YALOVA UNIVERSITY ★GRADUATE SCHOOL of SCIENCE ENGINEERING and TECHNOLOGY

A NOVEL CAN BASED ANTENNA MULTIPLEXING SYSTEM FOR UHF RFID APPLICATIONS

M.Sc. THESIS

Hüseyin Ulvi AYDOĞMUŞ

Department of Computer Engineering

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Thesis Advisor: Prof. Dr. Ahmet AKBAŞ

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Hüseyin Ulvi AYDOĞMUŞ, a **M.Sc..** student of YALOVA University **Institute of Science and Engineering** student ID 105105006, successfully defended the **thesis** entitled "**A NOVEL CAN BASED ANTENNA MULTIPLEXING SYSTEM FOR UHF RFID APPLICATIONS**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Ahmet AKBAŞ**
Yalova University

Jury Members : **Asst. Prof. Dr. Osman Hilmi KOÇAL**
Yalova University

Asst. Prof. Dr. Necla BANDIRMALI
Yalova University

Asst. Prof. Dr. Kayhan İNCE
Yalova University

Asst. Prof. Dr. Abdülkadir TEPECİK
Yalova University

Prof. Dr. Ahmet AKBAŞ
Yalova University

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To my family,

FOREWORD

I would like to express my gratitude and deep appreciation to my supervisor Prof. Dr. Ahmet AKBAŞ for his guidance and positive suggestions.

I would like to thank Özgür BOSTAN, my friend, colleague and partner at RFtek Electronics Ltd., for his great friendship and techinal support on hardware design process.

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January 2014 Hüseyin Ulvi AYDOĞMUŞ
(Electronics Engineer)

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ABBREVIATIONS

UHF	Ultra High Frequency
RFID	Radio Frequency Identification
CAN	Contoller Area Network
PCB	Printed Circuit Board
DSP	Digital Signal Processor
RF	Radio Frequency
PLC	Programmable Logic Controller
GPIO	General Purpose Input Output
NF	Near Field
USB	Universal Serial Bus
ETSI	European Telecomminications Standards Institue
FCC	Federal Communications Commission
ISO	International Organization for Standardization
EPC	Electronic Product Code
OSI	Open System Interconnection
MAC	Medium Access Control
LLC	Logical Link Layer
EOF	End of Frame
RTR	Remote Transmission Request
IDE	Identifier Extension
DLC	Data Length Code
CRC	Cyclic Redundancy Check
NRZ	Non Return to Zero
EMC	Electromagnetic Compability
ID	Identifier
MCU	Microcontroller Unit

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SUMMARY

UHF passive RFID is an emerging technology that is increasingly being used in many fields of industry where the identification and tracking is required. One of the major challenges in passive RFID is to increasing the tag reading zone. The most common method for increasing the tag reading zone is to use multi antenna systems which are placed at different locations. This method requires setting up a system with antenna multiplexers to increase the number of antenna outputs of UHF RFID reader. However, there are certain limitations when multiple antennas connected to a single RFID reader by using multiplexers such as insertion losses of ICs and number of antenna outputs.

In this thesis, design, implementation, and test results of a CAN based antenna multiplexing system for UHF RFID applications has been presented. Designed system has novel features that provide flexible configuration based on application requirements such as cascade connection up to three stages and reliable communication between multiplexers with reduced number of wires. The system is implemented with three major subsystems; the main controller node, which converts digital input signals to CAN messages and controls other CAN nodes, the multiplexer node which is responsible for switching the antenna channels and the RF switching unit that consists RF switch ICs that multiplex antenna channels.

Performance results of the embedded system showed that each of the CAN based multiplexer node could be controlled simultaneously and the time delay due to the command processing operations is insignificantly low. Insertion loss of the RF switching unit is measured as -1.342 dB at 865MHz, which is better than expected. The system was also tested with an RFID reader and antennas to demostrate antenna switching, cascade connection and tag reading performance.

This thesis is a part of Smart Shelf Design project funded by the Scientific and Technological Research Council of Turkey. Within the scope of this thesis, antenna multiplexing system of this project has been succesfully prototyped. Currently, the project is still under development and the large-scale testing with more antennas (near field) is scheduled in winter 2015.

UHF RFID UYGULAMALARI İÇİN YENİ BİR AKILLI ANTEN ÇOKLAYICI SİSTEMİ

ÖZET

UHF pasif RFID teknolojisi, kimliklendirme ve takip amacıyla endüstrinin birçok alanında artan bir kullanıma sahiptir. Etiket okuma menzilinin arttırılması bu teknolojideki en önemli kriterlerden birisidir. Menzili genişletmek için kullanılan en yaygın metod ise farklı yerlerde konumlandırılmış birden fazla antenin kullanımıdır. Kullanılması gereken anten sayısının okuyucunun desteklediği anten sayısından fazla olması, UHF RFID okuyucunun anten çıkışı sayısını arttıran çoklayıcılar ile bir sistem kurulumunu gerektirmektedir. Fakat, bu tekniğin sınırlı sayıda anten çıkışı ve iletilen sinyal gücünü düşüren geri dönüş kaybı gibi dezavantajları bulunmaktadır.

Bu tez çalışmasında, UHF RFID uygulamalarında, tek bir okuyucu ile kullanılabilecek anten sayısını arttıran ve geri dönüş kayıplarından dolayı iletilen sinyal gücündeki zayıflamanın sistemin performansına etkisini halihazırdaki sistemlere göre en aza indiren CAN tabanlı bir anten çoklayıcı sistemi tasarımı, uygulamasıgerçekleştirilmiş, test sonuçları sunulmuştur. Tasarlanan sistem, kullanılacağı uygulamanın gereksinimlerine göre esnek bir şekilde kullanılabilmektedir. Ayrıca, çoklayıcıların üç kata kadar kaskad bağlanabilmesi ve çoklayıcılar arası düşük kablolama maliyetli güvenilir bir haberleşme protokolü gibi özelliklerini de sunmaktadır. Sistem, üç temel altsistemden oluşmaktadır. Bunlar; dijital giriş sinyallerini CAN mesajlarına çeviren ve diğer CAN düğümlerini kontrol eden ana kontrol düğümü, anten kanallarının anahtarlanması işlemini gerçekleştiren çoklayıcı düğümü ve anten kanallarını çoklayan anten çoklayıcı ünitesidir.

Tasarlanan gömülü sistemin performans sonuçları, CAN ağına bağlı herbir çoklayıcı düğümünün eş zamanlı olarak kontrol edilebildiğini ve komut işleme sürelerinden kaynaklanan gecikmelerin sistemin hatasız çalışmasını engellemeyecek düzeyde düşük olduğunu göstermektedir. RF çoklayıcı ünitesinin geri dönüş kaybı 865MHz frekansında -1.342 dB olarak ölçülmüş ve beklenenden daha iyi bir sonuç elde edilmiştir. Ayrıca, sistem, RFID okuyucu ile test edilerek, anten anahtarma, kaskad bağlantı ve etiket okuma performansı gibi özellikler de test edilmiştir.

Bu tez çalışması, Türkiye Bilim, Teknik ve Araştırma Kurumu tarafından desteklenen Akıllı Raf Tasarımı projesinin bir parçasıdır. Bu kapsamda, projenin anten çoklayıcı sistemi tasarımı kısmı başarılı bir şekilde tamamlanmıştır. Proje kapsamında, tasarlanan sistemin daha fazla sayıda anten (yakın alan) ile geniş kapsamda test edilmesinin 2014 yılı sonuna kadar tamamlanması planlanmaktadır.

1. INTRODUCTION

1.1 Purpose of Thesis

The aim of this thesis is to design and implement an antenna multiplexing system for UHF RFID applications. RFID is a rapid expanding technology in many areas such as smart shelves, inventory management, access control, manufacturing, supply chain managemenet. Moreover, the many advantages of this technology rapidly extended its applicability to other areas. Number of the antenna outputs of the commercial RFID readers are enough for most of these applications. But especially in smart shelf applications, systems would operate more efficiently if it used with additional antennas. Therefore, this study focuses on operation of multi antenna RFID systems with one reader by the means of the combination of hardware and software based multiplexers.

This thesis is a part of Smart ShelfDesign project funded by the Scientific and Technological Research Council of Turkey and RFtek Electonics Ltd. Within the scope of this thesis, CAN based UHF RFID antenna multiplexing system has been modelled, designed and manufactured.

Based on the requirements of RFID smart shelves, several technical disciplines have been combined to find an efficient solution such as RFID and CAN bus. In this process, High frequency PCB design, embedded system design methods have been also used.

1.2 Literature Survey

This part of thesis is divided into two subparts. First, some of the previous academical researchesincluding antenna multiplexers, smart shelves, multi antenna applications and methods in RFID have been reviewed. Then, some of the patents and commercial products which is related with the subject of this thesis have been introduced.

Radio Frequency Identification is contacless automatic identification technology which is rapidly developed lately. Wang et al. (2007) presented design scheme of RFID reader using multi-antenna of difference spatial location. The receiving information from tags contains antenna code and data in tag's IC. As a result, the managing system of intelligent medicine-chest based RFID technology with reader were presented.

Automatic goods inventory applications of UHF RFID have some unique requirements such as confined read region to avoid the cross reads, positioning capability to know the tagged items location on the shelf and low system cost. As an innovate solution, five cascaded near field antennas that connected to the one antenna port were used to reduce the number of needed readers. Phase difference measurement based tag positioning method were proposed. To support different applications, it can provide both tier level and item level positioning for the goods on the shelf. Based on the measurement results, the proposed method can get the item level positioning accuracy with an average error of 4.16 cm. It can also get %100 tier level positioning accuracy (Yuan & Yu, 2012).

Multi antenna systems have wide spread of application area in RFID. The idea of pervasive gaming enhanced with wireless computing devices, has recently received increased attention. Floerkemeier and Mattern (2006)introduced a card game that is augmented with information technology to advise novice players and relieve the players of mundane tasks, such as score keeping. RFID system design results in a portable solution which requires minimal changes and disruptions to the conventional game flow and works reliably were presented. To reduce the cost of the system, a single short range RFID reader was used with a multiplexer that switches different antennas. The more expensive option would have been a design five readers, each connectedto one of the antennas.

Another research relatedto antenna multiplexing is an interactive table named TangiSense, which is equipped with RFID technology. The interaction is no longer the result of touching the table, but comes from handling tangible objects placed on the table. The use is closer to the natural use of a table. This technology makes it possible to identify the objects which can be coupled with the users. Starting from this principle, use of RFID tags to collect elements of context awareness in order to adapt workspaces to the various possible situations around table (work al one or with several users, on a common or invidual space) were proposed.The designed table is made up of “tiles” of 2.5 cm^2, each contains 64 antennas on a surface of 1x1 m. Each tile contains a DSP processor, which reads the RFID antennas, the antenna multiplexer and the communication processor. The reading strategies are prioritized and the code is distrubuted between the processor reader antennas, the processor in charge of multiplexing and the host computer. The table used in the study measures 1 m^2 and contains 25 slabs (5x5) or 1600 antennas in total (Kubicki, et al., 2012).

According to Maity et al. (2009) the major challenge in passive RFID system is to increase the tag reading zone. The most suitable and popular adaptive way is to use multi antenna which are used to be placed at different place to get a wide reading zone. In the present RFID sub-systems, the RFID reader scans data sequentially from invudial antenna port by switching the multiplexer once at a time. When the number of antennas increases, the subsequent time interval of scanning data from any particular antenna may be sufficiently large, hence the probability of loosing any tag information passing through that antenna in any dynamic domain is very high. As a result, virtual concurrent data processing algoritm to scan the data paralelly and simultaneously from all the antenna at the single data quantum, thus minimizing the probability of loosing any tag information passing through any antenna in multi ported UHF RFID reader sub-system was presented.

There are some other researches that focused on special antenna designs for RFID smart shelves and multi antenna applications. Medeiros et al (2009) presented a simple and effective antenna solution for confined RFID dedection within the limits of bookshelf, operating at the three assigned RFID sub-bands at UHF. The proposed concept uses leaking microstrip transmission line with extended ground plane embedded on the shelf. The proposed solution allows univocal dedection of tagged books above the shelf with proper field confinement to avoid undesired reading of neighboring shelves. Another work based on RFID antenna for smart shelf at UHF was presented by Wu et al (2012). The antennas were implemented by cascading two layers of micrositrip lines and being terminated with a matched load and it can produce a uniform magnetic field even though the size of the antenna is large. It has a low far-field gain and adoptability of its dimension as per requirement. These properties make the antenna suitable for smart shelf RFID readers.

There are some specific patents about multi antenna systems, multiplexers and smart shelves in RFID. In U.S. Patent 2006/00544, ”RF Switched Multiplexer” (Shafer, 2006), an RFID multiplexer and a network which includes the RFID multiplexer, which is configured to interpret an RF signal from an RFID reader as RFID tag data and to forward the RFID tag interrogation data as a multiplexer channel-change command were presented. In U.S. Patent 2009/0027202, “RFID System with Integrated Switched Antenna Array and Multiplexer Electronics” (Copeland & Shafer, 2009), an RFID dedection system for determining the location of tagged items within an interrigation zone was presented. The system includes one or more printed circuit boards coupled to each other and placed within a region of the interrigation zone. Each printed circuit board contains an antenna array having one or more antennas where each antenna dedects tagged items within a specific read zone in the region. The PCB also contains a multiplexer coupled to the antenna array, where the antenna array and the multiplexer are provided on a substrate. Upon an interrogation request from RFID reader, a specific antenna can be activated and selected by the multiplexer. In E.P. Patent 18723444 B1, “Smart Shelf” (Goyal et al, 2006), the system and methods related to the inventory monitoring were presented. More particularly, the presented invention provides systems and methods for identifiying stored items with the use of radio frequency identification tags attached to the storage shelves.

Commercial multiplexer products that provide easier set up for an RFID smart shelf system has become popular in last years. The Metratec Hypermux is 4 channel UHF RFID multiplexer that works at 868 to 915 MHz frequency band and allows up to 4W RF power. Antenna channels can be controlled by DC input pins (Metratec, 2013). The Advanmux is 8 channel UHF RFID multiplexer that can be connected to the other multiplexers and multiplex up to 32 antenna (Keonn, 2013). Another product is Impinj Speedway Antenna Hub that can be connected up to 5 to 32 antennas. Antenna channel switcing is controlled with GPIO adapter that allows up to 4 antenna hub connection (Impinj, 2013).

1.3 Structure of Thesis

This thesis divided into seven different parts. First, after the inroductory section, the section two gives the overview of the antenna multiplexing systems in RFID.

Thissection provides information forRFID smart shelf applications and explains its benefits. In addition, this section summarizes the related work conducted.

The third section provides background information about RFID fundementals that is necessary for better understanding for the following sections. Furthermore, the background for CAN bus technology used in the communication between the multiplexers is presented.

The fourth section focuses on the CAN based system design requirements. In addition, system configurations and operating methods of cascaded multiplexers are discussed.

The fifth section explains the implementation of the antenna multiplexing system. First, that section explains hardware design of two types CAN based node and RF multiplexer node. Then, that section describes the embedded software requirements and gives a detailed overview for the implementation used for the embedded system.

The last part provides conclusions and future work. That section also discusses the measurements and testing results of the designed system. RF measurements of the multiplexers and test results in the actual working environment of the whole system are given in the end.

2. MULTI-ANTENNA SYSTEMS IN RFID

This section gives an overview of antenna multiplexing systems and methods in RFID. First, antenna multiplexer systems and its potential applications are overviewed. Then, benefits of antenna multiplexing in RFID applications are explained. Next, specifications of the current antenna multiplexers systems are compared and their limitations are defined. And, finally, Designing an RFID Smart Shelf Hardware project, in which CAN based smart antenna multiplexer system developed in this thesis is utilized, and introduced.

2.1 Overview of Antenna Multiplexing Systems

Most of UHF RFID readers in the market have 1 to 8 antenna outputs. In some RFID applications, there are very valid reasons for using multiplexing systems with one reader such as reading tags in multiple zones with multiple antennas which are more than the number of antenna outputs of the reader. Antenna multiplexers reduce the hardware costs and complexity of the system in RFID applications with multiple antennas without using multiple readers and host systems.

A UHF RFID multiplexing system generally consists of an RF switching circuit and an internal or external logic control unit. An RF circuit is designed with cascaded RF switch integrated circuits. The most important criterias of RF switch circuits are having lower insertion loss and return loss to provide maximum RF power transmission.

Several methods are used in RFID antenna multiplexing systems based upon application needs such as single multiplexer unit or cascaded multiplexer networks. There are several interfaces to control the switching operations between antenna channels. For example, it can be controlled over ethernet, RS-232 or any external control unit such as PLC and digital output modules. The most common method to control the antenna channels is using the GPIO unit of the RFID reader. This method provides simplicty on the host controller side since of there is no necessity of using an external communication interface or driver. However, when building a network between multiple multiplexer units and controlling these units with GPIO unit of the reader is not a safe solution because of distance between multiplexer units, electromagnetic noise, communication speed etc. The most safest method to provide communication between multiplexer units and controller unit is using a reliable communication interface such as ethernet, can, RS485 etc.

