DEVELOPMENT OF UNIVERSAL LED DRIVER CIRCUIT FOR LOW POWER LED APPLICATION

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
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CERTIFICATION OF APPROVAL

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Approved:

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May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Isra Abbasi

ABSTRACT

In this work, a universal LED driver is proposed based on micro controller. The main function of the driver is to drive different current levels to power LEDs. Pulse width modulation is changed through micro controller in order to change output current. Two power LEDs with current rating of 350 mA and 700 mA respectively have been selected as load and a micro controller, ATmega328 programmed through Arduino UNO has been selected to change the current level. Proposed design is simulated and a prototype is designed and the validity of the designed driver is verified.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

LED	Light Emitting Diode
SMPC	Switch Mode Power Converters
PWM	Pulse Width Modulation
IC	Integrated Circuit
AC	Analog Current

CHAPTER 1
INTRODUCTION

1.1 Overview

Lighting consumes a significant part in total electricity consumption of the world. According to a recent data collected by Philips, an average of 19 % of electricity is consumed by lighting in whole world [1]. The main reason behind this huge consumption is inefficiency of the many artificial lighting sources available today. The high power Light Emitting Diode (LED) offers solutions to the key issues and problems that are caused by artificial lighting source such as high electricity bills, resource scarcity and energy crisis [2].

LED is one of the most efficient and competitive lighting sources to replace the conventional lamp and gradually becomes a commonly used lighting source in many lighting applications. The main reasons behind the popularity of high power LED is its high efficiency, superior longevity, directionality and light intensity control [3].

LED technology offers important benefits over conventional lighting technologies. LED efficiency is fast surpassing that of conventional lighting technology. Energy savings from 50 % to 70 % compared to conventional technologies result in similar cut to carbon emissions [4]. Superior control over light color, intensity and direction allows novel lighting system designs that can deliver a wide range of social co-benefits. With this unique feature of controllability, the total system energy savings can reach up to 80 % [5].

Being such a promising technology, LED is still facing barriers to completely penetrate in the society. Other than high cost of LEDs, one of the biggest barriers or hurdles in its way is the need of universal driver circuit. Unlike other artificial lighting system, which can simply operate with voltage applied to them, LED needs a voltage supply and a driver to drive a constant current. Hence this project aims to address this issue and proposes a design of a universal LED driver.

1.2 Project Background

LED is a semiconductor light source that glows when voltage is applied. Like an ordinary diode, forward biasing the LED turns it on and current starts to flow. As a result electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence and the color of light (corresponding to energy of photon) is determined by the energy gap of semiconductor [6].

In general, LEDs are current driven and regardless of type, color, power or size, LEDs work best when driven with constant current. However LEDs are very sensitive to the voltage used to power up them because the current changes a lot with a small change in voltage. Hence this is where LED drivers come into play. The main purpose of a driver is to keep constant current passing through LED under all conditions (change in input voltage or change in temperature) [7].

Generally LEDs fall into three basic power levels, low power, mid power and high power. From Table 1, it can be inferred that low power is less than or up to 20 W, mid power is between 20 W and 50 W and high power is above 50 W [8].

The important element in use of high power LED is its thermal management as about 75-85 % of the electricity is converted into heat, resulting in overheating [9]. Hence high power LEDs must be mounted on heat sink to allow for heat dissipation.

Table 1 Power Levels of LED [8]

Type	Description
Low Power LED	$P \leq 20$ W
Mid Power LED	$20 \text{ W} \leq P \leq 50$ W
High Power LED	$P \geq 50$ W

1.3 Problem Statement

Currently in market, there are several kinds of LED drivers available that are able to drive a certain amount of current on a certain range of voltage with a fixed output power. For instance one of the leaders in design of LED driver circuits, Harvard Engineering located at United Kingdom has introduced various types of LED drivers that have specific ratings of output current, voltage range and maximum power output [10]. On the other hand, there are many other designs of LED drivers available on different websites addressing the issue of driving string of high power LED with constant current.

However from current designs and solutions of LED driver circuit available at present, any LED with specific ratings will require a specific driver to drive the current. For instance, to drive a power LED with current rating of 350 mA, a driver would be specifically designed in order to deliver the desired output current. Likewise in order to drive power LED with current rating of 700 mA, a different driver would be designed to drive the required. Following this method, in order to use LEDs of different ratings, one needs to have separate drivers for each that can drive respective current required. This process will result in additional cost and complexity in design. However, a better alternative would be to have a universal intelligent LED driver circuit that can be used to drive different amount of currents. That is to say that a single universal LED driver can be used to drive LEDs of different current ratings (e.g. I= 350 mA, 700 mA, 1 A).

1.4 Objective & Scope of Study

The objectives of this work are

i. To design universal LED driver circuit based on micro controller that can drive different current levels
ii. To simulate the design
iii. To prepare a prototype of design

1.5 Significance of Project

Lighting matters. According to the CEO of the Climate Group, Mark Kenver, almost fifth of global electricity is used for lighting which accounts for 1.9 billion tons of carbon dioxide every year [11]. Undoubtedly, LEDs are revolutionizing the energy efficiency of lighting. They are infinitely scalable, extremely reliable and have a much longer life span than almost all types of lighting. But like any new technology, they are facing barriers to adoption from a market unfamiliar with their benefits. One of the common barriers faced by LED is a need of comprehensive and universal LED drivers. In order to install this technology in every house, skyscraper and city streets, LEDs need to overcome barrier like these. Hence this work is a step towards addressing these barriers with the hope of a brighter tomorrow using LED lighting.

1.6 Relevancy of Project

This project mainly revolves around understanding the present LED driver circuits and driver IC's available and using that understanding to design a universal LED driver circuit. As a whole, this work encompasses important electronic knowledge on how to provide a constant current source with addition of how the current can be controlled through micro controller.

1.7 Feasibility of Project

Time taken to design the driver usually depends on how fast the basics of designing can be understood and a suitable design is proposed. Certainly eight months of time frame for FYP (Final Year Project) is quite feasible to complete the project.

CHAPTER 2
LITERATURE REVIEW

2.1 Comparison between LED and other conventional lighting technologies

The most common lighting technology used these days includes compact fluorescent light bulb and Incandescent light bulb. Comparison among conventional lighting technology is shown in Table 2. The comparison is done based on luminous flux coming out of the light with respect to power consumed for each of the lighting system.

Table 2 Comparison Among Common Lighting Technology [12]

Light Output	LEDs	CFL	Incandescent
Lumens	**Watts**		
450	4-5	8-12	40
300-900	6-8	13-18	60
1100-1300	9-13	18-22	75-100
1600-1800	16-20	23-30	100
2600-2800	25-28	30-55	150

Lumens is the unit of measurement of the flow of light or luminous flux. It provides an estimate of the apparent amount of light that the bulb will produce. From Table 2 it has proved that LED is the most efficient lighting technology with least power required among the two other conventional lighting systems.

2.2 Led Driver

The growing adoption of LEDs as lighting source in different applications has simultaneously driven the demand for LED drivers to power them. To understand the obstacles in designing LED drivers, it is necessary to understand what an LED requires in order to produce light [12]. By definition, LED is a current driven device and regardless of any of its characteristics, LEDs work best when driven with constant current. The main purpose of LED driver is to deliver constant current under all conditions (for example change in input voltage or temperature) [13].

2.3 Led Driving Methods

There are three most common ways used to drive constant current in LEDs.

2.3.1 Resistors in Series

This is the most widely method used to limit the current in LEDs, in which LEDs are supplied from a constant voltage via series resistor connected in series. It is simple and inexpensive method. However simple is not always better. As voltage rises so does heat dissipation across the resistor which reduces both efficiency and lifespan of LED. A resistor can act only as a current limiter but not as current control circuitry for LED [14]. Example of resistors in series powering LED is shown in Figure 1 (a).
To calculate resistance value for any particular LED, Eq. (1) is used where R is the resistance value used to limit the current, V is the voltage supplied, v is the forward voltage drop of LED and I is the forward current.

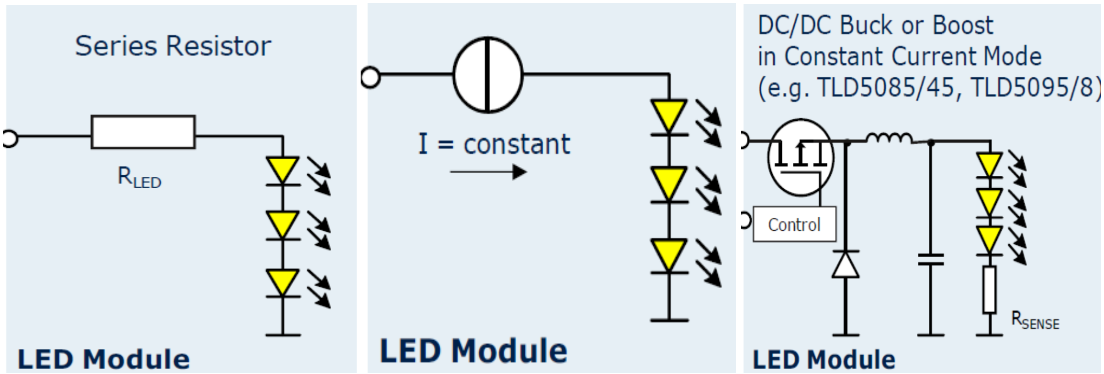
$$R = \frac{V - v}{I} \qquad (1)$$

2.3.2 Linear Current Source

A linear current source provides a constant output current to the LED over the entire supply voltage range. An example of a linear current source circuit to power LED is shown in Figure 1 (b). The good side of using this method is that the output current is entirely independent of the voltage supplied while the downside is its low efficiency and increased component count [15].

2.3.3 *Switch Mode Power Converters*

Switch Mode Power Converters (SMPC) is a circuit that uses a power switch, inductor and a diode to transfer energy from input to output. The basic components of SMPC can be rearranged to form step up (boost converter), step down (buck converter) or an inverter (fly back converter). . An example of a Switch Mode Power Converter circuit to power LED is shown in Figure 1 (c). Although all three types can be used to drive LEDs, a buck converter serves as a good design, providing cost effective and solid performance [16]. SMPC has one major advantage of higher efficiency over linear regulators. The efficiency of LED driver based on these converters is very high and can boost up to 95 % [17]. Some of the draw backs of this method are increased component count and design complexity. Generally SMPC are the common choices for high power LED driver as they can deliver high output current at high power conversion efficiency.



(a) (b) (c)

Figure 1 (a) Resistor in Series (b) Linear Current Source (c) Switch Mode Power Converters [17]

2.4 Proposed Designs of Led Drivers by Others

In recent years, a lot of research work has been done on improving performance of LED drivers by using different methods. Mainly the focus of those papers has been on achieving greater durability or higher efficiency. One of the potential designs for LED driver circuit is proposed in [18] in which the driver is designed to maintain a constant current through microcontroller PIC16F819.

Figure 2 shows the proposed circuit in [18] that is based on a Cuk converter topology and micro controller PIC16F819, supplying 350 mA output current, with different nominal values of input voltage (universal input voltage or battery). Another similar design is proposed in [19], in which current is also maintained through a micro controller PIC 16F877A. Similar to the design proposed in [18], the output current supplied is 350 mA. But this driver has a unique function to control the brightness of LEDs to low, medium and high.

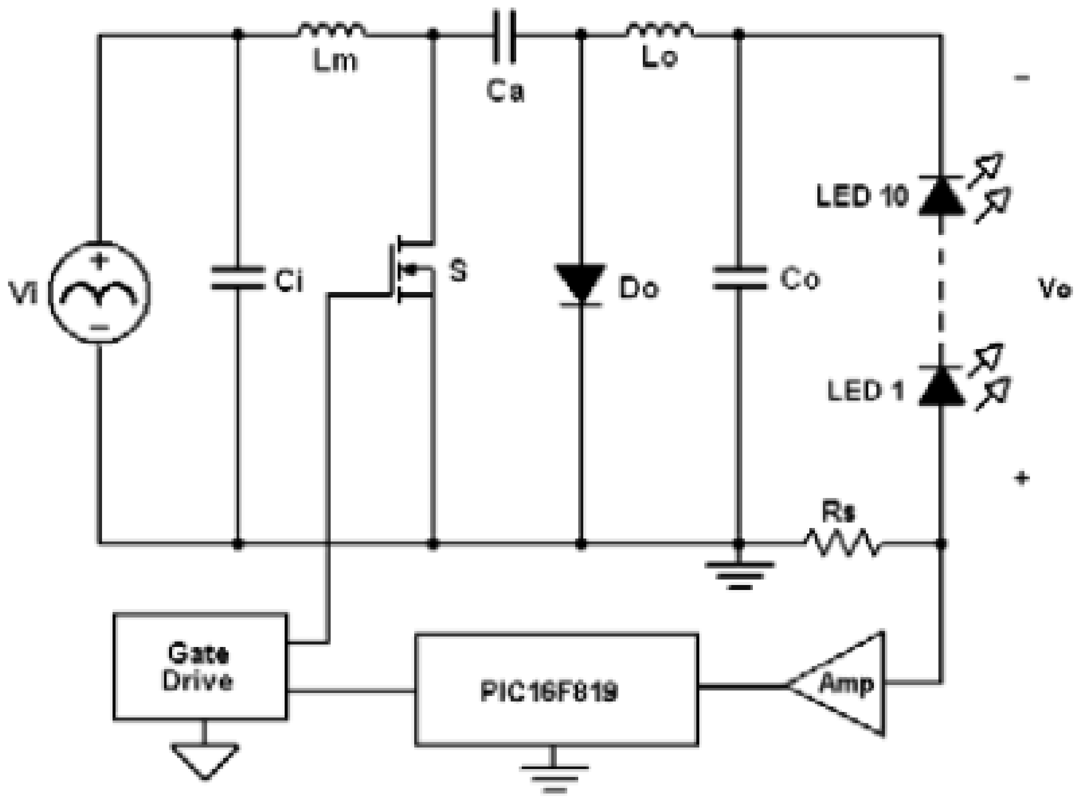


Figure 2 Cuk Converter Topology [18]

There have been number of other designs that are designed to work under universal input voltage, with high efficiency and high power factor. Table 3 summarizes five most recent and relevant research papers related with LED driver design. As can be inferred from Table 3, the main issue encountered in all these research papers is fixed level of output current. Therefore in order to address this issue and to allow LED technology to be easier to use, this work is aimed to develop a universal LED driver circuit based on micro controller that can deliver different nominal values of current for LEDs.

