THE DESIGN AND IMPLEMENTATION OF A FLEXIBLE DOMESTIC ILLUMINATION SYSTEM

by

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APPROVAL PAGE

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science of Electrical and Computer Engineering.

Head of Department

This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science of Electrical and Computer Engineering.

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ABSTRACT

This study aims at designing the fundamental conceptual background for a new illumination system which mainly targets LED based lighting. Besides offering efficient usage of LEDs, this system proposes a new patent valuable feature that has not yet been presented. It offers users to flexibly pair/impair control and driver units in illumination systems without a master unit or a technical service assistance. Following the background information, firstly conceptual details are defined and the detailed design of a prototype is given. Then the system settlement is accomplished. Finally, as expected a prototype system is obtained which has no master unit but has a multi mastered common language speaking system. Modules in the system, can dominate one another according to their coupling status which is settled by the user.

In this study, the conceptual design and prototype designs are given in detail, and thus the reader can easily understand the proposed concepts. Successfully working prototype is also presented.

Keywords: Flexible Illumination System, LED Lighting Control, Distributed Lighting Control.

ESNEK BİR İÇ MEKAN AYDINLATMA SİTEMİNİN TASARIMI VE GERÇEKLEŞTİRİLMESİ

Emin Arif BİRCAN

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ÖZ

Bu çalışmada, LED bazlı aydınlatma sistemlerini hedefleyen yeni bir aydınlatma sisteminin temel kavramsal altyapısının tasarımı ve gerçekleştirilmesi amaçlanmaktadır. LED'lerin verimli kullanımının dışında, bu çalışma aynı zamanda patentlenebilir nitelik taşıyan daha önce hiç sunulmamış bir özellik önermektedir. Bu sistem, kullanıcılara modülleri esnek bir şekilde merkezi bir üniteye veya teknik servis desteğine ihtiyaç duymadan eşleştirebilmeyi sağlamaktadır. Konuya esas teşkil eden temel bilgilerin verilmesinden sonra, ilk olarak kavramsal detaylar tanımlanmakta ve sonrasında prototipe esas detaylı tasarım sunulmaktadır. Son olarak sistem kurulumu gerçekleştirilir. Sonuç olarak, bu çalışma sonrasında, merkezi ünite olmadan ortak bir dilin konuşulduğu bir prototip sistem elde edilmiştir. Bu prototipte sistemi oluşturan modüller kullanıcıların yapmış olduğu eşleştirme durumlarına göre birbirlerine hükmetmektedirler.

Bu çalışmada, kavramsal tasarım ve prototip tasarımları detaylı olarak sunulmaktadır. Böylelikle, önerilen kavram ve tasarımların rahatlıkla anlaşılması hedeflenmiştir. Çalışmanın sonunda ise başarılı şekilde çalışan prototip sunulmuştur.

Keywords: Esnek aydınlatma sistemi, LED aydınlatma kontrolü, dağıtık aydınlatma kontrol sistemi.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL / ABBREVIATION

ANSI	The American National Standards Institute
CAD	Computer Aided Design
CAN	Controller Area Network
Ch	Channel
DALI	Digital Addressable Lighting Interface
DC	Direct Current
DMX	Digital Multiplex; A Communication Protocol for Light Control
EDA	Electronic Design Automation
EEPROM	Electronically Erasable, Programmable Read-Only Memory
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ESTA	The Entertainment Services and Technology Association
FDIS	Flexible Domestic Illumination System
GPL	General Public License
HVAC	Heating Ventilating and Air Conditioning
I/O	Input, Output
ICSP	In Circuit Serial Programming
ID	Identity Number
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LED	Light Emitting Diode
Mbps	Mega Bits Per Second Data Transfer Rate
MCLR	Master Clear
PCB	Printed Circuit Board
PIC	Peripheral Interface Controller
PWM	Pulse Width Modulation

RGB	Red-Green-Blue Color Representation
SMD	Surface Mounted Device
SPI	Serial Peripheral Interface
USITT	The United States Institute of Theatre Technology
ZVEI	Zentralverband Elektrotechnik und Elektronikindustrie

CHAPTER 1

INTRODUCTION

Consumers have a lot of technological seamless facilities that enable them have more comfortable life. As a result of this, evolving technologies and increasing consumer expectations force industry to come up with new illustration systems.

This study aims at designing the fundamental conceptual background for a new illumination system which mainly targets LED based lighting. Besides offering efficient usage of LED's in traditional lighting systems, this system proposes some new features that have not yet been proposed. There is no master unit in this system, instead it has a multi mastered common language speaking system. Modules, composing the system, can dominate one another according to their coupling status. This coupling feature is a new era for this industry as it offers users to make any combinations they want without a central control unit or a technical service assistance. This makes this process a patent valuable specialty that has not been offered before. The mentioned language is build up on CAN bus features and a well organized command structure that is known by all modules.

The remainder of this thesis is organized as follows. In Chapter 2, some background information is given. First section mentions about the existing systems and their comparisons. Secondly, brief information is given about CAN Bus which is a keystone for such a multi mastered futuristic system. Thirdly, the microcontroller that is used in this project is presented. Lastly, the MikroC programming language is shortly mentioned.

In Chapters 3, 4 and 5, the design and implementation of a prototype about the proposed system is presented. In Chapter 3, “Flexible Domestic Illumination System” concept is defined and introduced. The questions “Why do we need this system?” and “What does it propose?” are answered in detail. Chapter 4, consists of the design and the implementation of the prototype system. In this chapter, firstly, the design and the implementation of base module is given. Secondly the test rig, constructed from base modules, is mentioned. Software design of the system is explained in Chapter 5, which is one of the most important parts of the project. Most of the new features are realized by software. Firstly, the logical design of the top level software is given. Then, the command structure that lets modules talk to each other is defined. Finally, the most important feature, coupling the modules, is explained. This brings specialty of flexibility into the system. This process also adds patent valuable worth to this study.

Besides being a scientific project, this study is expected to be an infrastructure to a complete illumination system which has commercial purposes. Therefore, instead of giving complete details of the study, only conceptual issues are explained. The test settlement is build up to show proposed concepts. Instead of giving the program code, their algorithms are explained by means of flowcharts.

CHAPTER 2

BACKGROUND INFORMATION

2.1 EXISTING ILLUMINATION SYSTEMS

There are already existing commercial LED lighting control systems such as Philips; Color Kinetics [1], Legatronics; decaLED [2], Astera; ARC6 [5], etc. However, in general these systems are very expensive due to the fact that they are professional products and are not suitable for all end-users.

There are variety of systems and communication protocols in the industry. Before presenting existing lighting systems, some brief information about currently used two popular communication protocols DALI and DMX are provided below.

DALI System

DALI is simply defined in the published "DALI user manual" [3] by DALI AG of ZVEI as;

> *DALI is an acronym and stands for "Digital Addressable Lighting Interface". It is an international standard that guarantees the exchangeability of dimmable ballasts from different manufacturers. This gives planners, luminaire manufacturers, building owners, installers and end-users the security of supply from many sources. The DALI-interface has been described in the fluorescent lamp ballast standard IEC 60929 under Annex E. DALI is the ideal, simplified, digital way of communication tailored to the needs of present day lighting technology. Communication and installation have been simplified as much as possible. All intelligent components communicate in a local system in a way that is both simple and free of interference. There are no special requirements for the wiring of data cables, and there is no need to install termination resistors on the cables to protect them against reflections. DALI has been designed in a joint effort by all leading control equipment manufacturers with the idea of offering a standard to the lighting market that complies with all requirements. All lighting component manufacturers are now in a position to solve complex lighting tasks in a simple and comfortable way. With this standard you will now be able to*

> *offer your customer a full system solution (lamp – ballast – luminaire – control unit – lighting system).*

It can be clearly seen from this definition that DALI standard is provided to simplify lighting systems. It supports up to 64 channels on maximum of 16 groups. This group structure requires DALI gateways which increases the cost and the complexity of assembly of infrastructure.

DALI standard is an old work that aims ballasts for fluorescent light sources. This limits DALI in terms of effects so it has only 16 different scenes capacity. Since LEDs can be dimmed within high resolution, DALI is not good enough to efficiently use this feature of LEDs. Therefore DALI is a standard that is going to be out dated as the LEDs become more affordable.

DMX512 System

DMX512 protocol and its logic is simply summarized by Elation Lighting from USA, in DMX512 manual [4] by the following paragraph;

> *DMX is an acronym for **D**igital **M**ultiple**x**, a communication protocol (a set of rules) used to remotely control lighting dimmers and intelligent fixtures. It is designed to provide a common communications standard between these lighting devices regardless of the manufacturer. The 512 after the DMX refers to the number of control channels used on one network segment (often called a 'universe') of devices. In a simple dimming system, one channel controls the intensity of one dimmer. A single intelligent fixture, however, may require several channels to control its various parameters (one channel each for pan, tilt, color, gobo, etc.). A basic dimming control console (such as the 16 channel Elation Stage-Setter 8) may support only a few of the 512 available channels. Many professional control consoles (such as the 3 universe, 1536 channel Elation Show Designer 3) support multiple universes, allowing for thousands of control channels.*

DMX512 is an old standard originally published in 1986 by USITT (The United States Institute of Theatre Technology). In 1998 ESTA (The Entertainment Services and Technology Association) took over the control of DMX standard.

Finally, with the approval of ANSI (The American National Standards Institute) in 2004 DMX become the most popular and preferred lighting interface.

Although, DMX512 is the most widely used standard it is not suitable for very complex lighting effects, and any other future extensions of lighting, such as time scheduling. In addition DMX has no auto error checking mechanism that is essential for a secure futuristic system.

After getting some brief information about currently used protocols, now let us consider some of existing systems mentioned at the beginning of this section.

Philips Color Kinetics mainly focuses on power system solutions of LED illumination systems. In addition, they provide some ready to use effects and complex scenarios via the computer programming.

Astera, a German Company, has a product called Lumitouch (ARC6) [5], shown in Figure 1, which is one of the most developed wireless lighting controller interface in the industry. It presents fascinating 7 inch touch LCD user interface and features. However, as it uses DMX protocol (Digital Multiplex; investigated in the next section) it is just limited with the capabilities of DMX.

Figure 1: Astera ARC6 [5]

Another German company, Dilitronics, has a solution that offers to users change their system settlements easily [6]. Dilitronics uses a central controller, MMC16, and other modules are connected to this controller via DMX or DALI (Digital Addressable Lighting Interface) protocols. DALI is a similar replacement of DMX protocol. Systems consist of small modules (switchDot, sceneDOT, motionDot, etc.) that can be easily mounted on an existing infrastructure. Two of these modules are shown in Figure 2 and Figure 3.

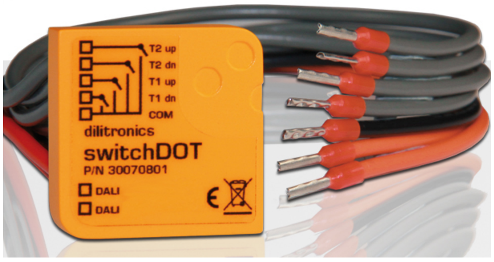


Figure 2: Dilitronics, switchDOT [6]

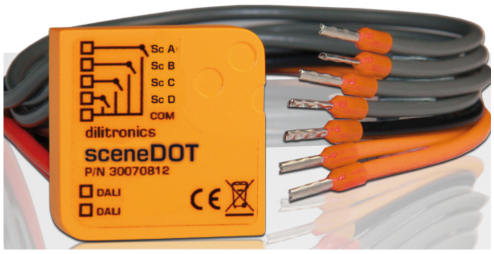


Figure 3: Dilitronics sceneDOT [6]

The weakness of this system is that it has only a few basic features such as on/off and dim. Also it is not easy to expand such a system in a whole house or office.

2.2 CAN BUS

In order to accomplish this project with a modular design, a stable communication system between modules without a master module is necessary. Details of communication method is discussed in following sub-sections.

2.2.1 Description of CAN Bus

Some brief information about CAN system and its features are presented in this section.

CAN bus (Controller Area Network), is originally designed to work in automative industry. Robert Bosch GmbH describes the CAN in specification sheet [7]; *"The Controller Area Network is a serial communications' protocol which efficiently supports distributed realtime control with a very high level of security"*.

The following is a brief explanation of CAN bus [8].

> *CAN is extensively used in automotive industry but has found ap plications everywhere. There are many "application" layers available for CAN such as ISO 15765 (cars), J1939 (trucks) and CANopen (factory automation) but it is very easy to develop your own protocol that will fit and simplify your needs. Modern CAN transceivers provide a stable and reliable CAN physical environment with out the need for expensive coaxial cables. Most of the mystery of CAN has dissipated over*

the years.

There is plenty of example CAN software to help you develop your own network.

A CAN controller is a sophisticated device. Nearly all the features of the CAN protocol described below are automatically handled by the controller with almost no intervention by the host processor. All you need to do is configure the controller by writing to its registers, write data to the controller and the controller then does all the housekeeping work to get your message on the bus.

The controller will also read any frames it sees on the bus and hold them in a small FIFO memory. It will notify the host processor that this data is available which you then read from the controller. The controller also contains a hardware filter mechanism that can be programmed to ignore those CAN frames you do not want passed to the processor.

