

# Design and Implementation of a Secured Automated Library Using RFID

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## Abstract

*For many years, libraries were operated manually which made the job of the Librarian tedious and slow. However, in recent years, modern life has increased the demand for reliable communication systems and internet technologies. Activity such as e-learning has forced the global educational institution to adopt an automated library, the Radio Frequency Identification (RFID) system was introduced and also, the need for tracking and identification of library resources. In this paper, an RFID-based detection system was used. It involves the use of radio frequency and microchip technology, alongside other components to identify books leaving the library efficiently. The RFID tag used is the passive read/write tag in the 13.56 MHz unlicensed Radio Frequency band, due to its affordability and ease of implementation. This paper seeks to enlighten library users, such as administrators about the importance of RFID technology in the improvement of library management. The proposed system consists of the antitheft security gate, used to detect, if a library book has been properly checked out and a database (middleware) to know which book or material was taken or is about to leave. The result showed that within the acceptable range of 40 mm, the RFID reader works efficiently in theft detection. This range can extend for large-scale deployment.*

**Key Words:** *Arduino, Library, Radio Frequency Identification (RFID), Reader, Security, Tags.*

## 1. Introduction

Libraries are regarded as large banks where books and other relevant materials which are meant to improve knowledge are kept and retrieved from. With the emergence of new research areas and the improvement of existing research areas, quite a large number of books and other informative materials are being introduced into the libraries on a regular basis (Gohil, 2015.). Examples of such library materials include books, journals, periodicals, audio/visual media, manuscripts, and maps (Library Books and Reference Materials, 2017). In a typical library management system, some tasks carried out are planning for and procurement of relevant resource materials, classification, arrangement and preservation of resource materials, cataloguing, borrowing and returning of library materials by library patrons (Yu, 2011).

Radio Frequency Identification (RFID) on the other hand, is a smart, low-cost chip or tag that can be embedded in or attached to products, devices, articles, books and the likes to convey information about the products via a scanner (U.S. Patent No. 6,853,303 B2, 5, 2005). Before the advent of RFID technology, barcodes are being used in libraries (barcodes are still in use by libraries who cannot afford the RFID technology). Many libraries have already installed barcode systems, where a barcode is attached to each book, and the LMS (Library Management System) uniquely identifies the book by reading the barcode, using a barcode scanner. This technology has enabled self-service and self-return to operate successfully for many years, functions which have since come to be synonymous with RFID technology.

However, with the emergence of RFID, the identity of subjects in the physical world is established using uniquely numbered electronic tags. When a tag is attached to an item such as a human, animal

or a supply chain product. Its ownership of the tag identifies the subject. In other words, as RFID assumes that the item in possession of a tag is the authorized entity; a change of tag ownership, for example, when an attacker clones or steals a tag, can result in the attacker obtaining access to the assets which RFID is being used to protect (in this case, library books).

Therefore, to address the security mentioned above issues, the preferred choice of RFID tags for this research is the passive read/write tags which acquire their power via inductive coupling with the RFID reader. Most libraries use RFID tags that operate on the 13.56 MHz high-frequency unlicensed band, which is widely accepted and has a maximum read range of approximately one meter (Mahajan, 2012). Passive tags are limited by the amount of power they can obtain from RFID readers. As the transaction time between tags and readers is limited to less than 400 milliseconds in the United States, to supply cryptographic components with sufficient power, tags would need to be read from a shorter distance, which would degrade the read-rate of RFID readers (Hartnett, 2007).

This study proposed a secure RFID based detection and anti-theft system model that can be used globally in most university libraries across the world to prevent theft of library books and other resources, replace barcodes and the manual means of keeping and monitoring of library assets. The other parts of this research paper are organized in the following order: Section 2 described the related work in RFID technology and library automation. Section 3 highlights the design, methodology and various components of the proposed model. Section 4 presents the results and analyses to show the feasibility of the RFID anti-theft automated library proposed model when compared with the manual means of automation especially in the developing countries.