2.2 Antenna Multiplexing Applications in RFID

Radio Frequency Identification is a rapid expanding technology that enables dedection and recognition of objects associated to a univocal identification code. In the beginning, RFID technology was widely used for access control and inventory management applications. However, the many advantages of this technology radiply extended its application areas (Medeiros, Costa, & Fernandes, 2009).

Currently, supermarkets and other retailers across the world are planning large-scale item level deployments of the RFID systems for consumer goods. These systems can be used for real time inventory management, tracking misplaced itemsapplications with smart shelves. Leading retailers such as Wal-Mart, Marks&Spencer, Tesco, Metro, Coles Myer and Mitsukoshi etc. are implementing RFID solutions for their supply chain management(Qing, Chen, & Cai, 2007). The demand for the RFID has been increased with the reduced cost of RFID tags. Therefore, usage of "RFID Smart Shelf' has been expanded. Besides for retail applications, smart shelf is also expected to be applied in advertisement applications that combined with tracking and monitoring.

A typical smart shelf as shown in Figure 2.1 consists four main parts: antennas, multiplexer system, RFID reader and host system. An RFID reader continuously scanning the RFID tagged items on the shelf, the RFID reader consistently notifies the back-end (host) system about the existing items and their movement. It will also identify items that do not belong on certain shelf as "misplaced items" (RFID Arena, 2013).

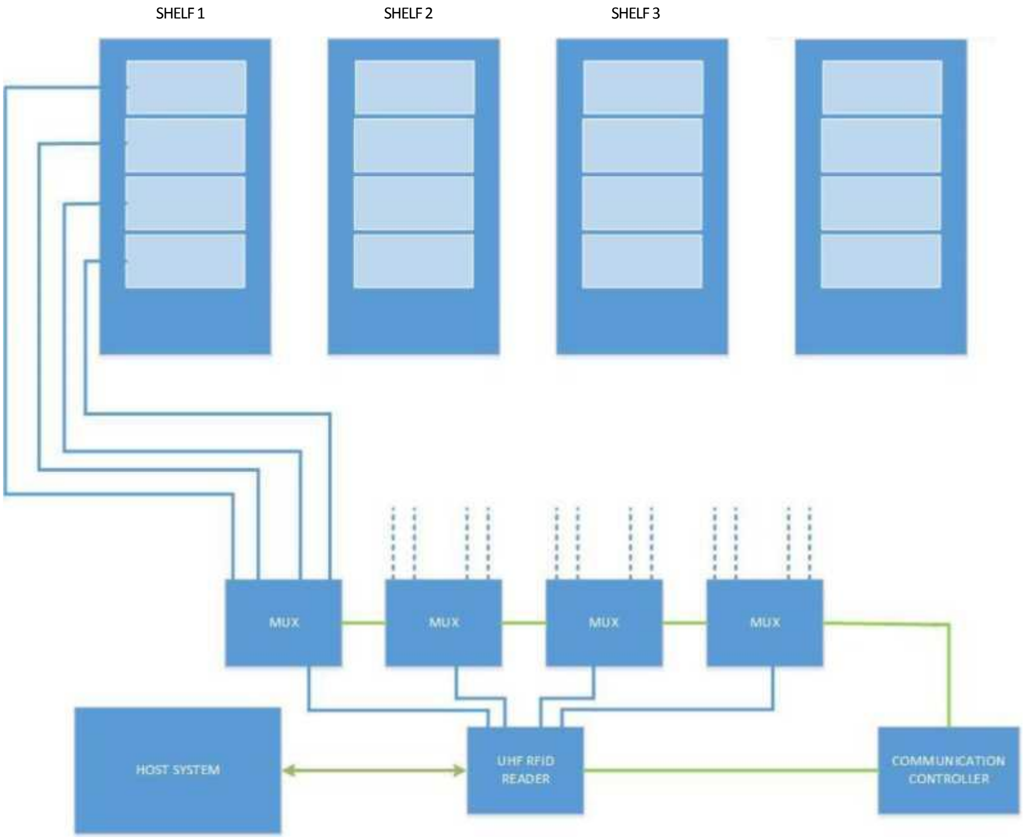


Figure 2.1 : UHF RFID Antenna Multiplexing Sytem

There are many application areas of smart shelf which are based on antenna multiplexing such as library smart shelves (Figure 2.2), RFID based displays in fitting room, smart mirrors (Figure 2.3). By tracking items in multiple zones, the system provides information that can be analyzed from customer preferences and various ways of digital signage opportunities to increase the sales.

Figure 2.2 : RFID library smart shelf(Beiyang Co., 2013)

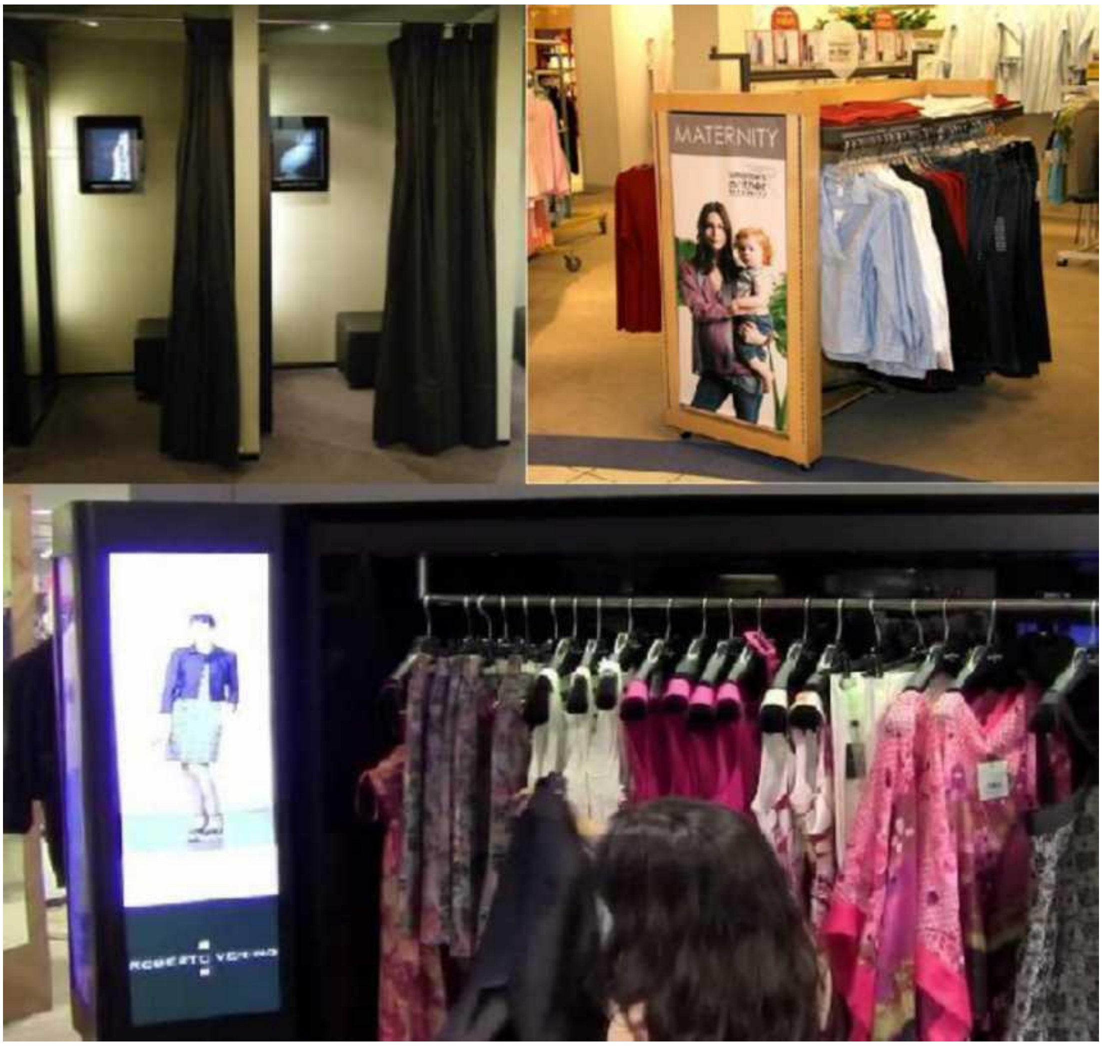


Figure 2.3 : RFID based smart fitting room and smart mirror (Keonn Technologies, 2013)

Compared with other RFID applications, smart shelves have some unique requirements. First, it needs to be confined read region on each layer. On the desired area, 100% reliability is expected to read all tags on the layer and outside of the layer, no reads should occur to avoid cross reads (Yuan & Yu, UHF RFID Shelf Solution with Cascaded Reader Antenna and Positioning Capability, 2012). It is the biggest challenge on UHF RFID smart shelf applications.UHF RFID technology adopts the far field radio propagation method. It is hard to provide the confined read region and due to cross reads and reflections especially in short range applications. The basic solution for this problem is using near field RFID antennas as shown inFigure2.2. A smart shelf system with near field antennas can be used in short range applications especially in pharmaceutical or cosmetic industry.

Figure 2.4 : RFID Smart shelf with NF antennas (Venture Research Inc., 2013)

2.3 Benefits of Antenna Multiplexing Systems in RFID

- Reduces hardware costs by eliminating external reader necessity.
- Automated tracking of item-level inventory or asset location in multiple locations.
- Scalable systems with adding extra antennas and multiplexers. o Antenna multiplexers are mostly compatible with all UHF RFID readers.

2.4 Smart Shelf Design Project

Smart ShelfDesign project is one and half year project that aims to design a UHF RFID smart shelf hardware and application. Project is funded by the Scientific and Technological Research Council of Turkey and Rftek Electonics Ltd. The main objective is to develop a low cost and easily scaleble RFID multiplexing system for RFID smart shelves.

The Project aims to develop a smart shelf that will be equipped with an RFID reader, antennas, multiplexers and a information display. When an item is picked up from the shelf, the display attached to the shelf will give information about the product. The contents of the information might be product features, alternative products, warnings, time of production etc. In this project,UHD RFID near field and far field antennas, UHF RFID antenna multiplexers will be designed and smart shelf demo application will be implemented with reconfigurable content management software.

This thesis is conducted as a part of Smart Shelf project. Within the scope of this thesis, CAN based UHF RFID antenna multiplexing system has been modelled, designed and manufactured. Currently, the project is still under development and the final demonstrations are scheduled to be held in December 2014.

3. KEY TECHNOLOGIES AND STANDARDS

Chapter 3 introduces the key technologies and standards used in this thesis. First, RFID technology, applications and RFID standards are overviewed for better understanding for the following chapters. Then, Controller Area Network is introduced and technical information about Controller Area Network is investigated in detail.

3.1 RFID Technology

Radio Frequency Identification is a low-cost compact wireless technology that identify, track or dedect a wide variety of objects from a distance. RFID systems consist of small transponders (tag), attached to physical objects. When wirelessly interrogated by RFID transceivers (reader), tags respond with some identifying information that may be associated with arbitrary data records. Thus, RFID is one type of automatic identification (Auto-ID) system (Weis, 2013).

3.1.1 Main components of an RFID system

An RFID system consists of four main components: a reader, which sends the interrogation signals to a RFID transponder. An RFID tag, which is to be identified and contains the identification code. An antenna and a host system. Typical RFID system is shown in Figure 3.1.

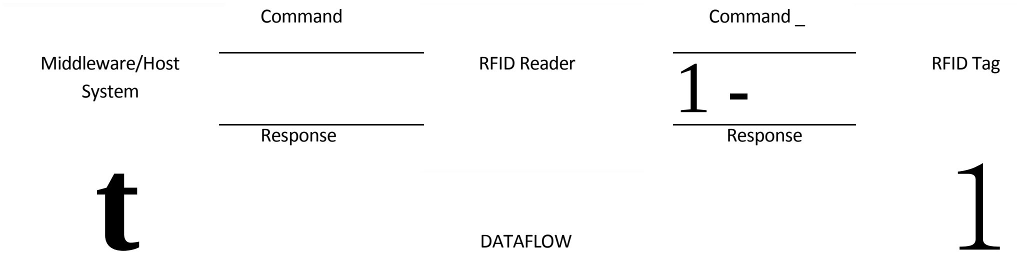


Figure 3.1 : Block diagram of a typical RFID system.

Reader: RFID readers communicate with tags through an RF channel to acquire identifying information. Reader can both read and write data on tags. It converts analog signal returned from the antenna into digital format and send the data to the host computer via ethernet, USB etc while it reading. While it writing on tag, reader converts digital data that received from the host computer into analog signal. Readers come in many forms such as handheld or stationary, operate in different frequencies and may provide various functionality (Finkenzeller, 2003).

Tag - A tag is typically composed of an integrated circuitry and an antenna. Each tag has its own identifier code that will be used identify the objects. Tags are categorized into three types depending on their power sources internally or externally. Tags can be read only (factory programmed), write once read only (factory or user programmed) and read/write (Finkenzeller, 2003). In some cases, depending on specific business process, they have sensors for measurement of values such as temperature and humidity.

A passive RFID tag consists of a microchip and a printed antenna. A passive tag energized by the signal, which is transmitted by the reader’s trasmission and backscatters the transmitted signal from the reader, which repserent tag’s ID. Propagation range of passive tags depends on the transmit power transferred from the reader and efficiency of the antennas.

A semi passive tag operates similarly to passive RFID tags but they consists battery for internal circuitry operations such as sensor reading applications. Communication of semi passive tags is completely same as the passive tags. The tag only reflects back the power transmitted by the reader.

An active tag uses internal battery for data transmission and powering the internal circuitry (they do not use harvested power). Propagation range of active tags is greater than passive tags. Active tags can also be equipped with built-in sensors.

Antenna -RFID antenna that connected to the reader transmits and receives the electromagnetic waves and converts the electrical signal to electromagnetic waves vice versa. RFID antennas can range greatly in cost, application area and operating frequency. Depending on application, antennas can be different shapes or functions such as directional or circular.

Host Controller - The host controller is a desktop or industrial computer that connected to the reader through network interfaces. This controller receives data from the readers and performs data processing. Additionally, it serves as a device monitor, making sure the complete system is functioning properly and securely (Finkenzeller, 2003).

3.1.2 Applications and benefits of RFID

Current and proposed uses of RFID systems span a wide spectrum of application areas as follows(Kaur, Sandhu, Mohan et all, 2011):

Instance of class identification - If RFID tags are only used for the purpose of item type or instance identification, usually, a data-base is maintaned in the background to provide or receive the additional information needed. Augmented with this support, destination or way of handling can be determined for the given item. There are several examples of RFID solutions in logistics industry such as UPS, FedEx, USPS (RFID Nordic).

Location identification - If a given reader is assigned to a known location, it is possible to track the current place of the objects. Numeruous logistics companies and some postal services have already integrated such RFID-based features in their tracking services.

Asset tracking - RFID can be used to prevent misplacement of items, or to facilitate locating items. One way to do this is to keep track of item movements in a database. For example, RFID readers can be installed at doors between rooms in a building. Evaluating the records of the RFID readers would then allow one to deduce in which room the item is located. It is worthwhile to note that this is typically not a good theft prevention method, because RFID readers can easily be inhibited by placing the item in a metal-lined bag for instance. However, this system can work well in an environment where one is more concerned about accidental misplacement of an item than about theft (Gaukler & Seifert, 2007)

Manufacturing - RFID has been used in manufacturing plants for more thana decade. It's used to track parts and work in process and to reduce defects, increase throughput and manage the production of different versions of the same product .

Retail Industry - Retailers such as Best Buy, Metro, Target, Tesco and Wal-Mart are in the forefront of RFID adoption. These retailers are currently focused on improving supply chain efficiency by using smart shelves. Smart shelves are retail shelves that have RFID readers built-in. The main purpose of smart shelves is to prevent out-of- stock situationsfrom occurring at the shelf(Gaukler & Seifert, 2007).

Payment, security,access control, Authentication and Counterfeit Protection- One of the most popular uses of RFID is to payment for road tolls without waiting. These active systems are being used in many countries. For access control, RFID is used as an electronic key to controlwho has access to office buildings or areas within officebuildings.There are several applications that use RFiD as an anti-counterfeiting measure. In 2005, the Wynn Casino in Las Vegas first opened and deployed RFiD- integrated gaming tables and gambling tokens. These “chips-in-chips” are designed to frustrate counterfeiting, prevent theft, detect fraud, and to offer enhanced games or service. Besides stored-value tokens like casino chips or event tickets, there have also been proposals to tag currency (Juels & Pappu, 2003). In 2005, a controversial proposal to attach tags carrying biometric identification data to United States passports began to be implemented (Weis, 2013).

As RFID technology evolves and becomes less expensive and more robust, it's likely that companies and RFID vendors will develop many new applications to solve common and unique business problems.

3.1.3RFID radio regulations

The operation of RFID systems worlwide is regulated by local govermental bodies which control the electromagnetic spectrum in region. There are three main RF bands in RFID; Low frequency (125 to 134 kHz), High frequency (13.56 MHz) and ultra high frequency (860 to 960 MHz). In this thesis, RFID antenna multiplexing system is designed at UHF band.