It is assumed that a CAN network consists of the physical layer (the voltages and the wires) and a frame consisting of an ID and a varying number of data bytes with the following general attributes:

1. *11 or 29 bit ID and from zero to 8 data bytes. Tip: These can be dynamically changed "on the fly".*
2. *Peer to Peer network. Every node can see all messages from all other nodes but can't see its own.*
3. *Nodes are really easy to add. Just attach one to the net work with two wires plus a ground.*
4. *Higher priority messages are sent first depending on the value of the ID. A lower ID has a higher priority.*
5. *Automatic retransmission of defective frames. A node will "bus-off" if it causes too many errors.*
6. *Speeds from approximately 10 Kbps to 1 Mbps.*
   Tip: All nodes must operate at the same frequency.
7. *The twisted differential pair provides excellent noise immunity and some decent bus fault protection.*
8. *The CAN system will work with the ground connection at different DC levels. Tip: Or no ground at all.*

A CAN network consists of at least two nodes connected together with a twisted pair of wires as shown below in Figure 4. A ground wire can be included with the twisted pair or separately as part of the chassis. One twist per inch (or more) will suffice and the integrity of the ground is not important for normal operation as described above. As in any differential systems; the important signal is the voltage levels between the wire pair and not their values to ground.

The maximum length of the network is dependent on the frequency, number of nodes and propagation speed of the wire. It is relatively *easy to have a 20 node (or more), 500 Kbps system running 30 or 40 feet (or more).*

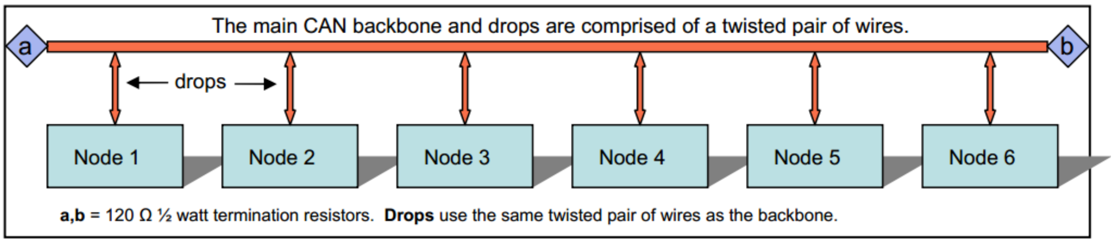


Figure 4: A sample diagram of relational connections of CAN nodes.[8]

2.2.2 Why CAN Bus Protocol is Chosen in This Project

Modularity is an essential for this system. Therefore it must be built upon a consistent and reliable method. It is already mentioned that, existing lighting control systems are using DMX or DALI like protocols. However, these protocols aim to simplify systems and to reduce accordance complexity of different producers. So the subjected new systems must use a new communication method.

DMX and DALI has no built in error checking mechanisms and don't support high numbers of modules. CAN communication protocol supports auto error check, built in prioritizing system, high data transfer rates. Originally CAN is invented to be used in between electronic parts of cars. It has become very popular as it supports 100% reliable data transfer with built in error check and re-transfer mechanisms. In physical layer, in case of appropriate settlement of the bus cabling system, CAN supports up to 1 Mbps [7] data transfer rate. CAN Bus works on a twisted pair cabling with differential voltage chasing. For a sample physical connection see Figure 4. Each closed shape presents a module that has a unique ID and they are connected on the same bus.

Criticizing and planning some fascinating futuristic properties which are mentioned in next sections require more commands than DMX and DALI has specified. This is another reason to use CAN bus in this project. CAN bus transfers up to 8 data bytes that can be changed. Addressing is done besides the data frame of package [7] so all of these 8 data bytes can be used to send commands to modules. Therefore, designers can use 8 data bytes in a hierarchical manner to bring about some new commands. An example data structure is given in command structure section.

As mentioned above, CAN Bus is designed for communication of automobile parts. Since it is used in very important electronic parts of cars there is no chance to have a faulty communication. Specification sheet says in case of appropriate settlement according to specification sheet; the faulty message probability is less than 1 in a million years. CAN protocol has a very consistent error detection and repeat mechanism that guarantees each node successfully gets the message.

As CAN bus supports multi-mastered, prioritized, reliable and fast communication it can be used in Flexible Domestic Illumination Systems.

2.3 MICROCONTROLLER

In this thesis, PIC16LF1936 microcontroller from Microchip (c) [9] has been chosen as the microcontroller unit. This section briefly mentions about the features of this series of microcontroller and the reasons why it is chosen for this project.

2.3.1 General Definitions

Microcontrollers are some special devices that combine microprocessor, memory units, and some peripheral units into a single chip. It provides a very flexible designing structure to developers and designers. Microcontrollers are widely used due to ease of programmability and affordability.

Microcontrollers are one of the most important parts of this project. Outputs (LEDs and PWM signals), inputs (buttons) and communication of modules are totally managed by microcontrollers.

2.3.2 PIC16LF1936 Microcontroller

Why PIC16LF1936 microcontroller is used in this project is mainly due to the special peripherals of this chip.

PIC16LF1936 provides lots of special functions and peripheral modules. 5 channel built in PWM module, SPI interface, Touch Sensing inputs and sufficient amount of memory are the main reasons that make this model suitable for this project. Detailed information about the hardware and specialties of this project are explained in detail in the following chapters.

In Figure 5, the pin diagram of the preferred type of PIC16LF1936 is provided. Detailed pin functions can be clearly seen on this diagram.

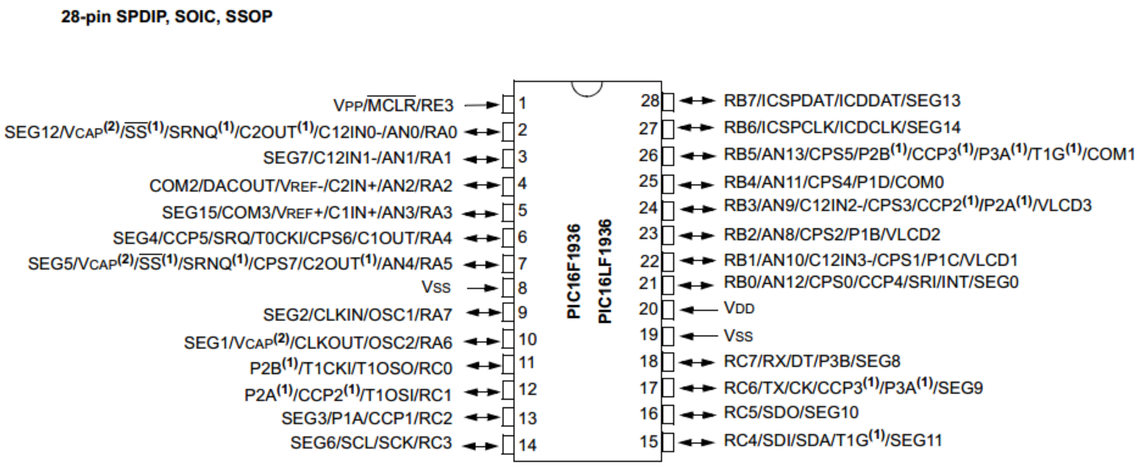


Figure 5: Pin diagram of PIC16F1936 [9]

PIC16F1936 has 28 pins and 3 main Ports; A, B, C. PORT A and PORT B are mainly designed for analog features. PORT C handles communication issues and digital interfaced functions.

Block diagram of the PIC16F1936 microcontroller is shown in Figure 6. This diagram shows the basic relational connections between core block, memory units, peripheral modules, input & output ports etc. Capture&compare module, timers, SPI, I/O ports, internal oscillator, RAM, EEPROM modules are used in this project.

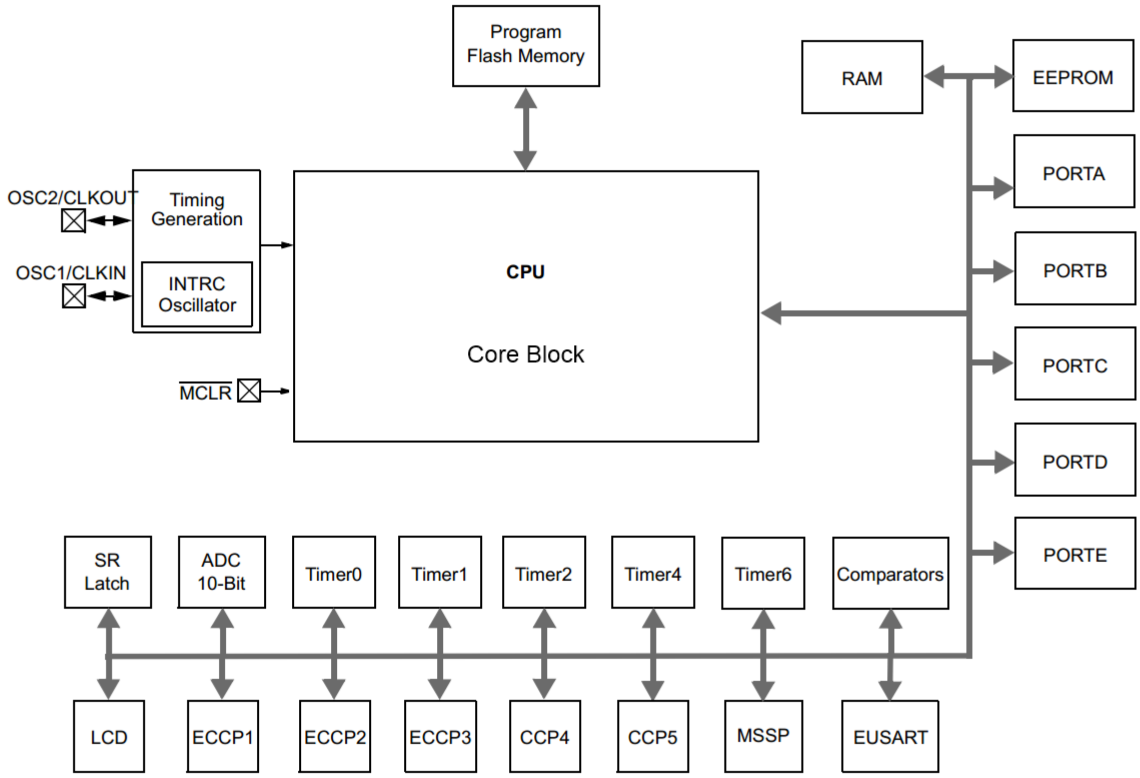


Figure 6: Internal block diagram of PIC16F1936 [9]

Detailed definitions of the subjected modules can be obtained from [9]. The detailed diagram of the core block shown in Figure 6 is provided in Figure 7.

Let us basically present how core block works. Firstly, program memory is read from flash memory according to program counter registers. Then the read instruction is executed. During this process direct RAM memory access may be used, an arithmetic logic operation may be executed and inputs may be fetched, outputs may be latched.

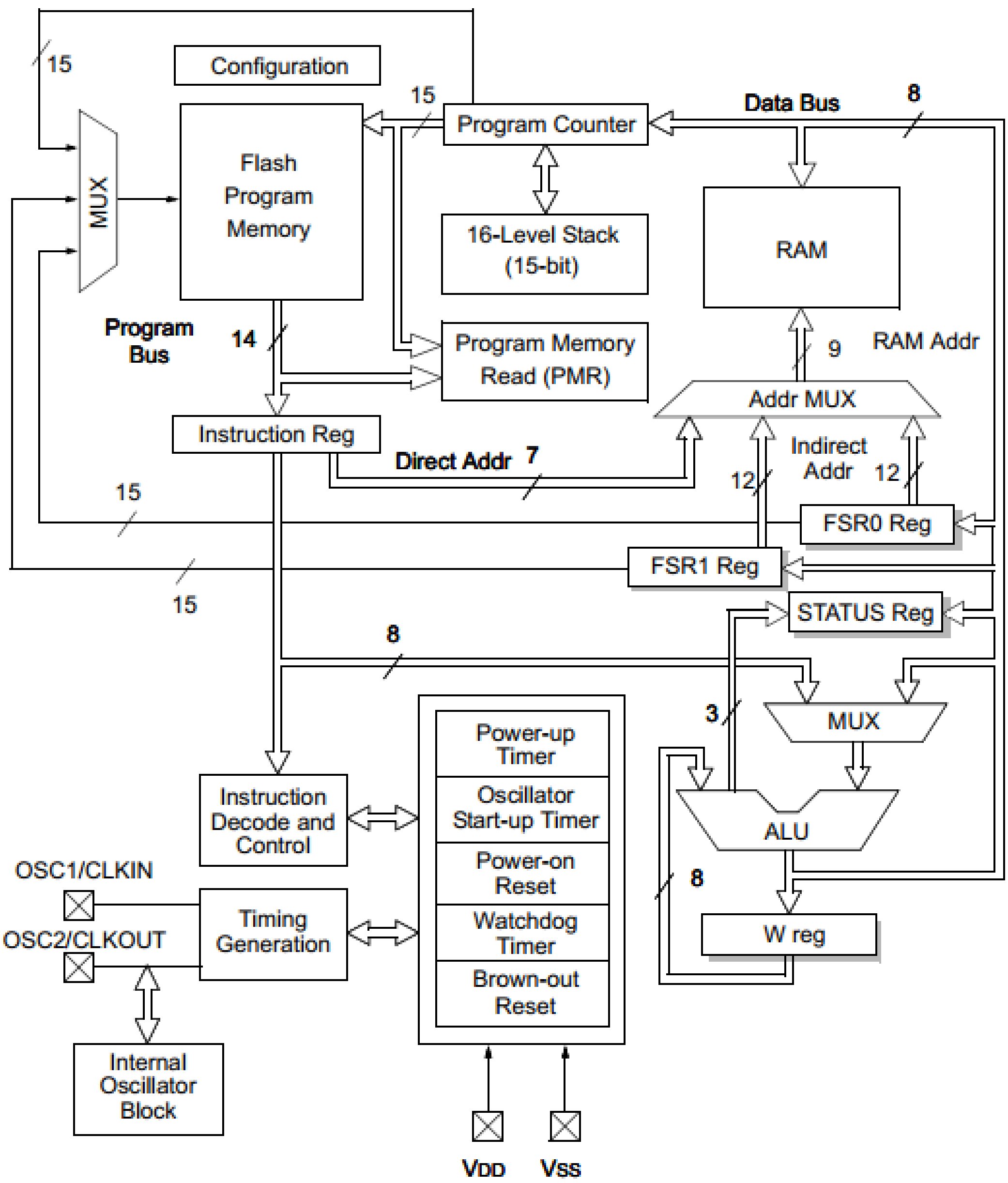


Figure 7: Core block diagram of PIC16F1936 [10]

Detailed pin definitions of PIC16F1936 are provided in Table1.

