



ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND COMPUTER
ENGINEERING

**A thesis submitted to the Addis Ababa Institute of Technology,
Addis Ababa University in partial fulfillment for the Degree of
Master of Science in Computer Engineering**

Design and Development of Vehicle Identification System for the
Ethiopian Road and Transport Authority

By

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Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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Place: Addis Ababa

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This thesis has been submitted for examination with my approval as a university advisor.

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Signature 26.3.2011

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Table of Contents

Acknowledgement	i
Table of Contents	ii
List of Tables	v
List of Figures	vi
Abbreviations.....	viii
Abstract.....	ix
1 Chapter I Introduction.....	1
1.1 Introduction to RFID	1
1.2 Historical background of RFID	4
1.3 Literature review	5
1.4 Problem statement	7
1.5 Objective	8
1.5.1 General objectives.....	8
1.5.2 Specific objectives.....	8
1.6 Methodology and tools.....	9
1.6.1 Methodology	9
1.6.2 Tools	9
1.7 Scope.....	10
1.8 Contribution	10
1.9 Thesis outline	10
2 Chapter II Review of basic theories and components of the design	11
2.1 How RFID works	11
2.1.1 Modeling of the RFID system	11
2.2 Current and magnetic field.....	12

2.2.1	Magnetic field by straight conductor wire.....	12
2.2.2	Magnetic field by circular loop wire.....	13
2.3	Capacitance	14
2.4	Inductance various antenna coils	15
2.4.1	Inductance of a circular loop antenna.....	16
2.5	Transformer principle and magnetic coupling.....	18
2.6	Study of the components used to develop the system	20
2.6.1	The EM4095 IC (the reader IC)	21
2.6.1.1	Some Features of the EM4095	21
2.6.1.2	Important facts about the EM4095	24
2.6.2	The EM4102 (the transponder IC).....	27
2.6.2.1	Functional description of the EM4102 internal blocks.....	28
3	Chapter III Design and Implementation	30
3.1	Introduction to the design principles	30
3.2	Note about the design	30
3.3	The main constituents of the overall system design	31
3.3.1	The e-plate RF subsystem.....	32
3.3.2	The reader RF subsystem	34
3.3.3	The enterprise system	36
3.3.3.1	The middleware	37
3.3.3.2	The Analytic subsystem.....	38
3.3.3.3	The network infrastructure.....	38
3.3.4	The inter-enterprise subsystem	39
3.4	The hardware design of the reader.....	40
3.4.1	The power regulator circuit.....	41

3.4.1.1	The +5V regulated voltage source.....	41
3.4.2	The reader antenna design	45
3.4.2.1	Function of the antenna in RFID systems	45
3.4.2.2	Identifying the transponder parameters	48
3.4.2.3	The capacitive divider circuit	51
3.4.3	Designing the RFID reader circuit.....	52
3.4.3.1	Calculating the resonant capacitor value	53
3.4.3.2	Reader antenna current and voltage	53
3.4.4	Microcontroller interface design.....	54
3.4.4.1	Manchester coding basics	56
3.4.4.2	Manchester Encoding	57
3.4.4.3	Manchester Decoding.....	58
3.4.4.4	Sampling based Manchester decoding.....	59
3.4.5	Overall hardware design and printed circuit board (PCB) assembly	61
4	Chapter IV Results and Discussions.....	65
4.1	Discussion	65
4.2	Challenges of antenna design.....	65
4.2.2	Antenna current verification	68
4.3	Voltage regulator design results	69
4.4	The output of the reader.....	69
4.5	Circuit assembly (The PCB)	74
5	Chapter V Conclusion and Recommendation.....	76
5.1	Concluding the work	76
5.2	The benefits of this work	77

5.3 Recommendation for future works.....	77
References	80
Appendix I	82

List of Tables

Table 1.1 Active and passive tag comparison [1].....	1
Table 1.2 Applications and frequency range in RFID systems [4].....	3
Table 2.1 Pin configuration of the EM4095 [14].....	23
Table 3.1 Maximum ratings of TA7805S at 25°C [20]	43
Table 3.2 Antenna design Procedure for RFID applications [22]	48
Table 4.1 Output of the regulator circuit.....	69

List of Figures

Figure 1.1 Inductive coupling principles of RFID [3]	2
Figure 2.1 System model for inductive coupled RFID system [11].....	11
Figure 2.2 Magnetic fields at a certain point [10]	13
Figure 2.3 Magnetic field due to single circular loop [10]	14
Figure 2.4 The off characteristic of a magnetic field with distance.....	14
Figure 2.5 Dimension of a circular magnetic loop.....	17
Figure 2.6 Multi-layer circular loop wires [10].....	18
Figure 2.7 Picture of the EM4095 (left) and pin outs of the EM4095 (right) ..	22
Figure 2.8 Block diagram representation of the EM4095 [14].....	27
Figure 2.9 Block diagram of the EM4102 [15]	28
Figure 3.1 Proposed E-plate.....	32
Figure 3.2 Memory array for Manchester encoded EM4102 chip	34
Figure 3.3 Vehicle reader RF subsystem	35
Figure 3.4 Connection of an enterprise system to vehicle RF subsystem [16]37	
Figure 3.5 Inter-Enterprise architecture of the vehicle identification.....	40
Figure 3.6 Pin configuration of the TA7805S	42
Figure 3.7 Equivalent circuits of the TA78XXS [20]	42
Figure 3.8 Schematic design of the +5V regulator circuit.....	44
Figure 3.9 Maximum EF strength H as a function of the loop antenna radius r_R with a fixed distance x [22]	47
Figure 3.10 Constituents of RFID cards	49
Figure 3.11 Typical read only configuration of EM4095	52
Figure 3.12 Flow chart of the controller program.....	55
Figure 3.13 Encoding signals	57
Figure 3.14 Timing diagram for sampling based Manchester Decoder	59
Figure 3.15 Schematic Design of the whole circuit as drawn on DipTrace.....	62
Figure 3.16 Routed equivalent of the schematic design.....	63
Figure 4.1 The formed antenna coil.....	66

Figure 4.2 Inductance (L) and quality factor (Q) of the antenna as measure by LCR meter.....	66
Figure 4.3 Series LR setup to compute inductance (L) of a coil.....	67
Figure 4.4 The resonant frequency of the RFID reader as it appeared on oscilloscope	68
Figure 4.5 EM4102 blank card	70
Figure 4.6 The 2kHz serial data of the EM4102 card ID as seen on the DEMOD_OUT pin.....	70
Figure 4.7 Waveform for demodulated cards' ID as seen on the DEMOD_OUT pin of the EM4095.....	71
Figure 4.8 Waveform for decoded card ID as seen on the TXD pin of the microcontroller.....	72
Figure 4.9 The GUI of the application program developed	73
Figure 4.11 The top (left) and bottom (right) side of the assembled board.....	75

Abbreviations

AIDC	Automated Identification and Data Capture
EPC	Electronic Product Code
IC	Integrated Circuit
ID	Identification
IFF	Identification friend or Foe
IoT	Internet of Things
LCD	Liquid Crystal Display
LED	Light Emitting Diode
MIT	Massachusetts Institutes of Technology
OOK	On-Off-Keying
PCB	Printed Circuit Board
PLL	Phase Locked Loop
PSK	Phase Shift Keying
PVC	Poly Vinyl Chloride
RF	Radio frequency
RFID	Radio Frequency Identification
UHF	Ultra High Frequency
UPC	Universal Product Code
VCO	Voltage Controlled Oscillator
VPN	Virtual Private Network

Abstract

The existing manual vehicle identification system is slow, inaccurate and provides little data about a vehicle. In this thesis work, fast, accurate and automatic way of vehicle identification system is proposed. The work focuses on producing a prototype system in which each vehicle is to be tagged with unique electronic Identification (ID). Radio frequency identification (RFID) reader is used to extract the ID in the electronic plate of the vehicle.

Contactless, read only integrated circuit identification device, EM4102 has been used to emulate the electronic plate of a vehicle while a reader built using the EM4095 (a CMOS integrated transceiver circuit) is used as RFID reader.

Experimental investigation was performed on the developed radio frequency identification system in the laboratory to check for the expected result. The experimental result demonstrates that the reader reads the ID of the card at close proximity confirming the functionality of the developed system within the read range of the used frequency. Finally, a clear set of changes that could upgrade the prototype to a working system has been presented.

Key words: Radio frequency identification (RFID), tag, reader, radio frequency (RF)

Chapter I Introduction

1.1 Introduction to RFID

RFID is a means of using radio signal to identify or track objects. The technology can also be used to sort or detect a wide variety of objects. RFID has two main components. The first part is the reader or interrogator while the second part is the transponder often called the tag. The reader reads the information embedded in the memory chip of the tag.

Tags constitute of a silicon chip and antenna and can be either active or passive, depending on whether they have a power source or not. Active tags have their own energy supply like long-life batteries and are capable of initiating their communication to a reader. “Advanced active tags might even form ad hoc peer networks with each other” [1]

Passive tags do not have their own power source and consequently are not able to initiate communication to reader. These kinds of tags obtain their energy source from a reader by means of inductive coupling or capacitive coupling [1]. Passive RFID applications that utilize low frequency use inductive coupling while the higher ones use capacitive coupling. These types of tags have short read range and are cheap to manufacture. Table 1.1 signifies the basic differences that exist between active and passive tags considering metrics like power source, communication type and the read range of the tags.

Table 1.1 Active and passive tag comparison [1]

Tag type	Passive	Active
Power source	RF energy	Battery
Communication	Response only	Response or initiative
Maximum read range	10m	>100m
Relative cost	Least expensive	Most expensive
Typical applications	EPC proximity cards	Large asset tracking

The fundamental operation principle of low frequency RFID system is electromagnetic induction. The tag, which usually is part of an object to be identified or tracked, is made to contain a unique code or ID. In the case of passive tags, the LC circuit which is tuned to the reader's frequency will have induced voltage whenever it arrives at the vicinity of the reader. At this moment, an inductive coupling will take place between the tag and the reader. The tag chip will start up when the induced voltage due to the coupling of the antenna passes the minimum threshold level.

Figure 1.1 shows the general block diagram of an RFID system. The block on the left is reader which contains a tuned LC antenna circuit, a band pass filter circuit and a demodulator circuit. The block on the right is the transponder consisting of the power supply, the chip and antenna.

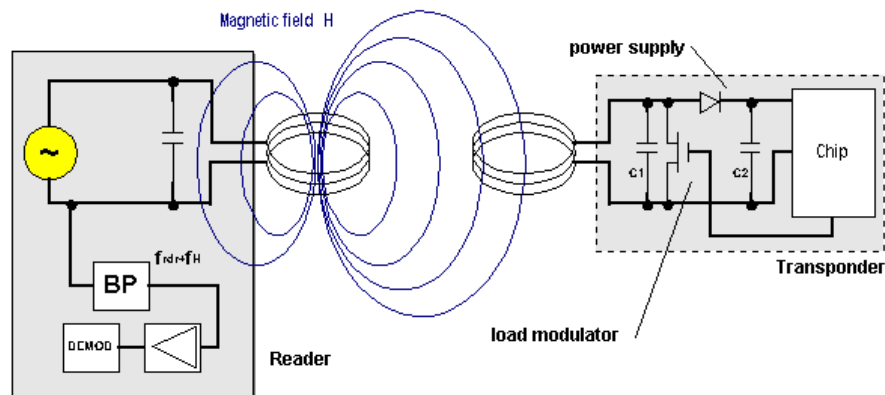


Figure 1.1 Inductive coupling principles of RFID [3]

The type of RFID application to be used directly determines the communication frequency. Table 1.2 shows an overview of RFID performances at various frequencies. It also highlights the performance of tags considering multiple read rate and ability to read near wet surfaces as a function of frequency. The general passive tag size relationship with frequency is also presented.

Table 1.2 Applications and frequency range in RFID systems [4]

	Low Frequency	High Frequency	Ultra High Frequency	Microwave
Frequency Range	<135KHz	13.56MHz	860-930 MHz	2.45GHz
Standards Specifications	ISO/IEC 18000-2	ISO/IEC 18000-3 AutoID HF class1 ISO 15693, ISO 14443 (A/B)	ISO/IEC 18000-6 AutoID class0, class 1	ISO/IEC
Typical read Range	<0.5m	~1m	~4-5m	~1m
General characteristics	Larger Antennas resulting in higher cost tags. least susceptible to performance degradations from metals and liquids	Less expensive than LF tags, Best suited for applications that do not require long range reading of high number of tags. This frequency has the widest application scope.	In volume UHF tags have the potential to be cheaper than LF or HF due to recent advances in IC design. Good for reading multiple tags at long range. More affected than LF and HF by performance degradations from metals and liquids	Similar characteristics to UHF but faster read rates. Drawback is microwaves are much more susceptible to performance degradations from metals and liquids.
Tag power source	Mainly passive using inductive coupling (near field)	Mainly passive using inductive coupling (near field)	Active and passive tags using E-Field back scatter in the far field	Active and passive tags using E-Field back scatter in the far field
Typical applications	Access Control, animal tagging, Vehicle immobilizer	Smart cards, Access Control, Payment, ID, Item level tagging, baggage control, Biometrics, Libraries, laundries, Transport, Apparel	Supply Chain- pallet and Box tagging, Baggage handling, Electronic toll collection	Electronic toll collection, Real Time Location of goods
Note	Largest installed base due to mature technology. However will be overtaken by higher frequencies	Currently the most widely available high frequency world-wide due to the adoption of smart cards in transport.	Different frequencies and power allocated by different countries US 4W(EIRP) 915MHz, Europe 0.5W (ERP) 868 MHz	5.8 GHz more or less abandoned for RFID
Multiple Tag Read Rate	Slower ◀.....▶ Faster			
Ability to read near metal or wet surfaces	Better ◀.....▶ Worse			
Passive Tag Size	Larger ◀.....▶ Smaller			

1.2 Historical background of RFID

RFID is said to have its origin late in the 19th century during when great innovations of electromagnetism were made. Discovery of electronic inductance by Michael Faraday, formulation of electromagnetic waves by James Clerk Maxwell and experimental setup by Heinrich Rudolf Hertz that was able to demonstrate the existence of electromagnetic waves can be mentioned as evidences. The collaborate effects of these discoveries has contributed a lot to the foundation modern the radio communications [1].

However, before anything like radio frequency identification began, the pioneering systems were automatic object detection system. One of such findings and patents was a radio transmitter for object detection systems designed by John Logie Baird in 1926 [2]. Nine years later, Robert Watson-Watt was credited with a patent for his “Radio Detection and Ranging” system or the RADAR. Henry Stockman in his seminar entitled “Communication by Means of Reflected Power” in 1948 had already presented the communication technology that is used in the current RFID system [5].

Later, applications based on radio frequency began to emerge. The first official application using radio frequency identification was during the World War II, when the British Royal Air Force used radio frequency to identify friendly aircrafts from an adversary one in a special “Identification of friend or Foe” (IFF) called application. IFF helped radar operators and pilots to distinguish friendly aircrafts from enemies using RF signals. IFF system has also helped in preventing “friendly fire” incidents [1], [6].

In the late 70s and 80s commercial applications involving RFID began to be seen. These applications were mainly concerned with identifying objects at a certain locations. Retailer companies like Wal-Mart and Metro adopted RFID to their supply chain and have benefited much from the advantages of the

technology. Automatic identification using RFID is based on the automated identification and data capture (AIDC) of the barcode standards. Since RFID enables out-of-sight communication, it is gaining more concern over the barcode and is being installed to read the electronic product code (EPC) on RFID tags which are normally attached to the object of interest. A remarkable era in the history of RFID began in 1998 when researchers at Massachusetts Institute of Technology (MIT) Auto-ID center began researching new ways of tracking objects as these objects move between certain physical locations [7].

1.3 Literature review

Following the start of RFID usages in various sectors, people have always asked what else could this technology be part of; in order to promote efficiency, reliability and accuracy.

Companies like SUPER RFID has developed an RFID based system for identifying vehicle and help control traffic managements [8]. This system includes functions like vehicle registration, annual check, traffic statics (counting car numbers and measuring speeds), anti-theft, police supervision, over-speed check, traffic light violation control, and so on [8]. To achieve its goal, the company has used two approaches. The first is Automatic Vehicle Identification. This is done by providing each vehicle with unique ID tag and the second being traffic management concern. The later uses wireless vehicle detector applied to check speed, count car numbers and work in conjunction with camera monitoring system to realize required functions.

P. Butani, Dr. Joseph John & Major Akash Dhole in their journal *Automatic Vehicle Identification using RFID- A firsthand experience*, describe the performance of different RFID systems purchased from CAEN (Italy) and Alien Technologies, after applying them to a rail system in India [9]. They located the tag either on the side or attached it to the undercarriage of a

train. Trials with CEAN systems work on ISO-18000-6b protocol. The tag they used can store 2k bits of data (256 Bytes).

Testing the system on a train moving up to 75kmph, they have succeeded in retrieving the tag ID along with 10 characters of data (Vehicle number). About the relation of the speed of the train to that reading the vehicle number is that whenever the speed increased beyond 75kmph, the vehicle numbers could not be read. And in addition to that, the longer the vehicle numbers, the slower the speed of the vehicle should become in order to have successful read. This is because; the system first interrogates for the tag ID and in the next interrogation reads the vehicle number (data). This implies that the tag should be available in the reading range for sufficient time for the reader to read the tag ID and the data. From this it can be seen that multiple interrogation cycle limits the speed of vehicles for automatic identification. Therefore the remedy to use this system for vehicle identification at higher speeds is to just read the tag ID and link it to vehicle database on a computer and find out the vehicle number. Missed reads have also been reported due to reflection of RF fields. [9]

System supplied by Alien Technologies works on EPC protocol. The tags can store 96 bits of user programmable data. The equipment was tested up to 150kmph by moving two vehicles, one with tags and the other with reader, in opposite direction. The system, however, was not tested on a wagon, wherein the limitation of reading the tags due to stiffeners, is experienced. Furthermore, they have tried to put the comparisons between each system and made important conclusions on the points of concern when developing automatic vehicle identification. These are;

- The operating environment plays a very important role while designing and implementing an RFID application. Metal objects and electrical noise in the vicinity of tags, extreme operating temperatures, presence

of liquids and physical obstructions can seriously affect the performance of the system. To have a reliable RFID system it is very important to do a detailed site survey and carry out extensive trials.

This can be supported by their findings that it was easier to read the tags on a coaching vehicle than on a wagon with stiffeners.

- Planar antennas have a higher reading range than circularly polarized antennas for the same power level although orientation of tags with respect to the antenna assumes importance.

The later researchers associated their work with the capability of the reader in reading a tag mounted on a train while the train moves at certain speed. They have used tags and readers and interface programs purchased from two RFID devices producers, the CEAN and Alien Technologies. SUPER RFID is however a commercial company that produces and sells RFID devices worldwide. Although there has been no detail information on how the system works, it seems that a complete set of the vehicle identification has been developed. Since both of these papers work on the developed system and do not propose the detailed constituents of the systems, there arises a need of developing a prototype. This work implements the prototype and demonstrates vehicle identification system.

1.4 Problem statement

In Ethiopia, vehicle identification process is entirely manual and is therefore provides little data about vehicles. For example, when a vehicle passes by a forbidden cross, personnel along road may not be able to find out as much information as it is needed about the vehicle. The speed at which the vehicle travels may hinder the personnel from seeing the plate number and even if he/she succeeds in getting the number, then the data has to be taken to the authority office in order to manipulate the detail information about the

vehicle like the owner, which year car model it is, the insurance status and so on.

Therefore it is very important to have a means of identifying vehicles efficiently and address all the flaws that exist in the manual vehicle identification system. In this thesis work, automatic way of identifying vehicles will be designed, implemented and will be tested on a prototype level. It is believed that the outcome of this thesis work will put a solid foundation towards modernizing vehicle identification system.

1.5 Objective

This thesis work aims at producing a prototype RFID based vehicle identification system.

1.5.1 General objectives

In general, a prototype system comprising of RFID that is capable of identifying vehicles at a certain access point will be designed and will be developed to demonstrate the identification process.

