [6, p.89] refers to the regulatory codes set by an international body for all products. Standards ensure a minimum level of product characteristics such as quality, interoperability, reliability and safety for the end user.

RFID technology and RFID systems rely heavily on the electromagnetic spectrum for communication, as previously discussed in this chapter. Therefore it is essential that RFID devices (readers and tags) should adhere to specific standards in the countries in which they are used.

The international bodies that set and monitor the standard for RFID technology are ISO (International Standards Organization) and IEC (International Electro technical Commission). These bodies are usually supported by a local body in the country in which the RFID products are used. In South Africa (where the study for this thesis was done) the body responsible is ICASA (Independent Communications Authority of South Africa).

There is much data pertaining to these ISO standards. Some are still being prepared at present, and others undergo constant scrutiny and changes. Therefore this section only gives

the essence of the relevant standards. However, the two standards employed in the RFID product used in this project, ISO 14443 and ISO 15693, are treated in depth.

2.5.7.1.1 Standards for animal identification

The standards used for animal identification [6, p209] are ISO 11784, ISO 11785 and ISO 14223.

The *ISO 11784* [7, p229] standard gives the code structure for radio frequency identification of animals. Basically the identification code in the tags for animal identification consists of 64 bits. Each of these bits (or block of bits) describes a certain function.

ISO 11785 [7, p.230] is the second standard for animal identification. It deals with the reader frequency (134 kHz ± 1.8 kHz) and the operation of the RFID system in full/half duplex and sequential mode.

ISO 14223 [7, p.233] is the third standard in animal identification. It defines the high-frequency (HF) interface and data structure of active transponders. It consists of three parts:

- Part 1 - Air interface
- Part 2 - Code and command structure
- Part 3 - Application details

2.5.7.1.2 Standards for smart cards

This is the major area of concern as far as this project is concerned. The standards discussed in this section concern the tags and reader used in this project. Three standards are defined under this heading: ISO 10536 [7, p.237], ISO 14443 [9, p.195] and ISO 15693 [9, p.204].

ISO 10536 defines the standards for close coupling of smart cards. RFID systems adhering to this standard have a range of up to 10 mm. The standards are subdivided into four parts.

Part 1 - **Physical characteristics**: These define the mechanical dimensions and physical properties of close-coupling cards.

Part 2 - **Dimensions and locations of coupling areas**: In close-coupling techniques (Section 2.5.5.3) antennas are replaced with electrodes. This part specifies the position and dimensions of the coupling elements.

Part 3 - **Electrical signals and reset procedures**: This part defines how the close-coupled cards are powered, how data are transferred from card to reader (the magnetic and capacitive coupling techniques used) and how data are transferred from reader to card (including the modulation and data coding).

Part 4 - **Answer to reset transmission**: This deals with the transmission protocols used in data transfer. This section is still in preparation by ISO.

ISO 14443 defines the standards for proximity-integrated coupling cards. RFID systems which follow this standard have a range of up to 100 mm. It should be mentioned that the RFID reader used in this project conforms to the ISO 14443 standard. This standard also has four parts.

Part 1 - **Physical characteristics**: The dimensions of smart cards are defined in the ISO 7810 standard. The dimensions are 85.72 mm × 54.03 mm × 0.76 mm ± tolerances. This part of the standard also includes notes on the testing of dynamic bending stress, dynamic torsion stress, irradiation with UV, and X-ray and electromagnetic radiation.

Part 2 - **Radio frequency interference**: This part defines how the smart card is powered by the reader which operates at 13.56 MHz. It also defines the means to determine the range of the reader. The range of a reader can be determined if the interrogation field strength, H_{min}, is known (Section 2.5.4.7).

In the ISO 14443 standard the magnetic field generated by the reader must be within the range $1.5 \text{ A/m} \leq H \leq 7.5 \text{A/m}$. This means that $H_{min} \leq 1.5 \text{ A/m}$.

If the field strength curve of a reader and the interrogation field strength are known, the range of the reader can be calculated. A typical field strength curve is given in Figure 2.34. The parameters in the equation for interrogation field strength used for

drawing the curve are as follows: antenna current, I = 1A, antenna diameter, D = 150 mm, number of windings, N = 1.

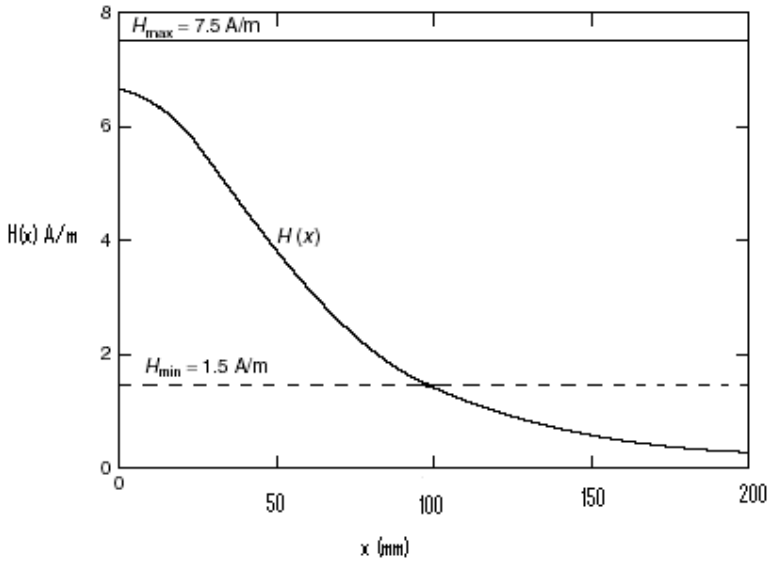


Figure 2.34: Field strength curve for a proximity-integrated circuit card

(From: RFID Handbook, K. Finkenzeller)

If H_{min} = 1.5 A/m, then it is clearly shown by Figure 2.34 that the H_{min} line cuts the curve at 100 mm, thereby proving that the range of the reader is about 100 mm.

A common communication interface could not be developed for the ISO 14443 standard, so two types of smart card are used in this instance. They are TYPE A and TYPE B smart cards. The ISO 14443 standard supports communication with both types of card.

Part 3 - **Initialisation and anti-collision**: This part of the standard defines the modulation, data-coding procedures, baud rates and anti-collision procedures used in both TYPE A and TYPE B smart cards. Table 2.3 summarises the data transfer between reader and smart card for both TYPE A and TYPE B cards. Table 2.4 details the same for data transfer from card to reader.

Table 2.3: Data transfer parameters between reader and smart card

FACTORS	TYPE A	TYPE B
Modulation	ASK 100%	ASK 10%
Data coding	Miller coding	NRZ coding
Synchronisation	At bit level	1 start and 1 stop bit per byte
Baud rate	106 kBd	106 kBd
Anti-collision mechanism	Tree walking procedure (binary search tree algorithm	Slotted ALOHA procedure

Table 2.4 shows the modulation and coding procedures for data transfer between reader and card.

Table 2.4: Modulation and coding procedures for data transfer between smart card and reader

FACTORS	TYPE A	TYPE B
Modulation	Load modulation with sub-carrier 847 kHz, ASK modulated	Load modulation with sub-carrier 847 kHz, BPSK modulated
Data coding	Manchester coding	NRZ coding
Synchronisation	1 bit frame synchronisation	1 start and 1 stop bit per byte
Baud rate	106 kBd	106 kBd

Part 4 - **Transmission protocols**: This part of the standard lists the commands for reading, writing and processing data from the reader to the card. It also describes the structure of the data protocol used for processing transmission errors.

ISO 15693: This is the standard for vicinity-integrated coupling cards. These cards have a range exceeding 1 m and are used in access control. This standard also has four parts.

Part 1 - **Physical characteristics**: This part is similar to the ISO 14443 and ISO 10536 standards. It conforms to the ISO 7810 standard.

Part2 – **Air interface and initialisation**: This part defines the modulation, bit coding and baud rate. These differ for data transfer from reader to smart card and data transfer from smart card to reader, and are summarised in Tables 2.5 and 2.6.

Table 2.5: Modulation and coding procedures for data transfer between reader and card

FACTORS	VALUE
Modulation	10% ASK,100% ASK
Data coding	1 of 256 and 1 of 4
Baud rate	1.65 Kbit/s and 26.48 Kbit/s

Table 2.6: Modulation and coding procedures for data transfer between smart card and reader

FACTORS	VALUE
Modulation	Load modulation with sub-carrier

Data coding	Manchester encoding
Baud rate	6.62 Kbit/s and 26.48 Kbit/s

Part 3 - **Protocols** and Part 4 - **Registration of Applications** are still being prepared by the governing bodies. Therefore they cannot be detailed at this point in time.

2.5.7.2 Container identification

The ISO standard defines the standard used in the identification of containers using active tags. These tags use microwave transponders. These are activated by unmodulated carrier frequencies ranging from 850 to 950 MHz and from 2.4 GHz to 2.5 GHz. The tags use backscatter coupling (Section 2.5.5.3) for data transmission via FSK modulation.

2.5.7.3 Item management

This is the standard used in item management, especially warehouse management. The standard used is ISO 18000 [7, p.268]. The standard consists of six parts:

Part 1 - Generic parameter for Air Interface Communication for Globally Accepted Frequencies

Part 2 - Parameters for Air Interface Communication below 135 kHz

Part 3 - Parameters for Air Interface Communication at 13.56 MHz

Part 4 - Parameters for Air Interface Communication at 2.45 GHz

Part 5 - Parameters for Air Interface Communication at 5.8 GHz

Part 6 - Parameters for Air Interface Communication – UHF frequency band

2.5.8 Data Integrity in RFID

As RFID involves data transfer using contactless technology, it is highly probable that some form of interference may occur during data transfer. It is essential for the proper functioning

of an RFID system that the data being transmitted (from tag to reader or vice versa) should not contain any errors. In other words, the integrity of the data should be maintained.

This section examines the different methods used for maintaining data integrity in RFID. This can be done by using checksum procedures. Three main types of checksum procedures are used in RFID: the parity checking method [7, p.195], the Longitudinal Redundancy Check (LRC) method [7, p.196] and the Cyclic Redundancy Check (CRC) method [7, p.197].

2.5.8.1 Parity checking method

This is the simplest checksum method available. It is also called the Vertical Redundancy Check method (VRC). In this method a parity bit is assigned to each transmitted data bit. Before the data are transmitted, a decision is taken to check for either odd or even parity by the sender and receiver. This is done to maintain synchronisation between both parties (tag and reader in RFID).

If odd parity is used then there should be an odd number of 1's in the sent data bits, and if even parity is used then there should be an even number of 1's in the data bits received at the receiver end. A simple parity check method can be implemented using XOR (EX-OR) gates. XOR gates are basic adders. By adding the two binary inputs to an XOR gate, their sum is obtained.

If even parity (even number of 1's) is used the sum of the bits is always equal to zero, and if odd parity (odd number of 1's) is used the output of the XOR gate will be equal to 1.

The parity checking method can be explained by means of an example. Consider the code $C6_{16}$ which must be checked for even parity. The circuit given in Figure 2.35 can be used. $C6_{16}$ is written as 1100 0110 in binary. Since the total number of 1's is equal to four (which is even), the output of the circuit should be LOW (binary 0). If an error has occurred during data transmission, the parity changes to odd and the output will be HIGH (binary 1).

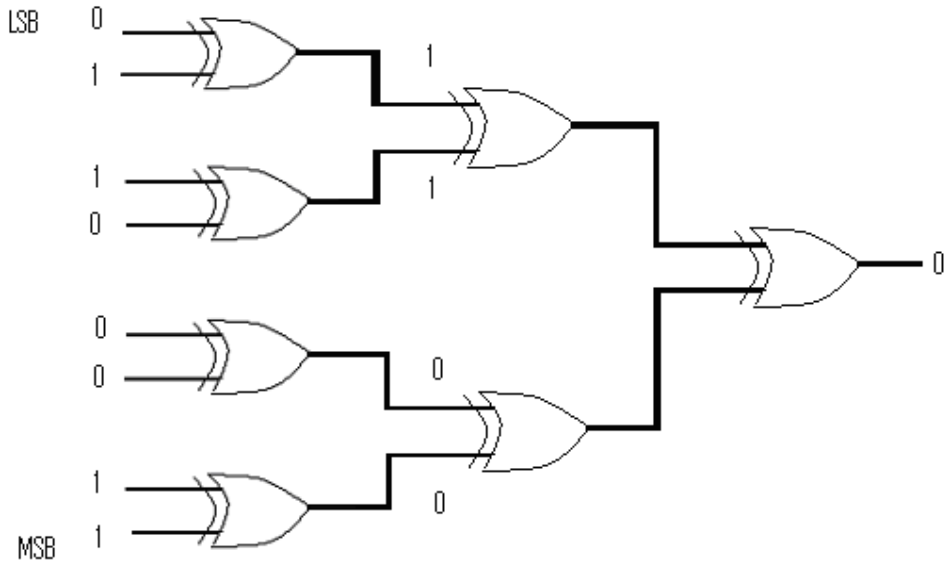


Figure 2.35: Parity checking method using sample data 1100 0110

Parity checking is the easiest method for checking data integrity, but it is the least preferred because if two errors occur simultaneously, then the errors cancel each other out. Therefore the chance of errors is not equal to one error.

2.5.8.2 Longitudinal Redundancy Check (LRC) procedure

This is another checksum procedure. This method is also called horizontal redundancy checking or cross-parity checking. In this method, not only the integrity of a single bit in transmitted data is checked, but the entire parity integrity of a group of characters.

Here the parity of the individual character in a data block is first found using the parity checking method. This is done for the whole data. The first parity bit is then XOR'ed with the next parity bit. This process is continued until the last parity bit is reached.

At the end an LRC bit is appended to the data block. The LRC bit when XOR'ed with the parity bits must generate a zero. The data byte, along with the appended LRC bit, is then transmitted. At the receiver the check is done again using an XOR gate circuit. If the final answer is zero then the data transmitted were indeed correct.

The LRC procedure can be explained by means of an example. Suppose a message 'HELLO' must be transmitted from the tag to the reader. The LRC method to check whether the correct data have appeared at the output is as follows:

Letters of message	**ASCII value**	**LRC parity**
H	1001000	0
E	1000101	1
L	1001100	1
L	1001100	1
O	1001111	1
LRC bit		0

The LRC method is used for very small data blocks, the reason being that with large data blocks multiple errors can occur which cancel out in the end and thereby give an incorrect data integrity check at the end.

2.5.8.3 Cyclic Redundancy Check (CRC) procedure

The Cyclic Redundancy Check is another technique for detecting errors in digital data. It does not correct the errors when detected. In the CRC method a certain number of check bits are appended to the data message that is to be transmitted. This is called the checksum.

The receiver checks whether the received checksum agrees with the checksum sent with the data when it is received. If an error has occurred during transmission, the receiver asks for a re-transmission of the data. The mathematical procedures and hardware implementations are similar to those discussed in the parity checking and longitudinal redundancy checking methods.

2.5.9 Security in RFID

Security is a vital aspect of any technology, none more so than in RFID technology. Since RFID involves contactless data transfer, it is highly prone to some security threats. This section discusses some of the possible security threats to RFID as well as measures against the threats.

2.5.9.1 Security threats in RFID

There are different types of security threats in RFID. Those analysed here are:

- Cloning
- Spoofing
- Eavesdropping.

Cloning: This type of threat arises when an 'attacker', posing as the reader, intercepts data from an RFID tag. The attacker then re-transmits the data. In this way the attacker abuses the RFID application by cloning [18, p.292-295] a genuine RFID tag.

This type of security threat is exemplified by automatic pay-points using RFID technology. The attacker can read and intercept an encrypted code from a tag using a reader which can read data from similar tags. Once the attacker has read the tag, he can re-transmit the data at the pay-point using the encrypted data, thus avoiding payment.

Spoofing: This type of threat arises when a foreign data carrier is placed within the interrogation zone of the reader with malicious intent [18, p.329]. If the security protocols of an RFID reader are known, the attacker can design a tag which follows similar security protocols and contains the same data as the original tag. This 'spoofed' tag can be used to gain access to an RFID-enabled room or building which is otherwise out of bounds.

Eavesdropping: All tags follow certain standards as explained in the study (Section 2.5.8). The readers are designed to capture data based on the standards followed by the tags. If the standards and protocols followed by a tag are known, the attacker can design a reader that can read data from a tag if the reader is brought within the data transfer range of the tag [18, p.283]. This is especially dangerous if the tag stores highly confidential data.

2.5.9.2 Overcoming security threats in RFID

The security threats mentioned in Section 2.5.9.1 can be overcome by using two methods: physical methods and technical methods.

Physical methods use certain physical parameters of RFID technology to create a barrier for unauthorised data access. Two methods are used here:

- The Faraday cage method
- The read range limiting method.

Faraday cage method: A Faraday cage [18, p.330] is an enclosure formed by a conducting material. Such an enclosure blocks external static fields. An external electric field on the conductor will cause the electric charges within the conducting material to re-align in such a way as to nullify the net electric field in the interior of the cage. This is shown in Figure 2.36.

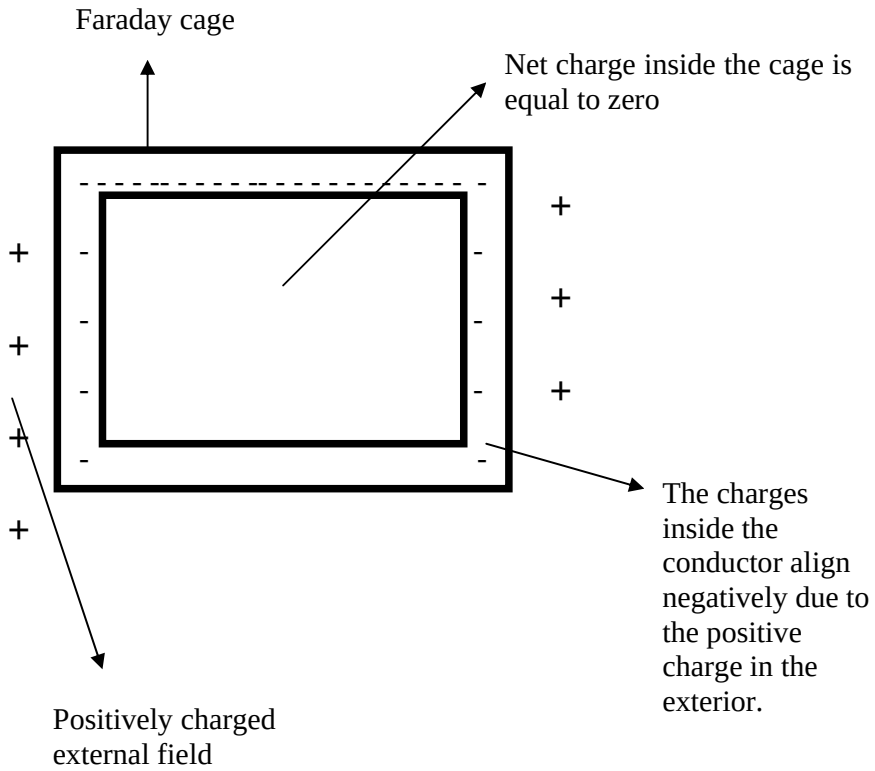


Figure 2.36: Faraday cage

A Faraday cage has the same effect on radio waves. The radio waves are unable to penetrate a Faraday's cage. Therefore if an RFID tag is placed inside a Faraday cage, the interrogation zone created by the reader will not have an effect on the tag and therefore data from the tag cannot be accessed.

This method requires the user to place the tag in a metallic enclosure at all times except when it is read by the authorised reader. The new American passports, which have embedded RFID tags, have metallic enclosures which shield them from unauthorised access.

A Faraday cage alone is not a very effective method to ensure RFID security. Therefore it is often incorporated with other security features such as encryption (discussed under technical security methods).

Read range limiting method: Most RFID fraud occurs when the attacker uses a tag to capture the data from a tag. If the read range of the tag is significantly reduced to a few centimetres, it would be practically difficult for an attacker to bring the RFID reader close enough to capture data from the tag.

This method reduces the cost of an RFID system, but offers minimal security as close monitoring by an individual is necessary to avoid malpractice. Therefore this method cannot be used for applications that store confidential data.

Technical methods of securing data in RFID use mathematical algorithms and electrical circuitry to prevent data from being accessed by unauthorised personnel. There are mainly four methods of accomplishing this:

- Kill command
- Blocking
- Mutual symmetrical authentication
- Encryption.

Kill command: The RFID tag not only transfers the data it contains, but acts as a transponder which allows it to be monitored from any given distance depending on the tag used. This is an advantage in the shipping industry where freight can be tagged and monitored from shore. But it becomes a major disadvantage and a security threat if the tag can be tracked without the knowledge of the user.

This can be better explained by an application of RFID in the textile industry [18, p.291]. Textile material can be tagged for keeping track of inventory at the time of fabrication. The same tag can be used in a retail store up to the point of sale. But after the point of sale, if the tag continues to be active, it poses a threat to the consumer as his/her whereabouts can be tracked by an attacker with a reader.

This obvious breach of security can be overcome by using a kill command [7, p.201]. The tags are designed such that at the point of sale when it is read by the reader, the reader executes a kill command which kills or deactivates the tag.

The kill command is a good technique to ensure security and privacy in RFID, but severely limits the functionality of RFID tags beyond the point of sale.

Blocking: This is a modification of the kill command technique. The difference is that the tags are given a privacy bit. The privacy bit can be activated or deactivated as intended by the user. The privacy bit can be set to '0' at or before the point of sale. Once it has passed the point of sale the privacy bit can be activated.

Blocking [13, p.332-335] requires a blocker tag which makes a normal tag unreadable in its presence but allows the same tag to be read once the blocker tag is removed. The advantage of blocking is that the tags are not killed, but are in effect put into sleep mode when required, thereby enhancing the life cycle of a tag as well as increasing the functionality of RFID technology beyond the point of sale.

Mutual symmetrical authentication: This is a security measure used by the reader and the tag. In this method both the reader and the tag check each other's knowledge of a common crypto-logical key [7, p.221].

The tag and the reader have a common crypto-logical key, *K*. When the tag enters the interrogation zone of the reader, both the reader and the tag will not be sure if they are communicating with the correct device.

In order to ascertain the validity of the tag in the interrogation zone, the reader sends a request for a random number from the tag. The tag responds by sending a random number, *Ra*. The reader encrypts this random number using the common crypto-logical key and sends it back along with another randomly generated number *Rb*.