UHF bandwith across the European Union is regulated by ETSI, and ranges from 865 to 868 MHz and readers are allowed to transmit 2 Watt (max). In North America, RFID bandwith is regulated by FCC, and ranges from 902 to 928 MHz and readers allowed to transmit 4 Watt (max)(Dobkin, 2007).

3.1.4RFID standards

There are multiple standardization organizations working for development of RFID standards. The most important organizations are International Standardization Organization and EPC Global, formerly known as Auto-ID Center.International Standardization Organization has established the ISO 18000 series of standards that specify the communication between tag and the reader. Current standards of RFID is ISO 18000-6 standard, Type-C which is also known as EPC Global Class-1 Gen-2 and it developed with collobration between ISO and EPC Global. International standardization for RFID can bring up three major benefits. First, an international standard will make sure that inter-operability among RFID readers and tags manufactured by different vendors and improve inter-operation across national boundaries. Secondly, having an international standard will decrease the cost due to compability and exchangeability. Third, an international standard help dramatically on proliferation of RFID technology worldwide (Huang, 2009).

EPC Global classifies tags into five class as follows(Violino, 2013);

Class 0: Factory programmable, read-only, passive tags .

Class 1: Write once, read many (WORM), passive tags.

Class 2: Passive, read-write tags up to 65 kb memory.

Class 3: A semi-passive tag with up to 65 kb read-write memory.

Class 4: An active tag that uses built-in battery to run the internal circuitry and to power the transmission unit that communicate with the reader.

Class 5: An active tag which is able to communicate with other Class 5 tags and other devices.

3.2 Controller Area Network

Controller Area Network is a serial bus system especially suited for networking “intelligent devices” as well as sensors and actuators within a system or sub-system (Bosch, 2013). The Controller Area Network (CAN) was developed in the mid 1980s by Robert Bosch GmbH, to provide a cost-effective communications bus for automotive applications, but is today widely used in factory and plant controls, in robotics, medical devices, and also in some avionics systems. (Natele, Zeng, Giustro, & Ghosal, Understanding and Using the Controller Area Network Communication Protocol, 2008).A single CAN network can theoretically can link up tp 2032 devices. However, due to practical limitation of the hardware, it can only link up to 110 nodes on a single network. It offers high speed communication range from 20 kb/s to 1Mb/s thus allows real-time control (as citied in Nilsson, 2007).

There are three three sepereted CAN standarts: CAN 1.0, CAN2.0A and CAN 2.0B. The main difference of these standards is the length of the identifiers that precede each message (Darr, 2004). In this thesis, CAN 2.0B is used and CAN bus is combined with UHF RFID multiplexing system to control switching operations between antenna channels.

3.2.1 Features of CAN

The CAN protocol has the following features (Renesas, 2010).

System Flexibility: The CAN nodes connected to the bus have no identifying information such as device adress. For this reason, when a node added to or removed from the bus, there is no need to change the hardware, software of application layer of any other node connected to the bus.

Communication speed: Within one CAN network, all nodes must have the same communication speed. If any node with different communication speed is connected to the network, it will generate error. Different communications speed can be set in one CAN network but it relevant with the network length.

Multimaster: When the bus is available, all of the nodes connected to the network can start sending a message. The unit that first started sending message to the bus is granted the right to send. If multiple nodes start sending message at the same time, the node that is sending a message whose identifier has the highest priority is granted the right to send.

Message transmission:In the CAN potocol, all messages are transmitted in pre- determined format. If two or more nodes start sending a message at the same time, their message priority is resolved by a message identifier. The message identifier does not indicate the destination of the message. Nodes has their message filters for receiving the right messages.

Error dedection, notification and recovery functions: All nodes that connected to the CAN network can dedect an error. The node that has dedected an error immediately notifies all other units simultaneously. If a node dedects error while sending a message, it notifies all nodes then it repeats retransmission until the message is transmitted.

Error confinement: There are two types of errors occuring in the CAN; a temporary error which becomes due to electromagnetic noise from the outside or for other reasons and a continual error on the bus due to internal failure, driver failure or disconnections. The CAN has a function discriminate between these types of errors. This function helps the priority of the node that has an error or separate the node that is the cause of the error from the bus.

Remote data request: Data transmission from other nodes can be requested by sending a “remote frame” to these nodes.

Connection: CAN bus permits multiple nodes to be connected at the same time. There are no logical limits to the number of connectable nodes. However, the number of units that can be actually be connected to the bus is limited by the delay time and electrical load on the bus. If the communnication speed is increased, the number of connectable nodes decreases.

3.2.2 Bus topology

The CAN controller determines the level of a bus by potential difference in two wires (CAN High and CAN Low). As shown in the Figure 3.1, all CAN nodes connected to the network on two wire and the bus is adjusted on both ends by using termination resistors to eliminate bounces on the line.

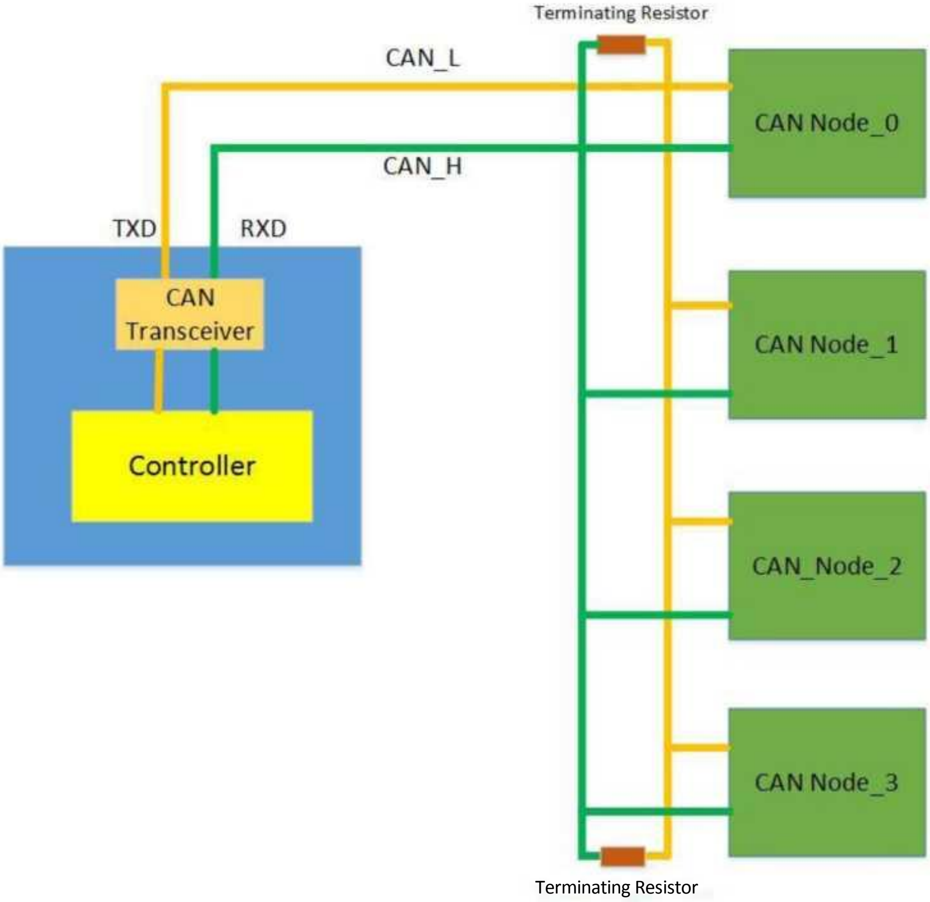


Figure 3.2 : Typical CAN connection diagram

The transceiver must convert the electrical representation of a bit from the one in use by the controller to the one defined for the bus. In addition, it must provide sufficent output current to drive the bus electrical state, and protect the controller chip against overloading. As a receiver, the transceiver provides the recessive signal level and protects the controller input comparator against excessive voltage on the bus lines. Furthermore, it dedects bus errors such as short circuits, short to ground, line breakage (Natele, Zeng, Giustro, & Ghosal, Understanding and Using the Controller Area Network Communication Protocol, 2008).

In high speed CAN networks, propagation delay of the transceivers is the biggest limitation of the bus length. The parameters of electrical medium become important such line resistance, signal propagation etc. when bus length is increased. Typical transmission speeds and coorresponding bus length is given in Table 3.1

Bit rate	**Bus length**	**Nominal bit- time**
1 Mbps	40m	1us
500Kbps	130m	2us
250Kbps	270m	4us
125Kbps	530m	8us
50Kbps	1300m	20us
20Kbps	3300m	50us
10Kbps	6700m	100us

Table 3.1 : Typical transmission speeds and corresponding bus lengths.

3.2.3 CAN and the OSI model

The Open System Interconnection Model is a reference to how to messages are transferred in a network and all the communication protocols are compatible with this standard. It divides the communications processes into seven layers. Each layer both performs specific functions to support the layers above it and offers services to the layers below it. The three lowest layers focus on passing traffic through network to an end system. The top four layers come into play in the end system to complete the process (Global Knowledge LLC, 2006).

CAN comprises data link layer and a part of physical layer of OSI reference model as shown in the Figure 3.1. The purpose of the physical layer is to define how bits are encoded into signals with defined physical characteristics, to be transmitted from one node to the another. In BOSCH CAN Standart, description of physical layer is limited with bit timing, bit encoding and synchronization. For this reason, physical specification of the CAN such as driver/receiver characterictics, the acceptable voltage levels, physical transmission medium, physical wiring and connectors can be optimized for their application.

The Data link layer consists of the Medium Access Control (MAC) and Logical Link Control (LLC) layers. The MAC sublayer is represents the kernel of the CAN protocol. It presents message from the LLC sublayer and accepts messages to be transmitted to the LLC sublayer. The MAC sublayer is responsible for message framing, arbitration, acknowledgement, error dedection and signalling. The MAC sublayer are supervized by a management entity called fault confinement which is self-checking mechanism for distunguishing short disturbances from permanent failures (CAN in Automation (CiA), 2013).

The LLC sublayer provides all the services for data transfer and remote data request and it decides which message received by the LLC sublayer actually to be accepted. The LLC sublayer also provides means for recovery management and overload notifications (Di Natale, 2008).

7	Application	
6	Presentation	
5	Session	
4	Transport	-Logical Link Control -Medium Access Control
3	Network	
2	Data Link	
1	Physical	-Physical Signaling -Physical Medium Attachment -Media Dependant İnterface

Figure 3.3 : CAN bus in OSI reference model

3.2.4 Frame types and architectures

In CAN protocol, communication is performed using the following four types frames according to their content and function;

- Data frame
- Remote frame
- Error frame
- Overload frame

The data and remote frames need to be set by user. Error and overload frames are set by the hardware part of CAN internally. The data and remote frames divided in two frame formats, standard and extended. The only difference between them is the length of the message identifiers. The standart frame has 11-bit identifier while extended frame has 29-bit identifier.

3.2.4.1 Data frame

This frame is used by transmitter node to send message to the receiver nodes. As shown in the Figure 3.3, each data frame start with a Start of Frame (SOF) field and end with an End of Frame (EOF) field(Renesas, 2010).

SOF field -A single dominant bit represents a start of frame. It also used for data transfer synchronization.

Arbitration field -This field contains a message identifier for each frame which can be standard format (11+1 bits) or extended format (29+3 bits). This field also contains Remote Transmission Request (RTR) part. The 1-bit RTR part distinguishes a data frame from a remote frame.

Control field -The control field contains 6 bits. IDE (Identifier Extension) is 1 bit of this field and indicates the format of the message ID in the frame, either standard or extended format. DLC (Data Length Code) field (4 bits) is used to set the amount of data being transferred from one unit to another unit.

Data field -This field contains the actual data. Data in range 0 to 8 bytes can be transmitted.

CRC field -This field is used to check the frame for transmission error.

Ack field -This field indicates a signal for confirmation that the frame has been transferred normally.

End of frame -This field indicates the end of a data frame. A seven bit continuous recessive bit represents the end of the frame.

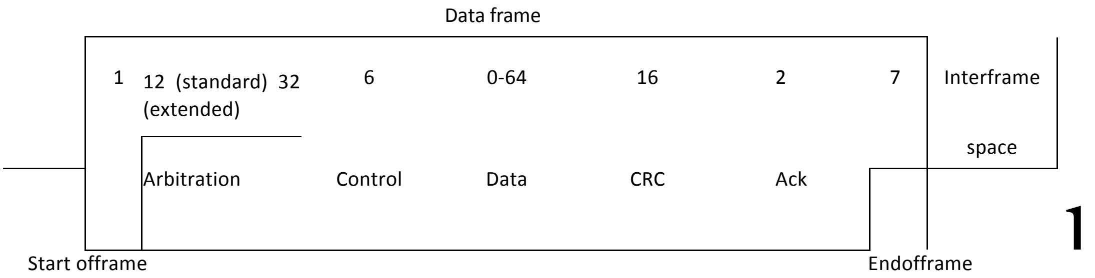


Figure 3.4 : The CAN data frame format

3.2.4.2 Remote frame

A remote frame is used by the receive unit to request the transmission of a message with a given identifier from the remote transmission unit. This frame is the same as a data frame except it does not have a data field but RTR bit in its artibration field of remote frame is in recessive level. Therefore, the data remote frame and the data frame without data field can be discriminated by the RTR bit.

3.2.4.3 Error frame

This frame is used to notify an error that has occurred during the transmission in CAN. An error frame contains error flag (6 bits) and error delimeter (8 bits). Error flag can be either active or passive and it indicates the transmitting or receiving error on the bus. Error delimeter is represented as a sequence of 8 recessive bits. After transmitting the error flag each node transmits a single recessive bit and waits for the bus level to change to recessive (Gurram, 2011). Only after the bus level is recessive, the remaining 7 bits will be sent onto the bus.

3.2.4.4 Overload frame

The overload frame is used by the receive unit to notify that is has not been prepared to receive frames yet. It consists of overload flag and overload delimeter fields.

Overload flag -This field contains 6 dominant bits and it indicates the transmitting and receiving error on the CAN bus.

Overload delimeter -This field contains 8 recessive bits. After transmission of the error flag each node transmits one recessive bit and waits for the bus level to change recessive. If bus level is recessive, the remaining 7 bits will be sent onto the line.

3.2.5 Bus arbitration

The CAN arbitration protocol is based on priorities of messages. The node that send a message first during a bus is in idle state is allowed to send. If multiple nodes started to sending a message at the same time, the messages are arbitrated for contention by the arbitration field of each transmitted frame (Renesas, 2010). The node higher priority than the other nodes is allowed to send. The unit that lower priority and lost the arbitration go to a receive operation until the bus is available.

If priority of standard and extended frame formats or the priority of data and remote frames are the same whose RTR bit is in dominant level is allowed for transmission.

3.2.6Error management

In addition to the priorization and arbitration, the CAN potocol performs error dedection mechanisms. At the message level, CAN provides CRC checks, frame checks and ACK checks. At the bit level, it provides transmission monitoring and stuffing (CiA, www.can-cia.org, 2013).

Cyclic Redundancy Check - The transmitter unit calculates the CRC and send it within the message. The receiver unit re-calculates the CRC. If they do not match, there has been CRC error.

Frame check - This mechanism checks each field against the fixed format and frame size.

Acknowledgement check - If ACK is not returned from the receive unit, an ACK error is indicated.

Transmission monitoring - Each unit that transmitting a message also monitors the bus level to be able to dedect differences between the bit sent an the bit received. This mechanism allows distinguishing global errors from errors local to transmitter only (Joaquim & Fonseca, 2013).

Bit stuffing - CAN uses NRZ coding to prevent units from loosing synchronization by receiving long sequences of dominant and recessive bits. Bit stuffing implemented during transmission of more than five consecutive bits of same polarity. If more than five consecutive bits of same polarity are transmitted, the bus takes it as an error frame as the first six bits of the error frame are dominant bits (Gurram, 2011).

3.2.7CAN 2.0A and CAN2.0B

The original CAN specification is known as CAN Specification 2.0 Part A. The upgraded version of the specification is named as CAN Specification 2.0 Part B (CiA, www.can-cia.org, 2013). The original CAN specifications defined the message identifier as having a 11 bits giving a possible 2048 message identifiers. The specification has since been updated to version 2.0B for removing this limitation. CAN specification version 2.0B allows message identifier lengths of 11 or 29 bits to be used. The 29 bit allows 536 million message identifiers. Version 2.0A is also known as “Standard CAN” and version 2.0B is referred to as “Extended CAN” (Microchip Technology Inc, 2006).

CAN units specified by CAN 2.0A are only able to transmit and receive standard frames with 11 bits identifier. If the message sent to the bus with 29 bit identifier, it generates error. CAN device that specified by CAN 2.0B can be passive or active. CAN 2.0B Passive can only transmit and receive standard frames but tolerate extended frames without generating error frames. CAN 2.0B Active devices can transmit and receive both standard and extended frames (University of Warwick CAN/EtherNet Research Centre, 2013).

4. CAN BASED SYSTEM DESIGN

This section describes the design of the CAN network for RFID antenna multiplexing system. First, CAN bus configurations and design specifications are examined in detail. Then, specifications and functions of two types of CAN nodes are overviewed. Finally, operating methods of cascaded antenna multiplexer nodes are explained.

