BUCK-BOOST POWER LED DRIVER USING PIC MICROCONTROLLER

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To my beloved mother, father, sister, brother and my love

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ABSTRACT

One traditional low-cost way of driving LED in electrical applications uses a resistor in series with the LED device. Although this driving scheme is simple and inexpensive, it suffers several disadvantages. The LED current can vary substantially over the battery voltage range even in normal operation of the device, thus affecting the brightness and reducing the service life of the lighting device. Additionally, protection is needed from automotive voltage transients and reverse polarity. These disadvantages are typically resolved by using constant-current linear regulators. Besides driving the LED at a programmed current, these regulators can inherently protect from a reverse-polarity application and block voltage transients up to tens of volts. Linear current regulators do not require input EMI filters and can yield inexpensive LED driver solutions. However, both the resistor ballasts and the linear regulators exhibit low efficiency. They may become impractical for driving high-brightness LED loads due to the excessive heat dissipation. Therefore, switching power converters are needed for driving many signal and lighting LED devices.

ABSTRAK

Pada masa dahulu, cara lama untuk menghidupkan lampu LED dalam semua aplikasi adalah dengan menggunakan perintang yang diletakkan dalam keadaan bersiri dengan lampu LED. Walaupun cara ini nampak mudah dan tidak menggunakan kos yang banyak tapi sebenarnya terdapat banyak kelemahan dalam menggunakan cara ini. Semasa menggunakan cara yang lama ini, arus elektrik yang digunakan untuk menghidupkan lampu ini akan berubah mengikut had lingkungan operasi voltan bateri itu dan ini akan menyebabkan keterangan lampu akan berkurang dan jangka hayat lampu juga sama. Namun begitu, masalah ini boleh diatasi dengan menggunakan arus terus regulator dan dengan menngunakan alat ini, masalah seperti perubahan voltan dapat diatasi. Arus terus regulator juga tidak memerlukan input penapis EMI dan juga ia sangat murah untuk digunakan. Namun begitu, dengan regulator ini keberkesanan kuasa yang masuk ke dalam lampu akan berkurang juga dan ini tidak sesuai untuk menjanakn lampu LED yang berkuasa tinggi jadi dengan menggunakan sistem yang direka inilah semua masalah itu akan diatasi.

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LIST OF ABBREVIATION

LED	-	Light emitting diode
LCD	-	Liquid Crystal Display
ROM	-	Read Only Memory
EPROM	-	Erasable Read Only Memory
RAM	-	Random Access Memory
OSC	-	Oscillator
SMPS	-	Switch Mode Power Supply
PWM	-	Pulse Width Modulation
ADC	-	Analog digital converter
PIC	-	Programmable Integrated Circuit

LIST OF SYMBOL

u	-	Micro
K	-	Kilo
m	-	mili
kHZ	-	Kilohertz
V	-	Volts
I	-	Current
L	-	Load

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CHAPTER 1

INTRODUCTION

1.1 Overview of Project

In this project, I will be designing a power LED driver using PIC microcontroller and also buck-boost converter. The reason for me to design such a driver is to provide an efficient solution to the old method using a resistor in series to limit the current through the power LED because by using the method the LED will result not having enough efficiency at the typical power levels required for it to operate. But by using the LED driver, the input voltage can be adjusted to the correct level of voltage and supply the desired current for LED and also with this driver it will provide a more efficient solution for driving a high power LED and increase the efficiency of the power levels required for the LED to operate.

Typically boost converter are used in many electrical application for driving long strings of LED such as in instrument panel backlights and other lighting devices that require series connection of multiple LED. A typical boost converter can drive strings of LED having forward voltage in excess of 100 V. However, recent advances in the high-brightness LED technology have substantially increased the power ratings of a single LED package. LED current of 350mA,700mA or even 1A are typical. Therefore, the number of series-connected LED in the string used in any lighting devices has become smaller. Despite its simplicity, the boost converter of suffers a serious drawback in many of the electrical application systems where the supply line voltage can easily exceed the forward voltage of the LED string.

Boost-buck converters can offer a solution for most of the higher-power lighting applications, including both exterior and interior lighting. It can fit well even in forward-lighting devices, when they become available.

A CCM buck-boost converter integrates an input boost stage and an output buck stage, thus being able to step the input voltage up or down as needed. Both the input and the output currents of the converter are continuous, yielding good EMI performance.

1.2 Scope of Project and Objective

In this project, there are three scopes that were proposed. One of it is to design and fabricate controller circuit using PIC microcontroller. The PIC microcontroller that I will be using is PIC16F785 because it has many suitable characteristic for it to be the Power LED driver. The second one is to design and fabricate Buck-Boost converter. Even thought that Buck-Boost converter circuit are fixed it still need to redesign again into more suitable circuit that is convenient to this application. The third one is to control Buck-Boost converter the PIC microcontroller.

The objective of this project is to design a system that provides more efficient solution for driving a high power LED by controlling the LED forward current using Buck-Boost converter. It is because the system that already has in lightning the power LED has a lot of power loss and decrease it efficiency and by using this designed driver, all the problems occurred in the previous mill be solved.

1.2 Efficient LED Control

LED’s must be driven with a source of constant current. Most of LED’s have a specified current level that will achieve the maximum brightness for that LED’s without premature failure. LED could be driven with a linear voltage regulator configured as a constant current source. However, this approach is not practical for higher power LED’s due to power dissipation in the regulator circuit. A switch mode power supply (SMPS) provides a much more efficient solution to drive the LED.

An LED will have a forward voltage drop across it terminal for a given current drive level. The power supply voltage and the LED forward voltage characteristic will determine the SMPS topology that is required.

The SMPS circuit topologies adopted to regulated current in LED lightning application are the same used to control voltage in a power supply application. Each type of SMPS topology has its own advantage and disadvantage and boost-buck can offer a solution for most of the higher-power lighting applications, including both exterior and interior lighting.

1.3 Trend of Power Electronic Switch

The key components of the proposed DC-DC converter are the power semiconductor switches. As the main the main advantage of the proposed DC-DC converter is to reduce power loss and increase the system efficiency using the appropriate power electronic power switch. So, it is worth to give some introduction to the trend of the modern power semiconductor device applicable to DC-DC converter mainly are IGBT,GTO and MOSFET.

IGBT’s of 3.3 KV 1200A are now commercially available in the market and GTO’s with the rating of 60 KV and 4500A have been commercially available for several years. The higher voltage and current rating of GTO’s can be manufactured with the existing manufacturing technology if required by market. GTO has the advantage of very low on-state conduction losses compared with other available power semiconductor device. However it has the advantage of being slow and required a complicated turn off circuit.

As a majority carrier device, power MOSFET has a very high switching speed. However since the conductivity modulation, a phenomenon of a minority carrier device such as BJT and GTO does not exist in power MOSFET, the on state conduction losses of this device are too high for application that required high voltage and high power.

The main advantage of MOSFETs for digital switching is that the oxide layer between the gate and the channel prevents DC current from flowing through the gate, further reducing power consumption and giving very large input impedance. This is the reason of choosing MOSFET in our application.

CHAPTER 2

Literature Review

2.1 Dc –dc converter

2.1.1 Definition

Dc-dc converters are power electronic circuits that convert a dc voltage to a different dc voltage level, often providing a regulated output. The circuits described are classified as switched mode dc-dc converter and also called switching power supplies or switcher. There are also some common variation of the dc-dc converter circuits that are used in many dc power supply design [2].

Dc-dc converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries. Such electronic devices often contain several sub-circuits with each sub-circuit requiring a unique voltage level different than that supplied by the battery. Additionally, the battery voltage declines as its stored power is drained. Dc -dc converters offer a method of generating multiple controlled voltages from a single variable battery voltage, thereby saving space instead of using multiple batteries to supply different parts of the device [4].

