SMART LED DRIVER

TANNY LEE CHUIN YIEN

A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons.) Electrical & Electronic Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

May 2011

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ___________________________

Name : ___________________________

ID No. : ___________________________

Date : ___________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"SMART LED DRIVER"** was prepared by **TANNY LEE CHUIN YIEN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical & Electronic at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ___________________________

Supervisor : Dr. Yong Thian Khok

Date : ___________________________

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my final year project supervisor, Dr. Yong Thian Khok for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement throughout the project.

SMART LED DRIVER

ABSTRACT

There is a trend to shift the lightning source towards LED due to the outstanding performance and efficiency. However the major problem faced in order to use LED as the main light source is the difference of operating power. Voltage stepping down conversion is needed since the LED is operating at a lower voltage level. There are many ways to do the conversion and the most efficient way is to use a converter circuit based on the power electronic concept. The main objective of this project is to design and built a smart LED driver. The main function of this driver is to step down the power and voltage rating so that a LED string can be light up when it is directly connected to the main supply. Besides, this driver has an extra feature to add in smart control with the use of a microcontroller. The microcontroller functions as the brain of the whole driver which will receive feedback of the load current and generates control signal accordingly in order to supply a constant current to the load. As summary, the expected outcome for this project is to build a working smart LED driver with the capability and flexibility to add in some smart controls such as the dimming and colour changing applications for the convenient of the user and also to meet the demand of future lighting market. The quadratic buck converter is used as the conversion circuit and with the help of the sensing and feedback system, a smart constant current supply driver for LED was made. A smart LED driver which allows the LED string to function at 67% of its maximum current level with less than 1% of ripple is made.

TABLE OF CONTENTS

DECLARATION				**ii**
APPROVAL FOR SUBMISSION				**iii**
ACKNOWLEDGEMENTS				**v**
ABSTRACT				**vi**
TABLE OF CONTENTS				**vii**
LIST OF TABLES				**x**
LIST OF FIGURES				**xi**
LIST OF SYMBOLS / ABBREVIATIONS				**xiv**
LIST OF APPENDICES				**xv**
CHAPTER				
1	**INTRODUCTION**			**1**
	1.1	Background		1
	1.2	Aims and Objectives		3
	1.3	Outline of Thesis		3
2	**LITERATURE REVIEW**			**5**
	2.1	LED as Lighting		5
	2.2	Advantages of Using LED		8
		2.2.1	Long Life Span	8
		2.2.2	Sizes	9
		2.2.3	Cost	10
		2.2.4	Colours	10
		2.2.5	Energy Saving	11
		2.2.6	Luminous Efficiency	12

	2.1	LED Driver	12
	2.2	Smart LED Driver	15
	2.3	Types of Converter Circuit	18
		2.3.1 Buck Converter	18
		2.3.2 Quadratic Buck Converter	20
		2.3.3 Cubic Buck Converter	21
		2.3.4 Boost Converter	22
		2.3.5 Buck Boost Converter	23
		2.3.6 Cuk Converter	24
3	**METHODOLOGY**		**25**
	3.1	Challenges	25
	3.2	Smart LED Driver	26
	3.3	Quadratic Buck Converter	26
		3.3.1 Modification of the Quadratic Buck Converter	31
		3.3.2 Quadratic Buck Converter Operation	32
		3.3.3 Application of Quadratic Buck Converter in Smart LED Driver	34
	3.4	Sampling and Feedback Circuit	36
	3.5	Smart Controlling System	38
	3.6	Application	42
4	**RESULTS AND DISCUSSIONS**		**44**
	4.1	Experimental Method, Procedure and Equipment	44
	4.1	Quadratic Buck Converter	46
	4.2	Sensing and Sampling	52
	4.3	Smart Control System	54
	4.4	Printed Circuit Board	57
	4.5	Testing Comparison for Breadboard and PCB	59
5	**CONCLUSION AND RECOMMENDATIONS**		**62**
	5.1	Conclusion	62
	5.2	Recommendation	62

REFERENCES **64**

APPENDICES **66**

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Parameter set for quadratic buck converter and load	43
4.1	Testing result for sensing circuit	54

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Conventional LED (Left) and SMD LED (Right)	6
2.2	LED traffic light	6
2.3	High brightness LED street light (Genting Highland, Malaysia)	8
2.4	Size difference for a LED and compact fluorescent bulb	9
2.5	Alam I-City LED tree (Malaysia)	11
2.6	ZXSC310 as flash light driver	13
2.7	ZXSC400 as photo flash driver	14
2.8	Microchip smart LED driver (LED Lighting Solution, 2010)	16
2.9	Colour controlled LED driver with microcontroller (LED Lighting Solution, 2010)	17
2.10	Buck converter circuit (Aziz E. Demian Jr, 2009)	19
2.11	Quadratic buck converter circuit (Aziz E. Demian Jr, 2009)	21
2.12	Cubic buck converter circuit (Aziz E. Demian Jr, 2009)	22
2.13	Boost converter (Boost converter, 2010)	23
2.14	Buck boost converter (Buck Boost converter, 2010)	23
3.1	Theoretical waveform across diode (Aziz E. Demian Jr, 2009)	29

3.2	Cascaded buck converter (Aziz E. Demian Jr, 2009)	31
3.3	Modification of the cascaded buck converter (Aziz E. Demian Jr, 2009)	32
3.4	Simplified quadratic buck converter (Aziz E. Demian Jr, 2009)	32
3.5	Operating stages for quadratic buck converter (Aziz E. Demian Jr, 2009)	33
3.6	Current sampling circuit	37
3.7	Microcontroller programming flow chart	39
3.8	Smart controlling system	41
3.9	Switching optocoupler schematic design diagram	42
3.10	Block diagram of smart LED driver	42
4.1	Schematic of Complete Smart LED Driver	45
4.2	Quadratic buck converter schematic diagram	46
4.3	Input voltage to the quadratic buck converter	48
4.4	Measured output voltage	48
4.5	Simulated output voltage of the designed load	49
4.6	Voltage across MOSFET switch at switching stage	50
4.7	Voltage across capacitor $C1$	51
4.8	Voltage across capacitor $C2$	51
4.9	Signal generated by the feedback circuit	53
4.10	Assigning data to variable	55
4.11	Comparison process	55
4.12	Microcontroller generated controlling signal for the case of feedback current < 20 mA	56
4.13	Microcontroller generated controlling signal for the case of feedback current >20 mA	56

4.14	Combined single board smart LED driver design	58
4.15	Quadratic buck converter schematic diagram (Left) and PCB final product (Right)	58
4.16	Smart Controlling & Feedback System schematic diagram (Left) and PCB final product (Right)	59
4.17	Current measurement during testing stage	60
4.18	Current measurement for final product	61

LIST OF SYMBOLS / ABBREVIATIONS

D	duty ratio
G	gain
t_{on}	on time, s
t_{off}	off time, s
T_s	switching time, s
V_{in}	input voltage, V
V_{out}	output voltage, V
ΔL	current ripple at inductor, A
ΔC	current ripple at capacitor, A
Ω	ohm
V	volte
W	watt

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Computer Programme Listing	66
B	Figures of Smart LED	68

CHAPTER 1

INTRODUCTION

1.1 Background

A light emitting diode lamp is a solid state lamp which uses the light emitting diode (LED) as the source of light. However a single LED supply not significant luminous flow of light as compare to the old type incandescent and the newer compact fluorescent light bulb thus numbers of diodes are used together to provide the sufficient light intensity.

The LED is known as the fourth generation of light source after the incandescent light bulb invented by Humphry Davy at the year of 1809 (Humphry Davy, 2010). As compare to currently used light bulb, the LED light bulb gives more advantages such as long life span, small in sizes, cheap in price, rich of colours and lastly which is the most important current issue, the energy saving (Fu Xiaoyun, 2009). At the same operating voltage and current level to those older generations' light sources, the LED provides much better luminous efficiency and advantages.

The LED technology was developed from the past indicator light until today's high quality LED television and monitor screen and now, the trend is moving towards the lightning source. However the operating voltage and current level for the LED is different from the currently used incandescent, tungsten halogen and fluorescent lamp. The major problem of using the LED in our house hole is that the cost of replacing the whole power supply system due to the different operating voltage level is high. The more economical way of applying the LED is that using a converter circuit. In advance of this, the green concept is important because the energy storage of the earth is becoming less. So other than discovering an alternative energy source, reduce the usage of current available energy source like the petroleum is equally important.

There are many different methods and types of circuit can be used to step down the voltage and current level. The most common way to step down the current and voltage level is using a transformer. Nevertheless this is not a good idea because the cost of a transformer is very expensive, requires frequent maintenance and most importantly, the lifespan in short. The reason for that is because the existence of eddy current, heat and the mechanical and electrical forces. Some may suggest using the current or voltage divider circuit to obtain lower power rating. This is also not a very good suggestion since the excess voltage or current are dissipated as heat moreover the output is changing with the input. This means that significant flickering might be result when the input voltage is not stable.

After comparing all the available alternatives to do the conversion of voltage, the use of a converter circuit is the better solution. There are four commonly used converter circuits which are the buck, boost, buck-boost and cuk converter. For this smart LED driver project, the quadratic buck converter was chosen because it is the most suitable circuit in term of the effective conversion range, cost and stability wise for the application.

A quadratic buck converter is the cascaded version of the ordinary buck converter. It has larger effective conversion range as compare to the ordinary converter with not much effect on the efficiency. Other than this, the switching of the quadratic buck converter is controlled by a microprocessor with pulse width modulation (PWM) technique. This enables the smart controlling process and makes the driver becomes an intelligent smart driver.

1.2 Aims and Objectives

Due to the outstanding performance of the LED over the old type and even the currently using light bulb, it is economically and most importantly environmental friendly to shift the main light source to LEDs. In order to apply this without investing large amount of money, a smart LED driver which can supply a constant current to the LED load directly from the main supply with sensing and control capabilities are needed. In this project, a smart LED driver system with complete feedback and controlling sub system which can supply constant current directly from the main to the LED string with the use of only power electronics concept is aimed to develop. This driver will save more energy due to the efficiency of LED and this is in line with the green environment concept. Other than this, with the flexibility brings by the microprocessor, the load current of the LED can be control at any desired level. Besides the LEDs can also be controlled and produce any visual effect by just feeding back correct data to the microprocessor and process with a proper programming code.

1.3 Outline of Thesis

The literature review on the future trend of lightning source, the advantages of the LED, various types of LED driver are discussed in Chapter 2. The main part of the LED driver is the converter circuit and the differences between them are discussed in this chapter as well.

The methodology and how a complete smart LED driver is built, tested and function is discussed and presented in Chapter 3. The working principle of the three major parts of the driver, i.e. converter, sensing and feedback, is separate and thoroughly discussed.

Chapter 4 presents the testing results on all the three major parts of the LED driver. All of these parts are tested separately and are integrated together into a single smart LED driver once they are functioning correctly.

Chapter 5 is the last chapter of this thesis which discussed on the conclusion, limitation and possible improvement for the driver.

CHAPTER 2

LITERATURE REVIEW

2.1 LED as Lighting

A LED was first discovered at the year of 1962 by Nick Holonyak, Jr. and the only colour is red. This type of red LED is applicable for indication purposes only due to the low brightness characteristic. As times moves, the technology of LED become more advance and until now LED not only replacing those old generations' light source but also expend to other area such as LCD display back light and aircraft instrument panel lighting.

In general there are two common types of LED panels which are the conventional and surface mounted device (SMD). The LED panel is the base of LEDs bulb which used for categorize the LED. Both of the panel comes with large colour profile. This means that both of them can generate different colour for different application. Any colour can be generated with the mixing of different intensity of the three primary colours which are the red, green and blue. For both of the panel, three primary colours' diodes are driven together to form a full colour pixel (NingBo xinyi electronic co., 2007). When they are arranged properly, any visual effect and even to write a word in the signboard become possible.

Figure 2.1: Conventional LED (Left) and SMD LED (Right)

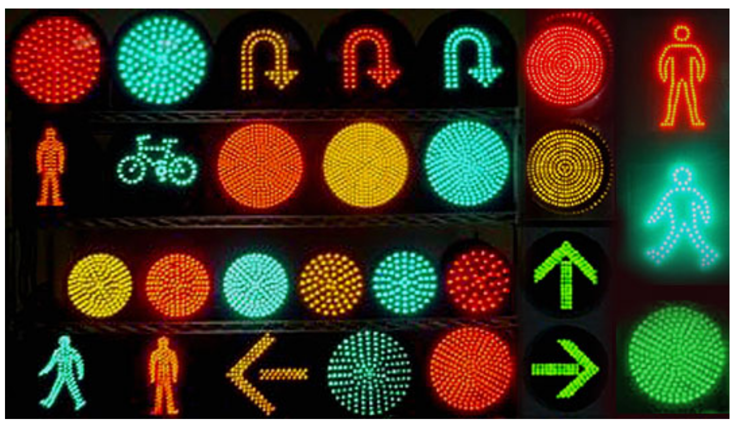


Figure 2.2: LED traffic light

Other than the advantages of large colour profile, LED can also provide high brightness and its efficiency can even replace the major light source using now a day. The high brightness LED becomes available after the invention of the blue LED. A blue LED was first invented by Jacques Pankove in 1971 but it is not very practically used because the material used to build a blue LED is not common and efficient. About 10 years time later, a key breakthrough in GaN epitaxial growth and p-type doping which discovered by Akasaki and Amano which makes the blue LED common to industry. With this blue LED, most of the colours can be generated and most importantly the high brightness white LED was created. The white colour from a white LED is generated by mixing the narrow band blue colour from GaN LEDs and a broad spectrum yellow colour from phosphor coating on the die and this die will absorb some of the blue and converts it to yellow. So the colour generated is actually not purely white but with little green and yellow colour.

A white LED bulb is a very high efficiency light source and there is a trend of becoming the major light source now a day. The efficiency of the light source is measured in lumens per watt. This is the measure of how much light can be supplied from the light source with 1 Watt of power supply. In the year of 2002, a 5 W LED was introduced by the Philips Lumileds company. This LED's efficiency reached 18-22 lumens per watt where the 60-100 watt incandescent light bulb only produces 15 lm/W. This makes the LED become more popular in the lighting market.

The technology of LED does not stop here. At the year 2003, the company Cree, Inc. successfully made a blue LED to give 24 mW at 20 mA. This enable the 65 lm/W white LED to be produced. This is the brightest white LED available at that time which is four times higher efficiency compared to the normal incandescent light. Not long after Nichia Corp. has developed a white light LED with the efficacy of 150 lm/W at the operating current of 20 mA. For now, the efficiency of LED is still improving and the highest efficiency high-power white LED is claimed by Philips Lumileds Lighting Co. with a luminous efficacy of 115 lm/W at the current of 350mA (NingBo xinyi electronic co., 2007).