4.1 Configuration of CAN

One of the most important feature of the CAN bus is user programmable bit rate, sample point, number of samples taken in a bit period. This gives the user the freedom to optimize the performance of the network for a given application (Jöhnk & Dietmayer, 2013). Selecting the bit rate is a trade-off between capacity for growth and application performance. Low bit rates can lead to performance bottlenecks, missed deadlines and limited growth space. However, high bit rates can reduce maximum bus length, amplify susceptibility to noise, and increase demands on both the network interface and the application (Upender & Dean, 1996).

Bit timing parameters are determined with the following steps;

$$t_{PROP\_SEG} = 2\,(t_{BUS} + t_{Tx} + t_{Rx}) \quad (4.1)$$

Where the t_{BUS} is the propagation delay of the signal along the longest length of the bus between two nodes, t_{Tx} is the propagation delay of the transmitter part and t_{Rx} is the propagation delay of the receiver part.

$$NBR = f_{NBT} = \frac{1}{t_{NBT}} \quad (4.2)$$

Where the NBR (Nominal Bit Rate) is the number of bits per second transmitted by an ideal transmitter and t_{NBT} is the Nominal Bit Time.

$$t_{NBT} = t_{SYNC\_SEG} + t_{PROP\_SEG} + t_{PHASE\_SEG1} + t_{PHASE\_SEG2} \quad (4.3)$$

The Nominal Bit Time is divided into four seperate non-overlapping time segments called ***PROP_SEG*** , ***SYNC_SEG, PHASE_SEG1*** and ***PHASE_SEG2(Robert*** Bosch GmbH, 1991). The sum of the segment durations is equal to the period of the Nominal Bit Time.

$$tq = 2 \cdot BRP \cdot T_{osc} = \frac{2 \cdot BRP}{f_{OSC}} \quad (4.4)$$

Each of the segments that make up a bit time are made up of integer units called Time Quanta (***tq***). The lentgth of each ***tq*** is based on the oscillator frequency (Richards, 2001). The CAN system clock can be adjusted by the user via programmable BRP (Baud Rate Prescaler) as given by equation 4.4. The relationship between CAN system clock and bit segments is as shown in Figure 4.1.

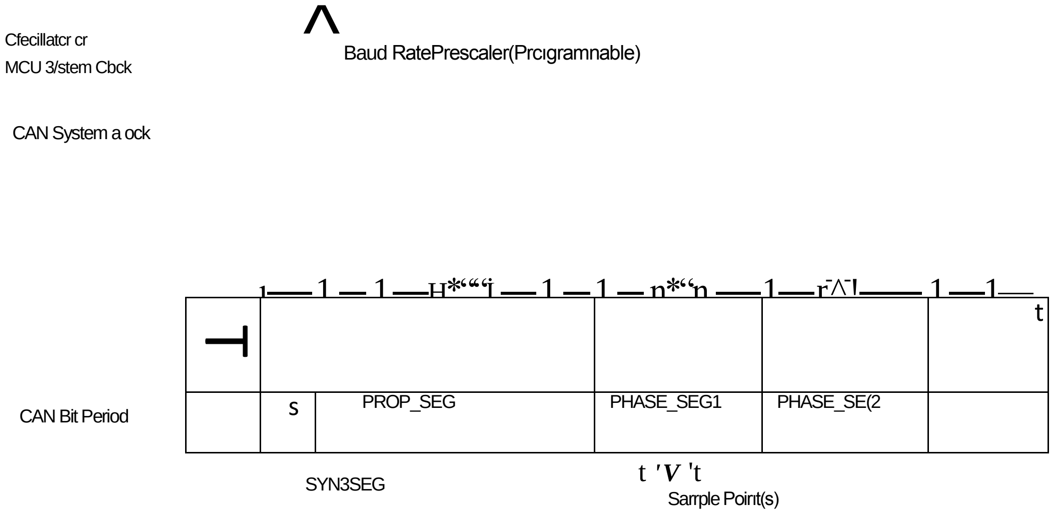


Figure 4.1 : Relationship between CAN system clock and CAN bit period (Robb, 2013).

$$PROP\_SEG = ROUND\_UP\left(\frac{t_{PROP\_SEG}}{t_q}\right) \quad (4.5)$$

The minimum number of Time Quantum (***tq***) that must be assigned to the ***PROP_SEG***.Where the ***ROUND_UP*** returns the argument rounded up to next integer value.

$$PROP\_SEG + PHASE\_SEG1 > PHASE\_SEG2 \quad (4.6)$$

$$PROP\_SEG + PHASE\_SEG1 > t_{PROP\_SEG} \quad (4.7)$$

$$PHASE\_SEG2 > SJW \quad (4.8)$$

There are several requirements for choosing the CAN bit timing segments as shown in equations 4.6. Where the SJW (Synchronization Jump Width) adjust the bit clock to maintain synchronization.

$$\boldsymbol{Af} = \boldsymbol{V}\text{-}^\wedge(4.9)$$
$$\boldsymbol{JN}$$

$$^{(2}\bullet{}^{A}\boldsymbol{f}^{)}\bullet{}^{10}\bullet \mathrm{t}\boldsymbol{NBT} < \boldsymbol{t_S jw}\ ^{(4}.^{10)}$$

$$^{(2}\bullet{}^{\mathrm{Af})}\bullet{}^{(1}3\bullet{}^{t}{}_{N}\mathrm{BT}\,{}^{-}\,{}^{t}\mathrm{PHASE\ \_SEG\ 2}^{)} < \boldsymbol{MIN}^{(t}\mathrm{PHASE\ \_SEG\ 1}< {}^{t}\mathrm{PHASE\ \_SEG\ 2}\ ^{)\,(4}.^{11)}$$

Where $\boldsymbol{Af}$ is the total CAN system clock tolerance, where $\boldsymbol{f}$ is the actual frequency and $\boldsymbol{f_N}$ is the nominal frequency. To guarantee effective communication, system frequency of each nodes must be in specified frequency tolerance to be able to receive and transmit every message correctly. Real systems must operate in the electrical noise which may induce errors on the CAN. While an error being dedected, error flag is transmitted on the bus. An error flag from an error active node consists of 6 dominant bits, and there could be up to 6 dominant bits before the error flag. If there is an error occured on the bus, a node correctly sample the 13th bit after the re- sysnchronisation as shown in the equation 4.10 and 4.11.

The length of the CAN network depends on the distance between multiplexed antennas. However, taken into consideration the power loss of the antenna cables in long distances, CAN nodes should be placed as close as possible to each other. According to the standard chart in Figure 3.1 (Chapter 3) the maximum data transfer rate of 1 Mbps can be achieved using 40 meter long cable. CAN bit segments are calculated for the following system constraints;

- Bit rate: 1Mbps
- Bus length: 40m
- Bus propagation delay : 5ns/m (CAT5 cable) **o**

Oscillator frequency: 30 MHz **o** Physical interface

propagation delay: 175ns Calculated bit segments:

NBT: 15 PROP

SEG: 5

PHASE_SEG1: 6

PHASE_SEG2: 3

SJW: 1

Oscillator Tolerance: 0.78 %

4.2 Main Controller Node

The main controller node acts as the interface between digital outputs of the RFID reader and the CAN network, shown in the Figure 4.1. The user can only interact with the main controller to control the rest of the network. To be able to send standard CAN messages the main controller unit has two ICs onboard, the dsPIC30F4012 DSC with integrated CAN and MCP2551 High Speed CAN transceiver. The DSC is responsible for converting digital input states to the single CAN messages and transferring it to the other nodes.

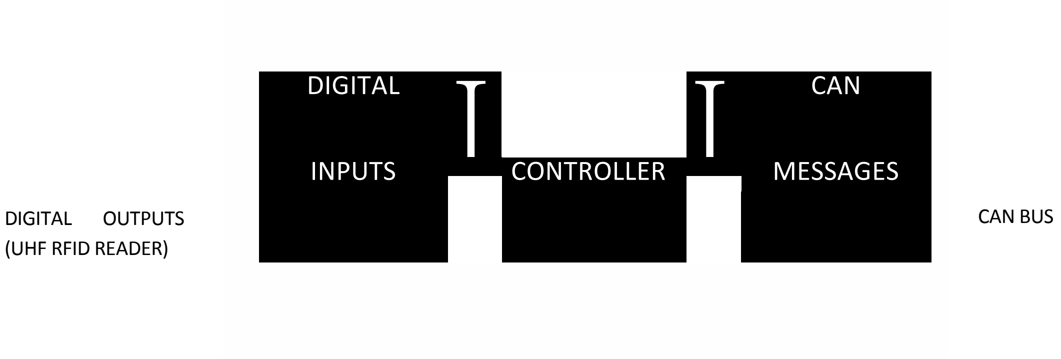


Figure 4.2 : CAN main controller node block diagram.

4.3 Multiplexer Node

For the multiplexer node, the same IC structure is used as in the main controller node. As shown in the Figure 4.2, all multiplexer nodes have same configurations except dip switches settings. Dip switches are used for adressing the stages when multiplexer nodes are cascaded.

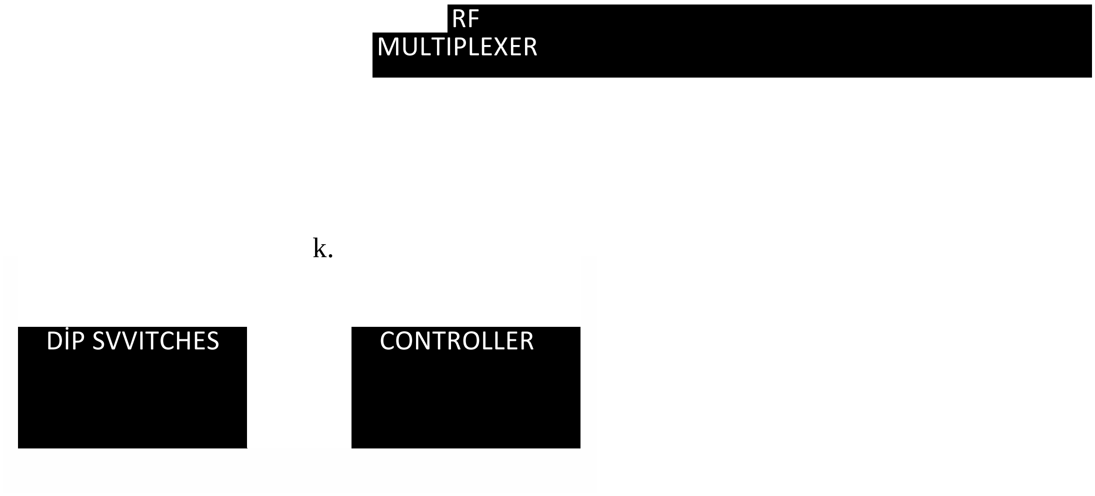


Figure 4.3 : CAN multiplexer node block diagram

Dip switch positions of all multiplexing nodes must be the same if they are connected to the same stage. Each CAN multiplexer node receives the same message which are sent from the main controller node. The message contains antenna switching commands for all nodes. The message processed in every node by their dip switch adresses and related two bits are used for switching the antenna channels.

This addressing method between stages makes the system more simple and configurable. The multiplexer system is easily expandable by adding external nodes. Moreover, bus load and traffic on CAN have been significantly decreased with using a single message to control all nodes.

4.4 Operating Methods of CAN Based Antenna Multiplexer System

Antenna multiplexer system allows cascaded multiplexer connection. Each multiplexing node is able to switch 4 antenna channels. As shown in the Figure 4.3, maximum 16 antenna can be multiplexed by using 4 multiplexer node and 1 main controller node.

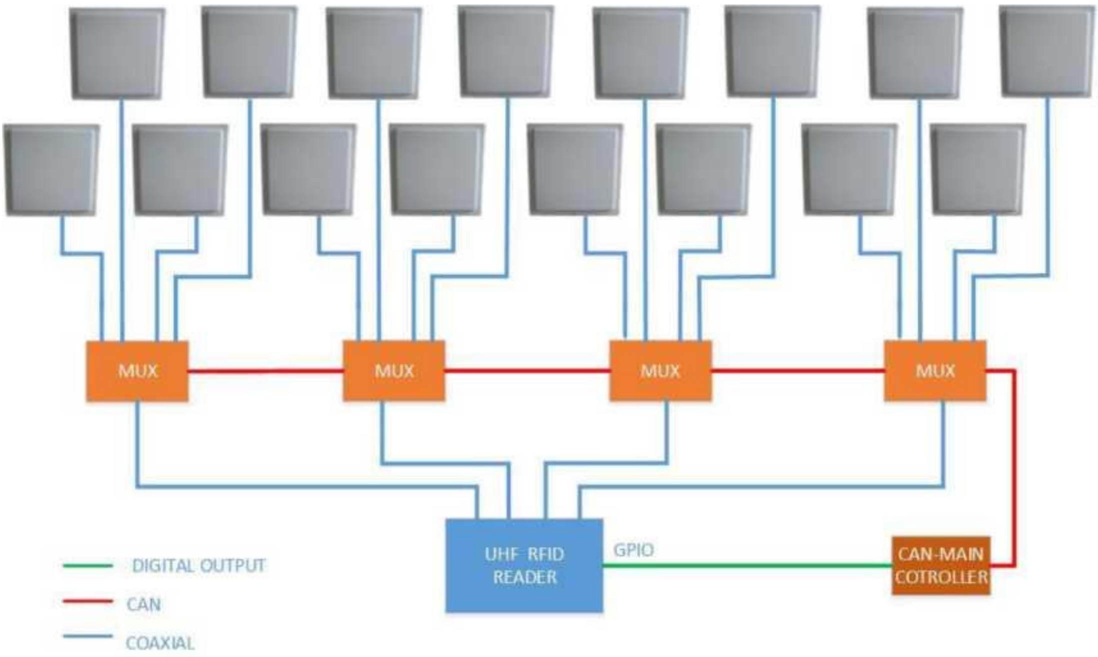


Figure 4.4 : Basic configuration of multiplexers

In cascaded two-stage multiplexer network, dip switch state values of each stages have to be different. Whereas every node in the same stage has to have same dip switch state values. As shown is the Figure 4.4, the system has the capability of multiplexing up to 64 antennas by using 20 multiplexing node and 1 main controller node.

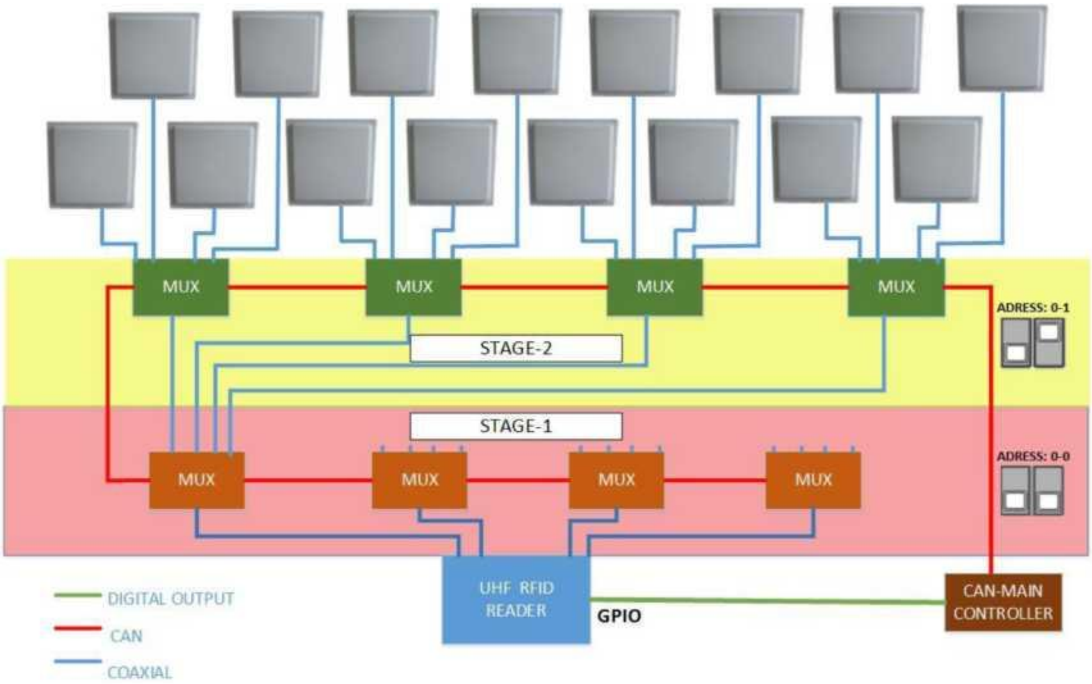


Figure 4.5 : Cascaded two-stage configuration of the multiplexers

As shown in the Figure 4.5, cascaded three-stage multiplexer network has the capability of multiplexing up to 256 antenna channel by using 84 multiplexing node and 1 main controller node.