## 2. Related Works

Gohil, Raviya&Dabhi (2015) defined RFID according to the World English Dictionary, as a technology that uses tiny computer chips to track items such as consumer commodities at a distance. They also stated that the first library suppliers started to market RFID systems in the mid-1990's. It is important to note that Singapore was undoubtedly one of the first to introduce RFID in libraries and Rockefeller University in New York may have been the first academic library in the United States to utilise this technology. Farmington Community library in Michigan may also have been the first public institution to begin the use of RFID in 1999. Therefore, the study has shown that RFID using countries are the USA, UK and Japan. In addition, Indian libraries have also started using RFID, and virtually all the academic libraries attached to the universities in the western world are now widely using RFID technology.

However, Edwards, S and Fortune, M (2008) established the main differences between using barcodes or RFID tags. One main difference is that RFID can issue multiple items simultaneously and to allow things to be read without having to open them to find the barcodes. Another critical difference between barcodes and RFID is that barcode data is uni-directional (i.e. you can only read it, not write it). RFID tags and workstations can also identify multi-part sets to detect whether these are complete on return or issue. Furthermore, Yu, D (2011) in his case study, implemented RFID technology in library systems to focus on the management aspect of a library particularly a self-service support system for patrons. Kim G.G. (2007), also added that the purpose of applying RFID in libraries would be to locate and tracking of assets to minimise searching time, effort, and investment cost. Lastly, Adeniran, T. C. (2015) described an analytic framework of RFID for use by the universities to decide whether or not to deploy an RFID based ID cards to identify and store the data of staff and students electronically. Also, describing the benefits of the technology and its effectiveness as a security mechanism and future trends. It was concluded that whether or not the university is deploying the RFID technology, indeed it will continue to replace the barcodes in the retail supply chain. Although, several hundred libraries in the developed countries have implemented RFID, mostly for self-service and the vast majority of these libraries are positive about their RFID investment and its benefits, but it is relatively unpopular in the developing countries. Hence, Shahid S.M. (2005) suggested that it is essential to educate the library staff and potential users about RFID technology before implementing it.

### 3. Methodology

RFID systems fall into two main categories: near-field systems which employ inductive (magnetic) coupling of the transponder tag to the reactive energy circulating the reader antenna, and far-field systems which couples to the real power contained in free space are propagating electromagnetic plane waves. The near-field system was adopted for this model implementation because its techniques generally apply to RFID systems operating in the LF and HF bands with relatively short reading distances. There is a distance, commonly known as the radian sphere, inside which one is said to be in the near field and outside of which one is said to be in the far field. Because changes in electromagnetic fields occur gradually, the boundary is not precisely defined; the primary magnetic field begins at the antenna and induces electric field lines in space (the near field). The zone where the electromagnetic field separates from the antenna and propagates into free space as a plane wave is called the far field. In the far field, the ratio of electric field E to magnetic field H has the constant value of  $120\pi$  or  $377\Omega$ . The approximate distance where this transition zone happens is given as follows (Kahng, 2009):

$$r = \frac{\lambda}{2\pi} \dots\dots\dots(1)$$

The reactive near-field region is a region where the E and H fields are not orthogonal; anything within this region will interfere with the antenna and distort the pattern, so the antenna gain is not a meaningful parameter here. Using (1), at 13.56 MHz ( $\lambda = 22\text{m}$ ), this places the near-field–far-field boundary at about 3.5m. Estimating far field distance for  $D > \lambda$ , we have:

$$r = \frac{2D^2}{\lambda} \dots\dots\dots(2)$$

Generally, the radiating near-field or transition region is defined as a region between the near reactive field and a far field. In this region, the antenna pattern is shaping but not fully formed, and the antenna gain measurements will vary with distance:

$$\frac{\lambda}{2\pi} < r < \frac{2D^2}{\lambda} \dots\dots\dots(3)$$

The RFID system was designed using RFID modules, which is commercially viable and a widely adopted solution because it is cheaper and more efficient to use.

- i. Class 2 (Read/Write) tags were used and these kinds of tags allow data to be written and rewritten to them several times.
- ii. The tags used were also passive tags based on the power supply. These kinds of tags do not have their power supply or internal battery but depend on energy generated by the RFID readers for communication. The significant advantage is that they are cheap as compared to active tags but their transmission distance is shorter due to their dependence on the RFID reader for power.
- iii. The tags were used alongside a reader which serves as the power supply to the tags.
- iv. Arduino Uno R3 board which is the brain of the whole system was used as the microcontroller. It has an operating voltage of 5V.
- v. Python programming language was also used in creating the database (middleware).