2.1.2 Switching Regulator

A switching regulator is a circuit that uses a power switch, an inductor, and a diode to transfer energy from input to output. The basic components of the switching circuit can be rearranged to form a step-down (buck), step-up (boost), or an inverter (flyback). These designs are shown in figures 2.1, 2.2, 2.3, and 2.4 respectively, where figures 2.3 and 2.4 are the same except for the transformer and the diode polarity. Feedback and control circuitry can be carefully nested around these circuits to regulate the energy transfer and maintain a constant output within normal operating conditions [3].

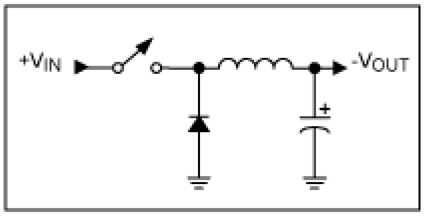


Figure 2.1: Buck converter topology

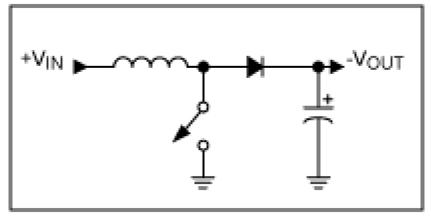


Figure 2.2: Simple boost converter

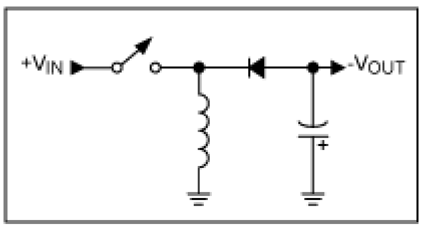


Figure 2.3: Inverting topology.

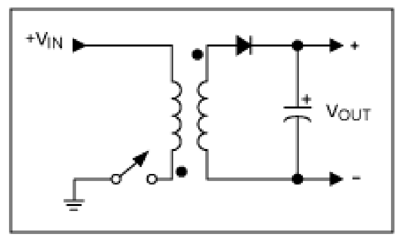


Figure 2.4: Transformer flyback topology.

Switching regulators offer three main advantages compared to a linear regulators. First, switching efficiency can be much better than linear. Second, because less energy is lost in the transfer, smaller components and less thermal management are required. Third, the energy stored by an inductor in a switching regulator can be transformed to output

voltages that can be greater than the input (boost), negative (inverter), or can even be transferred through a transformer to provide electrical isolation with respect to the input.

Given the advantages of switching regulators, one might wonder where linear regulators can be used. Linear regulators provide lower noise and higher bandwidth; their simplicity can sometimes offer a less expensive solution.

There are, admittedly, disadvantages with switching regulators. They can be noisy and require energy management in the form of a control loop. Fortunately the solution to these control problems is found integrated in modern switching-mode controller chips.

2.1.3 Switched-mode conversion

Electronic switch-mode DC to DC converters convert one DC voltage level to another, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magnetic components (inductors, transformers) or capacitors. This conversion method is more power efficient (often 75% to 98%) than linear voltage regulation (which dissipates unwanted power as heat). This efficiency is beneficial to increasing the running time of battery operated devices. The efficiency has increased in since the late 1980's due to the use of power FETs, which are able to switch at high frequency more efficiently than power bipolar transistors, which have more switching losses and require a more complex drive circuit. Another important innovation in DC-DC converters is the use of synchronous switching which replaces the flywheel diode with a power FET with low "On" resistance, thereby reducing switching losses [4].

Drawbacks of switching converters include complexity, electronic noise (EMI / RFI) and to some extent cost, although this has come down with advances in chip design [2]. DC to DC converters are now available as integrated circuits needing minimal additional components. DC to DC converters are also available as a complete hybrid circuit component, ready for use within an electronic assembly.

2.1.4 Buck Converter

A buck converter is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switched-mode power supply that uses two switches (a transistor and a diode) and an inductor and a capacitor. The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess voltage as heat; also, output voltage isn't regulated (varies with input voltage). A buck converter, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating, making it useful for tasks such as converting the 12-24V typical battery voltage in a laptop down to the few volts needed by the processor [4].

2.1.4.1 Principle of operation

In this circuit the transistor turning ON will put voltage Vin on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor provided the inductor current is continuous [4].

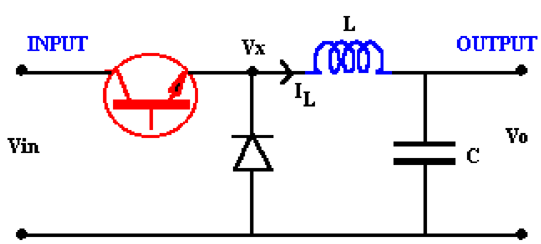


Figure 2.5: Buck Converter

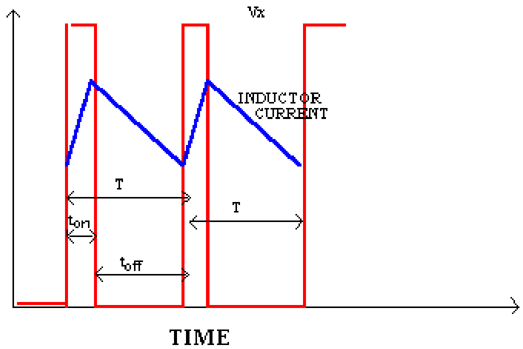


Figure 2.6: Voltage and current changes

To analyze the voltages of this circuit let us consider the changes in the inductor current over one cycle. From the relation

$$V_x - V_o = L\frac{di}{dt}$$ (Equation 2.0)

the change of current satisfies

$$di = \int_{ON}(V_x - V_o)dt + \int_{OFF}(V_x - V_o)dt$$ (Equation 2.1)

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time V_x=V_{in} and in the OFF V_x=0. Thus

$$0 = di = \int_0^{t_{on}}(Vin - Vo)dt + \int_{t_{on}}^{t_{on}+t_{off}}(-Vo)dt$$ (Equation 2.2)

which simplifies to

$$(Vin - Vo)t_{on} - Vo\ t_{off} = 0$$ (Equation 2.3)

or

$$\frac{Vo}{Vin} = \frac{t_{on}}{T}$$ (Equation 2.4)

and defining "duty ratio" as

$$D = \frac{t_{on}}{T} \qquad \text{(Equation 2.5)}$$

the voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average V_o* I_o = V_{in}* I_{in}. Thus the average input and output current must satisfy I_{in} =D I_o These relations are based on the assumption that the inductor current does not reach zero [4].

2.1.5 Boost converter

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple [2].

An AC mains voltage cannot directly power devices such as computers, digital clocks, and telephones. The outlet supplies AC and the devices and loads require DC. Power conversion enables DC devices to utilize power from ac voltage sources. A process called ac to dc conversion (rectification) is used to convert an AC voltage to power a DC load.

Power can also come from DC sources such as batteries, solar panels, rectifiers, and DC generators. A process that changes one DC voltage to a different DC voltage is called dc to dc conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it “steps up” the source voltage. Since power (V*I) must be conserved, the output current is lower than the source current.

