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FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRICAL & INFORMATION ENGINEERING

PASSIVE RADIO FREQUENCY IDENTIFICATION (RFID) SYSTEM

PROJECT INDEX: PRJ084

PRESENTED BY

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SUBMITTED ON: 18TH MAY, 2011
I dedicate my project and research study to all young entrepreneurs in Kenya and worldwide who develop ideas with ingenuity to help fellow mankind.

I also dedicate this to my mentor, the late Hon. Mirugi Kariuki, who inspired me to be whom I am today and for being like a father and a personal friend.
I would like to thank the many people who have provided both tremendous support and direct help to make my project worthwhile.

To Dr. V. K. Oduol, my supervisor, I am beyond grateful for guiding me and providing necessary materials to aid in completion of this study.

I also appreciate the entire community of University of Nairobi, for making the institution credible and creating an environment well-endowed with materials for study and research. I thank my classmates Martha Kyule, Kinyua Wachira, Wendy Chebet and the many people who went out of their way to help by reading early drafts and providing detailed advice and reviews.

To Mr. Joseph Nyongesa, the C.E.O of GS1 Kenya, I am honored that you took your limited time to provide me with the research data and guidelines on RFID management.

To Mr. Peter Martin Chivondo, staff of the Communication Commission of Kenya's Frequency Spectrum Management department, I thank you for your educative interview that brought a lot of insight to my research work.
DECLARATION AND CERTIFICATION

This is my original work and has not been presented for a degree award in this or any other university.

é é é é é é é é é é é é é é é é ..

BENJAMIN NG’ARU KARIUKI

F17/1788/2006

This report has been submitted to the Department of Electrical and Information Engineering, The University of Nairobi with my approval as supervisor:

é é é é é é é é é é é é é

Dr. V. K. Oduol

Date: é é é é é é é é
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<tr>
<td>$\Delta$</td>
<td>change in parameter</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$A_e$ effective aperture</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$B_i$ Bandwidth</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$d_B$ - decibels</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$dBm_i$ decibel-millimeters</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$f_i$ Frequency of operation (Hz)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$F_N$ - Noise figure</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$G_r$ Gain at receiver (dimensionless)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$G_t$ - Gain at transmitter (dimensionless)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$G_{fr,db}$ Gain (at receiver or transmitter) in decibels</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$i_N$ rms noise current</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$K_i$ Boltzmann's constant</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$N_i$ Noise floor</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$P_{out}$ Power out (Watts)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$P_r$ - Power received (Watts)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$P_t$ Power transmitted (Watts)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$P_{fr,db}$ Power (received or transmitted) in decibels</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$R_i$ read range or radius (meters)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$S_i$ Signal power</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$T_i$ temperature (Kelvin)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$T_o$ - Room Temperature (290K)</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$V_i$ voltage</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$v_N$ rms thermal voltage</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$W_i$ Watts</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$\lambda$ wavelength in meters</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>$\pi$ pi</td>
</tr>
</tbody>
</table>
LIST OF ABBREVIATIONS

• ADC – Analogue to digital converter
• ALE – Application Level Events
• Auto ID – automatic identification
• BCD – Binary coded data
• BER – Bit Error Rate
• CAD – Computer aided design
• CCK – Communications Commission of Kenya
• DOD – Department of Defense
• DSP – Digital Signal
• EIRP – Equivalent Isotropic Radiated Power
• EPC – Electronic Product Code
• EPCIS – Electronic Product Code Information Services
• ETSI – European Telecommunications Standards Institute
• FCC – Federal Communications Commission
• GID – Global Identifier
• GRAI – Global returnable asset identifier
• GTIN – Global Trade Identification Number
• HPBW – Half Power Beam Width
• IEC - International Electrotechnical Commission
• ISM – Industrial Scientific Medical
• ITU – International Telecommunications Union
• J2SE – Java 2 Standard Edition
• LLRP – Low Level Reader Protocol
• MIT – Massachusetts Institute of Technology
• ONS – Object Naming System
• OSGI – Open Services Gateway Initiative
• POS – Point of sale
• RF – Radio Frequency
• RFID – Radio Frequency Identification
• RTLS – Real Time Location Systems
• SGTIN – Serialized Global Trade Identification Number
SNR — Signal to Noise Ratio
SSCC — Serial Shipping Container Code
TDM — Time Division Multiplexing
TDS — Tag Data Standard
TDT — Tag Data Translation
UART — Universal Asynchronous Receiver / Transmitter
UPC — Universal Product Code
VCO — Voltage Controlled Oscillator
WORM — Write Once Read Many
ABSTRACT

Over the past couple of years, RFID technology has grown in preference to other Auto-ID systems such as magnetic stripes, barcodes and optical character recognition among others for the diverse applications especially in industries for identification, authentication and toll collection. Its benefits include its high speeds, its capability of reading multiple objects concurrently, not requiring a line of sight, longer reading ranges, low error rates, minimal counterfeiting and its relatively cheap cost have given it the competitive edge in these applications.

I intend to demonstrate how RFID technology can be used in the supply chain industry as an stock inventory and incorporated with sales systems. It can be proven that tags placed on items, pallets or cases and passed through fields emitted by interrogator(s) the tags exchanged data stored at the tags’ memory. This information, such as the Electronic Product Code® (EPC) could be processed by a host computer (middleware) through a convenient network interface to give product information stored in a local or remote database. It therefore would qualify in the design and implementation of sales system for a super/hypermarket where customers shopping can be read at the checkout without having to scan an object at a time.

For such an application the benefits include automation thus reducing labor cost — the number of cashiers and attendants at the checkout, limiting scope, cost and panic of recalls hence increasing profitability exposing and/or overcoming counterfeits and improving distribution efficiency.
CHAPTER 1

1. PREAMBLE

1.1. EXECUTIVE SUMMARY

Retail outlets such as supermarkets, hypermarkets and shopping malls use economies of scale to reduce costs of purchase and operations which in turn increases their profits and lowers selling prices of their merchandise. These benefits of bulk supply and variety of choice products lead to many customers preferring these retail outlets to ordinary kiosks.

These benefits subsequently pose shortcomings such as shopping delays, theft and fraud and counterfeiting, such retail outlets with huge inflow and outflow of goods, services and human beings information systems would require very fast, error-free, private, secure and efficient information systems for identification, tracking and payment.

Traditional systems such as the barcode systems are slow hence causing delay and frustration of customers. They deploy high manual labor costs and lack automation limiting their profitability. These systems due to their highly manual dependency are very prone to errors, counterfeiting, theft, inefficient restocking and fraud.

RFID technology comes to aid in supply chain management, toll collection, security systems and identification, tracking and authentication systems. Its benefits are reduced human intervention, higher throughput in supply chains, real-time information flow, serialized data and increased item security. One application that is likely to take the world by surprise is the ‘internet of things’. In this technology, any object, item, animal or human being could have a tag on it which is traceable on a global scale to create an entire internet. The addressing scheme needs to hold available serial numbers to uniquely identify all the traceable items over a period of time the technology is most likely to still be in use.

The main aim of my research is to look into better technologies of a stock inventory and sales system focusing on passive RFID. Passive tags have no battery attached, hence are suitable on apparels, products, pallets or cases at a cheaper cost than active tags. Passive tags use
backscattering, what is commonly known as reflected power, whereby the incident power from the reader is rectified at the tag’s circuit and used for retransmitting to the reader.

The significance of this research project would be to provide a basis for future development of many applications, such as aids to security, surveillance, military systems, toll collection systems, cargo-tracking, supply chain management systems and new upcoming ones.

1.2. PROBLEM DEFINITION

Certain factors have to be considered while developing an efficient stock inventory and sales system. They include manual labor costs, speed of transactions, security, counterfeiting problems, accuracy and efficiency of these systems.

Traditional systems such the barcodes deploy intense manual labor since each item has to be read at a time in close proximity by the scanner, therefore low speeds of transactions. Moreover the labels are not reprogrammable, they have low storage memory and they require a line of sight in operation, limiting their usability. The barcode systems have very low durability when exposed to harsh environmental conditions. Such considerations are fundamental for design of stock and sales management systems for retail outlets.

1.3. OBJECTIVES OF THE STUDY

The study was aimed to achieve the following:

- To understand how an RFID system operates
- To study active and passive RFID systems
- To identify the different frequency ranges for RFID and know how to select which one is appropriate for a particular use
- To understand the classless licensing by CCK.
- To determine what type of tag is required for supply chain management.
- To understand how to install, optimize, and troubleshoot an RFID read zone
- To identify and select the appropriate type of RFID printer and Label Applicators
- To understand RFID EPC data management and integration approaches
- To determine best practices around interrogation zone implementation
To understand some of the main standards and regulations around RFID

1.4. SCOPE OF THE STUDY

In my research I intend to simulate a typical RFID reader and tag environment run on Rifidi, an open-source RFID design software and emulator on J2SE. Since Java is cross-platform, it can be run in both Windows and Linux operating systems.

The simulator helps in building an accurate design environment without having to acquire the tags and readers themselves. It is therefore cost-effective and benefits from all advantages of computer aided design, C.A.D. The results obtained are attached in chapter 4 for analysis.