If the tag uses the same crypto-logical key as the reader, it will decrypt the message from the reader. The tag checks to make sure that the decrypted message is similar to the one it initially generated (*Ra).*

This process is reversed by the tag which encrypts the randomly generated number, *Rb*, which it received from the reader and transmits it back to the reader. If the reader is able to decipher the message, then the reader and the tag have mutually authenticated each other using a common crypto-logical key.

Encryption: This is the most logical method for securing data in RFID. Using encryption [7, p.224], the data to be transmitted from the tag to the reader are encrypted using a crypto-logical key K and a secret algorithm. The data can only be decrypted by the attacker if he knows the secret key as well as the secret algorithm. The secret algorithm is not a fixed one; it is generated at the time of encryption, so it cannot be decoded easily.

There are two types of encryption used in RFID: symmetrical and asymmetrical. Symmetrical encryption involves using the same key for ciphering and deciphering the data. If two different sets of ciphering keys are used for encrypting and decrypting data, then it falls under asymmetrical encryption.

Symmetrical encryption is most often used in RFID. The data to be transmitted are encrypted using a crypto-logical key. The ciphered data are then passed from the tag to the reader. A potential attacker cannot do anything with the ciphered data if he does not have the secret key or the secret algorithm used for encryption. The ciphered data can only be deciphered by the reader which has the secret key and the algorithm used for ciphering the data.

2.6 Need for Wireless Link between RFID Reader and RFID Middleware

Typical readers come with an RS232 or RS485 interface. These interfaces can be connected to the RFID middleware. However, wired links have some disadvantages, namely:

- Mobility limitations
- Flexibility limitations
- Cost of installation and maintenance
- Architectural limitations.

Mobility: A wired connection between a reader and the RFID middleware will mean that the reader has to be made stationary. In a system such as RFID in which all the components work on contact-less data transfer, a stationary reader will reduce overall mobility.

Flexibility: An RFID tagged object is usually placed in areas that cannot be easily accessed by human beings. A handheld RFID reader (discussed in Section 2.5.2.1) will be able to read these tags. If the handheld reader is wired to the middleware, the flexibility of the RFID system is compromised.

Cost of installation and maintenance: To set up a wired network for the RFID system in a university environment is expensive as many metres of cable have to be linked between each reader and the RFID middleware. The cost concerns do not end there. If a fault occurs somewhere along the line, the entire length of the cable has to be replaced.

Architectural limitations: Another problem with the wired approach is linking between a reader and the RFID middleware which are located in two different buildings. It is not

practical to have a wired link between two buildings as the cables are exposed to environmental factors.

This project examines the viability of a wireless link between the reader and the RFID middleware to overcome these challenges. A number of wireless technologies available on the market today were closely examined for this purpose. Three technologies were short-listed. They are Bluetooth technology, Wireless Local Area Network (WLAN) technology and ZigBee technology.

The different factors that were considered when short-listing the three technologies mentioned in the last paragraph were cost, power consumption, data bandwidth capabilities, transmission range and system complexity.

Section 2.7 compares the three technologies based on the criteria mentioned in the above paragraph. This comparison was undertaken to determine which wireless technique is most suitable for the desired end application of this project. Table 2.7 shows the comparison.

2.7 Comparison between Wireless Technologies

Table 2.7: Comparison between wireless technologies

MARKET NAME	ZIGBEE	WLAN	BLUETOOTH
Standard	IEEE 802.15.4	IEEE 802.11	IEEE 802.11.1
Application focus	Monitoring and Control	Web applications, e-mail	Cable replacement
Battery life (days)	100-1000	0.5-5	1-7
Bandwidth (KB/s)	20-250	11000	720
Transmission range (metres)	1-100	1-100	1-10
Advantages	Reliability, cost, power	Speed, flexibility	Cost, convenience
System Complexity	Low	Medium	Medium
Shortfalls	Relatively new technology	Cost	Range

The comparison shows that all three technologies have their own advantages and disadvantages and that any one of the three can be used for this project. WLAN technology would probably be the cheapest as the Central University of Technology (where this project was done) already has a well-established infrastructure. But WLAN needs an uninterrupted DC power supply as the battery life is very short.

Bluetooth technology also has distinct advantages (cost and convenience), but a transmission range of only 10 metres was an obvious disadvantage along with the limited battery life.

Throughout this project, the main idea was to stretch the limits of knowledge and study new techniques and methods which have not been used previously. Therefore when ZigBee presented itself as a possible cable replacement method, it was carefully considered. The

advantages of battery life and transmission range obviously strengthened the case and this ultimately resulted in the use of ZigBee technology as a wireless link between the RFID reader and the middleware. Section 2.8 analyses ZigBee technology in detail.

2.8 ZigBee Technology

ZigBee [19, p.3] is a low data rate, low-power consumption, low-cost, wireless networking protocol. It is based on the IEEE 802.15.4 standard for low data rate Wireless Personal Area Networks (WPAN). As seen from the comparison in the last section, ZigBee consumes very little power and transfers small packets of data over large networks with a substantial transmission range.

ZigBee technology is developed by ZigBee Alliance [19] (an association of companies that collaborate to develop standards and products for reliable, cost-effective, low-power wireless networking) and IEEE 802.15.4.

The technical specifications of ZigBee technology are based on the ZigBee stack. The ZigBee stack is made up of IEEE 802.15.4 [20] standards and the ZigBee standards [20]. IEEE 802.15.4 defines the physical [19, p9] and Media Access Control (MAC) layer [21] while the ZigBee standard defines the network layer [20] and the application layer [21]. The ZigBee stack and its components are defined in Section 2.8.2.

The discussion of ZigBee technology starts with a look at the different components of a ZigBee system. This is to give a rough idea of the working of ZigBee technology. Next, the different network topologies used in ZigBee are described in Section 2.8.2. The technical

details of ZigBee are then studied (Section 2.8.4 and 2.8.5) by analysing the ZigBee stack in Section 2.8.3, and finally issues of security in ZigBee technology are studied in Section 2.8.6.

2.8.1 Components of a ZigBee System

A typical ZigBee wireless network system consists of three types of devices:

- ZigBee coordinator
- ZigBee router
- ZigBee end device.

2.8.1.1 ZigBee coordinator

This is the most intelligent unit in a ZigBee wireless system. It is also called a Fully Functional Device or FFD. The coordinator is connected to middleware. When the coordinator is powered up, it scans the network to establish a connection. The ZigBee coordinator [22] establishes connection with the other components in the system by a unique 16-bit network address. This unique network address is used for finding each device in a ZigBee network. The coordinator can communicate with all the other components in a ZigBee network. There will always be only one coordinator per network.

2.8.1.2 ZigBee router

The ZigBee router [22] is an optional device in a ZigBee wireless network. It has less processing capability than a coordinator, and is therefore referred to as a Reduced Functional Device (RFD). The router can also be a Full Functional Device (FFD). The main purpose of the router is to connect a coordinator and an end device. The number of routers in a network is dependent solely on the size of the network.

ZigBee can drive up to 256 devices [19, p.4] in a single wireless network. It is in such a scenario that the router becomes essential, as the router can transmit the necessary data from the coordinator (given the correct destination address) to the end device. The router can communicate with both the coordinator as well as the end device.

2.8.1.3 ZigBee end device

The ZigBee end device [22] is connected to the end-user application. This component is usually powered down (sleep mode) and only active when it has to transmit data. Once it has transmitted data, it goes back to sleep, thereby saving battery life. The ZigBee end device can communicate only with the coordinator and cannot transfer data directly to other end devices in a network.

A simple diagrammatical representation of the ZigBee components and how they would work in real life is given in Figure 2.37.

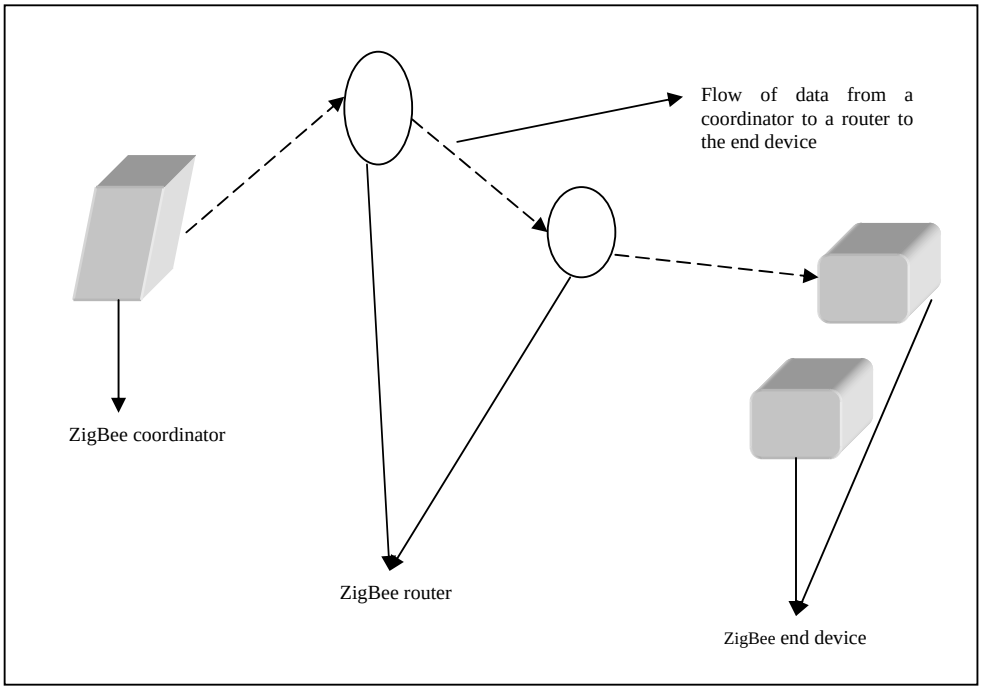


Figure 2.37: Data flow from the ZigBee coordinator to the end device through a router

2.8.2 Network Topologies in ZigBee Technology

Section 2.8.1 introduced the three components of a ZigBee network. This section examines the different means whereby data are transferred from the ZigBee coordinator to the end device and vice versa. There are three main network topologies used in ZigBee technology:

- Star topology
- Peer-to-peer topology
- Tree topology.

2.8.2.1 Star topology

Star topology [21] is comprised of one ZigBee coordinator and one end device (ZigBee routers are optional in this instance). The ZigBee end devices are electrically and physically isolated from each other. Communication between two end devices is therefore possible only

through the coordinator. Star networks are also called single-hop networks as there is only a single path between the coordinator and the end device. Figure 2.38 shows the star topology.

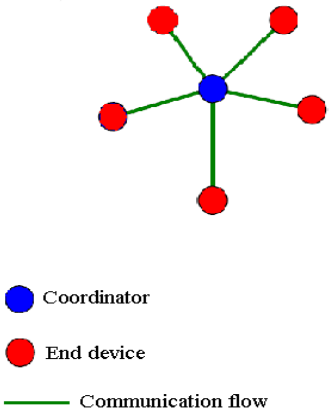


Figure 2.38: Star topology

2.8.2.2 Peer-to-peer topology

Peer-to-peer topology [21] can consist of all three components in a ZigBee system. Direct communication between two end devices is not permitted (as in star topology), but two routers can communicate with each other without linking through the coordinator. Peer-to-peer topology is also referred to as a multiple-hop network, because the topology allows multiple paths to transfer data from one end device to another. Figure 2.39 shows how peer-to-peer topology functions.

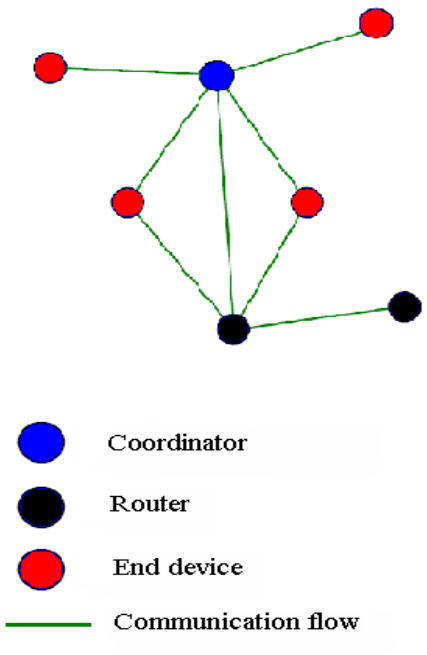


Figure 2.39: Peer-to-peer technology

2.8.2.3 Tree topology

The tree topology [21] is the third network topology used for data transfer. This is an extension of the peer-to-peer topology. This topology maximises the use of a router in a ZigBee network. A ZigBee router can be used to greatly increase the coverage area of the network by forming a tree-like structure. The coordinator is the 'tree' and the router forms the 'branch' of the tree. Tree topology eliminates the need for an end device to be within the read range of the ZigBee coordinator. Figure 2.40 shows how tree topology functions.

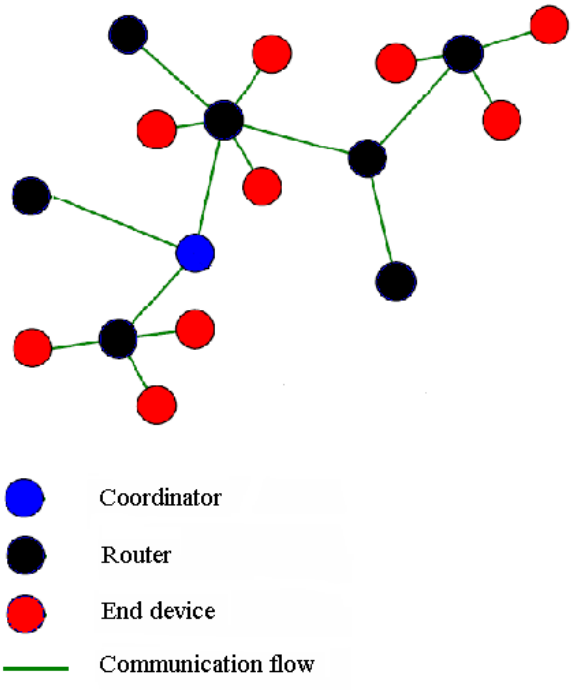


Figure 2.40: Tree topology

2.8.3 The ZigBee Stack

The ZigBee stack has several layers made up of the IEEE 802.15.4 standard and the ZigBee standard. Figure 2.41 shows the make-up of a ZigBee stack.

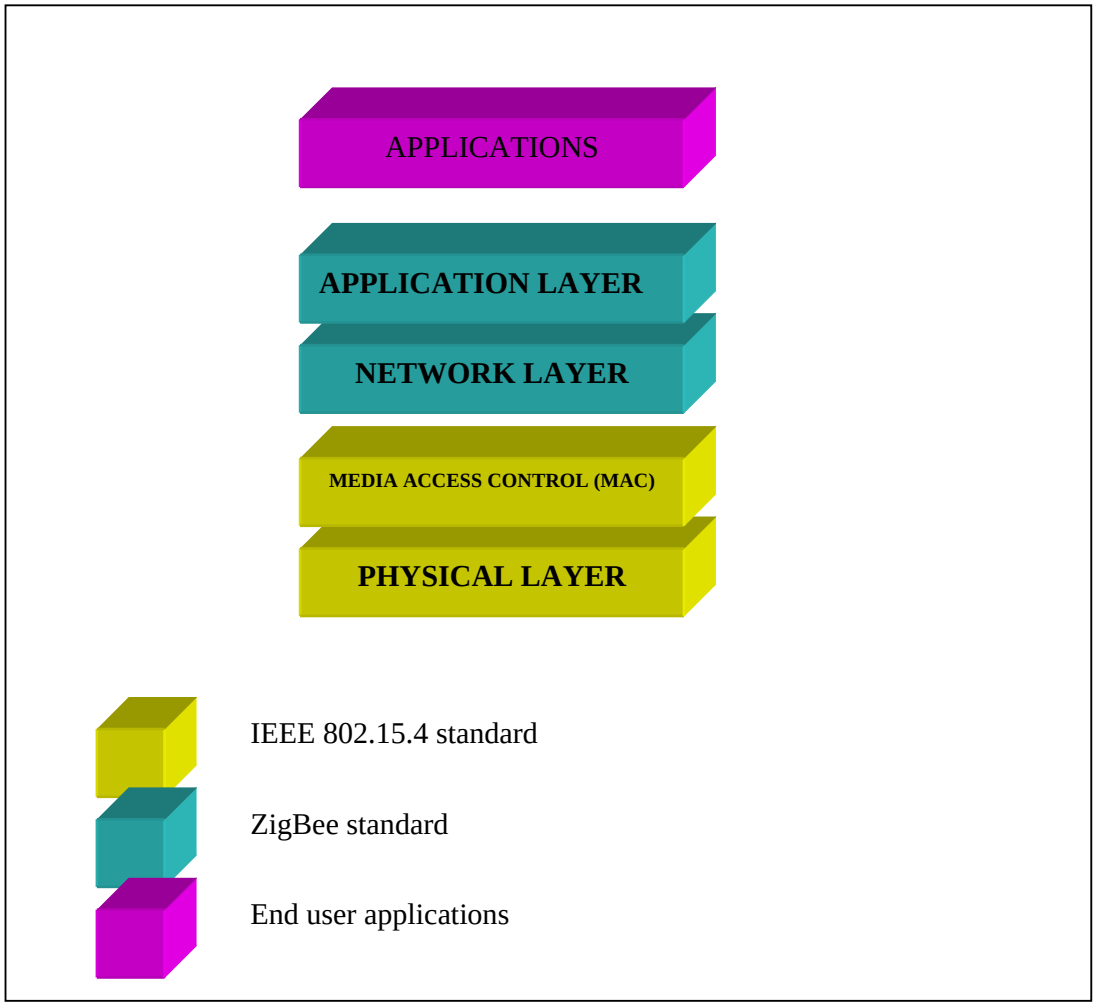


Figure 2.41: The ZigBee stack

2.8.4 The IEEE 802.15.4 Standard

IEEE 802.15.4 defines the physical characteristics of a ZigBee device. These include the frequency of operation, the types of modulation used and the types of devices for Low Rate Wireless Personal Area Networks (LR-WPAN). As shown in Figure 2.40 it has two layers, the physical layer and the Media Access Control (MAC) layer.

2.8.4.1 Physical layer

ZigBee technology, like RFID technology, transfers data using radio waves. ZigBee supports three frequency bands to transfer data. They are the 2.4 GHz band (the global ISM band) and the 868/915 MHz bands (the frequency bands used in Europe and North America, respectively).

Each of these frequency bands has different data bandwidth capabilities which depend on the number of channels used for data transmission. The 868 MHz band (868 MHz-870 MHz) has only a single channel and a data rate of 20 kbps. The 915 MHz band (902 MHz-928 MHz) offers ten channels for data transfer at a gross data rate of 40 kbps. The third frequency band is the 2.4 GHz band (2.4 GHz-2.48 GHz). This frequency band has the most number of channels, namely sixteen. It also has the highest data rate capability at 250 kbps. The three frequency bands and their channel width are shown in Figure 2.42.

The 2.4 GHz band has a 5 MHz channel bandwidth and the 868/815 MHz has a 2 MHz range. This is shown in Figure 2.42.

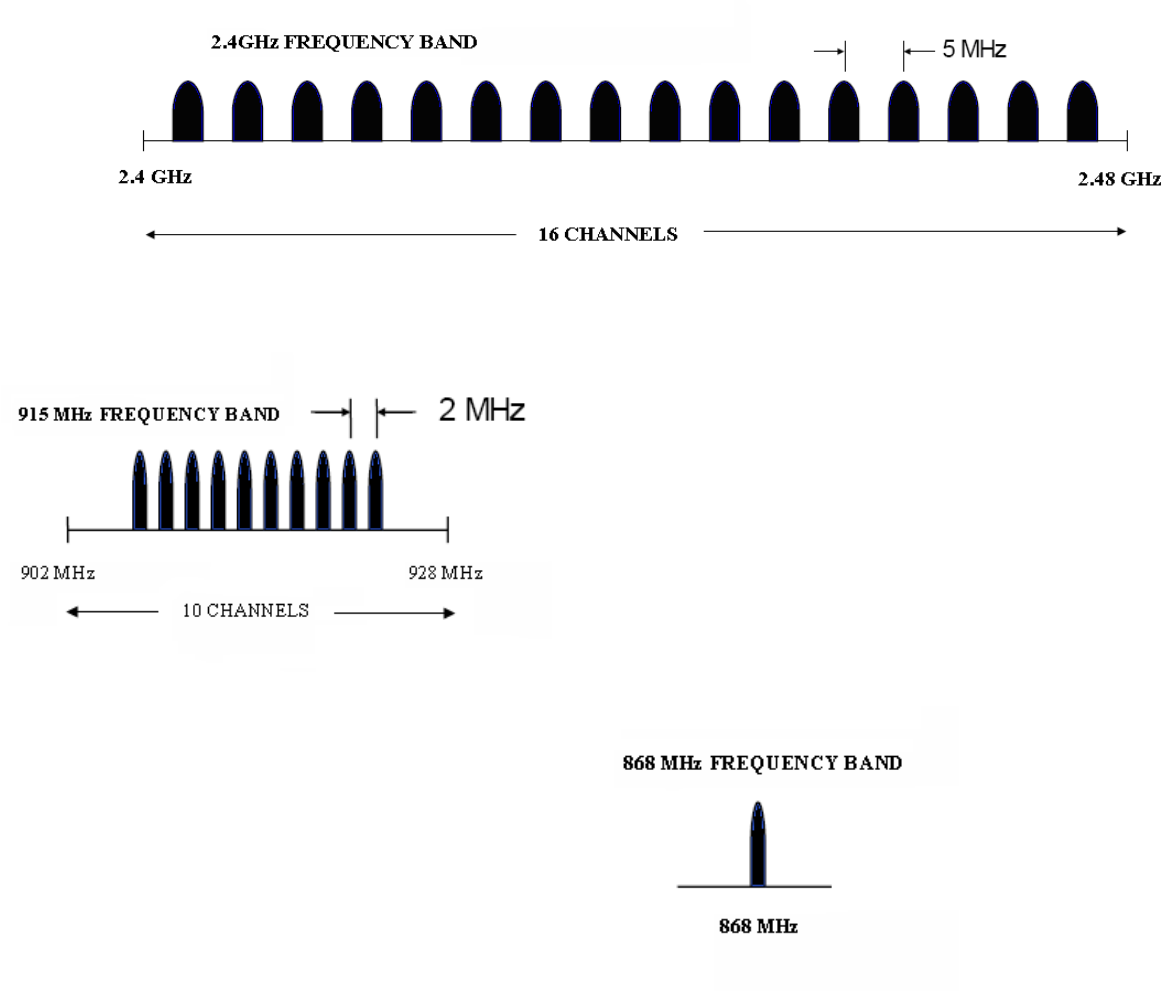


Figure 2.42: The different frequency ranges in the physical layer of the IEEE 802.15.4 standard

The main features of the three bands are summarised in Table 2.8. The physical stack is also responsible for link quality indication, clear channel assessment and receiver energy detection, but the primary purpose of the physical layer is to transmit and receive packets across the medium.