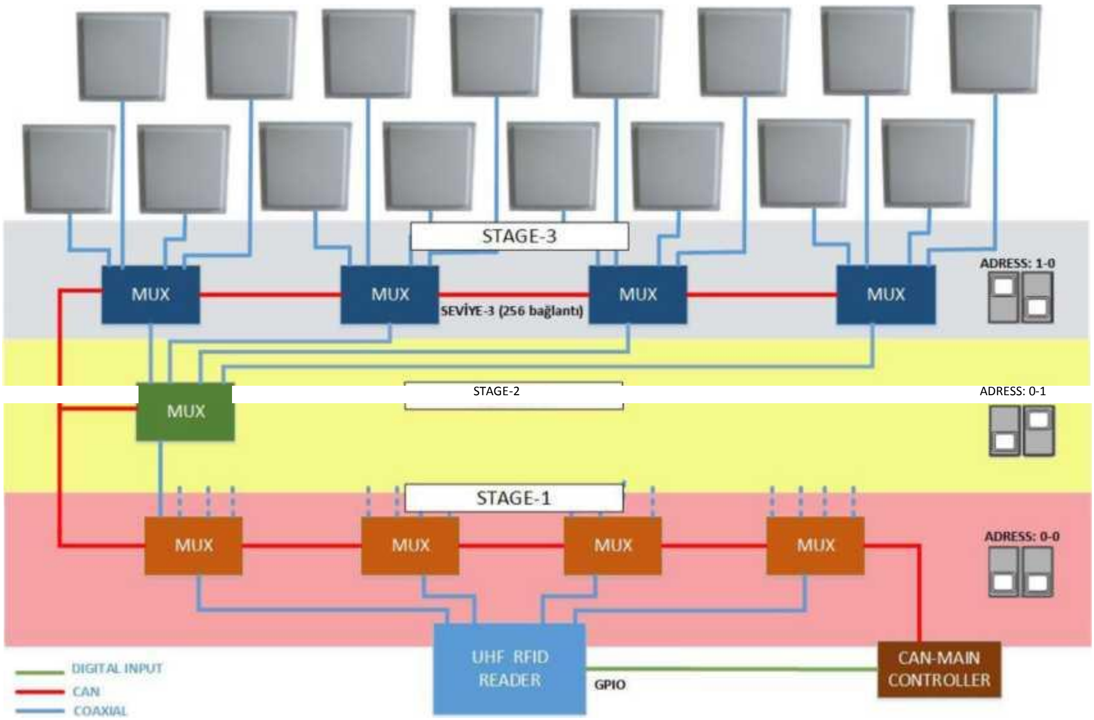


Figure 4.6 : Cascaded three-stage configuration of the multiplexers

5. IMPLEMENTATION OF THE SYSTEM

In this chapter of study, first, hardware design of CAN based antenna multiplexing system is described in three parts: main controller node, multiplexer node and RF switch unit. Then, implementation of the embedded software is introduced for main and multiplexer CAN nodes.

5.1 Hardware Design

As discussed previously in Chapter 4, CAN based system has been designed to control UHF RFID antenna multiplexers. To succesfully control the antenna multiplexer parts of all nodes, hardware must be designed specifically to satisfy the invidual needs of each node, while software which meets the CAN protocol criteria controls each node. The advantages of implementing CAN bus on the UHF RFID antenna multiplexer as follows ;

- Easy installation of devices on to the bus
- Error dedection and fault confinement
- Real time performance
- Robust in noisy environments
    - Does not effect the operation of the bus if a particular node breaks down
- Decreased wire harness

There are two types of CAN based control nodes have been designed. CAN main controller node acts as a bridge between GPIO unit of the UHF RFID reader and the CAN network. It converts I/O signals to the CAN messages. CAN multiplexer node receives incoming messages from the main controller node and switchs the antenna channels. First, two types of CAN nodes and RF switch unit have been designed and prototyped. Then, designed CAN based control parts has been integrated with the UHF RFID antenna switching unit.

In the design of CAN nodes and the RF switch unit, the following basic design principles were applied;

- Double sided pcb were used, with the ground plane on both top and bottom sides. This reduces the ground inductance within the circuit, thus minimizing self generated ground noise and EMC emissions from the circuit.
- Components onboard were placed as close as possible to each other in order to minimize the length of track used, thus, minimizing stray inductances.
- All ICs throughout to the network have decoupling capacitors to filter out the noise. To avoid capacitive coupling by ensuring that each circuit has its own decoupling capacitor which placed as close to the port being decoupled to ground as possible.
- To reduce reflection and losses, impedance of the traces in RF switch circuit matched to 50 ohms.

5.1.1 Main controller node

The detailed block diagram of the main controller node construction is shown in Figure 5.1. This block diagram shows the interconnections between various parts within the main controller node.

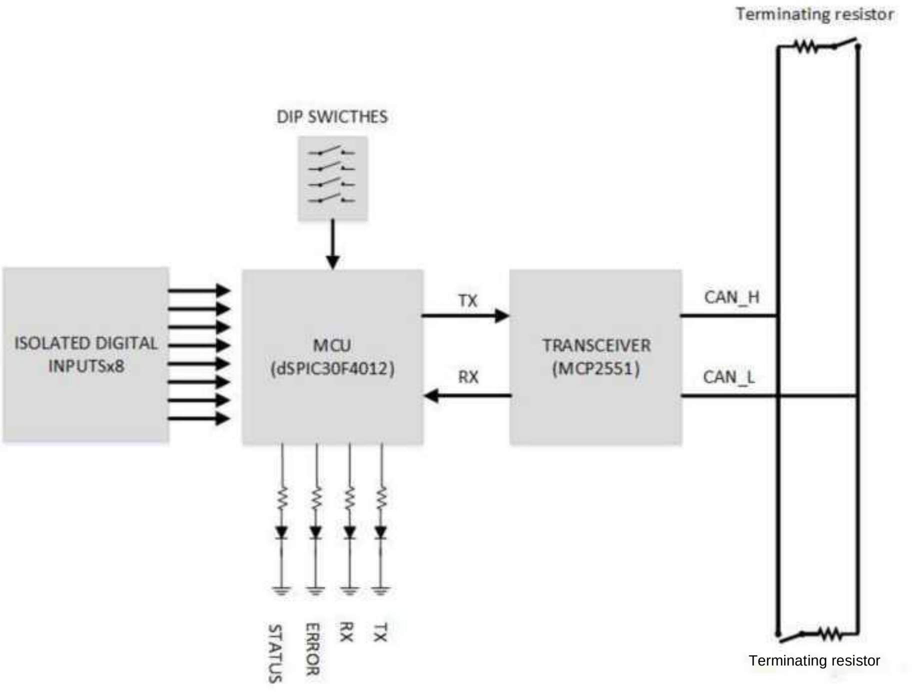


Figure 5.1 : Main controller node block diagram.

As mentioned in the previous chapter, the main controller node acts as an interface between the GPIO unit of the UHF RFID reader or any digital I/O control unit such as PLC, digital output modules and the rest of the multiplexer nodes connected to the network. Each opto-isolated 2 digital inputs control the one layer if multiplexer nodes are cascaded.

There are several CAN controllers available on the market. Some are available as stand-alone chips; however the most common option is that of a CAN controller integrated in a microcontroller unit, with a processing core, memory, and other devices. For the purpose of time predictability, controllers from Microchip exhibit the most desirable behavior. Microchip CAN controllers provide three transmission buffers, and the peripheral hardware selects the buffer containing the message with the lowest ID (the highest priority message) for attempting a transmission whenever multiple messages are ready. Furthermore, in those controllers, message preemption is always possible with the following behavior: the pending transmission communications are immediately aborted but the on-going communication will be terminated normally, setting the appropriate status flags (Natele et al., 2008).

The microcontroller for the main control unit is chosen from the Microchip dsPIC30F digital signal controller series. dsPIC30F microcontrollers are using in suitable for many applications such as motor control, power conversion and monitoring, internet connectivity, speech and audio processing, sensor control and automotive.The block diagram of dsPIC30F4012 is given in A.1.

The CAN controller unit of was implemented according to the specification of ISO 11898. It allows communication of messages in both standard identifier (11 bits) and extended identifier (29 bits). The CAN controller unit of dsPIC30F4012 provides registers for the configuration of the connection to a bus with given characteristics, including the selection of the bit rate, the bit sample time. The CAN controller unit also provides the functionality for managing all the aspects of the CAN protocol, including the management of the transmission modes and the handling of the bus off state. Moreover, the CAN controller unit offers a number of data registers for holding messages for outgoing transmissions and incoming data, and provides support for message masking and filtering on reception.

Each node on the bus has to have MCP2551 device to convert the digital signals generated by a CAN controller to signals suitable transmission over the bus cabling. The MCP2551 is used as CAN transceiver that serves as the interface between a CAN protocol controller (MCU) and the physical bus. The MCP2551 provides differential transmit and receive capability for the CAN controller and is fully compatible with ISO 11898 standard. It also provides a buffer between the CAN controller and the high voltage spikes that can be generated on the bus by outside sources (EMI, ESD, etc.) (Microchip Inc., 2013)

The Error led is used to indicate that an error has occured within the CAN network andthe status led indicates the status of the node if the node is working properly. RX and TX leds blink in every transmit and receive interrupts.

Dip switches used for activate or de-activate 120 Ohm terminating resistors for CAN bus. For high-speed CAN, both ends of the pair of single wires (CAN_H and CAN_L) must be terminated. This is because of communication that flows both ways on the bus. The termination resistors on a cable should match the nominal impedance of the cable. ISO 11898 requires a cable with nominal impedance of 120 ohms, and therefore 120 ohm resistors should be used for termination (National Instruments, 2013). If multiple devices are placed along the cable, only deviceson the ends of the cable need termination resistors as shown in the Figure 3.1. in Chapter 3. In this work, standart CAT5 type cable is used because of lower cost. Characteristic impedance of CAT5 cable is 100 ohms and it is close to the standard CAN cable’s impedance (100-120 Ohms).

PCB layouts and prototype version of the main controller node is shown in Figure 5.2, 5.3 and 5.4 respectively.

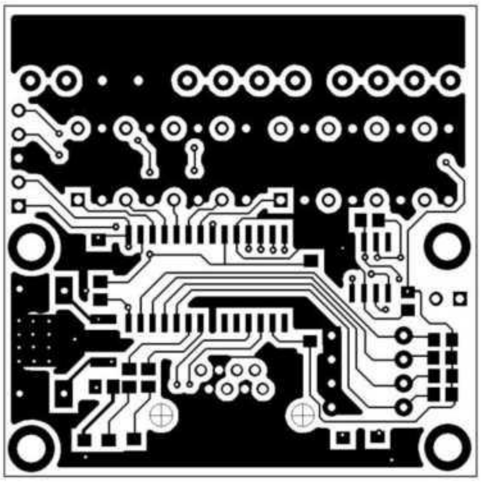


Figure 5.2 : Top layer of the main controller node.

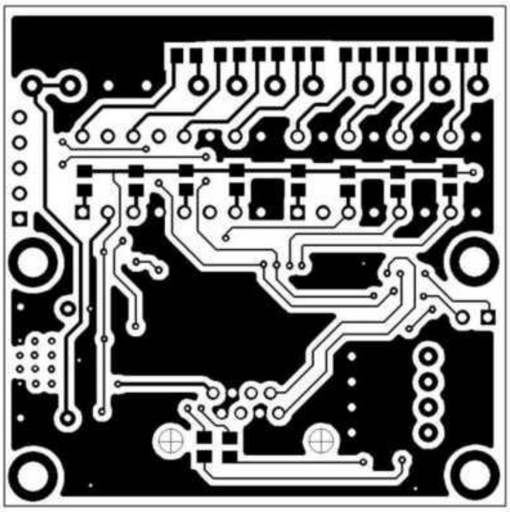


Figure 5.3 : Bottom layer of the main controller node.

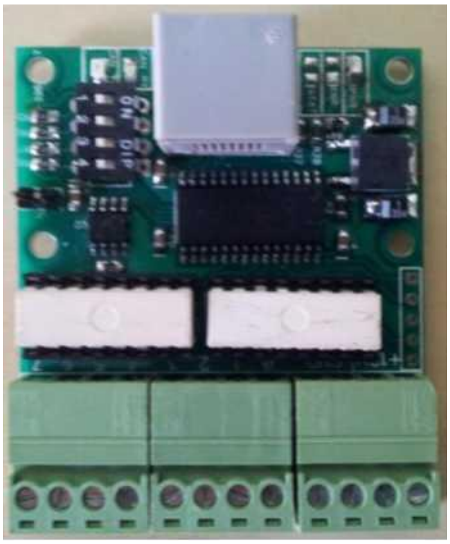


Figure 5.4 : Main controller node.

5.1.2 Multiplexer node

The CAN multiplexer node is responsible for controlling four antenna channels on RF switching unit. This node listens all CAN messages are sent from the main controller node and switchs the antenna channels. The block diagram in Figure 5.3 shows the general construction of this node. The overall construction of this node is similar to the main controller node described in previous section.

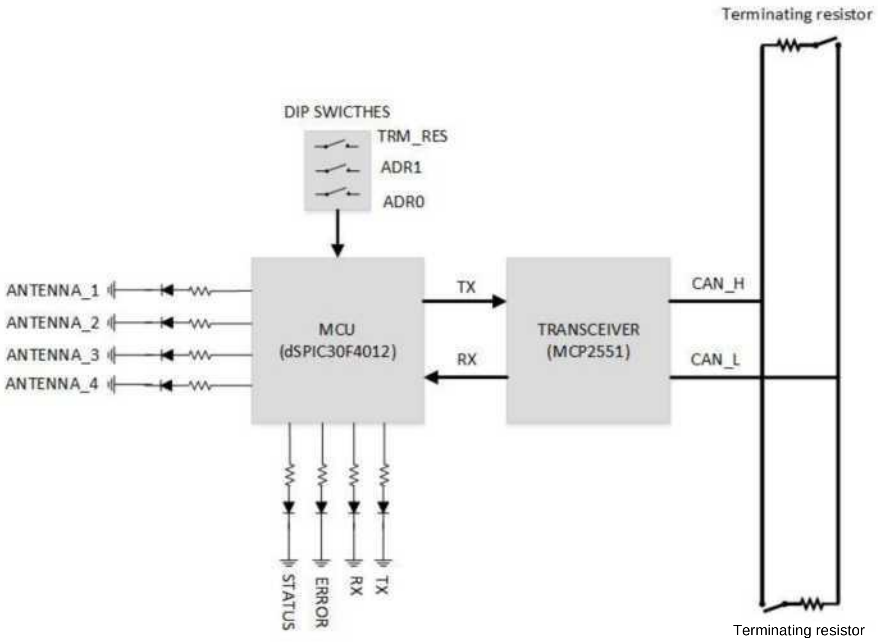


Figure 5.5 : Multiplexer node block diagram.

This node uses a dsPIC30F4012 microcontroller and MCP2551 CAN transceiver same as main controller node. Dip switches address the stages if multiplexer nodes are cascaded. First 2 bits are used for addressing as shown in the Table 5.1. Third bit of dip switch is used to activate or de-activate terminating resistor.

Dip Switch	Stage
01	1
10	2
11	3

Table 5.1 : Dip switch setting by stage.

The Error, Status, Tx and Rx leds provide same functions as the main controller node. Antenna leds indicate the switched antenna channel on the multiplexer node. PCB layout and prototype version of the multiplexer node are shown in the Figure 5.4, 5.5 and 5.6 respectively.

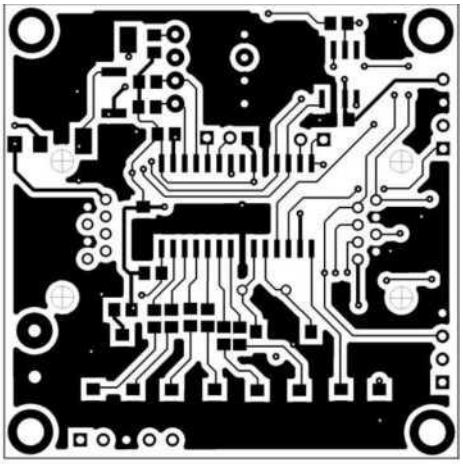


Figure 5.6 : Top layer of the multiplexer node.

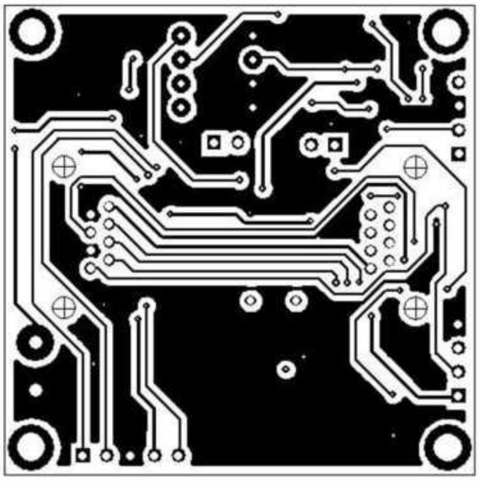


Figure 5.7 : Bottom layer of the multiplexer node.

Figure 5.8 : Multiplexer node.

As described in the CAN connector pin assigment document (CiA, CiA DRP 303-1, 2001)RJ45 pins are connected as shown in the Table 5.2.