Table 1 : Detailed pin definitions of PIC16F1936

I/O	28-Pin SPDIP	28-Pin QFN/UQFN	ANSEL	A/D	Cap Sense	Comparator	SR Latch	Timers	CCP	EUSART	MSSP	LCD	Interrupt	Pull-up	Basic
RA0	2	27	Y	AN0	—	C12IN0-/ C2OUT[1]	SRNQ[1]	—	—	—	$\overline{SS}$[1]	SEG12	—	—	VCAP[2]
RA1	3	28	Y	AN1	—	C12IN1-	—	—	—	—	—	SEG7	—	—	—
RA2	4	1	Y	AN2/ VREF-	—	C2IN+/ DACOUT	—	—	—	—	—	COM2	—	—	—
RA3	5	2	Y	AN3/ VREF+	—	C1IN+	—	—	—	—	—	SEG15/ COM3	—	—	—
RA4	6	3	Y	—	CPS6	C1OUT	SRQ	T0CKI	CCP5	—	—	SEG4	—	—	—
RA5	7	4	Y	AN4	CPS7	C2OUT[1]	SRNQ[1]	—	—	—	$\overline{SS}$[1]	SEG5	—	—	VCAP[2]
RA6	10	7	—	—	—	—	—	—	—	—	—	SEG1	—	—	OSC2/ CLKOUT VCAP[2]
RA7	9	6	—	—	—	—	—	—	—	—	—	SEG2	—	—	OSC1/ CLKIN
RB0	21	18	Y	AN12	CPS0	—	SRI	—	CCP4	—	—	SEG0	INT/ IOC	Y	—
RB1	22	19	Y	AN10	CPS1	C12IN3-	—	—	P1C	—	—	VLCD1	IOC	Y	—
RB2	23	20	Y	AN8	CPS2	—	—	—	P1B	—	—	VLCD2	IOC	Y	—
RB3	24	21	Y	AN9	CPS3	C12IN2-	—	—	CCP2[1]/ P2A[1]	—	—	VLCD3	IOC	Y	—
RB4	25	22	Y	AN11	CPS4	—	—	—	P1D	—	—	COM0	IOC	Y	—
RB5	26	23	Y	AN13	CPS5	—	—	T1G[1]	P2B[1] CCP3[1]/ P3A[1]	—	—	COM1	IOC	Y	—
RB6	27	24	—	—	—	—	—	—	—	—	—	SEG14	IOC	Y	ICSPCLK/ ICDCLK
RB7	28	25	—	—	—	—	—	—	—	—	—	SEG13	IOC	Y	ICSPDAT/ ICDDAT
RC0	11	8	—	—	—	—	—	T1OSO/ T1CKI	P2B[1]	—	—	—	—	—	—
RC1	12	9	—	—	—	—	—	T1OSI	CCP2[1]/ P2A[1]	—	—	—	—	—	—
RC2	13	10	—	—	—	—	—	—	CCP1/ P1A	—	—	SEG3	—	—	—
RC3	14	11	—	—	—	—	—	—	—	—	SCK/SCL	SEG6	—	—	—
RC4	15	12	—	—	—	—	—	T1G[1]	—	—	SDI/SDA	SEG11	—	—	—
RC5	16	13	—	—	—	—	—	—	—	—	SDO	SEG10	—	—	—
RC6	17	14	—	—	—	—	—	—	CCP3[1] P3A[1]	TX/CK	—	SEG9	—	—	—
RC7	18	15	—	—	—	—	—	—	P3B	RX/DT	—	SEG8	—	—	—
RE3	1	26	—	—	—	—	—	—	—	—	—	—	—	Y	$\overline{MCLR}$/VPP
VDD	20	17	—	—	—	—	—	—	—	—	—	—	—	—	VDD
Vss	8, 19	5, 16	—	—	—	—	—	—	—	—	—	—	—	—	Vss

Note 1: Pin functions can be moved using the APFCON register.
2: PIC16F1936 devices only.

In this project, RA0, RA5, RC3, RC4, RC5 pins are used for the connections of SPI interface. SPI interface is used to control SPI CAN module. RC1, RC2 & RC6 pins are used for PWM outputs. RB2, RB3, RB4, RB5 pins are used for button inputs. RA3, RA4, RA6, RA7 pins are reserved for future purpose I/O ports.

2.4 MIKROC PROGRAMMING LANGUAGE

In this project, it is required to use a high end programming language compared with assembly language. There are complex algorithms that is very hard to realize in assembly language. Therefore, in this project, C programming language is preferred.

Bodur and Asameh have mentioned about preference of C language and reasons to chose it in their article "C Programming of the Microcontrollers for Hobby Robotics"[11]. A paragraph from this article is submitted in below:

> *Almost 60 percent of the code development in the embedded system indus try is performed using C language, although the natural language of a microcontroller is its assembly language. The remaining 40 percent is shared by assembly coding and higher level coding such as C++, Java or other object oriented languages. There are many strong reasons for industrial preference:*
>
> *1 C is a 'mid-level' coding language, with high-level' features. It supports functions and modules in a well structured form. Yet, it supports all 'low-level' features. It provides access to hardware via pointers in a convenient structure;*
>
> *2 C is very efficient, popular and well understood programming language;*
>
> *3 Even desktop developers who have used only Java or C++ can soon understand C syntax;*
>
> *4 Good, well-proven compilers are available for every embedded processor, including the 8-bit lower end, 16-bit middle end and 32 bit or higher end microcontrollers;*
>
> *5 C programming is common practice for many applications, and it is a subset of C++. Thus, experienced staff are available;*
>
> *6 Books, training courses, code samples and web sites discussing the use of the language are widely available.*

In this project it is preferred to use MikroC. MikroC is a microcontroller programming language that combines the ease of "C language" and control power of "Assembly" language. MikroC is produced by mikroElektronika© a development tools producer located in Serbia, Belgrade [12]. Besides the general preference reasons of C language MikroC provides two more main benefits; Compact and efficient ready to use library routines and ease of building complex hierarchy through the efficiency of object oriented programming.

CHAPTER 3

FLEXIBLE DOMESTIC ILLUMINATION CONCEPT

This chapter defines the proposed Flexible Domestic Illumination System (FDIS), what is expected from it and what does it provide for consumers.

Firstly, what "domestic" concept is defined, then "flexibility" is defined. Next the question "Why do we need FDIS?" is answered. Finally what kind of features it offers are mentioned.

1.1 Domesticity And Flexibility

The domesticity of a system is not a new concept. The dictionary definition of domestic is interior, inside, inner and house. Parallel to this, it stands for home or office use but in this thesis it does not aim professional/commercial (theatre, concert hall, etc.) use.

Flexibility is a semi-new notion in illumination industry. Existing systems are mainly suitable for fluorescent lighting. In contrast to this fact, a future system must use LEDs efficiently and support their specialties fully due to their benefits. A flexible LED lighting system is going to be a new concept in terms features and efficiency. And also flexibility concept requires having a modular design in terms of connection and concordance.

The flexibility concept is realized in the real system as follows. The proposed system has specific modules for specific purposes, which will be explained in detail in hardware chapter. The system runs with the same code on each same type of modules. There exist slightly modified codes in the system for other types of modules. So that it supports almost unlimited combination of system configurations and sizes without a rush settlement process. This would enable architects and interior designers to freely make their designs.

In addition to the proposed flexibility in designing process, building the system on the real site will become very easy due to the modularity. The montage technician can freely use the required module without the necessity of serialization tracking. After assembling the whole system the montage technician can easily set the pairs of light control groups using flexible coupling algorithm. This feature will be explained in detail in the software section.

All remaining requirements of flexibility concept can be called as future properties which can be added into the system by the proposed command structure in software chapter. Although these are beyond the scope of this thesis for the sake of the clearance of the concept of flexible illumination system some examples are given in Section 3.3.

1.2 Why Do We Need a "Flexible Domestic Illumination System"?

Technology has brought about a new illumination source called LED (Light Emitting Diode). Besides having environmental benefits, LEDs present flexibility of lighting that never existed before. Such as high resolution dimming, millions of colors, fast up times, etc.

In contrast to those features of LEDs, high power LEDs (can be used as an illumination source) based lighting sources have yet to get affordable by the end users. There are not many complete end user illumination systems in the industry as high power LEDs are just almost affordable compared with the other lighting sources. Moreover, existing systems are professional and expensive systems that are not suitable for home or office users.

Maury Wright, a senior technical editor of LEDs Magazine, mentions about the lack of standards in the LED lighting industry in his article "Use of controls escalates in LED lighting despite lack of standards" which is published in LEDs Magazine [13].

> *"Standards-based networks would enable interoperable products from multiple vendors, but a robust, standardized, lighting-centric network is*

> *still a work in progress. The biggest obstacle to broader deployment re mains the lack of a full network stack for lighting. There are wired and wireless networks that could serve in lighting, but in every instance one or more required layers are missing."*

One of these missing layers that author has mentioned is the control layer.

As a result of above reasons, it is necessary to come up with a new system that efficiently uses LEDs and their features also meet the demand of domestic end-users and resolve the shortage of the control layer that Maury Wright has mentioned. This new proposed system is called "Flexible Domestic Illumination System" FDIS in short. Therefore, the main existence reason of FDIS is related with the lack of LED control systems in the industry.

Besides being a scientific thesis, this work builds up a base for a complete illumination system which is planned to be produced for commercial purposes. Also, as this illumination system structure designed totally modular it will be easily adapt to a whole home control system. For example, flexible structure and command sets for lighting can easily control HVAC systems too.

1.3 What Kind of Features are Asserted?

Through the reliability of CAN bus and the logic of coupling structure provide a totally consistent system for end-users.

Each sub-part of the system is built up on a modular concept. So that, this modular design would make the system run even if some modules are defective.

LED's let us use PWM technique so it can be easily dimmed. Therefore generating millions of colors is not difficult to do so.

Below some specific examples to futuristic functions are given to make the concept of flexibility to be understood.

A **vocation mode** perhaps called "home in" might set the lamps randomly during night time to keep burglars away.

Once, parents set the system for 10% maximum power for childrens' room after 22:00 pm then it cannot be altered by the children so they must fall asleep.

Leaving home mode might turn off all the lamps with a simple command via the user interface.
Lullaby scenario helps people who are scared from dark nights. Set the bedroom lights to turn off slowly within 30 minutes then you can safely fall asleep.
Wake me up mode; if you must wake up very early in the morning you can set up your lights to slowly shine like sun rises so you can easily and naturally wake up.

All of these features require an easy to use interface which is out of scope of this thesis. The proposed command structure supports such extensions. However, these functions are mentioned to clear what flexibility concept should provide in future.

CHAPTER 2

THE STRUCTURE OF THE PROPOSED FDIS

In this chapter, the design and implementation of hardware of the proposed system is provided step by step over a sample prototype. Firstly detailed design and structure of one module is given then a prototype system is provided.

As stated before, this system is designed to be totally modular from all aspects. In general, systems consist of 2 main module types; button modules and drivers. Button modules may have different types 1 to 3 channels on/off, 1 to 3 channels tactile, 1 to 3 channels dimmer. Perhaps in the future graphical touch panel etc...

In order to obtain high degree of flexibility there is no central control unit like a master module. Therefore, the proposed system has no master unit, rather it has multi-masters in it. In this structure, all button modules can generate some commands according to their sub-types and the whole system modules listen all of the issued messages on the system. Structurally, driver modules listen all messages and reacts to messages that come from their pair if such a module exists. There exist only one driver software and it knows how to react every command defined. Thus, it does not matter what kind of button modules coupled to it. This is what exactly the flexibilty concept is about in this system.