2.1.5.1 Principle of operation

The schematic in figure 2.7 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

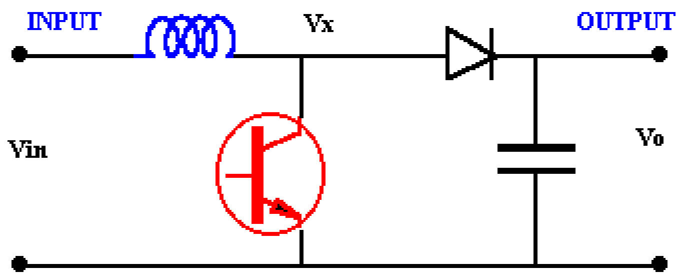


Figure 2.7: Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in figure 2.8 and the average must be zero for the average current to remain in steady state

$$Vin\, t_{on} + (Vin - Vo)t_{off} = 0$$ (Equation 2.6)

This can be rearranged as

$$\frac{Vo}{Vin} = \frac{T}{t_{off}} = \frac{1}{(1-D)}$$ (Equation 2.7)

and for a lossless circuit the power balance ensures

$$\frac{Io}{Iin} = (1-D)$$ (Equation 2.8)

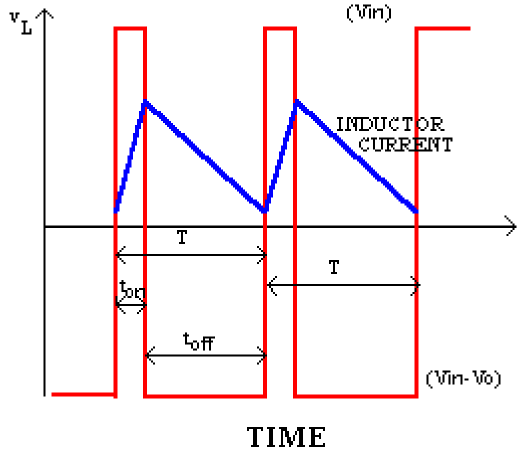


Figure 2.8: Voltage and current waveforms (Boost Converter)

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage [4].

2.1.6 Buck-Boost Converter

The buck-boost converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is a switch mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground, this complicates the driving circuitry. The polarity of the output voltage is opposite the input voltage so neither drawback is of any consequence if the power source is isolated from the load circuit (if, for example, the source is a battery) as the source and diode can simply be reversed and the switch moved to the ground side.

The circuit topology of buck-boost converter is similar with the buck converter and also buck converter, the different between this three converters are only the position

of their inductor, diode and the switch [2]. The output voltage is adjustable based on the duty cycle of the switching transistor and one of the possible drawbacks of this converter is that the switch does not have a terminal at ground [4].

2.1.6.1 Principle of operation

The schematic in figure 2.9 shows the basic boost converter.

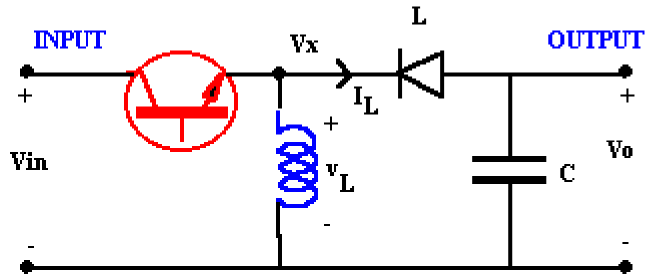


Figure 2.9: schematic for buck-boost converter

With continuous conduction for the Buck-Boost converter $V_x = V_{in}$ when the transistor is ON and $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero

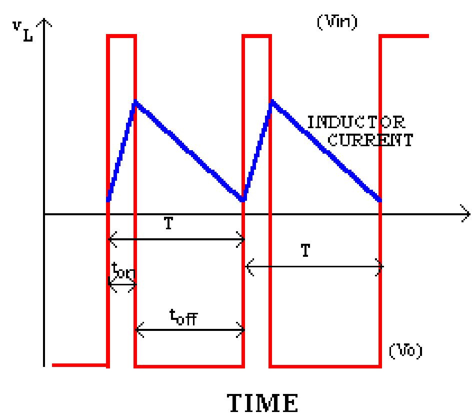


Figure 2.10: Waveforms for buck-boost converter

$$V_{in} t_{ON} + V_o t_{OFF} = 0$$ (Equation 2.9)

which gives the voltage ratio

$$\frac{V_o}{V_{in}} = -\frac{D}{(1-D)}$$ (Equation 2.10)

and the corresponding current

$$\frac{I_o}{I_{in}} = -\frac{(1-D)}{D}$$ (Equation 2.11)

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

2.1.7 Ćuk converter

The Ćuk converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude, with an opposite polarity. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. It is named after Slobodan Ćuk of the California Institute of Technology, who first presented the design in the paper [4].

2.1.7.1 Operating Principle

The buck, boost and buck-boost converters all transferred energy between input and output using the inductor, analysis is based of voltage balance across the inductor. The Cuk converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. The circuit in figure 2.11 is derived from duality principle on the buck-boost converter [2].

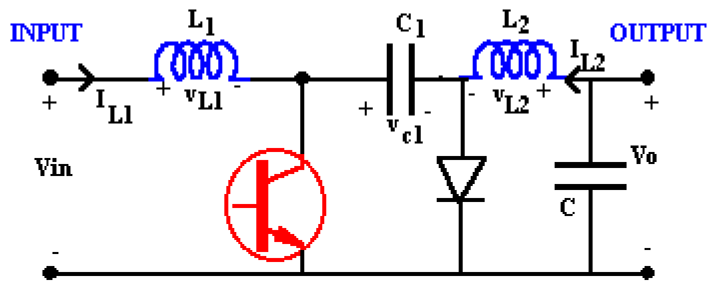


Figure 2.11: Cuk Converter

If we assume that the current through the inductors is essentially ripple free we can examine the charge balance for the capacitor C1. For the transistor ON the circuit becomes

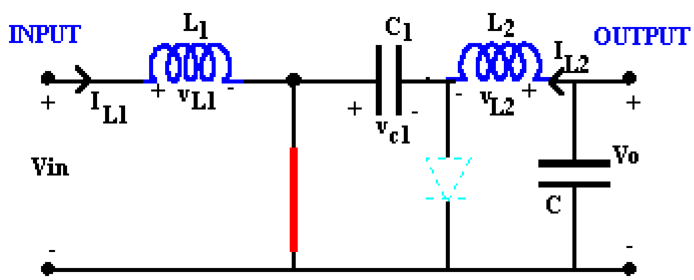


Figure 2.12: Cuk "On-State"

and the current in C1 is I_{L1}. When the transistor is OFF, the diode conducts and the current in C1 becomes I_{L2}.

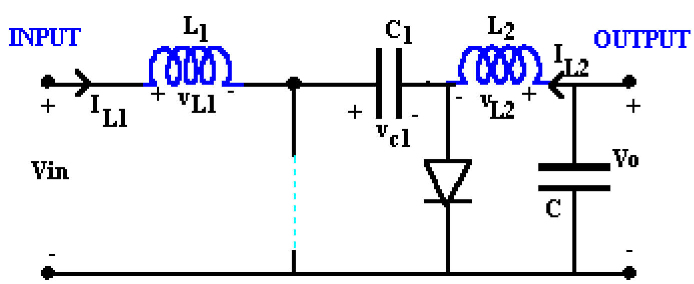


Figure 2.13: Cuk "Off-State"

Since the steady state assumes no net capacitor voltage rise, the net current is zero

$$I_{L1}t_{ON} + (-I_{L2})t_{OFF} = 0 \qquad \text{(Equation 2.12)}$$

which implies

$$\frac{I_{L2}}{I_{L1}} = \frac{(1-D)}{D} \qquad \text{(Equation 2.13)}$$

The inductor currents match the input and output currents, thus using the power conservation rule

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)} \qquad \text{(Equation 2.14)}$$

Thus the voltage ratio is the same as the buck-boost converter. The advantage of the cuk converter is that the input and output inductors create a smooth current at both sides of the converter while the buck, boost and buck-boost have at least one side with pulsed current [4].

2.1.8 Flyback converter

The Flyback converter is a DC to DC converter with a galvanic isolation between the input and the output(s). More precisely, the flyback converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation. When driving for example a plasma lamp or a voltage multiplier the rectifying diode of the Buck-Boost converter is left out and the device is called a flyback transformer.

2.1.8.1 Operating Principle

The flyback converter is an isolated power converter, therefore the isolation of the control circuit is also needed. The two prevailing control schemes are voltage mode control and current mode control. Both require a signal related to the output voltage. There are two common ways to generate this voltage. The first is to use an optocoupler on the secondary circuitry to send a signal to the controller [4]. The second is to wind a separate winding on the coil and rely on the cross regulation of the design.