All of the figures and proves shown that the advancement in LED technology makes a LED become more efficient. This means that with less power consumed, more brightness can be produced and this will greatly reduced the global energy consumption. This is no questionable a very important issue recently due to the shortage of energy source like the non renewable petroleum all around the world and anything which is green is more favourably. In the future, it is very possible that the LED will overtake and replace all the older generations' light source becoming the new generation of light source in the market due to the great advantages to the environment.

Figure 2.3: High brightness LED street light (Genting Highland, Malaysia)

2.2 Advantages of Using LED

LED is the fourth generation light source after incandescent, tungsten halogen and fluorescent lamp. Its environment friendly and outstanding performance characteristics on life span, sizes, price, colours and energy saving makes it becoming the most widely used light source in the electrical and electronic filed.

2.2.1 Long Life Span

The operational time for a white LED lamp under normal condition is around 100,000 hours. This is 4166 days of 24 hours nonstop operating under a normal condition. Basically one LED bulb can last for 22 years without any maintenance and replacement (Corporation, 2007).

The working lifetime of an incandescent bulb is approximately 5000 hours. This means that one may need to change 20 times of the incandescent light bulb but only once for the LED bulb. This not only saves the time but also the cost for maintenance.

2.2.2 Sizes

For the size wise, a LED is not questionable very small as compare to all of the older generations' bulb. Although a single LED bulb does not provide a very significant good luminous flow of light but they can be connected in string and yet consuming less energy to provide the same brightness as the fluorescent lamp. The string connected LED adds flexibility for those who have different requirement on the brightness based on their preference. Even when the LEDs are connected in a string the size is still relatively smaller than the older generation bulb. The benefit of smaller bulb is that the space can be fully utilise while providing better visual effect and in advance this gives additional advantage of building different shapes of LED bulb (Michael Lane,2000).

Figure 2.4: Size difference for a LED and compact fluorescent bulb

2.2.3 Cost

Generally the installation cost has not much different for LED and the traditional bulb. Using the fluorescent bulb, the actual cost is the replacement cost, labour expanses and also the time. As I mentioned in Section 2.2.1, a LED has around 20 times longer lifespan as compare to the fluorescent bulb, this means that the cost of using LED bulb is 20 times lower. All of these factors become significant when they come in large amount. Let us take an example of UTAR Setapak campus. There are more that 300 fluorescent bulbs and tubes in only the SA block and up to two thousand plus for the whole campus. The cost to replace few thousands of bulbs within the campus, hire technicians and spending time can be virtually eliminated or at least reduce by 200 % with the use of the LED bulb.

2.2.4 Colours

Now a day the LEDs are available in a big range of colour including the white light. White light is produced by the mixing of three primary colours; red, green and blue and it provides the maximum luminous flow. With proper intensity mixing of the three primary colours, dramatic range of colour and colour changing effect can be produced such as colour washing, cross fading and random colour changing (Michael Lane, 2000).

Figure 2.5: Shah Alam I-City LED tree (Malaysia)

2.2.5 Energy Saving

A LED bulb is very efficient. 80 % of the energy is converted to light while the remaining 20 % is lost as heat and vice versa for the incandescent type (Michael Lane). Let's take the traffic light signal as example. There are 196 of LEDs for a single red traffic signal which draw 10 W of power. In order to produce the same intensity of red light, 150 W is required for the traditional incandescent light bulb. It is estimated that the power can saves up to 82 % to 92 %. The power saved become extremely large when the traffic lights of the whole Malaysia are considered (Michael Lane).

2.2.6 Luminous Efficiency

The luminous efficiency of white LED is much higher as compare to the incandescent type and also the fluorescent type. For an incandescent white light, the maximum efficiency is around 15 lumens per watt, 70 lumens per watt for fluorescent light and 131-200 lumens per watt for the LED (Daniel A. Steigerwald, 2002). This shows that LED having the best efficiency. On the other hand the LED required less power to operate. Assuming the power of 150 W are supplied, this power can light up 196 LEDs while only one incandescent light bulb. Multiplying the number of LEDs to the efficiency, ideally 25676 lm/W can be achieve and this is more than 100 times of the incandescent type efficiency.

$$196\,x\,131 \;=\; 25676\,lm/W$$

$$\frac{196\,x\,131}{240} \;=\; 106.98\,times$$

2.1 LED Driver

LED has different operating power rating as compare to the ordinary electrical component, so different driver is required to drive the LED under different condition. Normally, the types of LED driver can be classified by its application. There are four major applications which are the portable lighting, general lighting and illumination, backlight and photoflash.

The development of LED driver started after the discovery of a blue LED. Traditionally a LED driver is designed to monitor the visual effect and power supply of LED. So a LED driver is developed based on the application and this trend carries until now.

LED is widely used in the portable application due to the characteristic of energy saving. As the technology of LED becomes more matured, the lumens and efficiency of LED is increasing while the cost of it is decreasing. In market, there are many different types of readymade driver which are used for driving LED under different condition.

The ZXSC310 is a product from ZETEX Semiconductor which is used to drive small amount of LED string for portable device with only battery supply. This driver can be power up by a battery up to 3 V and supply up to 4 high brightness white LEDs. Furthermore the ZXSC310 comes with the dimming function. By changing the connection of the shutdown pin, this driver can be configured and changed the operating mode. When the shutdown pin is connecting to the ground, the driver enters the standby mode and when connects it to the PWM signal, dimming of the LED can be done. Figure 2.8 shows the application of ZXSC310 when used to drive a flashlight.

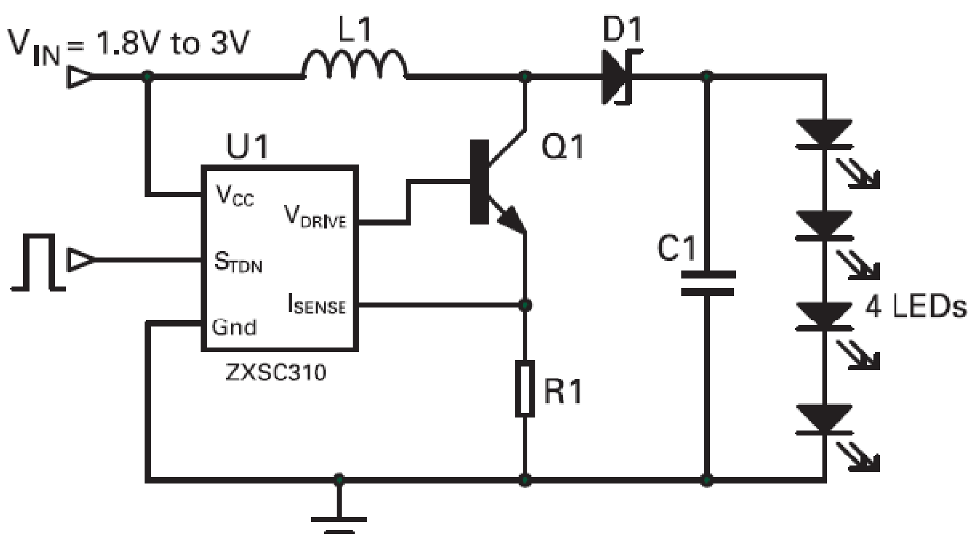


Figure 2.6: ZXSC310 as flash light driver

Other than this, a more unique driver from Zetex is the ZXSC400. This is a special driver which is used to drive a photoflash LED. A photoflash needs large amount of current in a small period of time. ZXSC400 required the input of only 3 V and the maximum output current pulsed can be generated reached 1 A for 2 seconds. The operating function of this driver is quite simple. Firstly the capacitor C_2 will be charged up to the regulated voltage in the charging mode and the driver acts as a boost converter. Later in the discharging mode, driver ZXSC400 acts as a buck converter which functions to provide 1A current to the photoflash LED. This high current which activates for a short duration will boost up the flash LEDs to provide its maximum bright at that particular time. The circuit diagram is shown in Figure 2.9.

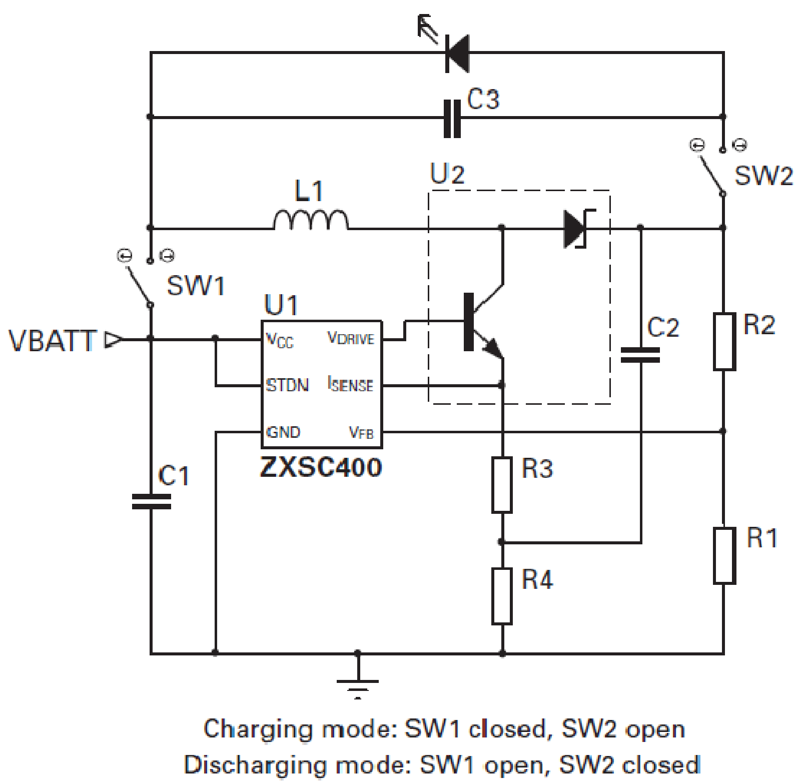


Figure 2.7: ZXSC400 as photo flash driver

For most of the driver designed by Zetex, there is a adjust pin which can be used for some simple control such as the dimming of LED. The dimming control can be done by controlling the current in the LED. It is common to use a proper designed hard wire as the controlling circuit due to its stability. Nevertheless it is not flexible. Any modification on the load required to change the hardware of the design.

For the quadratic buck converter, the switching of the MOSFET switch is controlled by a microcontroller. This gives more flexibility. Whenever there is any upgrade of the load or system, the programming code is the only thing to be updated instead of changing the hardware wire. This not only saves the money of customer but also the precious time and cost for the hardware development.

2.2 Smart LED Driver

A smart LED driver means that the driver comes with the capability to collect data, process it and send out the controlling signals to control the operation or supply of the LED string automatically under certain condition and the controlling can be done by either hardware or software.

It is very common to use hardware as the controlling media. The advantage of using hardware is that the signal is more stable. All of the signals are sent through wire and this enhances the reliability. Nothing is perfect in this world, the drawback of the hardware design appear when the users want to upgrade or modified the sensing device or the controlling system. As the connection is fixed, modification of the driver becomes difficult and costly. At most of the time, the entire driver needs to be redesign and replaced although there is only small a changes to the controlling circuit.

It is completely different story when the software is used instead of hardware. A software controlled microprocessor can be updated anytime to enhance the performance of the driver at almost zero cost. Since the programming code is the one controlling the logic and algorithm of the driver, any additional application can be done by proper changing of the programming code and this can be even done without the presence of an engineer or technician because the code can be updated through internet.

The purpose of software control smart LED driver can be achieved with the use of a microchip PIC microcontroller. The design shows in Figure 2.8 is the application of a smart LED driver with the use of a microcontroller PIC10f202.

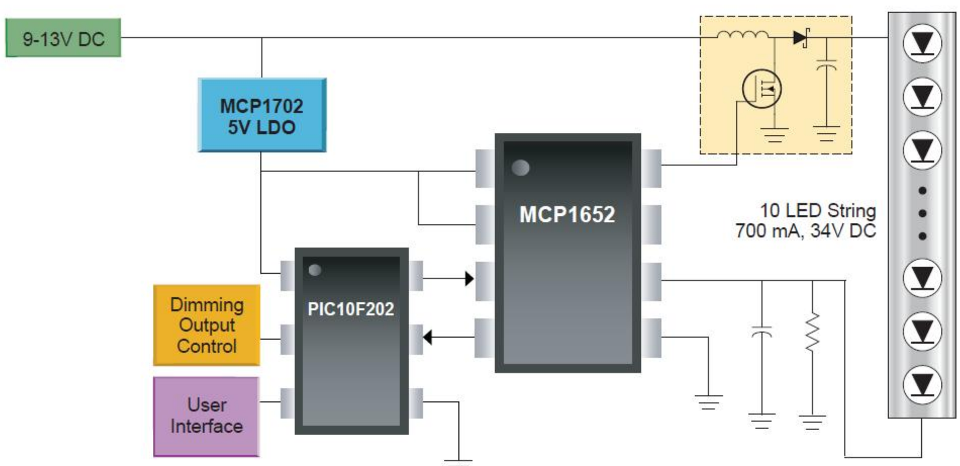


Figure 2.8: Microchip smart LED driver (LED Lighting Solution, 2010)

As in Figure 2.8, the MCP1702 is a 5 V voltage regulator. The regulator ensures a constant supply of 5V to the PIC and also the MCP1652. The MCP1652 is a 750 kHz gated oscillator boost controller which packaged in an 8 or 10 pins MSOP package. It works as a voltage booster to supply constant power to LED string. The PIC10F202 adds the intelligence to the driver. With proper programming and the correct use of sensors, any smart controlling required by the user such as thermal protection, load open or short circuit protection and even a user interface to control dimming or show the battery condition can be done. This intelligence makes the driver a more complex system which brings benefit to the development of LED lighting system.

Smart controlling not only use for lighting up an LED, colour mixing can also be done with a proper programming to the microcontroller. In order to generate different colour, three different intensity of the primary colour are mixed. Just like the Figure 2.7, with proper control of the base current for the transistors of all the three LEDs, almost all the colour could be generated.

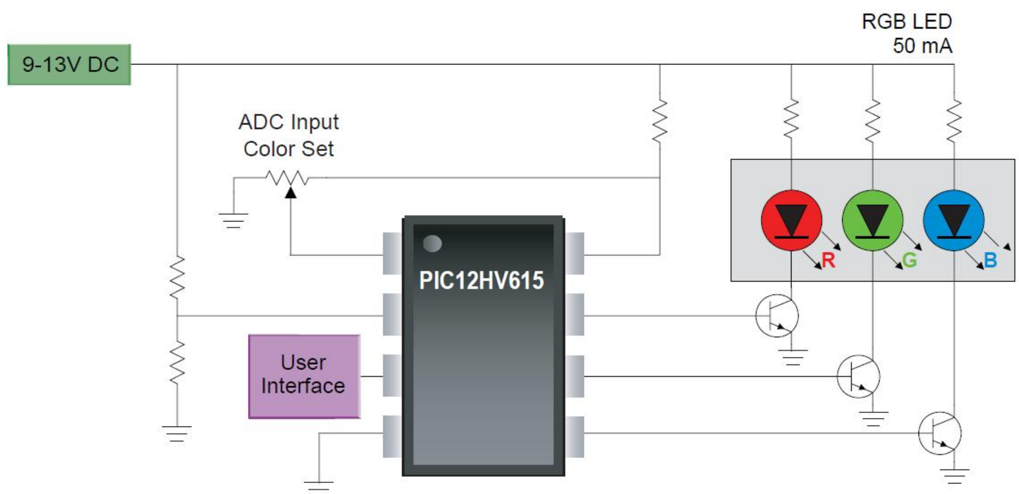


Figure 2.9: Colour controlled LED driver with microcontroller (LED Lighting Solution, 2010)

In a nut shell, the possibility of the intelligence added to the LED driver with the use of a microcontroller further enhance the technology of using LED as the major light source. This is a great move in saving energy while giving high brightness and a comfortable environment to the user.