1.5. LITERATURE REVIEW

Use of RFID for supply chain management is not new to research, documentation and implementation. In his paper, "RFID Overview" Greg Leeming of Intel Corporation says, "Wal-mart US, one of the leading outlet stores, implemented RFID for their retail outlets in 2003. In January 2005, its top 100 suppliers of the outlet integrated the technology on the pallets and cases of containers, about 30,000 suppliers adopted the technology by end of year 2006. Today Wal-mart processes over four billion tags a year, with 300,000 direct readers and 18,000,000 indirect readers installed." (Leeming, 2004)

Today many other leading companies have adopted RFID technology. Just to name a few, Gillette tracks razors, Ford tracks its spare parts, Delta tags its customer's luggage, and D.o.D order all suppliers to tag items in their purchase orders. In the ISRC briefing in September 2005, the University of Houston's Bauer College of Business projected a $2 billion market share in 2007 up from $700 million in 2003.

RFID is popular for supply chain traceability. It is used to locate lost items; it enables tracing recalls and could be used to pinpoint entry of counterfeits in markets such as pharmaceutical, auto parts, vehicle assembly, entertainment (DVDs) and casino chips. In his paper, "Productivity of RFID: 2005" Cipriani demystifies its benefits include reduced downtime and waste, tracking expirations, reduced labor costs, simplify quality plans such as ISO,
enhance consumer service, reduce out-of-stocks, and provide better product selection and limit scope, cost and panic of recalls.

This technology has its own shortcomings. The cost of tags and other hardware though going down is still beyond reach for common market. Many customers still have an issue with privacy and security of the technology. Cipriani also cites that there are instances of killer switches which deactivate the tags and implications of tags staying active beyond checkout.

EPCglobal and GS1 US are developing standards and regulations to govern RFID in order for the technology to compete with other auto-ID technologies.

1.6. METHODOLOGY

The passive RFID system is analyzed in two independent sections. The first section is the tag design; its frequency of operation, its EPC class and its placement. The second section is the reader environment sections which handles the reader & its antenna design for application in a retail entity of a supply chain.
CHAPTER 2

2. BACKGROUND INFORMATION

2.1. OVERVIEW OF RFID

Radio-frequency identification (RFID) is a technology that uses communication via radio waves to exchange data between a reader and an electronic tag attached to an object, for the purpose of identification and tracking. Some tags can be read from several meters away and beyond the line of sight of the reader.

![Figure 1: The main components of an RFID application.](image)

The main components of an RFID system are:

1. Tag also known as transponder or label. It is made up of a microchip, antenna and a support/encasement. The microchip basis has memory to store data like a unique serial number or other customized data. It also has an RF module to enable processes such as modulation. For active tags, it is connected to a power source, a battery. The antenna transmits and receives RF waves.

2. Reader also referred to as Interrogator. It is made up of the RF Module (Transmitter and Receiver), the control Unit, antenna(s) and a network Interface typically Universal
Asynchronous Receiver/Transmitters (UARTs) RS 232, RS 485 and Ethernet RJ45 jack for 10BaseT or 100BaseT Ethernet cables. Others may have Bluetooth and ZigBee.

The reader is a device that is used to interrogate an RFID tag. The RF module is a DSP chip which performs synthesis of incoming or outgoing signal. The control unit regulates communication modes such as half/full duplex, power regulation and other processes. The network interface consists of ports such as Ethernet to relay processed data to a host computer.

3. Host Computer (Middleware). The host computer is a work station which has high-level applications such as inventory Point-of-Sale software, interfaces to security systems and web & email protocols. It could also describe any middleware which processes this data such as iPads, programmable chips, Mobile phones, etc.

### 2.1.1. HISTORY OF RFID

RFID was first used in the early eighteenth century. The first barcode was patented in 1930s. The first use of RFID device was in the 2nd world war (1938-1945) where Britain used RFID-like technology for Identify, what was called, ‘Friend or Foe’. Harry Stockman published a paper in October 1948 titled Communication by means of reflected power (The proceedings of the Institute of Radio Engineers).

First RFID patent was done in 1973. Thereafter the Auto-ID center was founded at Massachusetts Institute of Technology in 1999 by the Auto-ID consortium with the aim of researching and standardizing RFID technology. It introduced the standardization effort taken over by EPC Global (Electronic Product Code). The current thrust in this technology was primarily driven by Wal-Mart (U.S) and the Department of Department for Automated Distribution. The effects have been reduced cost (manpower, shipping mistakes) and increased sales. The Department of Defense developed Total Asset Visibility Initiative. The technology has since grown in applications.
2.1.2. RFID SYSTEM CHARACTERISTICS

This section presents the general physics in the study of RFID design, for both active and passive systems.

2.1.2.1. FREQUENCY BANDS

<table>
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<th>Band name</th>
<th>Frequency range</th>
<th>ISM frequencies</th>
<th>Read Ranges</th>
<th>Read Rates</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>LF</td>
<td>30 - 300 kHz</td>
<td>&lt; 135 kHz</td>
<td>&lt; 0.50 m</td>
<td>Slow</td>
<td>Cheap &amp; unregulated</td>
</tr>
<tr>
<td>HF</td>
<td>330 MHz</td>
<td>6.78 MHz, 13.56 MHz, 27.125 MHz, 40.680 MHz</td>
<td>&lt;3.0 m</td>
<td>Medium</td>
<td>Cheap &amp; unregulated</td>
</tr>
<tr>
<td>UHF</td>
<td>300 MHz-3 GHz</td>
<td>433.920 MHz, 869 MHz, 915 MHz</td>
<td>&lt; 9.0 m</td>
<td>High</td>
<td>Expensive</td>
</tr>
<tr>
<td>Microwave</td>
<td>&gt; 3 GHz</td>
<td>2.45 GHz, 5.8 GHz, 24.125 GHz</td>
<td>&gt; 9.0 m</td>
<td>Very High</td>
<td>Expensive</td>
</tr>
</tbody>
</table>

Table 1: Frequency Range for RFID applications

The choice of a particular frequency band depends on the application, legislature and cost considerations. (Cipriani, 2005)

2.1.2.2. CARRIER FREQUENCIES AND BANDWIDTH

The carrier wave is used in telecommunications to transmit energy (message signal) over longer distances. This process is called modulation. The carrier is of higher frequency than the message, order of kHz-GHz.

Bandwidth, BW is the difference between two cut-off frequencies. It is the measure of the width of a range of frequencies, measured in Hertz or digital bandwidth: a rate of data transfer, bit rate or throughput, measured in bits per second (bps).
2.1.2.3. **FULL AND HALF DUPLEX PROCEDURE**

The transfer of data between the reader and the tag could occur in the following processes. (Paret, 2009)

- Full Duplex procedure
- Half Duplex procedure
- Sequential procedure

Full Duplex communication means that the reader and the transponder transfer data concurrently. The tag could use a fraction of the reader's frequency (sub-harmonic) or a different frequency (an-harmonic).

Half Duplex communication means that the reader and the tag transfer data alternately. It mostly occurs for frequencies less than 30MHz.

Sequential communication means that data transfer from tag to reader occurs at limited periods, called pulses. Normally, this period is the pause between power supply intervals to the transponder.

![Diagram of HDX, FDX, and Sequential systems](image)

**Figure 2:** Representation of HDX, FDX and Sequential systems.

2.1.2.4. **MAGNETIC COUPLING**

Inductive Coupling or Near Field Communication is the mode of transfer at low frequencies (less than 30MHz). Since these wavelengths (greater than 10 meters) are several times greater than the
distance between the reader's antenna and the transponder, the electromagnetic field may be treated as a simple magnetic alternating field with regard to the distance between transponder and antenna.

2.1.2.5. ELECTROMAGNETIC BACKSCATTER COUPLING

For communication of devices more than one meter apart, Long Field Communication, construction of short and efficient antennas is possible. This occurs at UHF and SHF band. The transition from NFC to FFC occur at a distance $\approx 2\mu$ meters from the antenna.

The EM waves from the reader are reflected by objects with dimensions greater than around half the wavelength of the wave. The efficiency with which an object reflects electromagnetic waves is described by its reflection cross-section. The RF front-end switches the input impedance to either match the antenna or strongly mismatched thereby attaining the highest reflection coefficient.

The EM wave from the reader is rectified by the tag and used as power for transmission. The chip is not reactivated until a sufficiently strong signal is received in the read range of a reader depending on its sensitivity, whereupon it switches back to normal operation.

Figure 3: comparison of the relative interrogation zones in RFID application
2.1.2.6. RANGE AND POWER LEVELS

The range is defined as the reading distance. It is the minimum distance the reader and tag must be before communication takes place. The required range is determined by the following:

- The power $P_t$ available at the reader (4W, EIRP) set by standards.
- The power available, $P_r$ within the tag (active or passive).
- The tag's sensitivity defined as the minimum value of power that awakens the tag. It depends on the silicon fabrication process and the RF front-end design. The sensitivity of most tags is -14 to -18 dBm.
- Impedance matching between the antenna and tag silicon. The chip's impedance varies with the received power (passive) and the operation frequency.
- The antenna gain, $G_{at}$ which is dependent on operational frequency, $f$ and antenna geometry.
- The orientation sensitivity. Linearly polarized antennas have more orientation sensitivity but longer read ranges, while circularly polarized antenna have less orientation sensitivity but lower read ranges due to the 3dB loss in this polarization.
- Tag antenna detuning by the surrounding which affects impedance matching in turn the read range.
- Path loss which is a reduction in the power density of an electromagnetic wave as the wave propagates through space. Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, and absorption. Path loss is largely influenced by environment, propagation medium (dry or moist air), surrounding structures, the distance between the transmitter and the receiver, and the height and location of antennas.
- Receiver sensitivity which is obtained from the reader's SNR and noise levels in the environment. Most readers today have receiver sensitivity of about -80 to -110 dBm.
- The positional accuracy of the transponder for portable readers.
- The minimum distance, $R_{min}$ between several transponders in practical operation.
- The speed of the transponder in the interrogation zone of the reader.