Table 3 Literature Review Summary

No.	Authors	Title	Methodology	Result	Issue
1	J. R. de Britto & et.al, 2008	A proposal of LED lamp driver for universal input using cuk converter	Cuk converter with digital control based on PIC16F819	Output current: 350 mA Input Voltage: 12 V Efficiency: 90 %	Fixed level of output current, I=350 mA
2	R. Xu & et.al, 2011	Research on a high efficiency LED driving circuit based on buck topology	Buck converter	Output current: 350 mA Input Voltage: 30 V Efficiency: 90 %	Fixed level of output current, I=350 mA
3	C. A. Cheng & et.al, 2011	Single stage driver for supplying high power light emitting diodes with universal utility line input voltages	Combination of buck boost converter with a non isolated flyback converter	Output current: 500 mA Input Voltage: 25 V Efficiency: 93.4 %	Fixed level of output current, I = 500 mA
4	R. Sinnadurai & et.al, 2012	Development of white LED down light for indoor lighting	Driver circuit based on PIC16F877A	Output current : 200 mA Input Voltage: 24 V	Fixed level of output current, I=200 mA
5	M. S. Lin & et.al, 2012	An LED driver with pulse current driving technique	LED driver based on a pulse current modulator	Output current : 220 mA Input Voltage: 5 V Efficiency: 95.3 %	Fixed level of output current, I=220 mA

2.5 Pulse Width Modulation

The very basic and common way used to change the amount of current in any circuit is by changing value of resistance. This method might be efficient with incandescent bulb or other circuits, where current can be adjusted through potentiometer but for LED, changing resistance values results in problems like color shift and drop outs and at the same time changing resistance through potentiometer or manually changing the resistor once the circuit is soldered is cumbersome [20]. These problems are addressed by a method named Pulse Width Modulation (PWM). PWM is a method to control power output which is sent to LED or it can also be defined as a technique for getting analog results with digital means [21]. Current and power are directly proportional, which means that in order to change amount of current, amount of power supplied has to be changed and this is exactly what PWM does. Digital control is used to create a square wave, a signal switch between on and off. Figure 3 shows Pulse Width Modulation for different duty cycle.

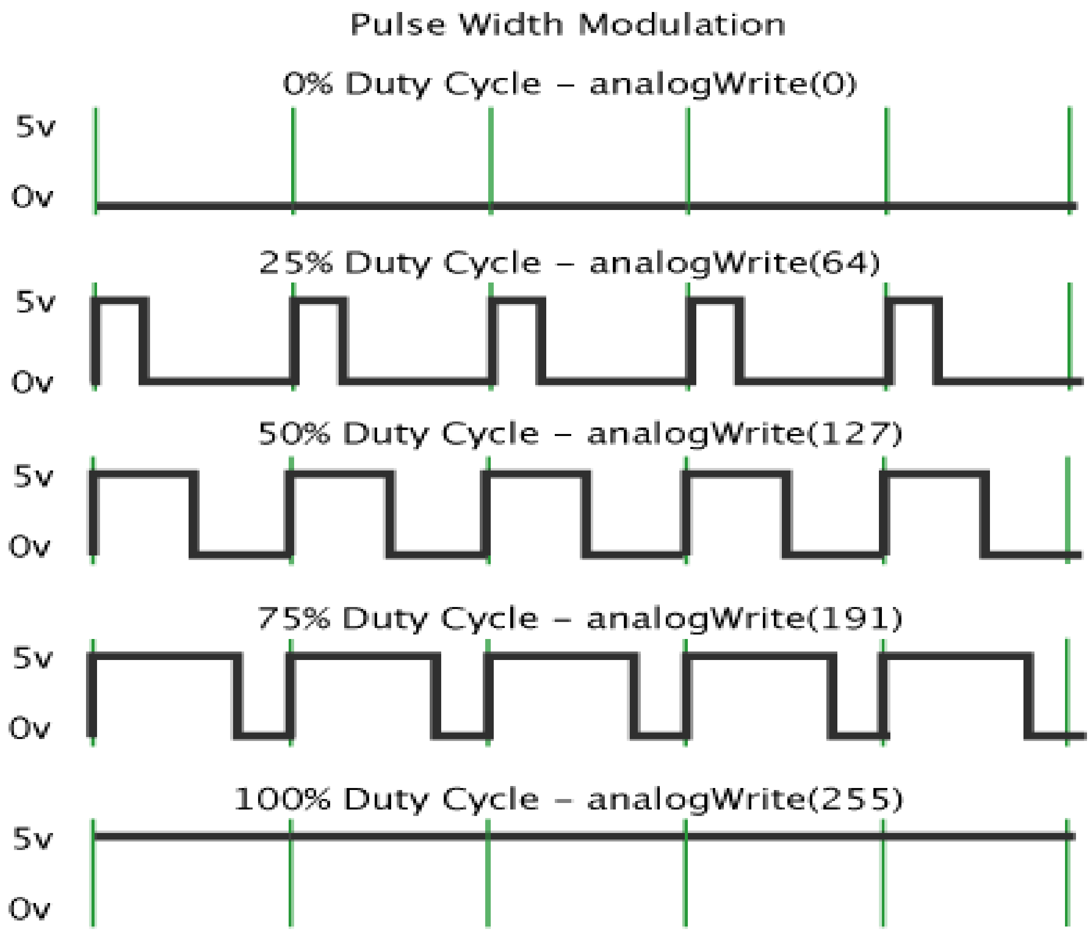


Figure 3 Duty Cycle in PWM [22]

This on-off pattern can simulate voltages in between on (5 volts) and off (0 volts) by changing the portion of the time signal spends on versus the time that signal spends off. The duration of on time is called pulse width. To get varying analog values, pulse width is changed or modulated. One of the most important terms in PWM is duty cycle. The term duty cycle refers to the total amount of time a pulse is 'on' over duration of cycle. As shown in Figure 3, 0 % duty cycle means that LED is off, 50 % duty cycle means signal is 'on' for half the time which results in less current supplied to LED, resulting in half the brightness, similarly 100 % duty cycle means the signal is always on resulting in full brightness [22].

2.6 Micro Controller

Micro controller is a small computer on a single integrated circuit containing a processor core, memory and programmable input/output peripherals. Micro controllers are designed for embedded application in contrast to micro processors used in personal computer or other general purpose application [23]. For this work, ATmega 328 micro controller is chosen that can be programmed through Arduino Uno (Micro controller board).

As shown in Table 4, arduino uno has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, 16 MHz crystal oscillator, a USB connection, a power jack and a reset button [24]. It contains everything needed to support the micro controller. In order to get started, it simply needs to be connected to computer with USB cable or to AC-DC adapter or battery to get voltage supply. The reason behind choosing this board is because it includes embedded PWM module that does all the hard work. Other important reason is because it is flexible and easy to incorporate hardware and software [25].

Table 4 Arduino UNO Specifications [24]

Micro Controller	**ATmega328**
Operating Voltage	5 V
Input Voltage (Recommended)	7-12 V
InputVoltage (Limit)	6-20 V
Digital I/O Pins	14 of which 6 are PWM output pins
Analog Input Pins	6
DC Current per I/O pin	40 mA
DC Current for 3.3V pin	50 mA
Flash Memory	16 kB
SRAM	1 kB
EEPROM	512 bytes
Clock Speed	16 MHz

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

3.1.1 Literature Review

The very first step suggested in this work is to get an insight and understanding of LED drivers. It is vital to understand the basic concepts and logic behind designing the driver. Furthermore, it is also beneficial to study data sheets of different components and ICs to understand their features and functions in order to choose suitable component/IC for the project. So far a good number of articles and papers related with LED drivers have been read and a basic understanding has been established as described in Chapter 2.

3.1.2 Selection of LEDs

The next task is to select two different types of LEDs with different current and power ratings. The LEDs selected in this work are listed in Table 5. LED #1 with 1 Watt power rating produces light equivalent to that produced by CFL with power rating of 2 Watts and Incandescent with power rating of 10 Watts. Similarly LED #2 with 5 Watt power rating produces light equivalent to that produced by CFL with power rating of 12 Watts and Incandescent with power rating of 40 Watts.

Table 5 Specifications of two different types of LEDs selected

LED #1	LED #2
High Power LEDs - Single Color True Green	High Power LEDs - Single Color Ultraviolet
Forward Current = 350 mA	Forward Current = 700 mA
Power Rating 1 Watt	Power Rating 5 Watts
Forward Voltage = 2.8 to 4 V	Forward Voltage = 3.9 V

3.1.3 Basic Design Block Diagram

A basic block diagram has to be designed to illustrate the main parts of the circuit and their functions. The block diagram designed for driver is shown in Figure 4. The driver circuit proposed in this work is divided into three main sub circuits.

i. Power Supply Circuit
ii. Micro Controller Circuit
iii. Led Driver Circuit

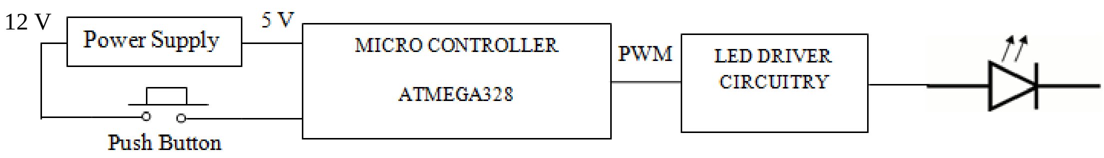


Figure 4 Basic Design Block Diagram

3.1.4 Circuit Design

After designing basic design block diagram, the next task is to design the circuit for each block of the diagram. As mentioned in 3.1.3, there are three sub circuits for universal LED driver circuit.

3.1.4.1 Power Supply Circuit

A power supply circuit is to be designed that gets an input voltage of 12V (from DC Voltage Adapter) and gives an output of 5 V. The power supply circuit designed for this work is based on a voltage regulator LM7804, that is connected with two 100 nF and two 100 uF capacitors. The schematic is shown in Figure 5.

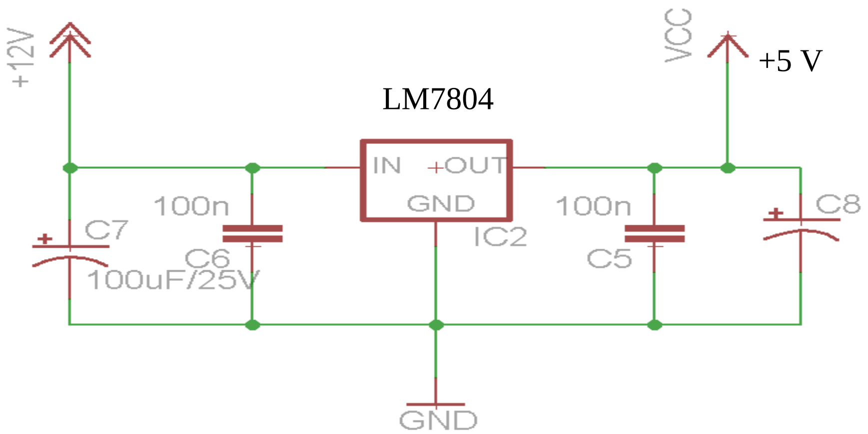


Figure 5 Power Supply Schematic

3.1.4.2 Micro Controller Circuit

A basic micro controller circuit is to be designed based on ATmega328 IC that can be programmed by using Arduino Software. The function of micro controller circuit is to send the required PWM signal to the LED Driver Circuit.

The micro controller circuit is based on ATmega328 IC, reset switch, 16 Mhz crystal, two 22 pf capacitors, 10 kΩ resistors and one mini switch button. The schematic is shown in Figure 6, where pin 14 of ATmega328 is connected with push button and dc voltage source of 5 V, 10 k ohm resistor is connected to pin 14 to ensure that pin always goes down to ground if button is not pressed. Pin#20 & #21 are connected to dc voltage of 5 V. A crystal oscillator is connected between pin#9 and pin#10 in parallel with two capacitors of value 22 pF. Pin #15 is connected with the input of LED Driver Circuit.