Pin	**Signal**	**Description**
1	CAN_H	CAN_H bus line (dominant high)
2	CAN_L	CAN_L bus line(dominant low)
3	CAN_GND	Ground / 0 V /V-
4	-	Reserved
5	-	Reserved
6	CAN_SHLD	Optional CAN Shield
7	CAN_GND	Ground /0 V /V-
8	CAN_V+	Optional CAN external positive supply (dedicated for supply oftransceiver and opto-couplers, if galvanic isolation of the busnode applies)

Table 5.2 : RJ45 pin assigment.

5.1.3 RF switching unit

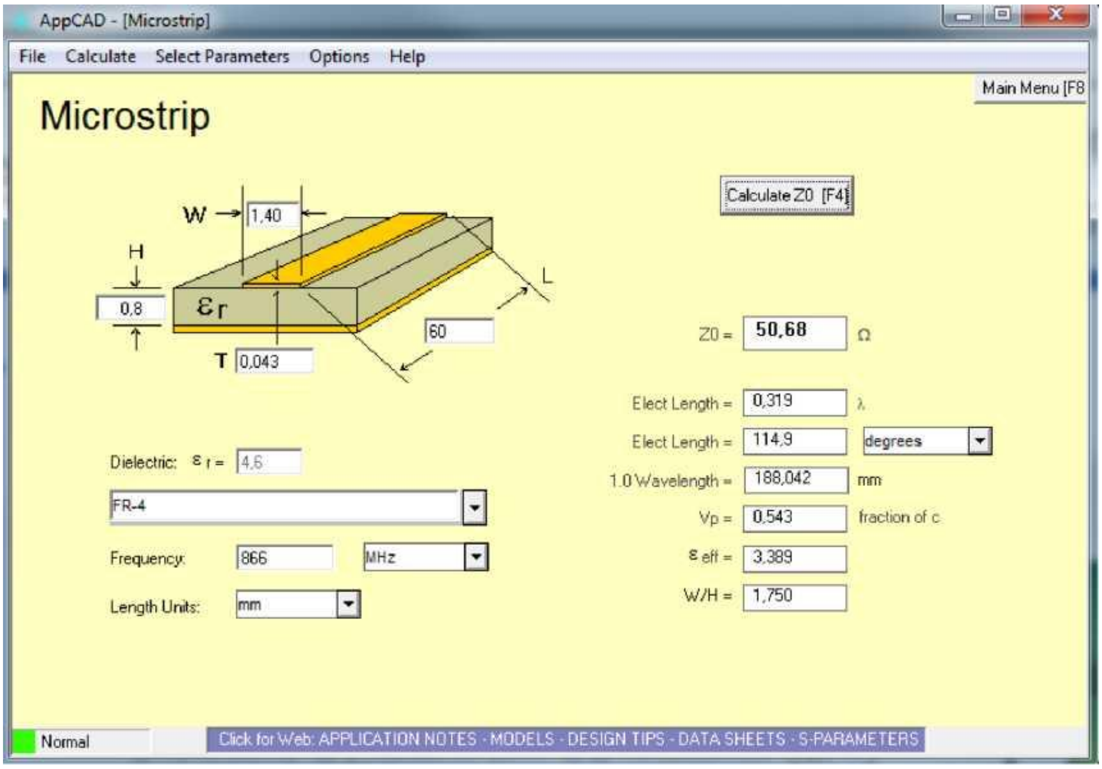
The RF switchingunit is responsible for multiplexing the antenna channels. This function is provided by RF3024 GaAs pHEMT single-pole double-throw (SPDT) RF switch ICs (300kHz-4GHz) that used for general purpose switchning applications which require very low insertion loss, moderate isolation and medium power handling capability(RFMD, 2013).For each RF switch circuit, three RF3024 IC were used to multiplex antenna channels. Each ICs has two control lines which are driven by the MCU. The truth table of control settings is given in Table 5.3.

V1	**V2**	**RFC-RF1**	**RFC-RF2**
1	0	ON	OFF
0	1	OFF	ON

Table 5.3 : Switch control settings.

While designing the RF circuit, microstrip transmission lines were used and the characteristic impedance of the PCB traces matched to 50 ohm. The width of the traces were calculated with the following parameters by using the “AppCAD” tool provided by Agilent Technologies as shown in Figure 5.9.

- Thickness of dielectric material (H)
- Length of Trace (L)
- Height of Trace (T)
- Dielectric Constant of PCB Material (ε_r)



W 1,40

H 0,8

T 0,043

L 60

Dielectric: εr = 4,6

FR-4

Frequency: 866 MHz

Length Units: mm

Z0 = 50,68 Ω

Elect Length = 0,319 λ

Elect Length = 114,9 degrees

1.0 Wavelength = 188,042 mm

Vp = 0,543 fraction of c

ε eff = 3,389

W/H = 1,750

Figure 5.9 : AppCAD tool for microstrip transmission line calculations.

The RF switching unit has also LM2575 T5.0 input range from 12V to 48V DC voltage regulator, TLP-521 optocoupler, PIC16F series microcontroller for LEDs. PCB layout and prototype version of the RF switch unit are shown in Figure 5.10 and 5.11.

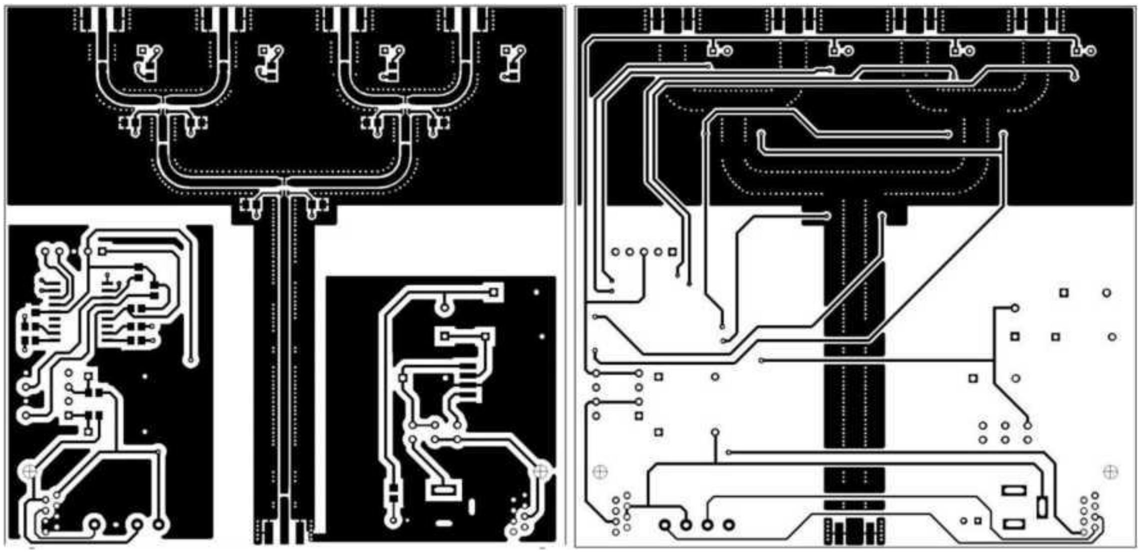


Figure 5.10 : Top and bottom layers of RF switching unit.

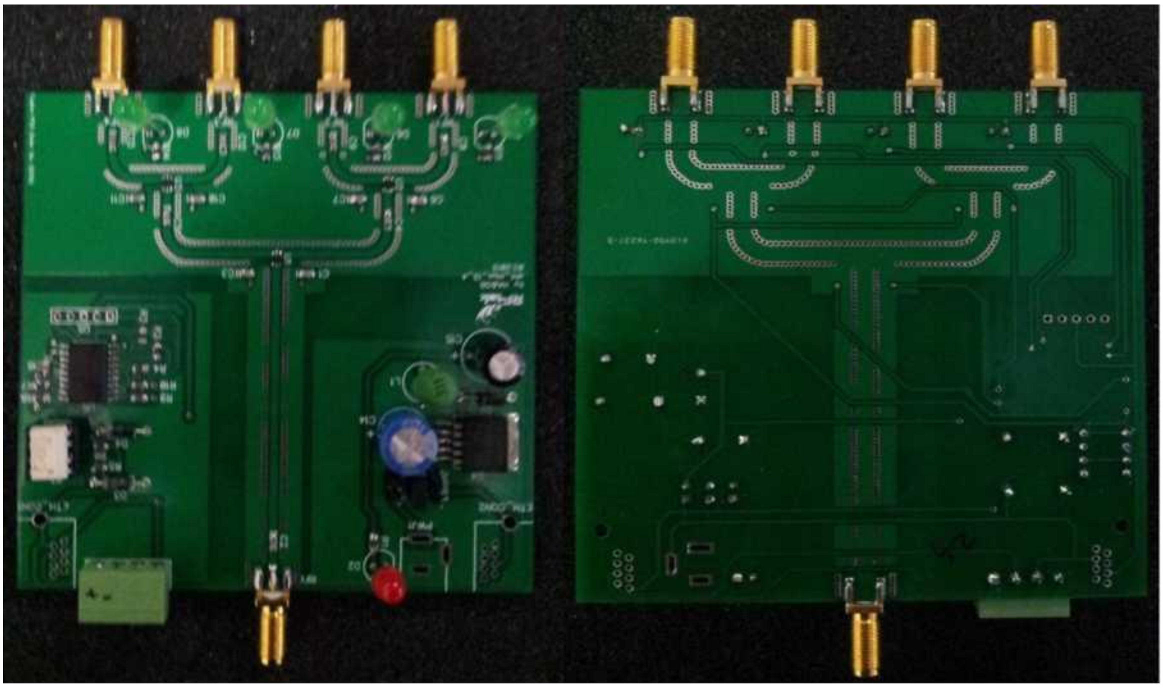


Figure 5.11 : RF switching unit.

5.2 Software Design

The embedded software for the CAN nodes is written in C (C30 Compiler) and installed onto the MPLAB X IDE. This section describes the method used in programming the CAN control system for the main controller and the multiplexer node.

5.2.1 Software methodology

A CAN communication system requires the implementation of a protocol stack from the application-level programming interface, down to the hard-ware implementation of the Medium Access Control and Logical Link Control layers inside the CAN control unit as mentioned in Chapter 3. Several properties of the communication, including latencies of messages, with possible priority inversions depend on the design choices at all levels including the hardware architecture of the CAN controller such as available number of message buffers and their management. The CAN control unit is the (hardware) component that consists of dsPIC30F microcontroller and external CAN transceiver IC and also responsible for the physical access to the transmission medium. It provides registers for the configuration of the connection to a bus with given characteristics, including the selection of the bit rate, the bit sample time. The control unit also provides the functionality for managing all the aspects of the CAN protocol, including the management of the transmission modes and the handling of the bus off state. The controller offers a number of data registers for holding messages for outgoing transmissions and incoming data, and provides support for message masking and filtering on reception.

The software part of the CAN controller unit is responsible for several tasks related to the low-level transmission of the messages. It also initializes the CAN controller, performs the transmission and reception of individual messages. The software part of the CAN controllerincludes several functions as follows:

- Initialization and restart of the microcontroller registers both after power-on and after bus-off.
- Transmission of messages, providing for the transmission of a single message, and the handling of errors.
- Reception of messages, both by interrupt or polling, with filtering and several queuing options on the receiving side.
- Other functions, including mode management, sleep states and wakeups.

There are different software implementation options based upon the applications requirements. In general, on the transmission side, the messages that need to be sent is put in a priority based software queue. The queue, sorted by message identifier (priority) if there are multiple messages as described in Chapter 3. The most common implementation methods are polling and interrupt based management of transmissions.

In interrupt based method, if buffer is empty, it is filled with the message data, otherwise the message is queued. If multiple messages are available with different message identifiers, messages are sorted by their identifiers. When a message wins the contention and leavesbuffer, the buffer becomes empty and an interrupt is triggered. Messages are dequeued by the interrupt handler, executed in response to the interrupt signal. The interrupt handler selects the message on top of the queue (the highest priority message) as the one that has to be placed into the peripheraltransmit buffer.

In polling based method, messages are queued as in the interrupt based method. In addition, transmission task is activated periodically. When a message is transmitted, the next message in the queue is not immediately fetched to replace it. Only when the period of the polling task expires, it checks if the buffer is empty. If the buffer is empty, it fetches the highest priority message from the queue and transfers it into the available buffer. In this case, the typical behavior is that the transmission of messages from the same node is separated by a time interval approximately equal to the period of the polling task.

On the receive side, the reception of a message triggers the receive interrupt.The interrupt sub-routine compares the incoming message with the existing one. Depending on the result of the comparison, a special flag associated with the message to indicate when new values are available. Than the interrupt sub-routine copy the message to the receive buffer(Di Natale, 2008).

In CAN based controller nodes of the UHF RFID antenna multiplexing system it was decided to implement interrupt based method since thesimplicity and predictable performance. In addition, in many CAN based systems, CAN nodes sent the acknowledgement message to the main node to confirm their presence and functionality. The reason of implementing the CAN control system in this way is to dedect if any node is missing. If a node was disconnected for some reason or completely shut down, then when a command message is issued by themain controller to that node, the node would not respond with an acknowledgement message, whichwould prove that the node is missing, and an error would be issued.Taking into consideration of the application needs of the CAN control system of the UHF RFID antenna multiplexing system, the main control node can only dedect if any node is connected to the network by broadcasting a message since the system is expandable by adding external multiplexer nodes.

5.2.2 CAN main controller node software

The main controller node software flow chart is shown in Figure 5.9. On power-up the registers within the microcontroller are initialised. This process involves setting up all the CAN registers, baud rate configurations and I/O pins of the microcontroller as either inputs or outputs depending on their function.

After the initialisation process is completed, the program enters the “node check” modeand broadcast a message to the network to dedect if any multiplexer node is connected. Then, the system constantly monitors the CAN bus for messages to be recived. At this point either an acknowledgement or an error message is expected in response to the sent message. If the node does not reply to the message after it being sent, it assumed that the multiplexer nodes are disconnected from the network and the Error LED switched on and MCU returns to the “node check” message transmission operation.

If an ACK message was received, however, the receive flag is are reset and the program enters the normal operation loop. The MCU starts to read the input pins. When the information is received the MCU checks to see if the received input status has changed from the previous states. If the status has changed, the program enters the “message transmission ” mode and generates CAN command message according to input states to switch the antenna channels that controlled by multiplexer nodes and transmits it onto the CAN bus. This transmission operation is run in the transmit interrupt of CAN. If message is succesfully transmitted, transmmit flag is reset, transmit LED is blinked and the program turn to reading the input pins for the next transmission.

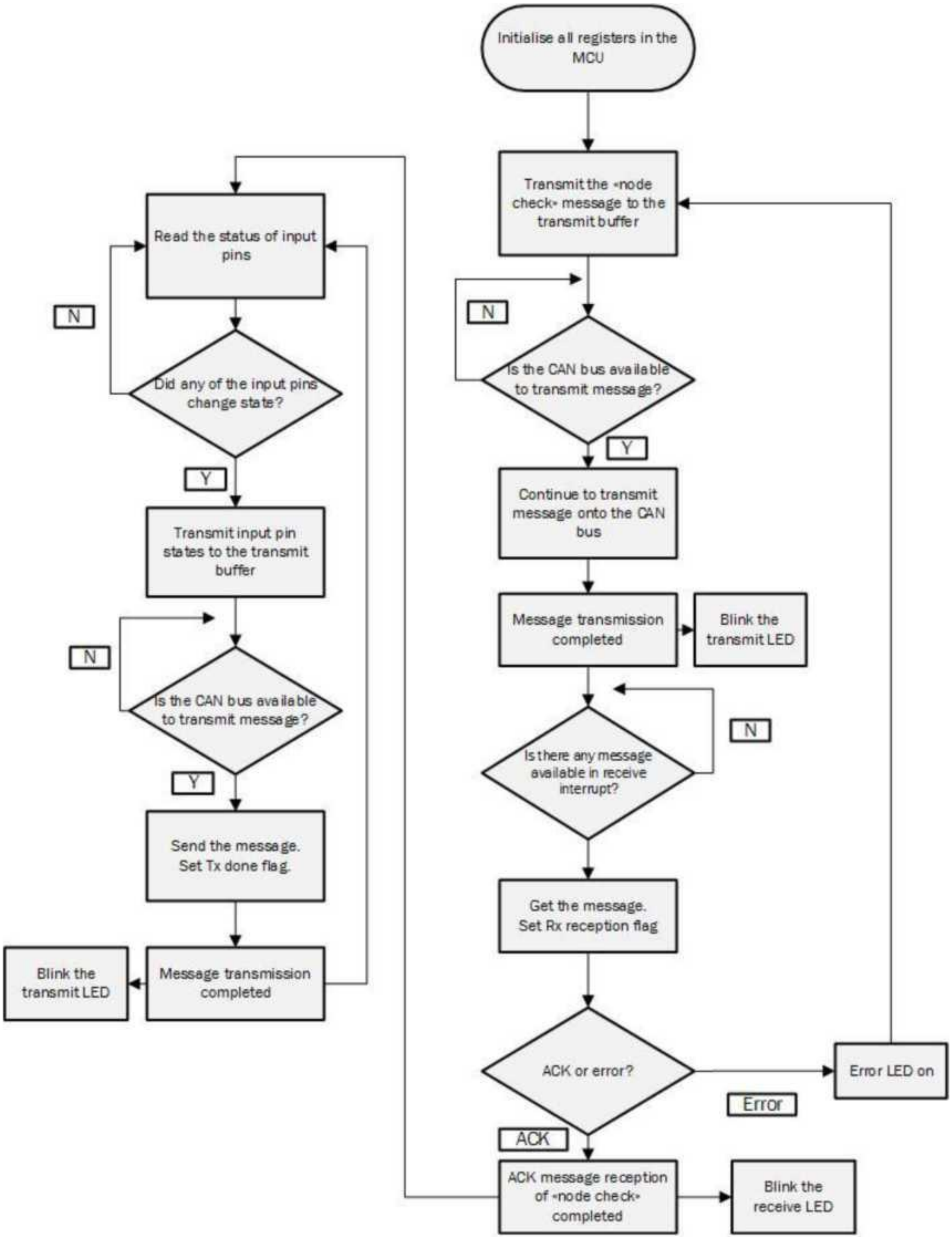


Figure 5.12 : CAN main controller node software flowchart.