Table 2.8: Features of the three frequency bands

FEATURES	2.4 GHz	915 MHz	868 MHz
DATA RATE	250 kbps	40 kbps	20 kbps
CHANNELS	16	10	1
MODULATION	Orthogonal Quadrature Phase Shift Keying	Binary Phase Shift Keying	Binary Phase Shift Keying
BITS/SYMBOL	4	1	1
SYMBOL PERIOD	16μs	24μs	24μs

2.8.4.2 Media Access Control (MAC) layer

The second layer of the IEEE 802.15.4 standard is the MAC layer. The MAC layer deals with the data transfer, channel scanning and association/disassociation functionalities in ZigBee technology. The MAC layer also defines to an extent the battery life of the wireless devices.

The explanation given in Section 2.8.1 shows there are different components in a ZigBee network. Some devices will be Reduced Function Devices or RFDs (end devices), while others will be Fully Functional Devices or FFDs (coordinator or router).

The MAC layer provides an FFD with a full set of functionalities that enable them to act as a coordinator or router. When acting as a coordinator, the FFD provides communication and network joining services by means of beacons.

Depending on the topology used for data transfer in a ZigBee network, the FFD can act as a Personal Area Network (PAN) coordinator. The PAN coordinator controls the operation of a network.

The PAN coordinator operates in one of two ways. It can operate with a super-frame structure or without one. To understand these operations the MAC super-frame [22] must be explained first. Figure 2.43 shows a typical MAC super-frame.

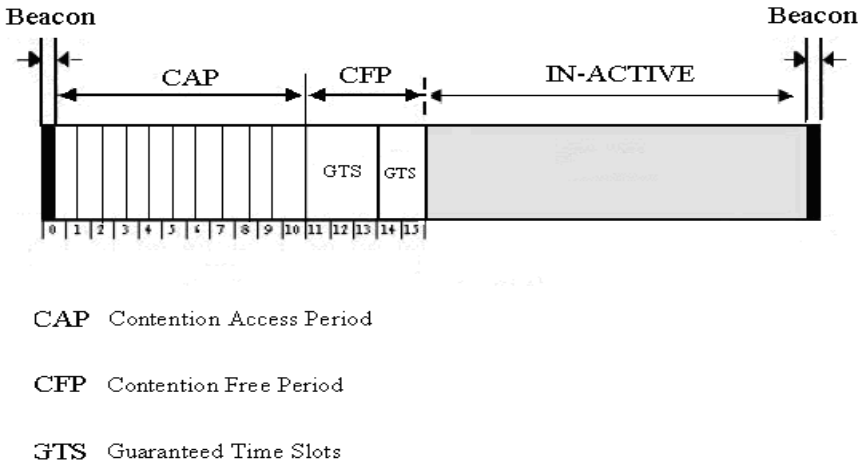


Figure 2.43: MAC super-frame

If a PAN coordinator operates with a MAC super-frame, it first sends a frame as shown in Figure 2.43. The MAC super-frame is divided into two halves: active session and inactive session. The coordinator goes into the sleep mode during the inactive session thereby saving power.

Data are transmitted during the active session. The active session is divided into two fixed size slots: the Contention Access Period (CAP) and the Contention Free Period (CFP).

The components of a ZigBee network compete among themselves for channel access during a CAP slot using slotted CSMA-CA [23, p.706] protocol to transmit data. Meanwhile, during the CFP, the ZigBee devices transmit without contending for a channel using the Guaranteed Time Slots (GTS). The GTS are assigned and administered by the PAN coordinator.

The end devices in a ZigBee network are usually in sleep mode, which means that they are only in an active state when they have to transmit data or ‘wake-up’ at periodic intervals to detect whether there is any incoming data from the coordinator.

If a PAN coordinator wishes to transmit data without using a MAC super-frame, then there are no beacons, and unslotted CSMA-CA is used for communication. The coordinator is always in the active state and ready to receive data from the end device. The transfer of data from the end device to the coordinator is poll based.

The MAC layer is also responsible for the association process as mentioned at the beginning of this section. Association is the process of joining the ZigBee devices to form a network. This is done by sending a request to the end device from the coordinator. If the request is accepted, the coordinator assigns a 16-bit short address to differentiate the different components.

2.8.5 The ZigBee Standard

The ZigBee standard is built on the IEEE 802.15.4 standard. This consists of two layers:

- Network layer
- Application layer.

2.8.5.1 Network layer

The network layer is responsible for routing over a network. In Section 2.8.2 the different network topologies used in a ZigBee network were discussed. The network layer is responsible for providing a multi-hop routing (peer-to-peer and tree topology), discovering a

route, maintenance of a route, security in a route and joining/leaving a network with 16-bit addresses obtained from the MAC layer.

The above functionalities of the network layer are created by using several algorithms and protocols [21]. A full explanation of these algorithms and protocols is not within the scope of this thesis.

2.8.5.2 Application layer

The application layer is made up of three components: the Application Object (APO), the ZigBee Device Objects (ZDO) and the Application Sub-layer (APS).

The APO falls under the application framework of a ZigBee system. It controls all the hardware units in a ZigBee network. The ZDO is a special object which allows the APO's to discover devices within a network and the services they implement. The ZDO also provides communication, network and security management services. The APS acts as an interface between the APO's and the ZDO's. Figure 2.44 illustrates the various components of the application layer and how they interact with each other.

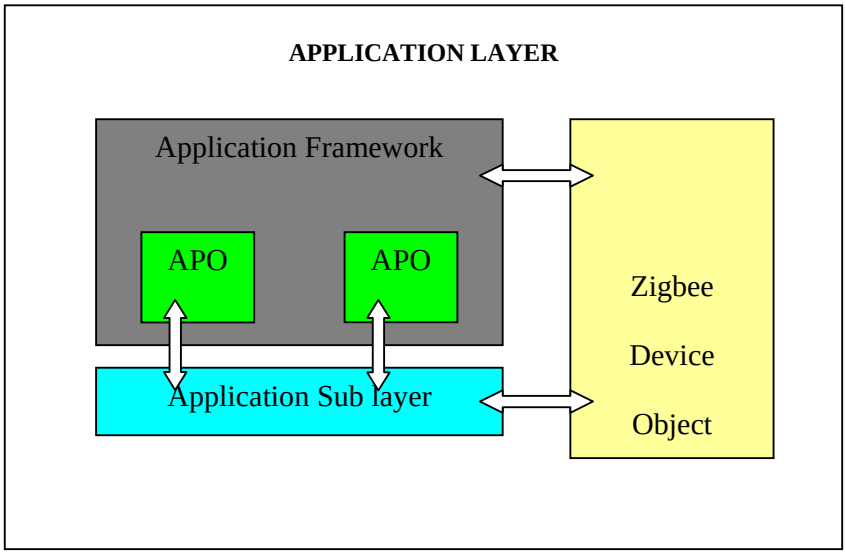


Figure 2.44: Components of the ZigBee application layer

2.8.6 Security Issues and Solutions in ZigBee Technology

Wireless networks are slightly disadvantaged when it comes to computational power and communication resources as compared to a wired network. As a result of these drawbacks the security features in any wireless network will not be as efficient as they are in a wired network. However, ZigBee Alliance describes security functionalities [20] on an open trust model where all applications running on a single device trust each other.

Some of the security issues that confront ZigBee and their solutions are discussed in this section.

Data freshness: This aspect refers to the data being transmitted or received in a ZigBee device. The data have to be refreshed in order to avoid the same data being sent over and over again. ZigBee devices contain counters for incoming and outgoing messages. These counters are reset every time a new key is created, thereby maintaining the freshness of the data.

Data integrity: This is similar to the problem discussed in RFID systems (Section 2.5.9). ZigBee tackles this problem by providing 0-, 32-, 64- or 128-bit data integrity for the transmitted messages. The procedure is similar to the checksum methods used in RFID. 64-bit data integrity is the default in most ZigBee devices. These bits are used in checksum procedures to ascertain the integrity of transmitted data.

2.9 Software Section

The data from the RFID reader make little sense on their own - the aim of this project is to automate attendance registration. The RFID reader can read a student card (tag) once it comes into the read range of the reader, but the data from the tag on their own cannot automate the attendance register. Therefore RFID middleware is used to automate the attendance register.

RFID middleware is the software part of this project. It contains the logic for the RFID application and a database system. The software section of this project runs on a personal computer for testing purposes.

2.9.1 The Components of RFID Middleware

The middleware is the software part of this project as mentioned in the last section. This project uses Java and Apache Derby to manipulate data from the reader and use it for automating the attendance register.

Java: Java is an object-oriented programming language developed by Sun Microsystems in 1995 [24]. It derives most of its syntax from C and C++. It has some distinct advantages that are suited to the structure of this project:

- Simplicity
- Robustness
- Security
- High performance
- Architectural neutrality.

Above all, the most important aspect is that Java is a write-once, compile-once, run-anywhere sort of program. This means that irrespective of the hardware used, Java adapts to it such that the original coding remains the same.

Another advantage of Java is that it has Application Program Interfaces (API) that can be used for linking two software components. One such API used in this project is called Java Data Base Connectivity (JDBC). JDBC allows an end user to query and update a relational database with the Java program.

In order to program with Java, one needs a platform. Netbeans 6 is the platform used for Java programming in this project.

Apache Derby: This is a Java relational database management system that can be embedded in Java programs and be used for data manipulation. The Apache Derby database works on the Structured Query Language (SQL) used by the majority of database programs such as MySQL and Oracle.

The reason for using the Apache Derby database is that it works with JDBC and Java as a single program. Therefore all the work relating to this project is done on a Java platform.

2.9.2 Programming Concept

This section outlines what is expected of the software section of this project. The detailed working of JDBC and the Apache Derby database are given in Part 3 of this thesis.

The data scanned from the student card (tag) by the RFID reader are brought to the serial port of the computer. A program is written in Java to retrieve the data from the serial port and bring it to the Netbeans Java platform.

A database containing the 8-bit numbers on a student card and the corresponding student numbers of all the students belonging to a class is created using the Apache Derby database.

The scanned data from the student card are compared with the data in the created database using JDBC. If there is a match, the scanned data are entered into another database with the date and student number. This process is repeated on all class days.

At the end of the academic term or semester, a ‘count’ function in the Apache Derby database is done on each student number. This will give the total number of days a student was present in class, thereby automating the attendance register.

2.9.3 JDBC Concepts

JDBC [25] is used by Java to access and manipulate a database. JDBC has four components:

- JDBC API
- JDBC driver manager
- JDBC test suite
- JDBC-ODBC Bridge

JDBC API: The API provides the industrial standard for connecting Java programming language and a wide range of databases. The API is designed such that it only needs to be written once and can be run any time. There are two packages in a JDBC API:

-java.sql

-javax.sql.

These two packages are used to connect the Java program and the databases.

JDBC driver manager: This is the backbone of the JDBC architecture. It defines objects which connect a Java application to a JDBC driver. The main responsibility of the JDBC driver is to load all drivers found in the system properly as well as to select the most appropriate driver for opening a database connection.

JDBC test suite: The test suite checks whether the driver will run a specific user program.

JDBC-ODBC Bridge: ODBC is an acronym for Open Database Connectivity. This is an interface language that enables applications to access data from various database management systems. The ODBC translates the JDBC method calls into ODBC function call.

The JDBC architecture better explains the concept of the JDBC-ODBC bridge explained in the last section. Figure 2.45 shows the JDBC architecture.

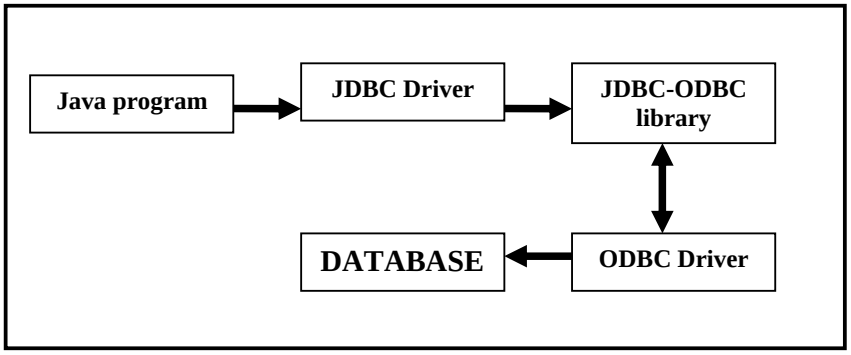


Figure 2.45: JDBC architecture

2.9.4 The JAVA.SQL Package

This is the main package of the JDBC API used in this project. Almost all the Java coding done in this project uses this package. This section examines the contents of the java.sql package.

2.9.4.1 Connection with database

To make a connection [25] with the database, java.sql provides the driver manager and the SQL permission class. The driver manager class helps to make the connection with the

database using a driver interface. The SQL permission class, on the other hand, provides the security for the connection by setting up a username and password to access the database.

2.9.4.2 Sending SQL parameters to a database

In order to access the database some SQL statements must be sent to the database. Using the java.sql package, the programmer can send basic SQL statements and prepared statements using the statement objects. The statements are sent through the connection interface which provides methods for creating statements and managing their connections and properties. The SQL statements will be discussed in detail in Section 2.10.

2.9.4.3 Updating and retrieving results of an SQL query

Updating and retrieving results from a database is a crucial aspect as far as this project is concerned. The *ResultSet* object is responsible for this process. The *ResultSet* maintains a cursor pointing to the current row of data at the start of the program and moves through each of the rows, until there are no rows left.

2.9.4.4 Metadata object

This object provides information to the application about the database. *ResultSetMetadata* is a method in the Metadata object that provides information about the columns of a database to the *ResultSet* object.

2.9.4.5 Exceptions

Exceptions are error messages generated by the Java program in various instances of the programming. Some of the common exceptions generated are:

SQLException - An error generated by the methods of a program whenever there is a problem accessing the database. The program will not execute if there is as SQLException.

SQLWarning - An exception which generates a warning due to some missing parameters. The program will execute with the warning, but might not output the desired results.

BatchUpdateException - Indicates that all commands have not been updated successfully.

Data Truncation - Indicates that some part of the code is missing.

2.9.5 SQL Concepts

SQL is a standard language for accessing and manipulating databases. There are different Relational Database Management Systems (RDBMS) that use SQL, such as MySQL, DB2, Oracle, MS Access and Apache Derby.

The data in a RDBMS are stored in database objects called tables. A table is a collection of related database entries and it consists of rows and columns. A database may contain one or more tables. Each table is identified with a name. Table 2.9 shows a database table called “students” with three columns for student name, age and student number. It has three entries, one for each student.

Table 2.9:'Students' table with three columns and three entries for the columns

Student name	Age	Student number
Alex	19	3229
John	21	3230
Mary	20	3231

A database table is created using certain SQL statements. There are basically two types of SQL statements: the Data Manipulation Language (DML) and the Data Definition Language (DDL).

The Data Manipulation Language statements are used for querying and updating a database table. Some of the DML commands are given below.

- SELECT - command used for extracting data from a database
- UPDATE - command used for updating data in a database
- DELETE - command used for deleting data from a database
- INSERT INTO – command used for inserting data into a database.

The Data Definition Language statements are used for creating and deleting database tables. They also provide indexes, specify links between tables and impose constraints between tables. Some of the commonly used DDL statements are as follows:

- CREATE DATABASE - used for creating new database tables
- ALTER DATABASE - used for modifying a database
- CREATE TABLE - used for creating a new table
- ALTER TABLE - modifies a created database table

- DROP TABLE - deletes a table
- CREATE INDEX - creates a search key for database tables
- DROP INDEX - deletes a search key for database table.

2.9.6 SQL statements and their syntax

This section explains the syntax used in some of the SQL commands. In order to facilitate understanding, all the syntaxes will be explained with the help of Table 2.10. All SQL statements must end with a semi-colon.

Table 2.10: Example of database table

Student name	Age	Student number
Alex	19	3229
John	21	3230
Mary	20	3231

2.9.6.1 SQL CREATE table statement

The first thing that needs to be done in database programming is to create a database table. Before creating a database table the user must know the exact amount of data that the table contains, i.e. the number of columns that will be needed. The syntax for creating a table [26, p.51] is as follows.

CREATE TABLE table_name (column_name1 data_type, column_name2 data_type, column_name3 data_type);

The data type specifies what type of data the column holds, for example variable character (names, addresses) and integer (student numbers, telephone numbers, ages).

In order to create the database table shown in Table 2.9, three columns are needed. The table is created using the following syntax:

CREATE TABLE students (student name varchar (255), age integer (40), student number integer (40));

The data types used in this instance are variable character (varchar) and integer. The number in the bracket specifies the maximum length of the data in characters.

2.9.6.2 SQL INSERT INTO statement

The insert statement [26, p.75] is used for inserting values into a database table. The syntax for the insert statement is as follows.

INSERT INTO table_name (column_name1, column_name2, column_name3) VALUES (value1, value2, value3);

The INSERT INTO statement is exemplified by inserting the first set of values into the ‘students’ table (Table 2.10). It is important to note that the variable characters must be placed in single quotes to differentiate them from integers.

INSERT INTO table_name (student name, age, student number) VALUES (‘Alex’, 19, 3229);

The result for such a statement will generate the first row of the ‘students’ database table. This is shown in Table 2.11.

Table 2.11: The result for INSERT INTO statement

Student name	Age	Student number
Alex	19	3229

2.9.6.3 SQL SELECT statement

The select statement is used for extracting data from the database table, as mentioned in the previous section. The syntax for selecting [26, p.54] data is as follows.

```
SELECT column name(s) FROM table_name;
```

OR

```
SELECT * FROM table_name;
```

An example of each of the select statements can be one using the ‘students’ table created in Table 2.9. Suppose the database programmer wants to obtain the student number of all the students from the ‘students’ table. The corresponding SQL statement will be:

```
SELECT student number FROM students;
```

The result for such a query statement is given in Table 2.12.

Table 2.12: Result of the SELECT student number FROM students statement

Student number
3229
3230
3231

The select statement can also be:

SELECT * FROM students; - This statement selects all the columns from the database table.

2.9.6.4 SQL UPDATE statement

The update statement [26, p.81] is used for making changes to data that are already present in the database table. A typical update statement is as follows:

UPDATE table_name SET column_name1 = newvalue1, column_name2 = newvalue2 WHERE column_name1 = oldvalue1, column_name2 = oldvalue2;

An example of an update statement is changing the Age of Alex in the ‘students’ table from 19 to 21. This is done by using the following statement:

UPDATE students SET age = 21 WHERE student name = ‘ALEX’.

The updated ‘students’ table is shown in Table 2.13.

Table 2.13: The updated 'students' table

Student name	Age	Student number
Alex	21	3229
John	21	3230
Mary	20	3231

2.9.6.5 SQL DELETE statement

This statement is used for deleting data from a database table. A delete [26, p.85] statement has the following syntax:

DELETE FROM table_name WHERE column_name1 = value1;

An example of the delete statement is writing a statement for deleting all the entries of John from the updated 'students' table. The statement is as follows:

DELETE FROM students WHERE student name = 'John';

The result for such a statement is shown in Table 2.14.

Table 2.14: 'Students' table with data of John deleted

Student name	Age	Student number
Alex	21	3229
Mary	20	3230

A detailed examination of the SQL statements and the JDBC programming used in this project is given in Section 3.3 (Software Section)

PART 3

CHAPTER 3 RESEARCH STRUCTURE

This chapter describes the research methodology of this thesis. It aims to practically implement all the topics discussed in Chapter 2. A step-by-step approach is used to bring together all the components discussed in the previous sections to automate the student attendance register using RFID technology.

This chapter is divided into three sections: the hardware section, the wireless section and the software section.

The hardware section examines the tags used in this project, the programming of an RFID module which can read the tags and the design of an antenna which will act as the interface between the reader and the tag.

The wireless section examines how ZigBee wireless technology is used to connect a reader and remotely located RFID middleware.

The software section examines how the data from the RFID reader are manipulated so that it can be used to automate student attendance register.

3.1 Hardware Section

This section examines three important aspects of this project:

- RFID tags
- RFID reader
- Antenna.

3.1.1 RFID Tags

RFID tags contain some data, and when they come within the read range of a reader, they transfer the data. In doing so they can identify the person or object that carries the tag. As mentioned in Section 2.5.1, there are different types of tags (active, passive and semi-passive).

This project was undertaken to automate the student attendance register at the Central University of Technology, Free State, South Africa. Upon enrolling at the institution, each student is given a student card. The student card contains a picture of the student, his/her name, the course for which s/he has enrolled, and a student number. The student number is a unique ID which is used to distinguish each student.

In one of the experiments done very early on this project, it was noted that the student card was indeed an RFID tag constructed in identification card format (Section 2.5.1.1). The student cards have the same dimensions as a credit card (85.72 mm x 54.03 mm x 0.76mm) and have a coil antenna with a microchip. The tags are designed to work at 13.56 MHz.

These student cards were tested with various RFID readers, and it was ultimately found that these cards fall under the ISO 14443 type B standard of tags (Section 2.5.8.2). There are different types of ISO 14443 cards. The student cards used in this project have the same memory organisations as SR176 cards. The SR176 cards fall under the ISO 14443 type B standard.

SR176 type RFID tags contain 30 bytes of data organised in two bytes per page. This is illustrated in the memory organisation diagram of the SR176 given in Figure3.1.