#### 3.1. Components of the RFID-Based Detection System

The components of the RFID-based detection system used for this research work are RFID Tag, RC522 RFID Reader, Arduino Uno R3 Board (Microcontroller Unit), 12 VDC Power Supply, LEDs, common cathode RGB LED, a buzzer, a push button switch and connecting wires.

- i. *Power Supply Unit:* Power supply is a vital part of any active system. The function of the power supply unit is to supply the required DC voltage needed for the running of the Arduino

board and all other peripheral components. The power for the MFRC522 RFID reader, which requires a 3.3 VDC power, and all other parts are sourced from the Arduino board. The power supply unit supplies 12 VDC from the wall adapter power supply or 9 VDC from the backup battery source, and a 12 V relay is employed to switch between them.

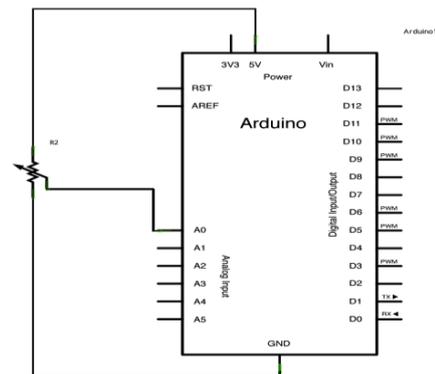
- ii. *Arduino Uno R3 Board:* The Arduino Uno R3 board is the brain of the whole system. The operating voltage of the board is 5V with a recommended input voltage of 7 – 12V. It contains an ATmega328P microcontroller. The Arduino Uno board can be powered via the USB connection or with an external power supply, and the power source is selected automatically. In the course of this project, the Arduino Uno R3 was powered via the USB connection.

**Some of the technical specifications of the Arduino Uno R3 board are:**

- i. It uses the ATmega328P microcontroller which has a flash memory of 32 KB of which the bootloader uses 0.5 KB, an SRAM of 2 KB, an EEPROM of 1 KB and a clock speed of 16 MHz.
- ii. It has 14 Digital I/O pins of which 6 provide PWM output.
- iii. It has a recommended input voltage via the DC input jack of 7 – 12 VDC and a maximum input voltage of 6 – 20 VDC.
- iv. It has an operating voltage of 5 VDC
- v. It has 20 mA DC per I/O pin and 50 mA DC for the 3.3 V pin



**Fig.1: Diagram of an Arduino Uno R3 board**  
(Agarwal, 2017)



**Fig.2: Diagram of Arduino Uno R3 board showing the pin connectors** (Agarwal, 2017)

**RFID Tag:** The tags as indicated in figure 4 below are the class 2 tags which are rewritable, this means that information on them can be changed but at the same time the information on them needs to be deleted before any new information can be added. The tags and the reader communicate in a full duplex manner.

**RFID Reader:** The RFID reader queries the RFID tag(s) and receives data from the tag (see figure 4). The MFRC522 RFID reader is a contactless reader module which communicates at 13.56 MHz with the RFID tag and supports ISO/IEC 14443 A/MIFARE cards. It supports all variants of the MIFARE cards RFID protocols. The reader communicates with the Arduino board via Serial communication. The typical operating distance in read/write mode is up to 40 mm but has an absolute maximum of 50 mm. It works with a power supply of 3.3V with a working current of 13 - 26mA and an idle current of 10 – 13 mA.



**Fig. 3: RFID tags**



**Fig. 4: RFID MFRC522 reader**

**Indicators:** The indicators are the components of the system used to relate the feedback to the user. The indicators used include LEDs, common cathode RGB (Red Green Blue) LEDs and buzzers.