2.3 Types of Converter Circuit

The main purpose for the LED driver of this project is to step the input voltage to a suitable level so that the LED string can be light up when directly connect to the main and there are few types of voltage stepping converter available. The four common converts available are the Buck Converter, Boost Converter, Buck-Boost Converter and also the Cuk Converter (Edwin van Dijk, 1995). As the name indicated the function for a converter is to convert or stepping the voltage level to higher or lower rating. Each type of these converter works well for different type of application. For this project, the Quadratic Buck Converter which is under the Buck Converter family was chosen as the stepping converter.

2.3.1 Buck Converter

Buck converter is a stepping down converter. Its design is very similar to the boost converter which is built up from active and passive switches, capacitors and also the inductors.

In fact, there are many different ways to reduce or step down the voltage level. Two of the most commonly used methods are the divider circuit and transformer. As mentioned in the introduction section, there are few weaknesses using these two methods hence the buck converter is the better choice.

There is more than one type of design for the buck converter circuit. Actually the types of converter circuit under the same family are built up by cascading the basic buck converter. As the basic structure is cascaded, the dependence of the duty cycle is reduced while providing wider conversion range without going into the discontinuous conduction mode (DCM) (Dragan MaksimoviC, 1991). One thing to highlight is that the buck converter circuit needs to operate under an extremely low duty cycle ratio in order to prevent flickering and the lowest switching frequency is limited by the minimum on time of the transistor switch (Aziz E. Demian Jr, 2009).

$$D = \frac{t_{on}}{T_s} \tag{2.1}$$

where

$t_{on} = Inductor\ on\ time$

$T_s = Switching\ Period$

$D = Duty\ Cycle$

Figure 2.10 shows a classical buck converter circuit. The basic operation of this converter is based on the current stored in the inductor. This type of circuit is designed to work under continuous conduction mode (CCM) so that the output is constant. This also means that the current level of the inductor never goes to zero. The charging and discharging process is depends on the on and off time of the switch S. With the pulse width modulation (PWM) technique the switching process can be controlled.

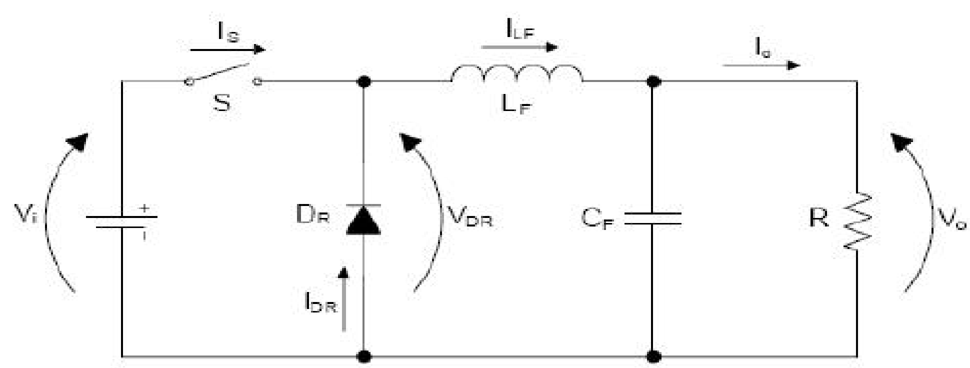


Figure 2.10: Buck converter circuit (Aziz E. Demian Jr, 2009)

There are two operating stages for buck converter. The first stage is when the switch S is on. The source will provide energy to the load and at the same time charging up the inductor. In the second stage, the switch is controlled to open. At this stage, the energy stored in the inductor during the last stage will flow and supply to the load. This process is possible since the diode D_R is forward biased (Aziz E. Demian Jr, 2009).

2.3.2 Quadratic Buck Converter

A quadratic buck converter is the cascaded version of the Buck Converter. This converter solve the problem of limitation on lower switching frequency since it only quadratic dependence on the duty cycle and simultaneously increase the range of conversion between the input and output.

As mentioned in Section 2.3.1, buck converter circuit needs to operate under CCM and this is also applied to quadratic buck converter. If the on time of the inductor is too long, the energy stored in the inductor might dropped to zero and hence go into the discontinuous conduction mode (DCM). When the inductor current level dropped into the DCM, the load LED bulb will experience flickering. Since this circuit only quadratic dependence on the duty cycle, the influence of duty cycle on the LED bulb which will cause flickering is reduced. Figure 2.11 shows the schematic diagram of a quadratic buck converter.

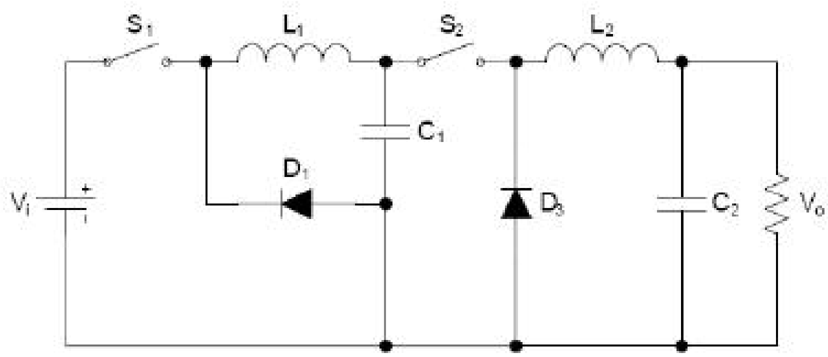


Figure 2.11: Quadratic buck converter circuit (Aziz E. Demian Jr, 2009)

2.3.3 Cubic Buck Converter

The idea of cascading the basic buck converter can be extend to the triple cascaded buck converter named the Cubic Buck Converter. This converter not only provides even less dependence on the duty cycle but also wider the conversion range as compare to the buck and quadratic buck converter (Aziz E. Demian Jr, 2009).

$$G = \frac{V_o}{V_i} = D^3 \tag{2.2}$$

$$\sqrt[3]{G} = D \tag{2.3}$$

where

$V_o = Output\ Voltage$

$V_i = Input\ Voltage$

$G = Circuit\ Gain$

$D = Duty\ Cycle$

Since this circuit is aimed to step down the voltage level, thus the smaller the gain is better. A smaller gain leads to larger conversion range and it is shown on Equation 2.2. The gain of this triple cascaded step down converter has a relation of directly proportional to the power of three of the duty cycle, thus with the same duty cycle as quadratic buck converter, the cubic buck converter gives larger range of conversion; proven by Equation 2.3.

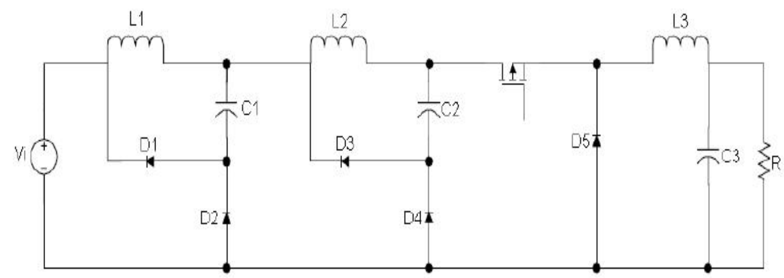


Figure 2.12: Cubic buck converter circuit (Aziz E. Demian Jr, 2009)

2.3.4 Boost Converter

A boost converter is known as the power step up converter which means the output voltage level is step up to higher level as compare to the input. This circuit consists of inductor and diode only. Since the power needs to be conserved thus the output current is smaller as compare to input (Buck Boost converter, 2010).

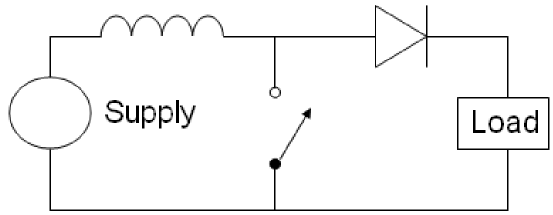


Figure 2.13: Boost converter (Boost converter, 2010)

The operation is quite similar to the buck converter circuit. The only different is that this circuit is operating under the DCM.

2.3.5 Buck Boost Converter

This converter consist the characteristics of both buck and boost converter. It can be used to step up or step down the voltage level. The main disadvantage of this type of circuit is that there is no ground terminal for the switch (STMicroelectronics, 2007). This brings trouble for designer as the output terminals are different to the input terminals. Other than this, it has not much different from the buck converter circuit.

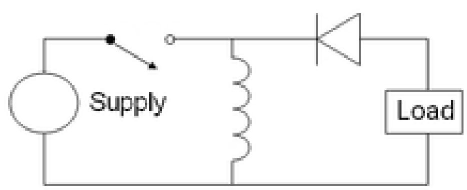


Figure 2.14: Buck boost converter (Buck Boost converter, 2010)

2.3.6 Cuk Converter

A cuk converter is also a common type of the voltage conversion circuit. It is just like the buck boost converter which can step the voltage level either to higher or lower level with opposite polarity between input and output terminals. However this type of driver uses the capacitor as the energy storage component instead of inductor (Ćuk converter, 2010).

CHAPTER 3

METHODOLOGY

3.1 Challenges

The major problem faced in order to use LED as the main light source is the difference of operating power. Voltage stepping down conversion is needed since the LED is operating at a lower voltage level. There are many ways to do to conversion and one of the easiest ways to do so is using a transformer. However this is not a good idea because there are many drawbacks of using transformer such as the life span and heating problem. An alternative and better way to achieve the objective of this project is to use a converter circuit based on the power electronic concept.

The power utility company in Malaysia, Tenaga Nasional Berhad (TNB) supplying 230 V_{ac} as the main supply to housing estate and this level of voltage is too high for a LED and for sure will burn the LED light bulb almost instantly when directly connected to the main. Furthermore a diode needs direct current to function thus a proper design converter is required to convert the supply from AC to DC and at the same time stepping down the voltage to a suitable level based on the load connected.

Other than that, the heat is also a factor needed to be take care of. Most of the time the LED light bulb is broken down not due to the life span but the heat. Although LED emit less heat but the high power LED which comes in few tens of size will still release significant heat and this high temperature will probably burnt the diode. On the other hand the electronic components used is the driver will also produce heat, thus proper cooling system is needed to elongate the life span of the driver.

3.2 Smart LED Driver

Generally, there are three major parts to build up a complete smart driver which are the quadratic buck converter, sampling and feedback and the smart control system. Every part is interconnected and works as a whole system to supply, sample, feedback and control the current supply to the LED.

The functioning concept for the whole system is that the high power rating source is supply to the quadratic buck converter after converting into DC. The quadratic buck converter will step down the power rating and supply to the load. Than the output current is sampled and send to the microcontroller (PIC) for data process. From the data obtained and compare to a reference value, the duty cycle controlling the switch is change accordingly and this is what controlling the current flow to the load.

3.3 Quadratic Buck Converter

The quadratic buck converter is roughly introduced in the Section of 2.3.2. Now the more detail analysis and application is discussed.

Among the common converters introduced in Chapter 2, the quadratic buck converter was chosen to be used as the smart LED conversion driver in this project. The reason for choosing this converter is that it is able to supply constant low power and voltage output from high input voltage without falling into DCM. This is very important because failing to maintain the operation in CCM will cause significant flickering to the load LED and this is also one of the main limitations of the designed LED driver for this project. Secondly this type of converter required a microcontroller to control the switching process and hence the smart controls become possible with just some sensing device and programming.

Normal white conventional LED is used in this project as the load and it needs 3.0 V to the maximum of 3.6 V and 25 mA to operate. For a string of 52 series connected white LED light bulb the voltage needed is 170 V and the current of 25 mA. The output voltage of 170 V is set based on the gain and the duty cycle. With this operating voltage level, the design needs 52 series connecter LEDs. This string of LEDs is able to provide 980 lumens of light with the efficiency of 2722 lm/W (Aziz Elias Demian Junior, 2009).

Besides, the quadratic buck converter is quadratic dependence on the duty cycle. This means that the switching process has only quadratic effect on the storage of current energy in the converter circuit which allowing the converter to function under CCM even operating at a large conversion range. This characteristic enable the effective conversion range extended significantly. The gain of a converter is the ratio of the output voltage to the input voltage and due to the quadratic dependence characteristic, the effective range of conversion which supplying a constant output is multiplied larger than the basic buck converter.

$$G = \frac{V_o}{V_i} = D^2 \tag{3.1}$$

$$\sqrt[2]{G} = D \tag{3.2}$$

where

$V_o = Output\ Voltage$

$V_i = Input\ Voltage$

$G = Circuit\ Gain$

$D = Duty\ Cycle$

Equation 3.2 (Aziz E. Demian Jr, 2009) shows that for the same duty cycle as the original buck converter, the gain of the circuit can be stepped 2 times lower and this leads the effective conversion range doubled up. The relation relating the duty cycle to the gain is proven below:

$$t_{on} = D$$

$$t_{off} = (1 - D)T$$

$$(V_{in} - V_{out})DT - V_{out}\,(1 - D)T = 0$$

$$V_{out} - DV_{in} = 0$$

$$D = \frac{V_{out}}{V_{in}} = G$$

where

$t_{on} = time\ for\ inductor\ supply\ energy$

$t_{off} = charging\ time\ for\ inductor$

$T = Period\ of\ a\ Complete\ Cycle$

$V_{out} = Output\ Voltage$

$V_{in} = Input\ Voltage$

$G = Circuit\ Gain$

$D = Duty\ Cycle$

The flickering of the light is virtually eliminated because the inductor is working under CCM. In order to make sure that the inductor is always functioning under CCM, an extremely low duty cycle is needed (Equation 2.1) (Aziz E. Demian Jr, 2009). Low duty cycle means that the inductor is in the charging mode for most of the time and for a very short period to act as the source. The minimum on time (t_{on}) is limited by the operation of the active switch and this is the factor limiting the circuit performance. Quadratic buck converter having quadratic dependence on the duty cycle hence the minimum t_{on} virtually seems to be smaller and the effect of flickering is eliminated.