Block address	Byte 1	Byte 0	
0Fh	Lock byte	RFU	Chip ID
0Eh	User data		
…	…		
04h	User data		
03h	Serial number		
02h	Serial number		
01h	Serial number		
00h	Serial number		

Figure 3.1: Memory organisation of the SR176 RFID tag

The conclusion that the student card used in this project was in fact the SR176 type was reached by testing the card with a smart-log reader. The student card, when in range of the reader, transmitted an 8-bit unique identification (UID) serial number. The SR176 is the only tag that falls under the ISO 14443 type B card which has an 8-bit UID serial number.

The UID is stored in the first four pages of the memory with Page 00h containing the LSB of the UID. The organisation of the serial number UID is illustrated in Figure 3.2.

Page 03h		Page 02h		Page 01h		Page 00h	
Byte 1	Byte 0	Byte 1	Byte 0	Byte 1	Byte 0	Byte 1	Byte 0

Figure 3.2: Serial number of the SR176 tag

This is an important point. The data transmitted from the student card is NOT the student number but a UID serial number. As far as this project is concerned, it is the UID that distinguishes each student and not the student numbers.

These types of tags are implemented as One-Time Programmable tags. The write access conditions of the tags are defined in the lock byte. The lock byte of the SR176 type tags is given in Figure 3.3. Each bit in the lock byte can only be set once. The procedure is irreversible.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Page 0Eh Page 0Fh	Page 0Ch Page 0Dh	Page 0Ah Page 0Bh	Page 08h Page 09h	Page 06h Page 07h	Page 04h Page 05h	Page 02h Page 03h	Page 00h Page 01h

Figure 3.3: Lock byte of the SR176 tag

3.1.2 RFID Reader

Since the RFID tag used in this project is of the ISO 14443 type B, the RFID reader should be capable of reading these tags. This section examines how such an RFID reader can be constructed.

The RFID reader used in this project is the ACG HF Multi ISO reader module. The reader module works in the high frequency range at 13.56 MHz. It was chosen for the project as it supports a broad range of tags including the ISO 14443 type B tags used in this project.

The reader module contains a reader IC, CL RC632 interfaced with an Atmel microcontroller. The Atmel microcontroller enables the reader module to be programmed to the specifications required by the end user using a personal computer.

The ACG HF Multi ISO reader module has 20 pins (Figure 3.4). The hardware specifications of the reader are given in Appendix A. The description of the pin numbers is given in Appendix B. The external connections to the reader module are shown in Appendix C.

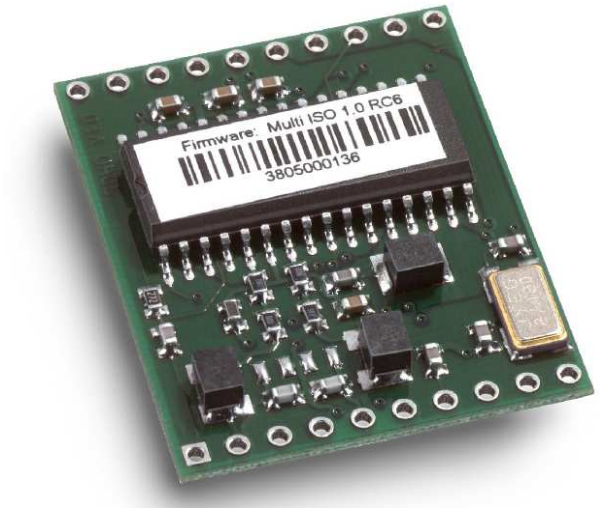


Figure 3.4: The ACG HF Multi ISO reader module

(Picture taken from ACG HF Multi ISO reader module datasheet)

3.1.2.1 Programming the reader module

The reader module is programmed by using the hyper-terminal program in the personal computer, the register set of the reader module and the instruction set of the reader module. The EEPROM memory organisation of the reader module is given in Appendix D. It is essential for the reader of this thesis to have Appendix D handy in order to understand the programming of the reader module.

In order to write to the internal EEPROM of the reader module, the 'wp' command is used. An example of how the write command is executed and the result are given in Table 3.1.

Table 3.1: Write command in an ACG reader module

Command	Data
'wp'	Address (1byte),valid range 0Ah-EFh

The response to the command can be fail error, out of range error (if the address exceeds the address range) or a write success. The responses are given in Table 3.2.

Table 3.2: Responses to a write command

Answer	Description
Data	EEPROM data (1 byte)
'F'	Error: Read after write failure
'R'	Error: Out of range failure

A write example is given in Table 3.3.

Table 3.3: Write command example

Command	Description
WpOD06	Set EEPROM address 0Dh (Command Guard Time) to 06h

It should be noted that the 'h' after the address denotes that the address is given in the hexadecimal number system. The hexadecimal number system is used throughout this thesis for programming the reader module.

Now that an example has been given of how to program the reader module, the actual steps to program the reader for this project can be detailed. The programming is described in a step-by-step manner.

Step 1- Connecting the reader module to Max 232

Connect PIN 12 (Transmit) of the reader module to PIN 11 (T2 IN) of a MAX 232 IC and PIN 11 (Receive) to PIN 12 (T1 IN) of the MAX 232. The MAX 232 IC interfaces the reader module with the computer via the serial port of the computer.

Step 2 –Connecting MAX 232 to DB 9 (female)

Connect PIN 13 (R1 IN) of MAX 232 to PIN 3 (Transmit) of a DB 9 female connector and connect PIN 14 (T1 OUT) of the MAX 232 to PIN 2 (Receive) of the DB 9 female connector. The circuit diagram for this set-up is given in Figure 3.5.

Step 3- Connecting DB 9 to serial port of personal computer

Connect the male part of the DB 9 connector to the serial port of the computer. Open the hyper-terminal program on the desktop computer (Windows XP OS).

Step 4- Setting up the hyper-terminal

The hyper-terminal of the computer must be set to the following settings to enable it to program the reader module:

Connect using COM1 port (serial port of the computer)

Baud rate = 9 600

Data bits = 8

Parity = None

Stop bits = 1

Flow control = NONE

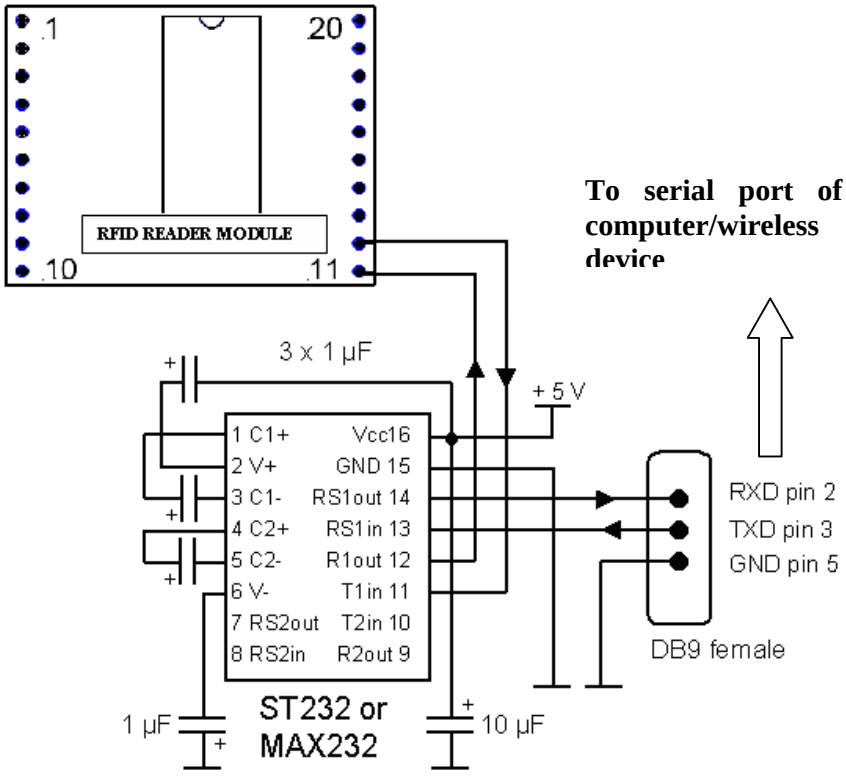


Figure 3.5: Circuit diagram for connecting the reader module to the computer

Step 5 –Programming the reader module: Setting baud rate to 9 600

The default settings of the registry of the reader module have to be altered for it to function according to the needs of this project. The baud rate control registry of the reader module (registry address 0Ch) has to be changed first. Figure 3.6 illustrates the baud rate registry

Baud rate register							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
RFU	RFU	RFU	RFU	RFU	BS2	BS1	BS0

Figure 3.6: Baud rate control registry

Bit 0, Bit 1 and Bit 2 define the baud rate of the RFID reader. The correct baud rate for the functioning of this reader is 9 600. The different baud rates that the reader module supports and their registry values are given in Figure 3.7.

BS2	BS1	BS0	Baud rate
0	0	0	9600 baud (default)
0	0	1	19200 baud
0	1	0	38400 baud
0	1	1	57600 baud
1	0	0	115200 baud
1	0	1	230400 baud (depends on the used interface chip)
1	1	0	460800 baud (depends on the used interface chip)

Figure 3.7: Baud rate settings

In order to set the Baud rate to 9 600, the bits 0, 1 and 2 must be equal to zero. Therefore, the 0Ch registry will have the value 00h. To write this data into the EEPROM of the registry, the following command is typed into the hyper-terminal screen:

wp0Ch00h

This results in the baud rate of the reader module being set to 9600. The communication settings are the same as those given to the hyper-terminal (8 data bits, No parity, 1 stop bit and No flow control).

Step 6 - Programming the reader module: configuring the OPMODE registry

The operation mode register (OPMODE) defines which types of tags the reader module supports. The registry address of the OPMODE register is 0Eh. Figure 3.8 illustrates the OPMODE registry.

Operation mode register							
Bit 7 (MSB)	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 (LSB)
RFU	ICODE UID	ICODE EPC	ISO 15693	ICODE	SR176	ISO 14443B	ISO 14443A

Figure 3.8: OPMODE register

From Figure 3.8, the reader module supports various tags, but for this project only the ISO 14443B tags need to be read. Therefore, Bit 1 of the OPMODE registry needs to be set to 1 and the rest to zero. This is done to prevent the reader module from picking up other tags.

In order to program the registry to read only ISO 14443B tags, the following command is give to the reader module through the hyper-terminal screen:

wp0Eh02h

This results in all the bits except Bit 1 being set to zero, thereby enabling the reader module to read only ISO 14443B tags.

Step 7 - Programming the reader module: configuring the Single Shot Time-out

The Single Shot Time-out occupies the 0Fh address in the reader module registry. The time-out value defines the delay time between two responses to the reader module, i.e. the interval between reading two tags. The time-out value should not be too small or too big in the context of this project. There are 8 bits in this register. The Least Significant bit denotes a time-out of 100 ms (refer to register set information in Appendix D). A delay of 1 second is suitable for the functioning of this device. The delay therefore has to be set to 1 000 ms. Table 3.4 shows how the time delay is set to 1 second.

In order to obtain a delay of 1 second (1 000 milliseconds), the Single-Shot Time-out register has to be set to 0Ah. The following command is written to the hyper-terminal to do this:

wp0Fh0Ah

Delay in milliseconds	Hexadecimal value of register
0 milliseconds	00h
100 milliseconds	01h
1 000 milliseconds	0Ah

This sets the time-out delay to 1 second.

Table 3.4: Delay and corresponding hexadecimal value

Step 8 - Programming the reader module: Configuring the PCON2 register

The Protocol Configuration 2 registry has the register address 13h. This is one of the most important registries as it enables/disables the anti-collision algorithm for the tags used by the reader module. Figure 3.9 shows the PCON 2 registry.

Protocol configuration 2 register							
Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Disable ISO 14443 -4 Error Handling	Enable ISO 14443B Anti-collision	Reset Recovery Time Multiplier		Noisy Environ-ment	Enable binary frame v2	Disable start-up message	Disable multi-tag reset

Figure 3.9: PCON 2 registry

In the PCON 2 registry, bit 6 is the most relevant bit. It enables or disables the anti-collision algorithm for the reader module. The rest of the bits do not influence the outcome of the reader module. Therefore bit 6 is set to HIGH and the rest to LOW.

This will result in the hexadecimal value of the registry being 40h. This value has to be written into the PCON 2 registry. The following command is used to do that:

wp13h40h

This will result in enabling the anti-collision algorithm for ISO 14443B tags, thereby avoiding any collision when student cards are scanned as they pass the reader module.

The reader module has now been programmed to read ISO 14443B type tags. Now an interface between the reader module and the tags has to be created. This is accomplished by designing an antenna.

3.1.3 Anti-collision in RFID reader

Collision is defined in section 2.5.6. The read range of the antenna used in this project is 3-4 cm (refer to Results Chapter 4 for experiment results done to arrive at this conclusion.), therefore collision does not pose a major problem in this chapter. If the read range were to exceed 15 cm then appropriate remedial solutions have to be used. Techniques used in the Multi ISO reader module to overcome collision in reader modules with greater than 15 cm range is given in Section 2.5.6.1 and 2.5.6.2

3.1.4 Antennna

Since the reader module and the tags operate at 13.56 MHz, the antenna should also be designed to operate at this frequency. The antenna should be connected to pins 1, 2, 5 and 6 of the reader module (refer to Appendix C). The antenna must have the correct combination of inductance, resistance and capacitance for optimised frequency and antenna matching. The inductance is achieved by using a coil antenna with a number of turns.

3.1.4.1 Circuit diagram for the antenna

A circuit diagram for the antenna was obtained from the manufacture of the reader module which is given in Figure 3.10.

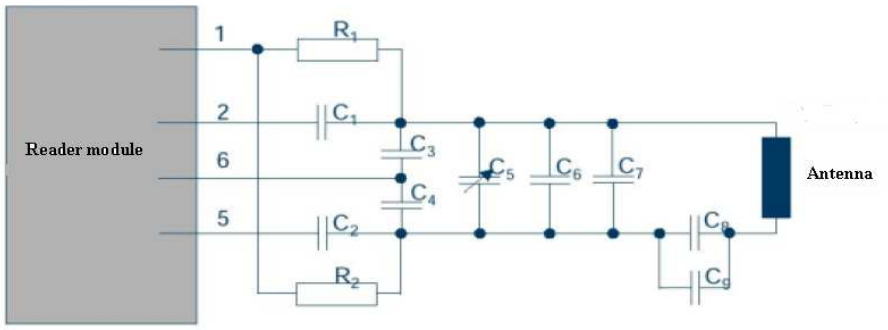


Figure 3.10: Equivalent circuit diagram for the reader antenna

Figure 3.11 shows a common circuit diagram for an antenna that uses the ACG reader module. As only ISO 14443B tags are read in this module, some of the components shown in Figure 3.10 are not necessary. The equivalent circuit for an antenna that reads only ISO 14443B tags is given in Figure 3.11.

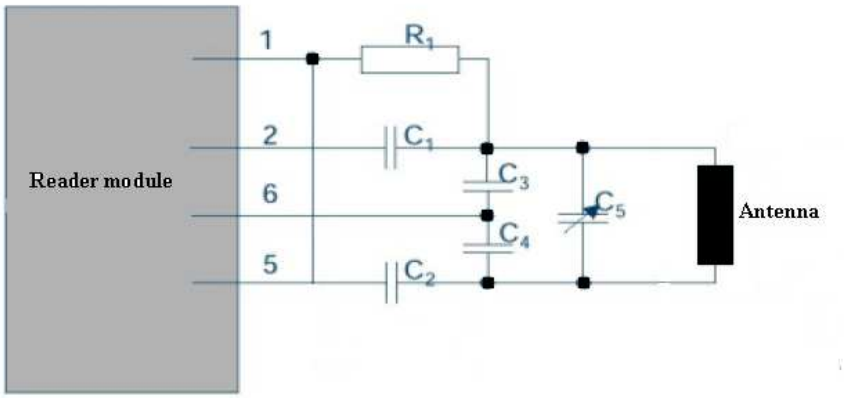


Figure 3.11: Equivalent circuit for an antenna that only reads ISO 14443B tags

3.1.4.2 Design of antenna components

Some design factors had to be considered before determining the values of the components of the antenna. The quality factor of the antenna is the first of these considerations.

The quality factor, or Q factor, as it is also called, is a dimensionless factor that compares the frequency at which a system oscillates with the rate at which it dissipates energy. In a parallel RLC circuit, such as the one shown in Figure 3.11, the Q factor [36] is given in 3-1

$$Q = R\sqrt{C/L} \tag{3-1}$$

The design specifications suggest that the Q factor should not be greater than 40 as this limits data transfer, and it should not be less than 20 as this will limit power transmission. Therefore, for design purposes, Q is assumed to be 22, therefore $Q = 22$.

The inductance of the circuit is generated from the number of turns in the antenna coil. The value of L is assumed to be 2.7 mH for designing the circuit.

So if Q = 22, L = 2.7 mH and the coil resistance of the antenna R_{COIL} is assumed to be 0.55 Ω, then using 3-2 [37] the resistance R_1 can be calculated.

$$R_1 = \omega.L\ /2(Q - R_{COIL}) \qquad (3\text{-}2)$$

Where;

ω = angular frequency = $2\Pi f$

f = 13.56 MHz

Q = Quality factor of antenna = 22

R_{COIL} = 0.55Ω

L = 2.7 mH.

When the calculation is done, the value of R_1 is theoretically obtained as 5.23 kΩ. However, during the experimentation, it was noted that there will be variations in the inductance values, and as a result a 10 kΩ potentiometer is used as R_1.

The value of capacitors C_3 and C_4 can be calculated similarly using Equation 3-3 [37]. In this instance input impedance is assumed to be 0.7kΩ. The rest of the terms are the same as in Equation 3-2.

$$C_3 = C_4 = \frac{1}{\omega \sqrt{\left[\omega L/(1\text{-}R/Z)\right]^2 - \frac{R_1^2 + \omega^2 L^2}{(1\text{-}R/Z)} + \omega L/(1\text{-}R/Z)}} \qquad (3\text{-}3)$$

The value of C_3 and C_4 is rounded off to the nearest value as 220 pF.

The value of C_1 and C_2 can be determined by using Equation 3-4. The value of $C_3 = C_4$ is used for this calculation.

$$C_1 = C_2 = \frac{R^2 + \left[\omega L - (1/\omega C_3)\right]^2}{\frac{\omega L}{C_3}\left[1/\omega\, C_3 - \omega L\right] - \left[\frac{R^2}{C_3}\right]} \qquad (3\text{-}4)$$

When the calculation is done, the value of C_1 and C_2 = 13.4 pF, and this is rounded off to 18 pF.

C_5 is used as a tuning capacitor for optimizing the antenna frequency. It is a variable capacitor with values ranging from 8.5 pF to 40 pF.

The values of the passive components used in the antenna circuitry have now been determined, and the equivalent circuit is given in Figure 3.12.

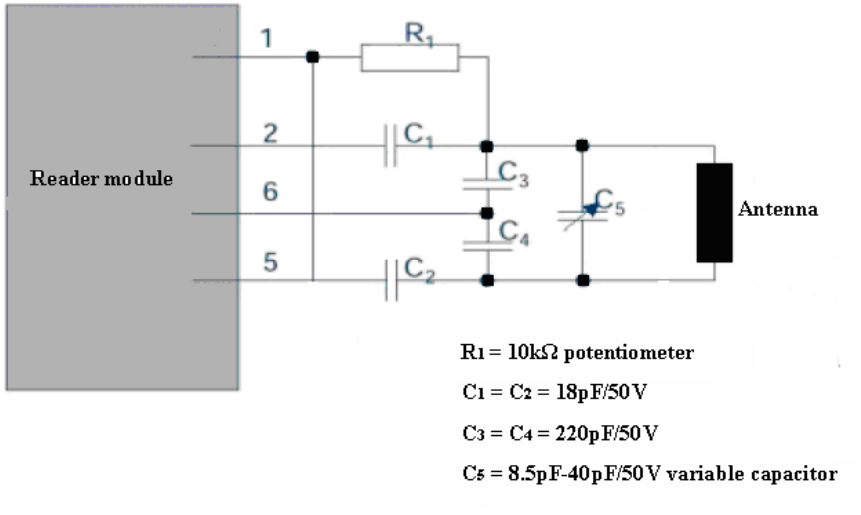


Figure 3.12: Antenna circuit indicating the values of components

3.1.4.3 Antenna design

The antenna must now be designed. The read range of a typical ISO 14443 Readers is about 100 mm depending on the size of the antenna that is used. A graph can be plotted for the antenna read range and the diameter of the antenna. This was done during the test process of the antenna design. Antennas with various diameters were constructed and the range was tested using the ISO 14443 tags (the student cards). The results can be plotted as shown in Figure 3.13.

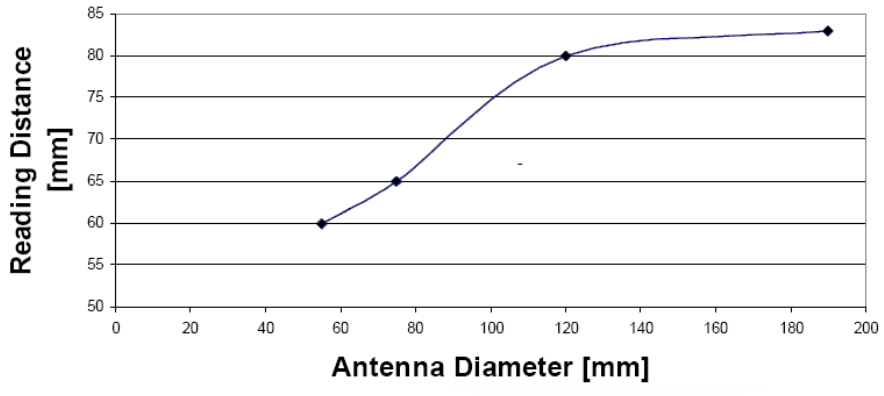


Figure 3.13: Correlation between read range and antenna diameter

It was observed that the read range increases with an increase in antenna diameter until it reaches a certain point (80 mm). After this point the read range continues to increase but only marginally. This observation was taken into consideration when designing the actual antenna.

The inductance of the antenna circuit is obtained by constructing a coil antenna, as mentioned in Section 3.1.3. The coil antenna designed for this project has 3 to 4 turns, a diameter of 80 mm and a track width of about 2 mm.

3.1.4.4 Antenna construction

The antenna is constructed using a milling process with Eagle software and a Roland Modela milling machine.

The Roland Modela milling machine mills a printed circuit board (PCB) to the exact specifications provided to the machine. This replaces the etching process previously used for constructing a PCB. For this project a Modela MDX-20 was used. A photograph of this etching machine is shown in Figure 3.14.