5.2.3 CAN multiplexer node software

The multiplexer node software flow chart is shown in Figure 5.10. On power-up the registers within the microcontroller are initialised. This process is similar with the main controller node, it involves setting up all the CAN registers, baud rate configurations and I/O pins of the microcontroller as either inputs or outputs depending on their function.

After the initialisation process is completed, the MCU starts to read the status of the dip switches that used for addressing the multiplexer stages if multiplexers are cascaded. The MCU is then brought to the “Listen to the bus” mode waiting for a command or node check message from the main controller. If a message is available on the bus, it is read and accepted whether its identifier is matched to the filter, otherwise it is discarded and the system returns to listening to the bus mode. Content of the message is processed and decided the type of message. If the message is “Node check” message, acknowledgement is loaded to the transmit buffer and sent to the main controller node if bus is available. Then the program returns to the “Listen to the bus” mode. This step runs only one time after the power-up to inform the main controller node that other CAN nodes are connected to the network.

If the message is “Command” message, states of the appropriate output pins are changed to switch the antenna channels. Content of the message is processed by using the dip switch states.On the other hand, if an error occurs while processing the message such as the message was invalid, Error led is turned on. Then, the system brought back to the “Listen to the bus” mode waiting for its next command message from the main controller.

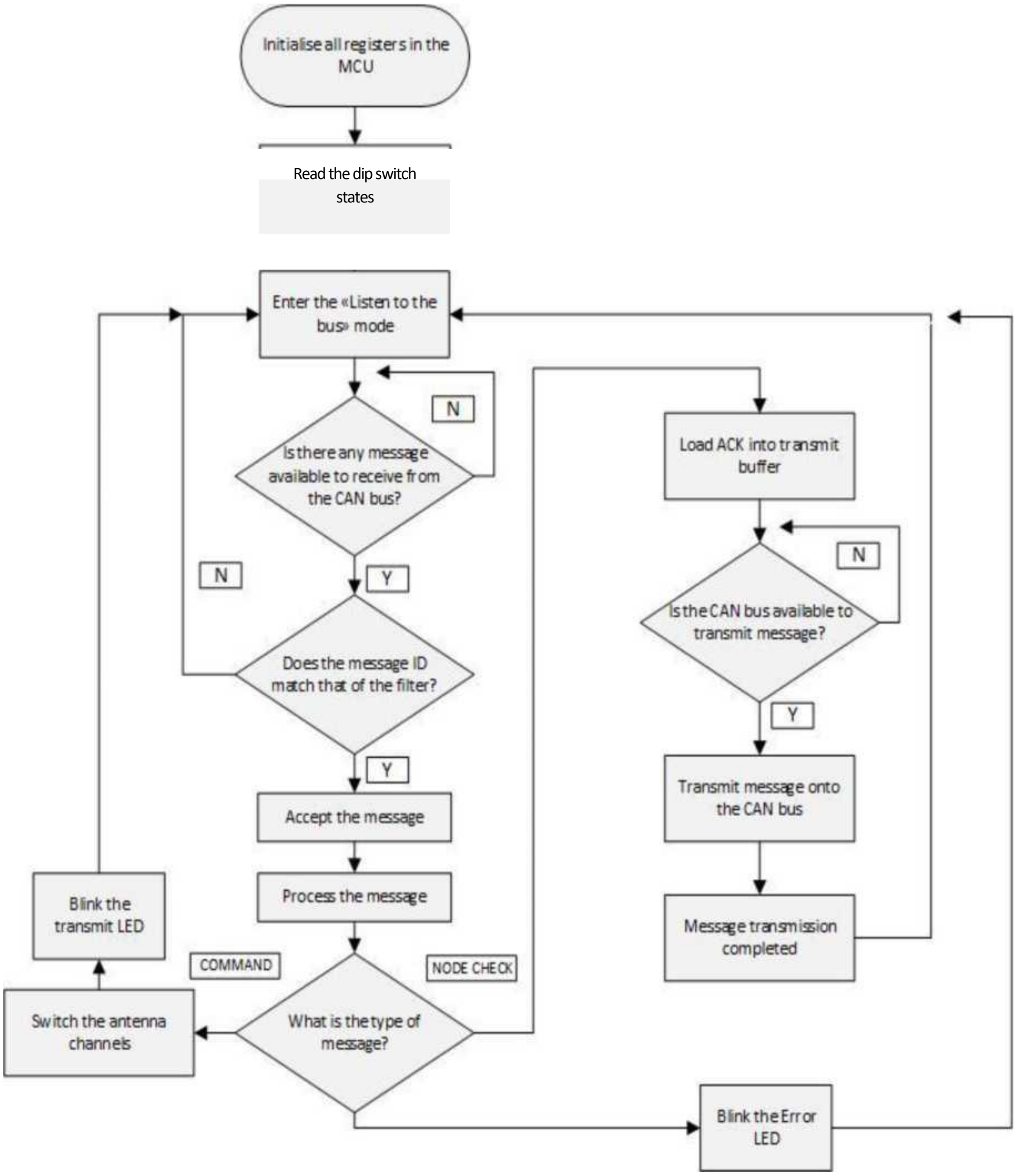


Figure 5.13 : CAN multiplexer node software flow chart.

6. **TESTING AND MEASUREMENT**

The test and the measurementprocesses were characterized in three parts; embedded system tests (CAN communication), RF circuit measurements, and performance test of the system with an RFID reader.

6.1 CAN System Tests

To demonstrate the correct operation of the CAN bus,it must be capable of controlling and maintaining efficiently the network between nodes. Figure 6.1 shows a photograph of the CAN control system that includes four multiplexer and one main controller nodes. All CAN nodes are connected to the CAN bus with standard CAT5 type cable, which is 6 meter length (1.5m x 4).

*jsrrrrrrrrrrrrrrrrrrrrrn***

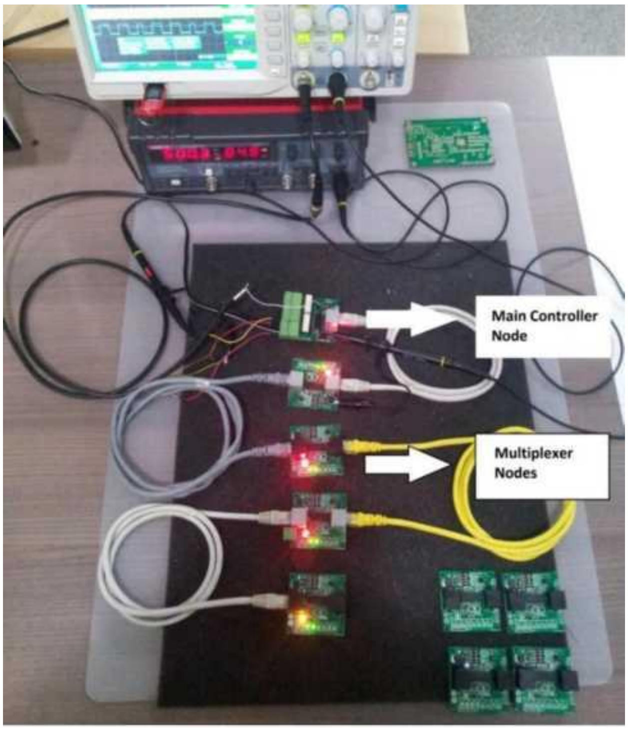


Figure 6.1 : CAN bus testing setup.

As mentioned in Chapter 5, after the initialization, the main controller node sends the node check message and waits for and ACK message as a response. Figure 6.2 shows that a node check message is generated from the main controller and an ACK message is sent back onto the CAN bus for the main controller node to detect and confirm any other nodes that connected to the network.

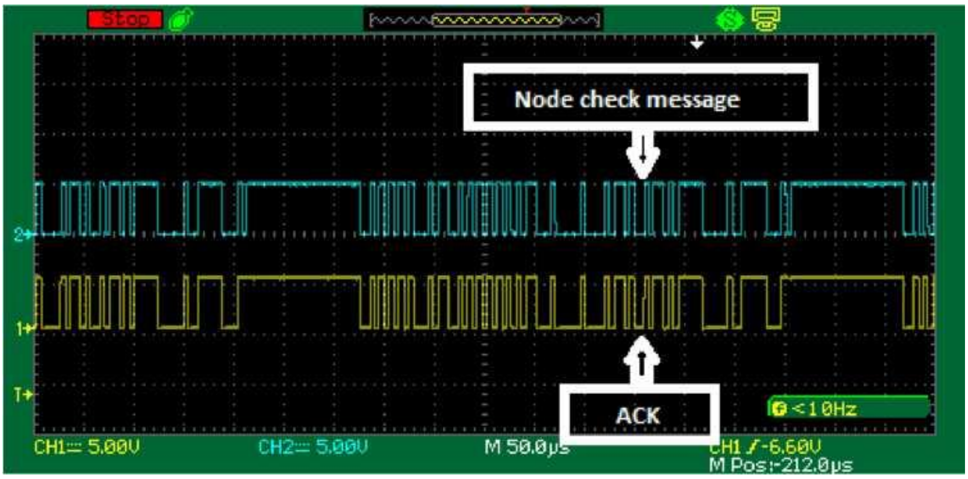


Figure 6.2 : Node check and the ACK messages.

If no ACK message is received, an error is generated in CAN interrupt, and the Error LED turned on as shown in Figure 6.3.

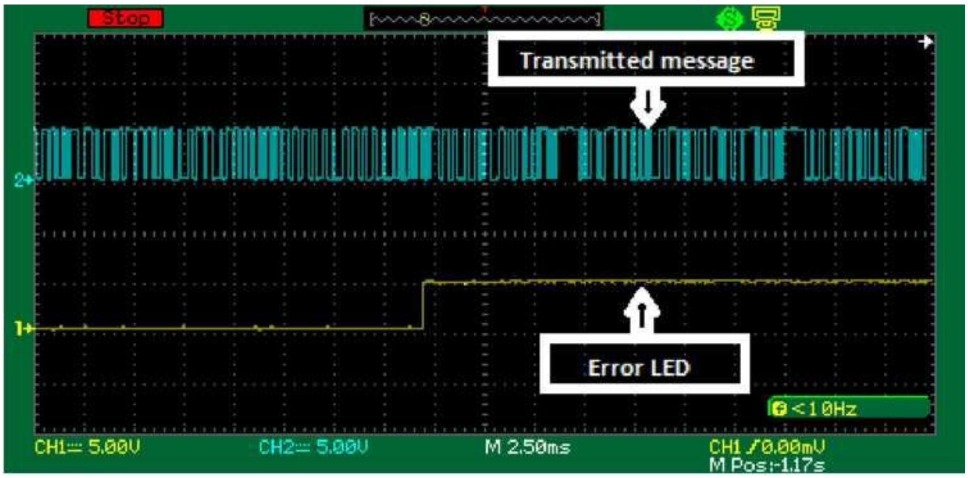


Figure 6.3 : Error LED.

Antenna switching commands are generetad by a function generator. 200 Hz square wave is applied continuously to the opto-isolated inputs of the main controller node. Period of applied signal to the main controller node and switching output of the multiplexer node are as shown in Figure 6.4 and 6.5 respectively.

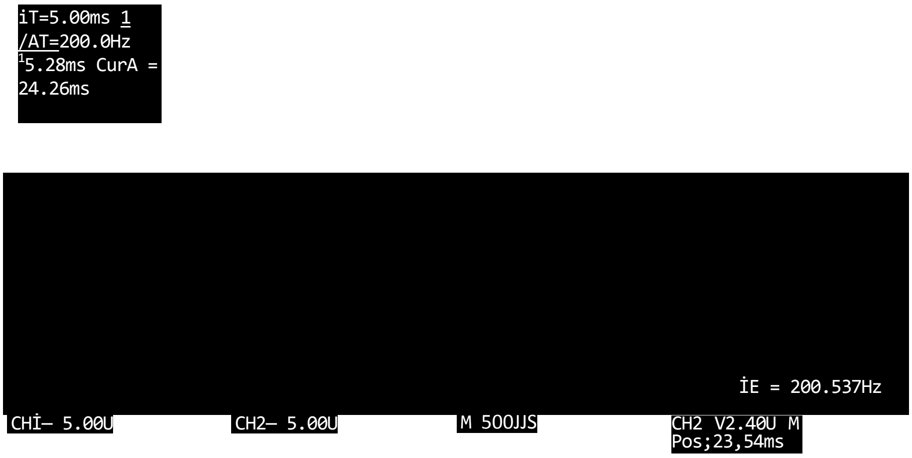


Figure 6.4 : Test signal.

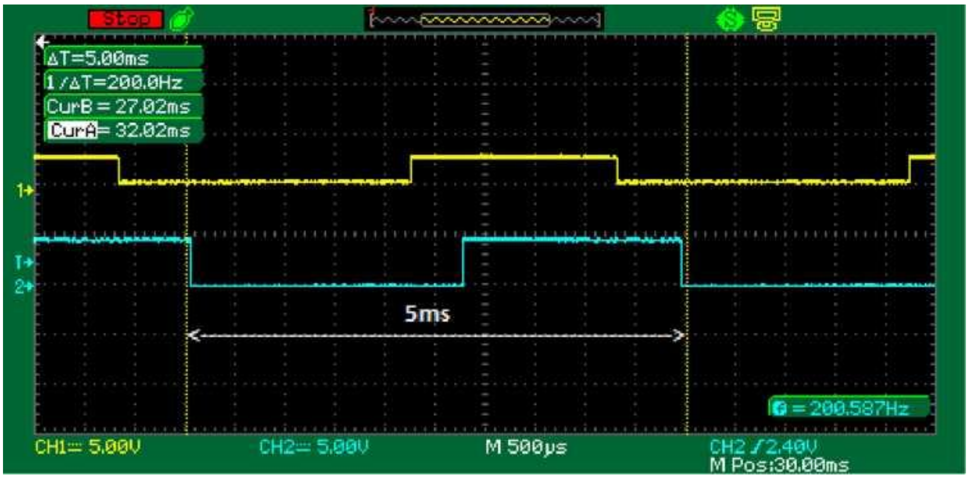


Figure 6.5 : Switch signal.

As mentioned in Chapter 5, at 1Mbps network speed, the propagation delay of the bus is calculated as 410ns from the equation 6.1 with the following parameters.

- Bus Length: 6m
- Propagation delay of the cable: 5ns/m (CAT 5)
- Delay of the physical interface (MCP2551, $t_{Tx} + t_{Rx}$) : 175ns

$$t_{PROP\_SEG} = 2(t_{BUS} + t_{Tx} + t_{Rx}) \quad (6.1)$$

Time delay between the test signal and switch signal is measured as 520us shown in Figure 6.6. The reason of the difference between calculated and measured time delays is software processing duration of CAN nodes. The time delay is very insignificant when the system is used with an RFID reader.