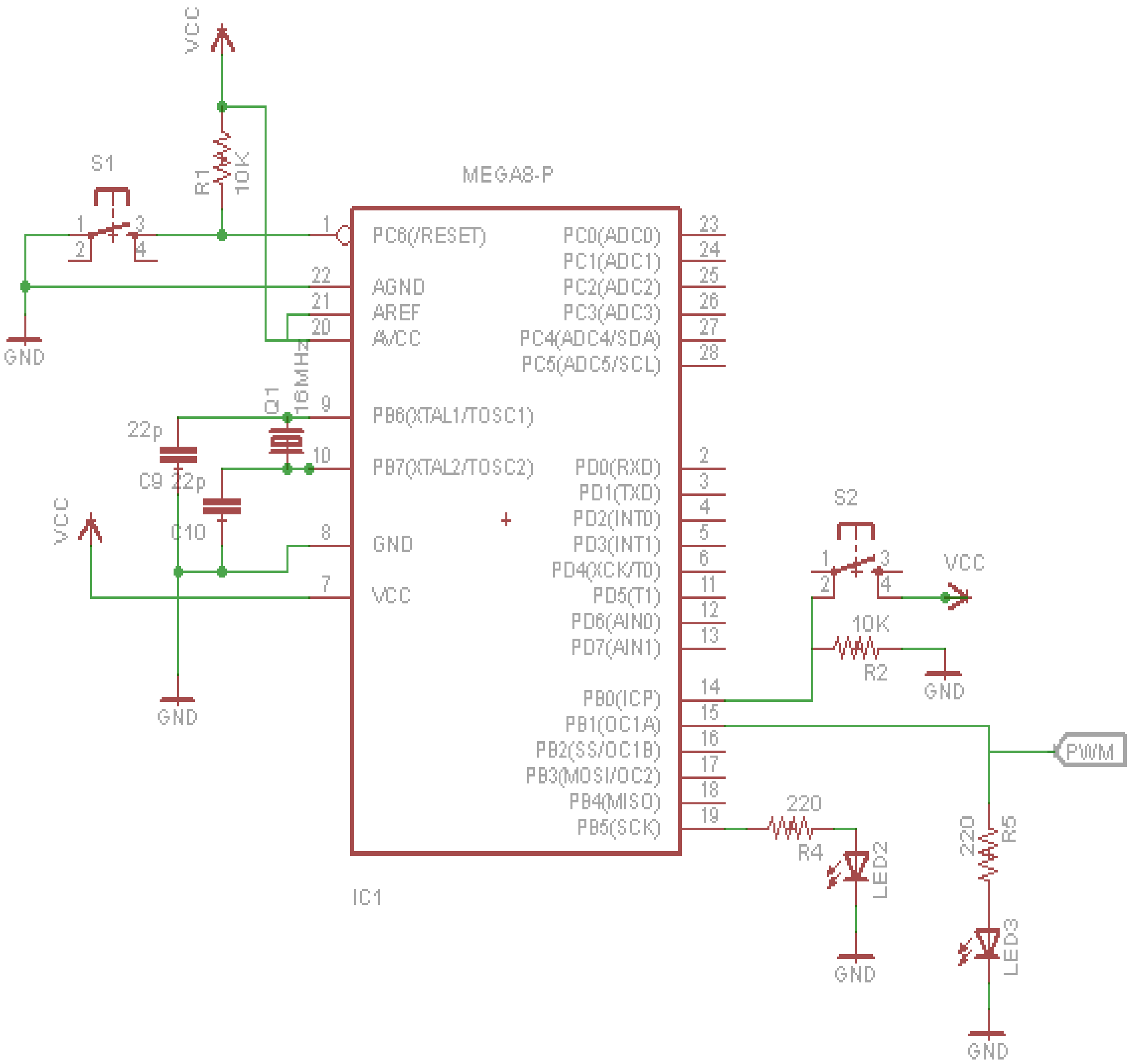
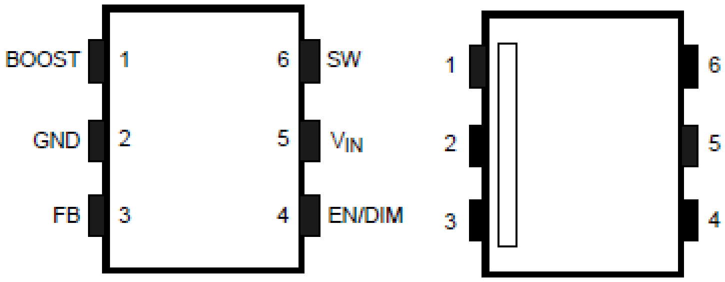


Figure 6 Arduino (Micro Controller) Schematic

3.1.4.3 LED Driver Circuit

The function of LED Driver circuit is to convert PWM output from micro controller to the high current required for high power LEDs, as the maximum possible output current from micro controller is only 250 mA which is not sufficient to drive high power LEDs. In this work the desired high output current levels are 350 mA and 700 mA respectively. There are two ways to design a driver circuit, first is by using MOSFETS or BJTs and second is by using a driver IC. There are number of ICs available in the market that are designed to drive power LEDs. Based on requirement of this project, LM3405 manufactured by Texas Instrument is proposed to be used. LM3405 is a 1 A constant current buck regulator, it is chosen because of its high output current 1 A, that can sufficiently supply 700 mA and because of EN/DIM input pin that can receive and detect/interpret PWM input. LM3405 IC is based on six pins as shown in Figure 7 (a & b). The description for each pin is given in Table 6



(a) (b)

Figure 7 (a) LM3405 Pin Layout (b) LM3405 Pin Identification [26]

Table 6 LM3405 Pin Specification [26]

Pin(s)	Name	Application
1	BOOST	Voltage at this pin drives the internal NMOS power switch. A bootstrap capacitor is connected between the BOOST and SW pins.
2	GND	Signal and Power ground pin. Place the LED current-setting resistor as close as possible to this pin for accurate current regulation.
3	FB	Feedback. External resistor from FB to GND to connected to set LED Current
4	EN/DIM	Enable control input. Logic high enables operation. Toggling this pin with a periodic logic square wave of varying duty cycle at different frequencies controls the brightness of LEDs. Do not allow this pin to float or be greater than VIN + 0.3 V.
5	Vin	Input supply voltage. Connect a bypass capacitor from this pin to GND.
6	SW	Switch pin. Connect this pin to the inductor, catch diode, and bootstrap capacitor.

The complete schematic of driver circuit is shown in Figure 8.

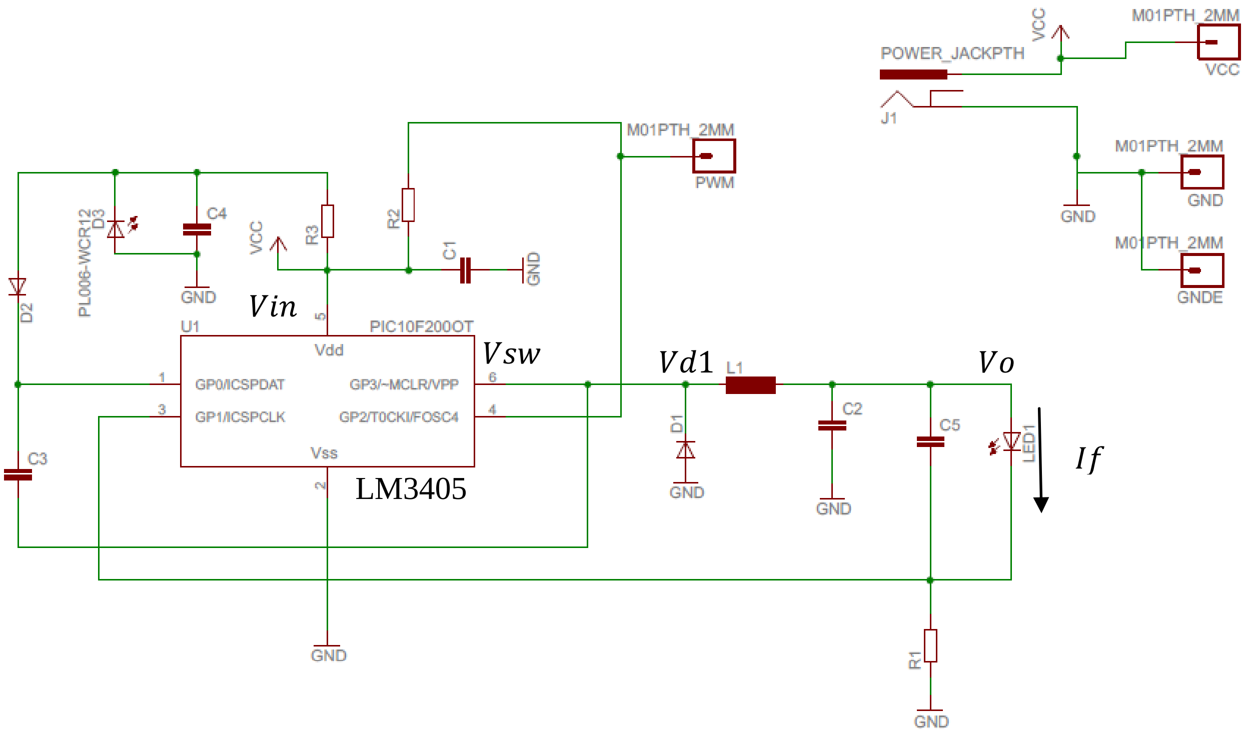


Figure 8 LED Driver Circuit Schematic

3.1.4.3.1 Design Guide for LM3405

For the development of the driver, following considerations are needed to be made.

- Vo = Output Voltage = 4 V;
- $Vd1$ = Voltage across Diode (D1) = 3.5 V;
- Vin = Input Voltage = 5 V;
- Vsw = Voltage across Switch Pin = 0.2 V;
- Vb = Voltage at Feedback (FB) pin = 0.205 V;
- If = Output/LED Current = 1 A;
- fsw = Switching Frequency = 500 Khz;
- r = maximum ripple ratio = 0.05;

Inductance (L_1): Inductance is calculated by using Eq. (2)

$$L_1 = \frac{Vo+Vd1}{If \times r \times fsw}(1-D) \tag{2}$$

Input Capacitor (C_1): A 10 uF multilayer ceramic capacitor is selected due to its low ESL (Equivalent Series Inductance) and to ensure that input voltage does not drop during switching transients. [26]

Output Capacitor (C_2): A 1 µF ceramic capacitor is chosen as output capacitor as it is suitable for low LED current ripple applications. [26].

Feed-Forward Capacitor (C_5): The feed forward capacitor is required to improve the large signal transient response and suppresses LED current overshoot that may occur during PWM dimming. For this application a 1 uF ceramic capacitor is sufficient. [26]. The effect of using feed forward capacitor is shown in waveforms as given in Figure 9 and Figure 10, where Figure 9 shows the PWM dimming without feed forward capacitor and Figure 10 shows PWM dimming with 1 uF feed forward capacitor.

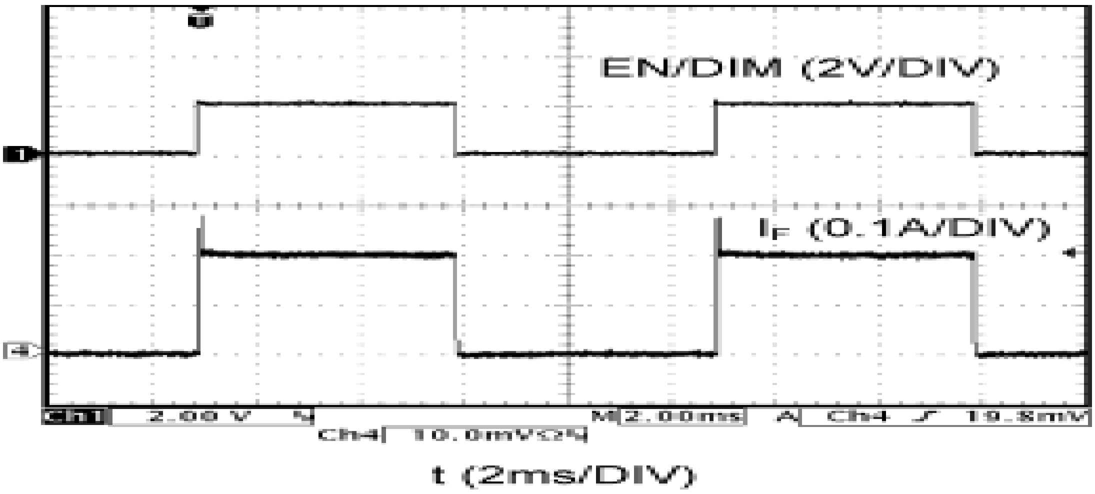


Figure 9 PWM dimming without Feed-Forward Capacitor [26]

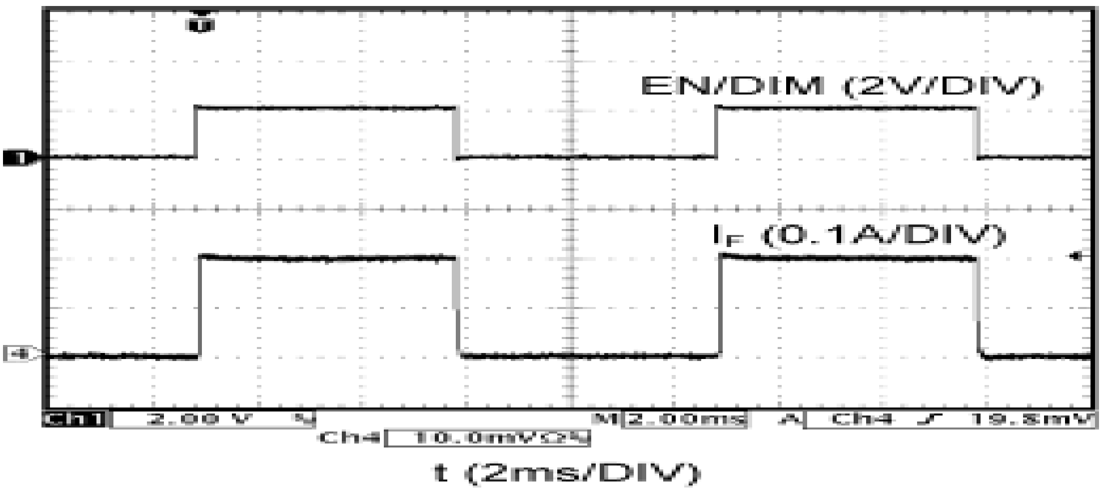


Figure 10 PWM dimming with a 1 uF Feed-Forward Capacitor [26]

Catch Diode (D1): A Schottky diode 30 V at 1 A is selected for high efficiency, since it has fast switching time and low forward voltage drop. [26]

Boost Diode (D2): A small signal schottky diode is used in this circuit for better efficiency as this circuit is derived from voltage less than 3.3 V. [26]

Boost Capacitor (C3): A boost capacitor is connected between the BOOST and SW pins to drive the internal NMOS power switch. A 0.01 uF ceramic capacitor with a voltage rating of 6.3 V is sufficient. [26]

Resistor ($\boldsymbol{R_1}$): R_1 is given by Eq. (3)

$$R_1 = \frac{Vb}{If} \qquad (3)$$

In this case If = 1 A and Vb = 0.205 V so R_1 = 0.2 Ω[26].

3.1.5 Micro Controller Programming

The micro controller selected for this project is ATmega328 that is programmed through Arduino UNO Board. Figure 11 shows Arduino UNO board with ATmega328 inserted on board. Pin mapping of ATmega 328 with respect to arduino is shown in Figure 12. The code for arduino is written in arduino software designed specifically for programming all kinds of arduino boards. Based on design block diagram of proposed driver circuit, the function of micro controller is to send required PWM signal to LED driver circuit. There are different ways in which PWM can be implemented in arduino. The easiest way is to call function analogWrite (pin#, Value), where pin# is the output pin selected and Value is analog Write() value calculated from 0 to 255 (where 0 is indicating 0 % duty cycle and 255 is 100 % duty cycle).