1.5.2 Specific objectives

The specific objective of the thesis work is to;

- 1 Design and implement a reader(interrogator) that is responsible for extracting data from the electronic plate and make it ready for further processing
- 2 Design and implement application that utilizes the data extracted by the reader

1.6 Methodology and tools

1.6.1 Methodology

- Reviewing literatures of related system design and find out supporting concepts
- List general and important constituents that the system must fulfill to have good performance
- Design the overall system with the specified components as constituents
- Develop the prototype system and test it

1.6.2 Tools

This work mainly uses the following tools in order to come up with the specified outcomes.

1. AVR Studio 4.0, AVR microcontroller simulator software (hardware and software). This tool is used to develop the controller program and simulate its performance on how it affects the needed ports and all other microcontroller parameters.
2. VMLAB, microcontroller simulator software (hardware, software analog and digital simulator capability). This tool simulates the microcontroller as it receives peripheral analog and digital inputs.
3. AVR microcontroller programmer kit. Burns the developed high level customized C language program into the microcontroller's program memory.
4. Different digital and analog electronic instruments such as LCR meter, oscilloscope, and digital multi-meter.

5. Computer terminal. Runs all the above computer programs and interfaces the reader hardware module to an application

1.7 Scope

This thesis work produces a prototype vehicle identification system at laboratory level with limited identification distance. It signifies how RFID technology can be applied to vehicle identification and provides a scaled down replica of the real system.

1.8 Contribution

This thesis work is believed to demonstrate modern traffic system for the future of Ethiopia. Modern vehicle identification system provides efficient and fast means of identifying, and tracking vehicles.

1.9 Thesis outline

The rest of the thesis work is organized as follows. Chapter II covers the basic principles of RFID technology and explains the components that are to be used in the design process. Chapter III provides the detailed design of each module in the RFID system. Chapter IV discusses the outcomes of the design, Chapter V is conclusion and recommendations.

Chapter II Review of basic theories and components of the design

2.1 How RFID works

Passive RFID tags utilize the induced antenna voltage for their operation. This induced ac voltage is rectified to provide a voltage source for the device. As the dc voltage reaches a certain level, the device starts operating. By providing an energizing RF signal, a reader can communicate with a remotely located device that has no external power source or battery. Since energizing and communication between the reader and tag is accomplished through antenna coils, antenna becomes one of the most significant components of RFID systems. Antennas for RFID system usually are made of coils of magnetic wire. A current flowing into the coil radiates a near-field magnetic field that falls off with r^{-3} (r is the distance away from the antenna) [10]. This type of antenna is called a magnetic dipole antenna.

2.1.1 Modeling of the RFID system

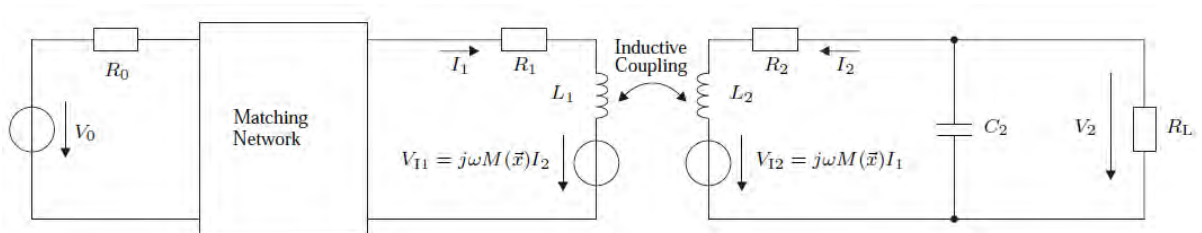


Figure 2.1 System model for inductively coupled RFID system [11]

An RFID system can be separated into two parts: the reader (interrogator) and the transponder (tag). An equivalent network is presented in Figure 2.1. The reader has to provide the power from a source to the transponder through its antenna. In the presented model the output stage of the reader is represented by a voltage source V_0 with an internal resistance R_0 . To deliver

maximum power to the antenna, the impedance of the source has to be matched to the antenna impedance. The antenna can be modeled by an inductance L_1 and a series resistance R_1 , in order to take ohmic losses into account. The transponder antenna is modeled in the same way by an inductance L_2 and a resistance R_2 . The transponder impedance is tuned to the resonance frequency by a capacitance C_2 . The transponder load is modeled by a resistance R_L . The quantity of the load resistance can be determined via the power consumption P_{req} of the transponder and the requirements to the dc supply voltage V_{DD} by $R_L = V_{DD}^2/P_{req}$. The inductive coupling is represented by the mutual inductance M which induces a voltage in the transponder V_{12} due to a current I_1 in the reader coil and vice versa.

2.2 Current and magnetic field

Ampere's law states that current flowing on a conductor produces a magnetic field around the conductor. The amount of magnetic field at certain location can be calculated using different formulas [10], [12], [13]. Furthermore, magnetic field that is produced by a current carrying wire is directly dependent on the shape of the wire not only the distance of measurement.

2.2.1 Magnetic field by straight conductor wire

Figure 2.2 shows the magnetic field produced by a current element. The magnetic field produced by the current on a round conductor (wire) with a finite length is given by:

$$B_{\phi} = \frac{\mu_0 I}{4\pi r} (\cos \alpha_2 - \cos \alpha_1) [10] \quad (2.1)$$

Where;

I is the current flowing through the wire

μ_o is permeability of free space and is given as, $\mu_o = 4\pi \times 10^{-7}$ (Henry per meter)

r is the distance from the center of the wire to the point of investigation

In a special case with an infinitely long wire where $\alpha_1 = -180^\circ$ and $\alpha_2 = 0^\circ$, Equation 2.1 can be re-written as:

$$B_\phi = \frac{\mu_o I}{4\pi r} [10] \tag{2.2}$$

From these equations it can be seen that magnetic field is inversely proportional to the distance at which it was measured.

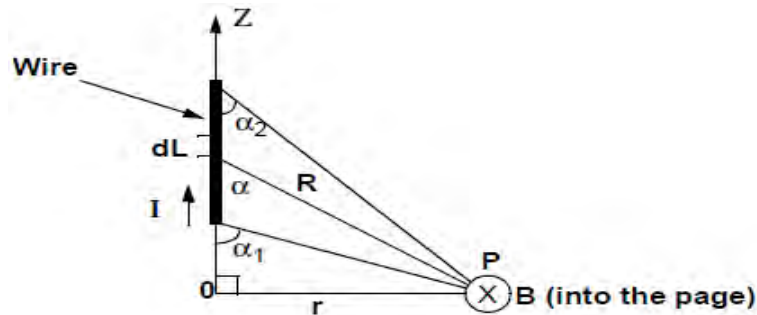


Figure 2.2 Magnetic fields at a certain point [10]

2.2.2 Magnetic field by circular loop wire

Figure 2.3 shows the magnetic field produced by a single loop of wire carrying current I . The value of the magnetic field at point P located at distance r from the center of the loop is given by [10];

$$B_z = \frac{\mu_o I N a^2}{2(a^2 + r^2)^{3/2}} \tag{2.3}$$

For $r^2 \gg a^2$

$$B_z = \frac{\mu_o I N a^2}{2r^3} \tag{2.4}$$

r is the distance from the center of the coil to the point of measurement

a is the radius of the coil.

Equation 2.4 indicates that the magnetic field produced by a loop antenna decays with factor of $1/r^3$ as shown in figure 2.4

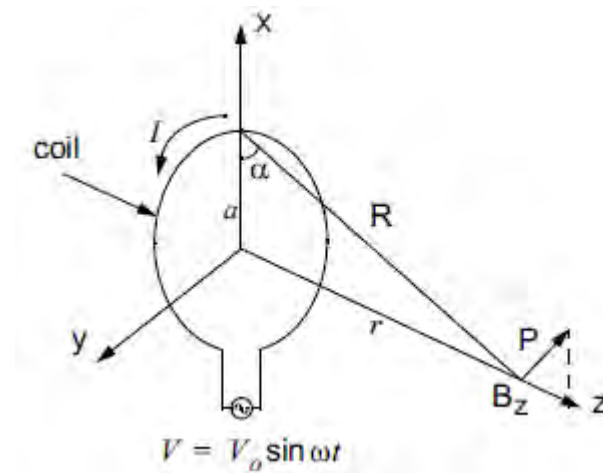


Figure 2.3 Magnetic field due to single circular loop [10]

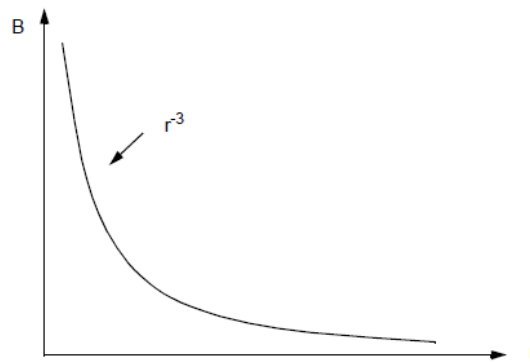


Figure 2.4 The off characteristic of a magnetic field with distance

2.3 Capacitance

The capacitance in a material structure is given by the distribution of charge in the structure and is generally correlated the conductor surface area. A capacitor is made up of two metal plates separated by a dielectric. Hence, the contribution of the metal plate and that of the dielectric to the total capacitance can be given as;

$$C = C_{\sigma} + C_{\delta} \tag{2.5}$$

where C_{σ} is the capacitance of the single metal section, and C_{δ} is the capacitance produced by the 2-layer sections having dielectric in between.

This consideration is very important for tag designers as it is crucial to integrate right valued capacitor into the tag.

2.4 Inductance various antenna coils

The electrical current flowing through a conductor produces a magnetic field. This time-varying magnetic field is capable of producing a flow of current through another conductor. This is called inductance. The inductance L depends on the physical characteristics of the conductor.

A coil has more inductance than a straight wire of the same material and a coil with more turns has more inductance than a coil with a single or fewer turns.

In inductive RFID systems, inductance is most commonly used in near-fields as means of coupling the reader to the tag and tuning the resonant frequency of the tag.

Inductance of a coil, more specifically known as self-inductance, is defined as the amount of flux it induces on itself per unit current, as given by the following equation [10]

$$L = \frac{\phi}{I} = \frac{1}{I} \iint_S B \cdot ds \quad (2.6)$$

where B is the magnetic field generated by a coil carrying current I . However, inductance of a wire is largely dependent on its shape and physical dimensions.

In a typical RFID antenna coil for 125 KHz, the inductance is often chosen as a few milli-Henrys (mH) for a tag and from a few hundred to a few thousand micro-Henrys (μ H) for a reader. For a coil antenna with multiple turns, greater inductance results with closer turns. Therefore, the tag antenna coil has to be formed in a limited space and often needs to be multi-layer winding to reduce the horizontal spreading of the turns. The design of an inductor would seem to be a relatively simple matter. However, it is almost impossible to construct an ideal inductor because,

1. The coil has a finite conductivity that results in losses, and
2. The distributed capacitance exists between turns of a coil and between the conductor and surrounding objects.

The actual inductance for that matter is not purely inductance; rather it is always a combination of resistance, inductance, and capacitance. The apparent inductance is the effective inductance at any frequency, i.e., inductive minus the capacitive effect. Various formulas are available in literatures for the calculation of inductance for wires and coils of different shapes.

An RFID antenna can be built from a magnetic wire. However, there are factors that can affect its inductance such as shape of the antenna wire (coil), the number of turns the coil has, the physical dimension of the wire and the coil as well.

In this section, some basic geometry of RFID antenna coils will be reviewed.

2.4.1 Inductance of a circular loop antenna

There are different ways (formulas) to calculate the inductance of a circular coil. Here two ways will be presented

The first way

This approach depends on the mechanical dimension of the coil and the wire. For multi-turn coil r should be the average radius and r_0 is the radius of the wire used in forming the coil [10].

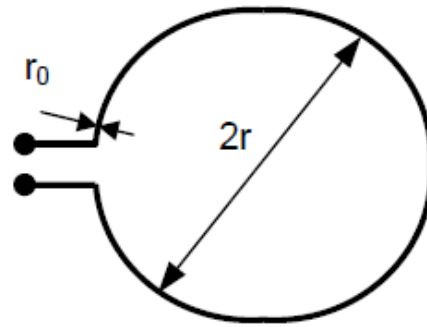


Figure 2.5 Dimension of a circular magnetic loop

The inductance of such a coil is given by the following formula

$$L = \mu_0 N^{1.9} r \ln\left(\frac{r}{r_0}\right) \quad (2.7)$$

This approach of calculating inductance of a multi-layer coil largely depends on the mechanical formation of the coil. Figure 2.6 shows a coil having radius of a and N number of turns arranged in layers. Although the radius of the wire is not directly affecting the inductance of the coil the height h and thickness b of the coil would take radius of the coil into consideration.

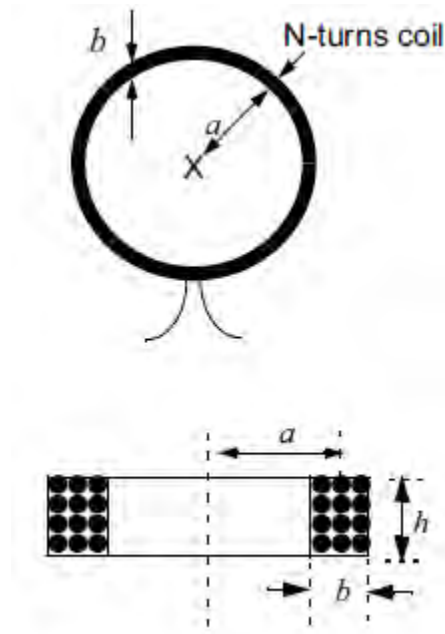


Figure 2.6 Multi-layer circular loop wires [10]

Hence the formula to calculate inductance of a coil made according to figure 2.6 is given as;

$$L = \frac{0.31(aN^2)}{6a+9h+10b} \quad (2.8)$$

L is in μH and all dimensions are in cm

2.5 Transformer principle and magnetic coupling

Referring to figure 2.1, in the earlier part of this chapter one can write the following equation using Kirchhoff's voltage law [11],

$$V_o = R_o I_o + I_1(R_1 + j\omega L_1) + V_{11} \quad (2.9)$$

$$V_2 = I_2(R_2 + j\omega L_2) + V_{12} \quad (2.10)$$

And it can be seen that V_{11} is the voltage induced on L_1 due to L_2 and V_{12} is the voltage induced on L_2 due to L_1 , therefore, more formally these voltages can be written as;

$$V_{11} = I_2 j \omega M \quad (2.11)$$

$$V_{12} = I_1 j \omega M \quad (2.12)$$

M is the mutual inductivity of the transformer coils and furthermore, the mutual inductivity is given by

$$M = k \sqrt{L_1 L_2} \quad (2.13)$$

And k is the coupling factor of the circuit, ignoring the source resistance R_o of the primary coil, we can have

$$V_o = I_1 (R_1 + j \omega L_1) + V_{11} \quad (2.14)$$

And the induced voltage in the secondary (tag) coil can also be given by

$$V_{12} = N \frac{d\phi}{dt} \quad (2.15)$$

Where N is the number of turns of the tag coil and ϕ is the total magnetic flux across the tag's antenna coil. The magnetic flux is defined as the amount of magnetic field crossing a certain area and can be written as,

$$\phi = \int B \cdot d_s = \frac{LI}{N} = B \cdot A \quad (2.16)$$

Therefore combining equation 2.3, 2.14 and 2.15, an expression for transponder induced voltage can be found to be;

$$V_{12} = - \frac{\mu_o N_R N_T a_R^2 S_T}{(a_R^2 + r^2)^{3/2}} * \frac{di}{dt} \quad (2.17)$$

Where N_R is the number of coils in the reader antenna

N_T is the number of coils in the transponder antenna

a_R is the radius of the antenna coil

r is the distance the tag is located at

and S_T is the surface area of the tag that is being crossed by the magnetic flux coming from the reader. The minus sign signifies that the induced current is in opposite direction to the current that caused its very happening. Since the current varies only with time and the rest of the parameters are constant, equation 2.17 can be written as;

$$V_{12} = -M \frac{di}{dt} \quad (2.18)$$

M is mutual inductance between the transponder and the reader; therefore, one can notice that the voltage induced on a transponder's antenna coil is a function of various mechanical parameters and the current flowing through the reader antenna coil. Generally speaking, increasing the number of turns both in reader and transponder coil will increase the voltage induced in the tag coil. However, there is limit in increasing the antenna size of the transponder as the main concern of a transponder is size.

Furthermore, coupling of two coils can be expressed by the coupling factor k which relates the mutual inductance to the self inductances in the following way

$$k = \frac{M}{\sqrt{L_1 L_2}} \quad (2.19)$$

Therefore, one can see that the coupling factor is a function of the mechanical dimension (the mutual inductivity) of the coils as well as the inductivity of the reader's and the transponder's antenna coil. When $k=1$, the reader and the transponder are totally coupled and when $k=0$, either the transponder or the reader is absent, practically $1 \leq k \leq 0$.

2.6 Study of the components used to develop the system

In order to build vehicle identification prototype system, two RF integrated circuits shall be used. These are

1. The EM4095 transceiver IC
2. The EM4102 transponder IC

Both of these ICs come from EM Microelectronic-Marin SA and are easy to deal with components. The EM4102 can be purchased in card form having contained its own antenna laminated within the card. Some important facts of each device shall be discussed below and the design of the hardware in the later chapter will be based on these assumptions.

2.6.1 The EM4095 IC (the reader IC)

The EM4095 chip is a CMOS integrated transceiver circuit intended for use in an RFID base station to perform the following functions [14]:

- antenna driving with externally adjustable carrier frequency
- AM modulation of the field for writable transponder
- AM demodulation of the antenna signal modulation induced by the transponder and communicates with a microprocessor via simple interface.

2.6.1.1 Some Features of the EM4095

- Integrated phase-locked-loop (PLL) system to achieve self adaptive carrier frequency to antenna resonant frequency
- No external quartz required
- 100 to 150 kHz carrier frequency range
- Direct antenna driving using bridge drivers
- Data transmission by on-off-keying (OOK) (100% Amplitude Modulation) using bridge driver
- Data transmission by Amplitude Modulation with externally adjustable modulation index using single ended driver
- Multiple transponder protocol compatibility (Ex: EM4102, EM4200, EM4450 and EM4205/EM4305)

- Sleep mode $1\mu\text{A}$

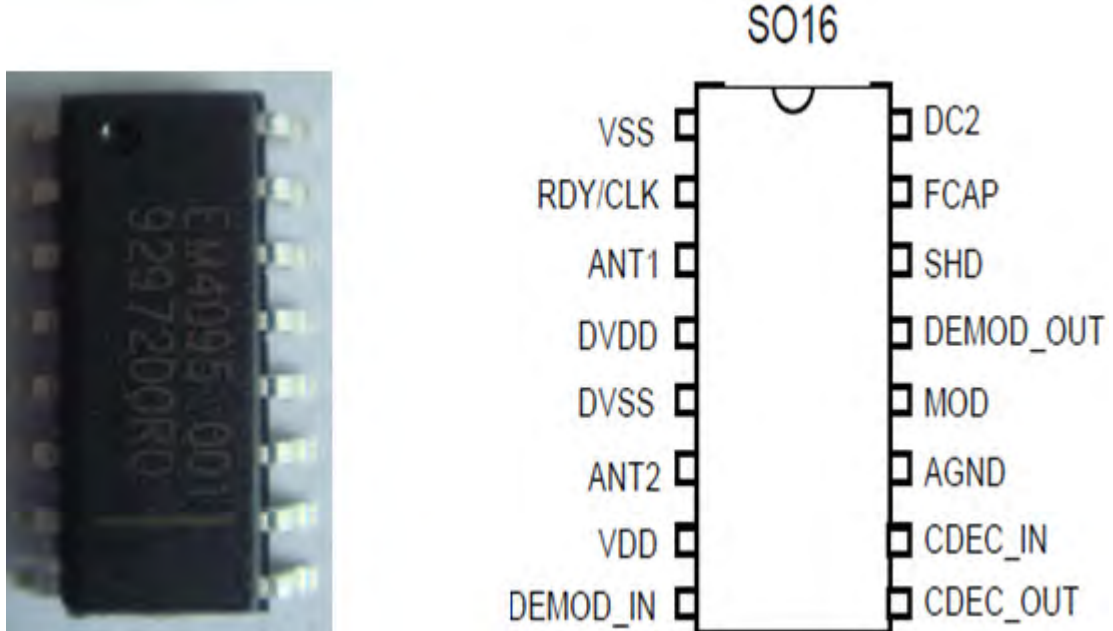


Figure 2.7 Picture of the EM4095 (left) and pin outs of the EM4095 (right)

The pin configuration of the EM4095 is shown in the following table.