### 3.2. Components of the RFID-Based Detection System

The block diagram of the RFID system is shown in the diagram below (see fig.5), in the diagram we can see that the reader and the tag communicate in a simultaneous way (full duplex) but the reader is connected to the microcontroller (see figure 5). The reader sends the signal at a frequency of interest to the tag, (each tag, which is composed of an antenna and a chip, should be responsive as efficiently as possible to the incoming RF signal). The received electromagnetic energy activates the chip through the antenna, and the chip provides the stored information for the antenna and then sends the data conveyed in the RF energy back to the reader. The interaction between the reader and the tag can be interpreted as what is made in the radar system. The only difference between the radar and RFID systems is that the RFID system concerns the impedance matching problem of the target, while the radar system does not. Assuming the impedance and polarisation matched between the reader and the tag, we derive the formulae on the power received by the chip in the tag and the power the reader will get as the re-radiation from the tag. We find them useful in determining the values of the antenna gains for the reader and the tag and input power at the beginning of the RFID system design, (Kahng, 2009).

$$P_L = P_{in} G_{reader} G_{tag} \lambda^2 / (4\pi R)^2 \dots\dots\dots(4)$$

$$P_{rec} = P_{in} G_{reader}^2 G_{tag}^2 \lambda^4 / (4\pi R)^4 \dots\dots\dots(5)$$

Where:

- $A_s$ : effective scattering aperture
- $A_e$ : effective receiving aperture
- $P_L$ : power received by the chip in the tag
- $P_{rec}$ : power received by the reader (through the re-radiation)
- $S_i$ : Power density at  $i$
- $G_i$ : antenna  $i$  gain
- $\sigma$ : radar cross-section

Using the power received by the reader and tag, we can read range as follows:

$$R_{max} = \min \left[ \left\{ \frac{P_{in} G_{reader}^2 G_{tag}^2 \lambda^4}{(4\pi)^2} \right\}^{0.25} \right] \dots\dots\dots(6)$$

According to the formula, it is clear to see what kind of parameter determines how far the RFID communication covers.

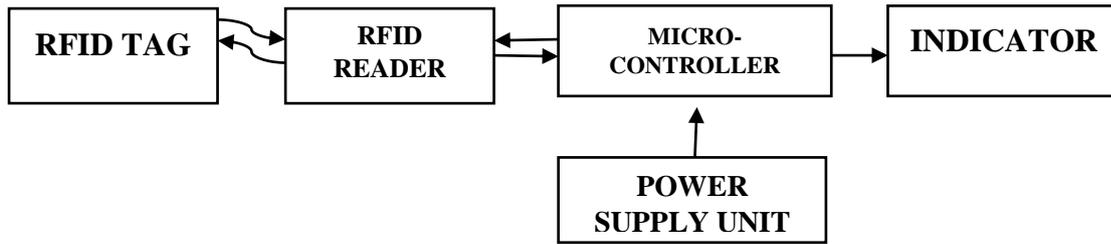


Figure 5: Block diagram of an RFID system

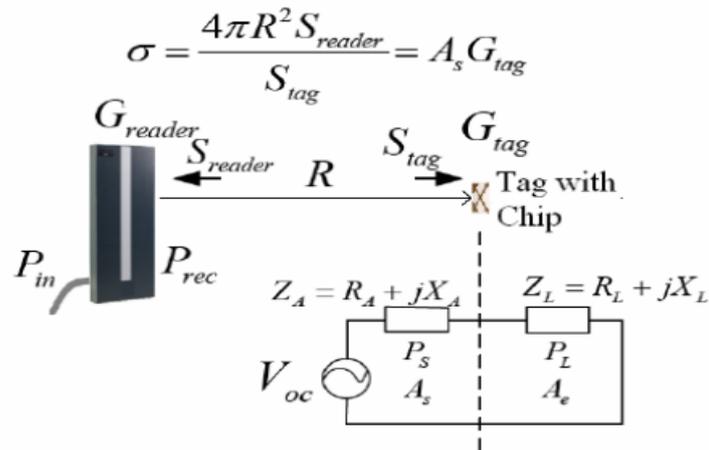


Figure 6: Sketch of a typical RFID System (Kahng, 2009)