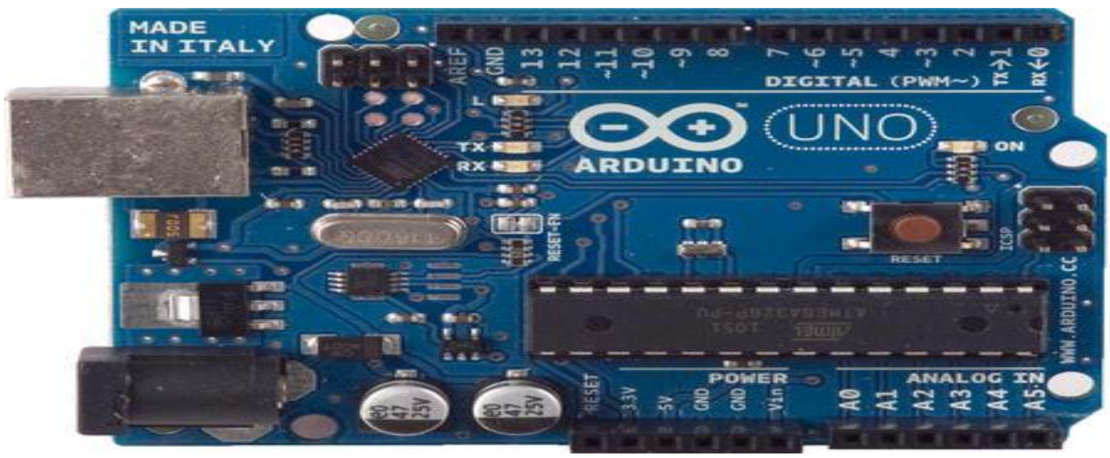


Figure 11 Arduino UNO

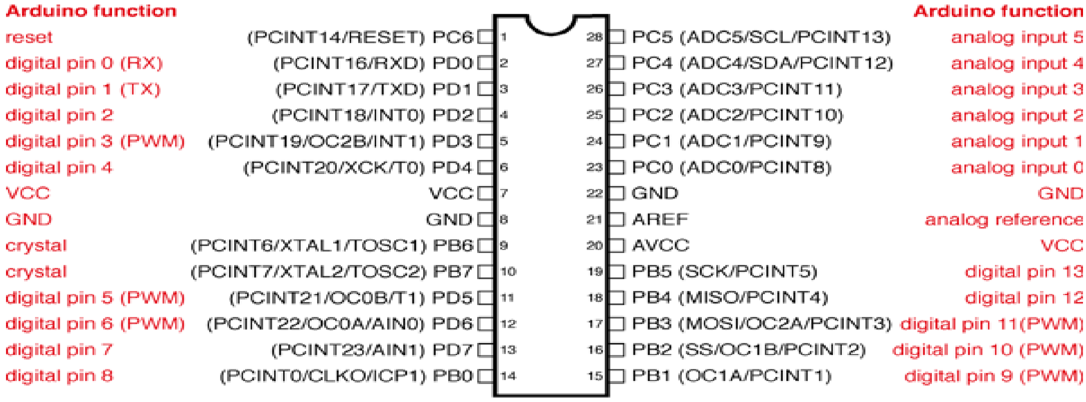


Figure 12 ATmega Pin Mapping With Respect to Arduino

Based on LEDs selected for this project, the current levels required are 350 mA and 700 mA. Analog Write() and duty cycle calculation for required output current is based on Eq. 4 and Eq. 5 respectively where I_r represents required output current in milliampere and *Imax* represents maximum current in milliampere, in this case *Imax*=1 A.

$$\text{Analog Write ()} = \frac{255}{Imax} \times I_r \qquad (4)$$

$$\text{Duty Cycle} = \frac{\text{Analog Write ()}}{255} \qquad (5)$$

The values of calculated duty cycle and analog write() are given in Table 7. Even though changing the value of duty cycle sounds quite simple but it is not an efficient way since it is cumbersome to connect the circuit with computer to change manually the value of PWM. Therefore a program based on mini switch button is proposed to be used in this project that can change the current level by merely pressing the button. However in the case of using a pushbutton, bouncing has to be considered as unwanted input and a code has to be written to tackle bouncing. The functionality of code can be verified on proteus software which includes ATmega328.

Table 7 Duty Cycle Calculation

Required Output Current (I_r)	Analog Write()	Duty Cycle
350 mA	90	0.353
700 mA	179	0.702
1 A	255	1

3.1.6 Optimize & Simulate the Design

After completing the code and driver design, the next task is to optimize the whole design which means to combine all three main parts of circuit which is power supply, micro controller and LED driver circuit. It must be ensured and verified that all three parts can communicate among each other as per required. This verification can be done by simulating the design and verifying the results from simulation. However the simulation of the complete circuit including both micro controller and LED driver circuit is not possible, since there is no electronic simulation software that contains all the components required by complete circuit.

Hence both circuits are simulated separately in different software. For micro controller circuit, Proteus (virtual system modeling software) is used as it contains required ATmega328 IC. For LED driver circuit, Multisim is used as it contains all the components required for driver circuit. The only important measurement to be made during simulation is output current. It has to be ensured that current level is the same as it is required to be and also that it can be changed by pressing the mini switch button.

3.1.7 Order the Components

Once the design is simulated and results are verified through simulation, the next task is to order all the components used in the design. In this work components are ordered online from RSonline, Element14 and Mouser Electronics website. The online order should be made as early as possible, so that components can reach on time.

3.1.8 Design & Fabricate Printed Circuit Board (PCB)

This step can be done simultaneously with step 3.1.7 (Ordering the components). After simulation, printed circuit board (PCB) has to be designed. In this work, Cad Eagle software is used to draw the schematic for PCB. After completing PCB design in Eagle software, the eagle file of the design has been given to Lab Technician for printing the PCB.

3.1.9 Solder the Components on PCB

After fabricating the PCB, the next task is to assemble and connect all components on board. In this work, circuit is divided into three sub circuit, each circuit is suggested to be fabricated separately and the output for each sub circuit is tested separately. This is done in order to easily troubleshoot any problem occurred in the board.

3.1.10 Test & Review the Board

Once PCB is fabricated and the circuit is connected, the next task is to test the board. This is the last and the most important step of this work in which the proposed circuit is tested and reviewed to ensure that the circuit is working as per required. The required output currents from this board are 350 mA and 700 mA respectively. This change in output current should occur with the press of mini switch button. The output current required in this work is with minimum ripple possible (maximum 5 %).

3.2 Project Activities

Figure 13 shows flow of project activities carried out in this work.

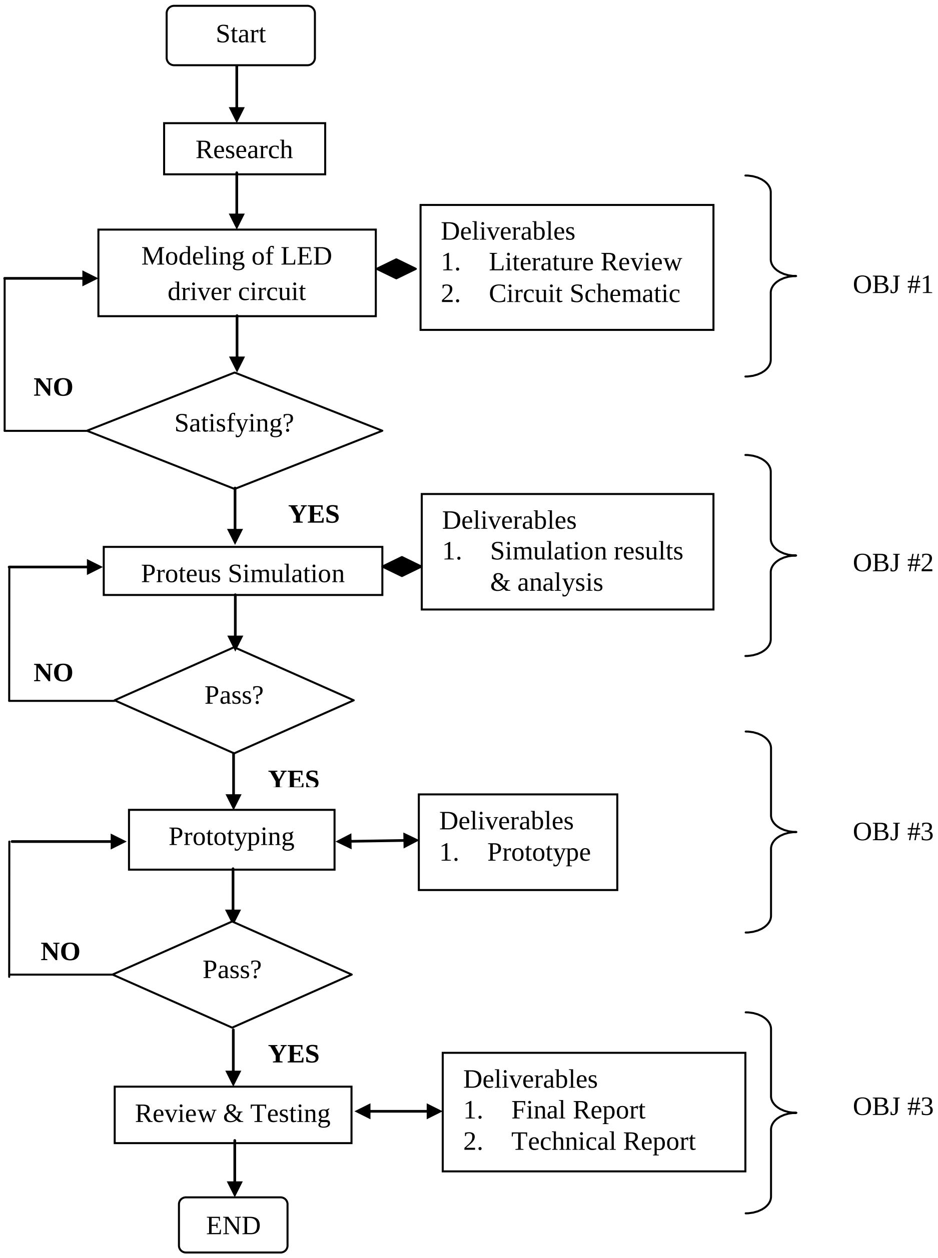


Figure 13 Project Activities Flow Chart

3.3 Key Milestones

Several key milestones have been achieved in order to complete the work.

3.3.1 Literature Review

This is done in order to get as much information and understanding as possible from research papers, journals and other sources available on internet.

3.3.2 Circuit Design

After getting a good understanding, the second key milestone is designing the circuit. While designing the circuit, two factors are of utmost importance, one is that the circuit must be designed based on requirement of the driver and that is to deliver two nominal current levels with minimum ripple and the second is the availability of the components used in the market.

3.3.3 Simulation

After designing the circuit, the third key milestone is simulating the circuit. The circuit is suggested to be simulated in Proteus that contains ATmega328 micro controller chip and Multisim that contains the required components for LED driver circuit.

3.3.4 Prototype

After simulation, next key mile stone is fabricating the designed circuit on a board and validating the results from prototype.

3.3.5 Documentation & Reporting

This is the mile stone that is done throughout the work in forms of different reports in order to get everything properly documented.

3.4 Gantt Chart

The Gantt chart for FYP-I & FYP-II can be referred in Appendix A and Appendix B respectively.

3.5 Tools & Software Required

The components and software used in this work are listed in Appendix C

CHAPTER 4
RESULTS & DISCUSSION

4.1 Arduino UNO (Micro Controller) Program

The program code for ATmega 328 is written in Arduino software that is available for free on Arduino website. ATmega 328 IC is programmed by using Arduino UNO board. The main function of the program is to change the output current level by using a mini push button and to tackle bouncing of mini push button.

4.1.1 Program Code

The program code is written to read the value from push button but it does not check if it is high or low, rather it checks if it was previously low and is currently high in order to detect that button has been just pressed. Two boolean variables are initialized named as lastButton and currentButton with initial value low. Boolean are variables that can have only two different values, on/off, true/false, high/low or 0/1. These Booleans variables are initialized to keep track of button state in previous loop.

```
boolean lastButton = LOW;
boolean currentButton = LOW;
```

In order to change the current level by sending high or low signals from mini push button to micro processor, a potential problem faced is switch bouncing. Since the time it takes for the push button to stop bouncing is in milliseconds and micro controller can respond in milliseconds. There are several ways to debounce the input signal that can be implemented either in hardware or software. In this project debouncing is done through software that is through code written in arduino.

To debounce the switch, a new function named debounce is made that is filled with Boolean value named last that will be the last status of the switch passed. This new function is similar to other functions of arduino, like digitalread with input ‘switch pin’, debounce is the function with input ‘last’. This new function debounce is defined by first reading the current status of the switch, then it is compared with the last status of the switch read in previous loop, if it has changed then delay for 5 ms is given.

This 5 ms delay is going to give enough time to switch to finish debouncing but short enough that the finger would not have been released from the button. Then after the delay, the input value is read again, basically this is done to detect the change in input value by waiting for 5 ms and reading the input again where it is presumably at steady state value and after that value can be returned from function. This function is then run in the main loop, where the condition for last button and current button is checked.