Description of corresponding pins is also given. While using a component in computer aided circuit maker programs, it is important to create the precise representation of the IC. Types of each pin must be entered correctly so that the program will run its design rule check correctly.

Table 2.1 Pin configuration of the EM4095 [14]

Pin	Name	Description	Type
1	V _{SS}	Negative power supply (substrate)	GND
2	RDY/CLK	Ready flag and clock output, drivers for AM modulation	O
3	ANT1	Antenna driver	O
4	D _{VDD}	Positive power supply for antenna drivers	PWR
5	D _{VSS}	Negative power supply for antenna drivers	GND
6	ANT2	Antenna driver	O
7	VDD	Positive power supply (substrate)	PWR
8	DEMOD_IN	Antenna sensing voltage	ANA
9	CDEC_OUT	DC blocking capacitor connection <<out>>	ANA
10	CDEC_IN	DC blocking capacitor connection <<in>>	ANA
11	A _{GND}	Analog ground	ANA
12	MOD	A high level voltage modulates the antenna	IPD
13	DEMOD_OUT	Digital signal representing the AM seen on the antenna	O
14	SHD	A high level voltage forces the circuit into sleep mode	IPU
15	FCAP	PLL loop filter capacitor	ANA
16	DC2	DC coupling capacitor	ANA

Key

GND: reference ground

IPD: input with the internal pull down

IPU: input with the internal pull up

ANA: analog signal

PWR: power supply

O: output

2.6.1.2 Important facts about the EM4095

The EM4095 integrated circuit takes care of most of the works of the wireless communication protocol. The specialty of the IC is therefore, few external components are needed to achieve ac and RF filtering, current sensing and power supply decoupling. The operation of device is controlled by the logic inputs SHD and MOD. When SHD is high EM4095 is driven in sleep mode, therefore current consumption is minimized. At power up, the input SHD has to be high to enable correct initialization. When SHD is low after the circuit has been initialized, the circuit is enabled to emit RF field, so, the RF field will induce current in any of the tag in the vicinity and then the tag sends information to the reader base station. At this point, it starts to demodulate any AM signal seen on the antenna. This digital signal coming from the AM demodulation block is provided through DEMOD_OUT pin to the microcontroller for decoding and processing [14].

The IC performs two main tasks of RFID base station, namely; reception and transmission. The transmission process involves antenna driving and AM modulation of the RF field, at this point the antenna driver block provides current to the external antenna to enable and cause it to emit magnetic field. Reception is the result of collaborate effect of the Phase-Locked-Loop and the antenna driver.

The antenna driver provides the antenna with appropriate energy and delivers current at resonant frequency which is typically 125 KHz. However, current delivered to the drivers depends on the quality factor Q of the antenna and while designing the antenna care must be taken so that the maximum peak current of 250mA is never exceeded. Another limit factor for the antenna current is the thermal convection of the package. Maximum peak current should also be designed in a way that internal junction temperature does not exceed maximum junction temperature at maximum application ambient temperature.

The PLL is composed of the loop filter, the Voltage Controlled Oscillator (VCO), and the phase comparator blocks. By using an external capacitive divider, pin DEMOD_IN gets information about the actual high voltage signal on antenna. Phase of this signal is compared with the signal driving antenna drivers. Therefore the PLL is able to lock the carrier frequency to the resonant frequency of the antenna. Depending on the antenna type the resonant frequency of the system can be anywhere in the range from 100 kHz to 150 kHz. Wherever the resonant frequency is in this range it will be maintained by the Phase Lock Loop [14].

The voltage sensed on the antenna is the demodulation input signal for the reception block. DEMOD_IN pin is input to reception chain and the voltage on this pin must be lower than $V_{DD}-0.5V$ and higher than $V_{SS}+0.5V$. The input level to the DEMOD_IN pin is adjusted externally by a capacitive voltage divider circuit. The effect of the capacitive divider network must be taken into consideration to the resonance capacitive value. The AM demodulation scheme is based on the “AM Synchronous Demodulation” technique. The reception chain is composed of sample and hold, DC offset cancellation, band pass filter and comparator. dc voltage of signal on DEMOD_IN is set to analog ground (AGND) by internal resistor. The AM signal is sampled, and the sampling is synchronized by a clock from VCO. Any dc component is removed from this signal by the CDEC capacitor. Further filtering to remove the remaining carrier signal, high and low frequency noise is made by second order highpass filter and CDC2. The amplified and filtered receive signal is fed to asynchronous comparator and the comparator’s output is buffered on the output pin DEMOD_OUT.

The RDY/CLK signal provides the external microcontroller with clock signal which is synchronous with the signal on ANT1 and with information about internal the internal state of EM4095. The indication of synchronous signal to ANT1 is that PLL is in lock and that reception chain operation point is set.

When SHD is high RDY/CLK pin is forced low. After high to low transition on SHD the PLL starts-up, and the reception chain is switched on. After time T_{SET} the PLL is locked and reception chain operation point has been established. At this moment the same signal which is being transmitted to ANT1 is also put to RDY/CLK pin indicating to microprocessor that it can start observing signal on DEMOD_OUT and giving at the same time reference clock signal.

Clock on RDY/CLK pin is continuous; it is also present during time the ANT drivers are off due to high level on MOD pin. During the time T_{SET} from high to low transition on SHD pin RDY/CLK pin is pulled down by 100 K Ω pull down resistor. The reason for this is in additional functionality of RDY/CLK pin in case of AM modulation with index which is lower than 100%. In that case it is used as auxiliary driver which maintains lower amplitude on coil during modulation.

Having these in mind, one has to fulfill all the design parameter for proper functioning of the EM4095 RFID transceiver IC. Section 3.4.2 this IC will be used to build RFID base station that can resonate within 100 kHz to 150 kHz. The selection of the right value for inductance and capacitance will put the IC in the desired frequency of oscillation. Below is the block diagram representation of the internal structure of the EM4095 transceiver IC [14].

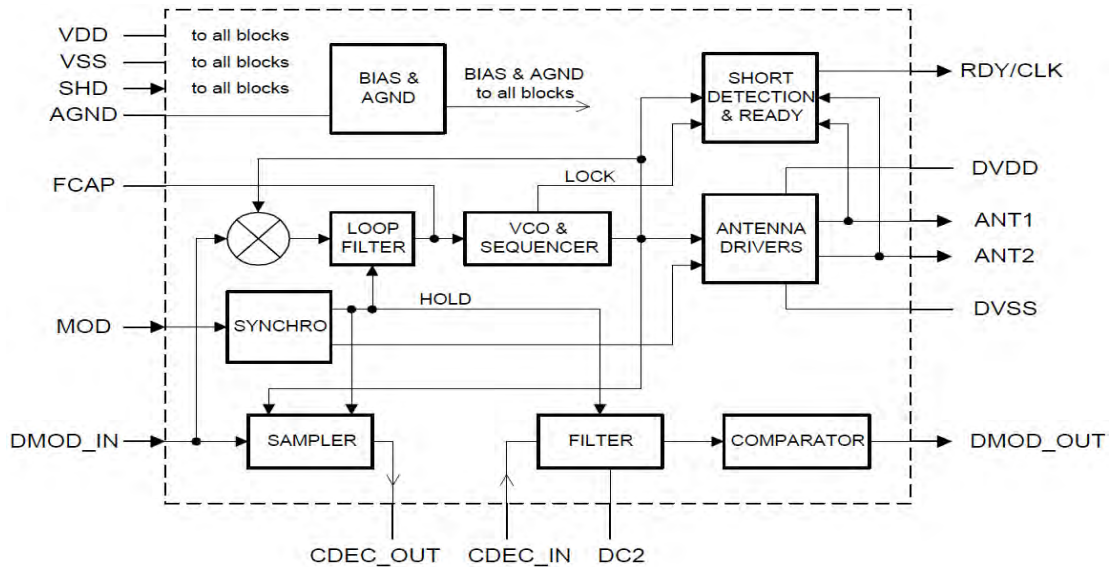


Figure 2.8 Block diagram representation of the EM4095 [14]

2.6.2 The EM4102 (the transponder IC)

The EM4102 is a CMOS integrated circuit intended for use of read only radio frequency transponders. Since the transponder is passive, it gets its power source and its master clock from the external electromagnetic field. By turning the modulation current on and off, the chip will send back the 64 bits of information contained in a factor programmed memory array [15].

The programming of the chip is performed by laser fusing of polysilicon links in order to store a unique code on each chip. The EM4102 has several data rate options like 64, 32 and 16 periods of carrier frequency per data bit. Data rate is a term used to signify the amount of clock signals used to send one bit. Data can be coded as Manchester, Biphasic or Phase Shift Keying (PSK). Due to low power consumption of the logic core, no supply buffer capacitor is required. Since the chip comes with integrated 78 pF resonant capacitor, the only external component necessary to get full functionality of the chip is an antenna coil [15].

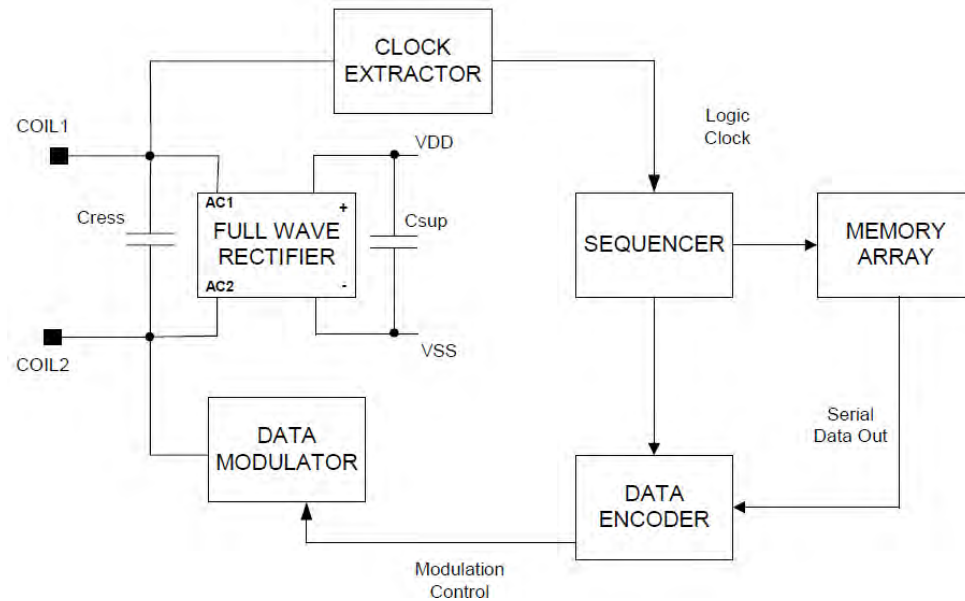


Figure 2.9 Block diagram of the EM4102 [15]

2.6.2.1 Functional description of the EM4102 internal blocks

Full wave rectifier

The ac input induced in the external coil by an incident magnetic field and is rectified by a Graetz bridge. The bridge will limit the internal dc voltage to avoid malfunction in strong fields.

Clock Extractor

One of the coil terminals (COIL1) is used to generate the master clock for the logic function. The output of the clock extractor drives a sequencer.

Sequencer

The sequencer provides all necessary signals to address the memory array and to encode the serial data out. Three mask programmed encoding versions of logic are available. These three encoding types are Manchester, Biphasic and PSK. The bit rate for the first and the second type can be 64 or

32 periods of the field frequency. For the PSK version, the bit rate is 16 RF clock cycles. The sequencer receives its clock from the COIL1 clock extractor and generates every internal signal controlling the memory and the data encoder logic.

Data Modulator

The data modulator is controlled by the signal Modulation Control in order to induce a high current in the coil. The coil 2 transistor drives this high current. This will affect the magnetic field according to the data stored in the memory array.

Chapter III Design and Implementation

3.1 Introduction to the design principles

In order to come up with a working low frequency RFID reader prototype module using the EM4095, the requirements of the various specifications have to be met. Current on each pin of a constituent IC must be within the recommended range. Voltage must appear to be on its right level at the right place. A well regulated voltage source must be designed and used. Microcontroller must act according to the desired procedure and its peripherals working conditions must be met with no exceptions.

Apart from the hardware level design requirements, the controller program (the embedded operating system) should cleanly handle all the exceptions and intermittent phenomena. Although the alleged output of this work is a system, a big emphasis however has been given to the hardware design. This is because the system in its visible nature majorly depends on the performance of the reader module as well as the tag. Next to this, the components that exist in building the being of the whole system are sets of computer programs and applications.

3.2 Note about the design

As the designed system in this work is a prototype, with few amendments, the real world functional system can be achieved. The choice to go for the prototype instead of the real system is because;

1. In real vehicle identification application the reader should have the ability to identify a vehicle at a long distance and do that again for many vehicles around at the same time. Though this is an important requirement that a good design must consider, the read range is largely dependent on the frequency of communication. This in turn claims

sophisticated electrical circuits that can deal with the given frequency and incur larger costs to the design. In addition to that, handling higher frequencies is just delicate process and the scope of this task is considered to be incapable.

2. Secondly, once the prototype is built, then, the rest job that would remain to get to the real functional system is to just upgrade the prototype with recommended settings. This is far from designing a system on theory (paper) level and would mean a lot to putting a landmark design guides.

3.3 The main constituents of the overall system design

As introduced in Chapter 1, all RFID systems contain two basic modules, the tag and the reader. Although the tag and the reader are the major constituents of an RFID system, there are additional systems on top of them that would enhance efficient integrated data processing. The enterprise and the network infrastructure are as equally valuable resources as the tag and the reader, when considering the whole system in general.

Each part has its own sets that makes it up and should be designed in a way that they can readily communicate with each other. The vehicle identification system therefore has the following sets of modules [16].

1. The electronic plate (e-plate) RF subsystem
2. The reader RF subsystem
3. The enterprise system
4. The inter-enterprise system

In this work however, only 1 and 2 shall be implemented. This is because 3 and 4 require deployment of more than one readers and connecting the readers together, but this work produces a single reader and tests it on a database designed on the local computer that the application runs.

3.3.1 The e-plate RF subsystem

In reality the tag is mobile (so can be the reader) and mounted on the object to be identified. It could stay for its lifetime on that object. And the reader is located at a certain place and provides the means of detecting the tag and sending the data to other system for further processing.



Figure 3.1 Proposed E-plate

Sticking to this fact, this work proposes a new kind of number plate for vehicles; the electronic plate (e-plate). It can be seen that the inside view of the e-plate is an RFID tag and the outer look may contain numbers as do the present plate for visual inspections. This makes the e-plate to have dual benefits and can be relied upon anytime.

The e-plate is an electronic circuit module that has its own memory and power source. It has just been discussed that a tag can either contain a read only memory or a re-writable memory module where the unique ID is stored. When considering applications like vehicle identification, it is demanding that the memory array of a tag should be re-writable for number of reasons. This could be for in application like traffic regulation violation, the reader can automatically write a punishment status to the e-plate and this can be scanned at the next reader station and will be reported to the central monitoring station. In addition to the above, the fact that the communication between the e-plate and the reader must be secured as it contains sensitive information. In order to achieve this, there must be a very light-weighted data encrypting algorithm which in turn requires modifying some variables on the e-plate [17]. Since this design aims to secure data and promote the

trustworthy of the party being identified, it must withstand possible forgery attacks pretty well. The National Institute of Standards and Technology in its special publication Guidelines for Securing Radio Frequency Identification (RFID) systems [16] has presented that securing RFID systems depends on the type of application to be used.

RFID attacks like cloning tags and eavesdropping are some of the most common ones reported. Cloning attack is much more identity theft and may result in granting of access to inappropriate party. Eavesdropping grants information to unauthorized party while when the intruder succeeds in seizing valuable data by wondering around the communication channel. In both cases, one can work to prevent them by designing a secured communication protocol. While working on security measures, most researchers have come up to protocols that requires re-writable memory in the tag field [18], [19].

For this prototype, the Em4102 card shall be used as e-plate. This card will be attached to a toy car and will be made to pass by a reader that shall be constructed in the later section of this chapter.

The EM4102 contains 64 bits divided in five groups of information. 9 bits are used for the header, 10 row parity bits (P0-P9), 4 column parity bits (PC0-PC3), 40 data bits(D00-D93), and 1 stop bit set to logic 0. The implementation of an extractor program will focus on retrieving only the 40 data bits. The column and the row parity will be checked in a function and only upon successful read the data will be available for further processing.

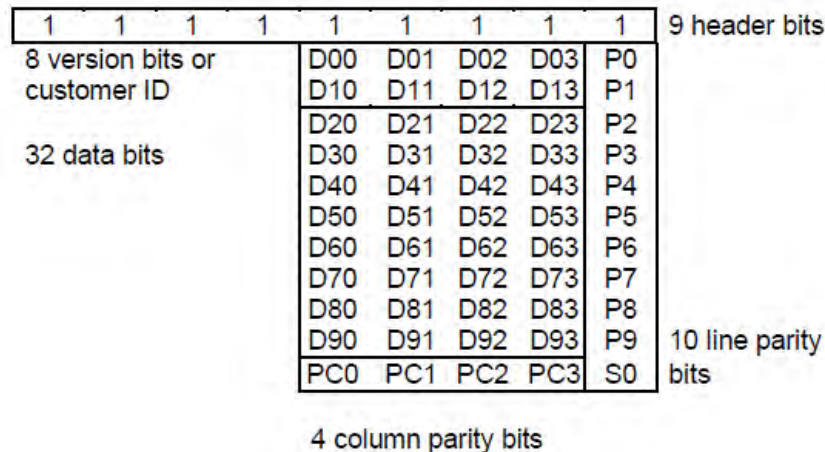


Figure 3.2 Memory array for Manchester encoded EM4102 chip

The header is composed of the 9 first bits which are all programmed to "1". Due to the data and parity organization, this sequence cannot be reproduced in the data string. The header is followed by 10 groups of 4 data bits allowing 100 billion combinations and 1 even row parity bit. Then, the last group consists of 4 event column parity bits without row parity bit. S0 is a stop bit which is written to "0" Bits D00 to D03 and bits D10 to D13 are customer specific identification. These 64 bits are outputted serially in order to control the modulator. When the 64 bits data string is outputted, the output sequence is repeated continuously until power goes off [15].

3.3.2 The reader RF subsystem

Readers to be deployed in vehicle identification system are of two types; mobile readers and fixed roadside readers. Both have their own application and enhance the power of the system. The requirements of a reader in general however must be fulfilled by both. These requirements are [16],

- Long read ranges
- Anti-collision support
- Reasonable duty cycle
- Power consumption

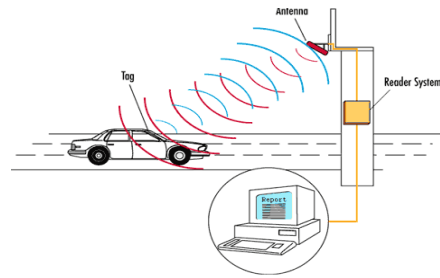


Figure 3.3 Vehicle reader RF subsystem

Long read ranges

This is desired for the matter that the objects to be identified are big (vehicles) and are mobile. There is a direct relationship between the frequency of communication and the distance an object can comprehend the commands of the reader. Although, the e-plate contains its own power source, the magnetic field the reader sends has to reach the e-plate in good strength and the information must be decodable. This in turn implies that readers with high frequency shall be used. As frequency is no more only signal, but asset also, the selection of the frequency of communication must comply with the international standards and interferences must be avoided.

Anti-collision support

This is another important requirement that a good reader must have. Anti-collision is a procedure of reading multiple tags at the same time (actually in different time slots) and addressing each tag uniquely. When it comes to vehicle identification, it is crucial that multiple vehicles at the reader's vicinity are identified and all necessary data modification on each of their e-plates is carried out with no collision to each other. Anti-collision performance of an RFID system is however the result of its communication protocol and the hardware performance of the reader.