In Figure 8, a sample structure is illustrated. This figure represents the proposed system with a variety of different modules. In this structure four different types of button modules (1Ch On/Off module, 1Ch Dim Module, 1Ch Tactile Module, 3Ch Advanced Touch Panel) and 3 different types of driver modules (Incandescent driver, LED PWM driver, 3Ch LED PWM driver) are used. Each of these modules can become couples with the user entries.

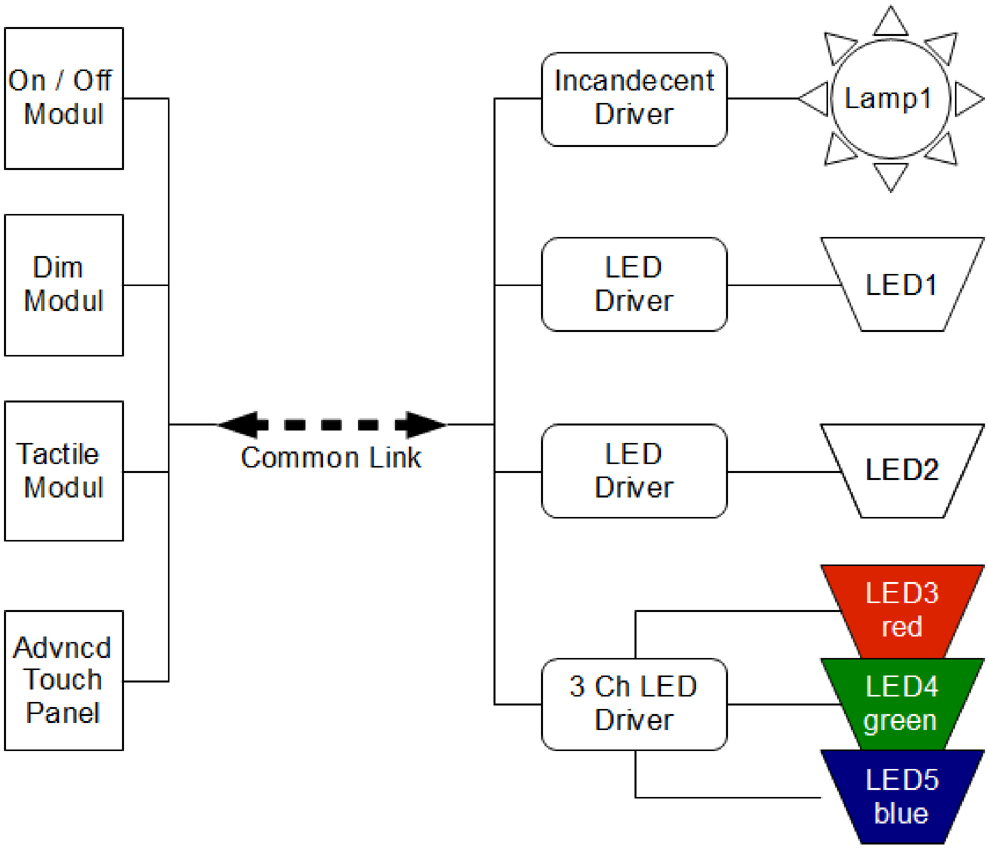


Figure 8: A sample system configuration built up with a variety of modules.

2.1 The Hardware Design of the Proposed System

This study is a first step towards a tremendous home control system project so it is not possible to construct the whole system with only one design. On the other side, as this study has been carried out for commercial purposes it is not possible to provide all the detailed information in here.

For the sake of simplicity and modularity only one type of physical module is designed and prototyped. Modules can work either as button module or as driver module. The design and implementation of this sample prototype module is provided in this section. What makes produced modules different one from the other is the software programmed in it.

Throughout the whole hardware design process KiCAD EDA suite is used [14]. KiCAD is an open source GNU GPL 2 licensed free to use CAD program to manage whole process of PCB production.

2.1.1 Electrical Design of a Module

In this section, electrical design and considerations of the previously mentioned module is explained.

Briefly, a module consists of 6 main units; microcontroller, power unit, CAN Bus unit, PWM output, Inputs and ICSP (In circuit serial programming) connection. In Figure 9, electrical scheme of the whole systems is provided which is drawn by using KiCAD EESchema platform.

Units represented with color and letter codes on the Figure 9. microcontroller; Green-A, CAN Bus Unit; Red-B, PWM output; Yellow-C, Power unit; Dark Green-D, Inputs; Blue-E and ICSP; Magenta-F.

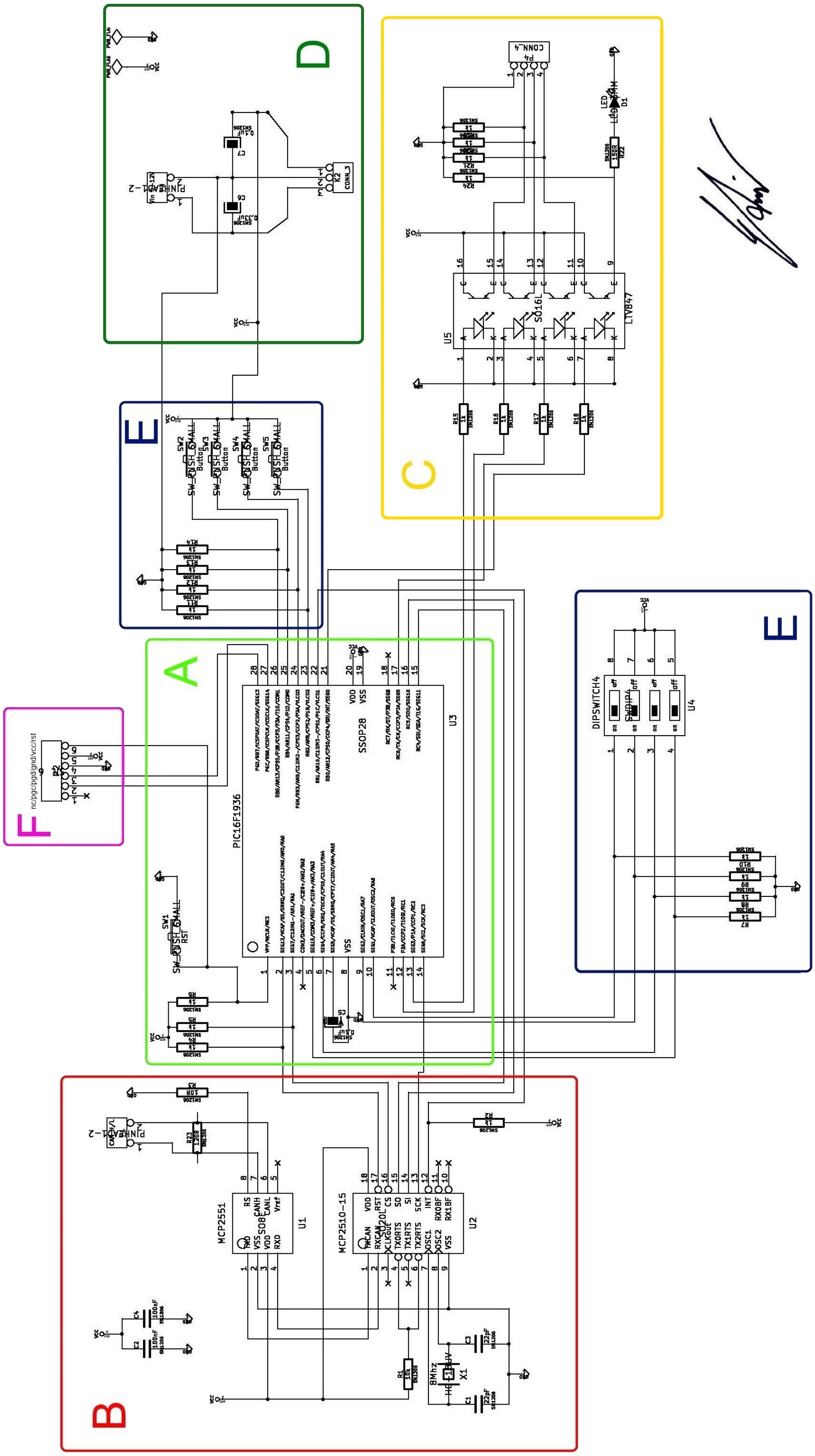


Figure 9: Electrical scheme of one module

Microcontroller Unit

Microcontroller unit is presented in Figure 10. As mentioned in previous chapter PIC16F1936 microcontroller is selected due to its useful peripherals.

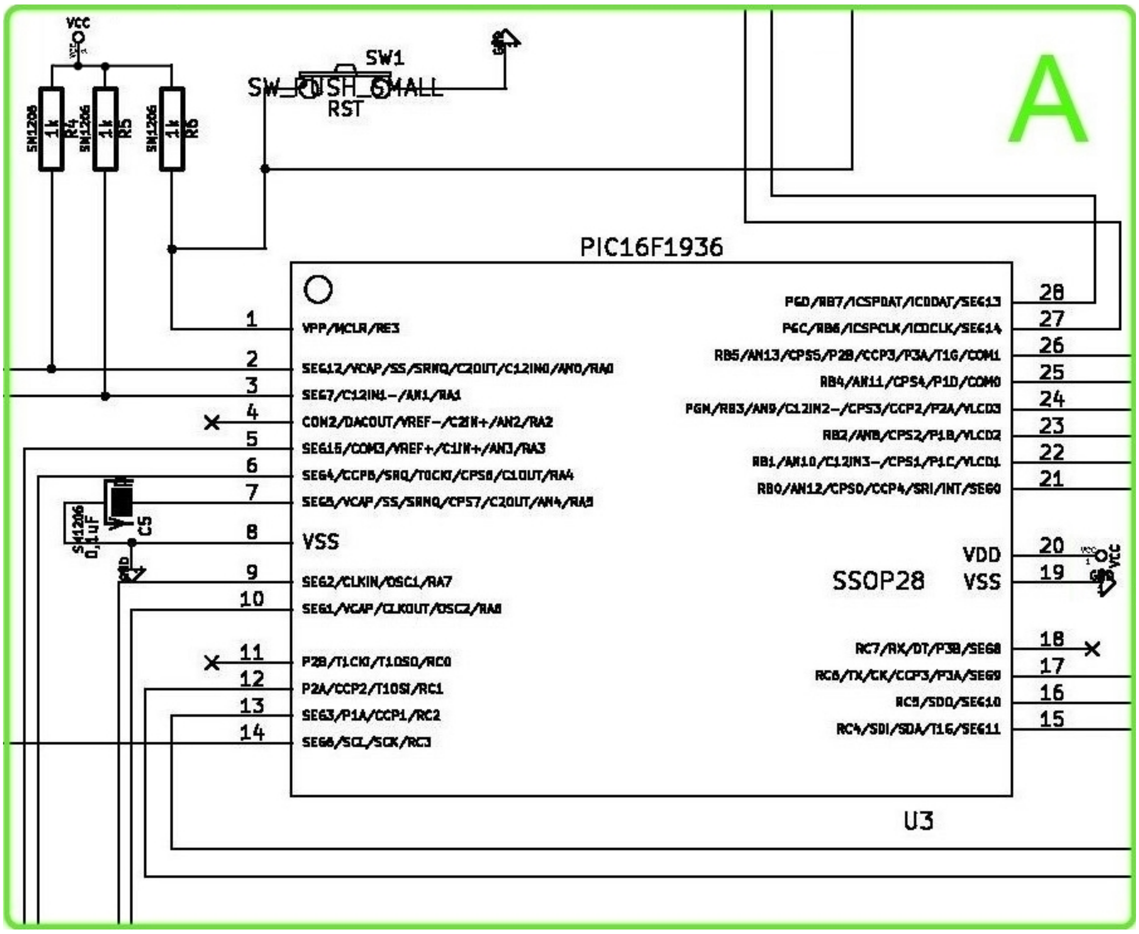


Figure 10: Microcontroller unit

This unit of module contains Microcontroller, Vcap capacitor, and MCLR reset circuit.

Vcap pin of PIC16F1936 has a special function that it provides extra regularity in voltage levels of power lines and the system is held in reset position until it gets fully charged. This is important for such a multi module containing system in order to provide stable system operation.

The organization of pin connections are very important and needs attention.

The Can Bus Unit

This part of the module consists of MCP2515 and MCP2551 and an oscillator source. Figure 11 illustrates CAN Bus unit of the module.