The output current required is 350 mA (0.353 duty cycle, 90 Analog Write()) and 700 mA (0.702 duty cycle, 179 AnalogWrite()). This change in duty cycle is implemented by increasing the analog write value in arduino by 90, once the button is pushed. If the last button status is low and the current button status is high then an increment of 90 is made in the ledLevel. Since the maximum value for analog write value in arduino is required is 179 so it has to be ensured that once ledLevel value increases above 179 then ledLevel brightness reduces to zero. This is done by introducing a condition at the end. If the value is less than or equal to 179 then duty cycle value is sent to the output pin, otherwise it goes back to reading switches. The complete code can be inferred from Appendix-D

4.1.2 Program Flow Chart

The program code is written based on flow chart as shown in Figure 14

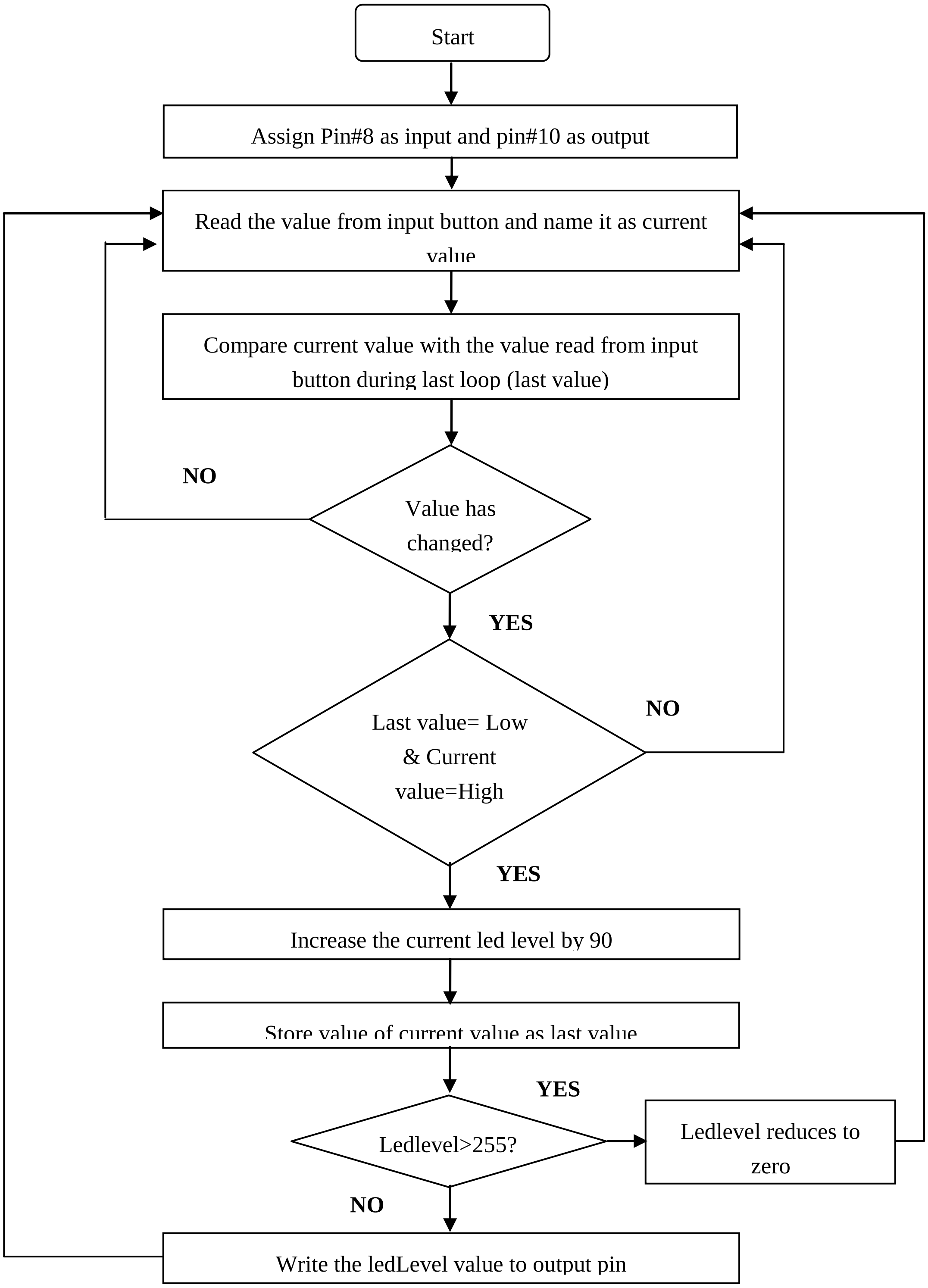


Figure 14 Program Flow Chart

4.2 Simulation Result

In this work, simulation is done by using two different softwares. Proteus is used to simulate micro controller circuit and Multisim is used to simulate LED Driver Circuit. Due to limited number of components in both software, the complete circuit cannot be verified in any one software.

4.2.1 Simulation Results of Micro Controller Circuit

An AC ammeter is connected in parallel with output LED to measure the output current. The program code as written in Appendix D is loaded inside ATmega328 IC. The circuit in Figure 15 shows when the button is not pressed. The output current at this point is 0 A

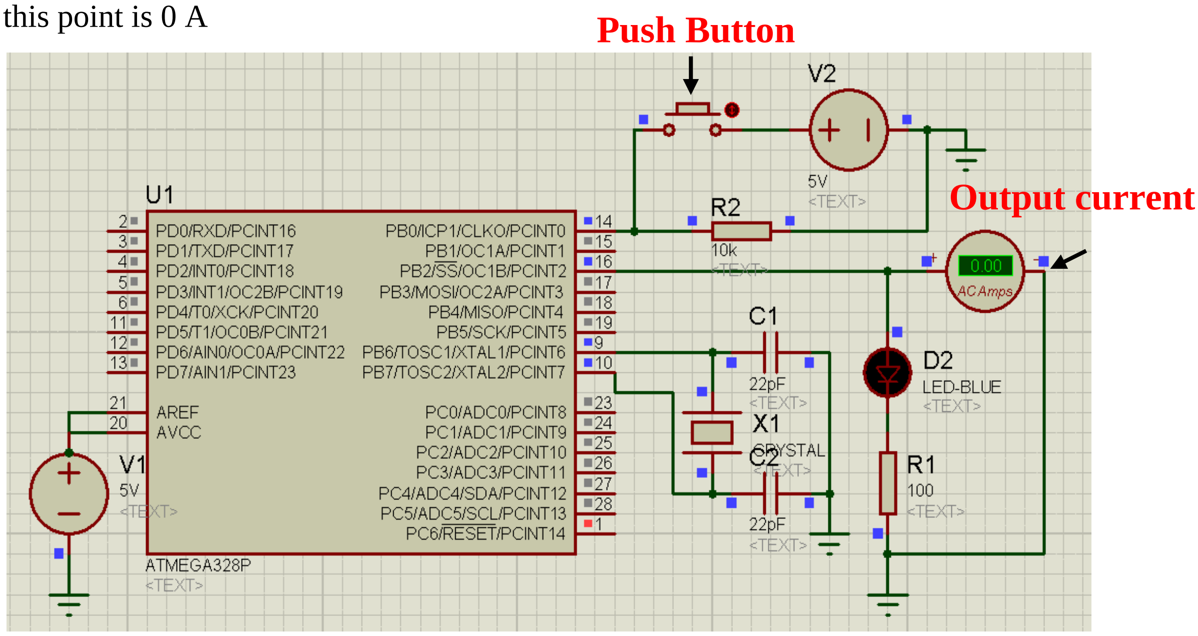


Figure 15 Arduino Simulation when button is not pressed

Figure 16 shows the simulation result when button is pressed for the first time, as programmed in the code pressing the button will increment duty cycle by 0.353 and delivers 160 mA output current. The current value shown in simulation is in amperes.

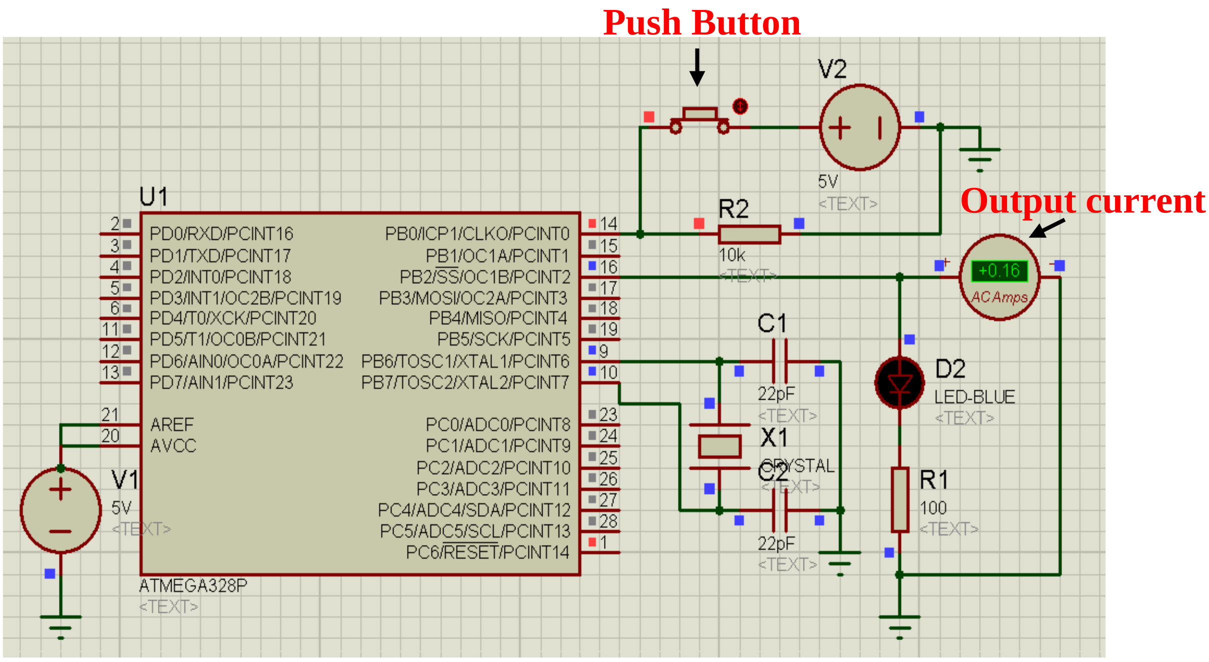


Figure 16 Arduino Simulation when button is pressed for first time

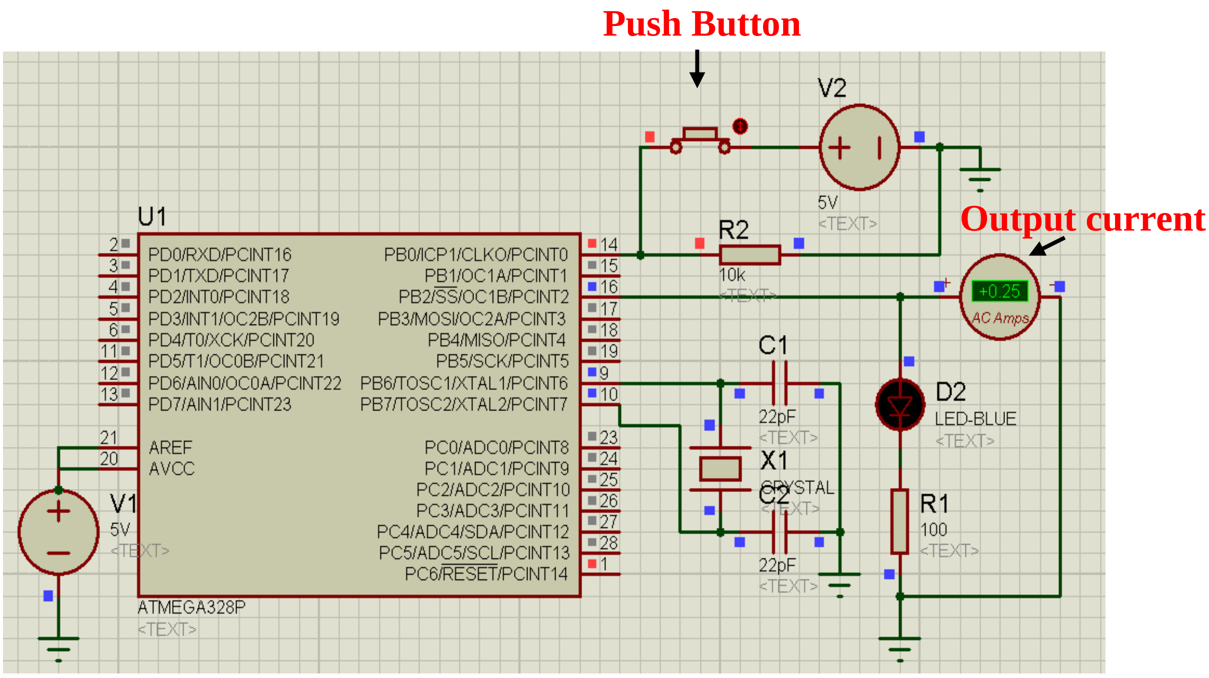


Figure 17 Arduino Simulation when button is pressed for second time

Figure 17 shows simulation when button is pressed for the second time which increments the value of duty cycle to 0.702 and results in output current of 250 mA. Pressing the button for the third time gives zero output current as shown in Figure 15, since further increment in the duty cycle will exceed 1 that is the maximum possible value for duty cycle. This is controlled by condition made in the code.

4.2.2 Simulation Result of LED Driver Circuit

LED Driver circuit is simulated in MultiSim. Figure 18 shows the simulation results when EN/DIM Pin is connected to VCC. By connecting VCC with EN/DIM, the circuit should deliver 1 A output current. This is verified by simulation as shown in Figure 18.