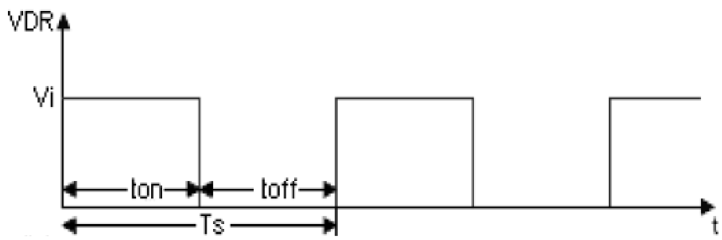


Figure 3.1: Theoretical waveform across diode (Aziz E. Demian Jr, 2009)

The next advantage is the stable and simple design. Since the majority components in this circuit are the passive element thus it is very stable and in addition, there is no dissipative element used. This makes the driver can works for a longer period hence reducing the maintenance cost. In order to ensure the long life span, the electrolyte capacitor is not used (Aziz E. Demian Jr, 2009). Although this will lead some ripples to the output but the net effect is not significant and will not be noticed by human eye so this component is discarded.

Thirdly is the advantages bring by the advancement of power electronics. Power electronics system is the circuit or system to process and control the flow of energy or power from input source optimally suited to the users' load (Chew, 2010). A quadratic buck converter uses only non linear components. There is a big difference of working principle between the linear and power electronics. All the electronics and electrical components can be categorized into these two major families. The method to differentiate them is by the working principle. Take a transformer as an example. A transformer is functioning under the linear region which means that when the input rise the output will change accordingly and the excess energy is dissipated as heat. This is totally different in power electronics. A transistor in the circuit will act like a switch, not in the linear region but fully on or off. This makes the power loss is minimized and hence the heating problem which will shorten the life cycle of the component.

Now a day, it is very popular to add communication link to the driver for the purpose of smart controlling. This purpose can be easily achieved by adding sensing devices and the appropriate programming routines into the microcontroller. The microcontroller provides a programmable and flexible platform for the purpose of controlling the in and output power, dimming, colour mixing, movement sensing and many other smart controlling applications (Design Forum - Intelligent Driver, 2010) for the purpose of more comfort and easy life.

Lastly, the chosen design is the “good enough” design in terms of cost, efficiency and also the conversion range. Comparing the quadratic buck converter to the basic buck converter, it provides larger conversion range. The conversion range had been discussed in the Section 2.3.3. Although the cubic buck provides much wider conversion range but for my project vice, the conversion range is enough for my application and more importantly, on the point of view of cost, fewer components are used for the quadratic buck circuit which means the production cost is cheaper. Other than that, the flickering problem is virtually eliminated due to the characteristic of quadratic dependence of the duty cycle.

The boost converter is not suitable for my application because it is used to step up the voltage and power rating but for LED application, it needs lower output power. Although the buck boost converter is seem to be more flexible to be used due to the capability to step up and down the power rating but this circuit is not as simple and steady as compare to the buck converter and this is also the reason why the cuk converter is not chosen. Shortly speaking, the buck converter is the best choice for the purpose to drive the LED bulb among the available designs and under the buck converter family, the double cascaded quadratic buck converter is the good enough choice.

3.3.1 Modification of the Quadratic Buck Converter

A quadratic buck converter is the cascaded version of the simple buck converter. One drawback for this design is that the total efficiency is reduced (Aziz E. Demian Jr, 2009). This is due to the loss in the switching device. Thus the circuit should be modified and for the simplified version only one active switch is used in order to reducing the switching loss.

The buck converter circuit consist of a LC filter, one active switch and one passive switch (diode). The circuit diagram is shown in Figure 2.3. Cascading two buck converters means two LC filters, two active switches and two diodes are required and the circuit is shown in Figure 3.2 (E. E. CARBAJAL-GUTI ´ERREZ, 2005).

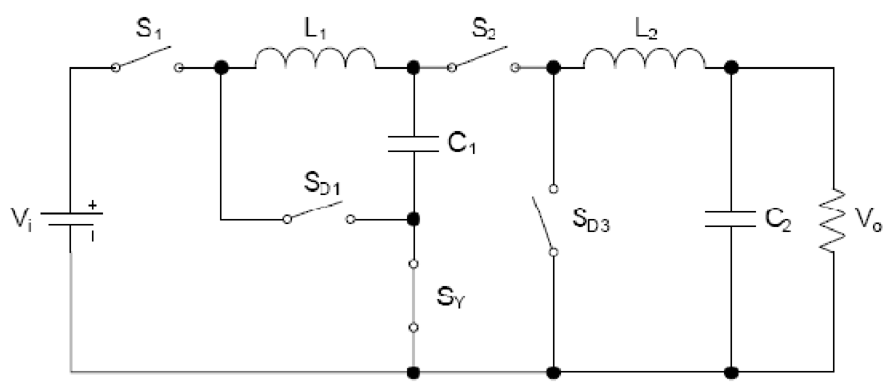


Figure 3.2: Cascaded buck converter (Aziz E. Demian Jr, 2009)

Referring to the Figure 3.3, the position of the S_1 is changed with the switch S_Y, this cause no different to the circuit. Since the S_Y is always closed, it can be treated as a wire connection and for the S_1 switch, it is substituted by a passive switch. The modified circuit is shown at the Figure 3.4 which uses only an active switch, pair of LC filters and three diodes. This circuit reduces the switch loss by almost 50 % (only 1 active switch is used) while providing the same output efficiency.

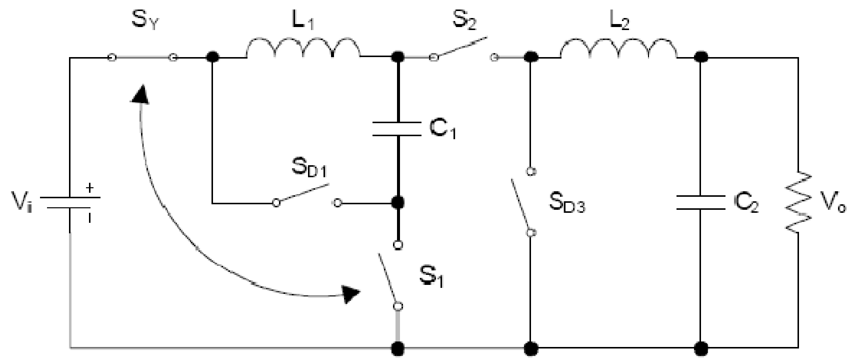


Figure 3.3: Modification of the cascaded buck converter (Aziz E. Demian Jr, 2009)

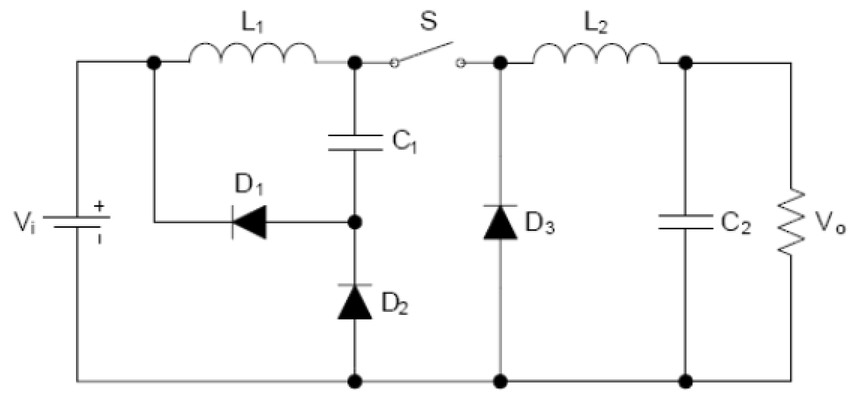


Figure 3.4: Simplified quadratic buck converter (Aziz E. Demian Jr, 2009)

3.3.2 Quadratic Buck Converter Operation

Just like the normal buck converter, the quadratic buck converter has two operating stages when operating under the steady state and CCM.

On the first stage, the switch is closed and the source and also the energy in capacitor will supply energy to the load and at the same time the energy is stored to the inductor. In this case, the diode D_1 and D_3 are reverse biased and the D_2 is forward biased. This enables the inductors been charging up and at the same time supplying energy to the load.

Come to the second stage, the switch S is opened. The D_1 and D_3 are now in the forward biased mode thus alloying the current stored in L_1 and L_2 flow through each of them and supply to the load. These two stages are changing in the frequency of 100 kHz so it appears to be a constant supply to the load (Aziz E. Demian Jr, 2009) and the operating two stage is shown in Figure 3.5.

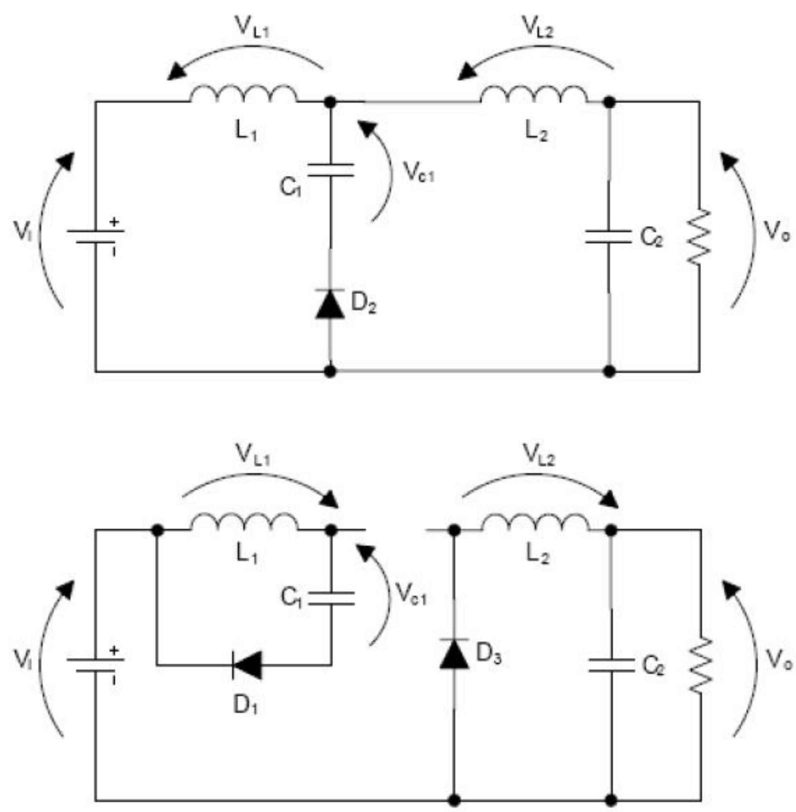


Figure 3.5: Operating stages for quadratic buck converter (Aziz E. Demian Jr, 2009)

3.3.3 Application of Quadratic Buck Converter in Smart LED Driver

The operation principle had been discussed earlier in the Section 3.3.2. There are two things added into the original quadratic buck converter design which are the bridge rectifier and also the resistor. The function of the bridge rectifier is to convert the AC input to the DC before feed into the converter. This is necessary since the buck converter is a DC to DC converter. Besides there are two resistors used to limit the current flow of the circuit before connecting to the load. This is important since a very high current will almost instantly burnt the LED string. One thing to highlight is that the resistor used is the 5 W resistor. The source is directly connected from the main and the power rating can shoot to very high thus a higher power rating's resistor is required.

The calculation for the inductor and capacitor used in the design is shown below and for a more stable output, the same but lager value was used for both the first and second components of inductor and capacitor.

$$G = \frac{V_o}{V_i} = \frac{60}{224} = 0.2679$$

$$D^2 = 0.2679$$

$$D = \sqrt{0.2679} = 0.5175$$

$30\%\ of\ current\ ripple\ is\ allowable$

$$\Delta I_{ripple} = \%\ allowable\ ripple \times I_o \tag{3.3}$$

$$\Delta I_{ripple} = 0.3 \times 0.02 = 6mA$$

$$L_1 = \frac{V \cdot D \cdot (1-D)}{\Delta I_{L1} \cdot f_s} \tag{3.4}$$

$$L_1 = \frac{224 \cdot 0.5175 \cdot (1 - 0.5175)}{0.006 \cdot 100k} = 0.0932\ H$$

$$L_2 = L_1 \cdot D \tag{3.5}$$

$$L_2 = 0.0932 \cdot 0.5175 = 0.0482\ H$$

$$C_1 = \frac{V_i \cdot D \cdot (1-D)}{8 \cdot {f_s}^2 \cdot \Delta V_{C1} \cdot L_1} \tag{3.6}$$

$$C_1 = \frac{224 \cdot 0.5175 \cdot (1 - 0.5175)}{8 \cdot 100k^2 \cdot 67.2 \cdot 93.2m} = 0.112\ \mu F$$

$$C_2 = \frac{V_o \cdot D \cdot (1-D)}{8 \cdot {f_s}^2 \cdot \Delta V_{C2} \cdot L_2} \tag{3.7}$$

$$C_2 = \frac{60 \cdot 0.5175 \cdot (1 - 0.5175)}{8 \cdot 100k^2 \cdot 18 \cdot 48.23m} = 0.2157\ \mu F$$

where

$G = Gain$

$V_o = Output\ Voltage$

$V_i = Input\ Voltage$

$D = Duty\ Cycle$

$\Delta L_{ripple} = Current\ Ripple$

$\Delta L_1 = Current\ Ripple\ Through\ L_1$

$\Delta L_2 = Current\ Ripple\ Through\ L_2$

$\Delta C_1 = Current\ Ripple\ Through\ C_1$

$\Delta C_2 = Current\ Ripple\ Through\ C_2$

3.4 Sampling and Feedback Circuit

The sampling and feedback circuit is the second part of the smart LED driver which functions to feedback the load current to the microcontroller data process and smart control.

Unfortunately only the signal of voltage is understood by the PIC while the current flow is what the desire feedback. So a sampling circuit is required to sample the load current instead of directly feed in the output signal. Other than this, the current level in mA scale is too small for the PIC to take reference so amplification to the current level is also needed.

Figure 3.6 shows the current measuring circuit of the driver. A very small value resistor (R_5) is connected in series with the load so that the current will pass through it but withdraw no current. The resistor R_5 is known as the sensing resistor. This resistor is purposely added to sample the current rating and later been amplified to the suitable range for a PIC to do comparison.

The Op-Amp is function as a differential amplifier, which subtract the two input signals and gives the difference of them. In the design, 5 V is used as the reference. When there is a current flow through the sensing resistor R_5, different potential between the two inputs of the op-am after amplification can be obtained and this value will be send to the PIC microcontroller for comparison.