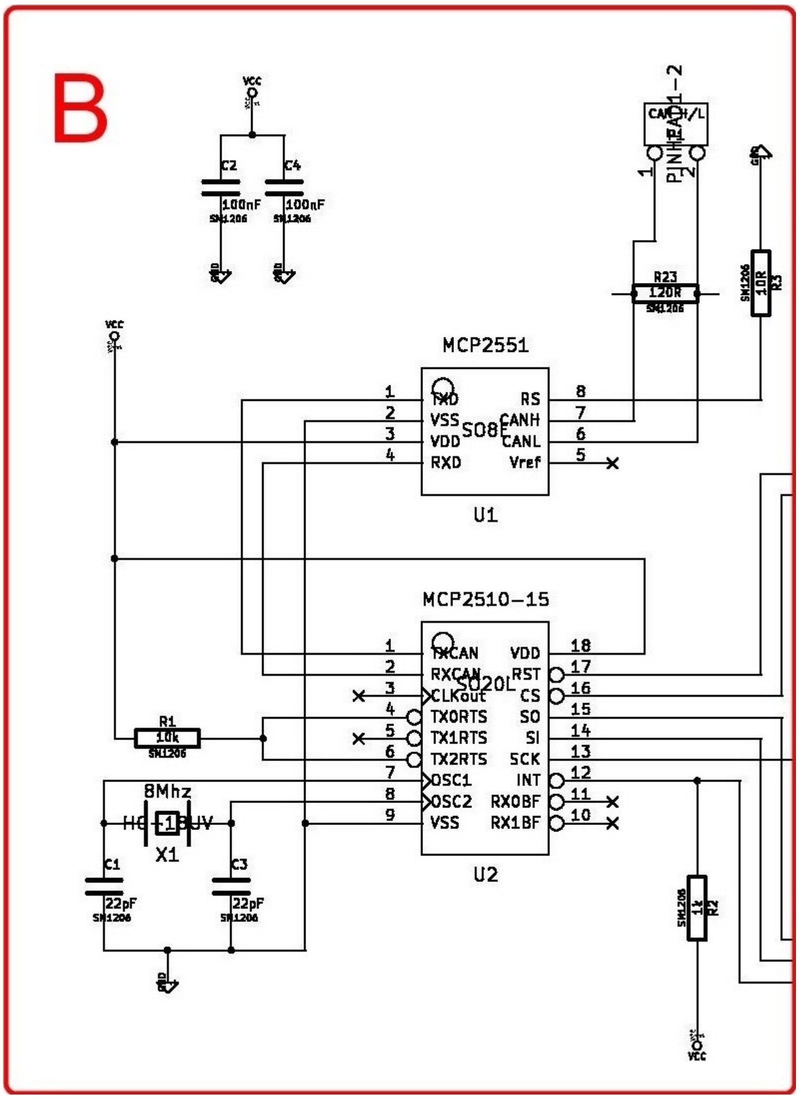


Figure 11: CAN controller unit

Used special parts are briefly described below and detailed information can be obtained from [15] and [16].

MCP2515 is defined in its producer catalogue as follows:

"Microchip Technology's MCP2515 is a stand_alone CAN controller that implements the CAN specification, version 2.0B. It is capable of transmitting and receiving both standard and extended data and remote frames. MCP2515 interfaces with micro-

controllers via an industry standard Serial Peripheral Interface (SPI).” [15]

MCP2515 properly connected to other parts as defined in its manual. This part needs an external oscillator source that manages communication timing. As a demanding issue; using different clock frequencies complicates the study. It requires another process in software layer. Therefore the clock frequency of 8 MHz is chosen on all modules.

MCP2551 is defined in its producer data-sheet as follows:

“*The MCP2551 is a high-speed CAN, fault-tolerant device that serves as the interface between a CAN protocol controller and the physical bus. The MCP2551 provides differential transmit and receive capability for the CAN protocol controller and is fully compatible with the ISO-11898 standard, including 24V requirements. It will operate at speeds of up to 1 Mb/s.*

Typically, each node in a CAN system must have a device to convert the digital signals generated by a CAN controller to signals suitable for transmission over the bus cabling (differential output). It also provides a buffer between the CAN controller and the high-voltage spikes that can be generated on the CAN bus by outside sources (EMI, ESD, electrical transients, etc.).” [16]

As it can be understood from the producers' manual, MCP2551 is a securely isolated data transformer designed for CAN Bus systems. It uses a differential output for data transferring to secure information from parasitic effects over the line.

To transmit data, microcontroller sends command to MCP2115 over SPI interface then it generates CAN protocol's data frame. Then MCP2551 transfers this data into differential voltage signal to be sent over the bus. In a similar fashion, the receiving cycle is the reverse order of the transmission process.

PWM Outputs

This unit provides a universal 5V PWM output for power drivers of any light source. Constant current source for power LEDS, 12V supplies for SMD LED sources, Phase cut drivers for incandescent lamps, dimmable ballasts for flourescent etc. The PWM output unit is shown in Figure 12.

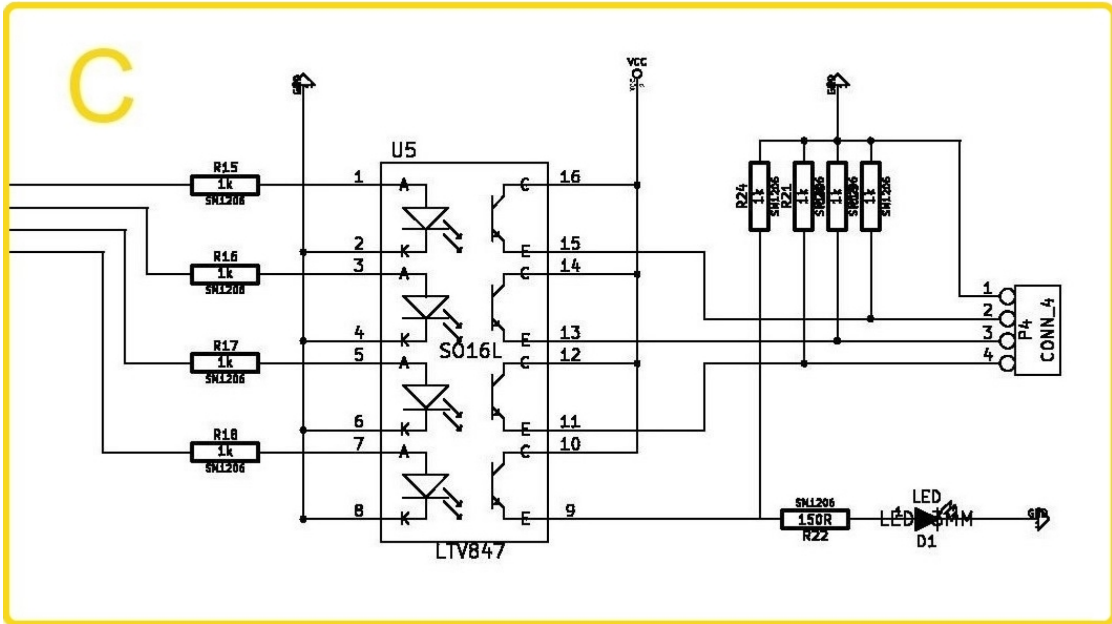


Figure 12: PWM outputs

The device LTV847 provides secure connection to the output devices. LTV847 is a 4 Channel opto-coupler driver. It isolates the microcontroller from the high power interface of the module. The PWM signal generated by the microcontroller is transferred via light in LTV847 so there is no physical connection between microcontroller pins and high power output from outside.

Power Unit

Power unit is simply achieved with an LM7805 voltage regulator and 2 capacitors as shown in its data-sheet [17]. Module accepts 8-18V DC input and provides 5V to the system. The detailed connection diagram of power unit is given in Figure 13.

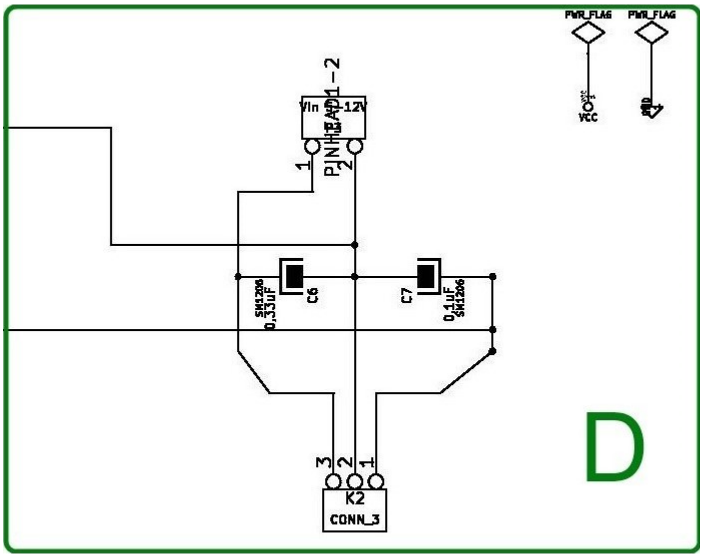
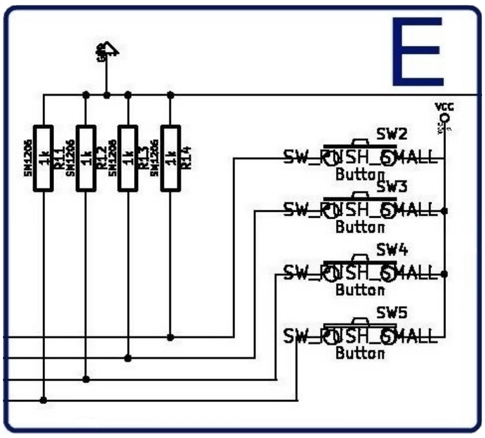


Figure 13: Power unit

Inputs

As illustrated in Figures 14&15, the module has two sets of 4 pin inputs. One of them is connected to 4 pull down push buttons, the other set is reserved for future purpose uses.



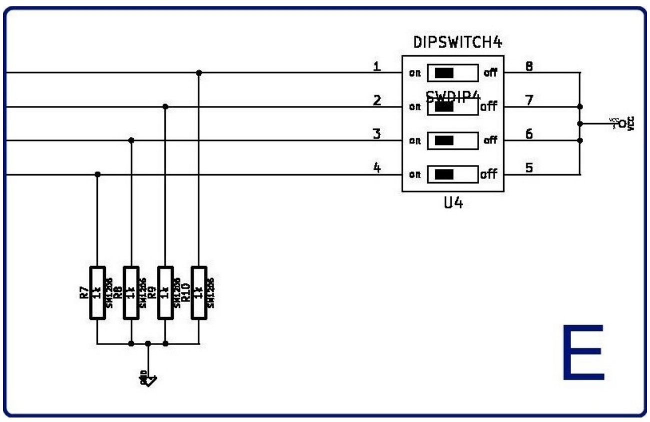


Figure 14: Button input set

Figure 15: Input set for future use

ICSP

ICSP is a special feature of middle and high end devices of Microchip. This interface lets microcontroller to be easily reprogrammed while it is on the circuit. 2 voltage and 3 signalling lines provide connection between the programmer and the microcontroller. Figure 16 illustrates ICSP pin connections.

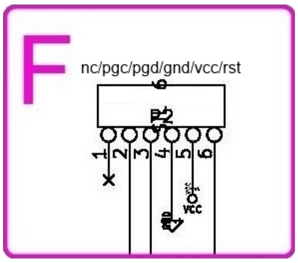


Figure 16: ICSP interface connection

2.1.2 Prototype Hardware Production

The designed module given in the previous section is converted and reorganized into PCB design using KiCAD PcbNew PCB editor. The PCB design constructed to be very compact and small so that it would be easy to adapt it in the possible commercial versions in future. Used circuit parts are all selected in various sizes with SMD case. Only hand soldering possible sizes are preferred.

In Figure 17, 3D view of PCB design and the real PCB are shown. Transfer paper technology is used to produce modules from the design.