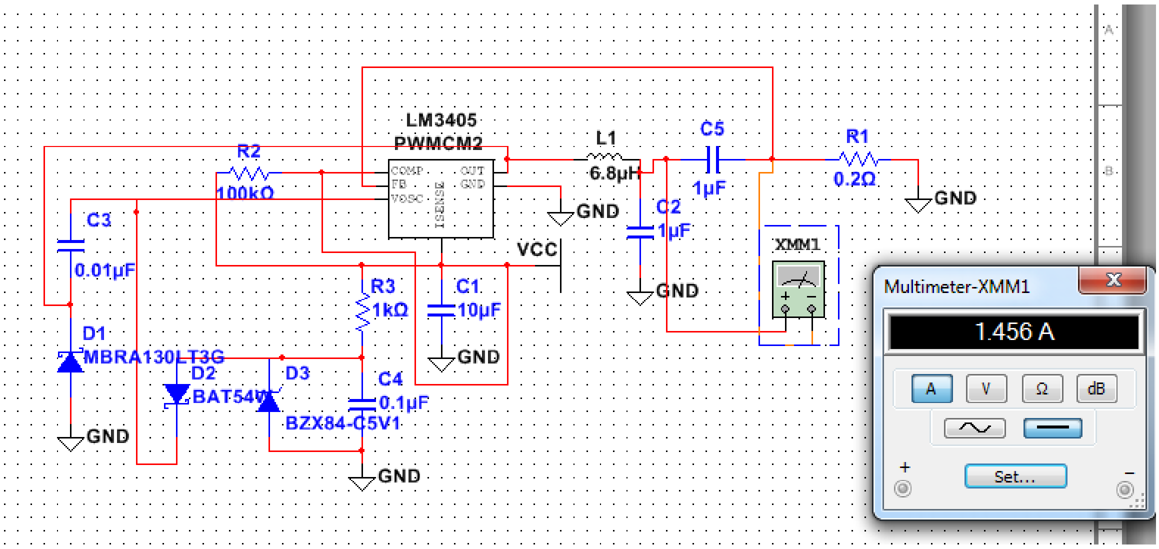


Figure 18 Simulation Result of LED Driver Circuit

4.3 Experimental Results

4.3.1 Printed Circuit Board

In this work, Printed Circuit Board is designed using Cad Eagle Software. In order to design PCB, it must be ensured that the footprint for all the components and devices used in the circuit are available in Eagle software. Once schematic is drawn, a printed circuit board will be automatically generated from the software. However components in the generated board from software are arranged so that complete (100 %) routing can be accomplished.

In this work micro-controller and LED driver circuit are fabricated on two different boards. This is done in order to troubleshoot easily, if any problem occurs. Figure 19 and Figure 20 shows PCB layout and the PCB for Micro Controller Circuit respectively.

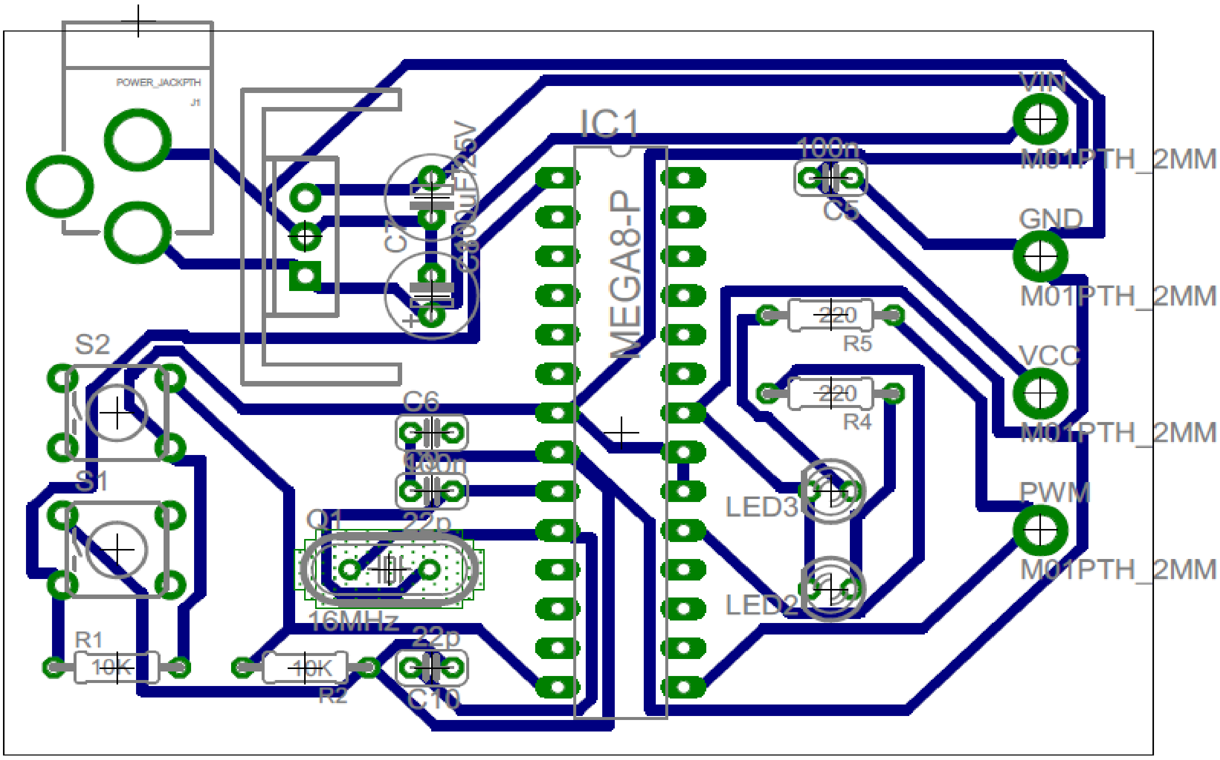


Figure 19   PCB Layout for Power Supply & Micro Controller Circuit

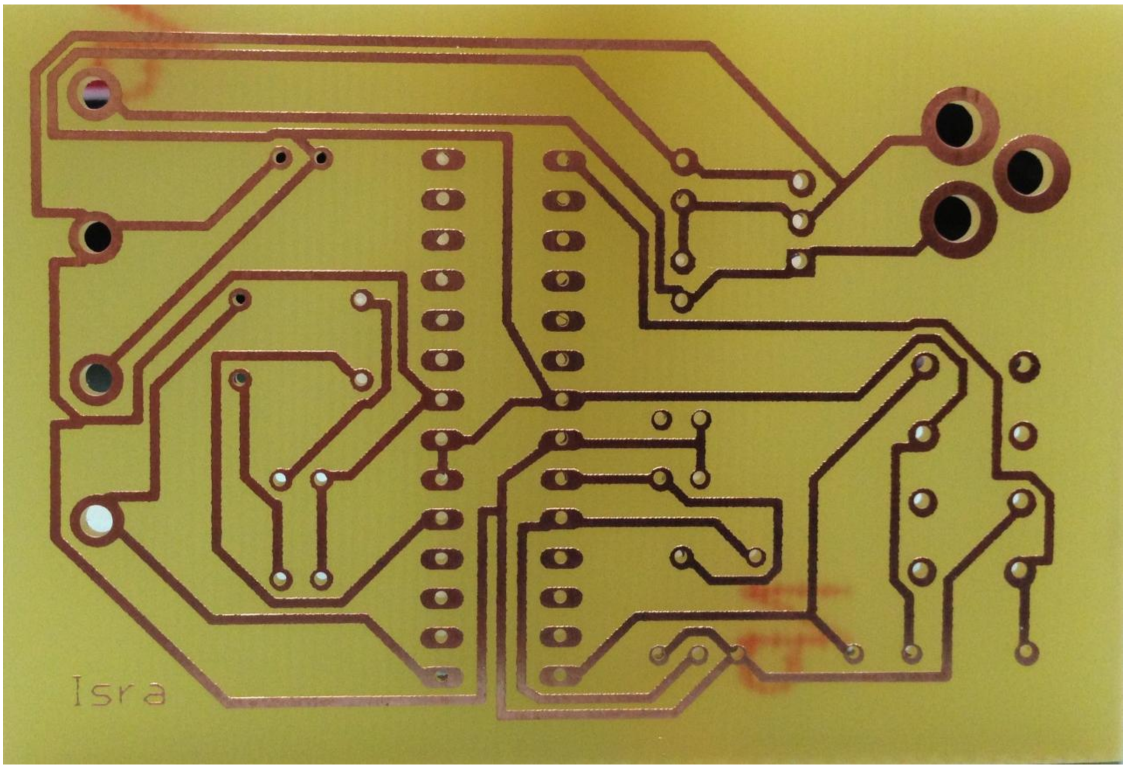


Figure 20   PCB for Power Supply & Micro Controller Circuit

Figure 21 and Figure 22 shows PCB Layout and the PCB itself for LED Driver Circuit respectively.

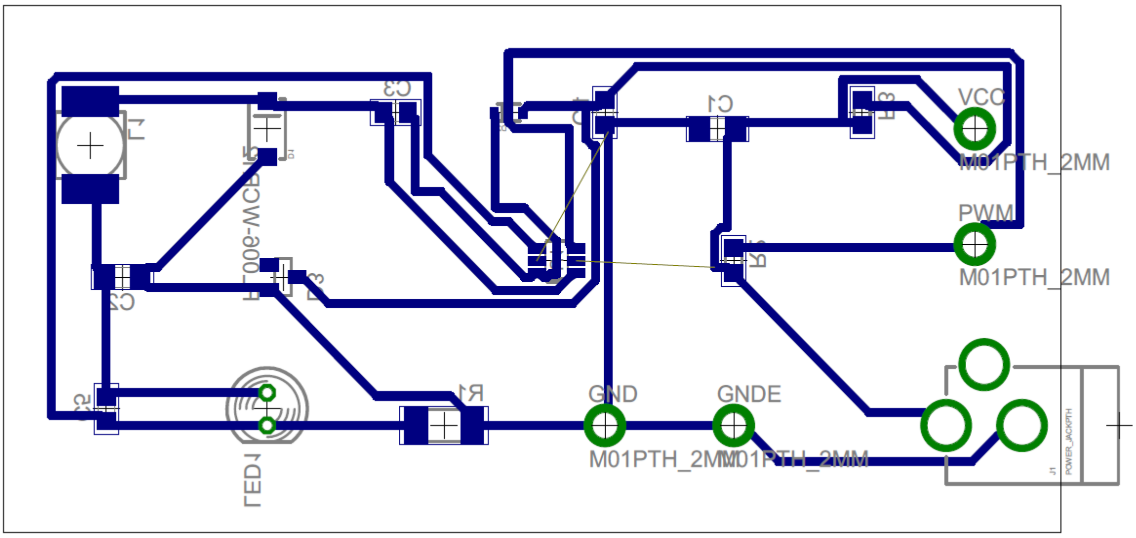


Figure 21 PCB Layout for LED Driver Circuit

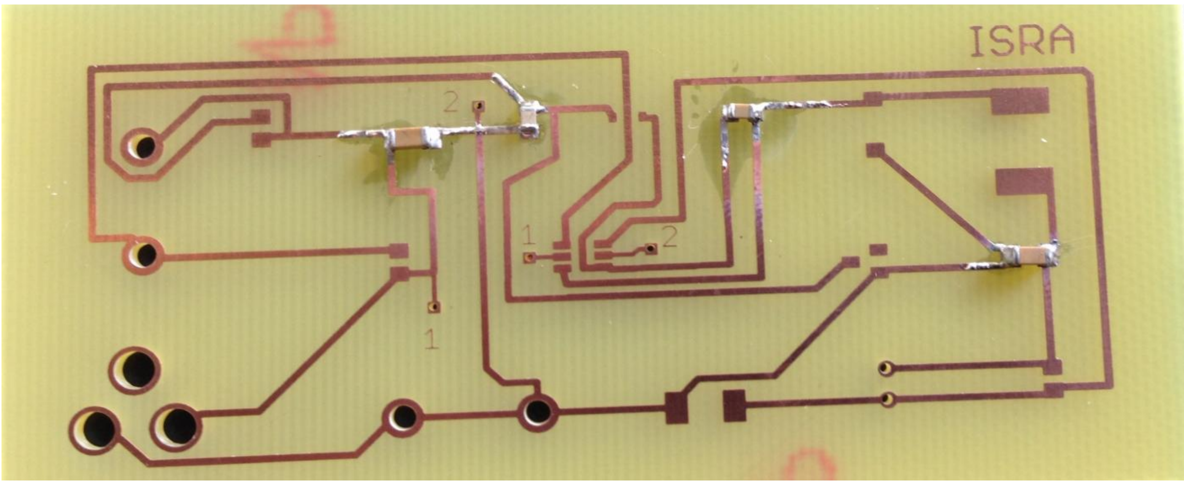


Figure 22 PCB for LED Driver Circuit

4.3.2 Testing & Reviewing

In this work, the output current from LED Driver Circuit is controlled by applying a periodic pulse signal from Micro Controller Circuit to LED Driver Circuit. A logic high level at EN/DIM turns on the LED current whereas a logic low turns off the LED current.

Figure 23 shows the PWM signal applied to EN/DIM from Micro Controller and output voltage from LED Driver Circuit, when button is not pushed yet. The frequency of PWM signal at this point is 0 Hz and the output voltage is 0 V as shown in Figure 23.

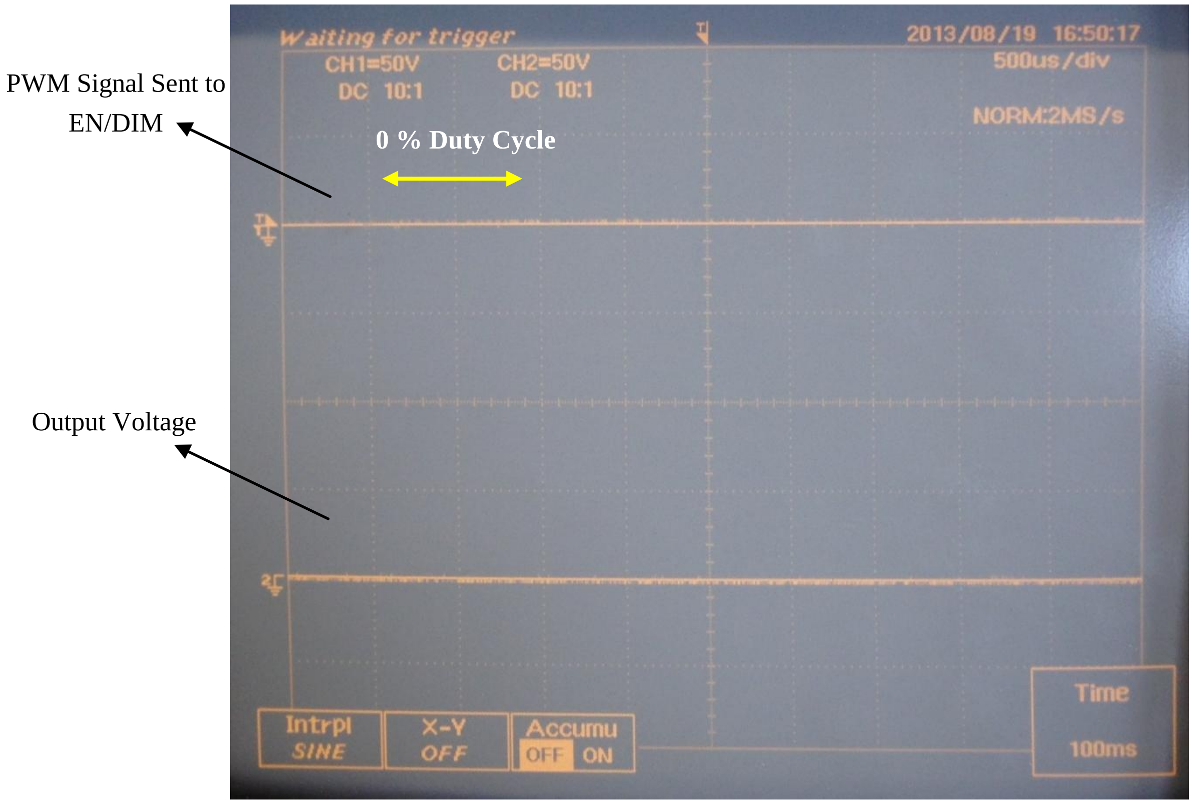


Figure 23 PWM Vs LED Output Voltage when button is not pressed

Figure 24 shows PWM signal and LED current waveform when button is pressed for the first time. The frequency of PWM signal at this point is 500 Hz, the output voltage is 3.53 V and the output current is 346 mA as shown in Figure 24.