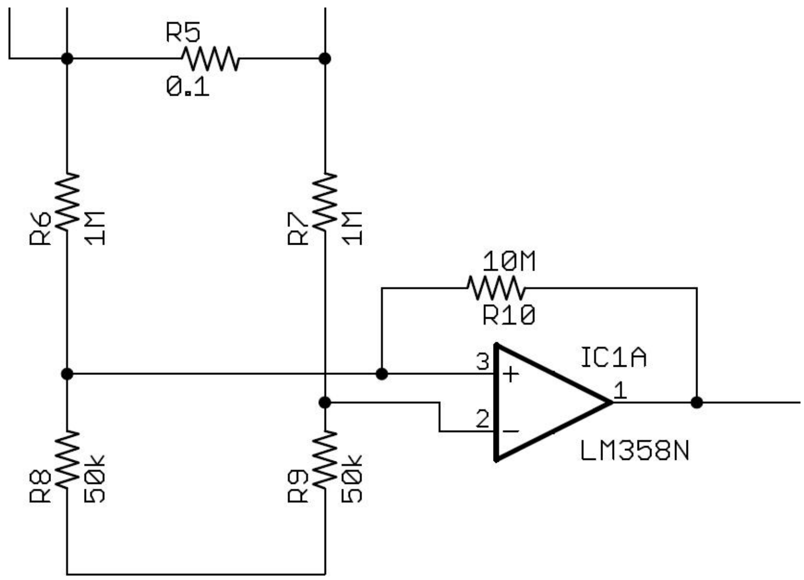


Figure 3.6: Current sampling circuit

For the design of a current sampling circuit, the range of the op-amp's output which indicating the load current and the amplification level need to be set. For this project's design, the range of measurement is set to 100 which mean that the PIC will be able to measure the current for the range from 0 to 100 mA with a built in 8 bits ADC. The 8 bits ADC means that there are 256 blocks in binary. The input voltage to the ADC is 1.96 V which able to generate the output of 100 counts (from 0 to 100 mA). The maximum output current from the feedback is 100 mA and at this point, the maximum input voltage to the op-amp is 0.01 V. With these two values, the gain required for measuring the interested range of current is 196. However the gain of 196 is not that practically used so the gain of 200 is chosen. All the calculations are shown below:

$$V_{ADC} = \frac{V_{ref} \times gain}{ramge\ of\ ADC} \tag{3.8}$$

$$V_{ADC} = \frac{5 \times 100}{256} = 1.96V$$

$$V_{in} = \max current \times sensing\ resistance \tag{3.9}$$

$$V_{in} = 0.1A \times 0.1\Omega = 0.01V$$

$$Gain = \frac{V_{ADC}}{V_{in}} \tag{3.10}$$

$$Gain = \frac{1.96}{0.01} = 196 \approx 200$$

For proving, let the input current to be 20 mA. The input of the op-amp is 0.002 V and the voltage of ADC is 0.4V. For the PIC, 5 V is the maximum value which representing the block of 256. For the 0.4 V output from the op-amp, 20.48 which representing the block of 20 is the result and this shows that the output current flow is 20mA. This proved that the data obtained by the PIC and the real current flow in the circuit is matched.

$$V_{in} = 0.02A \times 0.1\Omega = 0.002V$$

$$V_{ADC} = 0.002A \times 200[gain] = 0.4V$$

$$\frac{0.4}{5} \times 256 = 20.48$$

3.5 Smart Controlling System

Smart controlling system is the third part of the driver which is also the most interesting part of the whole driver because it gives the flexibility and intelligent to the classical LED driver.

The PIC16F873A microchip is used in this project due to the good functionality and cheap in price. The flow chart of the controlling program routine is shown in the Figure 3.7.

The sampled load current is firstly feed into the microchip's first built in analogue to digital converter (ADC); pin 2 to convert the analogue voltage signal into digital. Than the current rating in digital form is compare to a preset reference value which in the case of this project is 20 mA. Whenever the feedback current is larger than the reference, the duty cycle generated by the microchip which controlling the switch will be decreased and vice versa. With this, the output current can be controlled at a desired level and thus to light up the LED string.

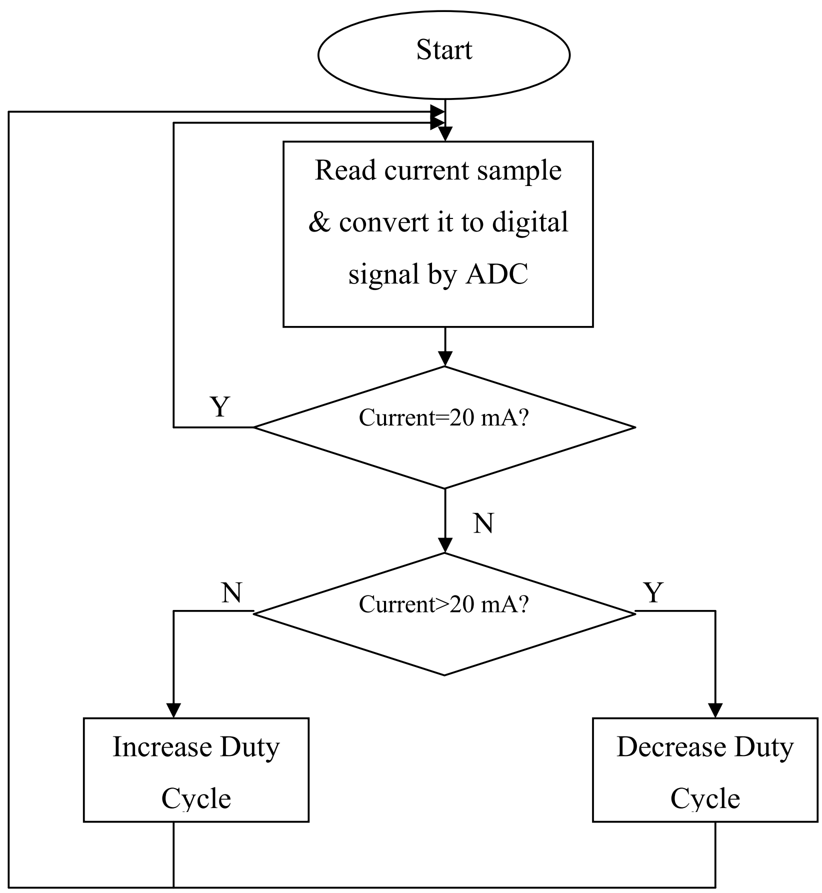


Figure 3.7: Microcontroller programming flow chart

The duty cycle generated from the microchip is based on the pulse width modulation (PWM) concept. For the case where higher duty cycle is required, the period of the on signal is elongate while maintaining the period of off signal. This will eventually increase the duty cycle and for the case of lower duty cycle is needed the off period will be elongated in order to tune down the duty cycle.

The programming was done using the PIC C Compiler since it is easier to program rather than the lower level programming language. The C language is used to write the code than it will be compile into binary code and later being programmed into the PIC with the universal lab programming tool. The code itself is quite simple and self explained and the complete code is attached in the attachment section.

As the Figure 3.8 shown, the feedback signal from the op-amp is feed into pin 2 for data process. As usual the pin 1 which having a resistor series with it is connected with pin 11 and 32 and later to 5 V source. This is to clear the memory after the source is turn off. Similar for the V_{ss} pin; pin 12 and 31 are connected to the ground. For clock cycle oscillation, external clock with crystal oscillator and capacitor parallel with it is connected. This is for controlling the clock cycle of the process. Lastly pin 33 is set as the output pin. This controlling signal provides the duty cycle of the switching period.

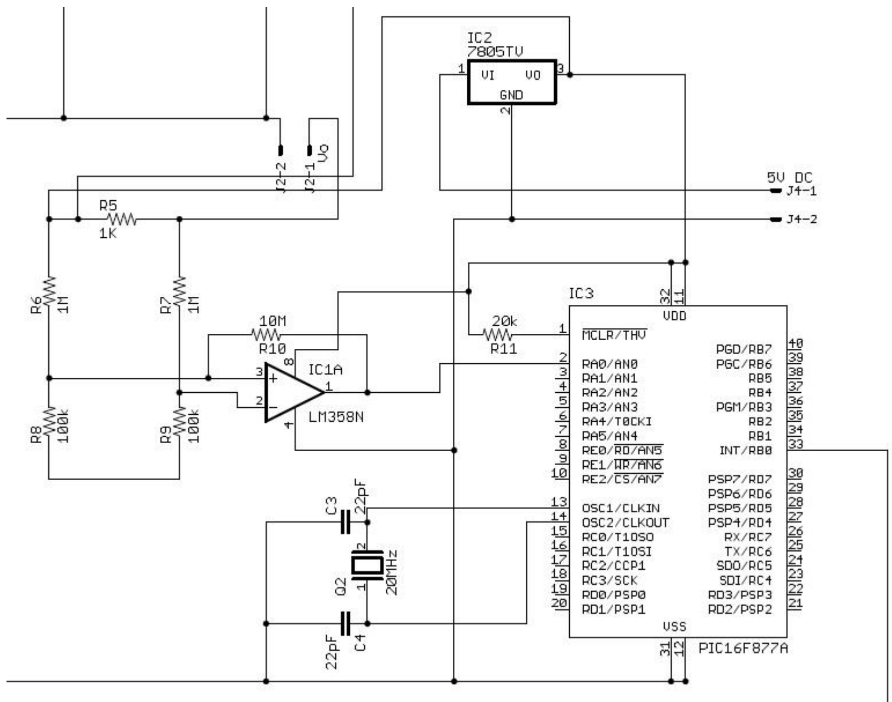


Figure 3.8: Smart controlling system

In order to drive the quadratic buck converter in the fast enough switching speed, an n-channel MOSFET IRFP250 switch is used to open and close the circuit. However, the output directly from the PIC is not sufficient to switch the power MOSFET switch. Thus an extra power source is required. In the design, an optocoupler is used to switch the MOSFET switch according to the PIC signal.

The actual function for an optocoupler is to exchange signal between two different power ratings' circuits while electrically remain isolated but for this project, the optocoupler is used in a slightly different way. There are two major parts in an optocoupler which are the source of light and a photo sensor. When the signal from the PIC passes through the light source, light will be emitted and the photo diode which received enough intensity of light will act like a closed switch; allowing the 12 V DC to flow through. By parallel the gate of the MOSFET switch at the pin 4 of the optocoupler, the supply of 12 V DC will switch the MOSFET switch according to the duty cycle generated from the PIC.

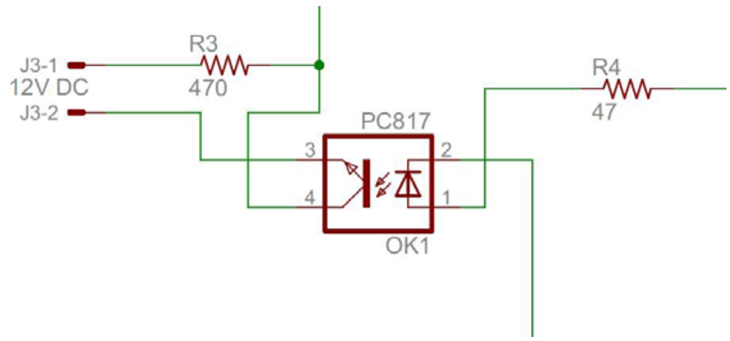


Figure 3.9: Switching optocoupler schematic design diagram

3.6 Application

Based on the calculation and researches, the final and complete smart LED driver was made and the rough schematic diagram shown in the Figure 3.10. Table 3.1 listed out the specification and components used in the smart LED driver.

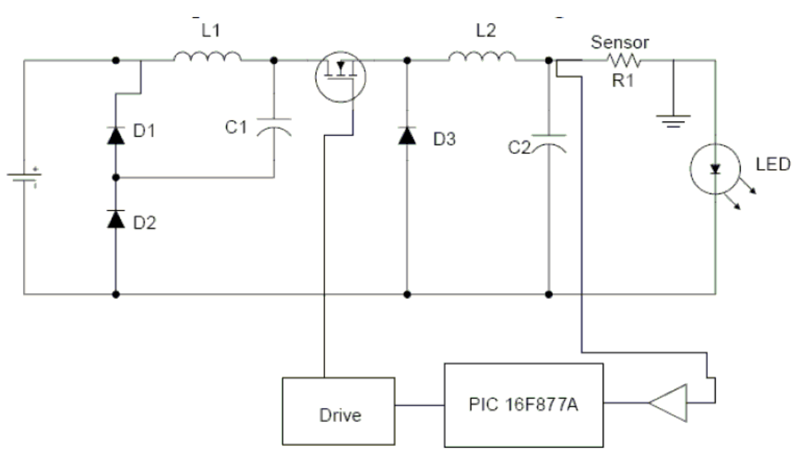


Figure 3.10: Block diagram of smart LED driver

Table 3.1: Parameter set for quadratic buck converter and load

20 Series Connected LED	
PARAMETER	**VALUE**
Nominal Voltage	60 V
Nominal Current	20 mA

Quadratic Buck Converter	
PARAMETER	**VALUE**
Input Ac Voltage	220 V
Switching Frequency	100 kHz
Input Current	36.2 mA
Output current	20 mA
Switch	IRFP250
Inductor x2	100 mH
Diode x3	IN5408
Capacitor x2	220 nF

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Experimental Method, Procedure and Equipment

Under this chapter, all the results obtained from simulation and actual testing were presented and discussed section by section. There are generally three major parts to build up a complete smart LED driver which are the quadratic buck converter, sensing and feedback circuit and lastly the smart controlling system. All of them are interlinking to convert, detect, process and control the voltage and current level based on the designed.

Figure 4.1 shows the complete schematic diagram of a smart LED driver. The functioning concept of this driver is that the power supply directly from the main is converted in to DC source before feed into the converter circuit. Than the quadratic buck converter will step down the voltage level to the suitable rating for the LED string and light them up. The sensing and feedback circuit is used to sample the load current and later feed into the microcontroller for data process. With a proper designed program wrote in to the microchip, the corresponding controlling signal will be generated to control the MOSFET switch thus the load current.

One thing to mention is that there is no linear electrical and electronic components used in the smart LED driver but there are two transformers used for this protocol. Actually they do nothing but just stepping the voltage from main to 12 V and later back to 230 V. This is just the precaution step to isolate the testing circuit from directly connected to the main because very large current which might probably cause explosion and kill people will be flowing if there is any accidentally shorting and for a well made smart LED driver which is going to be used practically, both the transformers can eliminated.