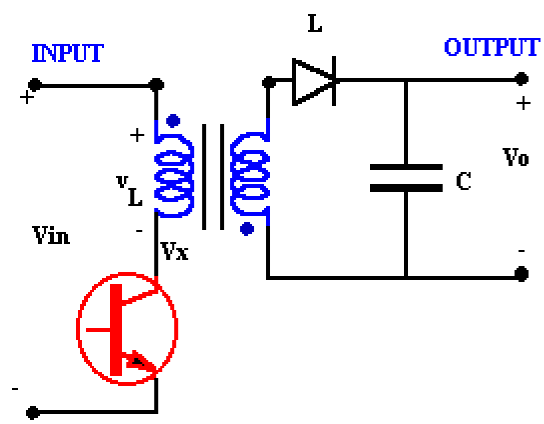


Figure 2.14: Flyback converter

2.2 Power LED

Figure 2.15: Power LED

Light-emitting diodes (LED) has emerged in recent years as viable sources of light and it's also extremely durable and has lifetimes exceeding tens of thousands of hours [1]. It has been the choice for automotive interior lighting for years, particularly for signal applications. And now, due to recent advances in solid-state lighting, power LED is being designed in the exterior applications as well. Although used primarily in center high-mount stop lamps (CHMSL) and rear combination lamps, power LED continue to gain ground for most automotive interior and exterior lights [3]. The widespread adoption of solid-state light sources is taking place because of appealing attributes such as small size, robustness, long lifetime and high efficiency.

Automotive manufacturers are attracted by the potential reduction in energy consumption as well as the space savings realized by smaller lighting fixtures. The styling potential of power LED also is a great benefit for consumers, which enables more attractive and distinctive designs [3]. Consumers also benefit from safety aspects of using solid-state signal lighting. For example, faster turn-on of the stop lamps can reduce the risk of rear-ends collisions. And perhaps the most compelling reason for using power LED is their expected reliability and lifetime. These are benefits manufacturers and consumers can both appreciate, as they will potentially significantly reduce replacement and maintenance costs for automotive lighting [3]. Exterior power LED lighting has been increasingly popular on trucks and buses because of the compact size and shock resistance of solid-state lights.

These advantages of the power LED lighting fixtures simplify compliance with various safety regulations. The exterior applications include tail lights, stoplights, marker lights and identification (ID) lights [3]. For example, the National Highway Transportation Safety Administration (NHTSA) has issued a new compliance that truck trailers 80-in. wide or over must have ID lamps mounted over the rear door even if the space available is only 1-in. high [3]. Power LED narrow-rail lamps provide the only solution practical in such minimum-space applications.

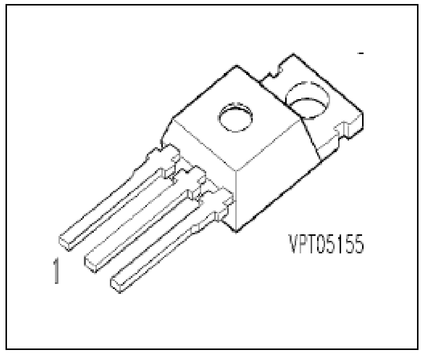
As we can see, the power LED is changing the world of lighting systems due to it characteristic and function. The main characteristic of the power LED is;

i. Last generation of Power LED have a luminous efficiency around 45 lm/W, with better performances than incandescent lamps (10 lm/W) or Halogen lamps (20 lm/W). Luminous efficiency in Power LED has been increased in the last 2 years [1].
ii. Power LED operating life is longer than other types of light [1].
iii. Another advantage is the broad temperature operation Range (-40 °C to 120 °C) and the low on-off times, around 100ns [1].

iv. Power LED is a good choice in lighting applications, because they do not need complex power topologies for working (unlike discharge lamps) [1].

The application of the power LED's can be found in product such as medical instrumentation, general and emergency alarm lighting, design and architectural lighting, interior and runway lights [3].

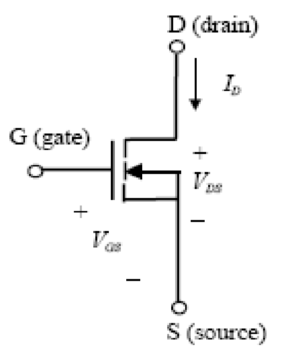
2.3 MOSFET



Pin 1	Pin 2	Pin 3
G	D	S

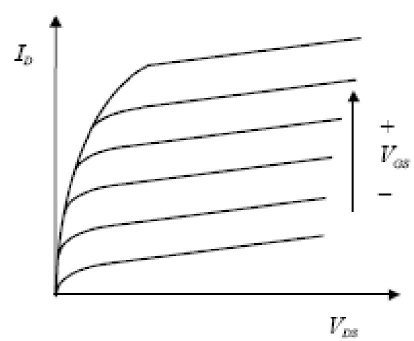
Figure 2.16: MOSFET

The MOSFET (figure 2.16) is a voltage controlled device which characteristic as shown in figure 4b. Power MOSFET is of the enhancement type rather than the depletion type. A sufficiently large gate to source voltage will turn the device on, resulting in a small drain to source voltage [6]. The drive circuit to turn on a MOSFET on and off is usually simpler than that for a BJT.



MOSFET: symbol (n-channel)

Figure 2.17a



v-i characteristics

Figure 2.17b

In the ON state, the change in VDS is linearly proportional to the change in ID. Therefore, the ON MOSFET can be modeled as an ON state resistance called RDS (ON).

Low voltage MOSFET have on state resistance of less than 0.1Ω, while high voltage MOSFET have ON state resistance of a few ohms [6]. Here are a few list of the MOSFET characteristic for it to be the guidance in switch selection:

I. It's a very fast switching device which may exceed 100 KHz. For some low power devices (few hundred watts) may go up to MHz range [6].
II. Turning on and off the MOSFET is very simple. It's only need to provide *VGS* =+15V to turn on and 0V to turn off. Their gate drive circuit is also very simple.
III. Basically, it's built in low voltage device. High voltage device are available up to 600V but with limited current and it can be paralleled quite easily for higher current capability [4].
IV. There are internal (dynamic) resistances between drain and source during the ON state that will limits the power handling capability of MOSFET. High losses especially for high voltage device due to RDS (ON) [6].
V. MOSFET is well known to be dominant in high frequency application because of it characteristic to be exceeding 100 kHz switching speed and it also one of the biggest application in switched-mode power supplies [4].

2.4 PIC microcontroller

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division [4]. The name PIC initially referred to "Programmable Interface Controller", but shortly thereafter was renamed "Programmable Intelligent Computer" [4]. PIC are popular with developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability [4].

Figure 2.18: PIC microcontroller

2.4.1 PIC16F785 microcontroller

PIC16F785 is a small piece of semiconductor integrated circuits. The package type of these integrated circuits is DIP package. DIP stand for Dual Inline Package for semiconductor IC. This package is very easy to be soldered onto the strip board. However using a DIP socket is much easier so that this chip can be plugged and removed from the development board. PIC16F785 is very cheap. Apart from that it is also very easy to be assembled. Additional components that need to make this IC work are just a 5V power supply adapter, an internal 20MHz crystal oscillator and 2 units of 22pF capacitors. This IC can be reprogrammed and erased up to 10,000 times. Therefore it is very good for new product development phase [5].

2.4.1.1 Feature

The PIC16F785 Flash microcontroller offers all of the advantages of the well recognized mid-range x14 architecture with standardized features including a wide operating voltage of 2.0-5.5 volts, on-board EEPROM Data Memory, and nanoWatt Technology. Analog peripherals include up to 12 channels of 10-bit A/D, 2 Operation Amplifiers, 2 high-speed analog Comparators, and a Bandgap Voltage Reference. Digital peripherals include a standard Capture/Compare/PWM (CCP) module, a 2-phase PWM with asynchronous feedback, a 16-bit timer and 2 8-bit timers [5].