Reasonable Duty-cycle

A duty-cycle shows how often the reader emits RF signals in order to find out if a tag is around. If a reader's RF is on for 30 seconds, then the reader is said to have 50% duty cycle if considering its period to be one minute. Duty-cycle of a reader directly dictates power consumption of the reader and should be point of concern for hand held mobile readers. Moreover, apart from power consumption, the duty cycle of a reader in vehicle identification system will strictly be related to traffic flow rate and vehicle speed. The probability that a vehicle arriving in the reading range of in reader's vicinity shall be analyzed and the duty cycle better are set accordingly. Setting of the reader's parameter such as duty-cycle must be flexible hence configurable as different hours and places may have different traffic flow rates.

Power consumption

When it comes to electronics, one of the most important parameter to judge certain device for quality is its power consumption. This can also be the measure of its efficiency. In general the reader shall work long on little power and should show reliable performance while doing so.

3.3.3 The enterprise system

The enterprise subsystem connects readers to computers running software that can store, process, and analyze data acquired from RF subsystem (both the reader and the tag) transactions to make the data available for the supported processes. For example, the RFID system in vehicle identification system has an RF subsystem that can read the ID number associated with each vehicle tagged with e-plate. The enterprise subsystem matches the identifier to the vehicle's record in a database to determine any information related with vehicle, like owner name, model number and so on. An enterprise subsystem consists of three major components as shown in figure 3.3.

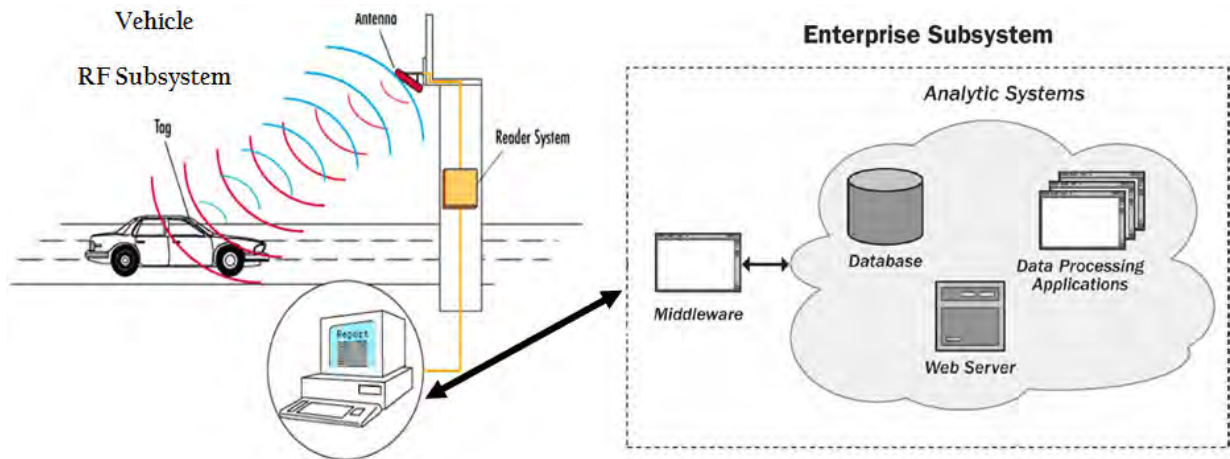


Figure 3.4 Connection of an enterprise system to vehicle RF subsystem [16]

These are;

- The middleware
- The analytic system
- The network infrastructure

3.3.3.1 The middleware

An RFID middleware is responsible for preparing data collected from readers in the RF subsystem and convert them so that they can be used by the analytic systems that directly support the required processes. Middleware hides the complexity and implementation details of the RF subsystem from the analytic systems. This allows the developers and users of the analytic systems to focus on the business implications of RFID data rather than the intricacies of RF communication.

System administrators also use middleware to monitor and manage readers. For example, system administrators use middleware to adjust the power output and duty cycle and reduce the number of transaction errors. Many middleware products also support event-based triggers that perform actions automatically under certain conditions. Middleware transaction logs help

with the identification of anomalous behavior, which could provide hints to an organization to detect unauthorized use of the RFID system.

3.3.3.2 The Analytic subsystem

Analytic systems are composed of databases, data processing applications, and Web servers that process the data outputs of middleware based on business requirements and user instructions. They contain customized logic functions for each desired process they support.

Analytic systems are often enterprise applications that draw inputs from multiple sources, many of which may not necessarily be the RF subsystem. There might be other systems like over-speed sensors that pass their outputs to the analytic system for combined work integration and identification and registration of a vehicle traveling faster than allowed speed limit. Analytic systems also correlate RFID data with non-RFID records imported from other databases, such as records from inland revenues of vehicle taxes.

3.3.3.3 The network infrastructure

Network infrastructure enables communication between the RF and enterprise subsystems, as well as among components of the enterprise subsystem. Some important characteristics of network infrastructure include:

- The physical and logical topology of the network
- The data communication protocols

The physical and logical topology of the networks

The topology of a network describes how network computing elements are physically and logically connected to each other. Physical topology describes the network's cable plant or air interfaces. Logical topology describes how the communications links between devices are arranged. Network

communications devices often are configured so that the logical topology is different than the physical topology.

The physical topology of a network infrastructure supporting an RFID system depends on the physical location of the components in its enterprise subsystem. For example, the RF to enterprise subsystem connections is physically located near readers.

The data communication protocol

Data communications protocols are a critical component of a network's performance, reliability, and security. Readers should be able to distinguish between link-layer and network-layer protocols to understand how RFID enterprise subsystem network infrastructures work and are secured. Link-layer protocols specify how devices communicate with each other over a common medium, or link. Network-layer protocols (sometimes called inter-network protocols) in turn describe how data traffic is routed across multiple network links, possibly over many types of media.

3.3.4 The inter-enterprise subsystem

The inter-enterprise subsystem connects enterprise subsystems together when information needs to be shared across geographic or organizational boundaries. Not all RFID systems contain inter-enterprise subsystems. In this case of vehicle identification system, there is a strong need to share the information of a car at a certain location across a city. In more general sense, the central database of the vehicle management authority needs to collect some information about a vehicle and it may also be desirable that an application in the enterprise subsystem may log into the central database and find out more information about a vehicle crossing its boundary.

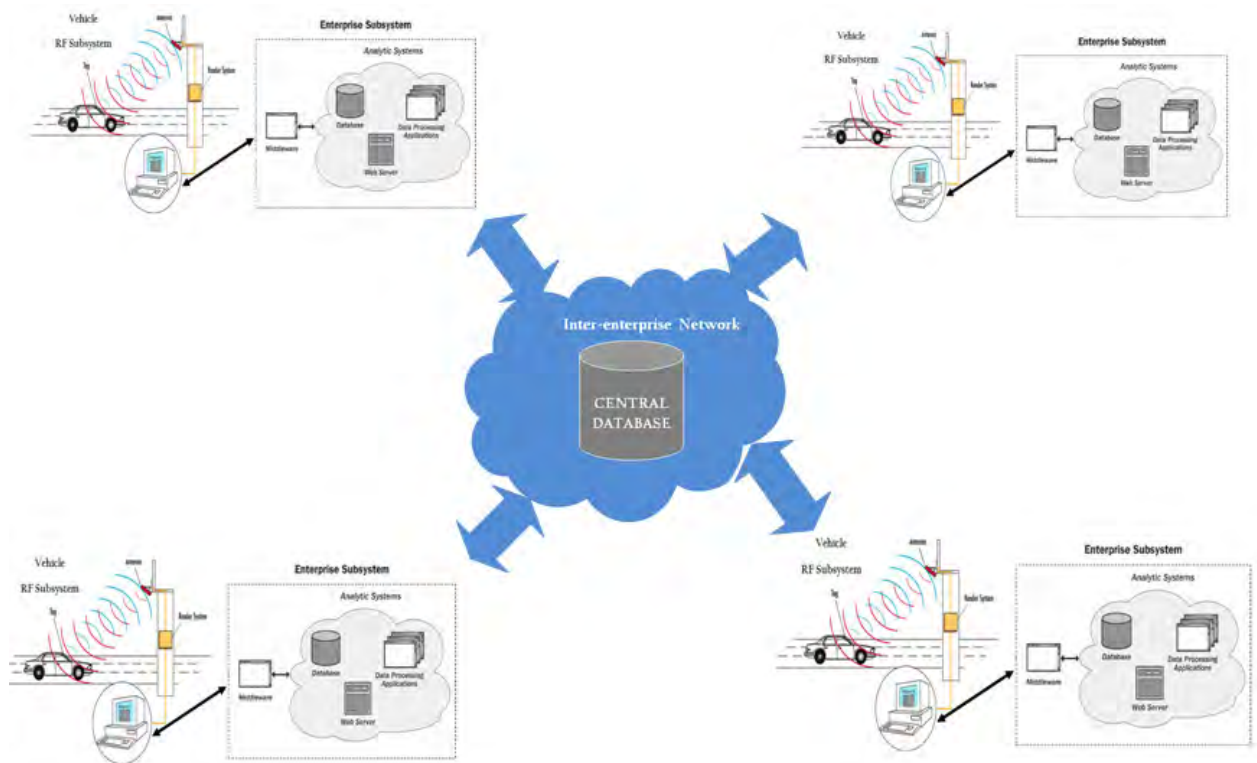


Figure 3.5 Inter-Enterprise architecture of the vehicle identification

So, the general frame work of the vehicle identification system would look like as in Figure 3.4. In the remaining section of this chapter, a consistent approach towards designing the RF subsystem namely the reader will be discussed. The reader is purely a device consisting of hardware and software components. Each components of the reader (the software and the hardware) will be separately dealt with.

3.4 The hardware design of the reader

The reader is an electronic circuit that contains parts which deal with the RF signals and all the necessary modules such as the power supply and peripheral interface.

+5V regulator circuit, RF circuitry, microcontroller, RS232 and 16x2 LCD interface are the building blocks of the reader device. We will see deep into each module separately and put basic design guidelines.

3.4.1 The power regulator circuit

Whether it is a small lithium battery or 220V alternating current or tiny dc battery, every electrical circuit contains its own power supply. When it comes to electronic circuits, a power supply has to have the right voltage level that doesn't swing and. This means, it must be stable around the desired voltage level. Furthermore, since the supply from a given input nourishes all the electronic components (RF IC, microcontroller, RS232 level converters), it should be able to provide the sum of all the amount of current required by each components.

3.4.1.1 The +5V regulated voltage source

The +5 volt regulated power supply is developed using the TA7805S regulator IC. This IC is a three terminal voltage regulator manufactured by TOSHIBA. In its part number, the 05 indicates that it is a +5V regulator IC. There are other series of this packaged IC that could output different values of regulated voltage. The only thing the designer needs to look for is the two digits in its part number positioned at XX as in TA78XXS. For example, an IC labeled with TA7806S will deliver a regulated volt of 6 [20].

Most electronic components are low power ICs and need 5volts to function. This is also true for this design and we have chosen the TA7805S to design the regulated power supply unit.

The TA7805S requires very few external discrete components in order to achieve its function. Upon having the recommended values of discrete components, it can provide stable voltage of 5 volts. It is built with internal thermal protection mechanism and has internal short circuit protection. It

provides maximum current of 1A upon being provided by appropriate heat sink plates.

The following figure shows the pin configuration of the TA7805S as seen from the marking side of the IC.

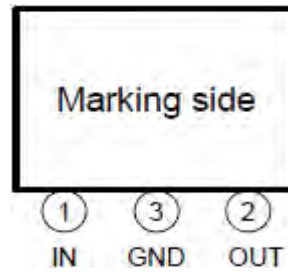


Figure 3.6 Pin configuration of the TA7805S

Without going into the details of the internal, the following is the equivalent circuit of TA7805S as provided in its datasheet [20].

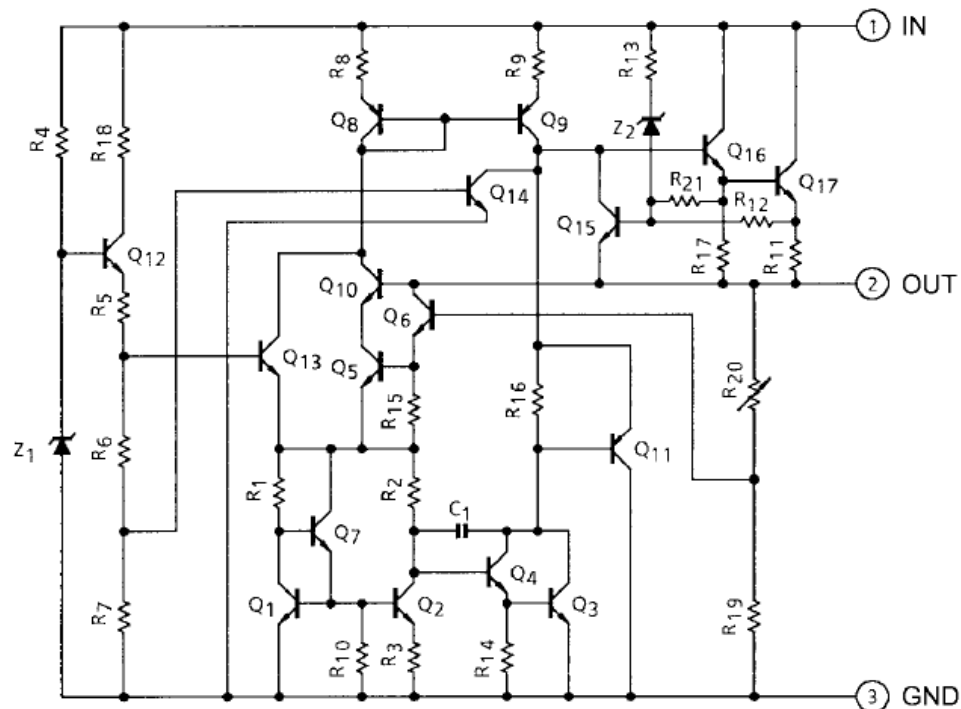


Figure 3.7 Equivalent circuits of the TA78XXS [20]

The following table provides important information for the TA7805S regulator IC. It can be seen that the input voltage for the TA7805S can be as much as 35V. This is a very important feature of the regulator IC because it enables it to operate on larger voltage sources such as car batteries. In reality, RFID reader may be suited in places where there is no ac main supply; in such cases heavy duty alkaline batteries that can deliver as much as 9V are the best options. Therefore the power regulator design for the reader module would be taking its power source from the latter option.

Table 3.1 Maximum ratings of TA7805S at 25°C [20]

Characteristics	Symbol	Rating	Unit
TA7805S	V _{in}	35	V
Power Dissipation	(T _a =25°C)	2	W
	(T _c =25°C)	20	
Operating temperature	T _{opr}	-30-85	°C

The schematic design view of the +5V power regulator circuit is presented in Figure 3.7.

The output voltage is usually 5 volts for the given IC. The regulator turns on red light emitting diode (LED) upon its connection to appropriate voltage source. The regulated voltage is then divided among the modules by using separate connector cables. These modules are the RFID circuitry, the microcontroller circuitry, the RS232 converter circuitry and the 16x2 LCD interface module.

The power supply module is equipped with dc power jack, power button and three plug-in connectors for the rest modules.

The design in figure 3.8 depends on the design procedure of the TA7805S as given in its datasheet [20]. None voltage boost configuration is used as there is no need of diminishing or amplifying the 5 volt that the IC outputs already.

The purpose of a shunt capacitor at the input of the regulator IC is that it removes the noise that is super imposed into the input signal. For high input voltage, it is highly recommended to insert serial resistor of certain value so that the junction temperature does not rise above limit.

In [20] it is highly recommended that $0.33\mu\text{F}$ capacitor should be used to filter the noise at the input side. It is assumed that the input voltage is from a step down transformer and otherwise if the regulator takes in dc, this capacitor can be omitted.

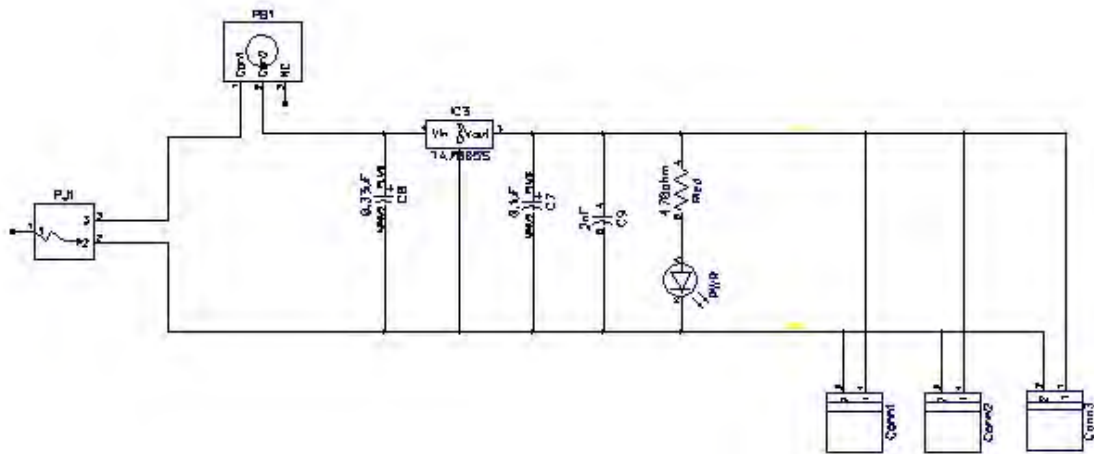


Figure 3.8 Schematic design of the +5V regulator circuit

The two capacitors at the output channel are used to operate the regulator at stable at its normal transient response. A capacitance of 102nF would be appropriate to stabilize the regulator at its transient response. However, this capacitance value is not standard and is impossible to find. Therefore, $0.1\mu\text{F}$ and 2nF are used in shunt. The purpose of the resistor in the output channel is to limit the current of the power LED. Since the output is 5 volt and the LED requires 10mA of current, $5/10\text{mA} = 470\Omega$ is used.

3.4.2 The reader antenna design

3.4.2.1 Function of the antenna in RFID systems

It is important that the reader must be equipped with a proper antenna circuit for successful RFID applications. RF signal can be radiated effectively if the linear dimension of the antenna is comparable with the wavelength of the operating frequency. However, the wavelength at 125 KHz is 2,400 meters (2.4 Km). Therefore, it is difficult to form a true antenna for most RFID applications. In order to compensate to the above flaw, a small loop antenna circuit that will be resonating at a given frequency is used.

For 125 KHz passive tag applications, a few nanohenries of inductance and a few pF of resonant capacitor are typically used. The voltage transfer between the reader and tag coils is accomplished through inductive coupling between the two coils. As in a typical transformer, where a voltage in the primary coil transfers to the secondary coil, the voltage in the reader antenna coil is transferred to the tag antenna coil and vice versa. The efficiency of the voltage transfer can be increased significantly with high quality factor (Q) of antenna circuits.

The great appeal of RFID technology is that it allows information to be stored and read without requiring either contact or a line of sight between the tag and the reader. As better fabrication techniques are being developed, and as more advanced algorithms and circuit designs arise, the reliability and the read range of passive RFID continues to improve, and the cost continues to come down [21].

The antenna serves two main purposes in RFID systems. Firstly, it provides energy to a passive tag and secondly like any other antenna in other applications, it resonates data at a given frequency. Hence it is very important that antenna design for RFID applications addresses both requirements.

For magnetically coupled transponders, inductive coupling is possible only in near field and the communication range (r_x) is limited by [22]

$$r_x \leq \frac{\lambda}{2\pi} \quad (3.1)$$

Where $\lambda = \frac{c}{f}$,

c is the speed of light given by 299.79Km/hr and f is frequency of oscillation which is 125 kHz. So having the above limit of r_x as near field, it is important to find out the minimum amount of magnetic field required to energize the tag at the given location. To set up proximity electromagnetic field, usually circular loop antenna wound of several turns is used, and so is that in this design. The strength of the electromagnetic field the reader emits at x distance located from the antenna is given by the equation [22],

$$H_R(x) = \frac{I_R N r_R^2}{2(r_R^2 + x^2)^{3/2}} \quad (3.2)$$

And now it is important to find the distance away from the antenna where electromagnetic field would be maximum. Calculating for the location where maximum electromagnetic field strength occurs by applying $\frac{dH_R(x)}{dx}$ and yields,

$$r_R = \sqrt{2} x \quad (3.3)$$

This shows that reader antenna having N turns, carrying current I and formed in circular loop has maximum electromagnetic field if its radius r_R is by 40% larger than the desired distance of reading. The following graph shows the variation of magnetic field for a fixed distance of a transponder as the radius of the antenna coil changes.