The above factors are related using the Frii formula

$$P_r = P_t \times (G_t, G_r, \lambda^2) / (4\pi R)^2$$

There term $\lambda$ is the wavelength of the designed RF signal.
The range $R$ (in meters), can therefore be found from the formula below

$$R = \left(\frac{\lambda}{4\pi}\right) \times \left\{ \frac{(G_t, G_r, P_t)}{P_r} \right\}^{1/2}$$
or

$$R = \left(\frac{c}{4\pi f}\right) \times \left\{ \frac{(G_t, G_r, P_t)}{P_r} \right\}^{1/2}$$
equation (II)

(Sachidananda, 2007)

A decibel representation of power received

$$P_{rdB} = P_{tdB} + G_{tdB} + G_{rdB} - 20 \log_{10} \left(\frac{\lambda R}{4\pi}\right)$$
equation (III)

To incorporate polarization and mismatch losses equation (III) becomes

$$P_{rdB} = P_{tdB} + G_{tdB} + G_{rdB} - 20 \log_{10} (f) - 20 \log (R) - 20 \log (\cos \theta)$$
equation (IV)

Where $\theta$ is the mismatch angle.

2.1.2.7. SIGNAL ATTENUATION LOSSES

The power available from the reader to the tag is affected by a couple of factors. Mainly, for near field communication the signal attenuates by the fourth root of the distance (reason for short NFC ranges) and for far field communication the signal attenuates with the square root of the range. Other factors are absorption by materials, reflections and antenna gain.

The specific absorption rate (damping) for water or non-conductive substances is lower by a factor of 100 000 at 100 kHz than it is at 1 GHz. Therefore, virtually no absorption or damping takes place. Lower frequency HF systems are primarily used due to the better penetration of objects. An example of this is the bolus, a transponder placed in the omasum (rumen) of cattle, which can be read from outside at an interrogation frequency of less than 135 kHz.

Change in antenna gain is caused by materials placed near the antenna creating a ground plane, affecting its directivity. For better performance the antenna should be in a line of sight with the batch of materials being read.

Multiple path reflections cause signal extending its interrogation zone, causing the reader to perform "ghost" reads.


2.1.2.8. TAGS CHARACTERISTIC

A tag is categorized by the means by which transponder is powered, data carrying options, data read rates, addressability, its physical form and its costs.

In addition, tags may contain an IC chip or not. IC-less tags use physical characteristics to represent unique identity. Such include the 1-bit transponder (which represent a high or low state) and those that implement surface acoustic waves and acoustic reflectors to create unique identities. However, most tags have chips embedded on them. (Amin Rida, 2010)

2.1.2.8.1. ACTIVE AND PASSIVE TAGS

Active tags are powered by an internal battery. They have a finite lifetime (because of battery) and greater read ranges. They have better noise immunity and higher data transmission rates. They are commonly used when Real Time Location Systems (RTLS). They can be used in sensing applications since the embedded battery also allows extra sensors to be powered.

Active RFID tags have two main disadvantages: acquisition and battery maintenance costs, and environmental limitations due to the presence of the battery.

Passive tags operate without battery, they derive power from the field generate by the reader through backscatter. They are usually less expensive. They have unlimited life. Moreover, passive tags can withstand challenging environmental conditions that can restrict the use of RFID tags with integrated batteries.

However, they are subject to noise. They require powerful readers and they are sensitive to orientation.

2.1.2.8.2. DATA CARRYING OPTIONS

A tag can contain an identifier (usually 16bits) and portable data files (mostly 64 KB) which is extendable with technology.

2.1.2.8.3. DATA READ RATE

Data read rate is linked to frequency of operation. Higher frequencies have higher the read rates.
2.1.2.8.4. **TAG ADDRESSABILITY**

There are three kinds of programmability options in tags.

a) **Read-Only (Factory Programmed):** data (tag-id) is only written once into the chip. It is cheap.

b) **Write Once Read Many (W.O.R.M):** The database pointer is reprogrammable.

c) **Reprogrammable (Field Reprogrammable):** The database pointer is reprogrammable.

d) **Read-Write (In-Use Programmable):** though expensive, write-read tags have greater flexibility since customers may change their requirements and/or standards may change. They have database dependence, the tag's data is owned by the writer also improving lag times. It is used in high risk applications.

2.1.3. **AUTO-IDS AND DATA CAPTURE TECHNOLOGIES**

The choice of an automatic identification technology is made based on a couple of criteria. The lifespan of the system, modification of data (read-only versus read/write), the security of data, the amount of data (depending on the storage technology), the cost, the reading distance, the reading speeds, the standards and regulations regarding to it and its potential for interference. These technologies are split into two fields: data carrier and feature extraction technologies.

(Finkenzeller, 2003)

2.1.3.1. **DATA CARRIER TECHNOLOGIES**

These technologies consist of a data representation that can be read using optical waves, electromagnetic waves or magnetic induction.

a) **OPTIC STORAGE**

- **BAR CODE**

The barcode is a binary code comprising a field of bars and gaps (wide and narrow) arranged in a parallel configuration. These gaps are in a predetermined pattern and represent data elements that
refer to an associated symbol. The sequence can be interpreted numerically and alphanumerically. They are commonly classified as linear or stacked (multi-row).

- **MATRIX CODES**

They are commonly classified as either in full matrix or dot codes.

- **OPTIC CHARACTER RECOGNITION (OCR)**

*Optical character recognition* (OCR) uses special fonts developed for this application that stylized characters so that they could be read automatically by machines. The most important advantage of OCR systems is the high density of information and the possibility of reading data visually.

Others are the OMR, Optic Memory Recognition and Magneto-optic systems.

b) **MAGNETIC STORAGE**

They are commonly classified as magnetic stripes, magnetic resonance and MICR.

c) **ELECTRONIC STORAGE**

- **Memory Card/Smart Card**

A *smart card* is an electronic data storage system, possibly with additional computing capacity (microprocessor card), which is incorporated into a plastic card the size of a credit card.

- **RFID System**

RFID is an AIDC technology that uses radio-frequency waves to transfer data between a reader and a movable item, where a tag is attached to identify, categorize & track.

Others are touch memory and charge injection.

2.1.3.2. **FEATURE EXTRACTION (BIOMETRIC) TECHNOLOGIES**
This is science of counting and (body) measurement procedures involving living beings.

a) **VISION**: This is the science of retina (or iris) identification. It is less common.

b) **SPEECH RECOGNITION**: In the science of voice recognition, the user talks into a microphone linked to a computer. This equipment converts the spoken words into digital signals, which are evaluated by the identification software.

c) **FINGERPRINT RECOGNITION SYSTEMS**: The dermal ridges of the fingertips (a unique physical characteristic) can be obtained not only from the finger itself, but also from objects that the individual in question has touched.

### 2.1.4. RFID VERSUS BARCODE

RFID tags are often a complement, but not a substitute, of barcodes. They may not ever completely replace barcodes, due to their higher cost and the advantage of multiple data sources on the same object.

<table>
<thead>
<tr>
<th></th>
<th>RFID (EPC)</th>
<th>Barcode (UPC)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Line of sight</strong></td>
<td>Not required</td>
<td>Required</td>
</tr>
<tr>
<td><strong>Reading distance</strong></td>
<td>up to hundreds of meters</td>
<td>Few centimeters</td>
</tr>
<tr>
<td><strong>Read rate</strong></td>
<td>Hundreds of tags read simultaneously</td>
<td>One at a time</td>
</tr>
<tr>
<td><strong>Dynamic updates</strong></td>
<td>Can be always updated</td>
<td>Static data</td>
</tr>
<tr>
<td><strong>Amount of data storage</strong></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Human assistance</strong></td>
<td>Virtually none</td>
<td>High</td>
</tr>
<tr>
<td><strong>Type of identification</strong></td>
<td>Can univocally identify each item</td>
<td>Can identify only the type of the item</td>
</tr>
<tr>
<td><strong>Counterfeiting</strong></td>
<td>Very difficult (unique tag ID)</td>
<td>Quite simple</td>
</tr>
<tr>
<td><strong>Durability in harsh environments</strong></td>
<td>High (converted tags)</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Problems due to metals and frequency</strong></td>
<td>High (frequency dependent)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td><strong>Capability to be read when dirty</strong></td>
<td><strong>High</strong></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td><strong>Event triggering</strong></td>
<td>Capable (i.e. door opening)</td>
<td>Not capable</td>
</tr>
<tr>
<td><strong>Public/Reserved data storage</strong></td>
<td>Public and reserved</td>
<td>Only Public</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

Table 2: a comparison of RFID and barcode technologies.

### 2.1.5. DIGITAL COMMUNICATION MODEL

This section explains the processes and models that digital information in form of BCD, binary-coded data is subjected to from the source to the output.