The new PIC16F785 actually reduces the number of devices in a design by including not only the necessary interface peripherals for a SMPS design, but also two channels of analogue pulse width modulation (PWM), two voltage comparators, and two op amps[5].

Now, all the parts needed to implement the analogue control sections of up to two SMPS channels are included in the microcontroller. This means fewer parts to handle, a simpler layout, and even a lower material cost. In addition, the microcontroller control over the SMPS analogue blocks allows control up through a Level 3 design (on/off control, output control, and topology/configuration control), something that is only rarely possible with a separate microcontroller/PWM controller solution [5].

CHAPTER 3

METHODOLOGY

3.1 Overview of Project

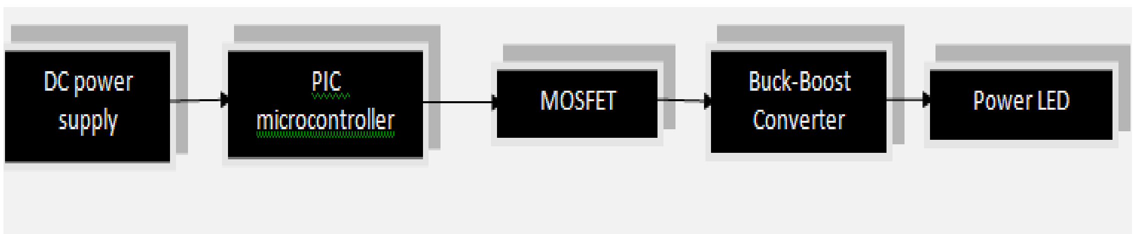


Figure 3.1

The whole idea of this project is to design a system that provides a more efficient solution for driving a high power LED by controlling the power LED current and the total amount of power going into the power LED by using PIC microcontroller. This system is designed to provide a more efficient solution for driving a high power LED and increase the efficiency of the power levels required for the power LED to operate.

PIC microcontroller will be used to control the level of voltage so it can produce the desired power LED's current. It is controlled by setting the duty cycle of the PWM signal generate in the PIC microcontroller at the average amount of time so that the power LED is energized.

The PWM frequency is chosen high enough so that the power LED current is turned on and off at a rate that will not cause the human eye to detect flickering. Through this, the efficiency of the power levels required for the power LED to operate will be increase.

3.2 Hardware Description

The hardware functionality of the buck-boost power Led driver circuit can be divided into four functional blocks**:**

i. Power Supply
ii. Buck-Boost converter
iii. Power LED driver system
iv. Power LED

3.2.1 Power Supply

Power supply is part of every electronic device, so wide variety of circuit is use to accommodate such factor as power rating, size of current, cost, and desired regulation and so on. A simple way to drop the ac voltage without a bulky and expensive transformer is to use a capacitor in series with the line voltage.

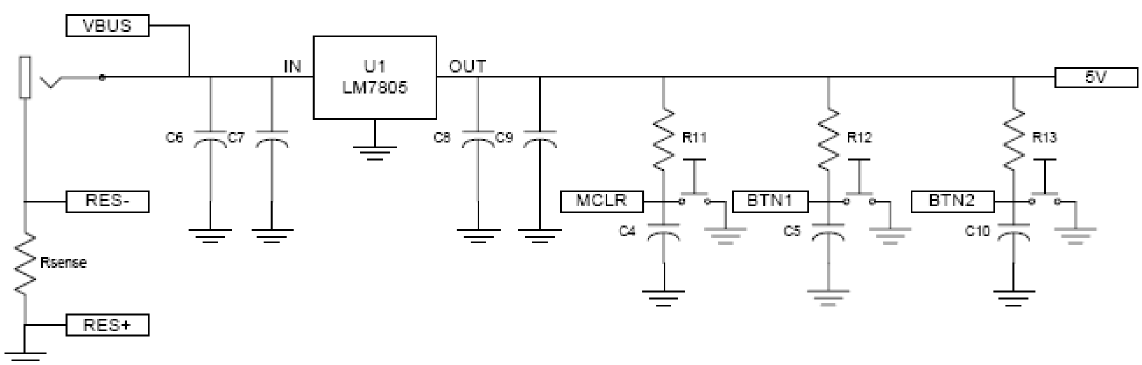


Figure 3.2: Schematic of power supply

In this project, the power supply were designed as in figure 3.2 were used to implant along with the fixed positive voltage regulator to provide a fixed regulated voltage. Before Vi entered the voltage regulator, it were filtered first using the capacitor and Vo produce from the voltage regulator were also filtered again using the capacitor. As you can see, there is has a current sensing resistor located at the negative connection of the power supply input. A low value resistor is used to avoid excessive power dissipation in the resistor. The voltage across the resistor is amplified using an op amp on the PIC16F785

3.2.1 Buck-Boost converter

The Buck-Boost converter is used when the supply voltage may be above or below the required output voltage. The Buck-Boost converter is especially useful for battery applications. The Buck-Boost topology is also known as a fly-back or inverting regulator. A simplified schematic of a Buck-Boost converter is shown in figure 2.9. The converter has a single switch, inductor, diode, and capacitor. As shown, the buck-boost converter produces a negative output voltage with respect to the circuit common.

3.2.1.1 Buck-Boost Design Equations and Component Selection

In this section, we will be determined the component values for the buck-boost converter to operate accordingly to how we want it. The output voltage of the buck-boost circuit is a function of the input voltage, duty cycle, and is given by the following formula which referring to equation 2.10 in chapter 2:

$$VOUT = -VIN \bullet \left(\frac{k}{1-k}\right)$$

(Equation 3.0)

At 0 duties, there will be 0 volts across the load. At 50% duty, the output voltage will have the same magnitude as the input voltage but will be inverted. The maximum duty cycle should be limited to avoid high peak currents and to prevent instability. Equation 3.1 can be used to relate the inductor ripple current to the input voltage, duty cycle, inductor value, and switching frequency:

$$\Delta I = \frac{VIN \bullet k}{f \bullet L}$$
(Equation 3.1)

Equation 3.2 relates the output voltage ripple to the output current, duty cycle, capacitor value, and switching frequency:

$$\Delta VOUT = \frac{IOUT \bullet k}{f \bullet C}$$
(Equation 3.2)

The Power LED is designed for power at 3W current at700 mA, this would mean that Vout should be 4.30V for full power LED light to the fullest of it brightness. Buck-boost converter is a converter that can buck or boost it input voltage, so the voltage that been supplied to the buck-boost circuit can be varied from 6V to 14V. Solving Equation 3.0 for k, the minimum duty cycle will be 24% (Vin = 14V) and the maximum duty cycle will be 42% (Vin = 6V).

Next, equation 3.1 and equation 3.2 can be used to determine the inductor ripple current and output ripple voltage. The switching frequency, f, is set to 250 kHz to reduce the size of the inductor. An inductor value of 100 µH was chosen for this design. The ripple will increase with reduced input voltage and increased duty cycle. At 42% duty and VIN = 6V, the ripple current will be 101 mA under these conditions. A capacitor must be used to supply current to the load while the inductor is charging. Equation 3.2 provides the ripple voltage value based on the switching frequency and capacitor value. A value of 47 µF will provide 25 mV voltage ripple for this design.

3.2.3 Power LED driver system

This power LED driver system is the brain or the central processing units that manage the operating system of the buck-boost converter and power LED brightness. Upon this system, the LED brightness will be controlled by simply adjusting the current reference voltage that is connected to the comparator input. This is accomplished by writing a different duty cycle to the CCP1 peripheral that generates the reference voltage using the appropriate software and coding.