Figure 3.14: The Roland Modela MDX-20

The Modela milling machine mills a PCB according to the Gerber file it receives from the computer. The Gerber file is generated by computer-aided-design (CAD) software. Eagle CAD software was used for circuit design in this project.

The steps used for generating the Gerber file are detailed below.

Step 1

The circuit for the antenna of this project is given in Figure 3.12.

The first step is to draw a schematic of the circuit using Eagle CAD software. This is done by opening a new schematic in Eagle software. A screenshot is shown in Figure 3.15.

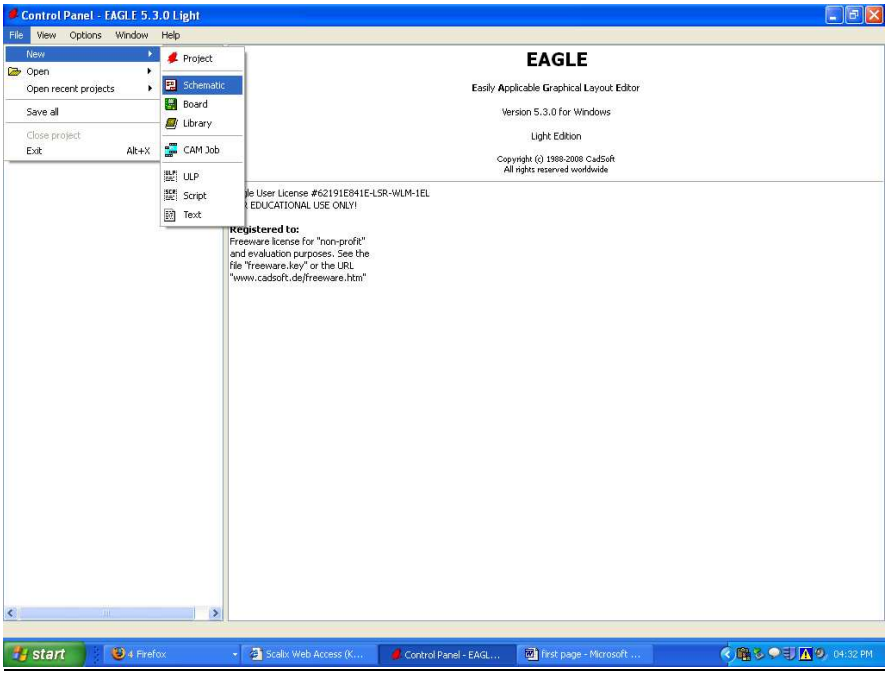


Figure 3.15: Screenshot of new schematic in Eagle software

Step 2

The circuit diagram for the antenna is drawn in the schematic page. This is done by selecting components from the Add components toolbar in the schematic box on the left of the schematic. This is shown in Figure 3.16.

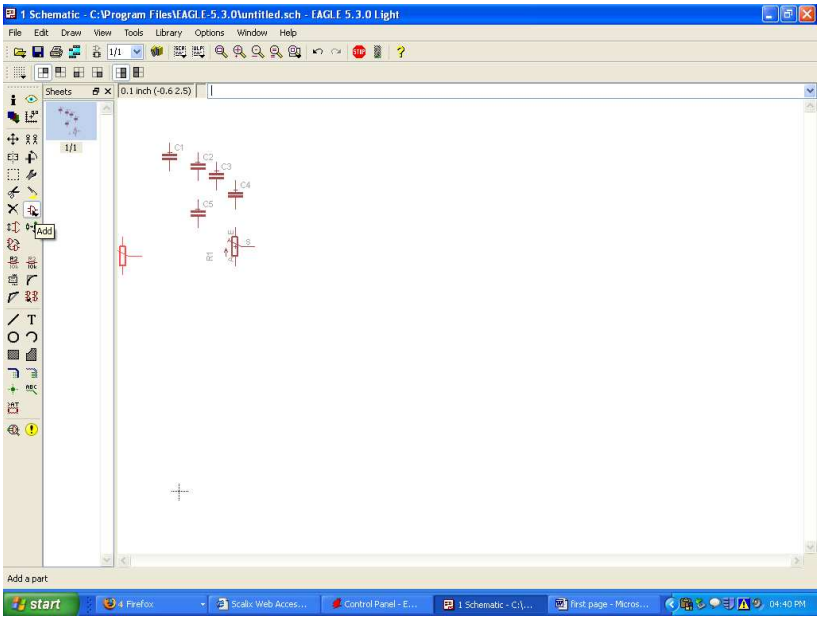


Figure 3.16: Adding components on the schematic page

Step 3

All the components necessary for drawing the circuit are placed on the schematic sheet as it is on the circuit diagram and the circuit is completed. A screenshot of the schematic for the antenna is shown in Figure 3.17.

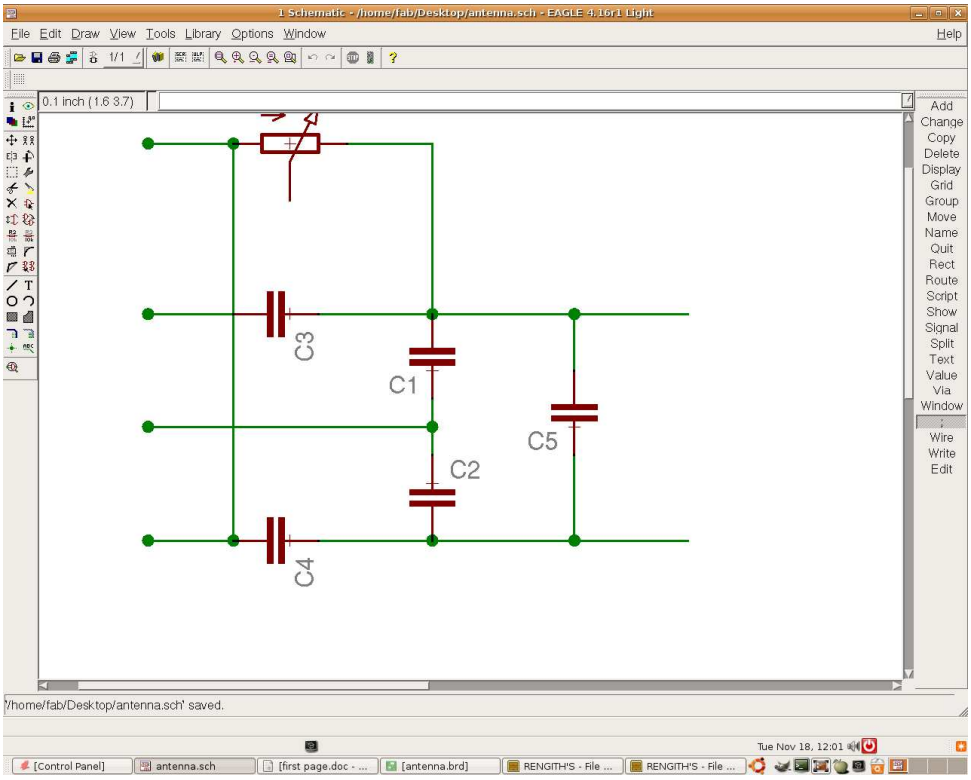


Figure 3.17: Schematic of the antenna in Eagle software

Step 4

Once the circuit is completed, the schematic is saved as a *.sch file. This particular file is saved as antenna.sch. The file has to be named because the next step is to convert the antenna.sch file to an antenna.brd file.

Step 5

The antenna.brd file is used for designing the loops of the antenna and placing the components. This is done using a trial-and-error method until there are no collisions between the two components. In keeping with the design rules of the antenna (Section 3.1.3.3), the antenna has 3 loops. The antenna.brd screenshot is shown in Figure 3.18.

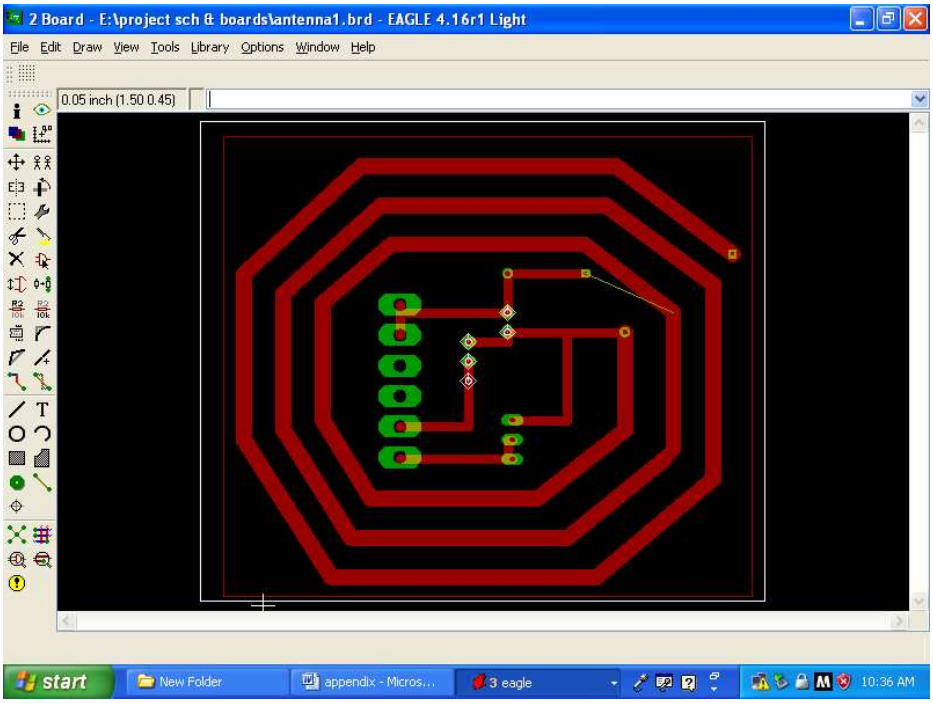


Figure 3.18: Board schematic of the antenna

Step 6

After the antenna.brd file has been created it is sent to the CAM processor. The CAM processor converts the .brd file to a file which is compatible with the Modela milling machine under file.

Step 7

The PCB on which the circuit is to be milled is placed in the Modela milling machine, along with the correct drill bit. The Modela machine starts on its own from one end of the PCB and works its way through the entire circuit as provided from the CAM processor.

Depending on the complexity of the circuit, milling can take between 30 minutes to 2 hours. Once the milling has been completed, the components are placed on the PCB and soldered. A photograph of the soldered antenna is shown in Figure 3.19.

Figure 3.19: Antenna constructed using the Roland Modela MDX-20

3.2 Wireless Section

The wireless section connects the RFID reader to the RFID middleware. It was decided that ZigBee technology would be used as the wireless link as discussed in section 2.7, and Section 2.8 gave the technical details of ZigBee technology. This section examines how the technical details are put into practice in this project.

3.2.1 Selecting ZigBee Modules

Although ZigBee is a relatively new technology, there is a vast number of retail vendors offering ZigBee products. Major electronics giants such as Atmel, Cirronet, Microchip, Panasonic and Silicon Laboratories are all actively competing in the ZigBee market.

The major consideration in this project were cost, data transfer range, size, reliability and availability. Due to time constraints not all the above ZigBee products were tested. However,

extensive research was done by consulting other researchers in various countries who had used several of these and other ZigBee products, bearing the considerations of this project in mind.

ZigBee technology was used in this project to eliminate what would otherwise have been a wired serial connection between the reader and the RFID middleware. The product which best fits the description is the Maxstream X-Bee module. The specifications of this product are given in Appendix F. X-Bee modules can be used as an RF interface between two devices by setting one device as the data transmitter and the other as the receiver.

This fits very well into this project as communication is always one way only (from the reader to RFID middleware). The next section discusses how the X-Bee modules were set up to operate as transmitter and receiver.

3.2.2 The X-Bee ZigBee Module

The X-Bee transceiver module is a 20-pin chip with an on-chip antenna for data transmission. The main advantage of the X-Bee module is that it has a Universal Asynchronous Receiver Transmitter (UART) interface which allows data transfer from the transmitter to the receiver using the ZigBee protocols.

The ZigBee hardware has to be designed such that the serial port logic levels are compatible with the X-Bee's 2.8-3.4 V logic levels. This is achieved by using a MAX 232 chip, the same technique used to connect the reader module to the computer. For this project, two X-Bee modules are needed. One module is connected to the reader and the other to the computer to

which the tag data must be transmitted. The X-Bee communications link for this project is shown in Figure 3.20.

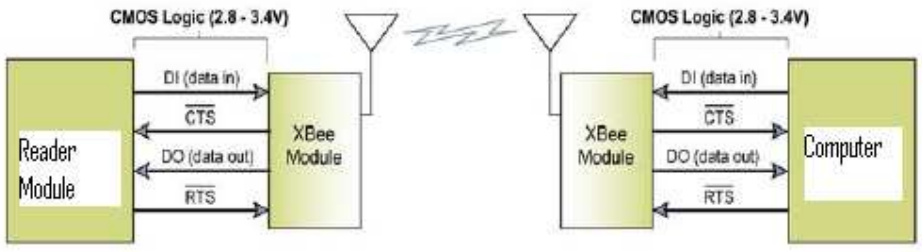


Figure 3.20: X-Bee communication link between reader and computer

The X-Bee module can work in the transparent mode for this project. In the transparent mode the X-Bee module acts as a serial line replacement. The incoming data are queued for RF transmission and channelled out through the transmitter. The operation of the transparent mode can be best understood by studying the internal pin diagrams of the X-Bee module. The pin diagram of the X-Bee module and the relevant information are given in Appendix G.

The internal configuration of the X-Bee module is given in Figure 3.21

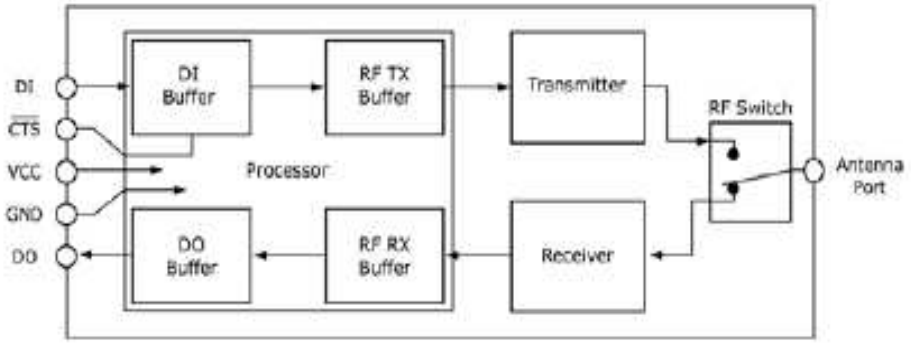


Figure 3.21: Internal configuration of X-Bee module

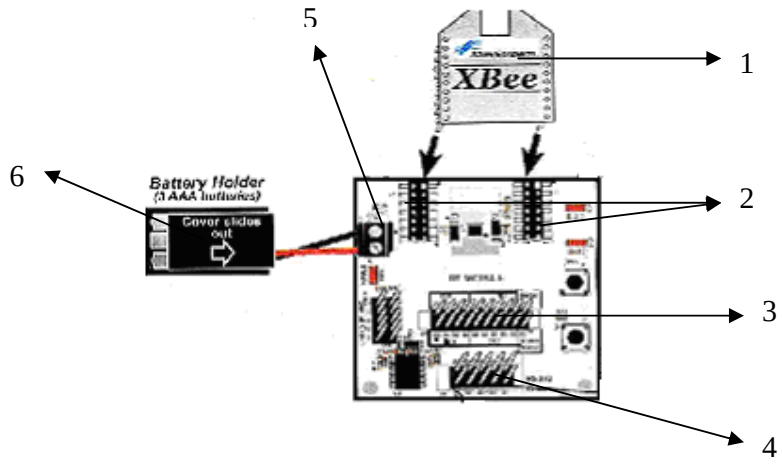
In Figure 3.22 DI is the data input pin, and DO is the data output pin. CTS is the Clear To Send flow control pin it is active LOW signal. The data that need to be sent from the RFID reader come to the DI pin and are sent to the DI buffer until they can be transmitted. The hardware flow control of the DI buffer is implemented using the CTS pin.

When the DI buffer is 17 bytes from being full, the CTS pin goes logically HIGH. This signals the reader to stop sending data. The data remaining in the DI buffer are sent to the RF Tx (RF transmitter) buffer and from there to the transmitter. The RF switch in the antenna port of the X-Bee module transmits the data. The CTS pin returns to logic LOW after the DI buffer has been cleared.

The same process is repeated but in reverse order at the X-Bee module connected to the computer. Here the data are collected by the receiver and passed on to the RF Rx (RF Receiver) input. In the receiver section the RTS (Request To Send Flow) pin checks whether the RF Rx buffer is full. If yes, it transfers the data in the RF Rx buffer to the DO buffer. The data are then transferred from the X-Bee module to the computer through the DI pin.

3.2.3 The X-Bee RF Interface Module

Section 3.2.2 explains the basic functioning of the X-Bee module. This section examines the RF interface module used for connecting the X-Bee module to external devices. Figure 3.22 shows the RF interface board.



1- X-Bee module

2- J1, J2

3- J5

4- J6

5- Battery terminal

6- Battery holder

Figure 3.22: The RF interface module and its parts

Shown in Figure 3.23 is the X-Bee module goes into J1 and J2. J5 determines whether the X-Bee module works as Data Communication Equipment (DCE) or Data Terminal Equipment (DTE). J6 is a 10-pin header used for connecting the RF interface board to the RS232 port of the external device.

The RF interface module can function either as Data Communication Equipment (DCE) or as Data Terminal Equipment (DTE). If the X-Bee module functions as DCE, it communicates with an external device and transfers data from it. If it functions as DTE, it transfers data from the X-Bee module to the terminal equipment. Figure 3.23 shows pin J5 in detail.

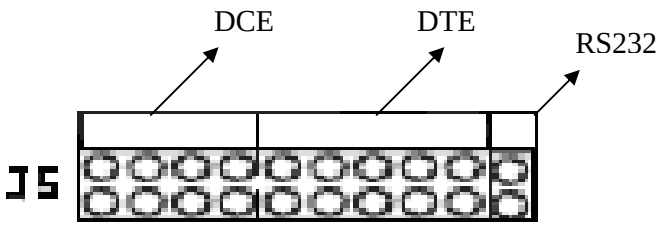


Figure 3.23: Pin J5 of the RF interface board

3.2.4 Setting up the X-Bee Module with the RFID reader

For the X-Bee module to transfer data from the RFID reader, jumpers have to be connected in the DCE pins and the RS232 enable pins of pin J5. These jumper settings are shown in Figure 3.24.

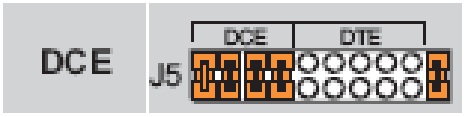


Figure 3.24: The jumper settings for X-Bee as DCE

Once the jumper settings are as shown in Figure 3.24, the RFID reader is connected to pin J6 using the RS232 interface that was used for programming the reader module. A 10-pin to DB

9 male connector is used for this purpose. Figure 3.25shows the actual set-up used in this project to connect the RFID reader module to the X-Bee module.

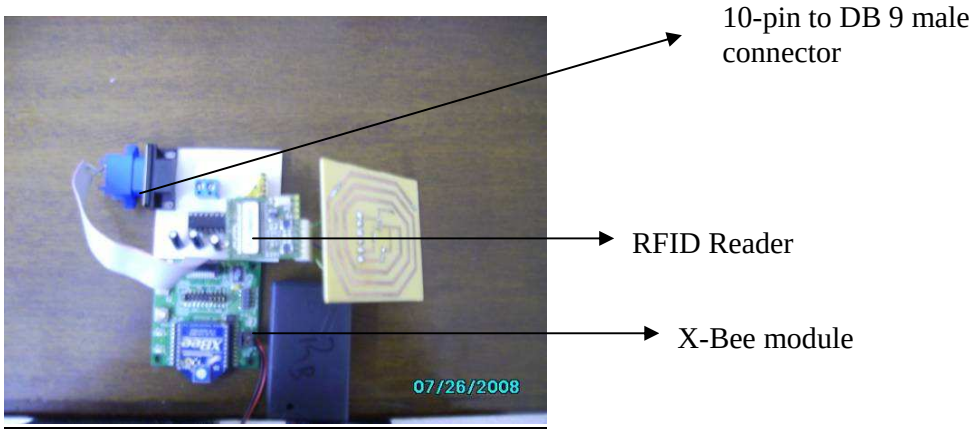


Figure 3.25: Experimental set-up of the RFID reader with X-Bee module

3.2.5 Setting up the X-Bee Module and RFID middleware

An X-Bee module must also be connected to the RFID middleware so that the data from the X-Bee module connected to the reader can be received and transferred to the computer.

The X-Bee module is connected to the serial port of the computer (RFID middleware) using a 10-pin to DB 9 female connector. The X-Bee module must also be set up to function as Data Terminal Equipment (DTE) so that it can receive the incoming data.

For an X-Bee module to function as DTE, jumpers must be connected to DTE pins and RS232 enabled as shown in Figure3.26.

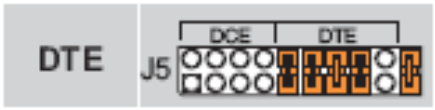


Figure 3.26: The jumper settings for X-Bee as DTE

Once the jumper settings are as shown in Figure 3.26, the X-Bee module is connected to the RFID middleware using pin J6 and a 10-pin to DB 9 male connector. The actual set-up used in this project is shown in Figure 3.27.