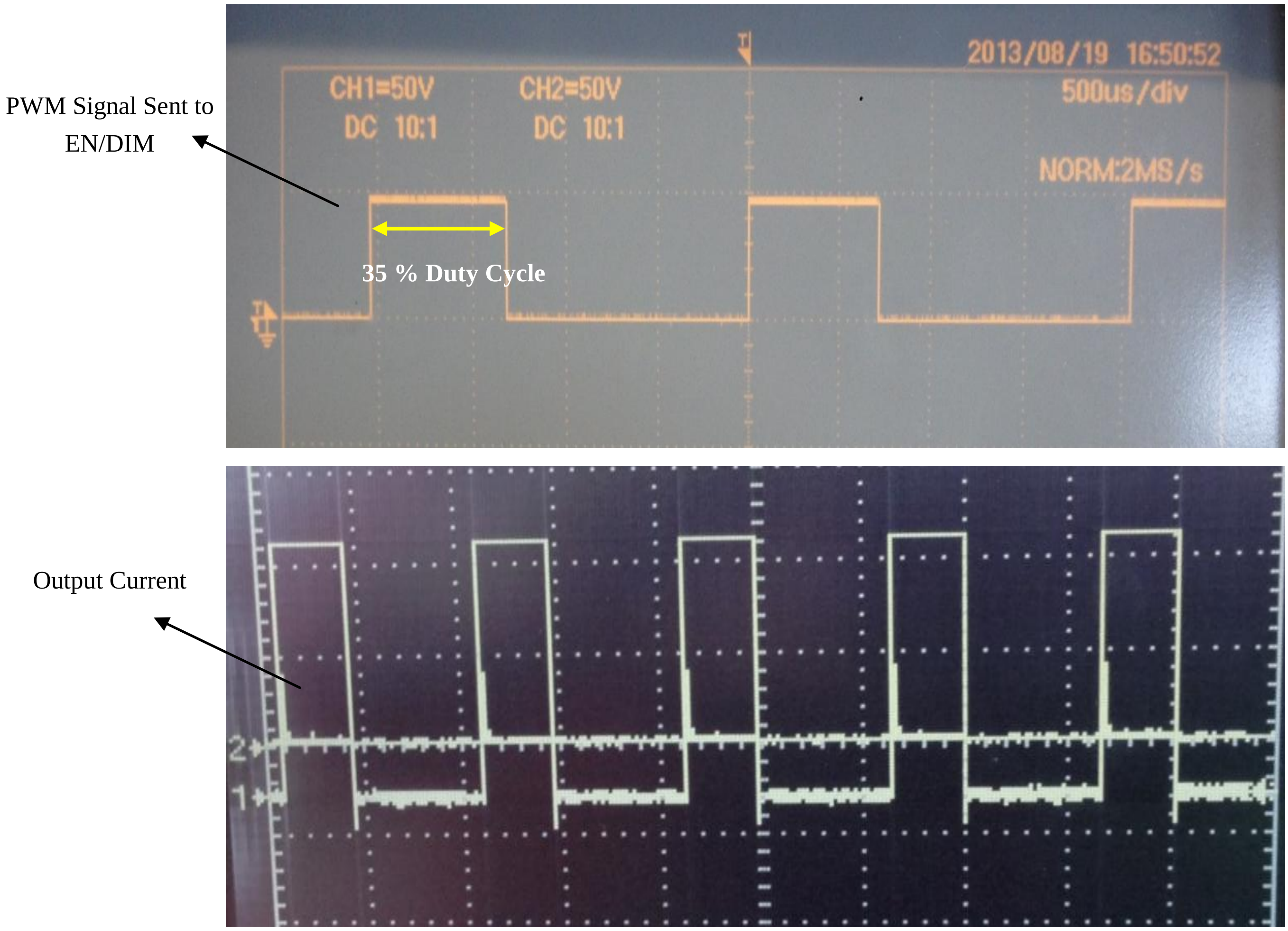


Figure 24 PWM Vs LED Output Current when button pressed for first time

Figure 25 shows PWM signal and LED current waveform when button is pressed for second time. The frequency of PWM signal at this point is 500 Hz the output voltage is 3.58 V and the output current is 713 mA as shown in Figure 25.

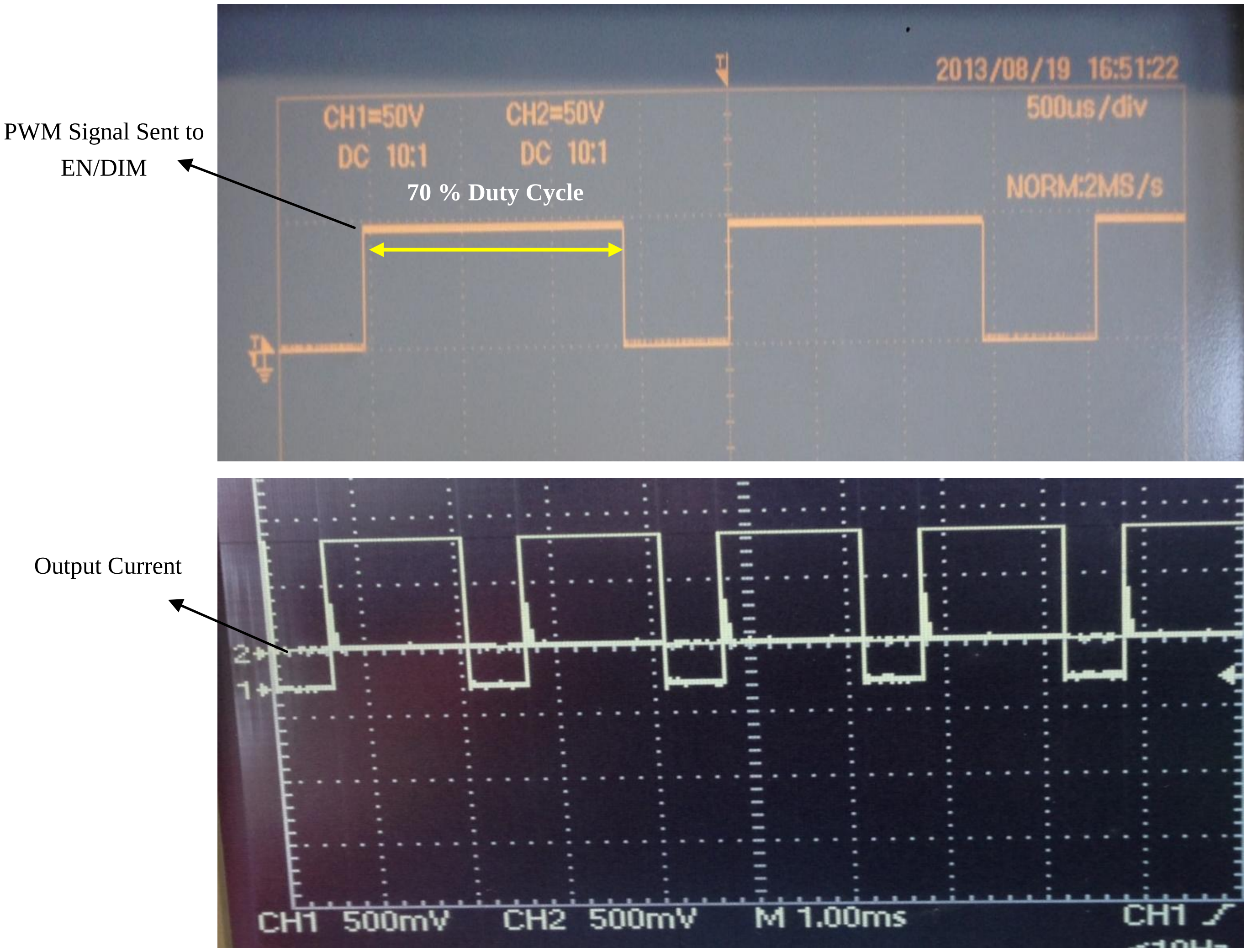


Figure 25 PWM Vs LED Output Current when button pressed for second time

4.3.3 Data Recorded

Table 8 gives the values recorded for some of the important measured variable. It is verified from Table 8, that the circuit proposed in this work is able to drive two different LEDs with different current rating. The button pressed in a single circuit for first time, delivers the output current required to drive LED #1 and button pressed for second time delivers the output current required to drive LED #2.

Table 8 Data Recorded

BUTTON IS NOT PRESSED		
Measured Variable	**Micro Controller Circuit**	**LED Driver Circuit**
Output Voltage	0 V	0 V
Output Current	0 A	0 A
Frequency	0 Hz	0 Hz
Duty Cycle	0	0
BUTTON IS PRESSED FOR THE FIRST TIME		
Measured Variable	**Micro Controller Circuit**	**LED Driver Circuit**
Output Voltage	1.68 V	3.53 V
Output Current	160 mA	346 mA
Frequency	500 Hz	500 Hz
Duty Cycle	0.353	0.353
BUTTON IS PRESSED FOR THE SECOND TIME		
Measured Variable	**Micro Controller Circuit**	**LED Driver Circuit**
Output Voltage	3.35 V	3.60 V
Output Current	250 mA	713 mA
Frequency	500 Hz	500 Hz
Duty Cycle	0.702	0.702

4.3.4 Final Prototype

The final Prototype is shown in Figure 26

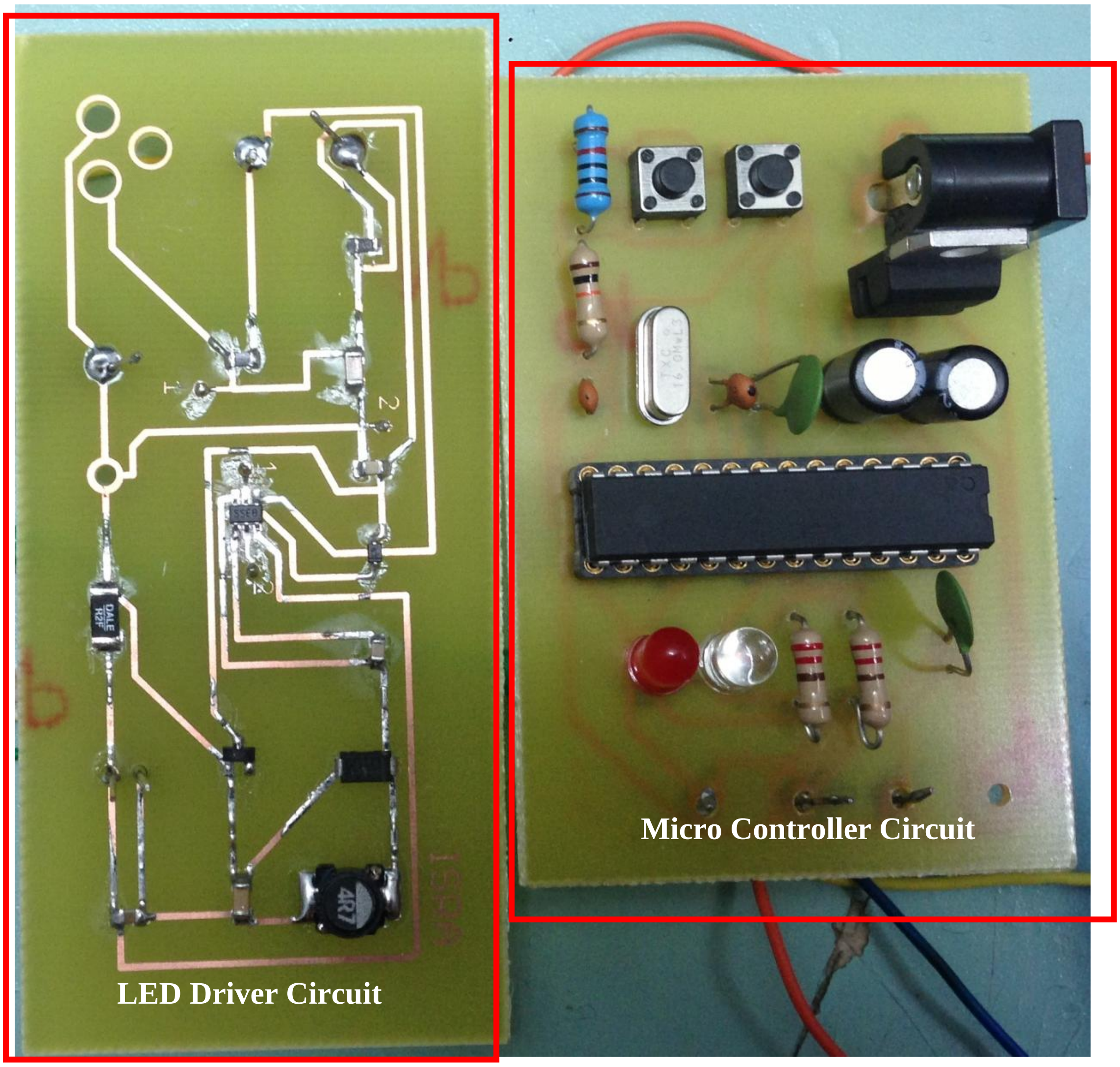


Figure 26 Final Prototype: Universal LED Driver Circuit

CHAPTER 5
CONCLUSION

Universal LED Driver Circuit is a step towards enhancing LED Technology. Undoubtedly LED is one of the most efficient lighting systems with all the benefits of high efficiency, superior longevity, directionality and light intensity control. LED has all the potential to revolutionize the present lighting system and play its role to deliver efficient lighting system that will not only save energy sources available on the planet but also lessen the burden of people by reducing electricity bills.