In the context of RFID systems, (Harmon, September, 2003) the following sequence of communication is encountered:

i. The host manages one or more readers and issues commands.

ii. The reader and tag communicate via RF signal. (LF, HF, UHF and USF)

iii. The carrier signal is generated by the reader. This is upon request from the host application.

iv. The carrier signal sent out through the reader’s antenna(s).

v. With threshold carrier signal, the tags in the interrogation zone are activated.

vi. The tag receives and modifies carrier signal. It could "send back" the modulated signal. One of the techniques is Passive Backscatter, also referred to as "field disturbance device."

vii. The tag’s antenna receives the modulated signal and sends it to the reader.

viii. Reader decodes the data. The results are returned to the host application.
The modifications made include encoding (source, channel & error control), modulation, demodulation, decoding (source, channel & error control) and equalization.

2.1.5.1. RFID COMMUNICATION PROTOCOLS

A communications protocol is a way of organizing the conversation between devices (tags and a reader) to ensure that information actually gets transferred. A protocol defines:

a. The air interface which defines the modulation, encoding methods for both tag and reader, what kind of signal the tag sends, the speeds of communication, if information is sent in discrete packets, and if so how they are formed.

b. The medium access control defines mode of communication (Full or Half Duplex) and how collisions in reading are resolved.

c. The data definitions it entails what sort of data the tag is associated with and its meaning.

These definitions are listed in the appendices of this study report.

Figure 4: The Elements of RFID Digital Communication System.

2.1.5.2. THE OSI REFERENCE MODEL
In reference to the popular OSI model (Open Systems Interconnectivity), mostly 4 out of 7 layers are deployed.

Layer 7: Application Layer: The host computer’s inventory & Point-of-Sale systems are run. It contains authentication methods, data manipulation and other high-end processes.

Layer 6: Presentation Layer: Data encryption and representation.

Layer 2: Data-Link Layer: The interrogators manage addresses such as the IP ports and heartbeat), perform error detection and correction and collision detection and recovery. These are encapsulated on the data before the data is sent by or to the application.

Layer 1: Physical Layer: The RF modules and antennas are in this layer. They perform transmission with specified data rates, modulation and encoding.

It is important to mention the medium of propagation. It is mentioned by particular authors as layer 0. The medium of propagation could be air, water, human/animal flesh or other matter combinations. The medium affects the wave penetration and is considered during choice of frequency of operation.

2.2. HARDWARE: TAGS

2.2.1. INTRODUCTION

There is a wide range of tags in the market today. The principle of selection for a certain application is therefore very important. The factors of consideration are type, size, cost, read range, read rate, memory and its programmability and the operation environment.

The operation environment determines the frequency of operation, the absorbance in the medium, EMI and noise suppression technique and subsequently its cost.

2.2.2. TAG TYPES

Tags could be active, passive or semi-passive. Active devices require a power source, thus they can be used to tag motor-vehicle, communication gadgets, jewellery other large high-valued
items. Passive and semi-passive tags do not require a power source and can be used to tag items such as apparels, shopping items, pharmaceutical drugs and other small low-valued items.

The form factor (physical dimensions) of the tag is an important factor which affects packaging. Tags are usually mounted on substrate, sandwiched between an adhesive layer and a paper label, embedded on plastic cards, key fobs and cases of palettes or special packaging with resistance to heat, corrosion and harsh cleaning conditions. Small tags are portable and are easily hidden from mutilation and physical damage. Large tags are more identifiable and they have a large surface area for antenna construction.

The cost of tags varies. However with the burst in semi-conductor technologies, the cost of tags is substantially reducing.

The read range varies with application. For instance in toll collection systems, the distance could be as large as tens of meters while in the contactless smart-card application, tags the distance is in the order of millimeters.

Read rate depends on the frequency of operation. In LF and HF implementations, the read rate is slower compared to the UHF and SHF.

Another fundamental factor in the choice of a tag is its memory and its programmability. Fundamentally, each tag has at least 16 bits to store the EPC identity. Other memory is either locked or unlocked. Read-only cannot be changed unlike write-read tags. In certain applications, like banking cards, it would be necessary to reprogram tags for security and recycling.

Typical tag manufacturers in the market are D.o.D, CustomEPC, GID, SGTIN and SSCC.

2.2.3. TAG STANDARDS

There are five tag standards which form the basis of developing tags in the market today.

Class 0 is a read-only passive tag using backscatter where the tag was programmed at the time the tag chip was made.

Class 1 is a read-only passive tag using backscatter with one-time non-volatile programme capability.
Class 2 is a passive backscatter tag with up to 65kB of read-write memory.

Class 3 is a semi-passive tag with up to 65kB read-write memory and a battery incorporated to provide increased range.

Class 4 is an active tag using a battery to enable extra functionality within the tag and also to provide power for the transmitter.

Class 5 is an active tag that provides additional circuitry to communicate with other class 5 tags.

2.2.4. TAG CONSTRUCTION

![Simple Tag circuitry](image)

Figure 5: Simple Tag circuitry

For the consideration of this study, the functional blocks of architecture, (Leeming, 2004) are

- **The antenna**, typically a dipole antenna with a resonant frequency chosen depending on application.

- **The rectifier**, which converts part of the incoming RF power to DC power for supply in active components of the tag.

- **The power-matching network**, which realizes maximum power transfer to the tag.

- **The series voltage regulator**, consisting a parallel capacitor and resistor to achieve constant regulated voltage.
- **The modulator**, which converts data from the control logic to changes in the input impedance using a PIN triode.

### 2.2.5. TAG FREQUENCIES

The standardized frequency ranges from 125 KHz - 5.8 GHz.

- **LF (125 kHz & 134 kHz) tags** use CMOS processing, the band enjoys relative freedom from regulatory limitations. They are well suited for applications requiring reading small amounts of data at slow speeds and minimal distances. They have limited quantity of memory and often read-only. They penetrate materials water, tissue, wood and aluminum well. They however do not penetrate or transmit well around metals such as iron and steel. They handle only small amounts of data, they have slow read speeds. They require large antennas compared to higher frequencies. They have minimal range (10 cm). The tag construction is expensive, more complex and thicker than higher frequencies. Typical applications are Smart Card, Ticketing, animal tagging, access and laundry, Integration into car key-fob and in environments with a high presence of liquids and metals.

- **HF (13.56 MHz) tags** use CMOS processing. They are well suited for applications requiring reading small amounts of data and minimal distances. The signal penetrates well in water and tissue. They have simpler antenna design (fewer turns of the coil) hence lower costs to build. They have higher data rate (approximately 50tags/second) and thinner tag construction (than 125 kHz). Used in contactless Smart Cards. The band is however a government regulated frequency worldwide. They do not penetrate or transmit around metals. They have large antennas (compared to higher frequencies). They have larger tag size than higher frequencies. Tag construction: requires more than one surface to complete a circuit and the reading range is around 0.7 m. Typical applications are Small item management, supply chain, anti-theft, library and transportation.

- **UHF (between 300 MHz & 1GHz) tags** are effective around metals. The tag size is smaller than 13.56 MHz tags. They have relatively smaller antennas. The read range is about 3-5 m. They have good non-line-of-sight communication (except in conductive, "lossy" materials). They have high data rate (approximately 150tags/second) and controlled read zone (through antenna directivity). However, they do not penetrate well in water/tissue. They have
regulatory issues (differences in frequency, channels, power, and duty cycle). Typical applications are transportation vehicle ID, access and security, large item management and supply chain.

**UHF (2.45GHz) tags** are smaller in size than inductive or lower range UHF. They have a range greater than inductive without battery tags. They have more bandwidth than lower range UHF because they have more frequencies to hop. They have smaller antennas than lower range UHF or inductive and high data rate. They enjoy good non-line-of-sight communication (except for conductive, "lossy" materials). They can transmit large amounts of data more quickly than lower frequencies. They have a controlled read zone (through antenna directivity) and are effective around metals with tuning/design adaptations. However, they are more susceptible to electronic noise than lower UHF bands, e.g. 433 MHz, 860-930 MHz, they use shared spectrum with other technologies (microwave ovens, RLANS, TV devices, etc.). They require non-interfering, "good neighbor" tactics like FHSS. They are in a competitive requirement since there are few single chip manufacturers; highly technical; limited number of vendors. Typical applications include road toll, access and security, large item management and supply chain.

**SHF (5.8 GHz) tags** are in the least congested band hence they suffer less interference. However, they are rare, they must orient antennas carefully. Their range is limited due to scaling issues and wavelengths used. Their chip is difficult to build.

### 2.2.6. PASSIVE UHF TAG COMMUNICATION

The principle of operation between the reader and the tag is categorized into two periods, namely the downlink and the uplink.

#### 2.2.6.1. DOWNLINK

This is the period the reader emits RF carrier signal to search for tags. For UHF Generation 2 readers, ASK is the modulation used. Digital RFID tag data is encoded using PIE (Pulse Interval Encoding).
In this encoding, the bit-rate is normally between 26.7kbps to 128kbps.

Encoding methods are FM0 baseband, which has a bit-rate ranging from 40kbps to 640kbps and Miller Sub-Carrier method which has a bit-rate between 5kbps to 320kbps.
2.2.7. **TAG PLACEMENT**

Tags can be attached to almost anything. They are attached to pallets or cases of products, vehicles, company assets or personnel, items such as apparel, luggage and laundry. They could also be attached to human beings, livestock, pets and high value electronics such as computers, TVs, camcorders, iPads.