3.2.3.1 Current Sensing Circuit

A simplified circuit design for the LED driver is shown in Figure 3.3. The topology of the Buck-Boost circuit has been changed so that a low-side transistor can be used to drive the inverter.

The op amp, comparator, and PWM module are all contained within the PIC16F785 device. All pins of the op amps and comparators are externally accessible so that any circuit configuration can be implemented.

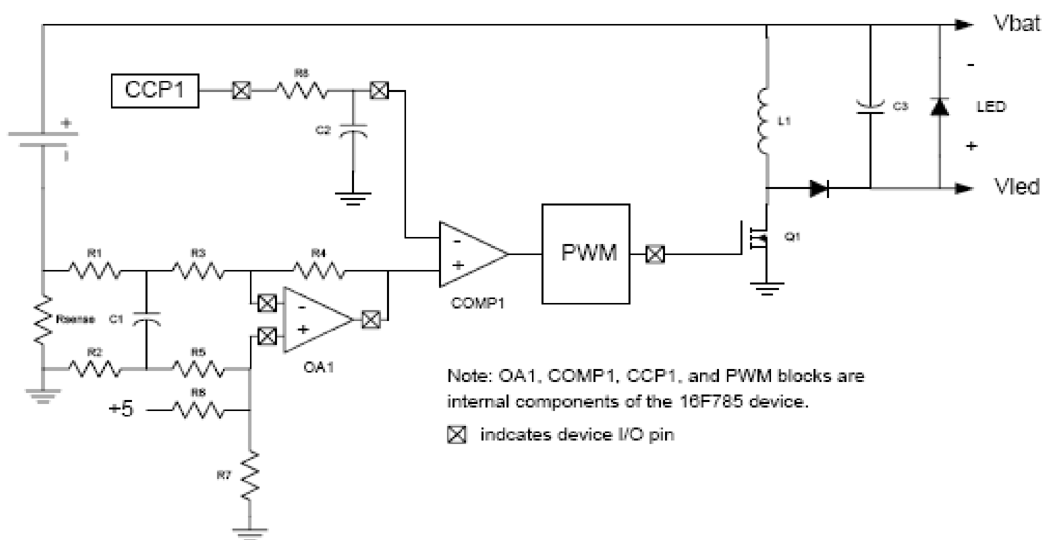


Figure 3.3: simplified circuit

This circuit has a current sensing resistor located at the negative connection of the power supply input. A low value resistor is used to avoid excessive power dissipation in the resistor. The voltage across the resistor is amplified by using an op amp on the PIC16F785. For this application the best location for current sensing would be at the terminals of the power LED itself. However, a sense resistor installed at this location would have a high common-mode voltage on its terminals that would exceed the limits of the PIC16F785 op amp.

Another possible place to measure the current is in the source leg of the MOSFET. This is a good place to install a current sense resistor, because there will not be a common-mode voltage present. This measurement would provide the inductor current, which is the same as the LED current. However, the MOSFET current is not continuous. The sense resistor would only indicate the LED current when the MOSFET is on. If current was sensed in the source of the MOSFET, the voltage across the sense resistor would look similar to the signal shown in figure 3.4. A fast op amp is required to amplify this signal to a usable value.

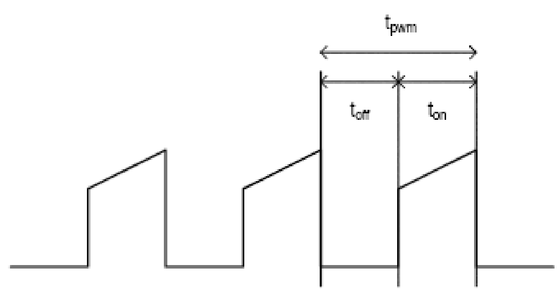


Figure 3.4: Current waveform measured at source of MOSFET

Basically, we want to control the LED current and the total amount of power going into the LED. If the power supply voltage is measured along with the current, then the total power going into the system is a known quantity. The input supply voltage and the LED anode voltage can be measured periodically using the PIC16F785 ADC. These two voltages can be used to calibrate the reference voltage that is used to regulate the supply current.

The LED presents a constant load, so the current reference voltage does not need to be set frequently. By referring to figure 3.3, the current sensing op amp is connected as a differential amplifier to obtain an accurate measurement of the voltage across the current sense resistor. R1, R2, and C1 form a low-pass filter to reduce any switching noise that may be present. However, the cutoff frequency of this filter must be chosen above the converter switching frequency to avoid limiting the control loop response. R6 and R7 are sized to provide a 1.75V offset at the output terminal of the op amp. This offset value is chosen to provide the maximum possible positive and negative current sensing range, based on the maximum common mode input voltage of the comparator.

3.2.3.2 Current Regulator Circuit

From the simplified circuit shown in figure 3.3, this application uses the Two-Phase PWM module, an internal comparator, and a voltage reference to regulate the amount of LED current. The Two-Phase PWM module is an ‘analog’ style PWM module that works on the set/reset principle. First, a clock signal derived from the system clock is used to periodically turn on the PWM output. The PWM clock signal sets the fundamental PWM frequency. Second, a reset signal from one of the on-chip comparators turns off the PWM output when a specified reference level has been reached.

The amplified current signal is internally routed to the positive input of Comparator 1 of the PIC16F785. Each of the on-chip comparators has a 4 input multiplexer to select different input options. The negative input of the comparator can be connected to 2 different locations. First, the negative input can be connected internally to an on-chip voltage reference with 16 adjustable levels. Second, the negative input can be connected to an external input pin.

For this application, the second option is chosen. The Capture-Compare Peripheral (CCP1) on thePIC16F785 is used in the PWM mode to generate the voltage reference for the comparator. Using the PWM allows finer control of the comparator reference voltage. The PWM signal is filtered with a RC filter to produce an analog voltage and is connected to the negative comparator input pin.

3.2.3 Power LED

Power LED were the application that we are trying to control by simply adjusting the current input through it so it can light to it full brightness. Furthermore, using this designed driver we also can increase the efficiency and reduce it power loss and also reduce the electricity cost

3.2.3.1 Setting the LED Brightness Level

A low frequency PWM signal can be used to modulate the LED drive current. Instead of reducing the current drive level, the LED is always driven at maximum current during the on-time. The duty cycle of the PWM signal sets the average amount of time that the LED is energized. The PWM frequency is chosen high enough so that the LED current is turned on and off at a rate that will not cause the human eye to detect flickering. The PWM frequency is also chosen low enough so that the current regulation circuit has enough time to stabilize during the PWM on time.

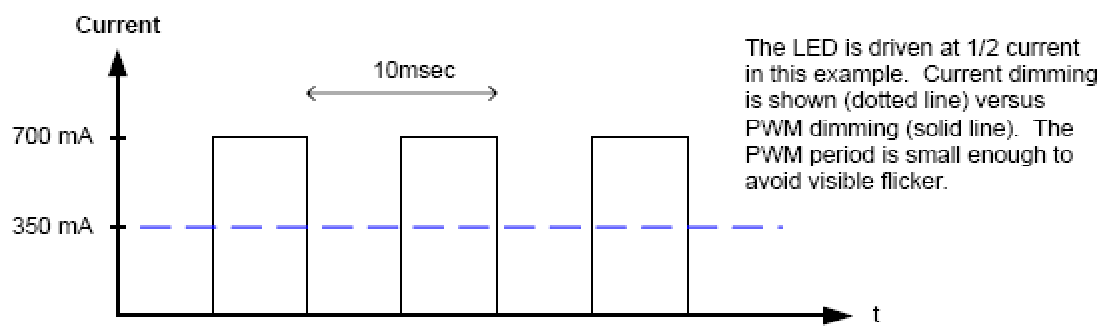


Figure 3.5 Current and PWM dimming

If these conditions are met, the human eye will average the light output from the LED over time. The frequency of the PWM dimming signal is usually between 60 Hz and 1000 Hz. Figure shows block diagrams that compare variable current and PWM dimming techniques.