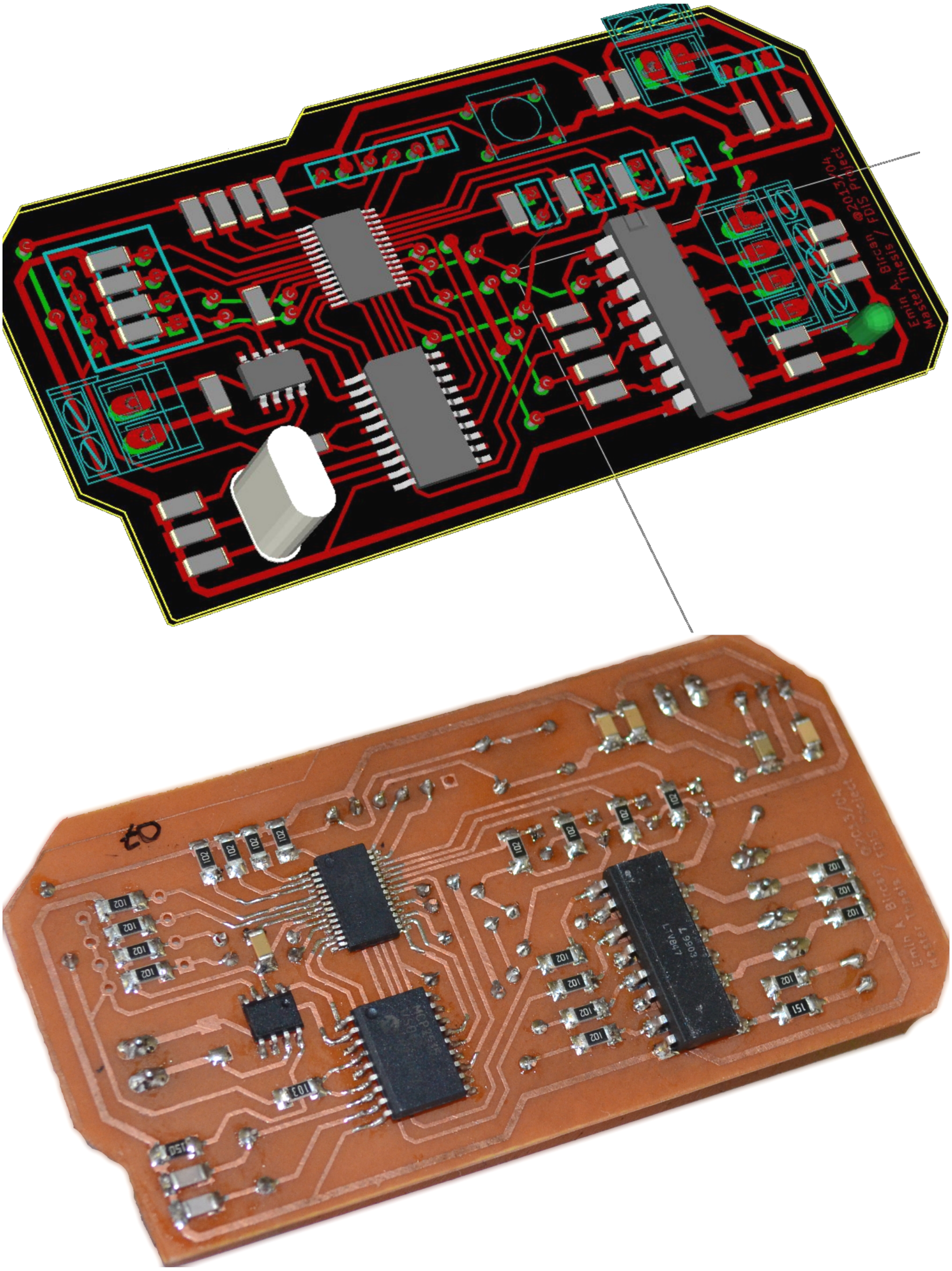


Figure 17: 3D PCB design and produced real PCB

2.2 Test Rig (Experimental Set Up)

To show how the system works a test set up is prepared using 6 pieces of physically produced modules. This set up simulates a house with 3 rooms. The basic schematic representation of the used set up is provided in Figure 18.

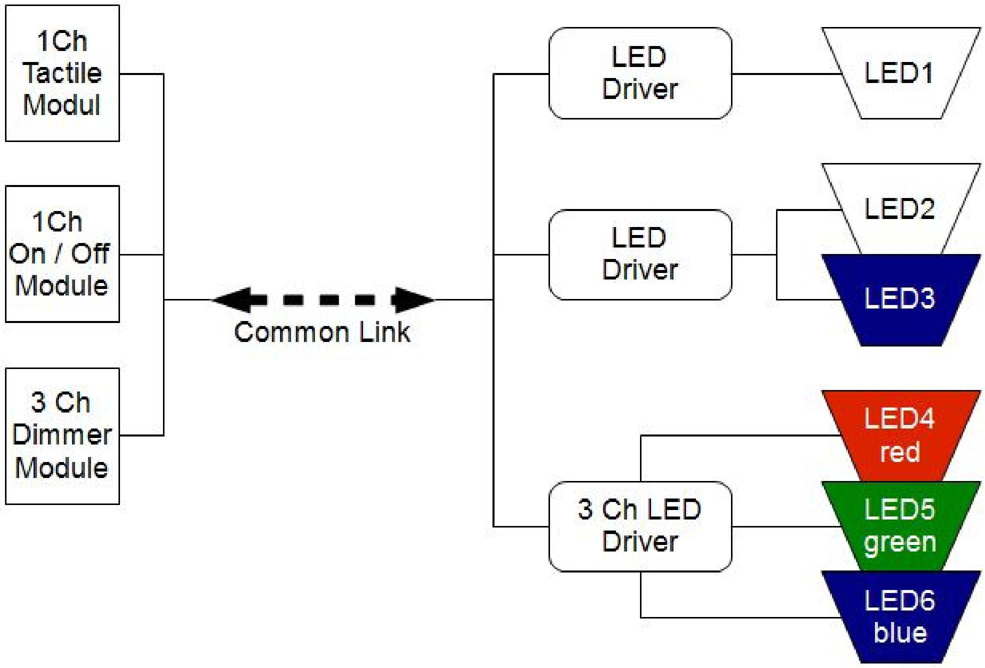


Figure 18: Schematic representation of the used set up

The test rig consists of 3 button modules and 3 driver modules and a power supply.

The tactile module has one button. With each press on this button, the duty ratio of light is inverted. While the lights are off when the button is pressed, the lights are turned on, and vice-versa.

On/Off module has two buttons one to turn on and one to turn off the lights.

3 Ch dimmer module has 6 buttons in total; 2 buttons for each channel. All channels work simultaneously. With each press on plus button of one channel the duty cycle of that channel is slighty increased. Minus buttons are used for decreasing the duty cycle in a similar way.

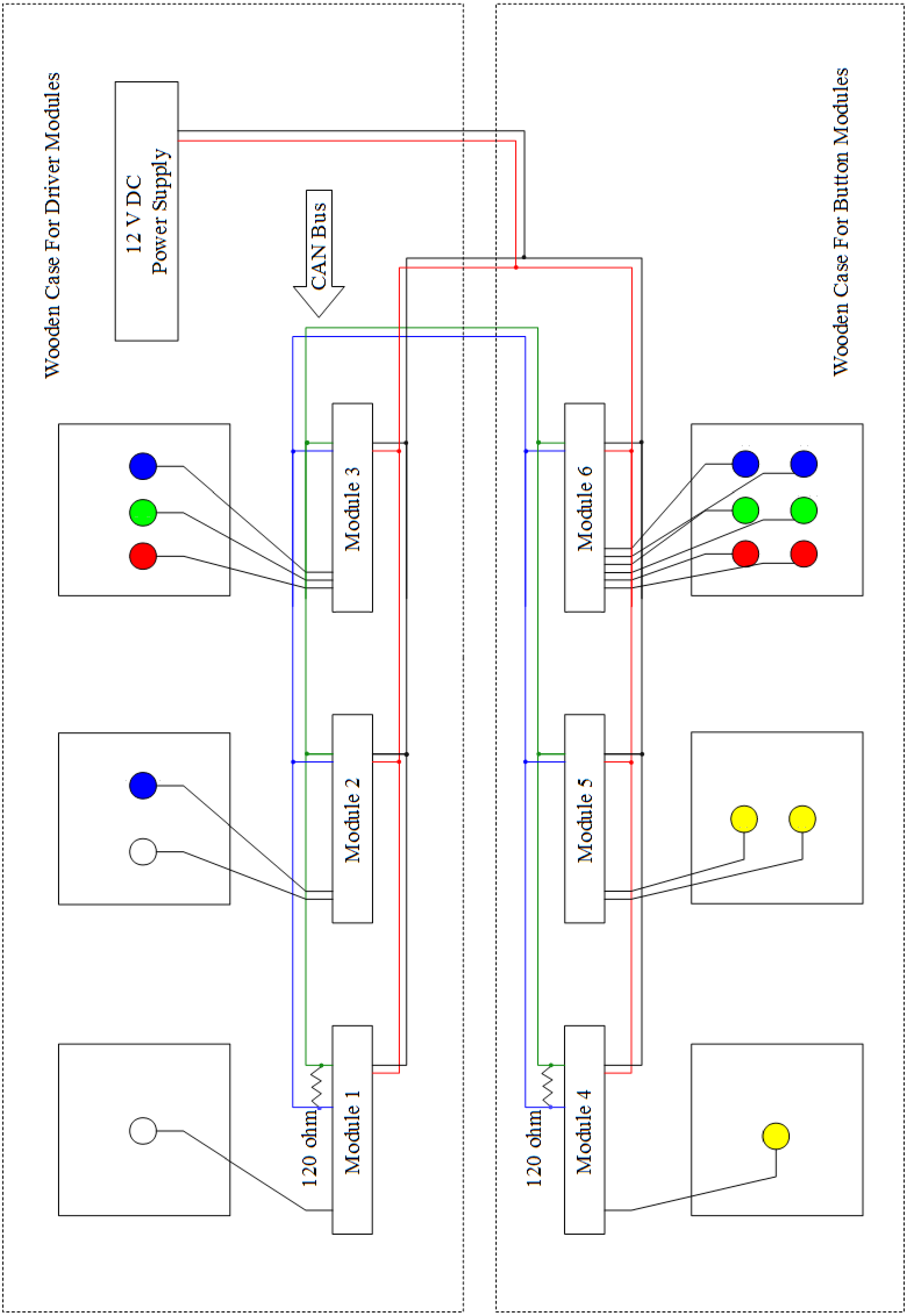


Figure 19: Schematic representation of the test settlement

Except for the number of output channels, the driver modules used in the setup are the same. As illustrated in Figure 19, the first driver operates one channel with white light, the second driver operates two channels (white and blue), the third driver operates RGB output with 3 Ch.

The first button of each module is designed to be multi functioning input. It is used for both light control and the system management. The detail of this multi function button is given in Section 5.1.

3 button modules and 3 driver modules are collocated on a two apart wooden case as shown in Figure 19. These two cases are used to represent the user interface of 3 rooms and the light sources of a house. The button case is shown on Figure 20 and the driver case is shown on Figure 21.

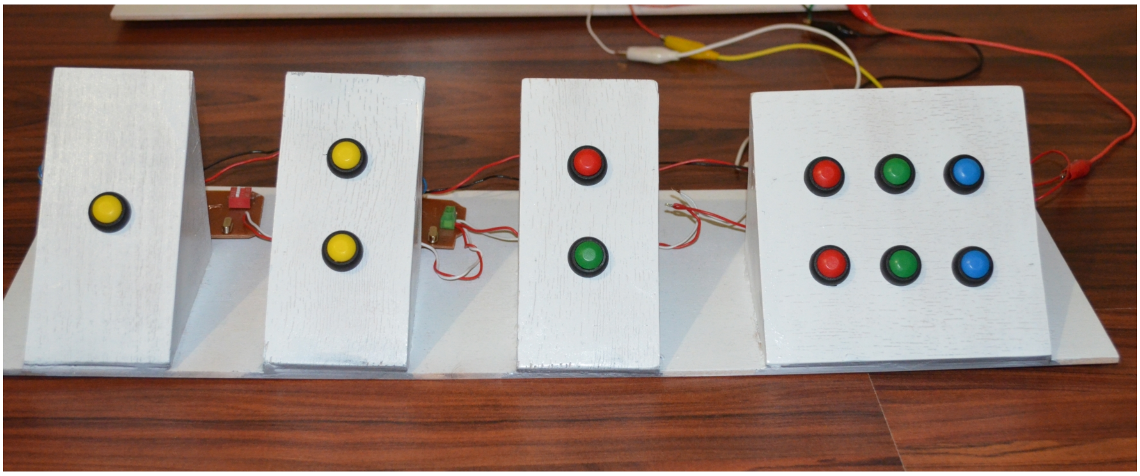


Figure 20: Button modules collected on a wooden case

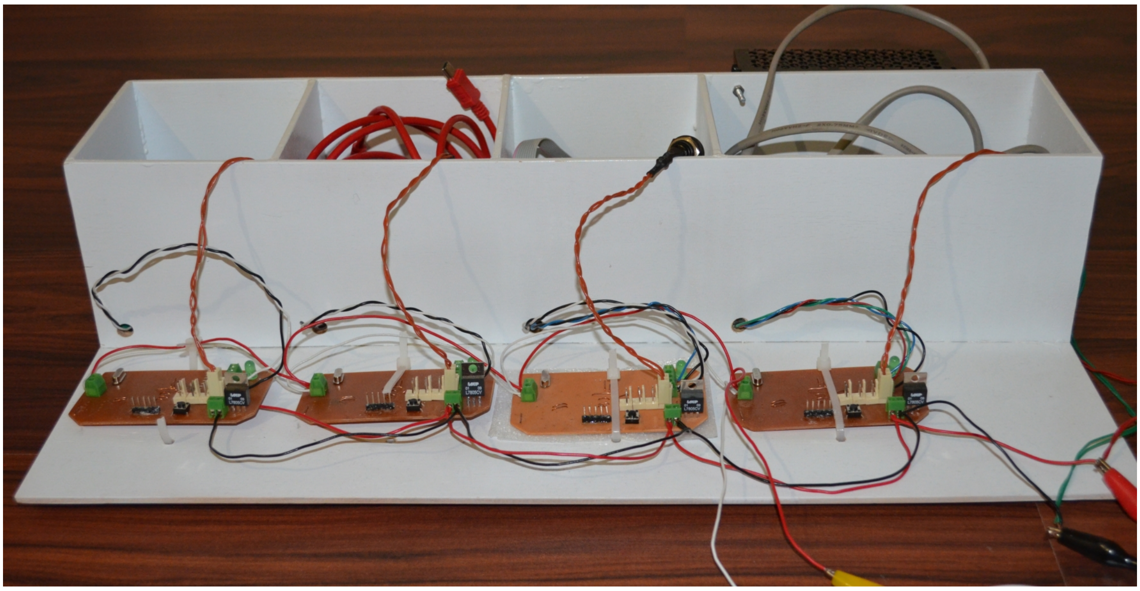


Figure 21: Driver modules collected on a wooden case

One of the four rooms and a button slot are left for trial of different combinations and future purposes. For example, 2 Buttons – 4 Drivers or 4 Buttons – 2 Drivers. These combinations are used for test process of multi coupling pairs.