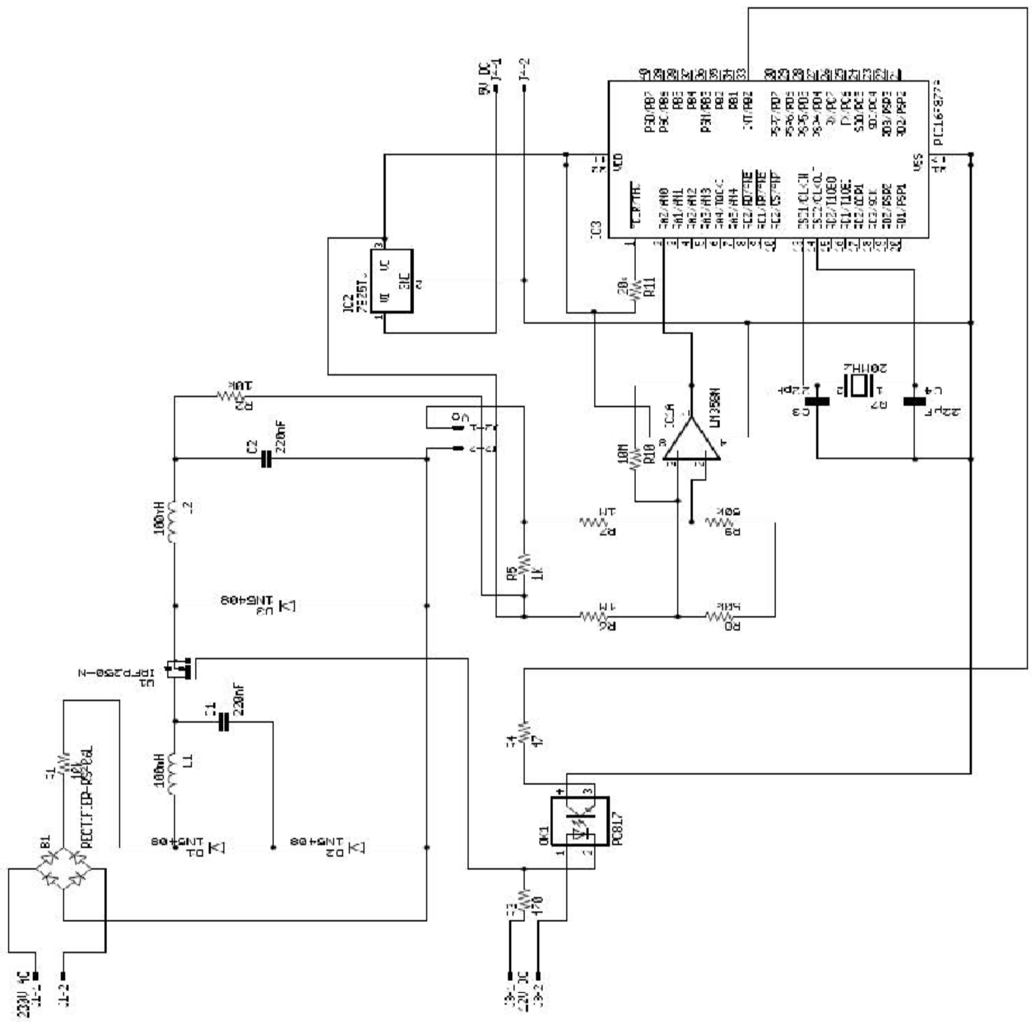


Figure 4.1: Schematic of Complete Smart LED Driver

4.1 Quadratic Buck Converter

A quadratic buck converter is the main part of the whole driver which functions similarly as a transformer; to step down the voltage and current rating with only power electronics components.

Based on the calculation from Section 3.3.3 the schematic diagram of a quadratic buck converter is shown in Figure 4.2. As discussed in Section 3.3.2 a quadratic buck converter operates in two stages which are the on and off state. The duty cycle generated by the microprocessor was used to control the switching process and thus the load current.

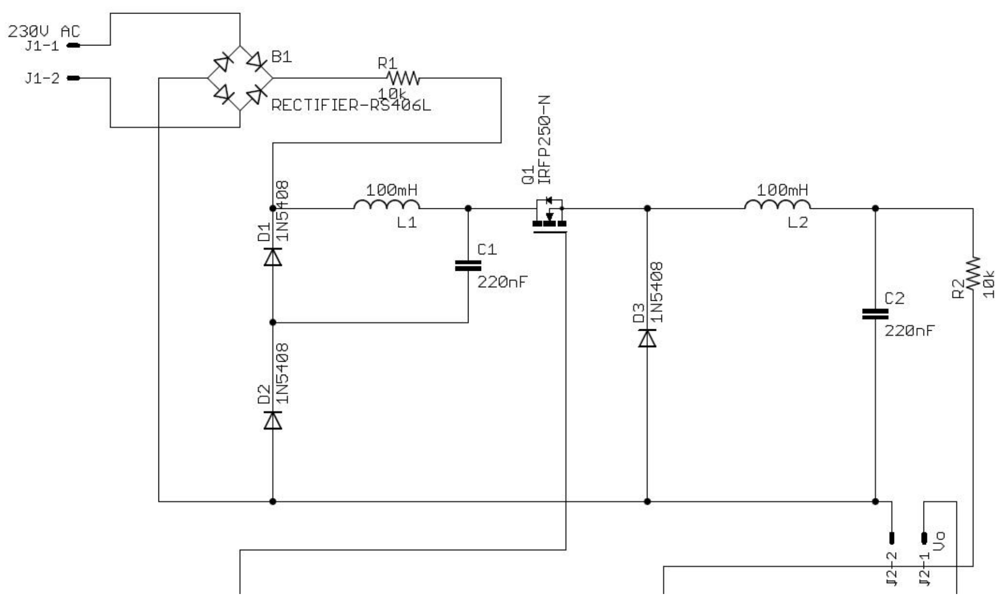


Figure 4.2: Quadratic buck converter schematic diagram

The expected output voltage for this quadratic buck converter is 60 V for the DC input of 224 V. These are the two key values used to calculate the gain of a converter circuit and also the duty cycle. Figure 4.3 shows the input voltage to the quadratic buck converter. The scale for the plot is 50 V per cm and for the measurement of 4.1 cm, the voltage measured is 205 V. Take notice to the figure again, the output waveform shown in Figure 4.3 appears as a square and AC like wave but not the theoretical DC input. This is because the converter is functioning under switching stage. When the switch is closed, current will pass through the circuit and there is only a low voltage measured at the input terminal and for the case of the switch is opened, no current is flowing and thus the maximum of the voltage supplied to the converter is measured.

The output voltage plot from the oscilloscope is shown in Figure 4.4 and the simulated result by Multisim is shown in Figure 4.5. Both of the result agreed that the output voltage is stepped to the level of about 60 V. Similar to the case of the input voltage (Figure 4.3), the plot from the oscilloscope appears as a sine wave and the cause of this is due to the switching process. However this does not mean that the converter is functioning under DCM. Noticed that the output voltage never droops to zero and this proved that the converter is functioning under CCM which gives constant supply to the load at the switching frequency of 100 kHz.

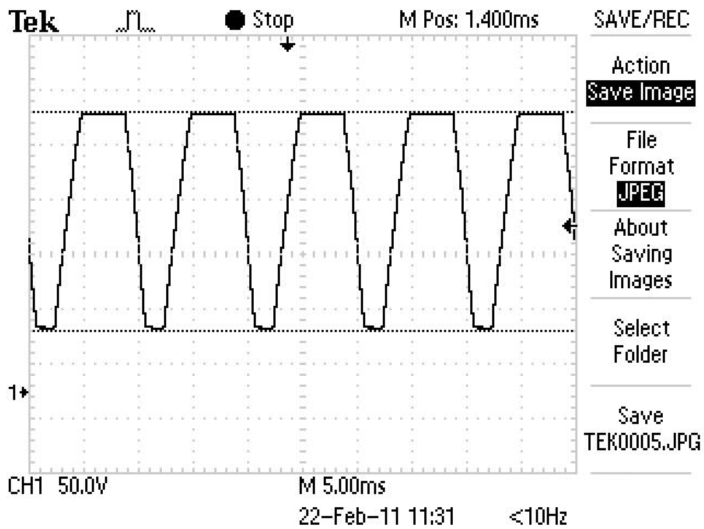


Figure 4.3: Input voltage to the quadratic buck converter

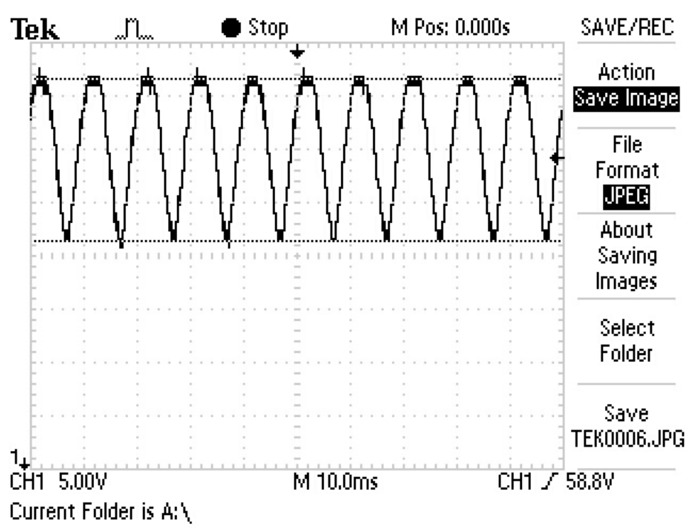


Figure 4.4: Measured output voltage

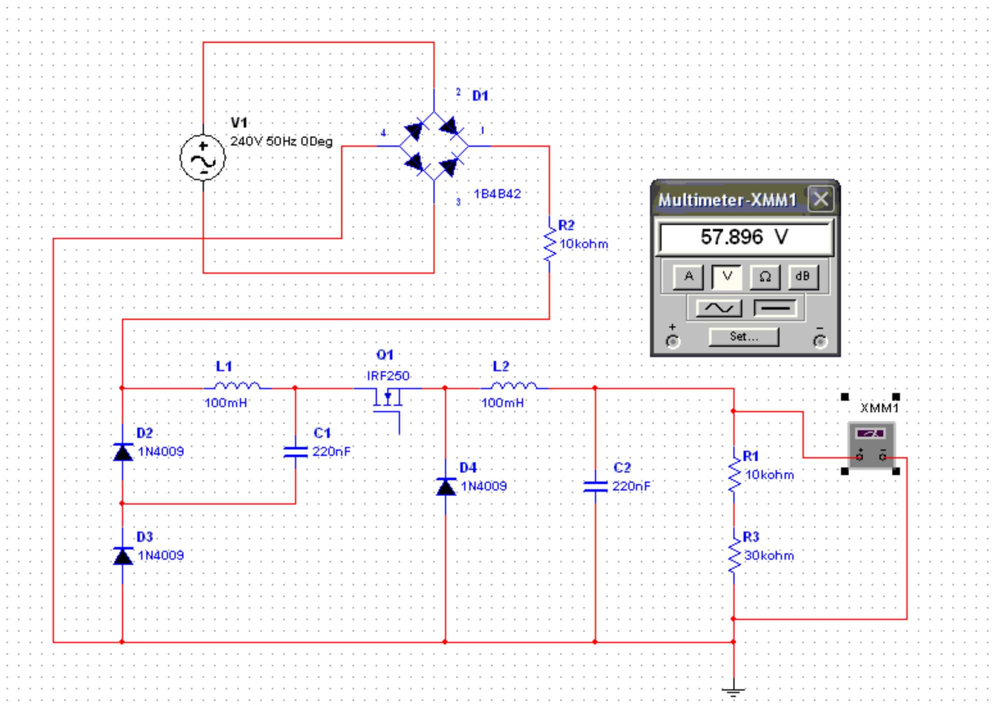


Figure 4.5: Simulated output voltage of the designed load

Figure 4.6 shows the voltage level across the MOSFET switch at the duty cycle of 0.8 and this means that 80% of the period is in the on stage. Noticed that there is noise during the on stage of the signal and is probably cause by the imperfection of the controlling signal and also the MOSFET itself. The noise is unavoidable because there are always some charges stored between the MOS layer. When signal passes through these layers the undesired charging and discharging process which will cause the ripple or noise might occur. The IRFP250-N is actually a metal oxide semiconductor field effect transistor and the name switch is given due to its functionality in the quadratic buck converter. For a switching converter circuit, the transistor operates as an electronic switch and operate under the completely on or off stage. The switching process is controlled by the signal generated from the microprocessor. Using the concept of the pulse width modulation (PWM), this switching process can be controlled and at different duty cycle, different output current can be generated.

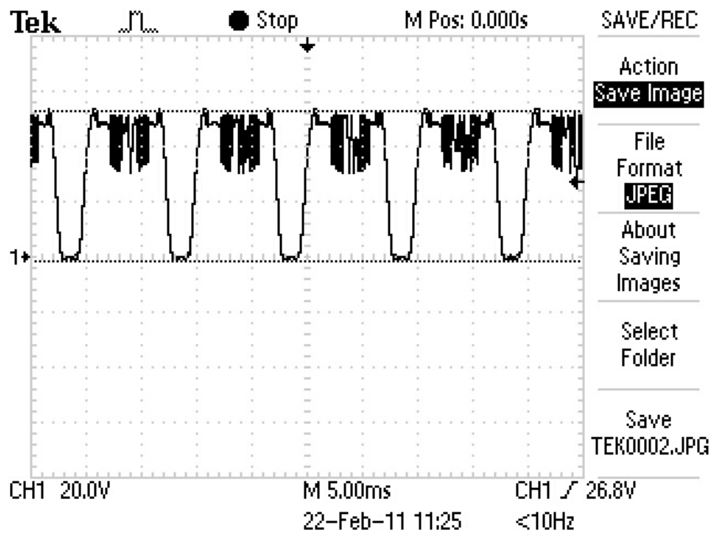


Figure 4.6: Voltage across MOSFET switch at switching stage

Besides, there are two pairs of LC low pass filter shown in Figure 4.2. For a classical buck converter, the LC low pass filter is used to step down the voltage level and it is the same for the quadratic buck converter. During the switch closed stage, the voltage and current energy will pass through the LC filter and the voltage will be stored in the capacitor and current in the inductor. The stored energy will be used as the source during the switch opened stage, and supply to the load. Figure 4.7 shows the voltage level stored in the capacitor C_1 and Figure 4.8 for C_2. The sine wave like wave form shows the charging and discharging process during the on and off stage of the switch. One thing to mention is that for the voltage stored in both of the capacitor never fall to zero. This again proved that the converter is function under CCM but not DCM.