3.3 PIC16F785

3.3.1 Schematic

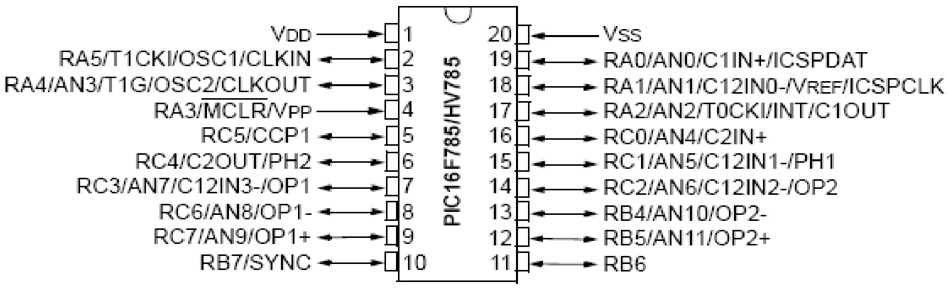


Figure 3.6: PIC16F785 20 pin

3.3.2 Device Overview

The peripheral features of the PIC16F785 are shown in table 3.1

Table 3.1

Device	Program Memory	Data Memory		I/O	10-bit A/D (ch)	Op Amps	Comparators	CCP	Two-Phase PWM	Timers 8/16-bit	Shunt Reg.
	Flash (words)	SRAM (bytes)	EEPROM (bytes)								
PIC16F785	2048	128	256	17+1	12+2	2	2	1	1	2/1	0
PIC16HV785	2048	128	256	17+1	12+2	2	2	1	1	2/1	1

The dual in line pin summary are shown in table 3.2

Table 3.2

I/O	Pin	Analog	Comp.	Op Amps	PWM	Timers	CCP	Interrupt	Pull-ups	Basic
RA0	19	AN0	C1IN+	—	—	—	—	IOC	Y	ICSPDAT
RA1	18	AN1/VREF	C12IN0-	—	—	—	—	IOC	Y	ICSPCLK
RA2	17	AN2	C1OUT	—	—	T0CKI	—	INT/IOC	Y	—
RA3(1)	4	—	—	—	—	—	—	IOC	Y	$\overline{MCLR}$/VPP
RA4	3	AN3	—	—	—	T1G	—	IOC	Y	OSC2/CLKOUT
RA5	2	—	—	—	—	T1CKI	—	IOC	Y	OSC1/CLKIN
RB4	13	AN10	—	OP2-	—	—	—	—	—	—
RB5	12	AN11	—	OP2+	—	—	—	—	—	—
RB6(2)	11	—	—	—	—	—	—	—	—	—
RB7	10	—	—	—	SYNC	—	—	—	—	—
RC0	16	AN4	C2IN+	—	—	—	—	—	—	—
RC1	15	AN5	C12IN1-	—	PH1	—	—	—	—	—
RC2	14	AN6	C12IN2-	OP2	—	—	—	—	—	—
RC3	7	AN7	C12IN3-	OP1	—	—	—	—	—	—
RC4	6	—	C2OUT	—	PH2	—	—	—	—	—
RC5	5	—	—	—	—	—	CCP1	—	—	—
RC6	8	AN8	—	OP1-	—	—	—	—	—	—
RC7	9	AN9	—	OP1+	—	—	—	—	—	—
—	1	—	—	—	—	—	—	—	—	VDD
—	20	—	—	—	—	—	—	—	—	VSS

3.3.3 PIC16F785/HV785 block diagram

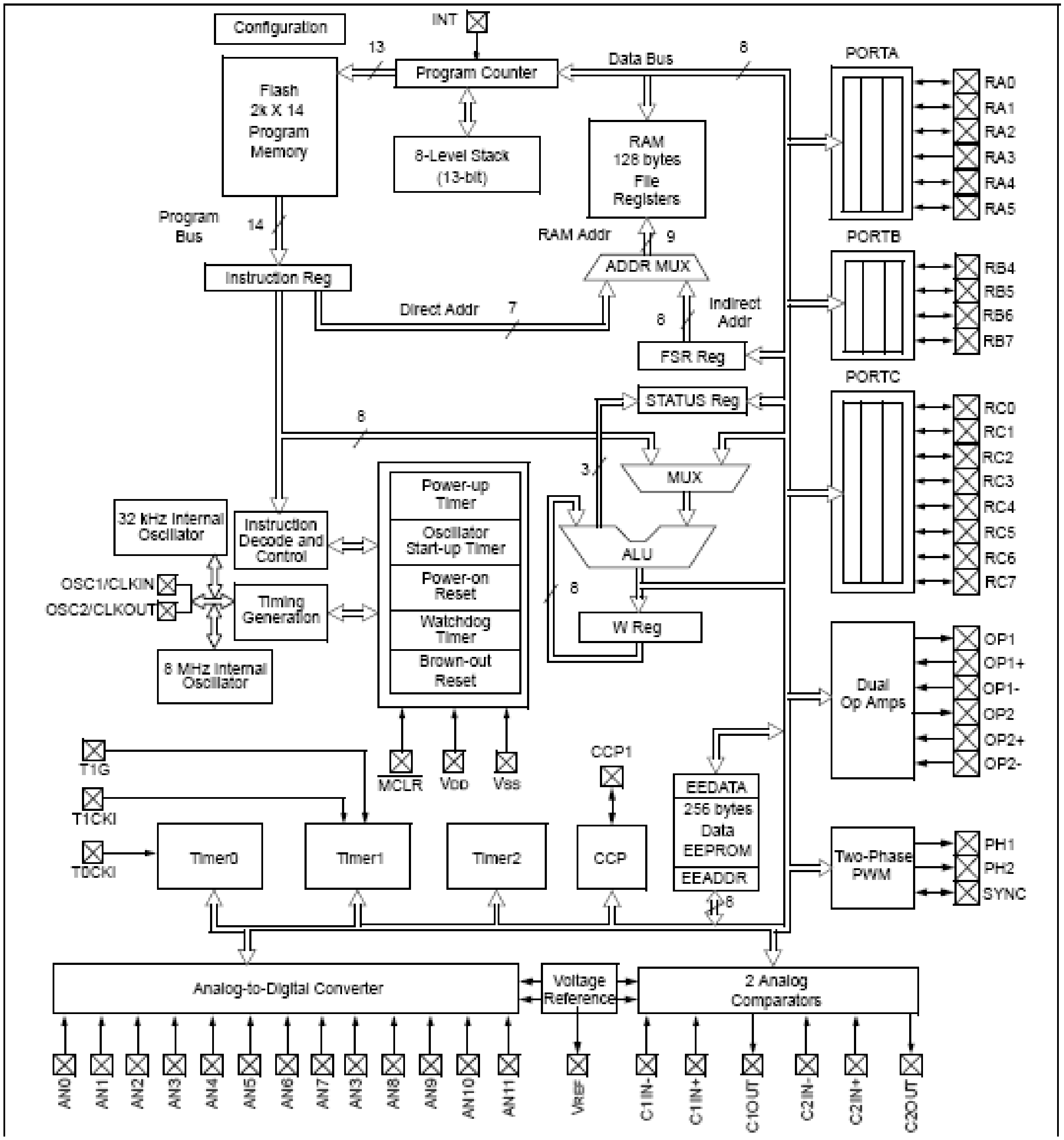


Figure 3.7: PIC16F785/HV785 block diagram

3.3.4 Programming PIC16F785

In order to instruct a PIC, it needs a command. However, C language deals with Computer Processor. Computer Processor will only understand instruction. By knowing what instruction to tell Computer Processor to do specific task, then it is can control of the Computer Processor. To differentiate that PIC Instruction, it must use Voice Command. However Computer Processor command must be written using C Compiler.