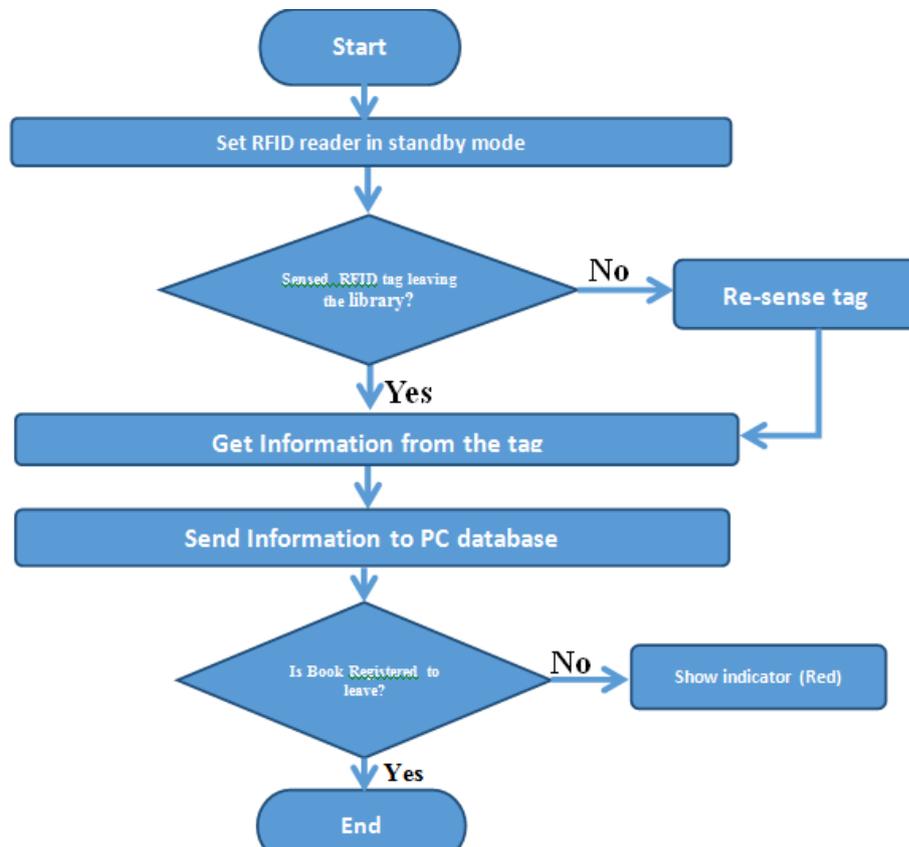


Figure 7: Flow chart showing the RFID system communication

The RFID-based detection system mounted at the security gate comprises of three different states, which are: The first state indicates that the system is powered on and has initialised. This is achieved by connecting a USB cable to the RFID system and to the computer (see Figure 8).



Fig. 8: A serial connection between the RFID Tag and reader.



Fig. 9: RFID system connection to the computer through the USB port.



Fig. 10: scanning the RFID tag

The second state of the system occurs when an RFID tag representing a library book, is checked from the database and the book is allowed to leave the library. The third state of the system occurs when an RFID tag representing a library book, which has not been properly checked out at the circulation unit, passes through the RFID antitheft security gate. There is also the database where the records of books registered are kept. The Graphical User Interface (GUI) of the database has the “ADD” and “CHECK” button to enable the library staff to add a book to the database and to check for the borrowing status respectively (see figure 11 and 12). From the results obtained, it indicated that the aim and objectives of this study have been achieved, as the system can detect library books leaving the library as well as the database.