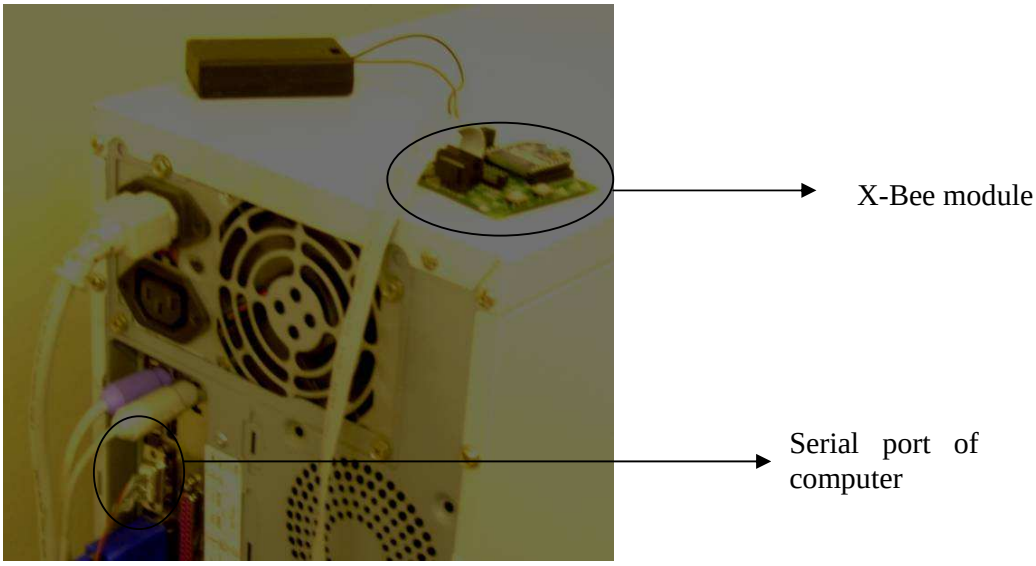


Figure 3.27: Experimental set-up of X-Bee module to computer

3.3 Software Section

In the software section of the project, data are collected from the serial port of the computer and entered into a database table. As indicated, Apache Derby Database and Java programming are used to manipulate data. The general idea is that a database table is initially created which contains all the details of a student in a class from his/her student card.

Once the student enters a classroom, s/he scans his/her card with the RFID reader. The reader picks up the unique card number from the student card and sends the data to the serial port of the RFID middleware (computer). Using the Java program, a comparison is made between the incoming data and the data contained in the initial database table. If there is a match between the two, the received data are entered into a second database table along with the date.

The second database table serves as the attendance register. It contains the attendance details of all the students who have been enrolled in the class. A flow chart showing detailing the complete process is shown in figure 3.28.

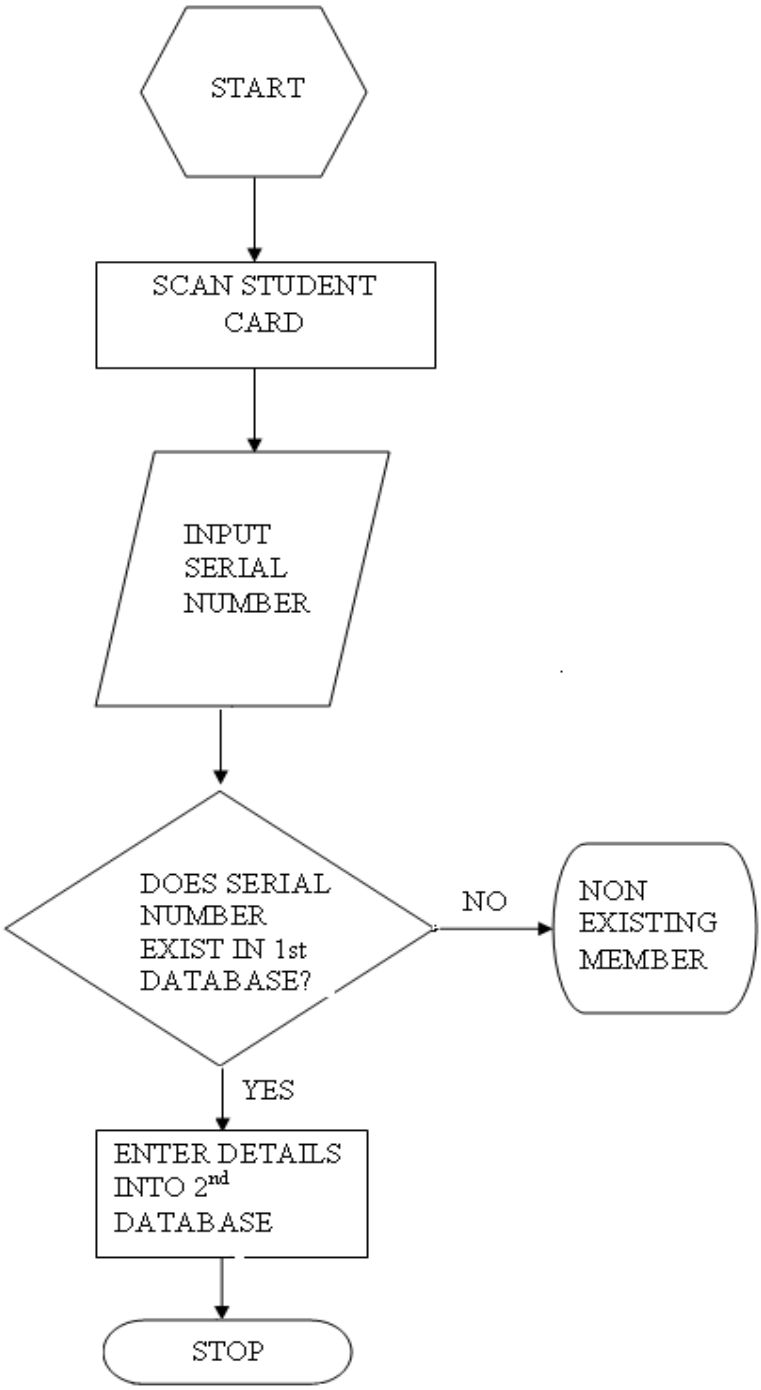


Figure 3.28: Flow chart explaining the software section.

The sections below explain how the two database tables have been set up and how the Java program is written to access the serial port of the computer.

3.3.1 Creating Database Tables using Apache Derby Database

Section 3.3 explains that this project needs two database tables. The first table contains four columns: the card number of the student (as mentioned earlier), student name, student surname and student number (distinguished from card number). This table is called ‘Admin’. Figure 3.29 shows the database table ‘admin’ being created.

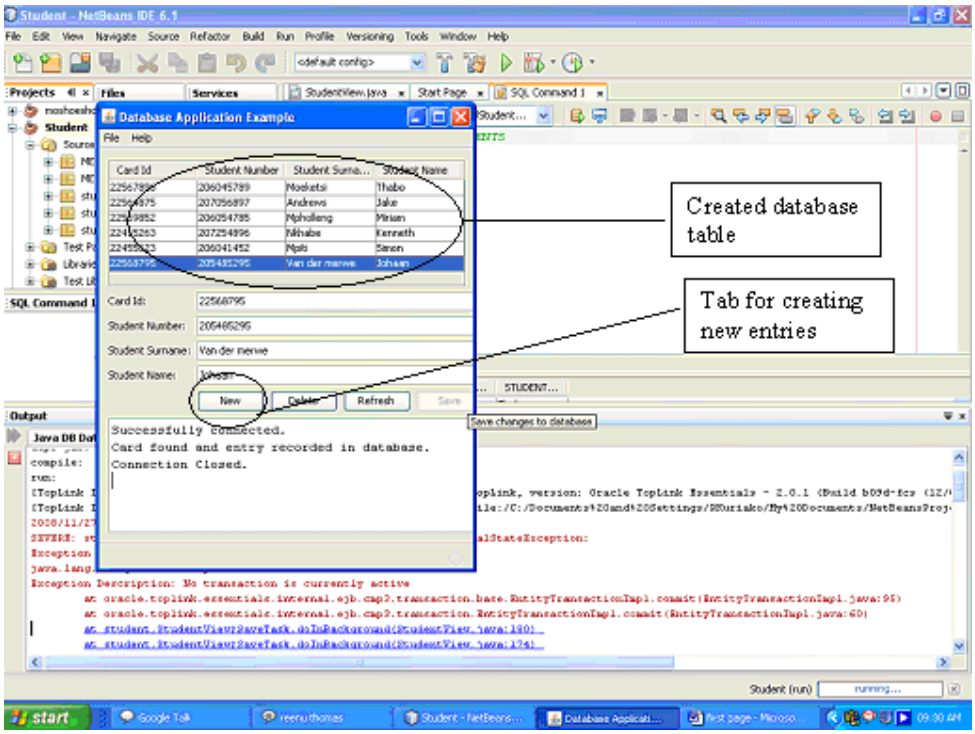


Figure 3.29: The ‘admin’ database table

The second database table is automatically updated once the student card is scanned by the reader. It is called ‘attendance’. It contains two columns: one for date and time of entry and one for the student number. Figure 3.30 shows the ‘attendance’ database table. The database in which the ‘admin’ and ‘attendee’ tables are stored is called ‘StudentAtt’.

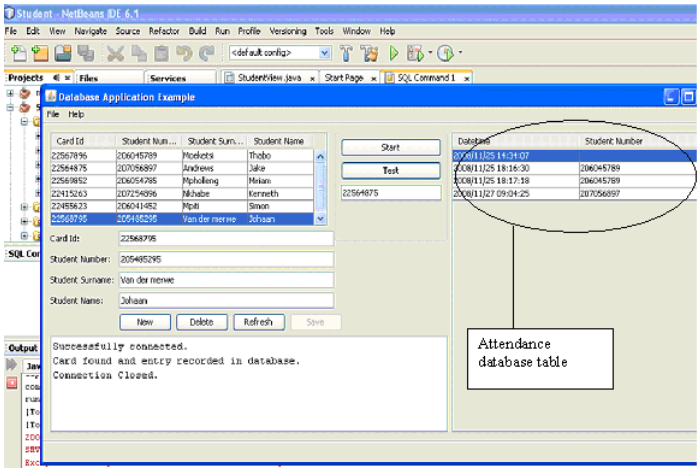


Figure 3.30: The 'attendee' database table

3.3.2 Java Programming

This section examines the Java coding. The actual program is given in Appendix H. The programming is explained step by step.

Step 1 - Importing java.sql packages

The first step is to import all the packages necessary for transferring data from the serial port of the computer to the Java IDE

Step 2 - Setting up connection with serial port

The second step is to set up a connection with the serial port (COM port) of the computer. This is done using the connection class. This Java class defines the serial port parameters such as baud rate, data bit, parity and stop bits. The parameters are similar to those used by the RFID reader.

Step 3 - Setting up a serial port event buffer

The third step is to set up a serial port event listener method. This method checks for incoming data from the reader to the serial port. If there are any data at the serial port, it is transferred to an output buffer.

Step 4- Setting up connection with database

This step of the Java coding uses JDBC to connect with the Apache database. The DriverManager.getConnection statement is used to establish a connection with the StudentAtt database.

Step 5 - Comparison of received data with database tables

The fifth step is to make a comparison between the received data from the reader and the ‘students’ database table. If there is a match then the data are entered into the ‘attendance’ database table along with date and time.

PART 4

CAHPTER 4 RESULTS

Tests were conducted at various stages of the project work. The results of these tests are detailed in this section. At the beginning of Part 3, the project was split into three sections: the hardware, the wireless and the software sections. Testing was done at the end of each section before proceeding to the next stage.

4.1 Hardware Setup

The RFID reader is placed by the entrance of the classroom where the attendance needs to be registered. The students walk into the classroom and scan their student cards as they enter the classroom. Therefore, the scanning of student cards is an instantaneous process. A laptop computer with a ZigBee end device is placed at lecturer's table. A schematic of the set-up is shown in Figure 4.1. The range between the RFID reader and the student card (indicated as a tag in Figure 4.1) is about 3-4 cm.

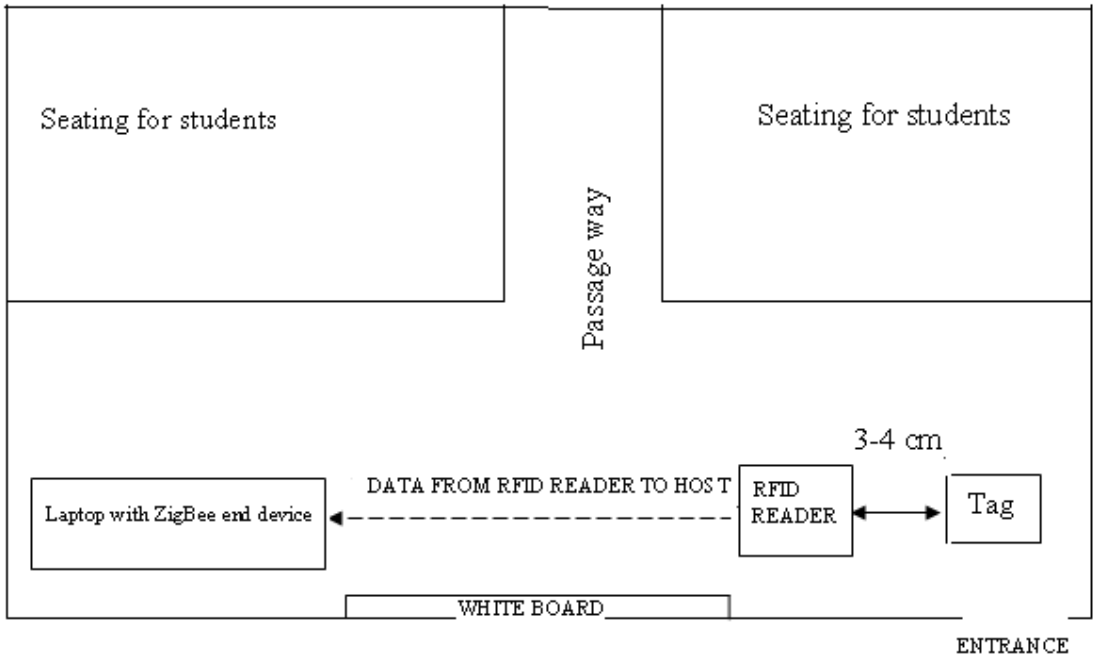


Figure 4.1: Schematic showing Hardware setup of the RFID reader and Host

4.2 Hardware Testing

The hardware part of the project consists of the reader module and the antenna. The programmed reader module could only be tested after the antenna was constructed. The hardware testing of both the antenna and the reader module was, therefore, done together.

4.2.1 Testing of the antenna

The antenna was connected to the programmed reader module as previously shown in Figure 3.12. In order to read the student cards (tags), the antenna had to be optimised to the frequency of the RFID reader module (13.56 MHz).

This testing was done by connecting the antenna to an oscilloscope and powering the reader module. The frequency of operation was monitored on the oscilloscope at the same time, and

was varied by changing the values of the variable capacitor and potentiometer on the antenna module. The process was continued until the frequency of operation was 13.56 MHz. Figure 4.2 shows a photograph of the testing equipment.

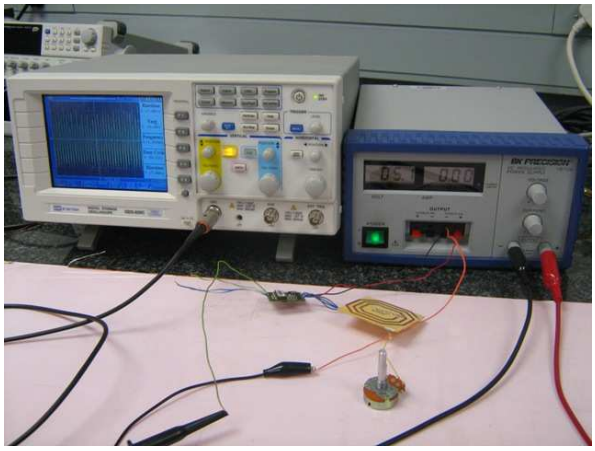


Figure 4.2: Fine tuning antenna operating frequency with an oscilloscope

4.2.2 RFID reader testing

Once the antenna was operating at 13.56 MHz, it was connected to the reader module. Now the reader module was tested to see whether it could read ISO 14443B tags (student cards in this case). In order to carry out this test, the reader (reader module and antenna) was connected to the serial port of the computer.

The hyper-terminal program in Windows XP was used to check whether there was an output when the student card was scanned by the antenna. The hyper-terminal settings, which are in accordance with the reader module, are shown in Figure 4.3.

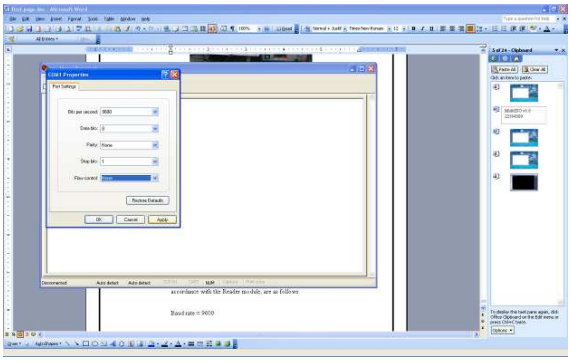


Figure 4.3: Hyper-terminal settings

The reader was programmed such that when powered it output the name of the reader module and the version it uses. After a student card is scanned the reader outputs the 8-character serial number as well. Figure 4.4 shows a screenshot of the hyper-terminal output.

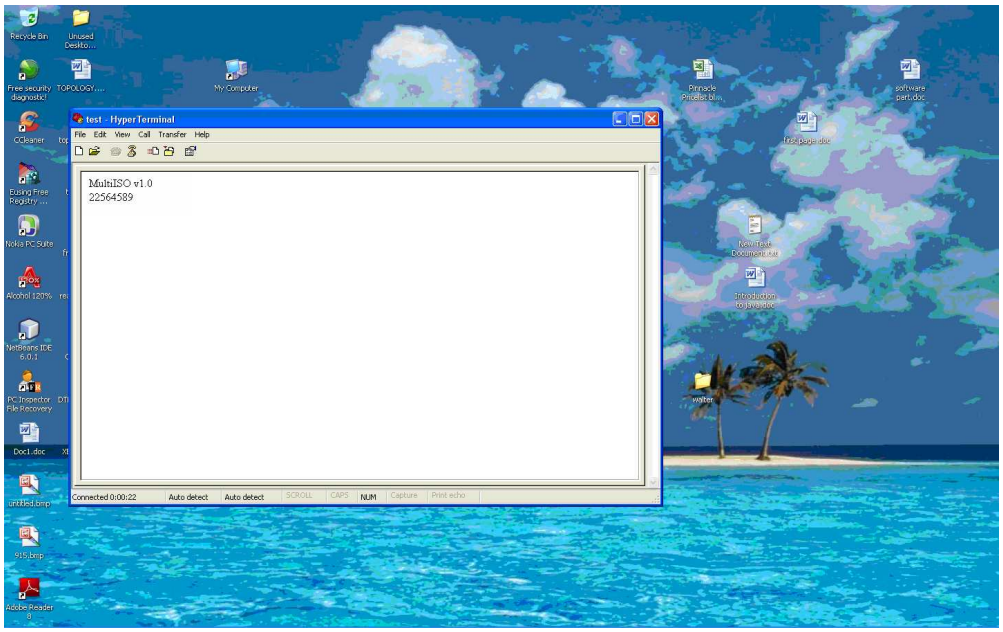


Figure 4.4: Hyper-terminal output after scanning a student card

4.2.3 Reader range testing

The third test done on the hardware was the range test. Theoretically the read range of an ISO 14443B tag is about 100 mm. However, in practice owing to various factors such as attenuation and antenna dimensions, the range is much less than the theoretical value. Twenty sample range tests were done to determine the range for this specific RFID reader. The results were mostly between 30 and 40 mm. Figure 4.5 shows a photograph of the range testing.

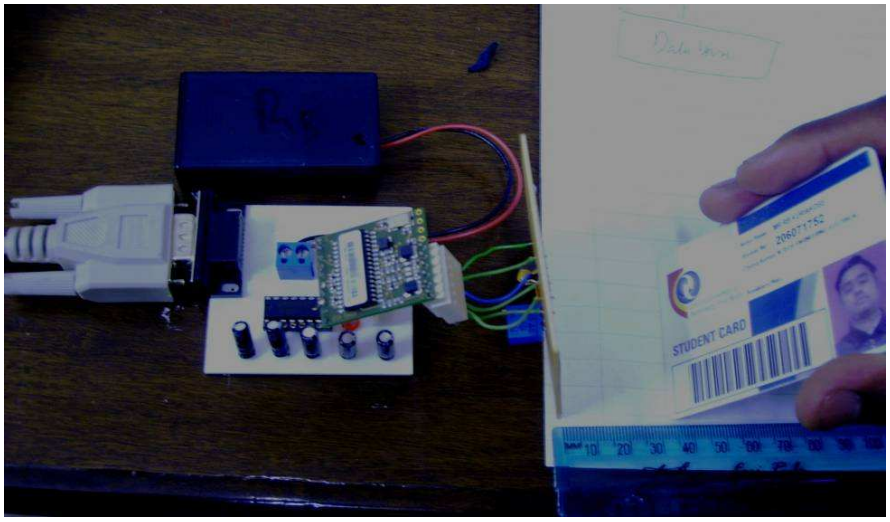


Figure 4.5: Reader range testing (note the range is about 35 mm in this test)

A graphical representation of the read strength of the RFID reader with respect to the distance between the reader and the tag has been plotted in figure 4.6

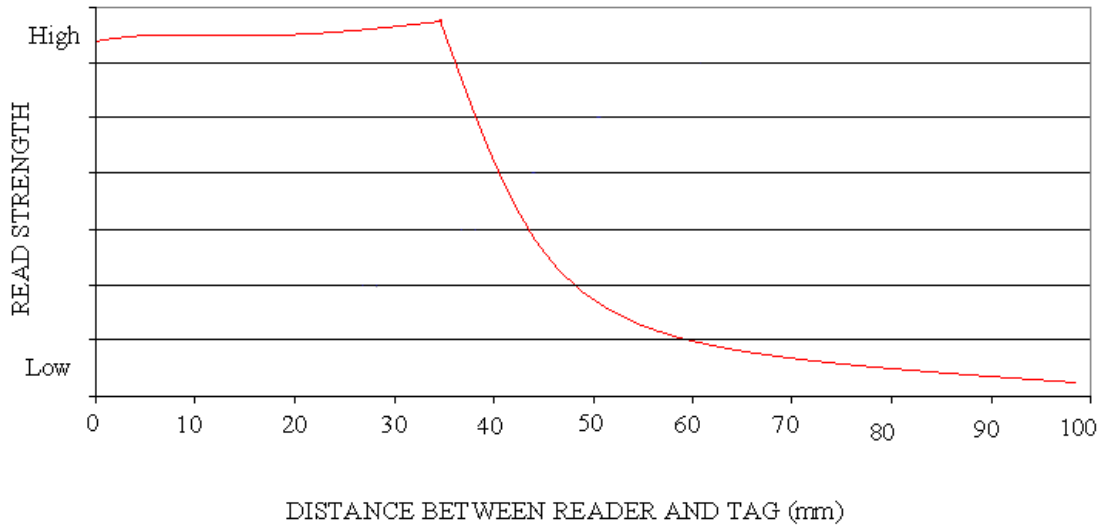


Figure 4.6: Graphical representation of read strength of the RFID reader with respect to the distance between the Reader and the tag

4.3 Wireless Testing

The X-Bee module was tested for its range. This was done using software from Rabbit semi-conductors called X-CTU. The theoretical internal range of the X-Bee module is 30 m. The procedures for the range test are detailed in section .4.3.1.