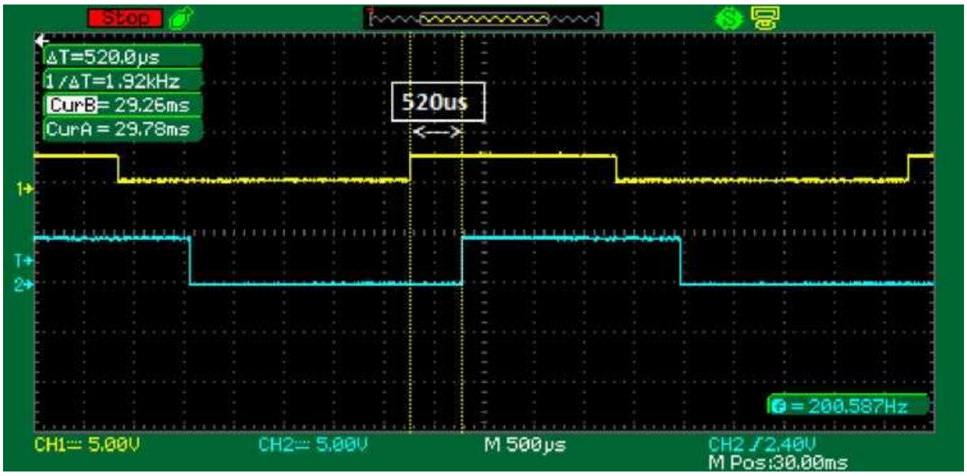


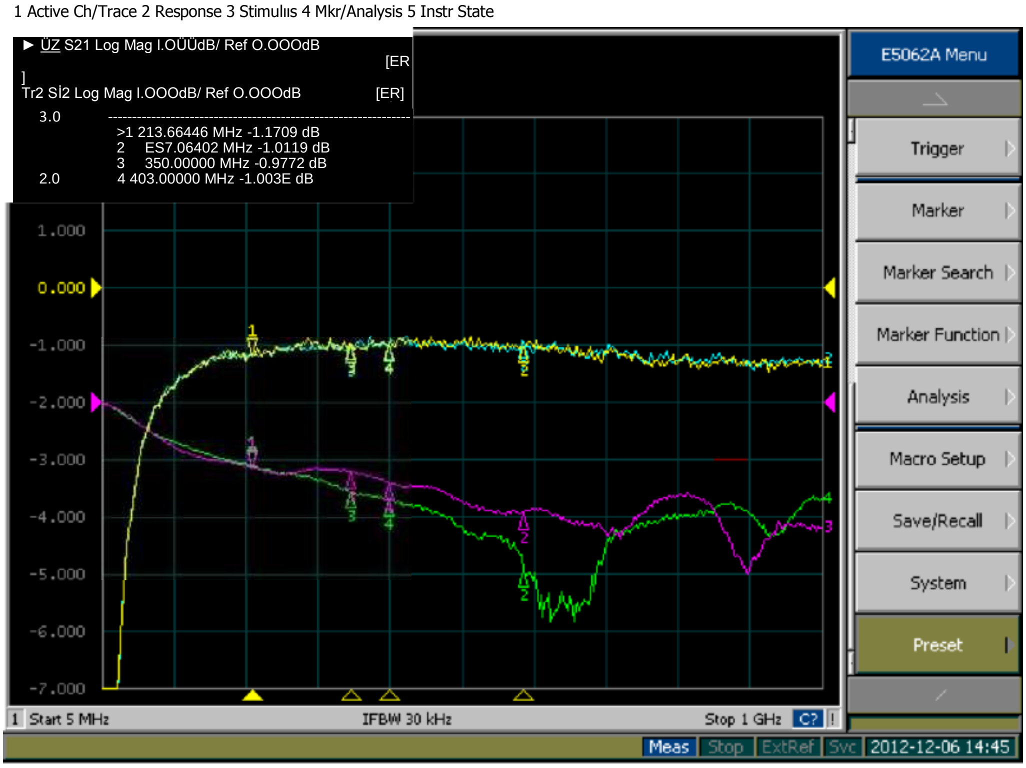
Figure 6.6 : Time delay between test signal and switch signal.

6.2 RF Switching Unit

As defined in equation 6.2, insertion loss measures the power loss and signal attenuation that dependent on operating frequency, microstrip transmission line and on-board component losses of the RF switch circuit.

$$IL = -20log_{10}| 5_{2}1 | d5(6.2)$$

Measurement results are presented in Figure 6.7 and Table 6.1 with 5Mhz steps.



1 Active Ch/Trace 2 Response 3 Stimulus 4 Mkr/Analysis 5 Instr State

```
► ÜZ S21 Log Mag l.OÜÜdB/ Ref O.OOOdB                [ER
]
Tr2 Sl2 Log Mag l.OOOdB/ Ref O.OOOdB                 [ER]
   3.0
          >1 213.66446 MHz -1.1709 dB
          2    ES7.06402 MHz -1.0119 dB
          3    350.00000 MHz -0.9772 dB
   2.0    4 403.00000 MHz -1.003E dB
```

Figure 6.7 : Measured insertion loss.

Frequency	**Insertion Loss**
860 MHz	-1.272 dB
865 MHz	-1.343 dB
870 Mhz	-1.361 dB
875 MHz	-1.313 dB
880 MHz	-1.383 dB
885 MHz	-1.331 dB
890 MHz	-1.443 dB
895 MHz	-1.312 dB
900 MHz	-1.398 dB
905 MHz	-1.294 dB
910 MHz	-1.404 dB
915 MHz	-1.323 dB
920 MHz	-1.399 dB
925 MHz	-1.360 dB
930 MHz	-1.408 dB

Table 6.1 : Measured insertion loss results with 5 MHz steps.

6.3 Performance Test with an RFID Reader

The overall system was tested with a UHF RFID reader prototype (measured output power, 23 dBm) designed by RFtek Electrocis Ltd. and circular antennasfrom Alien Technology (5 dBi). The purpose of this setup is testing antenna channel switching and tag reading operations with multiple antennas. As shown in Figure 6.8, on eof the outputs of the reader was multiplied with 1x4 antenna multiplexer as a first stage. As a second stage, three 1x4 multiplexers were cascaded with the first stage multiplexer and antennas were connected to the both first and second stages. As a result, tag reading operations for each antenna channels weresuccesfully tested for each stage. The antenna connected to the first multiplexer stagehas the reading range of 80 cm and the antennas connected to the second stage have the reading range of 60 cm due to insertion loss of the RF switch circuit and losses of cables between multiplexers.

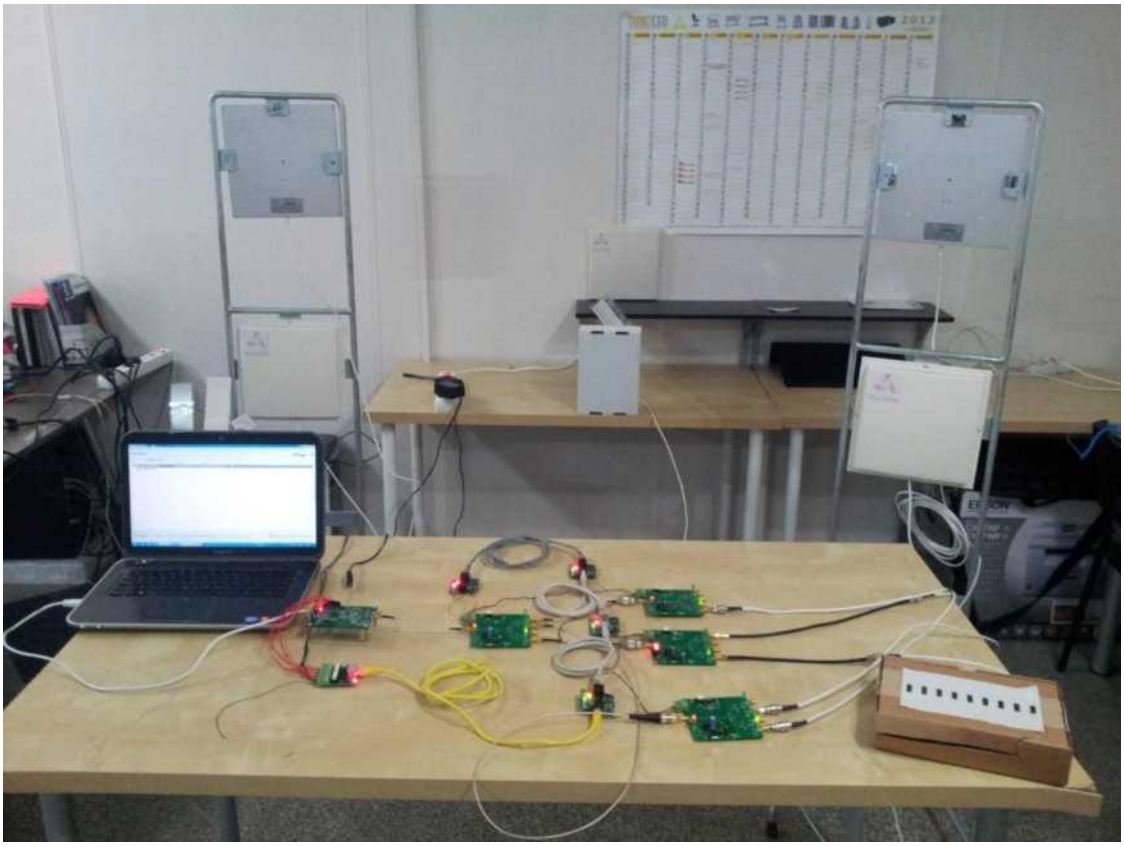


Figure 6.8 : Test setup with an RFID reader.

7. CONCLUSIONS AND FUTURE WORKS

7.1 Conclusions

Primary aim of this thesis is to design a CAN based antenna multiplexing system for UHF RFID applications as a part of Smart Shelf project. Within the scope of this thesis, RF switching unit and two types of CAN based hardware devices has been designed. Main controller node provides bridging operations between GPIO unit of the UHF RFID reader or any external I/O device. Multiplexer node is responsible for switching the antenna channels on the RF switching unit.

The requirements of the project include flexible and scalable hardwares that compatible with all commercial UHF RFID readers and allow cascaded connection of antenna multiplexers,low insertion and return loss on multiplexers, a robust and safe communication between multiplexers even in noisy environments. All the requirements were satisfactorily fulfilled and the system is ready to be used in any Smart Shelf project.

The CAN bus protocol is selected for communication between main controller and the multiplexers since the CAN bus is optimised for systems that need to transmit and receive a relatively small amount of information reliably to all nodes in the network. Since the protocol message based, all multiplexer nodes on the network receive every messages even the cascaded connnection is used. Each node processes different bits of the messages based on their stage addresses. Fast and robust communication with fault confinement is one of the most important advantage of the CAN bus. Faulty nodes will automatically drop off the bus that does not brake down the all communication on the network.

As a result, the system was tested succesfully and some measuremental and experimental results are presented in previous chapter. To verify the correct operation of CAN bus, the overall time delay of the transmission via CAN is fast enough for UHF RFID antenna multiplexing system. Measurement results of insertion is proved that performance of the RF switch circuit is close to the similar UHF RFID antenna multiplexer circuits in the market. The comparision table is given in A.2.

7.2 Future Works

In this thesis, CAN based antenna multiplexer system for UHF RFID applications has been designed and tested.There are number of features which can be added to the designed system.

- RF switching unit and multiplexer node can be re-designed as an integrated structure.
- CAN transceiver would be changed with isolated CAN transceiver in the next design.
- The implementation of the CANopen protocol features can be added to the current CAN Application Layer making the system CANopen compliant. With this feature, the system can be controlled with any CANopen compliant I/O controller.
- Various protocol converters can be added instead of the main controller node such as ethernet, RS232-CAN or USB to CAN.
- Internal power amplifiers can be added to the multiplexer nodes to tolerate the losses of cables.
- Future actions of the system should include additional tests with more antennas. However, it was not possible to test the system with more than 5 antennas. More tests would be required in cascaded configuration with near field antennas. As mentioned before, this thesis is a part of “Smart Shelf Design” project. Near field smart shelf antennas will be designed in the next step of the mentioned project. Therefore, limited performance tests were fulfilled with circular antennas.

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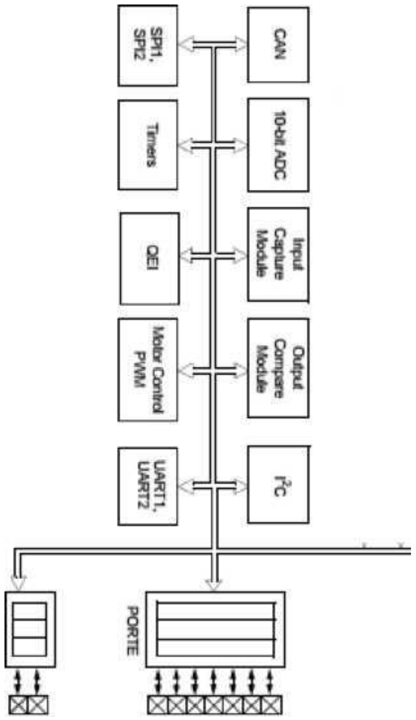
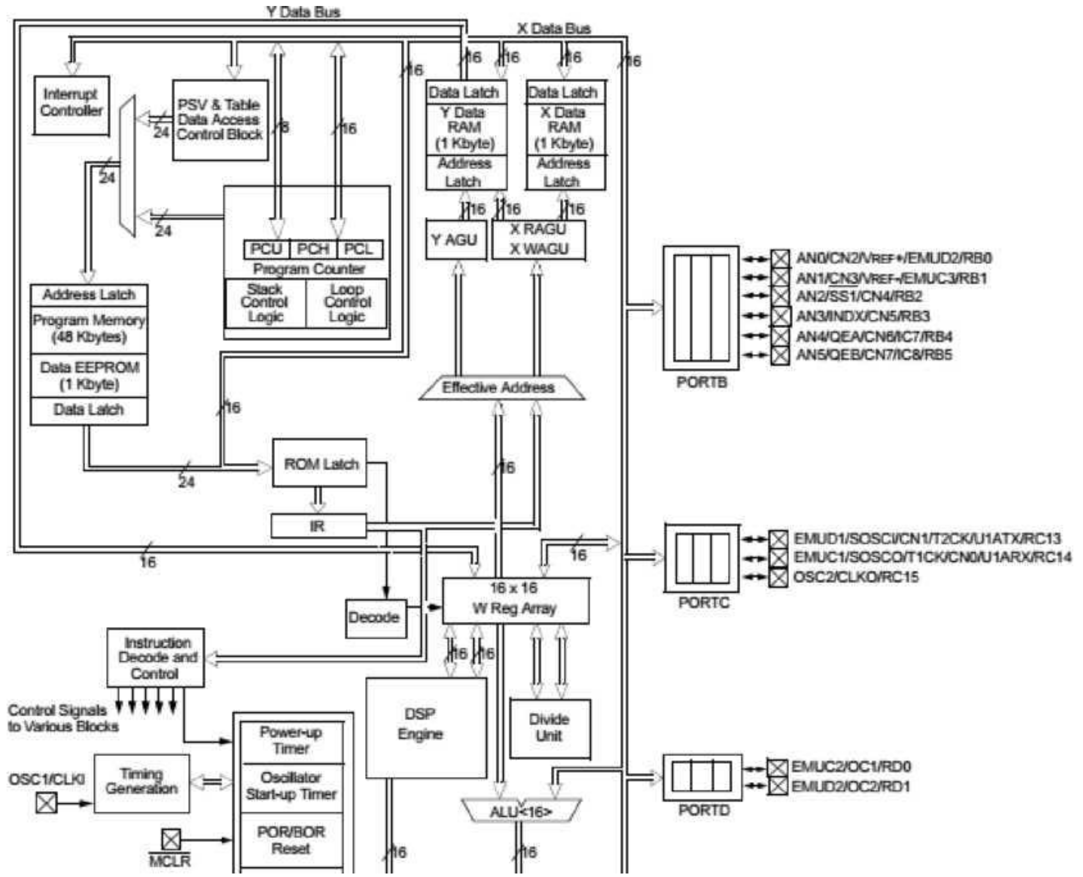
APPENDICES

APPENDIXA.1 :Block Diagram of the dsPIC30F4012.
APPENDIX A.2:Comparision table.


SPI1,
SPI2
CAN
Timers
10-bit ADC
QEI
Input
Capture
Module
Motor Control
PWM
Output
Compare
Module
UART1,
UART2
I^2C
PORTE

APPENDIX A.1: Block Diagram of the



APPENDIX A.2:Comparision table

	Maximum nuber of antenna	**Insertion loss**	**Return loss**	**Control Interface**
Metratec UHF Mux	4	0.9 dB		TTL
Keonn Advan Mux	32	1.3 dB	-20 dB	TTL
Impinj Antenna Hub	32	1.3 dB	-24 dB	TTL
CAN Based Antenna Mux	256	1.3 dB	<-20 dB	TTL+CAN

CURRICULUM VITAE

Name Surname:HüseyinUlvi AYDOĞMUŞ Place and Date of

Birth: Isparta, 01.03.1988

Address: IcerenkoyMah.OzturklerSok. No:29/3Atasehir/ISTANBUL E-

Mail: hsynaydogmus@gmail.com

B.Sc.:Maltepe University, Faculty of Engineering, Department of Electronics Engineering (2006 - 2010) (Full scholarship)

Professional Experience and Rewards:

-RFtek Electronics (05.2012-present)Co-Founder, *Electronics R&D Engineer-R&D activities in RF (Radio Frequency) circuits and hardware design of electronic devices.*

Sanlab Simulations (08.2010-05.2012)
-*Electronics R&D Engineer, Designing both hardware and software of electronic measurement and control systems for 3-DOF and 6-DOF construction machinery simulators such as forklift,back-hoe loader andexcavator.*

List of Publications and Patents:

-Smart Shelf Capabe of Inventory Management (Patent pending)This *patent is about a smart shelf, which is capable of performing promotion activities of RFiD tag attached goods and inventory management by using RFiD technology.*

PUBLICATIONS/PRESENTATIONS ON THE THESIS

-Designing a CAN Bus Based Measurement System for Forklift Simulator *The International Conference on Technological Advances in Electrical, Electronics and Computer Engineering* ***(TAEECE2013)***