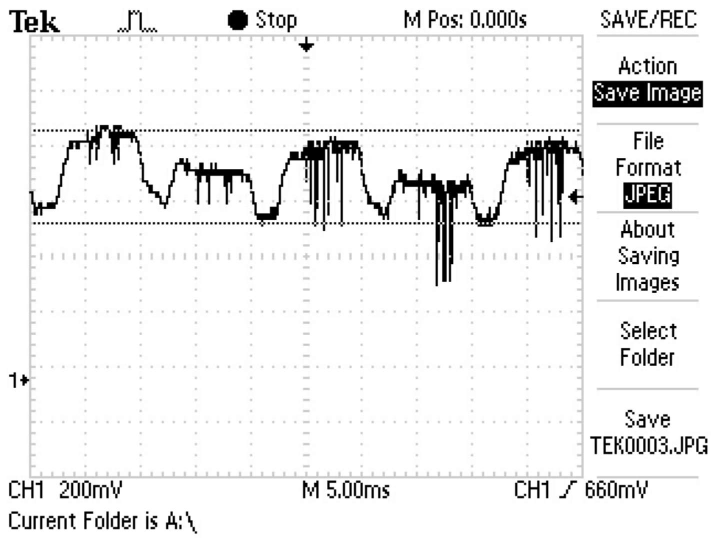


Figure 4.7: Voltage across capacitor C_1

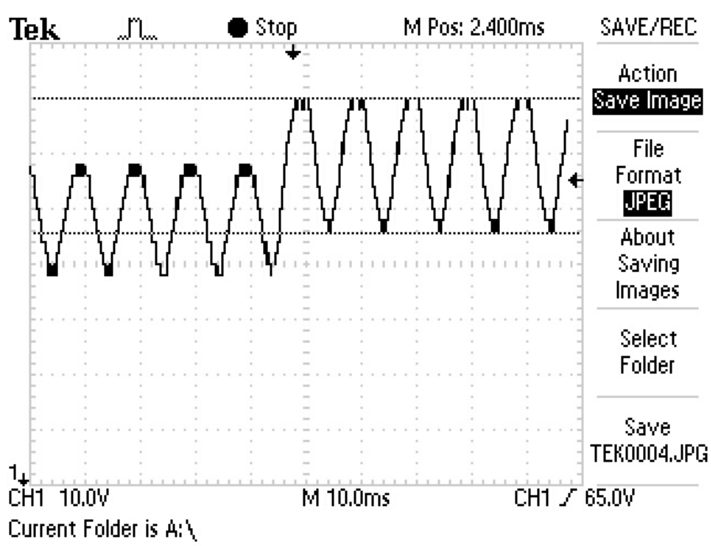


Figure 4.8: Voltage across capacitor C_2

4.2 Sensing and Sampling

For a smart controlling system, accurate feedback is very important and it is required for data processing so that a desired output can be achieved. The concept of the design is just sampling a signal from the output load and feed into a PIC for data process and comparison. Later a controlling signal is generated based on the situation of the feed backed data for output control.

For this project, load current is designed to flow through the sensing resistor which in the design of this project is the 0.1 Ω resistor and this will cause a potential difference across the sensing resistor. Before feeding the signal in to the microprocessor, the difference potential of the sensing resistor will be amplified with the pre determined gain shown in the calculation under the methodology section. Figure 4.9 shows the output of the sampling circuit after amplification. This is also the signal feed into the microchip for comparison. As the result shown, a pulse of 3.8 V is measured. For this result, a x10 oscilloscope probe is used for clearer reading. So the actual reading of the sampled signal from the sampling circuit is about 0.38 V and this indicates that the feedback current from the load is 19 mA.

$$V_{ADC} = 0.38V$$

$$\frac{0.38}{5} \times 256 = 19.456 \ \approx 19\ mA$$

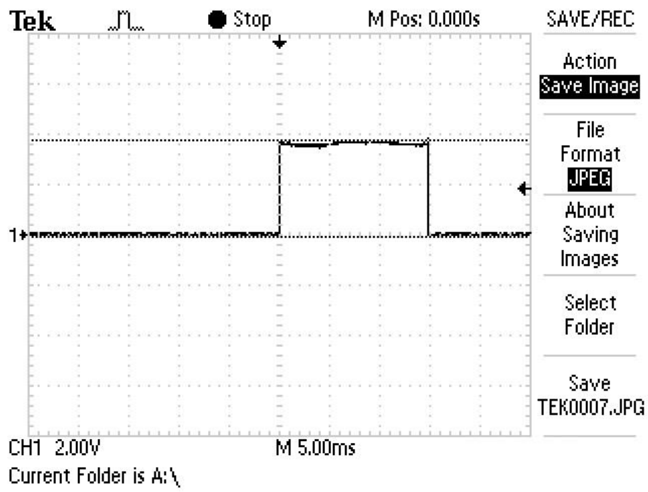


Figure 4.9: Signal generated by the feedback circuit

In order to prove that this circuit is working, some other sets of data within the range of measurement (0 to 100 mA) were tested with the same sampling circuit and all the result proved that the feedback voltage is accurate for the current feed in. This testing is done by supplying different voltage to a resistor in order to generate different current output and then was feed into the sampling circuit. The voltage output was recorded and shown in Table 4.1. Noticed that the results under 'Data for Processing' column are the digitalized values after the ADC. These are the values used for comparison done in the microprocessor and all of them are the calculated values. The calculated data are almost the same with the sensing current and this proved that the sensing circuit gives correct output in voltage form with reference to the current level.

Table 4.1: Testing result for sensing circuit

Voltage (V)	Resistor (ohm)	Current (mA)	Output Voltage (mV)	Data for Processing
0.50	100	5	92.5	5
1.00	100	10	189.0	10
1.50	100	15	279.2	15
2.00	100	20	380.0	20
2.50	100	25	472.1	24
3.00	100	30	582.0	30
3.50	100	35	696.5	36
4.00	100	40	772.0	40

4.3 Smart Control System

This is the most interesting part from all of the other. All of the fascinating smart controlling can be done by just feeding back the required value with the use of the proper instrumentation or circuit, process them by a microcontroller and later gives out the relevant control signal to control the relevant component. For this project, the output current is interested and it is also the only thing to be controlled.

The sampling circuit was discussed in Section 4.2 and with a proper feedback from the sampling circuit, the output current can be controlled at a desired level. Since the quadratic buck converter is functioning in the open and close stage, changing the duration of the switching process will definitely affect the output power.

In the design, all terminals in port A for the microprocessor are set as ADC input terminal and port B as output port. The whole function was done in an infinity loop and this is to ensure the process will keep obtaining data from port A and generates control signal to port B. The function starts with assigning the feedback data which is the load current level to a variable named ‘value’ and this data will be compared to the pre determined value which for the case of this project is 20 mA.

The code to change the analogue signal to digital form is shown in Figure 4.10. For the case when the feedback value is greater than the reference value, the on time of the generated signal will be decreased at the gap of 5 units time and this is for the purpose to fine tune the load current so that the current level can be maintained at 20 mA and the coding is shown in Figure 4.11.

```
check:
set_adc_channel(0);
value = read_adc();    //read data & assign to 'value'
```

Figure 4.10: Assigning data to variable

```
if(value > ref)
 {
    output_HIGH(PIN_B0);
    delay_ms(i);
    i=i-5;  // decrease the duty cycle
    output_LOW(PIN_B0);
    delay_ms(j);
    goto check;
 }
```

Figure 4.11: Comparison process

Figure 4.12 and Figure 4.13 show the difference of the duty cycle which generated by the microcontroller. When the feedback signal is lower than the pre set value which in this project is 20 mA, the duty cycle of control signal will be adjusted to become higher and this mean that the on time will be elongated while shorten the off time period. Figure 4.13 shows the control signal at lower duty cycle after a higher current, as compare to the pre set reference value is feedbacked. This sampling and processing process will keep on going unless the 5 V supply to the microchip is closed and the complete video for showing the changing of duty cycle due to the feedback current will be shown in the presentation section.

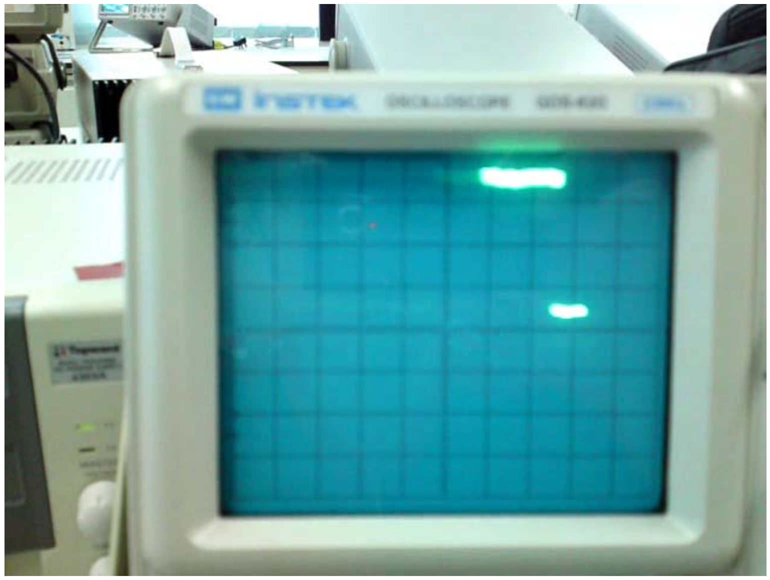


Figure 4.12: Microcontroller generated controlling signal for the case of feedback current < 20 mA

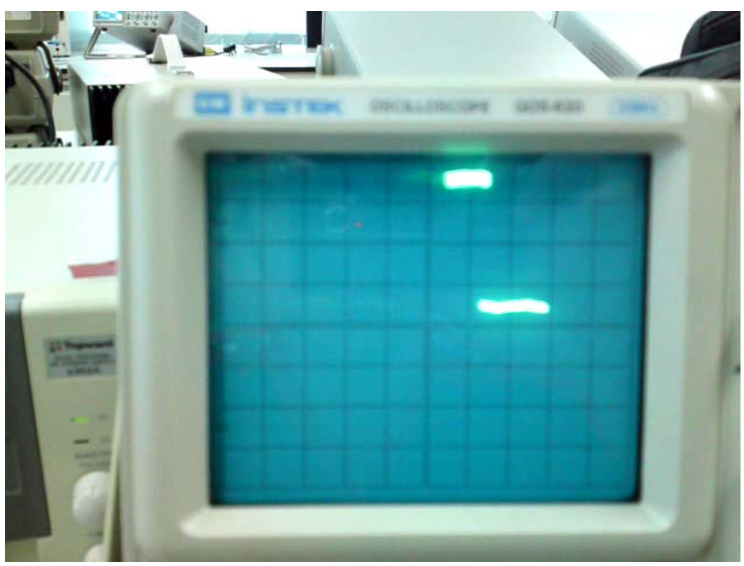


Figure 4.13: Microcontroller generated controlling signal for the case of feedback current >20 mA

As mentioned in the methodology section, the signal generated by the microcontroller cannot drive the MOSFET switch because the power rating is too low. With the use of the slightly modified opto-couple which had been discussed in the methodology section, the MOSFET switch was successfully switched based on the duty cycle generated by the PIC with the use of a 12 V input and the voltage across the electronic switch was shown in Figure 4.6.

4.4 Printed Circuit Board

After testing and proved that all the subparts are functioning, the final product was built in the printed circuit board (PCB) with the Eagle designing software. The design diagram and final product is discussed below.

Figure 4.14 shows the first draft of PCB design. All the three main parts are combined into one single board. However problem occurred when doing the signal line routing. There were many terminals cannot be connected due to the limitation of space. Thus the whole driver was separated into two boards which were the quadratic buck converter board and the controlling and sampling board. The required feedback and control signal using some extra connectors to connect them and the separated design for the quadratic buck converter and smart controlling are shown in Figure 4.15 and 4.16 respectively.

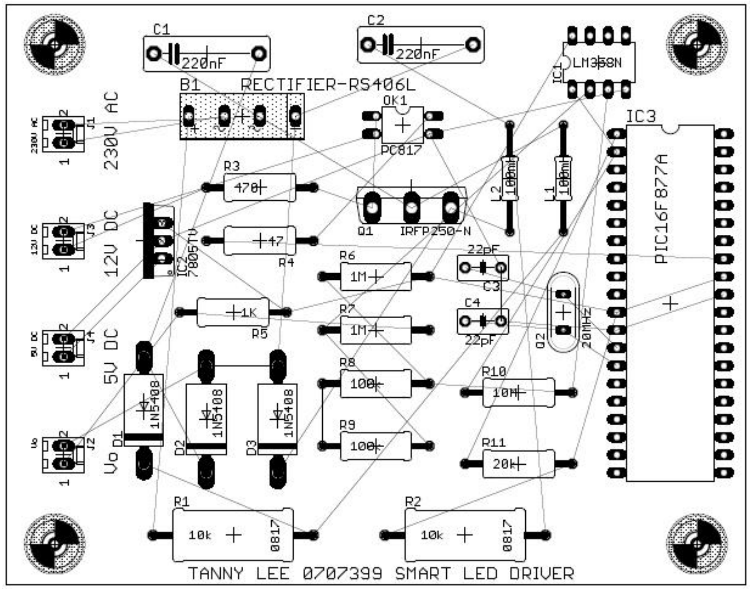


Figure 4.14: Combined single board smart LED driver design

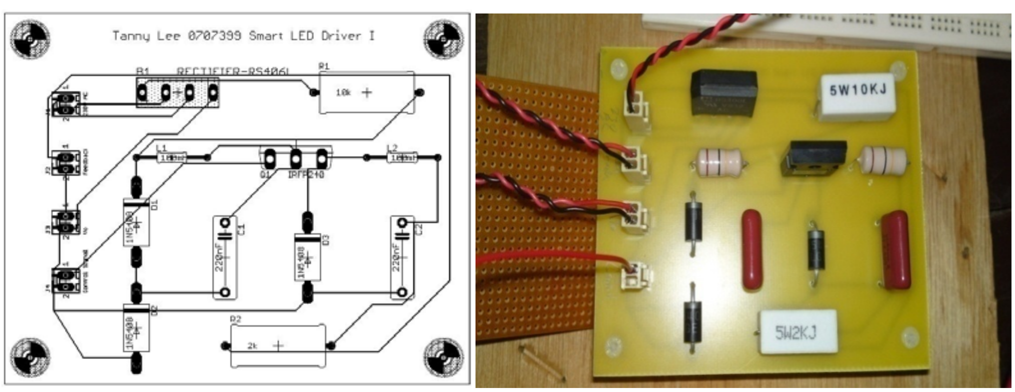


Figure 4.15: Quadratic buck converter schematic diagram (Left) and PCB final product (Right)

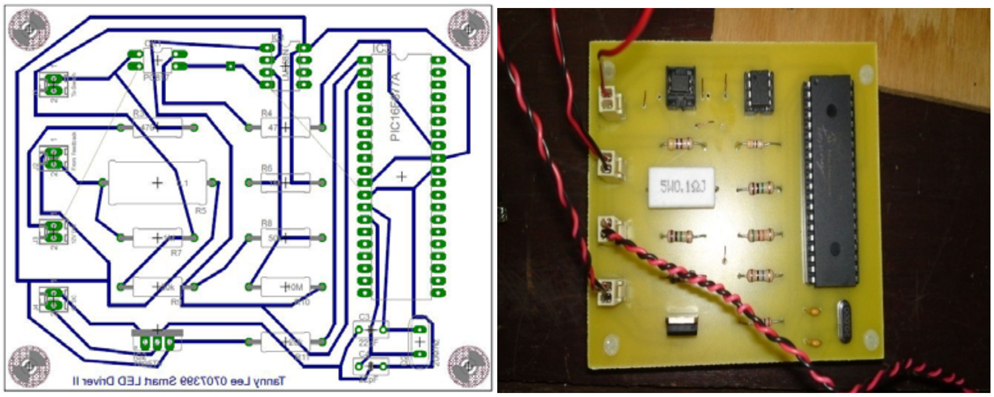


Figure 4.16: Smart Controlling & Feedback System schematic diagram (Left) and PCB final product (Right)

4.5 Testing Comparison for Breadboard and PCB

Any design also has its limitation. The performance for this smart LED driver is limited by the operating mode which is determined by the energy stored in the inductor. As discussed in the methodology section, a quadratic buck converter needs to be function under the continuous conduction mode. When the energy storage in the inductor is empty, the current supply to the load will drop to the reference level and become unstable and this will lead significant flickering to the light source.