CHAPTER 3

SOFTWARE DESIGN OF THE PROPOSED SYSTEM

The software design of the proposed system in this thesis is realized by using a well designed program structure and Mikro-C programming language.

In this chapter, firstly program infrastructure secondly the logic of system command set and finally the details of advanced features of the program are presented.

3.1 Top Design Logic

The theory behind this constructed software is straight forward. All of the modules composing the system are programmed with same code and definitions. As a result, all modules in the system know the same commands and the meaning of them according to their module types.

The PIC16F1936 microcontroller has 5 different hardware controlled PWM output channels. This is one of the reasons why it is chosen for this project. The hardware PWM modules enable the main loop run more efficiently. This means that allocated resources for PWM management is minimized. So that program structure may be built on scanning method. In this method, program continuously scans the code without pollings or pauses.

This software is a real-time depending program so any data may occur from CAN Bus or buttons suddenly or unexpectedly. In case of using polling for any inputs source, some data may be missed from inputs.

This problem is simply solved by using scanning method in the main loop. The flow chart of the main loop of the program is illustrated in Figure 22. Just after power up, initialization codes take effect, program continuously scans whether any CAN message is received or any button is pressed. If a CAN message is received or a button is pressed, then the main program gets the acquired data then interprets them under subroutines; *Interpret CAN* message and *Interpret Inputs*.

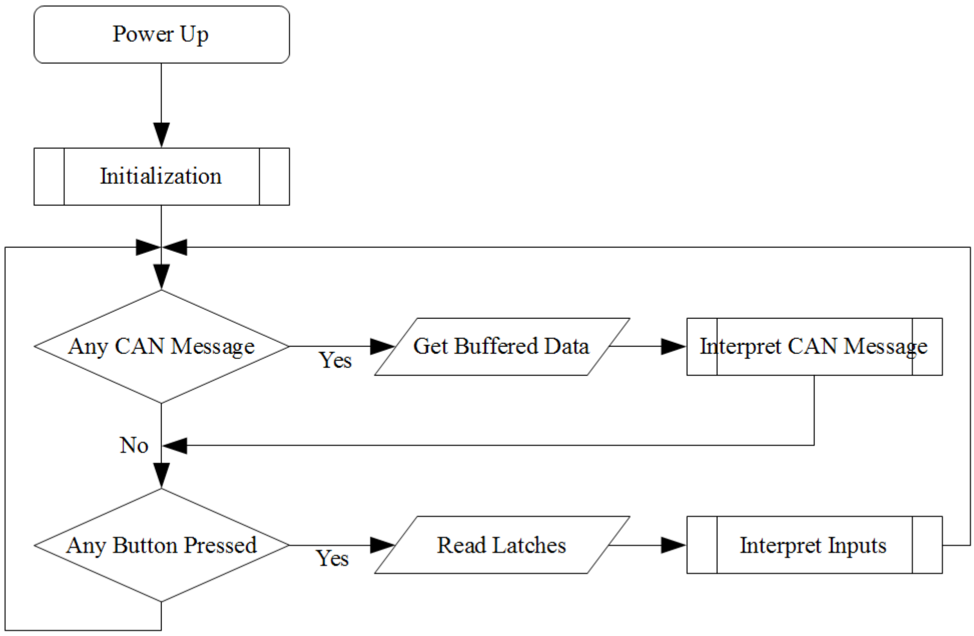


Figure 22: The flowchart of the main loop

As it is seen from Figure 22, the main loop is an endless loop. So program scans forever.

Interpret CAN Message Routine

Interpret CAN Message is a subroutine that is run every time a CAN message arrives into the buffers. These messages are detected by the main loop. Although MCP215 devices may apply some hardware level filters such as automatic ID filtering, it is not used in here. This filter would obstruct the system from making multiple couples to a button module. Modules of already existing systems in industry can be paired with just one module. As mentioned in the system definition, enabling the systems to provide multi coupled modules is a keystone of flexibility concept. Arriving CAN messages are not executed in main loop, they are directly sent to the Interpret CAN Message process. This process is not directly applying any filters too. Instead, it calls the previously defined command sub-routines. ID filtering is not applied at higher levels of program structure. This enables the system to have control over other modules although they are not coupled to each other. For example, Command 110 is written to reset all coupling data in the whole system. However probably there will be un-paired modules to the command generating module. In case of ID filtering applied at higher levels of software structure, such command could not be realized. To solve this problem ID filtering management is distributed over command execution routines. Some of the commands do not require ID information of the sender.

In this routine, command message arrives then routine calls the ordered command's sub-routine. Basic flowchart of Interpret CAN Message process is given in Figure 23. After execution of the command sub-routine; program returns to the main loop.

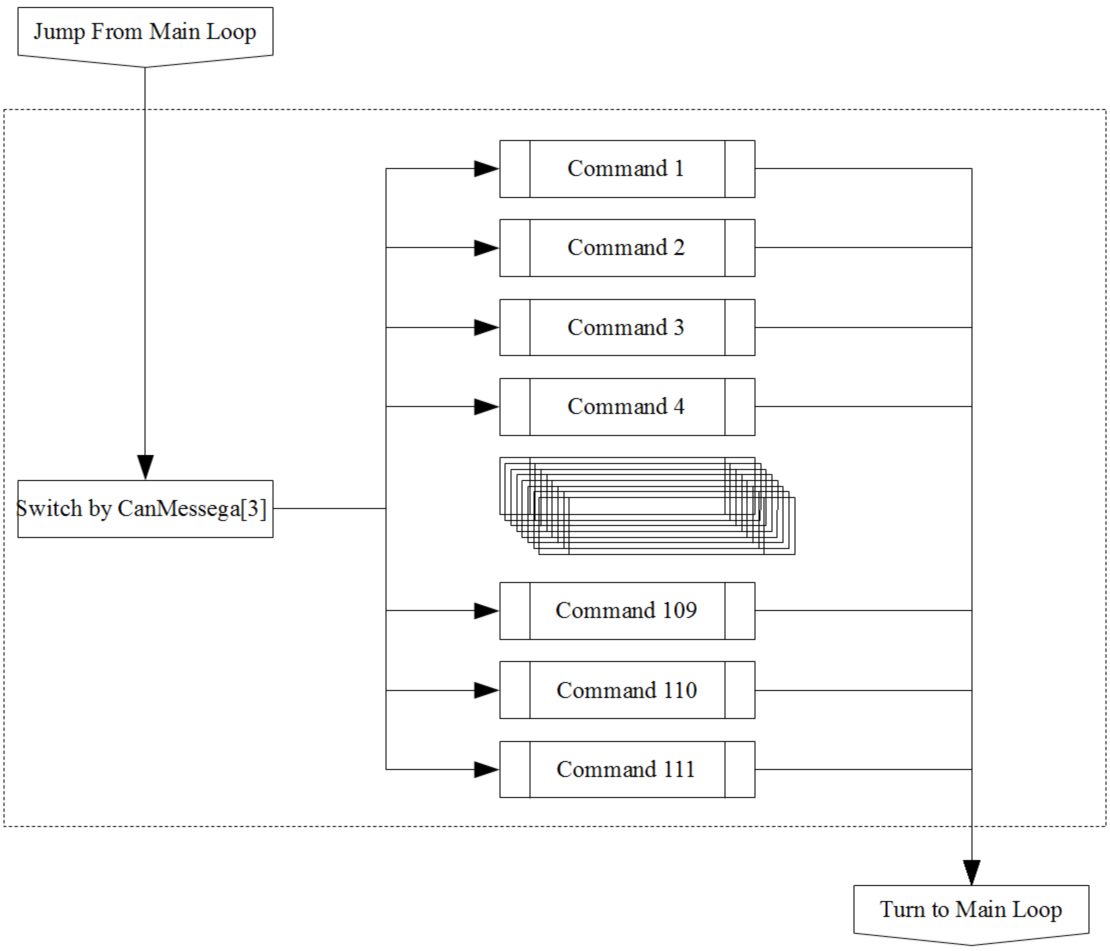


Figure 23: The flowchart of the CAN message interpretation process

Interpret Inputs Routine

This is the second main routine called by the main loop. In this process, predefined commands or routines are called according to pressed buttons. The processes is summarized in Figure 24.

The main loop calls this sub-routine in every main scan of program and in each scan buttons are checked according to their numbers in ascending order. There may be different amounts of buttons and they may generate different commands according to their module types and functions.

In Figure 24 functions of buttons are shown clearly. Button#1 is a special multi-function button. Button#2 is depicted in detail in Figure 24 to show standard button functions. And the grey box represents all other buttons which use the same procedure with Button#2.

Button#1 is a time depended button. While the main program is in normal state (not in coupling mode) button click works the same as all other buttons. In other words it calls related command. On the other hand pressing this button approximately 8 seconds toggles the coupling mode status. This defines whether button works for lighting functions or pairing functions. While in coupling mode, normal button click makes couples with all other modules in coupling mode too. To un-couple pairs the same process should be followed again. 20-25 seconds long presses cause ID check process which makes all modules in the system blink their status LED corresponding to their ID numbers. This function is especially important for debugging sessions. Last function occurs, for presses that takes longer then 50 seconds. This function resets all coupling registers and data through the whole of the system with no doubt or restrictions.

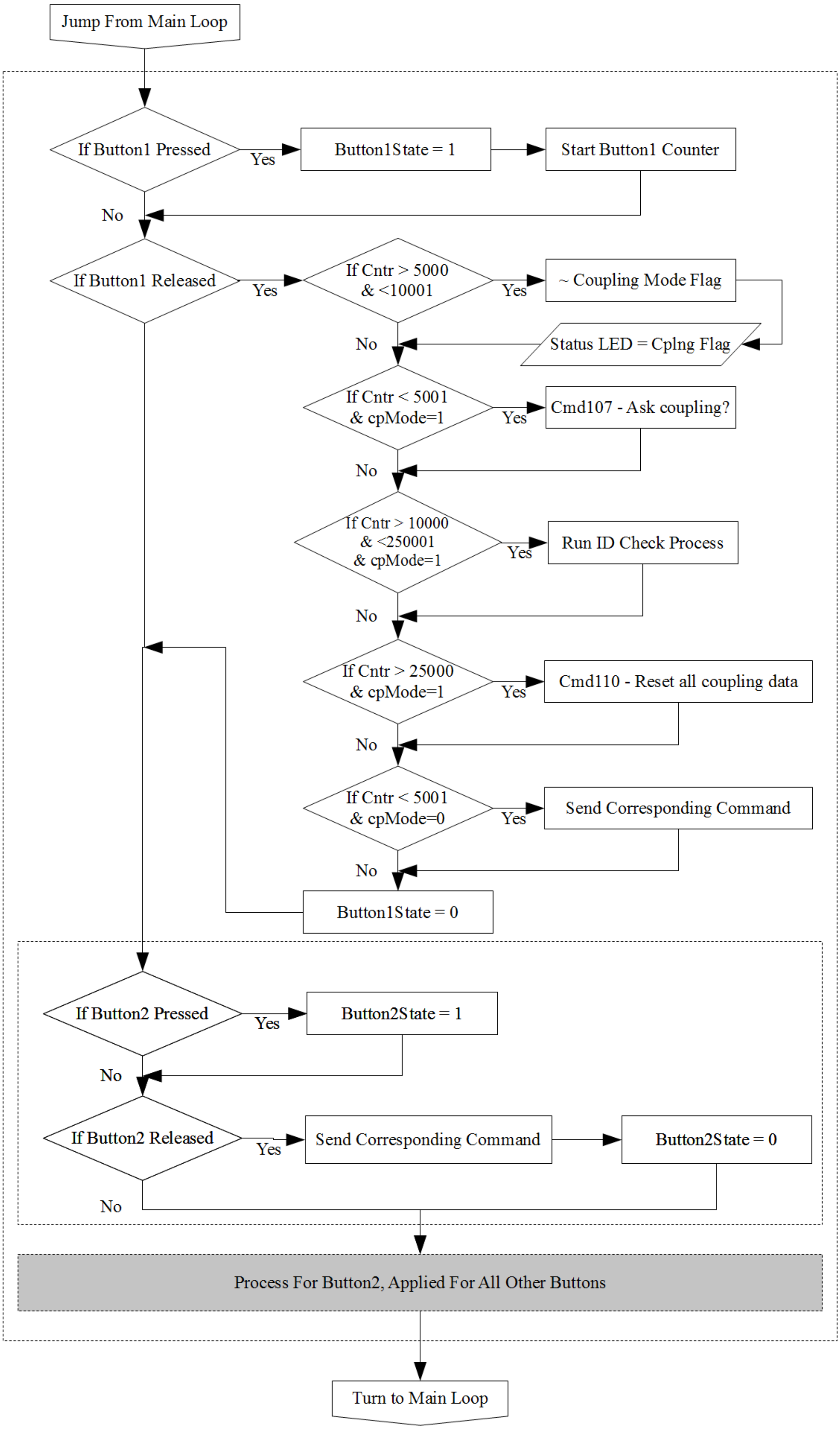


Figure 24: The flowchart of the interpretation process of a button press

3.2 The Command Structure

It is seen in the previous sections that this system uses some fixed commands to communicate. This command structure is designed to be a communication language between modules. Since the system has no master module which dominates and tells what to do to the other modules, it is required to have a language that lets all modules talk to each other.