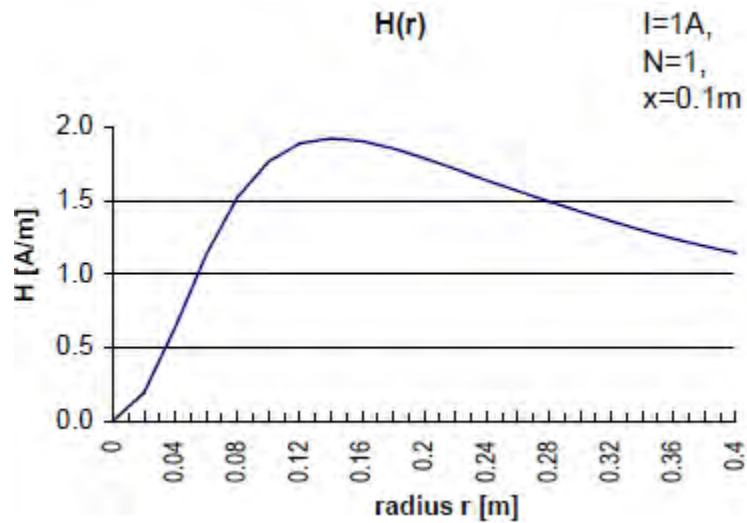


Figure 3.9 Maximum EF strength H as a function of the loop antenna radius r_R with a fixed distance x [22]

Most of the times, the transponders are specified with minimum magnetic field B_{\min} and the design of the reader antenna should take this into consideration. There are general rules that help the designer to come up with appropriate antenna for the reader [22]. The following table shows these rules and the steps in designing an RF antenna for RFID application. It marks the guidelines for designing a good RFID antenna. Usually the design procedure begins with identifying the transponder parameters as this will be very useful in maximizing the read distance. Then the mechanical parameters should be fixed based on the minimum magnetic field the reader is ought to produce. The design procedure then jumps to identifying the reader antenna parameters and proceeds forwards according to the steps.

Table 3.2 Antenna design Procedure for RFID applications [22]

Steps	Action	Parameter given	Parameter to calculate
1	Determine the transponder type	$V_{Tmin}, \Gamma_T,$ L_T, N_T, Q_T	R_T
2	Fix the mechanical parameters	r_R	H_{min}, B_{min}
3	Determine the inductivity and the quality factor of the reader antenna	L_R, Q_R	R_{L_R}, N_R
4a	Either fix maximum reader current	I_{Rmax}	X, R_R
4b	Maximize the read distance according to	X	I_R, R_R

Since the transceiver base station to be used in this prototype system design is the EM4095 and the transponder IC is the EM4102, it is important to pay attention to the requirements of the ICs and follow the design steps.

3.4.2.2 Identifying the transponder parameters

The transponder in this thesis work comes from EM, Microelectronics-Marine SA, Switzerland. The manufacturer of the card is HUAYAUAN, producer of various RFID products and is located in Shanghai China. The thing the latter do to the IC that EM, Microelectronics manufactures is just integrate a fine antenna coil and assemble the IC along with the antenna into a card, which is usually polyvinylchloride material (PVC). The following picture may aid to visualize this fact.

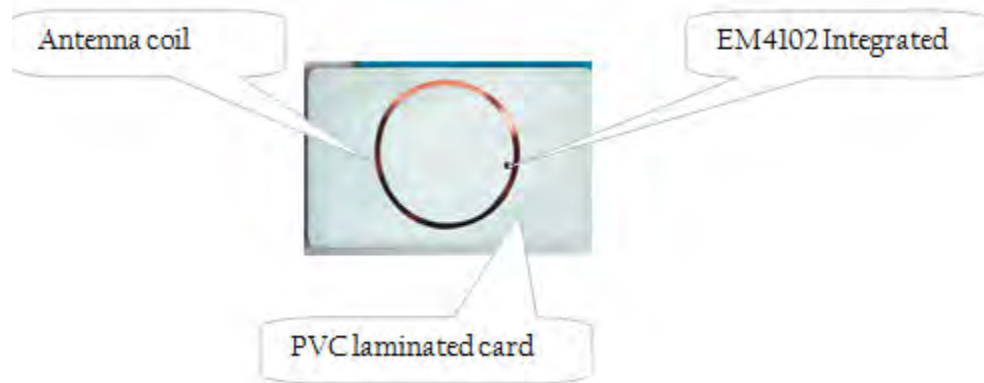


Figure 3.10 Constituents of RFID cards

The data sheet of the EM4102 shows that the chip comes with 78pF resonant capacitor and the minimum voltage needed for operation is 1.5V [15]. The frequency of oscillation (f_T) for the purchased EM4102 HUAYUAN card is 125 kHz, so the inductance value of the transponder antenna is

$$f_T = \frac{1}{2\pi\sqrt{L_T C_T}} \quad (3.4)$$

$$L_T = \frac{1}{78 * 10^{-12} (2\pi * 125000)^2}$$

So, $L_T = 20\text{mH}$

Furthermore, the other details like number of antenna coil turns of the transponder, the quality factor and the surface area could not be identified as the manufacturer refused to provide this information. Therefore we changed the procedure and began the design of the RFID reader by considering the specification for the Em4095 IC [14]. It is important to note that this design will not maximize the reading distance as it focuses only in

keeping the threshold of the maximum current the EM4095 would be able to handle.

For the reader's antenna, air core circular loop antenna is used. The average diameter of the reader antenna was chosen to be 2.9 cm (0.029m) and a magnetic wire of 0.5mm diameter was used for the construction of the reader antenna.

Since the circuit resonated at 125 kHz, the inductivity of the antenna was chosen to be 733 μ H. This is as recommended by the EM4095 application note to be within 300 μ H to 800 μ H. Using equation 2.7 in Chapter 2, the number of turns required is calculated as

$$N = \left(\frac{733 * 10^{-6}}{4\pi * 10^{-7} * 0.0145 * \ln\left(\frac{0.0145}{0.00025}\right)} \right)^{1/1.9}$$

$$N = 127$$

At this point, the inductivity of the antenna was measure by precision LCR meter and the following results were found.

Inductivity, $L_R=742\mu$ H

Quality factor $Q=19.63$

Both measurements were made at 100kHz and therefore it is important to re calculate the inductance and the quality factor at 125kHz latter. The dc resistance was calculated using the following formula

$$R_{L_R} = \frac{2 * \pi * f * L_R}{Q_R} \quad (3.5)$$

At $f=100$ kHz, Q is 23.75 Ω , so this is not supposed to be constant at 125 KHz and the equivalent value of the quality factor at 125 KHz would be, $\frac{5}{4}(19.63)$, which is 24.54. Therefore the quality factor of the antenna is 24.54 at 125kHz.

3.4.2.3 The capacitive divider circuit

For successful and proper functioning of the reader circuit, the capacitive divider C_{DIV1} and C_{DV2} are of crucial importance. The datasheet of the EM4095 allows 4Vpp (4 volts peak to peak) on the DEMOD_IN pin of the IC. The antenna voltage of an RFID circuit is given by the formula [14],

$$V_{ANTPP} = \frac{2*Q*V_{DD}}{\pi} \quad (3.6)$$

For that matter, one can read up to few hundred volts depending on the quality factor of the antenna. Using the measured value of the quality factor, 45V was expected. And when a measurement was taken using the above components and scenario, the voltage across the antenna coil was measured to be 43Vpp which is close to the calculated value.

So in order to provide 4Vpp on the DEMOD_IN pin of the EM4095, a capacitive divide has to be used. C_{DV2} can be any value between 1nF to 2nF, so, 1nF was chosen for sake of availability and the value of C_{DIV1} was determined to be 10nF by the use of the following equation.

$$\frac{V_{ANTPP}}{V_{DEMOD_INPP}} > d_c \quad (3.7)$$

Where d_c is the division factor of the capacitors, using 43V as V_{ANTPP} and the required voltage on DEMOD_IN pin V_{DEMOD_INPP} to be 4V d_c is calculated to be 10.75 using equation 3.7. Therefore the capacitors

$$\frac{C_{DV1}}{C_{DV1}+C_{DV2}} = d_c \quad (3.8)$$

3.4.3 Designing the RFID reader circuit

Having designed the antenna, now it is turn to design the reader module using the EM4095 integrated circuit. The circuit configuration of the reader circuit is as indicated in figure below.

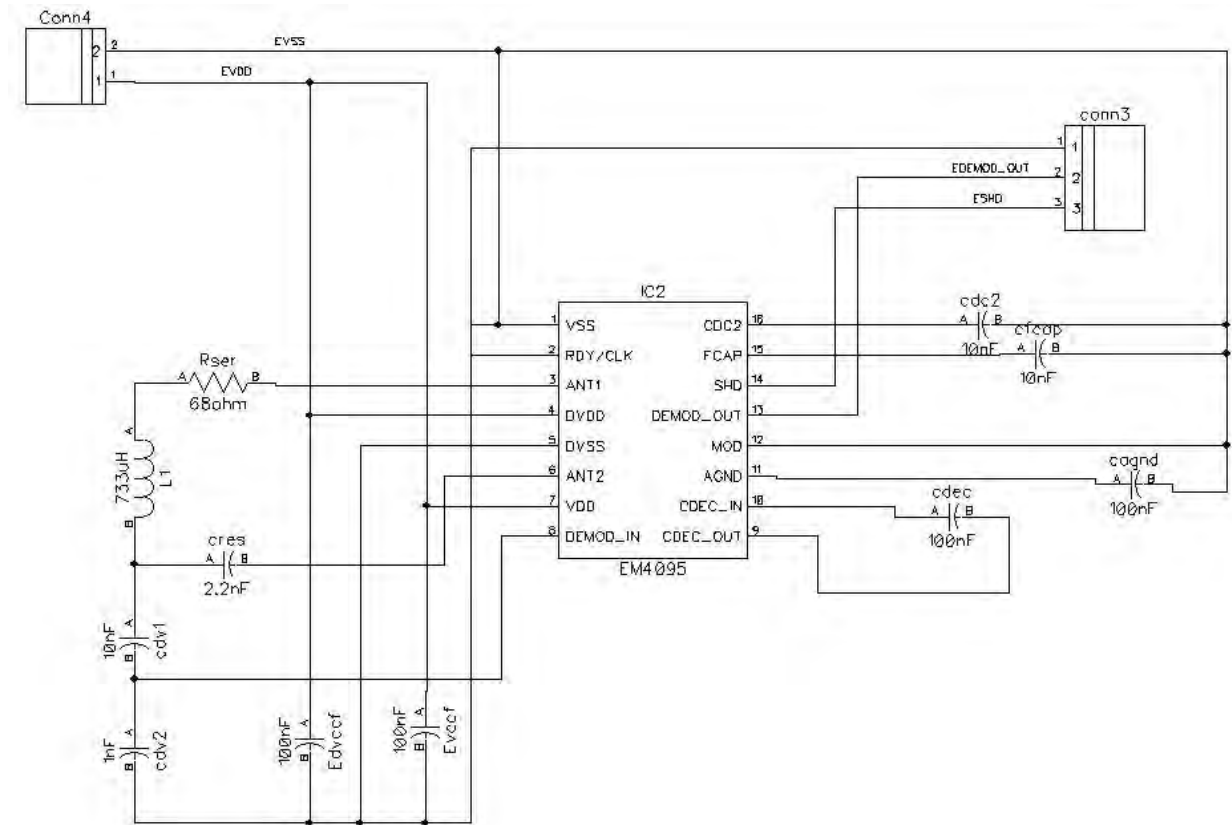


Figure 3.11 Typical read only configuration of EM4095

This is the manufacturer recommended read-only set up [14]. A 100nF filtering capacitor must be connected between Vss and Vcc as close possible to the IC. The rest values of the capacitors are manufacture recommended in [14]. The IC can be interfaced to a microcontroller using signals RDY/CLK, SHD and DEMOD_OUT. L_A , which is found to be 742 μ H in this design is used as the antenna and finding out the rest of the component values proceeded as follows.

3.4.3.1 Calculating the resonant capacitor value

For series LC resonant circuits, the resonant frequency is given by equation 3.4, using this equation the resonant capacitance is found to be

$$C_{RES} = \frac{1}{742 * 10^{-6} * (2 * \pi * 125 * 10^3)^2} F = 2.2nF$$

This is the capacitance value required to resonance at 125 KHz for a series circuit having inductor of inductance 742 μ H. However, the true capacitance value should take into consideration the effect of C_{dv1} and C_{dv2} . The effect of those capacitors on the resonant capacitance is therefore neglected as they are not yet calculated.

3.4.3.2 Reader antenna current and voltage

As indicated on the datasheet of the EM4095, the maximum permissible antenna current is 250mA, so for the above configuration, when $V_{SS}=5.0$ V and $V_{DD}=0.0$ V, the maximum current on the antenna can be found by applying the following equations [14]

$$I_{ANT_{peak}} = \frac{4}{\pi} \frac{V_{DD}-V_{SS}}{R_{ANT}+R_{SER}+2R_{AD}} \quad (3.9)$$

$$V_{ANT_{peak}} = \frac{I_{ANT_{peak}}}{2 * \pi * f * C_{RES}} \quad (3.10)$$

R_{AD} is the antenna driver resistance and is given to be 3 Ω , therefore $I_{ANT_{peak}} = 208mA$ and $V_{ANT_{peak}} = 120.6V$. Decimated antenna voltage on DEMOD_IN pin ensures proper demodulation of the incoming signal. So the antenna voltage must be divided by a factor of 60. The result looks good as the maximum current on the antenna coil is not violated. But to be on the safest side, it is recommended to insert a serial resistor in the antenna circuit. This effect will decrease the quality factor without affecting the reading distance of the reader.

So, not so big, but a resistance of 18Ω is chosen arbitrarily and the antenna design procedures above was repeated once more. And the following results were got,

$$I_{ANT_{peak}} = 120mA$$

$$V_{ANT_{peak}} = 69.45V$$

3.4.4 Microcontroller interface design

So, far the circuit requirements of the EM4095 have been calculated. The next job was designing the microcontroller interface that extracts the necessary data out from the output of the EM4095. Figure 3.11 shows the flow chart of the software development module used in driving the EM4095.

As indicated in the datasheet, the EM4095 outputs the demodulated data out through the DEMOD_OUT pin. It is therefore important to have a microcontroller that carries out all the necessary operation and deliver the necessary data to the appropriate interface. In this work, the ATmega32L PDIP microcontroller is used. Its functions are to control the EM4095 (force to sleep or fire up) by sending signal on the SHD connection, decode the data that the EM4095 outputs and run other programs that help transportation of data to PC station and some visual displays like the LCD.

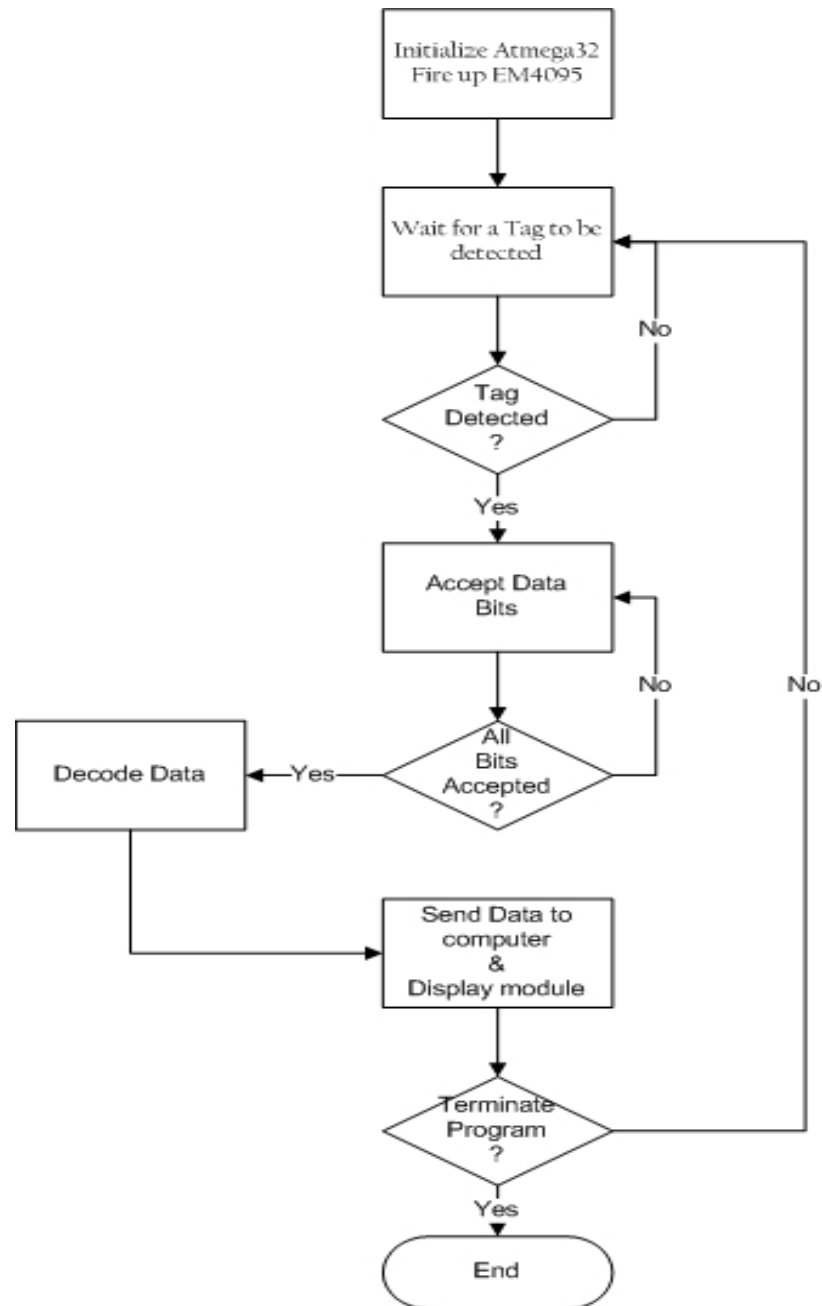


Figure 3.12 Flow chart of the controller program

A microcontroller can carry out much more complex operations provided that the code size of the operation can reside within the available program memory. It can be perceived as a small module running a small operating system for the given tasks.

As mentioned above, the main job of the ATmega32 is to decode the streams of serial data coming out from the EM4095. The data that is coming out from the EM4095 (through the DEMOD_OUT pin) is nothing but information stored in the read-only-memory of the tag. As mentioned in section 2.6.2, the transponder used to mitigate the electronic plate of a vehicle is the EM4102. Before decoding the data, it is important to know the scheme in how the original data has been encoded. The card purchased from HUAYUAN is built from the EM4102 transponder IC and uses Manchester Encoding. The programs are developed in highly customized C language in AVR studio version 4. This program has an inbuilt (gcc) or a plug-in compiler the WinAVR for AVR Studio running on windows platform. It can also connect varieties of programmer kits and load the bit equivalent of the developed program onto the read only memory of the microcontroller. The VMLAB is a tool that enables to develop and simulate the property of the microcontroller upon running the program. It shows how the internal registers are affected and an output can be tapped and displayed by connecting output devices like, USART, LCDs and oscilloscopes. The customized C code for the ATmega32 L, developed in AVR Studio is provided in the appendix I of this document.

3.4.4.1 Manchester coding basics

Manchester coding being one of the most widely used coding techniques today; it provides means of adding data rate to clock messages so that it can be used at the receiving end.

Manchester coding states that there will always be a transition of the message signal at the mid-point of the data bit frame. What occurs at the bit edges depends on the state of the previous bit frame and does not always produce a transition. A logical “1” is defined as a mid-point transition from low to high and a “0” is a mid-point transition from high to low [23] (see Figure).