In order to reduce the flickering due to the none-constant current supply, the inductor L_2 was changed to a higher value which is the same as L_1. With this modification, there was more current can be stored in the inductor hence a more constant supply was the outcome. Nevertheless this precaution step cannot completely solve the problem of flickering. Although it is not very significant yet is still quite noticeable.

The second approach taken was to reduce the current supply to the load. By reducing the output current to around 15 mA, the LEDs appear no flickering and stable. Although this approach will reduce the brightness of the LED string but it problem can be overcome by changing the inductor to a higher value. This allows more current to be stored and therefore supplying higher current without causing large ripples and fall into the DCM. Figure 4.17 shows the load current measurement during the testing stage. The microcontroller was programmed such that the regulated current is 15 mA. When it was measured with a multimeter, the load current was 13mA with not more that 2 % of fluctuation.

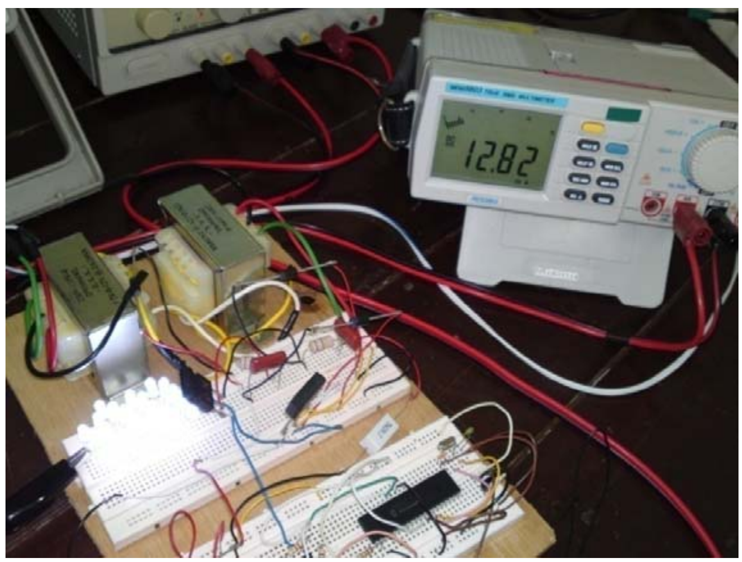


Figure 4.17: Current measurement during testing stage

Fortunately this current storage limitation occurred during the testing stage only. When the final product was built on a PCB, the stable rated load current can be achieved was 20 mA and this was the optimum operating current level for a LED. Figure 4.18 shows the measurement of the load current for the final product. The result shows that the load current is stable and maintain at 19.6 mA with less than 1 % of fluctuation. The videotaped result will be presented during the presentation section.

The reason for the difference of rated operating current is that the feedback signal for the PCB built driver is more accurate and stable as compare to the breadboard built driver. Besides, the loss and noise for the PCB built driver is reduced and minimized because no jumper was used and all the connections for the components are well connected with soldering lead. With the stable and well connected signal, feedback signal feed into the microprocessor is more accurate and hence the performance for the whole circuit is improved.

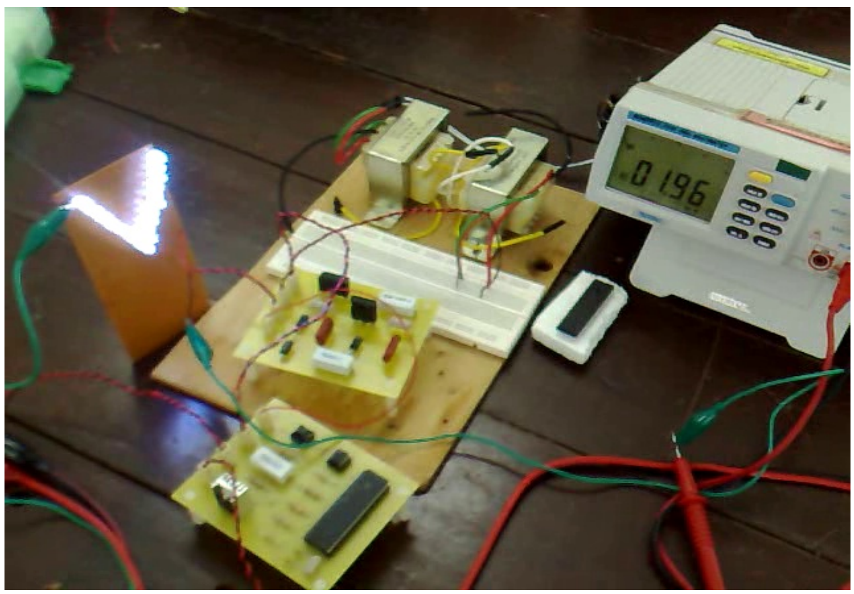


Figure 4.18: Current measurement for final product

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As conclusion the aim of designing a smart LED driver with the green concept which allows the LED string to function at 67 % of its maximum current level with less than 1 % of ripple is achieved. The purpose to stepping down the voltage level from the main supply to only 60 V at the current level of 20 mA with the use of power electronics concept is made. Other than this, smart controlling which include generating the visual effect from the LED light source become possible with a proper programmed coding to the microcontroller, feedback and control output signal. All of these are combined and with the modification on only the programme in the PIC, any visual effect becomes possible based on the preferences of the users. This is a very flexible driver which can meet the demand for the future market in the lighting field.

5.2 Recommendation

The main limitation of this driver is the storage of current and voltage energy so that the converter is able to function in CCM. When the load is larger, more stored energy is required to supply to the load during the off stage of the quadratic buck converter circuit. In order to achieve this, a larger inductor and capacitor value as compare to the theoretically calculated value can be used. This ensures that there is enough energy to be supply during the off stage. More to the point, the converter circuit can be upgraded to the cubic buck or even higher cascaded converter circuit. This will also ensure the constancy of the current supply due to the characteristics of wider effective conversion range and reduce the dependency on the duty cycle.

REFERENCES

Aziz E. Demian Jr, C. H. (2009). NON-ISOLATED DC-DC CONVERTERS WITH WIDE CONVERSION RANGE. 598-604.

Aziz Elias Demian Junior, J. R. (2009). MICROCONTROLLER-BASED QUADRATIC BUCK CONVERTER USED AS LED LAMP DRIVER.

Boost converter. (2010, July 4). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Boost_converter

Buck Boost converter. (2010, August 7). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/Buck%E2%80%93boost_converter

Chew, D. K. (2010). *Power Electronics Chapter 1.*

Corporation, L. L. (2007). *L .C. LED*. Retrieved from Advantages of LED Lights: http://www.lc-led.com/articles/ledlights.html

Ćuk converter. (2010, August 23). Retrieved from Wikipedia: http://en.wikipedia.org/wiki/%C4%86uk_converter

Daniel A. Steigerwald, J. C. (2002). Illumination With Solid State Lighting Technology. *IEEE journal of Selected Topics in Quantum electronics* , 310-320.

Design Forum - Intelligent Driver. (2010, April). Retrieved from LEDs: http://www.ledmagazine.com/

Dragan MaksimoviC, S. C. (1991). Switching Converters with Wide DC Conversion. *IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 6, NO. I* , 151-157.

E. E. CARBAJAL-GUTI ´ERREZ, J. A.-S.-R. (2005). Modeling of a Single-Switch Quadratic Buck. *IEEE TRANSACTIONS ON AEROSPACE AND ELECTRONIC SYSTEMS VOL. 41, NO. 4* , OCTOBER.

Edwin van Dijk, H. J. (1995). PWM-Switch Modeling of DC-DC Converters. *IEEE TRANSACTIONS ON POWER ELECTRONICS* , 659-665.

Fu Xiaoyun, L. X. (2009). Research and Analysis of the Desing Development and Perspective Technology for LED Lightning Product. 1330-1333.

Humphry Davy. (2010, August 18). Retrieved from wikipedia: http://en.wikipedia.org/wiki/Humphry_Davy

LED Lighting Solution. (2010). Retrieved from Microchip: http://www.microchip.com/stellent/groups/designcenter_sg/documents/devicedoc/en027001.pdf

Michael Lane, E. S. (2000). *Advantages of LED Lighting*. Retrieved from Lighting Design Lab: http://www.lightingdesignlab.com/articles/LED_fund/led_advant.htm

NingBo xinyi electronic co., l. (2007). *LED Technology*. Retrieved from Doubulb: http://www.doubulb.com/led-technology.html

STMicroelectronics. (2007). An MCU-based low cost non-inverting. 1-16.

APPENDICES

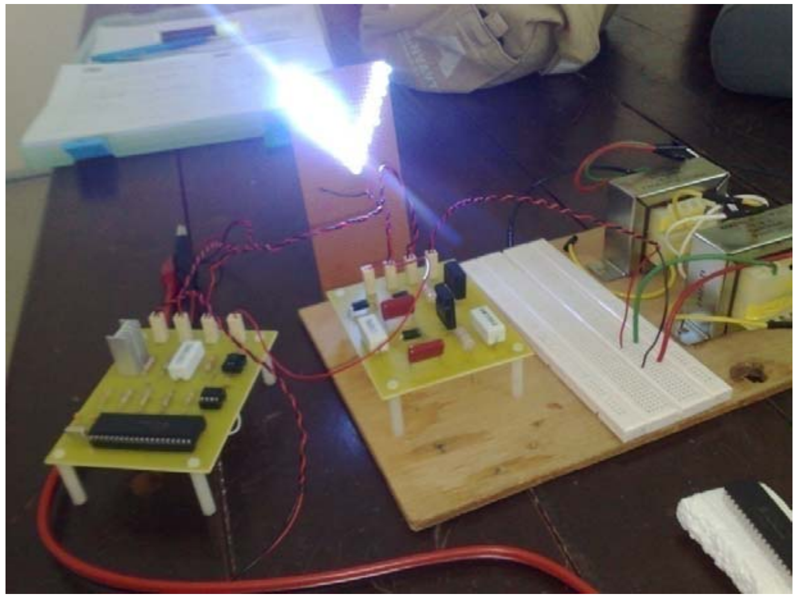
APPENDIX A: Computer Programme Listing

Attached is the programming code for the microcontroller which is done in PIC C Compiler and it will be compile into binary code before burning it into the microcontroller.

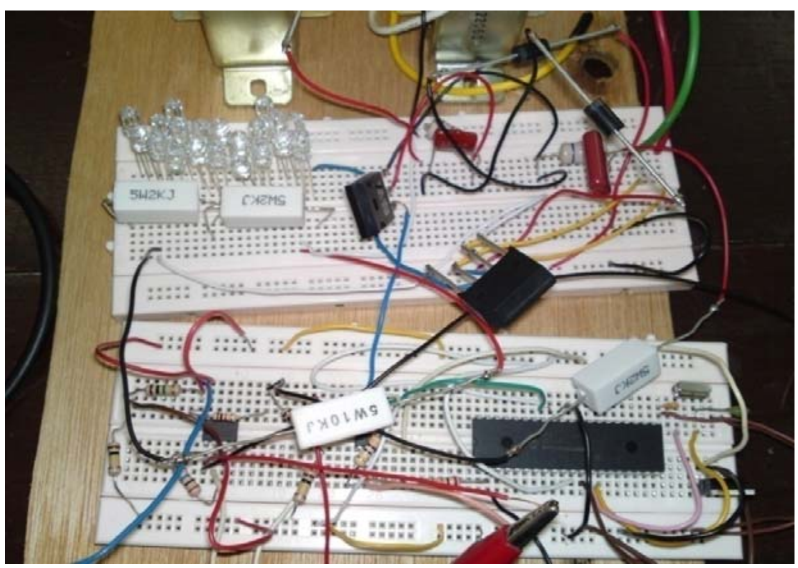
```
#include <16F877.h>       // preprocessor directive that selects PIC16F877
#fuses HS,NOWDT,NOPROTECT,NOLVP // preprocessor directive that defines fuses for the chip
#device ADC=8  // set the ADC to 8 bits
#use delay(clock=20000000)    // preprocessor directive that specifies the clock speed

void main()
{int i=1000, j=100, ref=15, value=0;

  /* pin a0 is the feedback signal
     pin b0 is the switch output
  */
    setup_adc_ports(AN0_AN1_AN2_AN3_AN4);
    setup_adc(ADC_CLOCK_INTERNAL);
    set_tris_b(0b00000000); // set all the port b terminals into output port

START:
do
{
  check:
  set_adc_channel(0);
       value = read_adc();    //read data & assign to 'value'
```

```
    if(value < ref)  // compare the feedback current to the reference value
            {
              output_HIGH(PIN_B0);  //output high
              delay_ms(i);
              i=i+5;  // increase the duty cycle
              output_LOW(PIN_B0);
              delay_ms(j); // output low
              goto check;  // return and wait for the new data
            }

    else if(value > ref)
            {
              output_HIGH(PIN_B0);
              delay_ms(i);
              i=i-5;  // decrease the duty cycle
              output_LOW(PIN_B0);
              delay_ms(j);
              goto check;
            }

            else
            {
     goto check;
            }


}while (1);
}
```

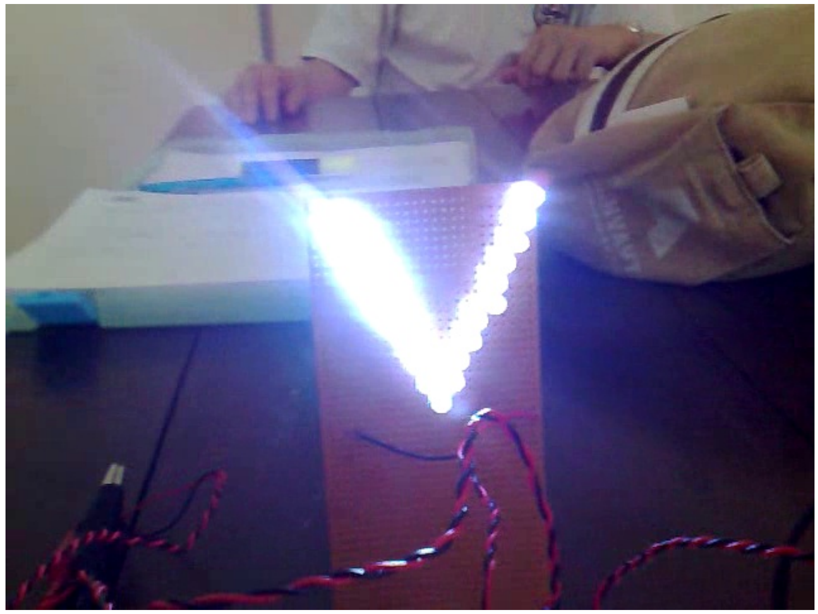
APPENDIX B: Figures of Smart LED



Complete Smart LED Driver



Complete Testing Module



Brightness of 20 LEDs at 20 mA

Isolation Transformer