### 2.3. HARDWARE: INTERROGATORS & INTERROGATION ZONES

#### 2.3.1. **INTRODUCTION**
The choice of an RFID reader, just like a tag, depends on the application. The factors that influence the choice are type, cost, frequency of operation and read range required. Normally, readers are more expensive than tags.

Readers (interrogators) can be at a fixed point such as the entrance/exit, sales and warehouse applications. They can also be mobile (tethered), hand-held, or wireless.

In reader design, my research will be focusing on sensor design as it determines the read ranges. Antenna design (consequently read range design) in supply chain applications is a very important since the systems should not be "ghost reading" a problem caused by reflections hence the reader"s carrier wave travelling long than the designed interrogation zone. This causes inaccuracy from reading items from the next customer's items and those on nearby shelves.

![Reader architecture diagram]

Figure 10: Reader architecture.

The reader usually has three main components; the RF module & antenna, the controller and the network interface.
In most installations, there are two antennas, one for transmitting and one for receiving the signal. The antennas operate on Time Division Multiplexing (TDM).

The controller is a DSP that either processes the signal or switches the data to a network. The network interface is used for transmission of RFID data for processing or programming.

2.3.2. TYPES OF INTERROGATORS

Typical readers in the market are AlienALR9800, SymbolXR400, LLRPReader, Sirit INfinity 510, Thin Magic, Reader Protocol v1.1 and Awid MPR 2010.

2.3.3. ANTENNAS & ANTENNA INSTALLATIONS

The key factors to consider during antenna design are the radiation characteristics and the input characteristics. (Wade, 1998)

Radiation Characteristics include the radiation pattern (both near field and far field patterns), gain, directivity, effective aperture and polarization.

The input characteristics are the input impedance, the bandwidth, reflection coefficient and the voltage standing wave ratio.

A broadband circularly polarized patch antenna is proposed for universal UHF RF identification (RFID) applications. The antenna is composed of two corner-truncated patches and a suspended micro strip line with open-circuited termination. The main patch is fed by four probes which are sequentially connected to the suspended micro strip feed line. The measurement shows that the antenna achieves a return loss of -15 dB, gain of 8.3 dBiC, axial ratio (AR) of 3 dB, and 3-dB AR beam width of 75 deg over the UHF band.

Some readers have only one or two antennas, packaged with the readers themselves; other readers may be able to manage many antennas at remote locations. The primary limitation on the number of antennas a reader can control is the signal loss on the cable connecting the transmitter and receiver in the reader to the antennas. Most installations keep the reader within about six feet (two meters) of the most distant antenna, but much longer runs are possible.
Some readers use one antenna to transmit and one to receive. In this sort of configuration, the tag's direction of motion through the reader's fields is particularly important. If the transmitting antenna is "ahead" of the receiving antenna, the receiving antenna will have a longer amount of time to receive signals from the tag. If the antennas are reversed, the tag will spend much less time energized and within range of the receiving antenna.

2.4. NOISE AND INTERFERENCE SUPPRESSIONS & CANCELLATIONS

2.4.1. INTERFERENCE

Interference can come from man-made sources such as microwave ovens, cell phones, PCs, and radio antennas. Since RFID systems make use of the ISM band of the electromagnetic spectrum (like Wi-Fi networks or cell phones), they are relatively easy to jam using energy at the right frequency. Other phenomena such as reflections, diffractions, material absorption change the theoretical read distance. Multiple readers could also interfere when using the same band. Adjacent channel interference is also realized when strong signals are carried by adjacent channels.

LF (inductive coupling) RFID systems suffer from electromagnetic interference more than UHF and Microwave.

The minimum detectable signal level is influenced by the undesired effects such as noise and distortion. Signal detection is more difficult in the presence of noise. Noise floor is the level of noise introduced at the receiver. The minimum detectable signal must be higher than the noise floor by some signal-to-noise ratio (SNR) to detect signals reliably and to compensate for additional noise added by circuitry.

2.4.2. NOISE TYPES

Noise comes from different related or unrelated sources. When these sources are random and have no relationship with each other, they are said to be uncorrelated. In such cases, noise power
from these sources is added. However, if the noise is correlated, noise voltages are added. (John Rodgers, 2003)

Resistors in a circuitry produce one of the most common noises used in analysis known as thermal noise. This noise arises from the thermal energy emitted in resistors which creates a random electron motion.

Noise \(_{\text{thermal}} = 4kTR\), where \(k\) is the Boltzmann\(\hat{\text{k}}\) constant, \(T\) is the temperature in Kelvin; \(R\) is the value of the resistor.

The rms thermal voltage \(V_n^2 = 4kTR\)\(\Delta f\), where \(\Delta f\) is the frequency range of operation. A better representation is the rms thermal current \(i_n^2 = (4kT\Delta f)/R\). Hence the available noise power at the receiver (when there is maximum transfer of power) \(P_o = V_n^2/4R = kT\). The power output, also known as the noise floor, \(P_{\text{out}} = kTB\). \(B\) is the bandwidth of operation.

2.4.3. SIGNAL-NOISE RATIO

Signal-to-Noise ratio, abbreviated as SNR, the RFID signal power \(S\) compared to \(N\), the noise floor. \(\text{SNR} = S/\text{Noise Floor}\).

The received signal power,

\[
S = (P_t \cdot G_r \cdot A_e \cdot \hat{\mathcal{U}}) / \{(4\pi)^2 \cdot R^4\} \cdot \hat{\mathcal{U}} \\
\text{equation (V)}
\]

Where \(P_t\) is the power transmitted, \(G_r\) is the receiver gain (dBi), \(A_e\) is effective aperture, \(\hat{\mathcal{U}}\) is the cross-sectional area of antenna and \(R\) is the range in meters.

The noise received at the antenna,

\[
N = kT_oB \times F_n \text{ or } N_o [\text{dB}] = 174 + 10 \log (B) \cdot \hat{\mathcal{U}} \\
\text{equation (VI)}
\]

Where \(k\) is Planck\(\hat{\text{k}}\) constant, \(T_o\) is the room temperature (290K), \(B\) is the bandwidth and \(F_n\) is the noise figure at the receiver.

Hence the Signal-to-Noise ratio,

\[
\text{S/N} = (P_t \cdot G_r \cdot A_e \cdot \hat{\mathcal{U}}) / \{(4\pi)^2 \cdot kT_oB \times F_n R^4\} \cdot \hat{\mathcal{U}} \\
\text{equation (VII)}
\]
The Bit Error Rate (BER) is the minimum SNR required to detect bits reliably and is normally 0dB.

The actual SNR depends on the bit rate (also dependent on the modulation technique used), energy-per-bit, IF filter implemented and the detection method used (synchronous or asynchronous).

The noise factor, $F$ is the ratio of SNR at the input over that at the output. The signal at the output $S_o$ compared to that at the input, $S_i$ is amplified by a factor $G$. Any noise added by the circuitry, such as amplifier noise is directly added to the noise at the receiver.

### 2.4.4. RFID READER AND TAG COLLISION

RFID Reader Collision occurs when the signals from two or more readers overlap. The tag is unable to respond to simultaneous queries. Most systems use an anti-collision protocol (also called a singulation protocol. Anti-collision protocols enable the tags to take turns in transmitting to a reader.

RFID Tag Collision occurs when many tags are present in a small area; but since the read time is very fast, it is easier for vendors to develop systems that ensure that tags respond one at a time.

### 2.4.5. METHODS OF CANCELLATION & SUPPRESSION

Noises in the RFID circuitry are usually filtered using DSP filters; as long as the operation bandwidth is known, the noise floor can be calculated. The filter also blocks signals that are not meant for RFID operation using band pass.

RFID systems may also deploy Frequency Hopping Spread Spectrum, FHSS. This is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels using a pseudorandom sequence known to both the transmitter and receiver. Its benefits are its highly resistant to narrowband interference, SS signals are difficult to intercept and transmissions can share a frequency band with many types of conventional transmissions with minimal interference.
2.5. HARDWARE: PERIPHERALS

2.5.1. INTRODUCTION

The primary advantage of smart tags is that the user, in addition to encoding the RFID tag with an identity, can print a bar code and/or human-readable text onto the paper label before attaching it to an item.

2.5.2. PRINTERS

RFID printers are devices that both encode tags and print to the paper labels that house the tags. There are readers that can also "write" to a tag that allows writes, so the primary difference between an RFID reader and an RFID printer has only to do with the laser or inkjet printer component of the RFID printer.

![Diagram of RFID printer components]

**Figure 11:** Components of an RFID printer.

The RFID printer has reader API embedded on the printer API. The reader component is often outsourced from common manufacturers.

The printer is used to encode the tag as well as to print physical features on the tag. The printer API receives unique parts of the label such as the serial number, the product manufacturer, the barcode and the logo images that are to be written on the label.
The verifier is the component that verifies the RFID tag and UPC embedded on the label that is then applied on a product or its case.

The applicator is the component that attaches the label on the product. There are three types of applicators; the wipe-style applicator, the tamp pad-style and the non-contact applicator.