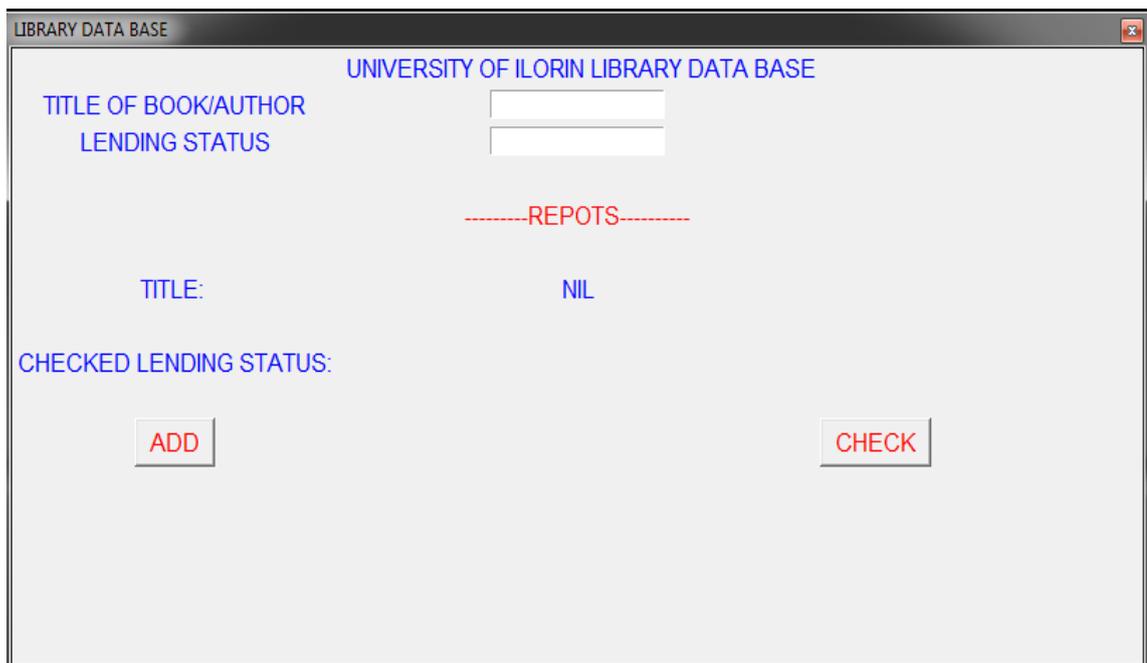


Fig. 11: GUI of the database with the “ADD” and “CHECK” button

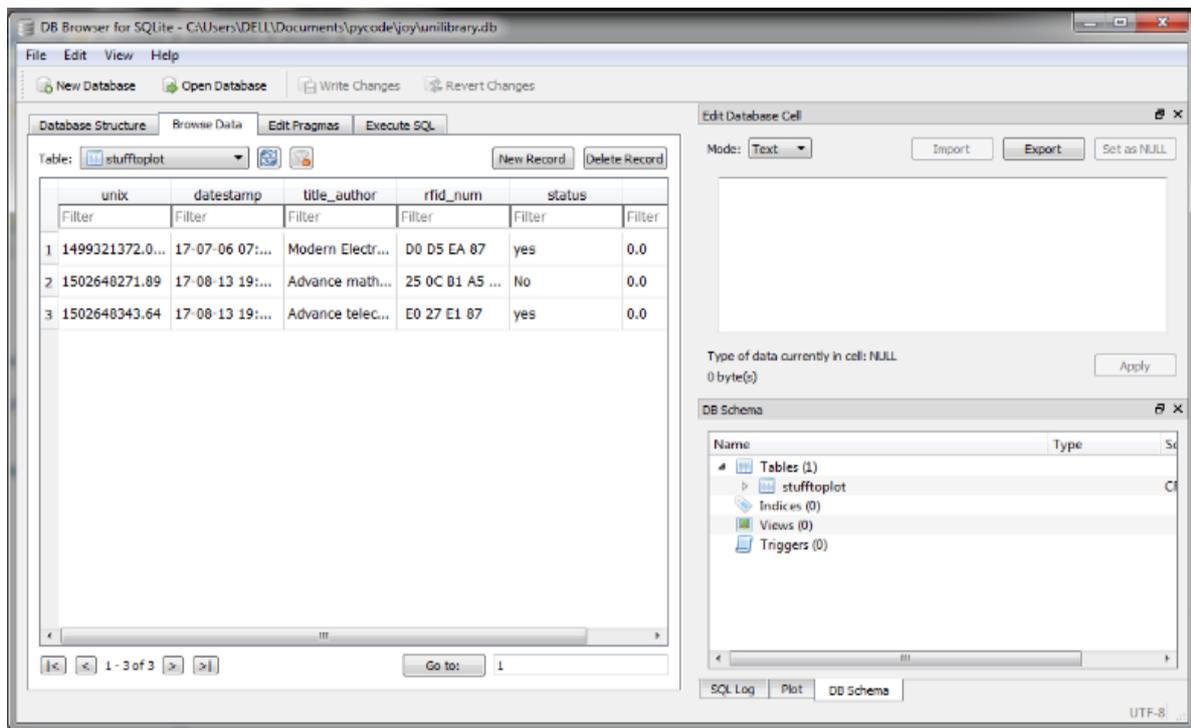


Fig. 12: Database of recorded books and materials with their respective UIDs

### 3.3. RFID Frequencies

RFID is based on radio waves, therefore, understanding the relationship between RFID and frequency bands can help to get a better understanding of how RFID can be applied. The frequency categories and most common RFID system frequencies are shown in Table 1, along with some key characteristics.