Other than high cost, one of the strongest barriers on the way of adaptation of LED Technology is a need of LED driver Circuit. This work proposes a single LED driver circuit that can be used to drive multiple types of LED with the ultimate aim of reducing cost of using different driver circuit for different LEDs and to enhance LED technology. In this work, only two LEDs with different specifications are used to verify the working of driver circuit.

Pulse Width Modulation (PWM) is used to achieve the purpose. Micro controller circuit with a simple program written in Arduino is used to change the PWM signal sent to LED driver Circuit with press of push button. The button pressed for first time, delivers output current required by LED #1, and the button pressed for second time, delivers output current required by LED #2. Proposed design is simulated and a prototype is designed and the validity of the designed driver is verified.

REFERENCES

[1] Philips, (May, 2012). "*The LED Lighting Revolution,"* Retrieved January 26, 2013 from http://www.lighting.philips.com

[2] R. Xu, H. Li, Y. Li and X. Hou "Research on high efficiency led driving circuit based on buck topology". *Scientific Research*, pp. 352-357, August 2011.

[3] C.J.Huang & Y.C.Chuang "Design of Closed-Loop Buck-Boost Converter for LED Driver Circuit". *Industrial & Commercial Power Systems Technical Conference (I & CPs), IEEE Technical Conference,* pp. 1-6, May 2011.

[4] T.P.Sun & C.H.Wung "Specially Designed Driver Circuit to Stabilize LED Light Output Without a Photodetector". *Power Electronics, IEEE Transactions on (Volume 27, Issue: 9),* pp. 4140-4152, September 2012.

[5] A.MirWakili & V.Joyner "A Digitally Controlled, Bi-level CMOS Led Driver Circuit Combining PWM Dimming and Data Transmission for Visible Light Networks". *GLOBECOM Workshops (GC Workshops),* pp. 1067-1071, December 2010.

[6] H.Wang, Z.Liu & J.Dong "High Power LED Constant-Current Driver Circuit Design and Efficiency Analysis". *Cross Strait Cross Regional Radio Science and Wireless Technology Conference,* pp. 705-710, July 2011

[7] D.Aguilar & C.P.Henze "LED Driver Circuit with inherent PFC". *Twenty Fifth Annual IEEE, Applied Power Electronics Conference and Exposition, ,* pp. 605-610, February 2010.

[8] Q.Hu & R.Zane "LED Driver Circuit with Series-Input-Connected Converter Cells Operating in Continuous Conduction Mode". *IEEE Transactions on Power Electronics (Vol.25, Iss.3),* pp.574-582, March 2010.

[9] Y.S.Chen, T.J.Liang, K.H.Chen, J.N.Juang "Study & Implementation of High Frequency Pulse LED Driver with Self-Oscillating Circuit". *Circuits & Systems, IEEE International Symposium*, pp. 498-501, May 2011.

[10] X.Zou, K.Yu, Z.Zheng, X.Chen, Z.Zou & D.Liao. "Dynamic Current Limitation Circuit for White LED Driver". *Circuits & Systems, IEEE Asia Pacific Conference,* pp. 898-901, December 2008.

[11] W.Chen, S.N.Li & S.Y.R.Hui. "A Comparative Study on the circuit topologies for Offline Passive Light Emitting Diode (LED) Drivers with Long Lifetime & High Efficiency ". *Energy Conversion Congress and Exposition*, pp. 724-730, September 2010.

[12] Philips, (June, 2012). *"LED,"* Retrieved February 14, 2013 from http://thecleanrevolution.org/_assets/files/LED_report_web1.pdf

[13] A. E. D. Junior, J. R. D. Britto, L. C. D. Freitas, V. J. Farias and E. A. A. Coelho, "Microcontroller-based quadratic buck converter used as led lamp driver," *Power Electronics and Applications, European Conference*, pp. 1-6, September 2007.

[14] National Semiconductor, (2011). *"LED Drivers for High Brightness Lighting,"* Retrieved February 10, 2013 from http://sva.ti.com/assets/en/appnotes/national_lighting_solutions.pdf

[15] B. Johnson and J. Lee, Fair Child Semiconductor, (2011). *"Solution for today's Low Power LED Lighting Trends,"* Retrieved February 20, 2013 from

http://www.fairchildsemi.com/collateral/whitepapers/AEP2415_Low_Power_LED_Lighting.pdf

[16] US department of energy efficiency and renewable energy, (2007). *"Thermal management of white leds,"* Retrieved March 4, 2013 from http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/thermal_led_feb07_2.pdf

[17] Harvard, (2012). *"Cool LED Driver,"* Retrieved February 16, 2013 from http://www.harvardeng.com/productscoolled.do;jsessionid=920A67EF6686E8DF044DCADBE15B7F6F

[18] National Semiconductor, (2011). *"LED Drivers for High Brightness Lighting,"* Retrieved February 10, 2013 from http://sva.ti.com/assets/en/appnotes/national_lighting_solutions.pdf

[19] M. T. A. Rahman, "Buck-boost power led driver using pic microcontroller," B. Eng. Thesis, Dept. Elect. Eng., UMP, Pahang, 2008.

[20] W. Y. Leung, T. Y. Man and M. Cha "A high-power-led driver with power-efficient led-current sensing circuit," *Solid-State Circuits Conference, 34th European*, pp. 354-357, September 2008.

[21] T. L. Chern, T. M. Huang, W. Y. Wu, W. M. Lin and G. S. Huang. "Design of led driver circuits with single-stage pfc in ccm and dcm," *6th IEEE conference on Industrial Electronics and applications Conference (ICIEA),* Pp. 2358-2363, June 2011.

[22] J. R. Britto., A. E. Demian, L. C. Freitas, V. J. Farias, E. A. A. Coelho and J. B. Vieira, "A proposal of led lamp driver for universal input using cuk converter," *IEEE Power Electronics Specialists Conference, PESC 2008.* pp. 2640-2644, June 2008.

[23] R. Sinnadurai, M. K. A. A. Khan, M. Azri and Vikneswaran. “Development of white led down light for indoor lighting,” *IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (STUDENT),* pp. 242-247, October 2012.

[24] S. Cha, D. Park, Y. Lee, C. Lee, J. Choi, J. Lee and H. Lee, “Ac/dc converter free led driver for lightings,” *IEEE International Conference on Consumer Electronics (ICCE),* pp. 706-708, January 2012.

[25] H. J. Chiu, Y. K. Lo, J. T. Chen, S. J. Cheng, C. Y. Lin and S. C. Mou, “A high-efficiency dimmable LED driver for low-power lighting applications,” *IEEE Transactions on Industrial Electronics Journal,* pp. 735-743, February 2010.

[26] Texas Instruments. “LM3405 datasheet,” Retrieved March 20, 2013 from http://www.ti.com/lit/ds/symlink/lm3405.pdf

APPENDICES

APPENDIX A

GANTT CHART FOR FYP-I

No	TASK		Week No.														
			1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	**DESIGN LED DRIVER**																
	1.1.	Literature Review															
	1.2.	Block diagram of design															
	1.3.	Selection of LEDs															
	1.4.	Selection of Micro controller															
	1.5.	Getting familiar with micro controller															
	1.6.	Design LED driver circuit															
	1.7.	Program micro controller															
	1.8.	Optimize the whole design															
2.	**SIMULATE THE DESIGN**									**B**							
	2.1.	Learning Proteus								**R**							
	2.2.	Simulation in Proteus								**E**							
	2.3.	Analyzing output current								**A**							
	2.4.	Place order for components								**K**							
3.	**EXTENDED PROPOSAL (10 %)**																
	3.1.	Extended proposal writing															
	3.2.	Extended proposal submission															
4.	**PROPOSAL DEFENSE (40 %)**																
	4.1.	Proposal defense preparation															
	4.2.	Proposal defense presentation															
5.	**INTERIM REPORT (50 %)**																
	5.1.	Interim report writing															
	5.2.	Draft interim report submission															
	5.3.	Final interim report submission															

APPENDIX B

GANTT CHART FOR FYP-II

No.	TASK	Week No.															
		1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1.	**SIMULATE THE DESIGN**																
	1.1. Simulation in proteus																
	1.2. Analyze output current																
2.	**PROTOTYPE**																
	2.1. Fabricating circuit on PCB																
	2.2. Testing & Reviewing																
3.	**PROGRESS REPORT (10 %)**																
	3.1. Progress report writing								**B**								
	3.2. Progress report submission								**R**								
4.	**PRE-EDX (10 %)**								**E**								
	4.1. Pre-EDX preparation								**A**								
	4.2. Pre-EDX presentation								**K**								
5.	**TECHNICAL REPORT (10 %)**																
	5.1. Technical report writing																
	5.2. Technical report submission																
6.	**FINAL REPORT (40 %)**																
	6.1. Final report writing																
	6.2. Draft report submission																
	6.3. Final report submission																
7.	**VIVA (30 %)**																

APPENDIX C

LIST OF TOOLS & SOFTWARES

No	Name of component	Description	Manufacturer	Part #	Supplier	Qty	Price/Unit (RM)	Total Price (RM)
1.	Arduino UNO	Micro controller Board	Arduino	DT-ARD-UNO	E-shore Technologies	1	83.00	83.00
2.	USB Type A-B Cable	Standard issue 2.0 cable, A to B Male/Male Peripheral cable	N/A	CC-USBB	E-shore Technologies	1	4.00	4.00
3.	High Power LEDs - Single Color True Green 1 Watt Starboard	If = 350 mA, Vf = 2.8-4 V, Luminous Flux = 90 lm,Color = Green, Mounting Style = Screw	VCC	Mft Part No. VAOL-ST1XAX-SA , Order Code. 593-VAOL-ST1XAX-SA	Mouser Electronics	2	20.67	41.34
4..	LedEngin LZ1-10UA00-U4	If = 700 mA, Vf = 3.9 V Color = Ultra violet, Mounting style = Screw	LED Engin	Mftr Part No. LZ1-10UA00, Mouser Part No. 897-LZ110UA00	Mouser Electronics	2	84.32	168.64
5.	LM3405	1 A Constant Current Buck Regulator for powering LEDs	Texas Instruments	Mtfr Part No. LM3405AXMK/NOPB, RS Stock No. 761-5665	RSonline	4	7.84	31.36
6.	Resistor (R1)	0.2 ohm, 0.5 Watt, 1 %	Vishay	Mtfr Part No. WSL2010R2000FEA, RS Stock No. 2508442332	RSonline	5	3.95	19.75
7.	Inductor (L1)	6.8 micro Henry, 1.5 A, 35 mΩ	TDK	Mtfr Part No. SLF6028T-6R8M1R5-PF, RS Stock No. 604-4589	RSonline	10	4.02	40.20
8.	Capacitor (C1)	10 micro Farad, 25 V, X5R	TDK	Mtfr Part No. GRM31CR61E106K12L, Order Code. 1962129	Element14	10	0.23	2.30
9.	Capacitor (C2 & C5)	1 micro Farad, 25 V, X7R	Taiyo Yuden	Mtfr Part No. LMK107B7105MA-T, Order Code. 1683563	Element14	15	0.13	1.68
10.	Capacitor (C3)	0.01 micro Farad, 16 V, X7R	AVX	Mtfr Part No. 0805YC103KAT2A, Order Code. 4538717	Element14	10	0.16	1.58
11.	Capacitor (C4)	0.1 uF, 16 V, X7R	Murata	GRM219R71C104KA01D	Element14	10	0.18	1.80

12.	Schottky Diode (D1)	Schottky, 30 V at 1A, SMA	On Semiconductor	Mtfr Part No. MBRM110LT1G Order Code. 1651127	Element14	5	1.70	8.50
13.	Schottky Diode (D2)	Schottky, 30 V at 200 mA	Central Semiconductor	Mtfr Part No. CMDSH-3TR Mouser Part No. 610CMDSH-3TR	Mouser Electronics	10	2.07	20.70
14.	Diode (D3)	5.1 V, 0.35 W, SOT-23	Fairchild Semiconductor	Mtfr Part No. BZX84C5V1 Order Code. 1651127	Element14	10	2.5	20.5
15.	Proteus 7.6	Software for micro processor simulation	Labcenter Electronics	N/A	Downloaded	N/A	N/A	N/A
16.	MultiSim	Software for Electronic Simulation	National Instruments	N/A	Downloaded	N/A	N/A	N/A
17.	Cad Eagle	Software for drawing PCB	Eagle	N/A	Downloaded	N/A	N/A	N/A
18.	LM3405, 1A LED Driver	Evaluation Board for LM3405	Texas Instruments	Mtfr Part No. LM3405XEVAL/NOPB, Order Code. 2212979	Element14	1	178.24	178.24
							TOTAL COST (RM)	**623.59**

APPENDIX D

PROGRAM CODE

```
int switchPin = 8;
int ledPin = 9;
boolean lastButton = LOW;
boolean currentButton = LOW;
int ledLevel = 0;
void setup()
{
 pinMode(switchPin, INPUT);
  pinMode(ledPin, OUTPUT);
}
boolean debounce(boolean last)
{
  boolean current = digitalRead(switchPin);
  if (last != current)
  {
    delay(5);
    current = digitalRead(switchPin);
  }
  return current;
}
void loop()
{
  currentButton = debounce(lastButton);
  if (lastButton == LOW && currentButton == HIGH)
  {
    ledLevel = ledLevel + 90;
  }
  lastButton = currentButton;
  if (ledLevel > 255) ledLevel = 0;
  analogWrite(ledPin, ledLevel);
```