4.3.1 X-Bee module range testing

The range testing was done using two X-Bee modules which were mounted on the RF interface module. One X-Bee module was connected to the computer (Base module) and the other (remote module) was used for testing the range. The hardware set-up for the range testing is shown in Figure 4.7.

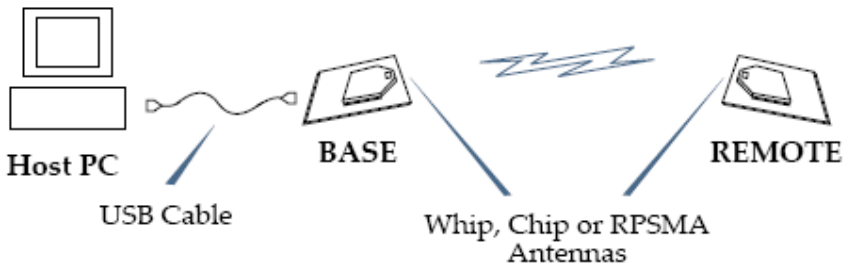


Figure 4.7: Hardware set-up for X-Bee module range testing

Once the hardware set-up was completed, the following steps were carried out to determine the range of the module.

Step 1

Launch X-CTU software (Desktop → Start menu → Programs → Maxtream → X-CTU).

Figure 4.8 shows a screen shot of the X-CTU window.

Figure 4.8: X-CTU window screen shot

Step 2

Click on PC settings, select serial port com port and set baud and data settings as follows:

Baud rate = 9 600

Flow control = NONE

Data bits = 8

Parity = NONE

Stop bits = 8.

Step 3

Click on range test, check the Received Signal Strength Indicator button (RSSI), and click on the start button to start the range test. Figure 4.9 shows a screen shot of this tab.

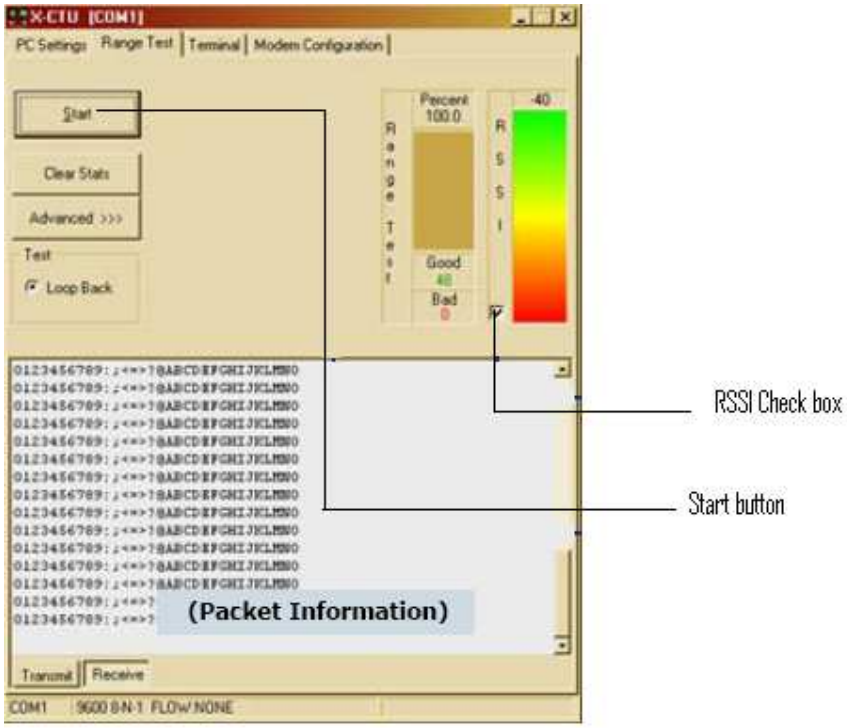


Figure 4.9: The range test window of X-CTU software

Step 4

The remote module is moved away from the base module. The RSSI display indicates the signal strength. Green indicates a high signal strength and read indicates a weak signal.

4.4 Software Testing

After all the testing was done, as explained in sections 4.1,4.2 and 4.3, the RFID reader was setup in a classroom for automating attendance registration. The testing was done on a group of students belonging to a specific class for one month (28-01-2008 to 11-02-2008). In this one month there were four classes for this group of students. (This group of students is referred as the test group as attendance registration using RFID reader was first done on them)

Initially the details of each student were entered into a computer using the RFID reader and their respective student cards. Each student was required to pass by the RFID reader with his/her student card. The student cards have a unique identification number referred to as the card number. As a student scans his/her student card, the card number appears on a database table named ‘admin’.

The name of the student and the student number corresponding to a card number has to be manually entered into the database. Figure 4.10 shows the ‘admin’ database table that was created for this specific class.

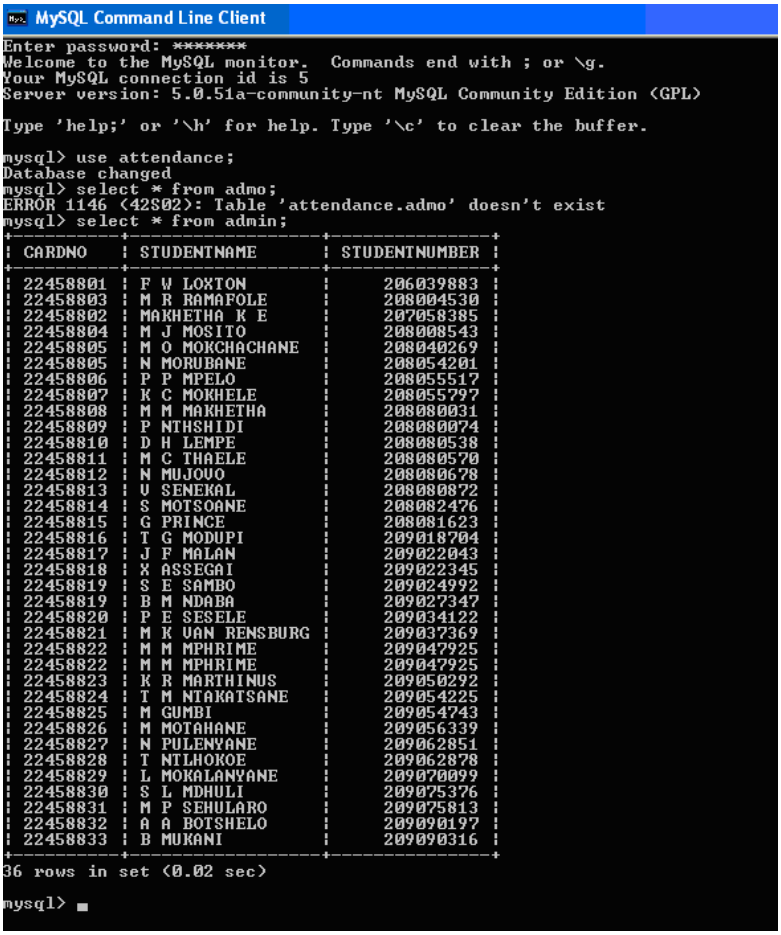


Figure 4.10: 'admin' database table created for the test group.

It is seen in Figure 4.10 that the card number is represented in the first column, the student name in the second column and the student number in the third column. Each row designates the card number along with the student name and student number corresponding to that card number.

The first class for the test group was on 21st January 2008. The students were asked to scan their student cards on their way into the classroom. Once a student card was scanned and data was read from the card, a green LED would flash on the RFID reader. This indicates that data has been successfully read from the student card.

If the card number of the scanned student card is present in the ‘admin’ database then the student number and student name corresponding to the card number are entered into a second database table with the date of entry. This database table is referred to ‘attendee’. Figure 4.11 shows the ‘attendee’ database table.

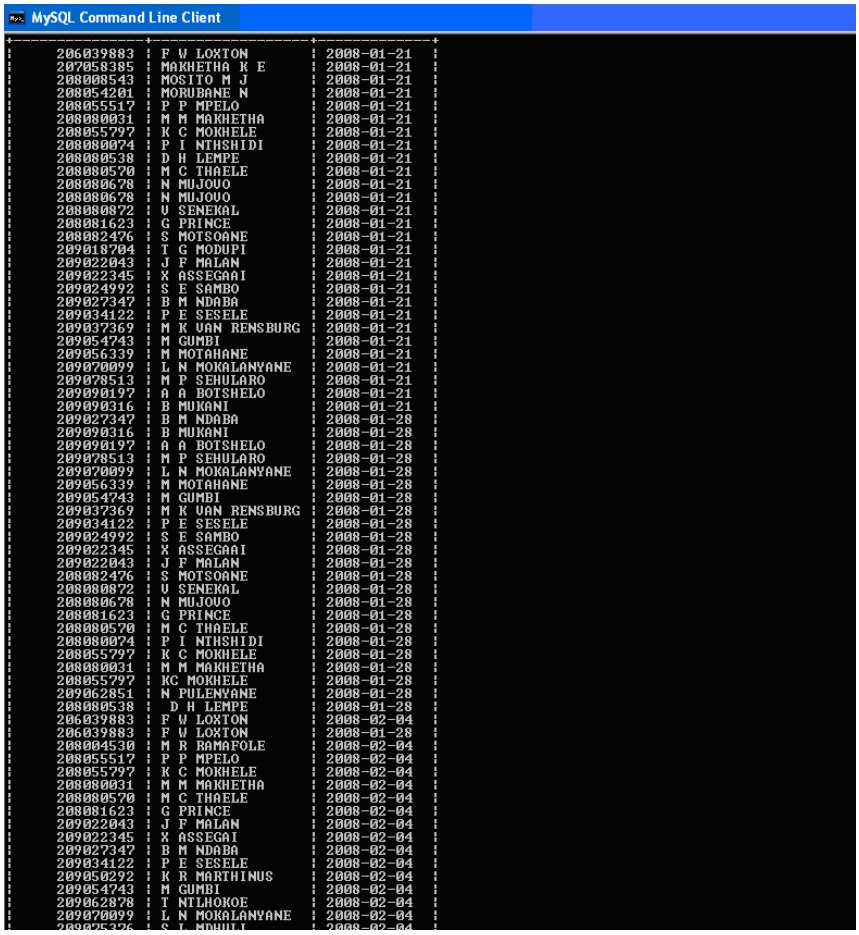


Figure 4.11: The ‘attendee’ database table.

The attendee database table is the attendance register that is generated using the RFID reader and the software manipulations. It contains the names and student number along with the date of entry into a classroom for each student.

Once all the students have scanned their student cards the RFID reader was switched off and put aside for the lecture to continue. This process was repeated on three occasions for the remainder of the month. The attendance list for every other day that class was conducted is shown in figure 4.12, 4.13, 4.14 and 4.15.

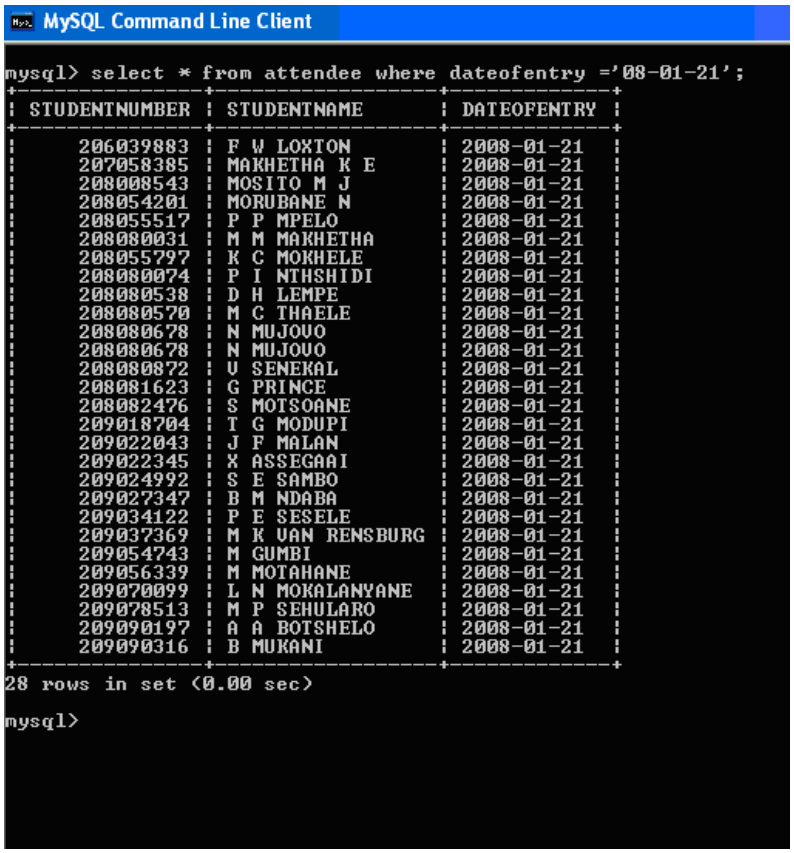


Figure 4.12: Attendee database table for 21 -01-2008

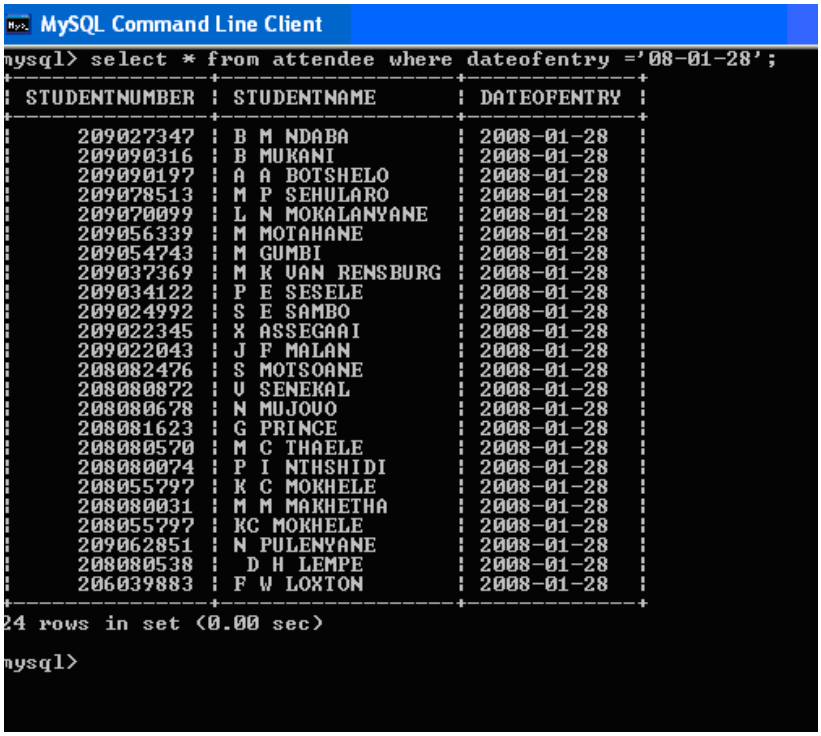


Figure 4.13: Attendee database table for 28 -01-2008

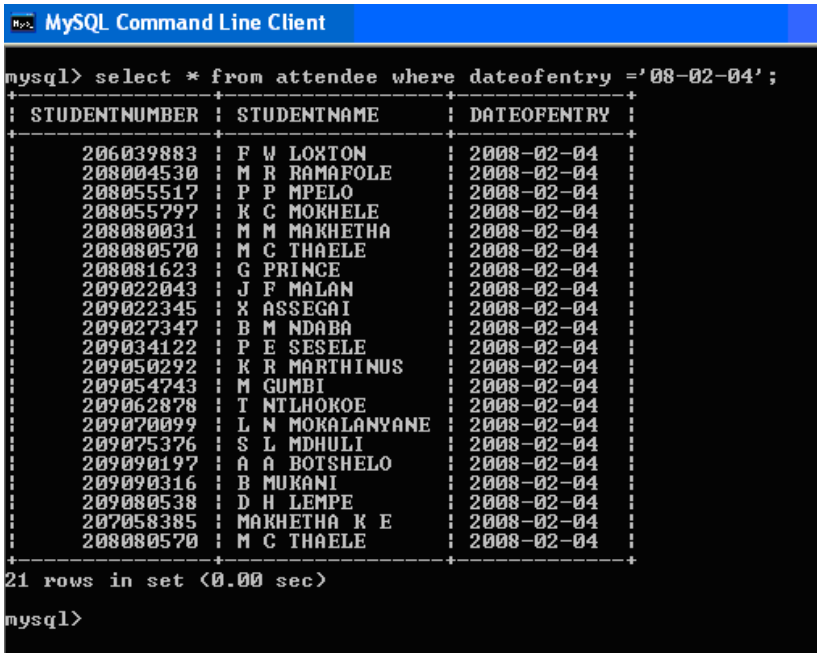


Figure 4.14: Attendee database table for 04 -02-2008

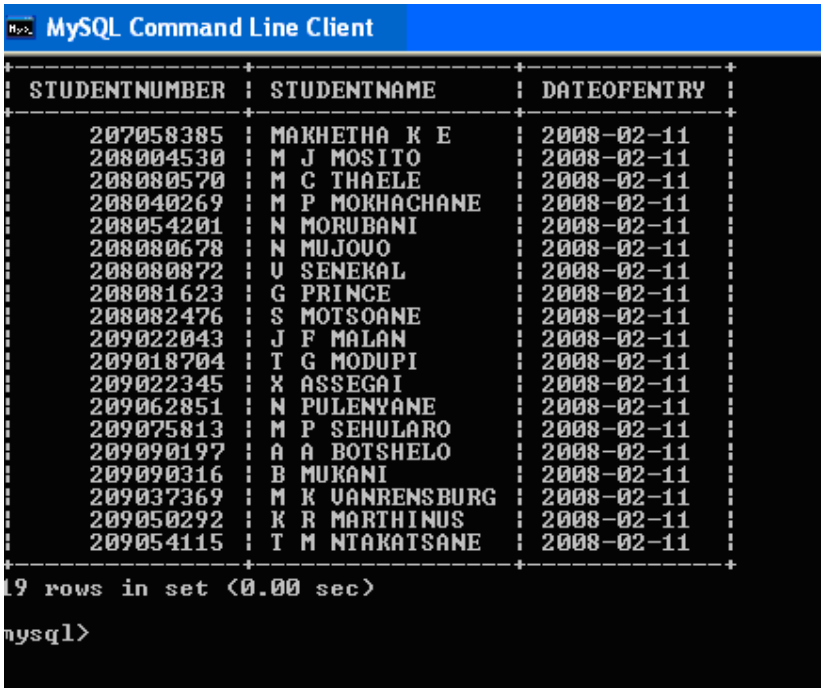


Figure 4.15: Attendee database table for 11 -02-2008

As explained at the beginning of this section, there were four classes for this specific subject in a month. At the end of the four classes, the lecturer in charge of the subject can specifically check the how many classes each student has attended. An example is done using student number 206039883. It is shown in Figure 4.16.

Figure 4.16 shows that student F W Loxton (student number 206039883) attended three classes, out of four, in a month. The dates that he appeared in class are also shown in Figure 4.16. It can be easily deduced that the student has a 75% attendance for the duration of the month.

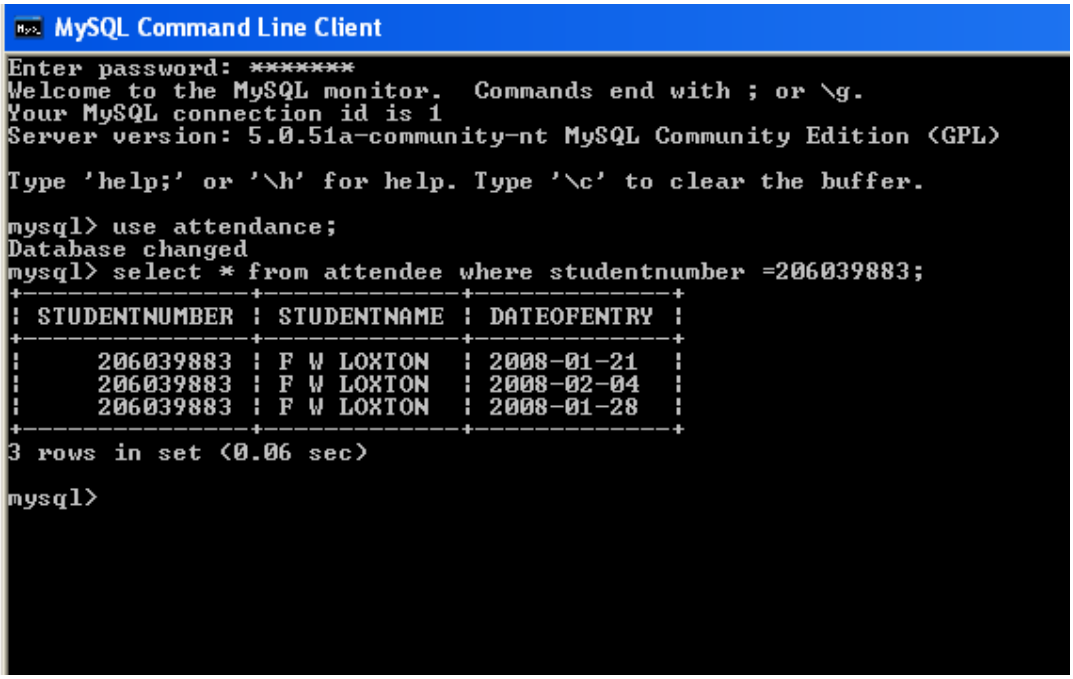


Figure 4.16: Shows the attendance of a student during the test period

This was done for every other student in the class, thereby generating an attendance list for the whole class.