Table 1: Passive RFID Frequency Bands and Characteristics (Lieshout, 2007)

Frequency Band	Common Frequency	Coupling	Data Rate
LF	125 to 135 kHz	Inductive	Low
HF	13.56 MHz	Inductive	High
UHF	868 to 928 MHz	Backscatter	Medium
Microwave	2.45 GHz	Backscatter	Medium
	5.9 GHz	Backscatter	Medium

The HF (13.56 MHz) is the globally accepted frequency for RFID systems in library automation. The significant advantages of HF as compared to LF are that the costs of tags are lower, the communication speed is better, and it is possible to read multiple tags at the same time (U.S. Patent No. 6,853,303 B2, 5, 2005).

### 3.4. RFID Standards

There are three significant benefits derived from the development of international standards for RFID systems:

- i. A general RFID standard helps to foster interoperability among RFID tags and readers produced by different manufacturers, even in different parts of the world.
- ii. If there is compatibility between RFID readers and tags from various vendors, then the demand for those readers and tags becomes high which in turns leads to the reduction in the cost of the RFID readers and tags.
- iii. An internationally accepted RFID standard will facilitate the growth of the RFID market on a global scale (Pandian, 2010).

There are already existing and also proposed RFID standards that deal with the air interface protocol (the way tags and readers communicate), data content (the way data is organized or formatted), conformance (ways to test that products meet the accepted standard) and applications (how standards are used, on shipping labels or library books for example) (Violino, 2005). Two organisations are mainly involved in drafting standards for RFID technology: the International Organization for Standardization (ISO) and EPC global (Electronic Product Code) (Pandian, 2010).

ISO has developed RFID standards for automatic product identification and item management, known as the ISO 18000 series, which covers the air interface protocol for systems likely to be used to track goods in the supply chain. They cover the significant frequencies used in RFID systems around the world, and the seven parts of the series are:

18000-1: Generic parameters for air interfaces for globally accepted frequencies

18000-2: Air interface for 135 KHz

18000-3: Air interface for 13.56 MHz which describes two non-interfering and non-interoperable modes of operation which both use a 64-bit identifier:

18000-4: Air interface for 2.45 GHz

18000-5: Air interface for 5.8 GHz

18000-6: Air interface for 860 MHz to 930 MHz

18000-7: Air interface at 433.92 MHz

### 3.5. Communication between RFID Tag and Reader

Whenever communication is established between an RFID tag and a reader, usually there is a transfer of energy from the reader to the tag. There are three main procedures to achieve this transfer: Full Duplex (FDX), Half Duplex (HDX) and Sequential Transfer (SEQ). In the full and half duplex procedure, the energy is transferred continuously, that is, it is independent of the direction of data flow, but for the sequential process, the energy is transferred for a short period only, and data transfer to the reader occurs in the pauses in-between the supply of power to the tag. In the half-duplex procedure, the data transfer from the transponder to the reader alternates with data transfer from the reader to the transponder. In the full-duplex process, the data transfer from the RFID tag to the RFID reader (uplink) and the data transfer from the RFID reader to the RFID tag (downlink) co-occur (Shephard, 2005).

The main coupling techniques used are:

- i. **RFID backscatter coupling:** This uses the RF power transmitted by the RFID reader to provide power for the RFID tag. They mostly "reflect" back some of the power transmitted by the reader, but with some change in the properties, thereby sending information back to the reader, that is, to transfer data back to the reader, the tag modulates the reflected power. The backscatter coupling is used for frequencies below 100MHz (Adeniran, 2015). In this case, the tag antenna receives energy and signal from the electromagnetic field emitted by the reader. RFID backscatter coupling operates in the far-field region, and the radio signal propagates away from the RFID reader. In order to achieve a simultaneous transmission and reception of a signal, directional couplers are often used to allow the received signal to be separated from the transmitted one.
- ii. **RFID capacitive coupling:** RFID capacitive coupling is used for short ranges where a form of close coupling is required. It is usually used for smart cards for which the ISO 10536 standard may be applied. RFID capacitive coupling operates best when items like smart cards are inserted into the reader to provide proximity to the reader. Examples are those used indoor access control systems in some hotels.
- iii. **RFID inductive coupling:** It is usually used for "Proximity coupled" defined under the ISO 14443 or "vicinity coupled" cards defined in the ISO 15693 standard. Regarding operation, inductive coupling is the transfer of energy from one circuit to another via the mutual inductance between the two circuits, just like in the principle of operation of a loosely coupled transformer (Violino, 2005).