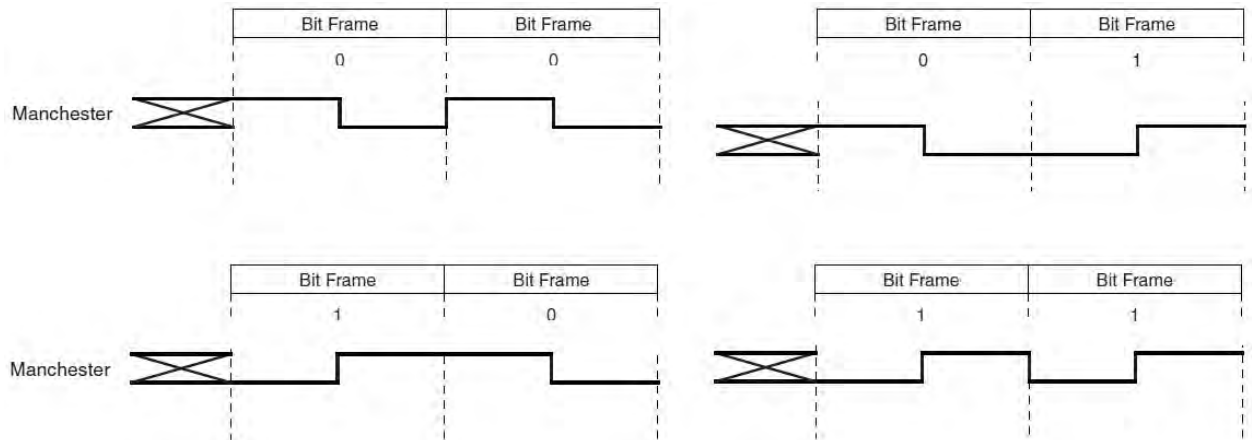


Figure 3.13 Encoding signals

3.4.4.2 Manchester Encoding

Encoding is the process of adding the correct transitions to the message signal in relation to the data that is to be sent over the communication system. The first step is to establish the data rate that is going to be used. Once this is fixed, then the mid-bit time can be determined as $\frac{1}{2}$ of the data rate period. In our case, the transponder requires 64 RF clock cycles to send a bit. One RF clock cycle is $\frac{1s}{125000}$, or $8\mu s$. so, the data rate of the transponder would be $64 \cdot 8\mu s = 512\mu s$ (≈ 2 KHz). Dividing by two gives us the mid-bit time of $256\mu s$ (which we will label with “T”). The easiest method to encode data using microcontroller is to use a timer set to expire or interrupt at the T interval. We also need to set up a method to track which $\frac{1}{2}$ bit period we are currently sending. Once we do this, we can easily encode the data and output the message signal. The following is a pseudo-code to encode a serial data that is primarily stored in a buffer [23].

1. Begin with the output signal high.
2. Check if all bits have been sent, If yes, then go to step 7
3. Check the next logical bit to be coded

4. If the bit equals “1”, then call ManchesterOne(T)
5. Else call Manchester Zero(T)
6. Return to step 2
7. Set output signal high and return to the caller program

Implementation of the ManchesterOne(T) [Source [23]]

1. Set the output signal low
2. Wait for mid-bit time (T)
3. Set the output signal high
4. Wait for mid-bit time (T)
5. Return

Implementation of the ManchesterZero(T) [Source [23]]

1. Set the output signal high
2. Wait for mid-bit time (T)
3. Set the output signal low
4. Wait for mid-bit time (T)
5. Return

3.4.4.3 Manchester Decoding

Manchester decoding is much more difficult than Manchester encoding. Decoding can be implemented in various ways though. For microcontroller based decoding, there are two most widely used approaches [23].

1. Timing based Manchester decoding and
2. Sampling based Manchester decoding

In this thesis work, sampling based Manchester decoding is used for the following reason.

1. It does not require special timer facilities

- The processor can work on other functions as the timer can run in parallel and hence does not always require intensive processor involvement.

However, this approach requires much memory than the timing based approach.

3.4.4.4 Sampling based Manchester decoding

While using this technique, the state of an input pin is simply buffered as rate S , much higher than the data rate of the message. Recalling that the data rate for the EM4102 is 2kHz, we set the timer to interrupt or expire many times before a bit transmission is over. In order to get more insight about this technique the following figure is helpful.

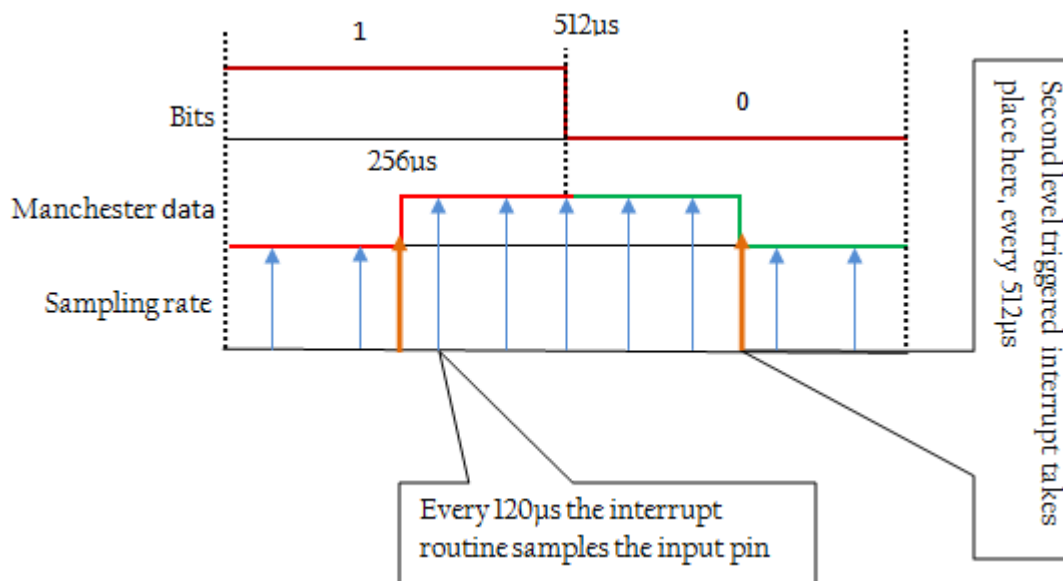


Figure 3.14 Timing diagram for sampling based Manchester Decoder

S is 120μs and two samples are taken for 256μs or mid-bit time and five for full bit,

512 μ s. below is the pseudo-code of the sampling based Manchester decoding [23],

1. Set up timer to interrupt every $2T / S$
2. SR routine should check and store the state of the microcontroller pin (1 or 0)
3. Repeat step 2 for desired number of bits * S occurrences
4. Process through the captured buffer counting the number of consecutive ones or zeros
5. When the next logic value changes
 - a. Check if count $\geq (S/2)$; Then skip to step 6
 - b. Else reset count and loop to step 4
6. Set current bit = logic value in buffer currently pointed too
7. Reset count and count to the next logic change
 - a. Compare count with $(S/2)$
 - b. If count $< (S/2)$
 - i. Reset and count to next logic change
 - ii. Make sure count also $< (S/2)$
 - iii. Next bit = current bit
 - iv. Store next bit in data buffer
 - c. Else if count $\geq (S/2)$
 - i. Next bit = opposite of current bit
 - ii. Store next bit in data buffer
 - d. Else
 - i. Return error
8. Loop to step 7 until completely through captured data. Exit for further data processing
9. Exit for further data processing

3.4.5 Overall hardware design and printed circuit board (PCB) assembly

In order to have the whole modules organized into a single circuit, it was important to design Printed Circuit Board (PCB) that can accommodate all the interfaces and components together. For the PCB design, computer aided PCB design software known as DipTrace was used. It is a powerful PCB design tool that enables its users to use wide variety of components already created and placed in its own library. Its most important flexibility features is that it has two integrated editor program modules apart from PCB and Schematic Editors, which are used to edit or create components which are not included in the already provided library [24].

These modules are the Pattern and the Component Editor program. The Pattern Editor enables the creating the exact representation of the device as it would appear on a board. So, while creating the pattern of a device, the datasheet must be referred very carefully.

The Component Editor program enables creation of a device's representation diagram and enables one to draw appropriate schematic of his/her own circuitry.

Unfortunately, the EM4095 and the TA7805S were not available in the default library and had to be created. Figure 3.14 shows the schematic wiring of the whole circuit while figure 24 presents the routed and finished PCB equivalent of the schematic.

In order to produce the printed circuit board, paper transfer procedure is used. The steps involved in this production are listed as follows

1. Print the artwork of the PCB on a glossy paper using laser jet printers. Be sure to print it to 100% scale and set the printer's setting to maximum darkness.
2. Prepare the copper clad by cleaning and sizing.
3. Turn the paper against the copper side of the clad and then heat it using iron
4. Cool the clad in a basin of water and then remove the paper
5. Etch the unwanted copper using ferric chloride solution
6. Remove the tonner using acetone and then drill all holes using appropriate sized drill-bits

Following the above procedure, a board was made and components were assembled accordingly.

Chapter IV Results and Discussions

4.1 Discussion

According to the design procedure described in Chapter three, each component of the hardware setup was designed and results were collected. It is evident that a very good RFID reader module relies on a good antenna design, as that matter of fact; intensive time and energy were allocated to this task.

4.2 Challenges of antenna design

Most RFID readers utilize loop antenna. Although there are plenty of empirical formulas to calculate an inductance of various shapes of antenna made up of plain enamel copper wire, none of them is exact and provide accurate results indicated by the formula. Therefore it is very important to have a device to measure the inductance, quality factor and DC resistance of a given antenna coil.

Main challenges encountered in this section of the thesis work (antenna design) are

- Determination of inductance and quality factor of the loop antenna
- Failure in meeting the exact geometrical shape as described in the formula

Using the formula in equation 2.7, a loop antenna of inductance $733\mu\text{H}$ was calculated to have consisted of 127 turn with circular configuration, air core and inner diameter of 0.03 meter.



Figure 4.1 The formed antenna coil

However, the measured inductance value at 100 kHz was 0.742mH (742 μ H) and the quality factor was 19.28.

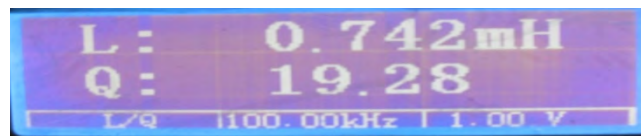


Figure 4.2 Inductance (L) and quality factor (Q) of the antenna as measure by LCR meter

Both parameters seem to be excellent, however, the precision LCR meter operates at maximum of 100 kHz and the RFID reader module operates at 125 kHz, there was not clear method on how to determine the inductance of the coil at RFID operating frequency. An immense search for methodology to find the inductance of the built coil, finally better procedure of finding the inductance was proposed by friends on edaboard forum. It was including the inductance in a series resonant circuit with a known resistance value and then measuring the voltage across the inductance and the DC resistance of the coil.

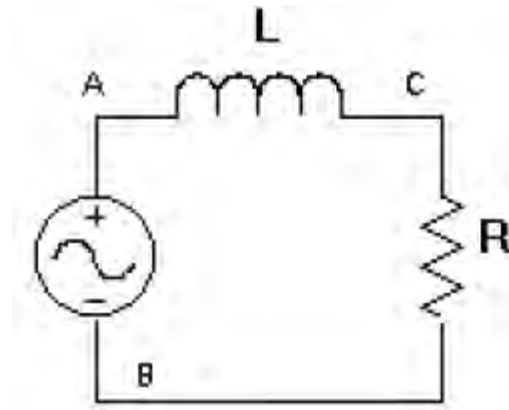


Figure 4.3 Series LR setup to compute inductance (L) of a coil

$$L = \frac{1}{2\pi f} \sqrt{\frac{R}{V_R} - (r + R)^2} \quad (4.1)$$

Voltage from the signal generator is actually ac signal of certain frequency (125 kHz in this case), resistance of 10K Ohm was used and the DC resistance of the coil was measured to be 4Ω. The voltage from the signal generator was set to 1V rms. Having completed the set up, the voltage across the resistor was measured and was found to be $V_R=9.6\text{mvolts}$. Therefore the calculated value of the inductance of the coil would be

$$L = 691\mu\text{H}$$

This was again another discouragement. The point is that the inductance of a coil at 100kHz and 125kHz is quite different. So furthermore, it was decided to tune the antenna by inserting the coil right into the RFID circuit. This method is known as ‘fine tuning’ loop antenna. It is achieved by removing or adding more coils from or on the antenna. The series resonant circuit for the RFID reader constituted of the following items with respective values.

$$C_{RES} = 2.2\text{nF}$$

$$R_{SERIAL} = 68\Omega$$

$$L_{ANT} = 691\mu\text{F}$$

$$R_{AD} = 3\Omega$$

With the above components the antenna resonant frequency was measured to be 138 kHz. This too large from the acceptable $125\text{ kHz}\pm 1.5\%$ range. So fine tuning was made in attempt to increase the inductance. Surprisingly, the inductance of the coil increases when many coils were taken from the antenna. It was also observed that tying the coils tight together reduces the inductance. Finally, resonance of 123.8 kHz was achieved after tedious attempts as shown in figure below.

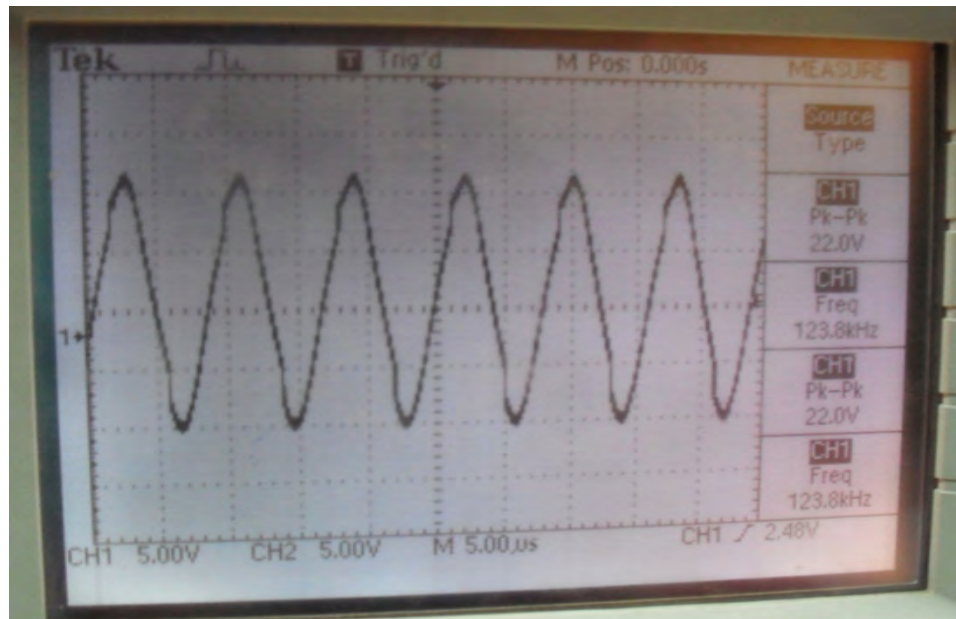


Figure 4.4 The resonant frequency of the RFID reader as it appeared on oscilloscope

This value of resonance frequency implies that the inductance of the coil is $L_{ANT} = 736.881\mu\text{H}$ and the quality factor $Q=14.2$ was measured. So with this final value the circuit was made.

4.2.2 Antenna current verification

According to the datasheet of EM4095, the maximum current allowable in the antenna driver circuit is 250mA. So this value must be checked to be

valid. Using values from antenna design in chapter 3 $R_{SER}=68\Omega$, $R_{ANT}=1.8\Omega$, $R_{AD}=3\Omega$ $V_{ANTpp}=43V$ current of 84mA expected after applying equation 3.6, and current of 100mA was read. This difference could have risen from the fact that the voltage induced on the antenna coil would increase as a tag comes in its vicinity and the current rises as the result.

4.3 Voltage regulator design results

Using the components described in section 3.4.1 (The power regulator circuit design), the regulator circuit was made and was tested to have achieved its purpose. The result gathered from the test is organized in the following table

Table 4.1 Output of the regulator circuit

Input Voltage (V)	Output Voltage (V)
6.21	4.98
7	4.98
9	5
12	5
15	5

4.4 The output of the reader

In the prototype design, EM4102 card was used to imitate plate of a vehicle. The card was purchased from SHANGHAI HUAYAN ELECTRONIC CO., LTD in China. This corporation assembles the chip produced by the EM Electronics by integrating antenna and sandwiching it between PVC cover. Below is one of the picture these cards



Figure 4.5 EM4102 blank card

The card was brought near the reader's antenna when power was switched on. The moment the card passed by the antenna of the reader, the following was what was seen on the oscilloscope.

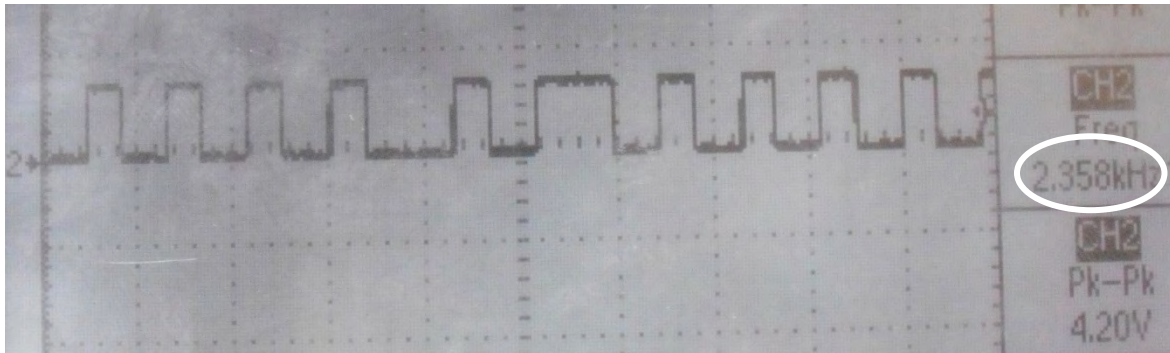


Figure 4.6 The 2kHz serial data of the EM4102 card ID as seen on the DEMOD_OUT pin.

The waveform on the channel 2 of oscilloscope is the output of the DEMOD_OUT pin as of one of the EM4102 card was brought near the antenna. The Manchester encoded data streams can be seen to have been demodulated. This data streams represent the read only memory data of the card and the output has demonstrated on how to read this data.

Furthermore, recalling that the data rate of the EM4102 is 64 RF clock cycles, the frequency of the data stream would be $\frac{125\text{kHz}}{64}$ which is 1.953125 kHz or nearly 2 kHz. This expected frequency was measured to be 2.358kHz and is displayed on the picture where highlighted with white ellipse.

This waveform is only present as long as the card is residing in the magnetic field of the antenna. Otherwise, when the card is removed from the magnetic field area of the antenna, the signal disappears immediately. This can be a claim of the ability of the reader to have demodulated the data imposed on its antenna. In others words, the reader is able to read the cards.

To assure this fact, six cards were scanned independently and a waveform at the DEMOD_OUT pin of the EM4095 was captured. The following figure shows this,

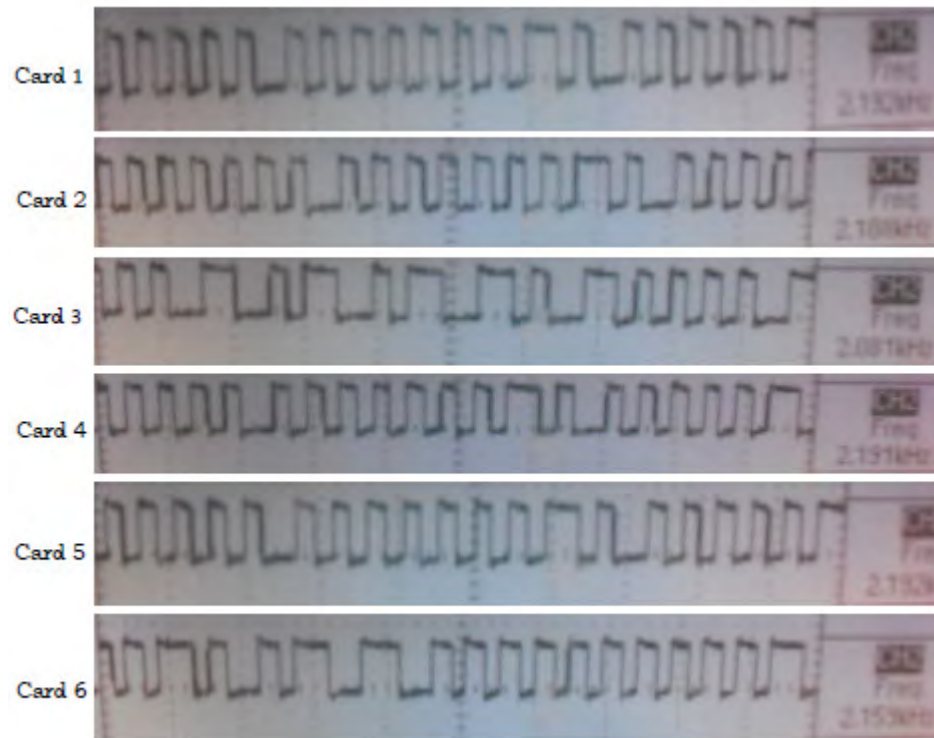


Figure 4.7 Waveform for demodulated cards' ID as seen on the DEMOD_OUT pin of the EM4095

Having the RFID module demodulated a signal from six tags; the next point to test the reader is its Manchester decoder module. As described in section 3.4.4, the Manchester decoder module is a program that is implemented on a microcontroller according to the sampling based decoder approach. Since the

microcontroller is also programmed to communicate with a computer terminal through USART, the data it has decoded will be available on TXD pin of the microcontroller. So signals on this pin were captured on oscilloscope. Similarly again during no card around the antenna, nothing is expected from this pin and that is what is observed. However, for the six cards the waveform captured at this pin is as shown in figure below.