Table 2 shows the available commands and their structures. CAN Bus have ability to send and receive 8 Bytes in one data package each time. In this command structure all of the 8 bytes are used. Top most row of Table 2 shows the corresponding value in 8 Bytes package. 0, 1 and 7 numbered bytes of command package are reserved for future use. Channel Byte shows which output of the receiver module will be affected. ComNo Byte accepts the command number shown in Table 2. And remaining bytes, Data 1-4 might have several information which are listed in Table 2.

In order to make the command structure idea clear, an example is given. Let us assume that a command is arrived which consists of the [0,0,2,14,0,0,0,0] array. This means, Ch#2 of receiver module should apply 0 Duty Command (14). In short, Ch2 is turned off.

Some brief information about the available commands are provided below.

Command 1: Direct Change

Accepted Bytes: Channel, Data1

Duty cycle of the related PWM output channel is directly set to the value provided by Data1 Byte.

Command 2: Direct Change RGB

Accepted Bytes: Data1, Data2, Data3

Duty cycles of the PWM output channels are directly set to the values provided by Data1, Data2 and Data3 Bytes. Data1-2-3 Bytes sequentially correspond to the red, green, blue channels.

Table 2 : Proposed Commands Table

0	1	2	3	4	5	6	7	
Future Use	**Dest Adress**	**Channel**	**ComNo & Command Name**	**Data1**	**Data2**	**Data3**	**Data4**	**Availabilty**
0			1 Direct Change	Duty				Yes
0		X	2 Direct Change Rgb	Red	Green	Blue		Yes
0			3 Fast Fade	Duty				Future
0		X	4 Fast Fade Rgb	Red	Green	Blue		Future
0			5 Slow Fade	Duty				Future
0		X	6 Slow Fade Rgb	Red	Green	Blue		Future
0			7 Blink					Future
0			8 İncrement By 1					Yes
0			9 İncrement By 10					Yes
0			10 Full Duty					Yes
0			11 Full Duty All					Yes
0			12 Decrease By 1					Yes
0			13 Decrease By 10					Yes
0			14 0 Duty					Yes
0			15 0 Duty All					Yes
0			16 İnvert					Yes
0			20 Change By Time	New Duty	Time			Future
0			21 Ask Current Duty					Future
0			22 Return Current Duty	Current Duty				Future
0			101 Scenario	Sc No				Future
0			106 My Id, Chng Urs İf Collide	Id				Yes
0			107 My Id Xx; Lets Be Pair	Myıd	Pairing Status			Yes
0			108 My Id Xx; I Admit Your Request	Myıd	Pairing Status			Yes
0			110 Reset All Coupling Registers					Done
0			111 İf Your İd=X Blink. Ask For Next	Id				Done

Command 8: Increment By 1

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is incremented by 1.

Command 9: Increment By 10

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is incremented by 10.

Command 10: Full Duty

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is set to the maximum value.

Command 11: Full Duty All

Accepted Bytes: -

Duty cycles of all PWM output channels of all modules existing in the system are set to the maximum value.

Command 12: Decrease By 1

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is decremented by 1.

Command 13: Decrease By 10

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is decremented by 10.

Command 14: Zero Duty

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is set to zero.

Command 15: Zero Duty All

Accepted Bytes: -

Duty cycles of all PWM output channels off all modules existing in the system are set to zero.

Command 14: Invert

Accepted Bytes: Channel

Duty cycle of the related PWM output channel is inverted according to binary operations. Ex: duty = 100d = b01100100

inverted duty = 155d = b10011011

Command 106: My Id is .. Change Yours if Collide

Accepted Bytes: Data1

This command broadcasts ID number of the transmitting modules. Other modules receiving this command on the line increments their ID numbers if it is the same as the received ID number.

Command 107: My Id is .. Lets Be Pair

Accepted Bytes: Data1, Data2

This command broadcasts the transmitting modules ID number. Other modules receiving this command on the line accepts pairing if both the Data2 (Pairing Status Register) and its own pairing status register are positive.

Command 108: My Id is .. I Admit Your Request

Accepted Bytes: Data1, Data2

This command is generated by the modules that received command 107. Module changes couples info then broadcasts its own ID number. Other modules receiving this command on the line accepts pairing if both the Data2 (Pairing Status Register) and its own pairing status register are positive.

Command 110: Reset All Coupling Registers

Accepted Bytes: -

This command is used to impair all coupled modules existing in the system. Once this command is broadcasted all modules in the system reset their coupling array, and coupling status registers. There is no return from this execution.

Command 111: If Your ID=X Blink. Ask For Next

Accepted Bytes: Data1

This command asks all modules if their ID is equal to the value provided in

Data1. In case of any equality the related module blinks its own status LED twice then broadcasts command 111 again however this time Data1 value is increased by 1.

Besides available commands, some other commands planned to be included are shown in Table 2 as futuristic commands. Command 3 to 6 are similar to command 1 and 2. These new commands will be smoothly changing the duty instead of directly changing it. Command 20 is going to change the duty within a specified time interval. Command 21 and 22 are used to learn duties of other modules. Finally, command 101 will enable the user to select some predefined lighting scenarios that will automatically change the duties over the time.

3.3 Advanced Software Routine; Coupling Process

Coupling process is the most important feature of this study as it gives the system a real flexible structure that no system has offered before. This part of the study also presents a patentable value.

It is already mentioned that in existing systems only one module can be paired to another due to their addressing topologies. In this study, the user couples the desired modules as s/he whishes through the offered method without necessity of knowing the address of any module. A simple chart that compares conventional and the proposed coupling topologies is provided in Figure 25.

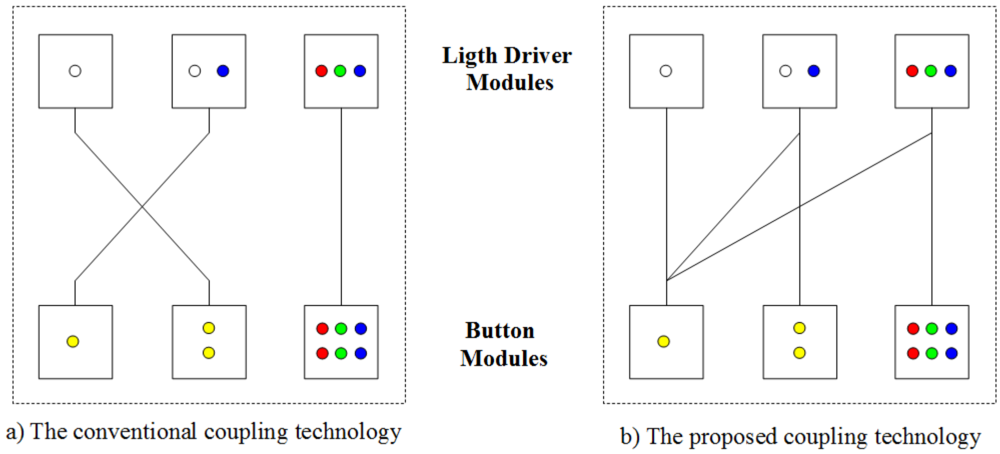


Figure 25: Comparison of old and new coupling capability

In Figure 25(a), the conventional coupling is shown. In such a system a button module can only control one driver module. In Figure 25(b), the proposed coupling method offers unlimited control to button modules. In Figure 25(a) all button modules control their corresponding driver modules. Moreover, being different then usual, the first button module controls all three drivers. By the new coupling algorithm it is possible to obtain any other matching scenarios.

The flowchart of the coupling process is shown in Figure 26. For coupling process the module must be in coupling mode. When Button#1 is pressed once on button module, it generates command 107 to initiate the coupling process. All modules listen to that. However only the ones set in coupling mode react. Firstly they send command 108, meaning coupling is accepted, then they reset their own coupling status after that microcontroller sets the corresponding value in couples array. Finally, the data in couples array is backed up to the EEPROM for the sake of security. The dashed line goes out from command 108 represents the modules which get feedback from others. Again the modules in coupling mode react to this and they set their couples arrays corresponding values then they back up this array. This second procedure guarantees that the first initiator module of coupling process writes to its own “couples array” too.

Yet, in this way it is possible for all modules to know their pairs. On the other hand, to impair any couples the process must be repeated exactly in same way, as the adjustment of couples array works in inversing mode. In short, when this procedure works any two modules are couples, process impairs them, or if they are not a couple then process pairs them.

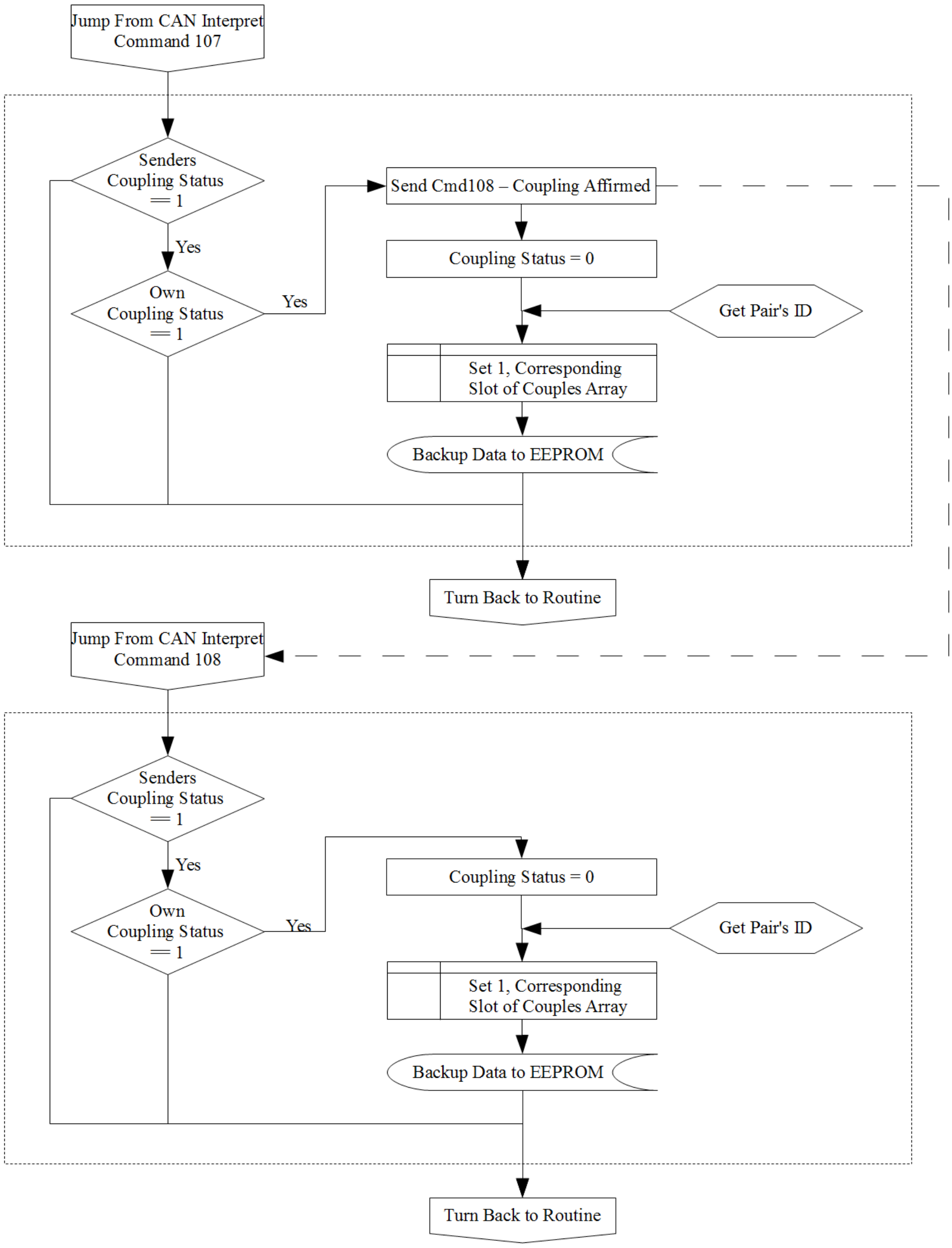


Figure 26: The flowchart of the advanced coupling process

CHAPTER 4

CONCLUSIONS

This study has been carried out in order to establish the conceptual basis of a flexible domestic illumination system and has shown the applicability of this idea by means of an example implementation.

Existing lighting systems, their properties and details of communication methods are considered in this study. Due to high costs and lack of abilities over LEDs and their strict addressing and matching structures, existing systems do not satisfy consumer demands. This requires industry to develop new systems that use features of LEDs efficiently and meet the consumers' futuristic demands examples of which are given trough this thesis.

A prototype has been built up for the proposed Flexible Domestic Illumination System. This prototype system can control LED outputs in various commands such as turn on/off, dim, blink etc. Moreover, the system lets users flexibly make any pair between driver and button units with the help of the proposed coupling algorithm. Hereby users can take advantage of LED sources.

In this thesis, due to the commercial purposes complete details could not be given. However, the conceptual design and prototype designs are presented in detail.

CV

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