### 2.5.3. LABEL APPLICATORS

The applicator is one of the components of the print and apply systems. Wipe-style applicators and tamp pad-style applicators have differing strengths and weaknesses. A wipe-style applicator has fewer moving parts and does not require an air compressor, but it can jam if a tag curls incorrectly. Tamp pad-style applicators are more reliable and arguably faster, but as mentioned earlier, many require an air compressor to drive the pneumatic ram. Electric solenoids can also be used to drive tamp pads, but the magnetic field generated by the coil may be a problem in RFID applications. An additional type of applicator used for bar code systems blows the tag onto the item with a puff of compressed air. This is called "non-contact labeling."

### 2.6. RFID DATA MANAGEMENT

#### 2.6.1. INTRODUCTION

RFID data can be classified under two categories: event data and master data. The event data is used for dynamic tracking information about RFID-tagged assets. The master data provides supporting contextual information about the event data.

RFID event data is made up of observations of the existence of some thing at some place at some time. Its elements are identity (such as SGTIN, GRAI, SSCC, etc.), location (normally the reader antenna’s where-about) and time (the timestamp the tag was read).

The master data includes the EPC, the manufacturer, the serial number and any other information that identifies the object tagged.
The master EPC data standard is 96-bit and contains the following sections:

a. Header - Tag version number
b. EPC Manager - Manufacturer ID
c. Object class - Manufacturer's product ID
d. Serial Number - Unit ID

*Figure 12: Electronic Product Code*

With 96 bit code, 268 million companies can each categorize 16 million different products where each product category contains up to 687 billion individual units

The UHF generation 2 tags have 4 banks of non-volatile memory.

- Bank 00: Reserved memory which stores access (32-bit) and kill (32-bit) passwords. This memory is read-locked.
- Bank 01: EPC memory which contains Cyclic Redundancy Check (16-bit), Protocol control (16-bit) EPC data.
- Bank 10: TID memory which contains tag identification information such as the tag's serial number, mask-designer ID, model number and 8-bit ISO 15963 allocation class identifier (EPCglobal has ID 0xE2)
- Bank 11: User memory which contains user specified data.
2.6.2. DEALING WITH DATA

The impact of RFID on a business application depends on what data you collect, how much of it, how often you collect it and what you plan to do with it.

Scalable planning needs to be done on data storage measures. This depends on the data collected with the above factors. A reliable database system and a well structured database are necessary to process queries and reports. Data manipulation is key to benefiting an organization’s RFID investment.

2.6.3. INTEGRATION APPROACHES

There have been efforts by many standards communities to integrate this key information obtained at reader points to track the location of a product. This is of great benefit to the supply chain. For instance, if all cars of make L and cruiser VX that were assembled in a certain Toyota plant in 2009 were to be recalled due to brake deterioration problems, the current methods are manual. They would write in distributor publications and the media. However if there was a centralized internet database, they would track the EPCs to the consumer level and request a recall.

These issues led to the EPCglobal Network approach being established in 1999.

2.6.4. EPC GLOBAL NETWORK

EPCglobal envisions a network of EPC-enabled data services that is used by trading partners to enable near-real-time tracking information on items in their supply chains. The network introduces two dedicated components; ONS (Object Naming Service) and EPCIS (the Electronic Product Code Information Services).

The EPCIS defines a standard interface for capturing and sharing EPC-related data.

The ONS maintains mappings between EPCs and the EPCIS servers maintaining information.
The services offered by EPCglobal network are assigning unique identities, detecting and identifying items, collecting and filtering events, storing and querying events and locating EPC information.

The EPCglobal network offers fast, reliable, efficient and accurate tracking of products within the supply chain, through the RFID and EPC technologies as well as the established internet infrastructure.

Figure 13: RFID Integration.

2.7. STANDARDS AND REGULATIONS

2.7.1. INTRODUCTION

RFID standardizations achieve a milestone in customer application acceptance due to investment protection. Manufacturers compete to produce these components hence reduction in prices and increased supply. Hence these components have a global use, labeling methods conform to a standard and open systems are realizable. (AG)
Standardization ensures that different standard-conforming products communicate with each other with a global acceptance.

One of the key issues addressed by the regulatory boards is the usage of channel. A channel has a primary service and a secondary service. The secondary cannot interfere with primary service; it cannot claim protection of interference from primary service but can claim protection of interference from other secondary users. It also overlooks the usage of ISM Bands. Other regulatory issues are Narrowband or Spread Spectrum, the power levels and the duty cycle.

2.7.2. I.S.O & E.P.C. GLOBAL

ISO is the longest established RFID standardization body. In 1996 it set up a joint committee with IEC to look at standardization for RFID technology. The ISO/IEC document defines RFID communication in LF, HF, UHF and SHF. Of interest is the part 6 which defines communication in air interface parameters for UHF 860-960MHz. It defines the forward and return link parameters for technical attributes including, operating frequency, operating channel accuracy, occupied channel bandwidth, maximum effective isotropic radiated power (EIRP), spurious emissions, modulation, duty cycle, data coding, bit rate, bit rate accuracy, bit transmission order, and, where appropriate, operating channels, frequency hop rate, hop sequence, spreading sequence, and chip rate. It further defines the communications protocol used in the air interface.

(catalogue)

EPCglobal is from Electronics Product Code Global Incorporated. It split from the Auto-ID consortium in 2003. It has an Identify-Capture-Exchange architectural framework. It looks into interface standards (ONS, EPCIS, CBV, ALE, DCI, RM, LLRP, Tag protocol for UHF Class 1 Gen 2) and data standards (TDS and TDT). (epcglobal)

2.7.3. REGIONAL REGULATORY BODIES

The frequency ranges available for RFID depend on the region and government policies implemented in those regions.

FCC, (Federal Communications Commission) is the major RF communications regulatory body in the United States of America. RFID products using the UHF 902-928 MHz band have to apply
a frequency hopping spread spectrum modulation technique so as to derive the maximum reader transmitted power allowances. UHF readers are allowed to operate at a maximum power of 1 watt (ERP) and can go up to 4 watt (EIRP) if they have a directional antenna and if they hop across at least 52 channels of 500 kHz each with spurious limits of -50dBc. The regulations are documented in FCC Part 15.247.

ETSI (European Telecommunications Standards Institute) is the major RF communications regulatory body in Europe. In the EN-302-208 Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 Watts (ERP) if they have a directional antenna and if they hop across at least 10 channels of 200 kHz each with spurious limits of -63dBc. The regulations are documented in ETSI EN 302 208.

ITU, the union international des télécommunications provide regulatory regions for its over 170 member countries. Kenya lies in Region 1 which includes parts of Europe and Africa.

In Kenya, the Communications Commission of Kenya, CCK regulates and licenses the frequency spectrum, allowing close consultations licensing of the low powered devices, what is called, classless licensing. In this licensing, devices can maximally output power of 500mW or less. In the service provider license, CCK offers consultation on frequency spectrum management and testing for interference.

2.7.4. SAFETY & PRIVACY ISSUES

They are three key guidelines or best practices that should be taken into consideration when venturing into RFID system design. (Himanshu Bhatt B. G., 2006)

**Technology Neutrality:** RFID technology in and of itself does not impose threats to privacy. Rather privacy breaches occur when RFID, like any technology, is deployed in a way that is not consistent with responsible information management practices that foster sound privacy protection.

**Privacy and Security as Primary Design Requirements:** Users of RFID technology should address the privacy and security issues as part of its initial design. Rather than retrofitting RFID
systems to respond to privacy and security issues, it is much preferable that privacy and security should be designed in from the beginning.

**Consumer Transparency:** There should be no secret RFID tags or readers. Use of RFID technology should be as transparent as possible, and consumers should know about the implementation and use of any RFID technology (including tags, readers and storage) as they engage in any transaction that utilizes an RFID system. At the same time, it is important to recognize that notice alone does not mitigate all concerns about privacy. Notice alone does not, for example, justify any inappropriate data collection or sharing, and/or the failure to deploy appropriate security measures. Notice must be supplemented by thoughtful, robust implementation of responsible information practices.

There is a public perception that limits the venture into RFID as most people say it leaks information about one's whereabouts as well as other sensitive data like medical history, product preference, bank account info and so on. While this technology poses viable solutions, the public should join forums and debates and discuss their concerns.

> „Privacy concerns should be balanced against the benefits offered to consumers. Ironically, sensationalism and paranoia may actually distract us from the real issues.” – (Himanshu Bhatt B. C., 2006)

Specifically, consumers should have the right to:

- Be informed, prior to purchase, whether an item or product contains an RFID tag
- Use, deactivate or remove RFID tags after purchase of an item
- Opt out of RFID-enabled services
- Be informed, at time of purchase or issuance, of what type of data is stored on an RFID tag on a product or card in their possession
- Be informed, at time of purchase or issuance, about when, where and for what purpose a tag in their possession would be read.
CHAPTER 3

3. THE SUPPLY CHAIN MANAGEMENT

3.1. INTRODUCTION

Supply Chain Management (SCM) was developed in the early 90s to eliminate the barriers between trading partners and help synchronize information between them. A simple supply chain comprises of end-consumers who purchase goods or services from a retailer. The retailer stocks these from a distributor, manufacturer or a direct supplier.

3.2. ENTITIES OF SCM

A supply chain has two or more of the following entities or tiers of certain entities.