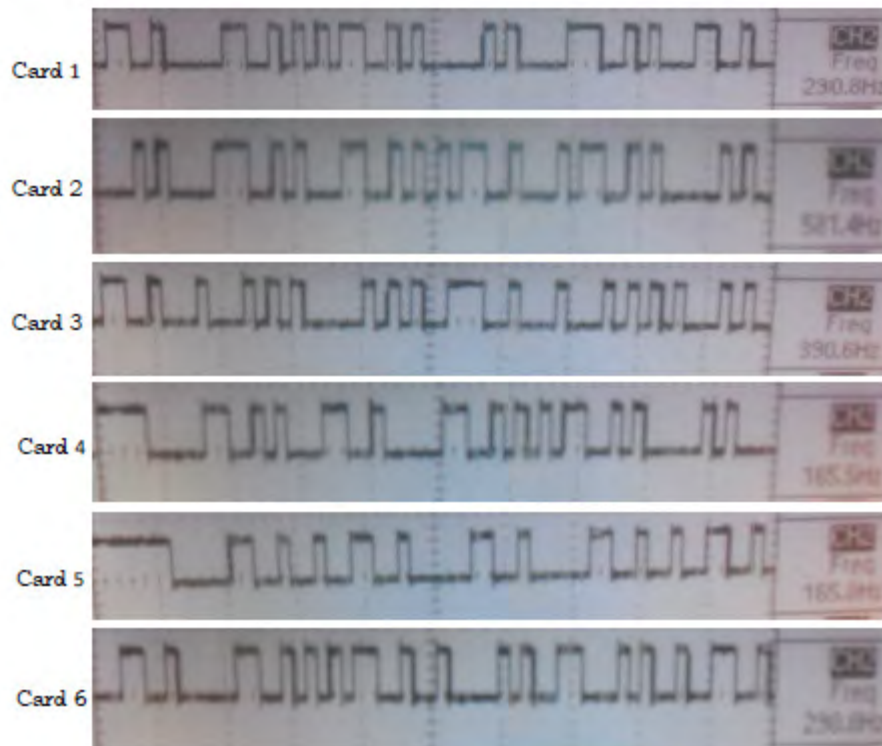


Figure 4.8 Waveform for decoded card ID as seen on the TXD pin of the microcontroller

The limitation is the capability of the used oscilloscope for viewing the whole range of data has resulted in capturing only part of the data stream. In fact it is possible to view the whole range of the data, but the time scale of the oscilloscope shrinks and the waveform will not be sparse enough and high of the data cannot be distinguished from its low and interpreting it becomes impossible.

If it were possible to view the whole range of the data, then the output on the DEMOD_OUT pin could have been decoded manually according to definition for Manchester zero and one as in section 3.4.4.1 and cross checked against the final results.

Furthermore, the data exported to a computer terminal was captured with an application designed to interact with the reader module. The decoded data will be sent to a computer terminal a byte at a time. Hence the serial port interface program will translate it into ASCII equivalence and display the data on a text area provided. Accordingly, the values in Log the GUI of figure 4.9 are displayed as each card was brought near the antenna of the reader in the same order as in figures 4.7 and 4.8.

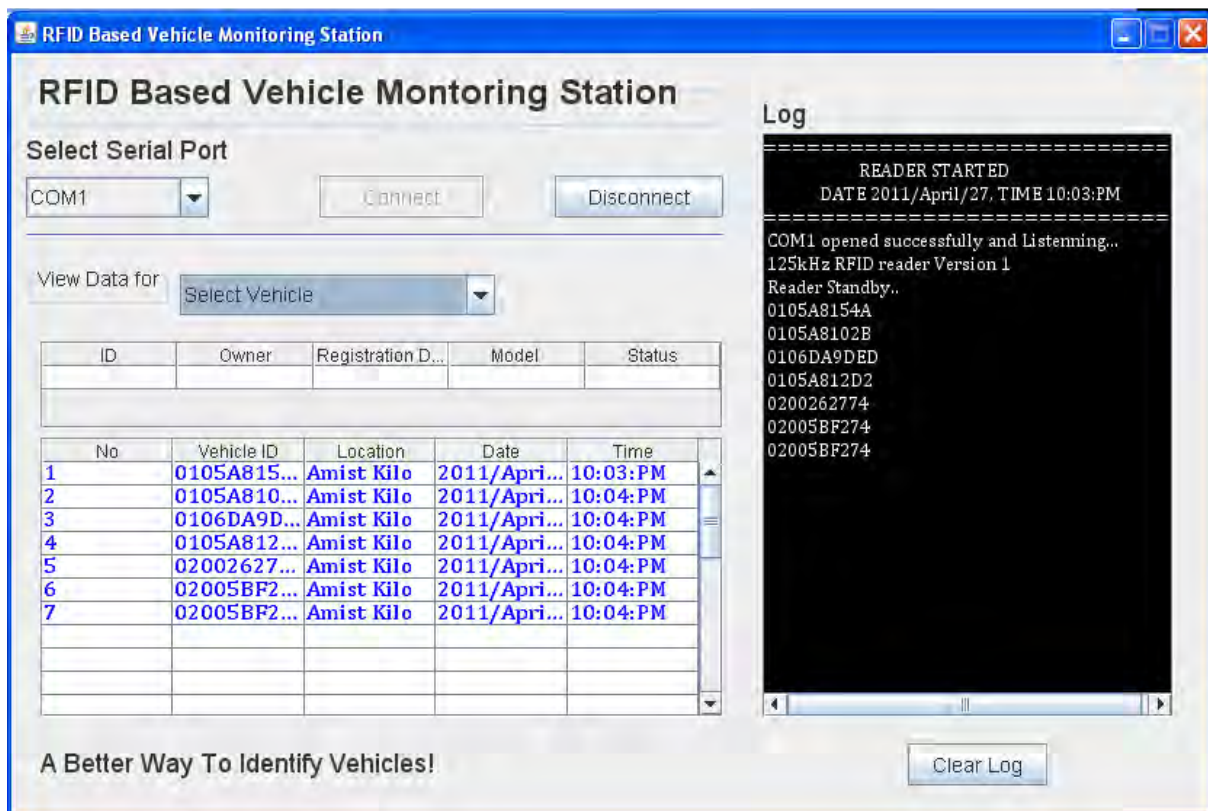


Figure 4.9 The GUI of the application program developed

By scanning each card many times (as in case of the sixth card in Log of the GUI being scanned twice); a normal functioning reader would output the

same value. This could be one way of verifying if the reader is really reading the card, otherwise if it misses even once, then it could be said that it is acting absurd. Reading a card many times has resulted in the same ID to be displayed and hence this could be evidence that the reader is logically reading the cards following the procedure provided in section 3.4.4. The results show that the reader is able to read the IDs of each EM4102 cards and as the result has demonstrated the vehicle identification process.

4.5 Circuit assembly (The PCB)

In order to have the whole modules organized into a single circuit, it was important to PCB that can accommodate all the interfaces and components together. For the PCB design, computer aided PCB design software known as DipTrace was used. It is a powerful PCB design tool that enables its users to use wide variety of components already created and placed in its own library. Its most important flexibility features is that it has two integrated editor modules apart from PCB and Schematic Editors, which are used to edit or create components which are not included in the already provided library.

These modules are the Pattern and the Component Editor program. The Pattern Editor enables the creating the exact representation of the device as it would appear on a board. So, while creating the pattern of a device, the datasheet must be referred very carefully.

The Component Editor program enables creation of a device's representation diagram and enables one to draw appropriate schematic of his/her own circuitry.



Figure 4.10 The top (left) and bottom (right) side of the assembled board

Figure 4.8 shows the picture of the overall printed circuit board assembled. The right side picture shows the bottom side of the circuit. Since the EM4095 is surface mounted IC, it can be seen that it is located on the copper side of the circuit. The left side of the picture is the top or the component side of the circuit. Each and every component is mounted in its place and all the necessary connector wires are also soldered. The board has 10cm of width and 10cm of height.

Chapter V Conclusion and Recommendation

5.1 Concluding the work

The RFID based vehicle identification requires tagging of each vehicle with electronic plate and deployment of readers along roads. As the built reader was able to read the ID of the tag IC in the prototype design, it can be said that the RFID based vehicle identification system has been demonstrated successfully.

The read distance of the built reader would have been improved if some information about the EM4102 card could have been known. According to the design procedure in table 3.2, after identifying the transponder's parameters the read distance can be maximized while still obeying the maximum allowable reader current on the reader's antenna.

As this thesis work is focused only on how to identify a vehicle using RFID technology, there should be other applications to be integrated to the system in order to have wide variety of functionalities.

While scaling up this work to real system, there are few points to make mention of, these are;

1. Designing RFID systems with higher frequency that result in longer read range. (few hundreds of meters)
2. Designing e-plate that contains its own power supply and is tamper resistant.
3. Designing the network infrastructure in large scale (town/ city level)

5.2 The benefits of this work

This thesis work has laid foundation of efficient prototype vehicle identification by introducing use of RFID technology. A well-organized data of vehicle registration will result in an excellent management and will play significant role in reducing time spend in performing the identification process. Specifically, the followings are some among many points that this work has contributed to vehicle identification system

-
- Enhanced speed in identifying a vehicle with all its details
 - Will rescue personnel from doing all the tedious works
 - Helps to track a vehicle easily and locate

5.3 Recommendation for future works

Having laid down the skeleton of vehicle identification system using RFID, there are numerous tasks to be supplemented to this, in order to come up with complete, mature and efficient working system. We would like to pin point the following issues for anyone who is interested to work on this subject

- Securing the communication protocol between the reader and the electronic plate of a vehicle
- Improving the read distance of vehicle identification RFID readers
- Developing tamper resistant electronic plates
- Development of plug-in applications
- Design of network infrastructure for the RFID based vehicle identification systems

Securing the communication protocol between the reader and the electronic plate of a vehicle

This is a point worth considering. In this work this security flaw persists as anyone capable of building 125 kHz RFID reader and knows the memory organization of the EM4102 card will effectively scan the inbuilt unique ID of the tag card. What this means to real vehicle identification system is that, apart from authorized bodies, one would be able to get information about vehicle details. This is intolerable, and puts the reliability the system under question.

Therefore, to alleviate this flaw and bring security to the system, the communication protocol between electronic plate and readers must be secured with light weighted encryption algorithms. While selecting or designing encrypting algorithms, care must be taken that the algorithm does not involve extensive computing which will result in costly and larger hardware.

Improving the read distance of vehicle identification RFID readers

The few centimeters read distance (as long as 4cm) got in this work is just enough for the prototype description. However, in the real system, many vehicles should be scanned concurrently hundreds of meters away. This will require using higher frequencies and improving antenna efficiencies. It also requires designing of active electronic plates that contain their own energy supply.

Developing tamper resistant electronic plates

When electronic plates come to the scene, they are no more ordinary plates. They can be considered miniature computers that contain critical information about a vehicle. In case the vehicle has committed crime and this status is registered on the electronic plate by a smart reader or personnel,

the electronic plate should always stay in its normal state to report the status to the appropriate station. So, the attempt to remove the electronic circuit or tamper it mechanically should result in generating a special fraud signal that can be reported to central security station. By this, the authority can identify who is working against the system.

Developing plug-in applications

RFID based vehicle identification system will do great if appropriate applications are integrated to it. After vehicle's ID is extracted and made ready on a computer, different applications can make use of it and bring about better performances. For example, if one is using this system to a fleet company (like Anbessa city bus), vehicle arrival informer application can be developed to be displayed for people waiting for the bus (train or taxi) at all stations. Furthermore, additional means of measuring vehicle's speed can be integrated to this system and provide an integrated functionality.

Design of network infrastructure for the RFID based vehicle identification systems

This is one of the most important tasks to be considered. As the RFID readers are distributed and the data they fetch need to be located to the central database; there must be efficient network infrastructure to enable data transitions. Readers along road sides should all be connected to the network by appropriate facility.

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Appendix I

Customized C code for the ATmega32L

```

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
#include <avr/io.h> //included library files from the avr internal libraries
#include <avr/pgmspace.h>
#include <util/delay.h>
#include "LCD_LIB.h" // built library for LCD interface
#include "EM4095.h" //built library for working with the EM4095
#include "USART.h" //built library for USART communication
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//
//*****Strings stored in AVR Flash
memory*****
const uint8_t readerStatus[] PROGMEM="Reader Standby..\0";
const uint8_t ATmega32[] PROGMEM="ATmega32 OK\0";
const uint8_t tagCode[] PROGMEM="CODE:\0";
const uint8_t vehicleID[] PROGMEM="VEHICLE ID: \0";
const unsigned char readerTitle[]="125kHz RFID reader Version 1.0\0";
const uint8_t newLine[] PROGMEM="\n";
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//
int main(void) //start of main
{
    uint8_t tag[5]; // variable: array of 8-bits to store the 40-Bit of EM4102 tag
    uint8_t tstr[20]; //variable : holds data to be sent to 16X2 LCD
    ATmega32_init(); // initialize the ATmega32 subsystem ;
    LCDinit(); //initialize the LCD
    USARTinit(51); //innitalize the USART settings
    LCDclr(); //clear the LCD screen
    RFID_PORT|=(1<<RFID_LED); //turn on LED on port D
    sendString(readerTitle);
    sendString(newLine);
    _delay_ms(3000); //wait 3 seconds
    RFID_PORT&=~(1<<RFID_LED);
    CopyStringtoLCD(ATmega32,0,0);
    _delay_ms(1000); //wait 1 seconds
    while(1) //endless loop
    {
        sendString(readerStatus);
        sendString(newLine);
        CopyStringtoLCD(readerStatus,0,0); //displays the status of the reader
        if (read_tag(tag) // if a tag is read successfully(this function is
implemented in EM4095.c file and declared in EM4095.h file )
        {
            CopyStringtoLCD(tagCode,0,0);

```

Appendix I

```
    sprintf(tstr,"%0.2X%0.2X%0.2X%0.2X%0.2X", tag[0], tag[1], tag[2], tag[3],
tag[4]);

    LCDstring (tstr,10);
    sendString(vehicleID);//notify PC program what is being sent now
    for(int i=0; i<5; i++)
        {
            for(int j=1; j>=0; j--)
                {
                    USARTWriteChar(formated(tag[i],j));
                }
        }

        _delay_ms(200);    //also send the data to the PC
    }

    return 0;
}

//end main program here
////////////////////////////////////
////header file for the EM4095
#ifndef RFID_LIB
#define RFID_LIB
//*****
#include <inttypes.h>
//*****
//hardware configuration
#define RFID_PORT PORTD
#define RFID_DDR DDRD
//*****
#define PC_RX 0 //PIND0 used to receive data from PC
#define PC_TX 1 //PIND1 RS232 transmitter pin
#define RFID_RDY 2 //PIND2 Connected to RDY/CLK pin of the EM4095
#define RFID_DEMOD 3 //PIND3 demodulated signal input from EM4095;
#define RFID_SHD 4 //PIND5 EM4095 control pin, fire up or down
#define RFID_LED 5 //PIND5 lights up LED when a tag is read
//*****
#define F_RFID 125000UL //the frequency used by the RFID system
#define F_CPU 8000000UL //
#define RFID_DATA_RATE 64 //defines the data-rate of the EM4102
#define TIMER0_PRESCALER 64 //prescaler value used for TIMER0
//*****
#define BIT_PERIOD_COUNT ((F_CPU*RFID_DATA_RATE)/(F_RFID*TIMER0_PRESCALER)-1)
#define HALF_BIT_PERIOD_COUNT
((F_CPU*RFID_DATA_RATE)/(F_RFID*TIMER0_PRESCALER*2)-1)
#define MIDDLE_BIT_COUNT (HALF_BIT_PERIOD_COUNT+BIT_PERIOD_COUNT)/2
//*****
//Function to be used:: DEFINED HERE!!!!!!!
extern uint8_t read_tag(uint8_t *d);
```

Appendix I

```
void ATmega32_init(void);
char RFIDprogress(void);
static uint8_t check_parity(uint16_t param);
uint8_t read_tag(uint8_t *d);
//*****
#endif
////////////////////////////////////
///C implementation code for definitions in EM4095.h
// headers to be included
//*****
#include <avr/io.h>
#include <avr/interrupt.h>
#include <string.h>
#include "em4095.h" //contains the declaration and initializations *****
//*****
static unsigned char data[8]; //global char data t hold 64, bits of the tag data
static volatile uint8_t flag; //global flag to show if reading is completed
static volatile uint8_t rfid_progress; //shows the RFID progress
//*****
void ATmega32_init()
{
    RFID_DDR &= ~(1<<RFID_DEMOD); //this serves as for the input for
INT1*****
    RFID_DDR &= ~ (1<<RFID_RDY); //this pin is also input for INTO
    RFID_DDR &= ~ (1<<PC_RX); //this pin is used to receive data from PC
    RFID_DDR |= (1<<RFID_SHD | 1<<PC_TX | 1<<RFID_LED); //both these ports are
outputs*****
    RFID_PORT&=~(1<<RFID_SHD); //enable the EM4095 IC
    //timer0 initialization
    TCCR0|=(1<<ISC01)|(1<<ISC00); //supply timer0 with prescaler value of 64**
    //set external interrupt,*****
    MCUCR|=(1<<ISC10); //any logical change on RFID_DEMOD will cause an
interrupt*****
    GIMSK|=(1<<INT1); //interrupt by external pin on RFID_DEMOD pin is enabled*****
    //*****
    sei(); //enabe interrupts globally*****
    //send RFID status to PC here;
    rfid_progress=0;
}
////////////////////////////////////
//
char RFIDprogress(void)
{
    if (rfid_progress)
    {
        rfid_progress = 0;
        return '*';
    }
    else
```

Appendix I

```
{
    return ' ';
}

}

////////////////////////////////////
//
ISR (EXT_INT1_vect)//interrupt serice routines to hold interrupt request1*****
{
    //
    static uint16_t buffer;    // buffer to hold 16-bits*****
    static uint8_t bitcount;  //counts the number of bits received*****
    static uint8_t synchronised = 0; //tells if all the headers are received*****
    static uint8_t old_cnt;    //the previous counter0 value*****
    //above are variables used to read the manchester formatted data*****
    rfid_progress=0xFF;

    //set the status of the RFID here: <is accepting data>*****
    if ((uint8_t)(TCNT0 - old_cnt) > MIDDLE_BIT_COUNT)
    {
        old_cnt = TCNT0;    //save TCNT0 value for the next comparison*****
        buffer <<= 1;      //shift left buffer once
        bitcount++;        //increment bit count
        if (bit_is_clear(PIND, PD3)) //if the logic level on the INT1 pin is
low,*****
            buffer |= 1;    //it means that the manchester encoded data is logic1

        if ((buffer & 0x3FF) == 0x1FF)//if all the headers are read 9-bits and the row
parity is also 1
        {
            data[0] = 0xFF;    //then put the header value in the first index of the
data array*
            bitcount = 1;      //refers to the valuable data bits ignoring the buffer
synchronised = 1;    //reception of the headers is over and the system
is synchronised
        }    //to read the rest valuable data

        if (synchronised )
        {
            if ((bitcount % 8) == 0)
            {
                data[bitcount / 8] = buffer & 0xFF;// retrieve the rescent 8 bits

                if (bitcount == 56)    //THESE ARE THE REST OF THE BITS,
1 header bit plus 55 other data bits , 40 id bits, 10, row parity bits, 4 column parity bits and stop
bits
                {
                    flag = 1;    //
                }
            }
        }
    }
}
```