The type of coupling used affects several aspects of the RFID system including the detection (read) range, the frequency to be used and other elements of the RFID hardware. The read distance or range of the RFID system can be grouped into three aspects:

- i. **Close range** – within 1 cm, which could either be by capacitive-coupling or inductive-coupling and usually requires the RFID tag to be inserted into the RFID reader.
- ii. **Remote range** – between 1 cm and 1 m, which are usually inductive-coupled, and can be referred to as proximity or vicinity inductively, coupled cards depending on the range.
- iii. **Long range** – more than 1 m, which are typically coupled using backscatter technique.

## 4. Results and Analysis

The table below contains a summary of the test carried out with the reader and tags. The rewritable tags were registered and tested at different read ranges (20mm to 50mm). The category of the antenna used which is the *near-field* system, the number of trials, the number of detections and also the number of errors (negatives) that occurred.

Table 2: Results Obtained from Testing the RFID-based Detection System

S/N	DETECTION DISTANCE (mm)	CATEGORY OF ANTENNA	NO. OF TRIALS	NUMBER OF DETECTIONS	NUMBER OF ERRORS
1.	50	Near field	5	3	1
2.	45	Near field	5	3	1
3.	40	Near field	5	5	0
4.	35	Near field	5	5	0
5.	30	Near field	3	3	0
6.	25	Near field	3	3	0
7.	20	Near field	3	3	0

### 4.1 Analysis

The above table shows a summary of the experimental test carried out to demonstrate the effectiveness of an RFID system. In course of testing from a distance of 50mm and 45mm, a trial was done five times consecutively, however, only three times trials were detected, one error was returned. The error was because the data contained in the tag does not tally with the data that was initially recorded in the database. From a distance of 45mm and 35mm, there was a 5 times repeated trial and all the tags were detected with no error returned. Also, ranges 30mm, 25mm and 20mm, were all tried three times each, all tags were identified and no errors were returned.

These results clearly state that, the closer the tag, the more the tags would be detected. One item of importance here was the type of RFID tags used which are the passive rewritable tags that operate in the 13.56MHz RF range, and this should be the recommended standard tags for libraries to implement. The category was in the near-field system as explained in the former part of this paper. This is because Low frequency (LF, 125-134 KHz) and high frequency (HF, 13.56 MHz) RFID systems are short-range systems based on the inductive coupling between the reader and the tag antennas, through a magnetic field. Also, the near field of a reader antenna can have several tangential, radial electric and magnetic field components which can all contribute to coupling.

From the table above, it can be deduced that maintenance of patron records will be more efficient using RFID because staff members will no longer be saddled with the responsibility of the majority checkouts. Self-checkout patron records are automatically updated with items borrowed when RFID is implemented. Employees will be responsible for checking items in, but RFID automation technology will handle the process, through automatic item identification and the ability to check-in multiple objects simultaneously. Patron record maintenance will also become more flexible and efficient. Finally, Library books and other materials will now be properly tracked and maintained with the implementation of RFID, and this process will save the library management and the university the cost of procuring books due to loss or theft.

## 5. Conclusion

It is clear; therefore that security is a critical issue in today's library management system. Theft of library resources has given rise to a lot of problems such as an increase in operational cost due to stolen books/materials and unaccountability of library repositories. It also deprives other library patrons of acquiring the required knowledge stolen books could have provided. Based on the objectives and results obtained from the experiment, it can be inferred that the RFID based detection

system is a useful tool that can be used globally to reduce mismanagement of library resources. Also, to completely replace the traditional barcodes and eradicate the manual means of tracking library materials. It also has an added advantage of aiding the library staff thereby improving the efficiency of library management. However, due to the limited scope of this study, it has further provided an insight into the design of a new system that can present an empirical validation of the use of RFID for library management over a long period.

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