SUPPLIER: A supplier sells raw materials to the manufacturer for processing or manufacture. He could also sell certain goods to the retailer or consumer.

MANUFACTURER: The manufacturer buys raw materials from the supplier. He turns the supplies to finished goods in a factory or a production facility.

DISTRIBUTOR: The distributor buys goods from the manufacturer in bulk for resale. He has warehouse services to sustain the supply chain.

RETAILER: The retailer owns a store, an online marketplace or other channels to stock goods and services for sale to the consumer. He can warehouse the goods or outsource the service from the distributor.

CONSUMER: This is the end-customer who buys goods or services from the other entities for personal consumption.
Figure 14: a retail supply chain

3.3. CHALLENGES OF SCM

Supply chain faces enormous challenges which degrade efficient of the supply lifecycle. For instance losses and shrinkage due to expirations, shoplifting, theft by staff and physical damages result to low profitability. It relies on human interventions leading to errors, delays and labor costs. Shortcomings like bottlenecks and congestions cause shortages in supply over demand. Lack of proper inventory control, panic of recalls, high profit margins by middlemen, lack of unique item serialization, counterfeiting, are among the drawbacks that lower the SCM metrics.

3.4. BENEFITS OF RFID IN SCM

RFID is promising to bridge the gaps in SCM, reduce inefficiency in the supply process and share crucial information in tracking products. Some of these solutions and benefits are listed below:
a) Inventory visibility. Manual record keeping of count of items is costly, requires human intervention and is error-prone. RFID systems can transmit real-time information of remaining items in the warehouse, assembly line, etc.
b) Major reduction in losses and shrinkage.
c) Tracking lot, food freshness and expiry dates. The information management systems can be maintained to provide warning on expiration of perishable items
d) Work-in-progress data management.
e) Enabling tags to carry real-time databases of tagged item information.
f) Assigning unique serial numbers to tagged items.
g) Sharing EPC and other product data with partners in the supply chain.
h) High resolution product recalls.
i) Identification of bottlenecks and congestions.
CHAPTER 4

4. DESIGN & IMPLEMENTATION

4.1. SYSTEM SPECIFICATION

The RFID system aims to read and identify all tagged items/products which are passed in its read zone, typically the retail outlet’s check in and checkout.

![Diagram of product lifecycle in retail SCM]

**Figure 15:** The product Lifecycle in retail SCM

Items are brought to the retail outlet via the check-in and later leave the outlet via the checkout. The read zones become the critical design factor in order to achieve this objective especially the feed reader antennas. These antennas emit RF signals to activate the tags embedded on the items.
These tags send the EPC and other information to the reader via the antennas for processing. The reader manipulates the data received and transmits the necessary data to the high-level software updating the store records and sales. The reader (optionally) deactivates/kills the tags after purchase.

![Diagram of checkout perspective views](image)

Figure 16: the checkout perspective views diagram.

### 4.2. LINK BUDGET CALCULATIONS

Read range was could be controlled by link budget calculations to determine the power radiated by the reader, the quality factor, Q and also shielding the read zone with a field-conducting material.

For retail outlets, UHF band was suitable for system design since most readers such as the common AlienALR9800 reader operate in this spectrum. Moreover, the band provides sufficient data rates i.e. 640kbps depending on the encoding technique used and short antenna would be constructed. The band's main shortcoming is tendencies of reflections which could extend the read range. This shortcoming is overcome by shielding the read zone and minimizing the obstacles between reader and tags.

#### 4.2.1. DOWNLINK BUDGET

The power radiated (ERP) by the reader antenna was determined using the equation below

The cable losses are computed using the equation

Transmission Line Loss = att. Constant (dB/m) x Length (m) Equation (IX)

The gain of the reader antenna $G_r$ and the gain of the tag $G_t$ were converted into decibel format as follows

$G_{[dBi]} = 10 \log (G) + 2.15$ Equation (X)

The SOM (System Operating Margin) was then be evaluated with knowledge of the tag's sensitivity as follows;

SOM [dBm] = reader ERP [dBm] - Tag Sensitivity [dBm] Equation (XI)

The SOM gave the estimation on allowable losses in transmission including antenna mismatch losses, polarization losses, fading, absorption by liquids and path loss.

Path loss using the inverse square law was summarized as

Path Loss (Pl) [dB] = 32.4 - 20 log (f (MHz)) - 20 log (R (km)) Equation (XII)

The polarization losses depended on the three main polarization methods used; linear, circular and elliptical. The axial ratio (AR) is the ratio of the field's major axis to the minor axis, and could be represented as 10 log (AR). The polarization mismatch was represented by the following equation;

Polarization mismatch ($L_p$) [dB] = 20 log (cos $\theta$) where is the mismatch angle Equation (XIII)

The power available at the tag is therefore given by the equation below

Power received by tag [dBm] = $P_t + G_t + G_r - L_p$ Equation (XIV)

The noise power $N_o$ at the tag receiver is given by equation (VI) and depending on the signal-to-noise ratio required to uniquely process the signal by the tag, the tag's sensitivity is given by

Tag sensitivity ($S_t$) [dB] = (S/N) [dB] + $N_o$[dB] Equation (XV)
4.2.2. UPLINK BUDGET

The power backscattered by the passive tag and received by the tag depends on the tag’s differential radar cross-section $\sigma_{\text{RCS}}$, the tag’s power consumption or quality factor, $Q$.

The return loss expresses the loss in power lost due to mismatch between the tag’s antenna and chip’s impedances. It is defined by the equation below.

\[
\text{Return Loss} (L_r) [\text{dB}] = 20 \log \left( \frac{(\text{VSWR} - 1)/(\text{VSWR} + 1)}{1} \right) \text{ Equation (XVI)}
\]

In decibel format, the power reradiated back to the reader was defined by the equation below.

\[
\text{Power backscattered} (P_{\text{back}}) [\text{dBm}] = P_t + G_r + G_t - \times (P_l + L_p + L_r) \text{ Equation (XVII)}
\]

The noise power $N_o$ at the reader’s receiver is given by equation (VI) and depending on the signal-to-noise ratio required to uniquely process the signal by the reader, the reader’s sensitivity is given by

\[
\text{Reader sensitivity} (S_R) [\text{dB}] = (S/N) [\text{dB}] + N_o [\text{dB}] \text{ Equation (XVIII)}
\]

4.3. SYSTEM SOFTWARE DESIGN

The system required as software to control the read range for typical retail application. It utilized the link budget calculations to enhance the read zone. I developed as Java Enterprise application dubbed UHF RFID simulator for retailers to help design the check-in and/or check-out for such applications. The user inputs the appropriate dimensions; length, breadth and height, speed and other parameters then the systems calculates the required budget parameters such as system operating margin, gains, etc.

FLOW OF INFORMATION

The system flow of information & the input/output process is described in the data flow diagram below.
Figure 17: **Flow Chart of the system Software**

The Read zone Algorithm was developed from section 4.2. It is the core of the system software since it contains the computations of the read ranges, power and gain calculations. The java class `linkbudget.java` which has public methods in its constructor to compute the power-distance curves.

The software also stores configurations of the read environment in the database `uhfrfid`. The MySQL database is used to preload the configurations for simulation and analyses in the proceeding system usage periods.

- **APPLICATION LAYOUT**

  The system software was designed in a user friendly, scalable, and interactive layout using the Java Swing framework, the look is displayed below.
4.4. SIMULATION RESULTS

The system software was used to simulate the read environment and displayed the side antenna parameters for two different configurations. The reader and tag sensitivities, polarizations, and
tag backscatter efficiencies were held constant for both configurations for a design frequency of 915MHz.

<table>
<thead>
<tr>
<th>DETAILS</th>
<th>ENVIRONMENT A</th>
<th>ENVIRONMENT B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration Name</td>
<td>hypermarket_config</td>
<td>warehouse_config</td>
</tr>
<tr>
<td>Dimensions (LxBxH)</td>
<td>6 x 3 x 2</td>
<td>8 x 4 x 3</td>
</tr>
<tr>
<td>Power Radiated (dBm)</td>
<td>26.99</td>
<td>26.99</td>
</tr>
<tr>
<td>Cable attenuation (dB)</td>
<td>0.90</td>
<td>1.25</td>
</tr>
<tr>
<td>Antenna Gain (dB)</td>
<td>9.93</td>
<td>10.28</td>
</tr>
<tr>
<td>Maximum Range (m)</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Polarization losses (dB)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Free Space Path Losses (dB)</td>
<td>27.19</td>
<td>29.69</td>
</tr>
<tr>
<td>System Operating Margin (dB)</td>
<td>40.99</td>
<td>40.99</td>
</tr>
</tbody>
</table>

**Table 3: Software simulated results of two configurations**

The power-distance graph of the environments was plotted. The power radiated in Watts versus distance in meters. The FriiΔ transmission formula was used as power received at any range is inversely proportional to the square of the distance covered. For environment A with gain 6.5012969 and environment B with gain 5.99791076 the curves were displayed below.
Power-Distance Curves

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Power (W) A</th>
<th>Power (W) B</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.09963</td>
<td>0.0092</td>
</tr>
<tr>
<td>0.2</td>
<td>0.05604</td>
<td>0.00517</td>
</tr>
<tr>
<td>0.3</td>
<td>0.02491</td>
<td>0.0023</td>
</tr>
<tr>
<td>0.4</td>
<td>0.01401</td>
<td>0.00129</td>
</tr>
<tr>
<td>0.5</td>
<td>0.00897</td>
<td>0.00083</td>
</tr>
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<td>0.6</td>
<td>0.00623</td>
<td>0.00057</td>
</tr>
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<td>0.00277</td>
<td>0.00026</td>
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<td>1</td>
<td>0.00224</td>
<td>0.00021</td>
</tr>
<tr>
<td>1.1</td>
<td>0.00185</td>
<td>0.00017</td>
</tr>
<tr>
<td>1.2</td>
<td>0.00156</td>
<td>0.00014</td>
</tr>
<tr>
<td>1.3</td>
<td>0.00133</td>
<td>0.00012</td>
</tr>
<tr>
<td>1.4</td>
<td>0.00114</td>
<td>0.00011</td>
</tr>
<tr>
<td>1.5</td>
<td>0.00099</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
4.5. DISCUSSION

From table 3 above, both configurations had an antenna radiated power of 26.99 dBm which is approximately 500 mW. They both comply with CCK standards of classless licensing of low-power devices.