Appendix I

```
synchronised = 0; //reception is over so reset
synchronised;
GIMSK &= ~(1<<INT1); //DISABLE INTERRUPT
INT1, BECAUSE READING HAS BEEN FINISHED
    }
    }
}
////////////////////////////////////
//
static uint8_t check_parity(uint16_t param)//this uses even parity
{
    uint8_t bit;
    uint8_t par = 0;

    for (bit=0; bit<16; bit++)
        par ^= (param >> bit) & 0x01;

    if (par)
        return 0; //if the number of ones is odd, then return 0, else 1
    else
        return 1;
}
//*****
*****
uint8_t read_tag(uint8_t *tag_id)
{
    uint8_t timeout = 50;

    do
    {
        //NOTE THAT TOV0 IS SET WHEN TCNT0 REACHES BOTTOM,
        if (bit_is_set(TIFR, TOV0))// if the overflow is reached, or if TOV0 in TIRFO
register is set to one.
        {
            timeout--;
            TIFR|= 1<<TOV0; //
        }
    } while ((!flag) && (timeout > 0));

    if (!flag) //if there is no tag read
        return 0;

    flag = 0;
    uint8_t temp_data[8];
    memcpy(temp_data, data, 8);
    memset(data, 0, 8);
    GIMSK|= 1<<INT1; //enable external interrupt by RFID_DEMOD
```

Appendix I

```
//below this line, check if all data bits are received correctly
    if (((temp_data[0] << 8 | temp_data[1]) & 0xFF80) != 0xFF80) //Check startbits
whether it is 11111111 this are the header bits in EM4102.
        return 0;

    if ((temp_data[7] & 0x01)) //Check stopbit, the stop bit in EM4102 is 0
        return 0;
//*****error checking begins here-it uses parity bits to find out if error
is there*****
    if (!check_parity(temp_data[1] & 0x7C))//row wise parity check for row no 1/refer to
EM4102 datasheet page 4
        return 0;

    if (!check_parity((temp_data[1] & 0x03) | (temp_data[2] & 0xE0)))//row wise parity
check for row no 2/refer to EM4102 datasheet page 4
        return 0;

    if (!check_parity(temp_data[2] & 0x1F))//row wise parity check for row no 3/refer to
EM4102 datasheet page 4
        return 0;

    if (!check_parity(temp_data[3] & 0xF8))//row wise parity check for row no 4/refer to
EM4102 datasheet page 4
        return 0;

    if (!check_parity((temp_data[3] & 0x07) | (temp_data[4] & 0xC0)))//row wise parity
check for row no 5/refer to EM4102 datasheet page 4
        return 0;

    if (!check_parity(temp_data[4] & 0x3E))//row wise parity check for row no 6/refer to
EM4102 datasheet page 4
        return 0;

    if (!check_parity((temp_data[4] & 0x01) | (temp_data[5] & 0xF0)))//row wise parity
check for row no 7/refer to EM4102 datasheet page 4
        return 0;

    if (!check_parity((temp_data[5] & 0x0F) | (temp_data[6] & 0x80)))//row wise parity
check for row no 8/refer to EM4102 datasheet page 4
        return 0;

    if (!check_parity(temp_data[6] & 0x7C))//row wise parity check for row no 9/refer to
EM4102 datasheet page 4
        return 0;

    if (!check_parity((temp_data[6] & 0x03) | (temp_data[7] & 0xE0)))//row wise parity
check for row no 10/refer to EM4102 datasheet page 4
        return 0;
```

Appendix I

```
        if (!check_parity((temp_data[1] & 0x40) ^ (temp_data[1] & 0x02) ^ (temp_data[2] &
0x10) ^ (temp_data[3] & 0x80) ^ (temp_data[3] & 0x04) ^
                                (temp_data[4] & 0x20) ^
(temp_data[4] & 0x01) ^ (temp_data[5] & 0x08) ^ (temp_data[6] & 0x40) ^ (temp_data[6] &
0x02) ^
                                (temp_data[7] &
0x10))))//column parity check for column 1
            return 0;
```

```
        if (!check_parity((temp_data[1] & 0x20) ^ (temp_data[1] & 0x01) ^ (temp_data[2] &
0x08) ^ (temp_data[3] & 0x40) ^ (temp_data[3] & 0x02) ^
                                (temp_data[4] & 0x10) ^
(temp_data[5] & 0x80) ^ (temp_data[5] & 0x04) ^ (temp_data[6] & 0x20) ^ (temp_data[6] &
0x01) ^
                                (temp_data[7] &
0x08))))//column parity check for column 2
            return 0;
```

```
        if (!check_parity((temp_data[1] & 0x10) ^ (temp_data[2] & 0x80) ^ (temp_data[2] &
0x04) ^ (temp_data[3] & 0x20) ^ (temp_data[3] & 0x01) ^
                                (temp_data[4] & 0x08) ^
(temp_data[5] & 0x40) ^ (temp_data[5] & 0x02) ^ (temp_data[6] & 0x10) ^ (temp_data[7] &
0x80) ^
                                (temp_data[7] &
0x04))))//column parity check for column 3
            return 0;
```

```
        if (!check_parity((temp_data[1] & 0x08) ^ (temp_data[2] & 0x40) ^ (temp_data[2] &
0x02) ^ (temp_data[3] & 0x10) ^ (temp_data[4] & 0x80) ^
                                (temp_data[4] & 0x04) ^
(temp_data[5] & 0x20) ^ (temp_data[5] & 0x01) ^ (temp_data[6] & 0x08) ^ (temp_data[7] &
0x40) ^
                                (temp_data[7] &
0x02))))//column parity check for column 4
            return 0;
```

```
//11111111 11000110 00101111 10001100 01010011 00010000 00100101 00110110
//   DDDD D DD DDDD DDDD DDD D DDDD D DDD DDDD DDDD DD DD DDDD
//   0000 00 00 1111 1111 222 2 2222 3 333 3333 4444 44 44
```

```
        tag_id[0] = (temp_data[1] & 0x70) << 1 | (temp_data[1] & 0x03) << 2 | (temp_data[2] &
0xC0) >> 6;
        tag_id[1] = (temp_data[2] & 0x1E) << 3 | (temp_data[3] & 0xF0) >> 4;
        tag_id[2] = (temp_data[3] & 0x07) << 5 | (temp_data[4] & 0x80) >> 3 | (temp_data[4] &
0x3C) >> 2;
        tag_id[3] = (temp_data[4] & 0x01) << 7 | (temp_data[5] & 0xE0) >> 1 | (temp_data[5] &
0x0F);
```

Appendix I

```
    tag_id[4] = (temp_data[6] & 0x78) << 1 | (temp_data[6] & 0x03) << 2 | (temp_data[7] &
0xC0) >> 6;

    return 1;
}
////////////////////////////////////////////////////////////////////////////////
///header file for LCD interface
/// Change the following to reflect hardware connections

#define LCD_RS           0      //define MCU pin connected to LCD RS
#define LCD_E           1      //define MCU pin connected to LCD E

#define LCD_SHLEFT      2      //define number of left shifts to address the 4 data
bits in the port

#define LCD_PORT        PORTC //define MCU port connected to LCD data/control
pins
#define LCD_DDR        DDRC  //define MCU direction register for port connected
//to LCD data pins

// No changes under this
line////////////////////////////////////

#define LCD_DLINES      (0b00001111<< LCD_SHLEFT) //define where data lines are
connected on port it is PC2, PC3, PC4 and PC5
#define LCD_USED        (LCD_DLINES | 1<<LCD_RS | 1<<LCD_E)
#define LCD_UNUSED      ~LCD_USED

#define LCD_DATA        1<<LCD_RS //Bit to set to signal data transmission
#define LCD_CMD         0        //Bit to set to signal
command transmission

#define LCD_PORT        PORTC //define MCU port connected to LCD data/control
pins
#define LCD_DDR        DDRC  //define MCU direction register for port
connected to LCD data pins

#define LCD_CLR         0      //DB0: clear display
#define LCD_HOME        1      //DB1: return to home position
#define LCD_ENTRY_MODE  2      //DB2: set entry mode
#define LCD_ENTRY_INC   1      //DB1: increment
#define LCD_ENTRY_SHIFT 0      //DB2: shift
#define LCD_ON_CTRL     3      //DB3: turn lcd/cursor on
#define LCD_ON_DISPLAY  2      //DB2: turn display on
#define LCD_ON_CURSOR   1      //DB1: turn cursor on
#define LCD_ON_BLINK    0      //DB0: blinking cursor
#define LCD_MOVE        4      //DB4: move cursor/display
#define LCD_MOVE_DISP   3      //DB3: move display (0-> move cursor)
#define LCD_MOVE_RIGHT  2      //DB2: move right (0-> left)
```

Appendix I

```
#define LCD_FUNCTION    5 //DB5: function set
#define LCD_FUNCTION_8BIT 4 //DB4: set 8BIT mode (0->4BIT mode)
#define LCD_FUNCTION_2LINES 3 //DB3: two lines (0->one line)
#define LCD_FUNCTION_10DOTS 2 //DB2: 5x10 font (0->5x7 font)
#define LCD_CGRAM      6 //DB6: set CG RAM address
#define LCD_DDRAM      7 //DB7: set DD RAM address

// cursor position to DDRAM mapping
#define LCD_LINE0_DDRAMADDR    0x00
#define LCD_LINE1_DDRAMADDR    0x40
#define LCD_LINE2_DDRAMADDR    0x14
#define LCD_LINE3_DDRAMADDR    0x54

void LCDwait1(void); //wait one millisecond
void LCDsendbyte(uint8_t,uint8_t); //send a byte in 4 bit mode
void LCDinit(void); //Initializes LCD
void LCDclr(void); //Clears LCD
void LCDstring(uint8_t*, uint8_t); //Outputs string to LCD
void LCDGotoXY(uint8_t, uint8_t); //Cursor to X Y position
void CopyStringtoLCD(const uint8_t*, uint8_t, uint8_t); //copies flash string to LCD at x,y
////////////////////////////////////
///C implementation codes for the declared LCD.h
// This file contains driver program for LCD interface
//
//*****
#include "LCD_LIB.h"
#include <inttypes.h>
#include <avr/io.h>
#include <avr/pgmspace.h>
#include <util/delay.h>

void LCDwait1(void)
{
    _delay_ms(1);
}

void LCDsendbyte(uint8_t data , uint8_t rs )

// Purpose : Send a command or a data byte to the LCD in 4 bit mode
// Dependencies : Definitions in h file. Delay routine.
// Assumptions : Display connected in 4 bit mode
// R/W pulled low in hardware
// Control and data lines are on the same port (6 lines needed)
// 0=RS, 1=E, 2-5=D4 to D7 on LCD (adapt shifts if differing)
// Parameters : data: byte to transfer, rs= either LCD_DATA or LCD_CMD

{
```

Appendix I

```
uint8_t ctmp;

// first (upper) nibble

ctmp = LCD_PORT & LCD_UNUSED;          // Read previous status of unused bits into
temporary variable
ctmp |= ((data >> (4-LCD_SHLEFT)) & LCD_DLINES);    // map the upper nibble of
data into position 2-5
ctmp |= ((1<<LCD_E) | rs);             // set the E bit and RS in dependency of the
parameter

LCD_PORT = ctmp;                       // Push data in tmp variable to port

LCDwait1();                             // Wait a while so LCD sees
us

LCD_PORT &= ~(1<<LCD_E);                // Reset E bit

LCDwait1();                             // Wait again to ensure
next write does not collide

// second (lower) nibble

ctmp &= ~LCD_DLINES;                   // Null out the nibble we just wrote
ctmp |= ((data << LCD_SHLEFT) & LCD_DLINES);    // Now take the lower nibble

LCD_PORT = ctmp;                       // Push it to LCD

LCDwait1();                             // wait a while so LCD sees us

LCD_PORT &= ~(1<<LCD_E);                // Reset E bit

LCDwait1();                             // another while
}
```

```
void LCDinit(void)
//Initializes LCD
// Purpose           : Initialize the LCD for usage in 4 bit mode
// Dependencies      : Definitions in h file. Delay routine.
// Assumptions       : Display connected in 4 bit mode
//                   : R/W pulled low in hardware
//                   : Control and data lines are on the same port (6 lines needed)
//                   : 0=RS, 1=E, 2-5=D4 to D7 on LCD (adapt shifts if differing)
// Parameters : n/a
{
```

Appendix I

```
        _delay_ms(200);                                // Give the display a
generous time to initialize

        // Step 1: Setup the direction registers for LCD and Control port (all to output mode)

        LCD_PORT = 0x00;
        LCD_DDR |= LCD_USED;

        // Step 2: Switch the display to 4 bit mode (it is in 8 bit mode now)
        // The 44780 apparently has this completely obscure 4 bit init procedure where the
        // chip needs to be switched to 4 bit mode 3 times in a row. Looking at the chips
behaviour
        // it seems that it really wants this..

        // round one
        LCD_PORT = (0x3 << LCD_SHLEFT) | 1<<LCD_E;    // 4 bit mode and E going up
        LCDwait1();

        LCD_PORT &= ~(1<<LCD_E);                    // pull down E line
        _delay_ms(5);

        // round two
        LCD_PORT |= 1<<LCD_E;                        // E going up
        LCDwait1();

        LCD_PORT &= ~(1<<LCD_E);                    // pull down E line
        LCDwait1();

        // round three and four can be simplified as a 4 bit operation

        LCDsendbyte(0x32,LCD_CMD);

        // Step 3: Switch the display to 4 bit again and set font and lines (now in 4 bit mode)

        LCDsendbyte(0b00101000,LCD_CMD);

        // Step 4: No blinking, display on, no cursor

        LCDsendbyte(0b00001100,LCD_CMD);

    }

    void LCDclr(void)
    // Purpose          : Clears the LCD
    // Dependencies     : LCDsendbyte
    // Assumptions      : none
    // Parameters      : n/a
    {
```

Appendix I

```
        LCDsendbyte(1<<LCD_CLR,LCD_CMD);
    }

void LCDhome(void)
// Purpose      : Move cursor to home position
// Dependencies  : LCDsendbyte
// Assumptions   : none
// Parameters   : n/a
{
    LCDsendbyte(1<<LCD_HOME,LCD_CMD);
}

void LCDstring(uint8_t* data, uint8_t nBytes)
// Purpose      : output a string on the LCD
// Dependencies  : LCDsendbyte
// Assumptions   : none
// Parameters   : data: pointer to first byte of string, nBytes: number of characters to output
{

    register uint8_t i;

    // check to make sure we have a good pointer
    if (!data) return;

    // print data
    for(i=0; i<nBytes; i++)
    {
        LCDsendbyte(data[i],LCD_DATA);
    }
}

void LCDGotoXY(uint8_t x, uint8_t y)
// Purpose      : Move the cursor to a x,y position on the screen
// Dependencies  : LCDsendbyte, content of h file
// Assumptions   : none
// Parameters   : x and y (integers)
{

    register uint8_t DDRAMAddr;
    // remap lines into proper order

    // The position on the screen is identified by a memory address so we
    // need to convert x and y into that address

    switch(y)
    {
```

Appendix I

```
        case 0:      DDRAMAddr = LCD_LINE0_DDRAMADDR+x; break;
        case 1:      DDRAMAddr = LCD_LINE1_DDRAMADDR+x; break;
        case 2:      DDRAMAddr = LCD_LINE2_DDRAMADDR+x; break;
        case 3:      DDRAMAddr = LCD_LINE3_DDRAMADDR+x; break;
        default:DDRAMAddr = LCD_LINE0_DDRAMADDR+x;
    }

    // set data address
    LCDsendbyte(1<<LCD_DDRAM | DDRAMAddr,LCD_CMD);
}

void CopyStringtoLCD(const uint8_t *FlashLoc, uint8_t x, uint8_t y)
// Purpose          : Copies 0 terminated string from flash memory to LCD at x,y position
// Dependencies     : LCDsendbyte
// Assumptions      : none
// Parameters       : Pointer to flash, x and y
{
    uint8_t i;

    LCDGotoXY(x,y);

    for( i=0 ; (uint8_t)pgm_read_byte(&FlashLoc[i]) ; i++ )
    {
        LCDsendbyte((uint8_t)pgm_read_byte(&FlashLoc[i]),LCD_DATA);
    }
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
///header file for USART communication
#ifndef USART_LIB
#define USART_LIB
//*****
void USARTinit(uint16_t ubrr_value);
void USARTWriteChar(char data);
char formatted(uint8_t number, int position);
void sendString(const uint8_t *FlashLoc);
//*****
#endif
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
///C codes for the UASART.h file
#include <avr/io.h>
#include <inttypes.h>
#include <avr/pgmspace.h>

//This function is used to initialize the USART
//at a given UBRR value
void USARTinit(uint16_t ubrr_value)
```

Appendix I

```
{
//Set Baud rate

UBRRL = ubrr_value;
UBRRH = (ubrr_value>>8);

/*Set Frame Format

>> Asynchronous mode
>> No Parity
>> 1 StopBit

>> char size 8

*/

UCSRC=(1<<URSEL)|(3<<UCSZ0);

//Enable The transmitter

UCSRB=(1<<RXEN)|(1<<TXEN);

}
// this function is used to send a character

void USARTWriteChar(uint8_t data)
{
//Wait untill the transmitter is ready

while(!(UCSRA & (1<<UDRE)))
{
//Do nothing
}

//Now write the data to USART buffer

UDR=data;
}
////////////////////////////////////
char USARTReceive()
{
return UDR;
}
////////////////////////////////////
char formatted(uint8_t number, int position)
```

```
{
    if(position==1)
        {
            switch(number&0xF0)
            {
                case 0x00:
                    return '0';
                    break;
                case 0x10:
                    return '1';
                    break;
                case 0x20:
                    return '2';
                    break;
                case 0x30:
                    return '3';
                    break;
                case 0x40:
                    return '4';
                    break;
                case 0x50:
                    return '5';
                    break;
                case 0x60:
                    return '6';
                    break;
                case 0x70:
                    return '7';
                    break;
                case 0x80:
                    return '8';
                    break;
                case 0x90:
                    return '9';
                    break;
                case 0xA0:
                    return 'A';
                    break;
                case 0xB0:
                    return 'B';
                    break;
                case 0xC0:
                    return 'C';
                    break;
                case 0xD0:
                    return 'D';
                    break;
                case 0xE0:
                    return 'E';
            }
        }
}
```

```
        break;
    case 0xF0:
        return 'F';
        break;
    }
}
if(position==0)
{
    switch(number&0x0F)
    {
        case 0x00:
            return '0';
            break;
        case 0x01:
            return '1';
            break;
        case 0x02:
            return '2';
            break;
        case 0x03:
            return '3';
            break;
        case 0x04:
            return '4';
            break;
        case 0x05:
            return '5';
            break;
        case 0x06:
            return '6';
            break;
        case 0x07:
            return '7';
            break;
        case 0x08:
            return '8';
            break;
        case 0x09:
            return '9';
            break;
        case 0x0A:
            return 'A';
            break;
        case 0x0B:
            return 'B';
            break;
        case 0x0C:
            return 'C';
            break;
    }
}
```

```
        case 0x0D:
            return 'D';
            break;
        case 0x0E:
            return 'E';
            break;
        case 0x0F:
            return 'F';
            break;
    }
}

}
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
void sendString(const uint8_t *FlashLoc)
{
    uint8_t i;
    for( i=0 ; (uint8_t)pgm_read_byte(&FlashLoc[i]) ; i++ )
    {
        USARTWriteChar((uint8_t)pgm_read_byte(&FlashLoc[i]));
    }
}
////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//
```