CHAPTER 5 CONCLUSION AND FUTURE WORK

The RFID system used for automating the attendance register in this project can scan a single student card at a time. The reason for this being that the read range of the RFID reader is about 3-4 cm (Section 4.2.3). The range was fixed at this level so as to avoid anti-collision (Section 3.1.3). Once the student card is scanned at this read range by the RFID reader, the data from the student card (Section 4.4) gets transferred to the software section. The software section is by design very flexible, thus allowing search function (Figure 4.6) and results in percentile as well.

The design of the software section is such that if the same student card is scanned by the RFID reader twice within a very short space in time, the student card will be read twice by the RFID reader. But the software section is designed such that only a single entry will be made into the database table for student card accidentally scanned twice.

This project was aimed at automating the student attendance register of the Central University of Technology (CUT) using RFID technology. It was noted during the project that the student cards issued to students at the time of registration were indeed RFID tags. This considerably reduced the cost of the project and also made the application of the project cost effective.

After testing with various RFID readers in order to better understand the concepts of RFID, the MIFARE MultiISO reader module was selected as the best for this project. The module was consequently programmed and an interface between the reader and the tag was created using an antenna.

The design of the antenna posed the first challenge as slight variation in the value of the antenna components resulted in the malfunctioning of the antenna. However, after many trials the antenna parameters were finally corrected and the antenna was able to read data from the RFID tags (student cards) and transfer them to the reader.

The software section of the project was then designed. Programming was done using Java and Apache Derby databases. A lot of thought went into the most suitable programming languages. In the end the versatility of Java programming, and the ease of use and user flexibility of the Apache Derby database resulted in their being selected over C-Sharp and MySQL.

The programming offered the second set of challenges for the project as it required knowledge of some of the major components of a huge programming language. This was achieved with the help of some of the classes from the Information Technology staff of the University. It is worth mentioning that only a part of the Java programming language was used and is discussed in this thesis.

The final and undoubtedly most challenging part of the project was to set up the wireless link between the reader and the middleware. This was because ZigBee technology was a fairly new technology in South Africa at the time of the project (April 2007). There was very little local support for ZigBee devices, but using the social networking site, ORKUT, many people overseas (mainly in Finland, India and USA) who had worked with ZigBee technology were contacted.

After very detailed discussions with several people in various countries, the idea of Maxstream's X-Bee modules came to the fore. The same people also provided much-needed support with the installation.

Finally, after months of planning and detailed study of all the components used in the project, they were put together and the project started functioning exactly as planned. The project was implemented on a test basis in the Digital Electronics laboratory of the Central University of Technology. The laboratory was chosen as there were only two batches of students per week and it provided the best opportunity to uncover any glitches in the project. The results mentioned in Section 4 were taken from the use of the RFID reader in this lab.

5.1 Future Works

This Central University of Technology uses Oracle as the software for maintaining its database. A person doing further research in this field may look at ways to integrate Java program with Oracle instead of MySQL used in this project. MySQL was used at the time because it was a freeware and it considerably reduced the cost of the system.

This specific project looks at automating attendance registration from a single class room point of view. Research can be done to see if multiple RFID readers can be placed in different classes at the same time and their outputs be channelled into a single server machine. A web interface for such an application can also be a focus area for students working in Information Technology department of the university.

RFID is a technology which is still in its growing phase in South Africa as well as the world. This thesis dwells into one of the applications of RFID and how it can be set about to solve a real environment problem. Research can be done by students on certain aspects mentioned in this thesis like anti-collision, increasing the read range of the antenna or making RFID systems with onboard memory.

The possibilities of research in this field are endless and it I sincerely hope that readers of this thesis will be able to think of ways to innovate their surroundings using RFID technology

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APPENDIX A: HARDWARE SPECIFICATION OF THE READER MODULE

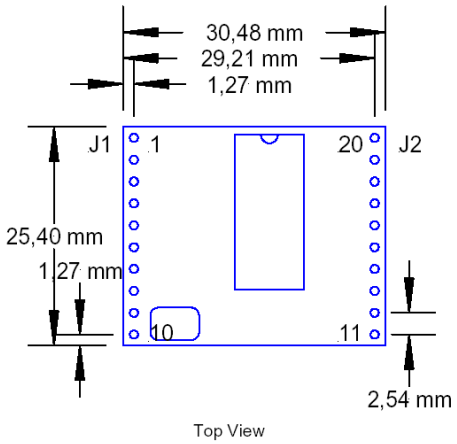
APPENDIX A

ACG id

11 Hardware

11.1 Dimensions

All dimensions listed in mm



Top View

ACG Identification Technologies GmbH

APPENDIX B: PIN NUMBERS OF THE READER MODULE

11.1.1 Pin out of J1

PIN	PIN No.	Description
ARX	1	Antenna RX
ATX1	2	Antenna TX1
VDD	3	Supply Voltage
GND	4	Ground
ATX2	5	Antenna TX2
TGND	6	Antenna Ground
SAM CLK	7	SAM clock
SAM IO	8	SAM IO
SAM RESET	9	SAM Reset
RTS	10	Request to Send

Figure 11-1: Pin out of jumper 1

11.1.2 Electrical characteristics of J1 PINs

PIN	PIN No.	Min	Typ.	Max.	Description
ARX	1	1.1V		4.4V	Antenna RX
ATX1	2		13,56 MHz 34 V_{PP}	100 mA_{PP} 50V_{PP}	Antenna TX1
VDD	3	+4.5V	+5.0V	+5.5V	Supply Voltage
		32mA	150mA	250mA	Supply Current (without SAM)
GND	4		GND		Ground
ATX2	5		13,56 MHz 34 V_{PP}	100 mA_{PP} 50V_{PP}	Antenna TX2
TGND	6		GND		Antenna Ground
SAM CLK	7		TTL		SAM clock
				25mA	
			3,39MHz		
SAM IO	8		TTL	25 mA	IO for SAM Input and SAM Output
SAM RESET	9		TTL	25 mA	SAM Reset
RTS	10		TTL	25 mA	Request to Send

Figure 11-2: Electrical characteristics of pins

11.1.3 Pin out of J2

PIN	PIN Nr	Description
VDD	20	Supply Voltage
GND	19	Ground
LEDg	18	LED green (reading LED)
LEDr	17	LED red
EN	16	Enable reader, open or logic high
MCLR	15	Master clear
USER	14	User Port
DIR	13	Direction of RS 485
TX	12	TX to PC
RX	11	RX to PC

Figure 11-3: Pin out of jumper 2

11.1.4 Electrical characteristics of J2 PINs

PIN	PIN No.	Min	Typ.	Max.	Description
RX	11		USART-TTL[1]	25 mA	RX to PC To RS232, RS485 or RS422 device driver
TX	12		USART-TTL[1]	25 mA	TX to PC To RS232, RS485 or RS422 device driver
DIR	13		TTL	25 mA	Direction of RS 485 Logic High = Reader to Host Logic Low = Host to Reader
USER	14		TTL[2]	25 mA	User Port
MCLR	15		TTL[3]		Master clear Leave unconnected. Low will reset the register and the key management to default values.
EN	16		ST[4]	25 mA	Enable reader logic low will disable the reader Open or logic high
LEDr	17		TTL	15 mA	LED red
LEDg	18		TTL	15 mA	LED green (reading LED) With 330 Ω (internal serial) resistor
GND	19		GND		Ground
VDD	20	+4.5V	+5.0V	+5.5V	Supply Voltage
		32 mA	150 mA	250 mA	Supply Current (Without SAM)

Figure 11-4: Electrical characteristics of pins

[1] Universal Synchronous Asynchronous Receiver Transmitter

[2] TTL buffer output / input

[3] Voltage spikes below GND at the MCLR/V_{DD} pin, including currents greater than 80mA, may cause latch-up. Thus, a series resistor of 50-100Ω should be used when applying a "low" level to the MCLR/V_{DD}, rather than pulling this pin directly to GND.

[4] Schmitt trigger buffer input

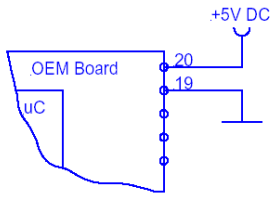
APPENDIX C: EXTERNAL CONNECTION TO THE READER MODULE

11.1.5 External Connections

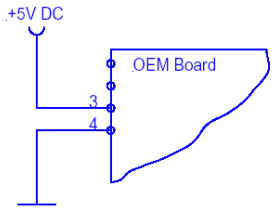
11.1.5.1 Power Supply

If the supply voltage and any noise modulated on the supply voltage remains within the specified limits, no further filtering is required. In some cases it is recommended to use additional filtering for the power supply line. Insufficient power line filtering could cause unexpected or irregular performance drops.

Option 1



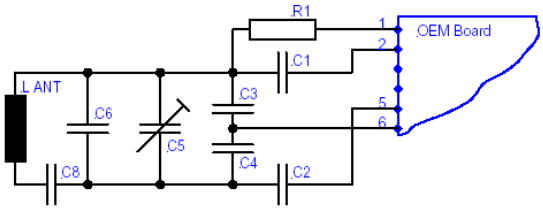
Option 2



The board can be connected as shown above. Both alternatives are possible and can be used as they fit best into the layout of the carrier board. The two VCC PINs and the two GND PINs are connected internally.

11.1.5.2 Antenna

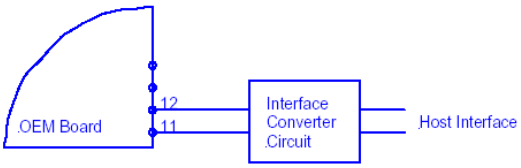
The external antenna needs to have the right inductance and a certain resistor and capacitor combination for optimized frequency tuning and antenna matching.



More Details about the antenna design are available in the antenna design guide manual. This Document can be downloaded from www.acg.de

11.1.5.3 Serial Interface

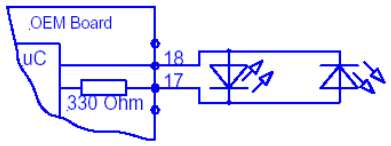
The OEM Board can be connected directly with a micro controller. Alternatively the OEM Board also can be connected to most serial interface types by using the right interface converter circuit. In order to optimize the communication quality the specific application note of the interface converter circuit needs to be taken into consideration.



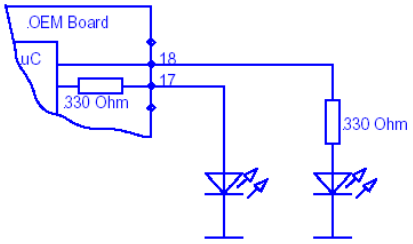
11.1.5.4 Function Control LEDs

Two external LEDs can be connected to the OEM Board. There are two alternatives possible.

Option 1



Option 2



In both cases the LED supply voltage levels are TTL levels.

APPENDIX D: EEPROM MEMORY ORGANISATION

12.3.1 EEPROM memory organization

Register	Description
00h ... 04h	Unique device ID; read only
05h ... 09h	Administrative data; read only
0Ah	Station ID
0Bh	Protocol configuration
0Ch	Baud rate
0Dh	Command Guard Time
0Eh	Operation Mode
0Fh	Single shot time-out value
10h	Internal use / Do not change
11h	Internal use / Do not change
12h	Internal use / Do not change
13h	Protocol configuration 2
14h	Reset Off Time
15h	Reset Recovery Time
16h	Application Family Identifier
17h	ISO 14443A Selection Time-out
18h	ISO 14443B Selection Time-out
19h	SR176 Selection Time-out
1Ah	ISO 15693 Selection Time-out
1Bh	Protocol configuration 3
1Ch	Page Start
1Dh	Internal use / Do not change
1Eh	Internal use / Do not change
1Fh	Page number
20h - 7Fh	RFU
80h ... EFh	User data

APPENDIX E: X-BEE MODULE SPECIFICATIONS

APPENDIX E

1.2. Specifications

Table 1-01. Specifications of the XBee/XBee-PRO OEM RF Modules

Specification	XBee	XBee-PRO
Performance		
Indoor/Urban Range	up to 100 ft. (30 m)	Up to 300' (100 m)
Outdoor RF line-of-sight Range	up to 300 ft. (100 m)	Up to 1 mile (1500 m)
Transmit Power Output (software selectable)	1mW (0 dBm)	60 mW (18 dBm) conducted, 100 mW (20 dBm) EIRP*
RF Data Rate	250,000 bps	250,000 bps
Serial Interface Data Rate (software selectable)	1200 - 115200 bps (non-standard baud rates also supported)	1200 - 115200 bps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)	-100 dBm (1% packet error rate)
Power Requirements		
Supply Voltage	2.8 – 3.4 V	2.8 – 3.4 V
Transmit Current (typical)	45mA (@ 3.3 V)	If PL=0 (10dBm): 137mA(@3.3V), 139mA(@3.0V) PL=1 (12dBm): 155mA (@3.3V), 153mA(@3.0V) PL=2 (14dBm): 170mA (@3.3V), 171mA(@3.0V) PL=3 (16dBm): 188mA (@3.3V), 195mA(@3.0V) PL=4 (18dBm): 215mA (@3.3V), 227mA(@3.0V)
Idle / Receive Current (typical)	50mA (@ 3.3 V)	55mA (@ 3.3 V)
Power-down Current	< 10 µA	< 10 µA
General		
Operating Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)	0.960" x 1.297" (2.438cm x 3.294cm)
Operating Temperature	-40 to 85° C (industrial)	-40 to 85° C (industrial)
Antenna Options	Integrated Whip, Chip or U.FL Connector	Integrated Whip, Chip or U.FL Connector
Networking & Security		
Supported Network Topologies	Point-to-point, Point-to-multipoint & Peer-to-peer	
Number of Channels (software selectable)	16 Direct Sequence Channels	12 Direct Sequence Channels
Addressing Options	PAN ID, Channel and Addresses	PAN ID, Channel and Addresses
Agency Approvals		
United States (FCC Part 15.247)	OUR-XBEE	OUR-XBEEPRO
Industry Canada (IC)	4214A-XBEE	4214A-XBEEPRO
Europe (CE)	ETSI	ETSI (Max. 10 dBm transmit power output)*
Japan	n/a	005NYCA0378 (Max. 10 dBm transmit power output)**

* When operating in Europe: XBee-PRO RF Modules must be configured to operate at a maximum transmit power output level of 10 dBm. The power output level is set using the PL command. The PL parameter must equal "0" (10 dBm).

Additionally, European regulations stipulate an EIRP power maximum of 12.86 dBm (19 mW) for the XBee-PRO and 12.11 dBm for the XBee when integrating high-gain antennas.

** When operating in Japan: Transmit power output is limited to 10 dBm. A special part number is required when ordering modules approved for use in Japan. Contact MaxStream for more information [call 1-801-765-9885 or send e-mails to sales@maxstream.net].

Antenna Options: The ranges specified are typical when using the integrated Whip (1.5 dBi) and Dipole (2.1 dBi) antennas. The Chip antenna option provides advantages in its form factor; however, it typically yields shorter range than the Whip and Dipole antenna options when transmitting outdoors. For more information, refer to the "XBee Antenna" application note located on MaxStream's web site (http://www.maxstream.net/support/knowledgebase/article.php?kb=153).

APPENDIX F: X-BEE MODULE PIN CONFIGURATION

APPENDIX F

1.5. Pin Signals

Figure 1-03. XBee/XBee-PRO RF Module Pin Numbers
(top sides shown - shields on bottom)

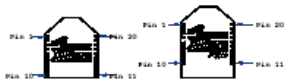


Table 1-02. Pin Assignments for the XBee and XBee-PRO Modules
(Low-asserted signals are distinguished with a horizontal line above signal name.)

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / **CONFIG**	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	**RESET**	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	$\overline{\text{DTR}}$ / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	$\overline{\textbf{CTS}}$ / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / **SLEEP**	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	$\overline{\textbf{RTS}}$ / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

* Function is not supported at the time of this release

Design Notes:

- Minimum connections: VCC, GND, DOUT & DIN
- Minimum connections for updating firmware: VCC, GND, DIN, DOUT, RTS & DTR
- Signal Direction is specified with respect to the module
- Module includes a 50k Ω pull-up resistor attached to $\overline{\text{RESET}}$
- Several of the input pull-ups can be configured using the PR command
- Unused pins should be left disconnected

APPENDIX G: JAVA PROGRAM

Java program used for the project

```
/*
 * StudentView.java
 */

package student;

import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
import java.sql.ResultSet;
import java.sql.SQLException;

import java.text.SimpleDateFormat;
import java.text.DateFormat;

import javax.comm.*;
import java.io.*; // enables input and output streams
import java.util.*; //?

import org.jdesktop.application.Action;
import org.jdesktop.application.ResourceMap;
```

```
import org.jdesktop.application.SingleFrameApplication;
import org.jdesktop.application.FrameView;
import org.jdesktop.application.TaskMonitor;
import org.jdesktop.application.Task;
import java.awt.event.ActionEvent;
import java.awt.event.ActionListener;
import java.util.ArrayList;
import java.util.List;
import javax.persistence.RollbackException;
import javax.swing.Timer;
import javax.swing.Icon;
import javax.swing.JDialog;
import javax.swing.JFrame;
import javax.swing.event.ListSelectionEvent;
import javax.swing.event.ListSelectionListener;
import org.jdesktop.beansbinding.AbstractBindingListener;
import org.jdesktop.beansbinding.Binding;
import org.jdesktop.beansbinding.PropertyStateEvent;

/**
 * The application's main frame.
 */
public class StudentView extends FrameView {

    /** Creates a new instance of Connection */
```

```
    public SConnection()
    {/*Open COM1 port for communication*/
      try
      {
        TimeStamp = new java.util.Date().toString();
        serialPort1 = (SerialPort) portId1.open("Connection", 1000);
        taOutput.setText(taOutput.getText() + TimeStamp + ": " + portId1.getName() + "
opened for scanner input\n");
      }
      catch (PortInUseException e)
      {

      }
      try
      {/*check for incoming input*/
        inputStream = serialPort1.getInputStream();
      }
      catch (IOException e)
      {

      }
      try
      {
        serialPort1.addEventListener(this);
      }
```

```
        catch (TooManyListenersException e)
        {

        }
        serialPort1.notifyOnDataAvailable(true);
        try
        {/*Define properties of the serial port*/
           serialPort1.setSerialPortParams(9600,
           SerialPort.DATABITS_8,
           SerialPort.STOPBITS_1,
           SerialPort.PARITY_NONE);

           serialPort1.setDTR(false);
           serialPort1.setRTS(false);
        }
        catch (UnsupportedCommOperationException e) {}

        readThread = new Thread(this);
        readThread.start();

}

public void startPort()//old main method
{/*establish the existance of serial port COM1 - moved to button click*/
   try
```

```
    {
        portId1 = CommPortIdentifier.getPortIdentifier("COM1");
        SConnection reader = new SConnection();
    }
    catch (Exception e)
    {
        TimeStamp = new java.util.Date().toString();

        System.out.println(TimeStamp + ": COM1 " + portId1);//display port identifier
        System.out.println(TimeStamp + ": msg1 - " + e);//display an exception
    }
}
public void run() {
    try
    {
        Thread.sleep(100);
    }
    catch (InterruptedException e)
    {

    }
}
public void serialEvent(SerialPortEvent event)
{/*Check for data */
    switch(event.getEventType())
```

```
{
   case SerialPortEvent.OUTPUT_BUFFER_EMPTY:
      break;
   case SerialPortEvent.DATA_AVAILABLE:
      StringBuffer readBuffer = new StringBuffer();
      int c;
      try
      {

         while ((c=inputStream.read()) != 10)
         {
            if(c!=13)  readBuffer.append((char) c);
         }
         String scannedInput = readBuffer.toString();
         TimeStamp = new java.util.Date().toString();
         handleInput(scannedInput);
         outputStream = serialPort1.getOutputStream();
         outputStream.write(scannedInput.getBytes());


         javax.swing.JOptionPane.showMessageDialog( null,TimeStamp + "\n Received
Message: " + scannedInput );
         inputStream.close();
      }
      catch (IOException e)
```

```
            {


            }
            break;
        }
    }
```

```
}
private void handleInput(String input)
{
    Connection connection = null;
    Statement statement = null;
    ResultSet resultSet;
    int numberOfRows;
    try
    {
        connection = DriverManager.getConnection("jdbc:derby://localhost:1527/StudentAtt");
        taOutput.setText(taOutput.getText() + "Successfully connected.\n");
        statement =
connection.createStatement(ResultSet.TYPE_SCROLL_INSENSITIVE,ResultSet.CONCUR
_UPDATABLE);
```

```
        resultSet = statement.executeQuery("Select * from Students where CARD_ID ='" +
input + "'");
        resultSet.last();
        numberOfRows = resultSet.getRow();
        if (numberOfRows == 1)
        {
            Attendance a = new Attendance();
            DateFormat dateFormat = new SimpleDateFormat("yyyy/MM/dd HH:mm:ss");
            java.util.Date date = new java.util.Date();
            String s = dateFormat.format(date);
            a.setDatetime(s);
            a.setStudentNumber((resultSet.getObject(2).toString()));
            try {
                entityManager.persist(a);
                entityManager.getTransaction().commit();
                attendanceList.add(a);
            } catch (Exception e) {
                e.printStackTrace();
                entityManager.getTransaction().rollback();
            }
            attTable.setName("attTable"); // NOI18N

            org.jdesktop.swingbinding.JTableBinding jTableBinding =
org.jdesktop.swingbinding.SwingBindings.createJTableBinding(org.jdesktop.beansbinding.A
utoBinding.UpdateStrategy.READ_WRITE, attendanceList, attTable);
```

```
            org.jdesktop.swingbinding.JTableBinding.ColumnBinding columnBinding =
jTableBinding.addColumnBinding(org.jdesktop.beansbinding.ELProperty.create("${datetime
}"));
            columnBinding.setColumnName("Datetime");
            columnBinding.setColumnClass(String.class);
            columnBinding =
jTableBinding.addColumnBinding(org.jdesktop.beansbinding.ELProperty.create("${student
Number}"));
            columnBinding.setColumnName("Student Number");
            columnBinding.setColumnClass(String.class);
            bindingGroup.addBinding(jTableBinding);
            jTableBinding.bind();

            taOutput.setText(taOutput.getText() + "Card found and entry recorded in
database.\n");
        }
        else
        {
            taOutput.setText(taOutput.getText() + "Card not in database.\n");
        }

    }
    catch (SQLException err)
    {
        taOutput.setText(taOutput.getText() + err.toString() + "\n");
```

```
}
finally
{
   try
   {
      statement.close();
      connection.close();
```