The cable attenuation losses are greater in the warehouse_config since the dimensions of the environment are bigger i.e. cable length of 2.5m compared to 1.8m in the former configuration.

The system operating margin is the same for both configurations since the radiated ERP power and tag sensitivities are equal.

The gain in the warehouse_config is less than that of the hypermarket_config since the design of the antennas requires a broader HPBW for the hypermarket_config.

The free space path losses of the warehouse_config are more than those of the hypermarket since the range of the hypermarket is smaller than that of the warehouse_config. The pathlosses are directly proportion to the frequency and the distance covered.

The power curve was used to prove that the power received beyond the software’s read range for both environments. The tag sensitivity specified was -14 dBm or 39.8 mW. From the power curves, the read range of 0.8m. The curve slopes exponentially with the square of distance.
CHAPTER 5

5. CONCLUSION & FURTHER WORK

5.1. CONCLUSION

The developed software reliably calculated the required read zone parameters such as gain, power radiated (ERP) and the losses associated with reader tag communication. It successfully obtained a system operating margin for the environment in case of high noise or interference. A safety operation margin of 40.99dB obtained for the both environments simulated in the section 4.2 above is necessary for dense-obstacle environment with probable multipath fading and signal absorption in liquids.

The study shows the benefits of a more reliable and speedy system for identification and tracking objects. The EPC code can uniquely and reliably serialize items in the universe for coming years. From my study and simulation I can conclude that RFID technology can be used in retail outlets for inventory and sales management. Most of its drawbacks are be handled by standards from ISO/IEC and EPCglobal. The cost of tag makes this technology shy of implementation; however the chip tags can be substituted with chip-less technology such surface acoustic wave tags or the combinations of 16 one-bit transponders to represent uniquely an item.

5.2. RECOMMENDATION FOR FURTHER WORK

The research problem would have been more extensive with provision of a greater budget. It was also limited on the period of project work.

I recommend more research on the following:

a) Design Implementation: as much as simulation is affordable, actual design of the read zone would give more accurate and pragmatic results.

b) Cheaper technology to manufacture tags such as surface acoustic wave and one-bit transponders.
APPENDIX A: CODE SECTION: JAVA CLASS

The code provided below is not completely the running software. It is a snippet from the class Link budget which computes the main power, gain and losses calculations.

```java
//define project package
package uhfrfid;

// link budget constructor
public class linkBudget {

    //variable declaration
    public double readerpower;
    public double readerconnectorlosses;
    public double readergain;
    public double readerantennalosses;
    public double pathlosses;
    public double polarizationlosses;
    public double misalignmentangle;
    public double tagmismatchlosses;
    public double tagreceievedpower;
    public double tagbackscatterpower;
    public double readerpowerreceieved;
    public double readersensitivity;
    public double tagsensitivity;
    public double taggain;
    public double noisepower;
    public double cableatt;
    public double frequency;
    public double readrange;
    public int readerpolarization;
    public int tagpolarization;
    public int tagbackscatterefficiency;
    public final double radiatedpower = 26.99;
    public final double cableattpm = 0.5;

    public void linkBudget() {
    }

    // method to calculate the forward link budget
    public double getforwardlinkBudget() {
        tagreceievedpower = (radiatedpower - getpathlosses(readrange, frequency)
        + readergain + taggain - getpolarizationlosses(null, null, taggain));
        return tagreceievedpower;
    }

    // method to calculate the return link budget
    public double getreturnlinkBudget() {
        readerpowerreceieved = (getbackscatteredpower()+readergain + taggain
        - getpathlosses(readrange, frequency)
        - tagreceiverpower;
    }
```
- getpolarizationlosses(null, null, taggain));
return readerpowerreceieved; }

public double getbackscatteredpower()
{
readerpowerreceieved = getforwardlinkBudget() + taggain + readergain - getpathlosses(taggain, taggain) - getpolarizationlosses(null, null, taggain) - getreaderreturnloss(taggain);
return tagbackscatterpower;
}

//calculating cable losses
public double getcablelosses(double length)
{
double cablelosses = cableattpm*length;
return cablelosses;
}

//calculating reader gain
public double getreadergain(double EIRP, double length) {

double readergain;
double cablelosses = length*cableattpm;
readergain = EIRP - radiatedpower + cablelosses;
return readergain;
}

//calculating path losses
public double getpathlosses(double a, double b) {

pathlosses = (32.4 + ((20*Math.log(a/1000))/2.302585093) + ((20*Math.log(b))/2.302585093));
return pathlosses;
}

//calculating tag-reader polarization mismatch
public double getpolarizationlosses(String tagpol, String readerpol, double angle) {
String circ = "Circular";
String line = "Linear";
if (tagpol.equals(circ)) { polarizationlosses=0;}
else if (tagpol.equals(line)) {polarizationlosses= 3;}
else {
    polarizationlosses = (20*Math.log(Math.cos(angle)))/2.302585093;
}
return polarizationlosses;

}

//calculating return losses
public double getreaderreturnloss(double VSWR) {

double readerretloss;
readerretloss = (20*Math.log((VSWR-1)/(VSWR+1))/2.302585093);
return readerretloss;
}

//calculating noise power
public double getnoisepower( double a) {
    noisepower = 174 + (10*Math.log(a))/2.302585093;
    return noisepower; }

//calculating reader sensitivity
public double getreadersensitivity(double snr, double noise)
{
    readersensitivity = snr + noise;
    return readersensitivity;
}
}
# APPENDIX B: READER DATA SHEET

<table>
<thead>
<tr>
<th>Model Number</th>
<th>ALR 9800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>XScale processor, Linux, 64 Mbytes RAM, 32 MBs Flash</td>
</tr>
<tr>
<td>Supported RFID Tag Protocols</td>
<td>EPC Gen 2; ISO 18000-6c</td>
</tr>
<tr>
<td>Reader Protocols</td>
<td>Alien Reader Protocol, SNMP, firmware upgradeable</td>
</tr>
<tr>
<td>LAN Protocols</td>
<td>DHCP, TCP/IP, NTP</td>
</tr>
<tr>
<td>Dense reader Management</td>
<td>Dense Reader Mode, Event triggering</td>
</tr>
<tr>
<td>Frequency</td>
<td>902.75 MHz ÷ 927.25 MHz</td>
</tr>
<tr>
<td>Channels</td>
<td>50</td>
</tr>
<tr>
<td>Channel Spacing</td>
<td>500 KHz</td>
</tr>
<tr>
<td>RF Power</td>
<td>Max 4 watts EIRP with Alien Antenna</td>
</tr>
<tr>
<td>Power</td>
<td>Tri-voltage AC/DC power converter; 45 Watts Maximum 120 or 240 VAC</td>
</tr>
<tr>
<td>Communications</td>
<td>RS-232 (DB-9 F), LAN TCPI/IP (RJ-45)</td>
</tr>
<tr>
<td>Antennas</td>
<td>4 ports; multistatic topology; circular or linear polarization, reverse polarity TNC; requires minimum of 2 antennas or external circulator</td>
</tr>
<tr>
<td>General Purpose Inputs/Outputs</td>
<td>4 inputs, 8 outputs, optically isolated, 0.5 amp, requires external power source of no more than 24 volts</td>
</tr>
<tr>
<td>Dimensions</td>
<td>(L) 11ô x (W) 9.0ô x (D) 2.2ô</td>
</tr>
<tr>
<td>Weight</td>
<td>2.0 kg (4.4 lb)</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20°C to +50°C (-4°F to +122°F)</td>
</tr>
<tr>
<td>Dust and Moisture</td>
<td>IP53</td>
</tr>
<tr>
<td>LED Indicators</td>
<td>Power, Link, Active, Ant 0-3, CPU, Read, Sniff, Fault (red)</td>
</tr>
<tr>
<td>Software</td>
<td>SDK Java and .NET APIs</td>
</tr>
<tr>
<td>Compliance</td>
<td>Certification Emissions: FCC Part 15</td>
</tr>
<tr>
<td>Safety</td>
<td>UL 60950</td>
</tr>
</tbody>
</table>
APPENDIX C: RETAIL MARKET FLOOR PLAN

Figure 20: The floor plan of the Retail Outlet showing the checkout section
BIBLIOGRAPHY