Computer Processor Instruction (written command) :

- printf – print character to monitor
- scanf – read character type on the keyboard
- for(;;) – do the task forever
- getchar() – Gets a single character from the input/keyboard
- putchar() – Puts a single character on the screen
- while
- if
- else if
- else

Relational Operators

== equal to

!= not equal to

> greater than

< less than

>= greater than or equal to

<= less than or equal to

3.3.5 MPLAB

MPLAB Integrated Development Environment (IDE) is a free, integrated toolset for the development of embedded applications employing Microchip's PIC® and dsPIC® microcontrollers. MPLAB IDE runs as a 32-bit application on MS Windows®, is easy to use and includes a host of free software components for fast application development and super-charged debugging. MPLAB IDE also serves as a single, unified graphical user interface for additional Microchip and third party software and hardware development tools. Moving between tools is a snap, and upgrading from the free software simulator to hardware debug and programming tools is done in a flash because MPLAB IDE has the same user interface for all tools.

Compiler Overview:

MPLAB has a very flexible customizable programmer's text editor. It is fully integrated debugging with right mouse click menus for breakpoints, trace and editor functions tabbed editor option or separate source windows for user needs. It's also has Context sensitive color highlighting for assembly, C and BASIC code readability and mouse over variable to instantly evaluate the contents of variables and registers. This feature is available to alert user when there is an error in the writing code whether it's in the assembly, C and BASIC code.

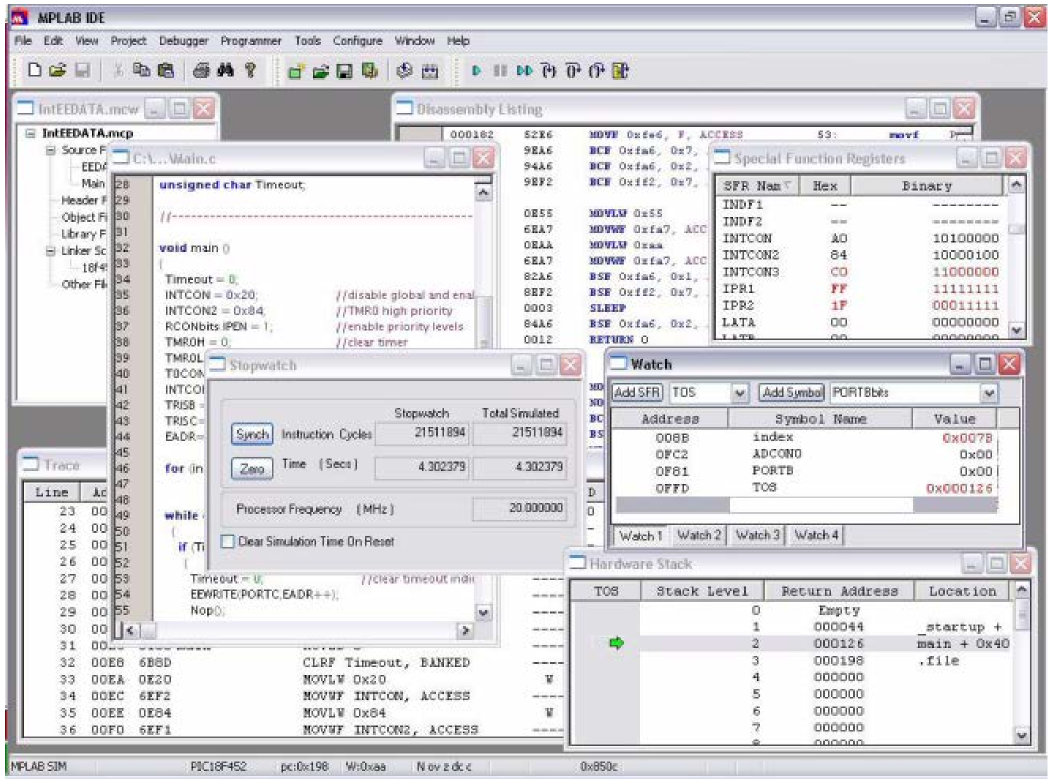


Figure 3.8: MPLAB software

The MPASM assembler, the MPLINK object linker and the MPLIB object librarian are typically used together under MPLAB IDE to provide GUI development of application code for PIC microcontroller devices. The three applications are integrated together to maximize the application to the fullest so PIC MCUs and dsPIC DSC devices HI-TECH C PRO for PIC10/12/16 MCU Families can running in lite mode and also

Advantages:

- Easy to use.
- Easy to understand or learn.
- Have simplest command.
- Widely use→easy to make a discussion (forum).

3.3.6 PIC Programmer

To be able for the coding to be downloaded into the PIC16F785, I use a Melabs programmer product. It uses serial port to interface with the computer. It can use to program any PIC that has 14, 18, 20 and also 40. The melabs programmer software is compatible with the standard Microchip HEX format files. Any assembler or compiler for PIC microcontroller can be used to create the program, including MPASM, "C", PICBASIC. The same software that controls the U2 Programmer can be used with all models of our programmers, including EPIC parallel port programmers and melabs Serial Programmer.

The software can even control multiple programmers on one computer.The software allows you to set configuration bits on the PIC with an easy-to-use list of options. Each configuration option is selectable in a drop-down list. Configuration data may be read from a hex file or from a PIC. The consolidated view-memory window lets you view each section of memory in the PIC with a click.

A formidable list of options allows you to customize the way you interact with the software. You control what areas of the device are erased, programmed, and verified. Save mouse clicks with options like "Disable completion messages" and "Erase before programming".

Figure 3.9: melabs programmer

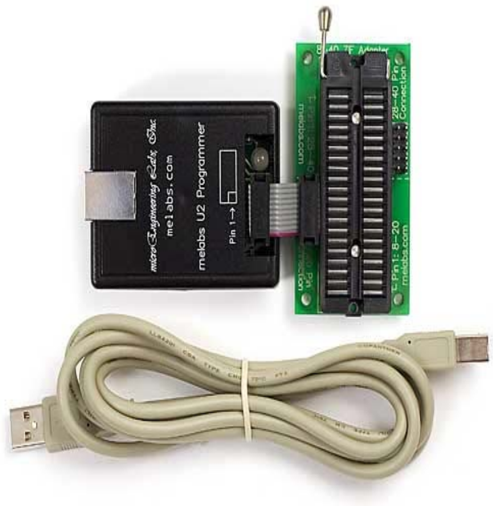


Figure 3.10: programmer

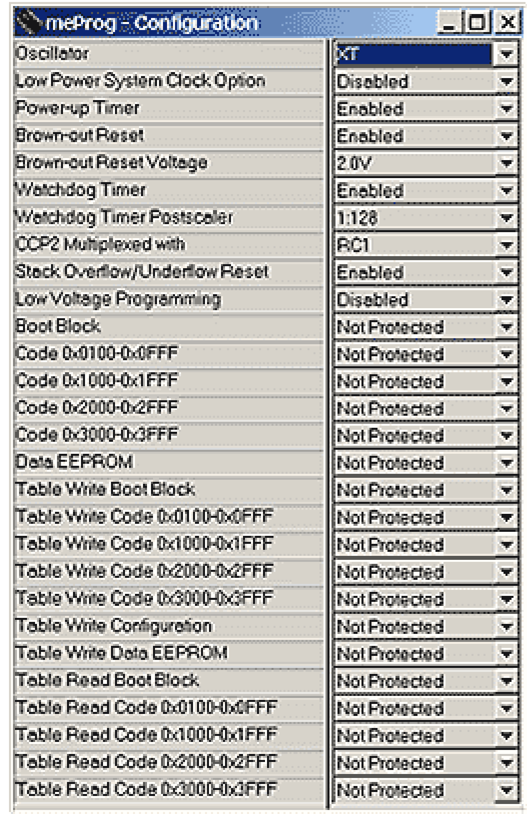
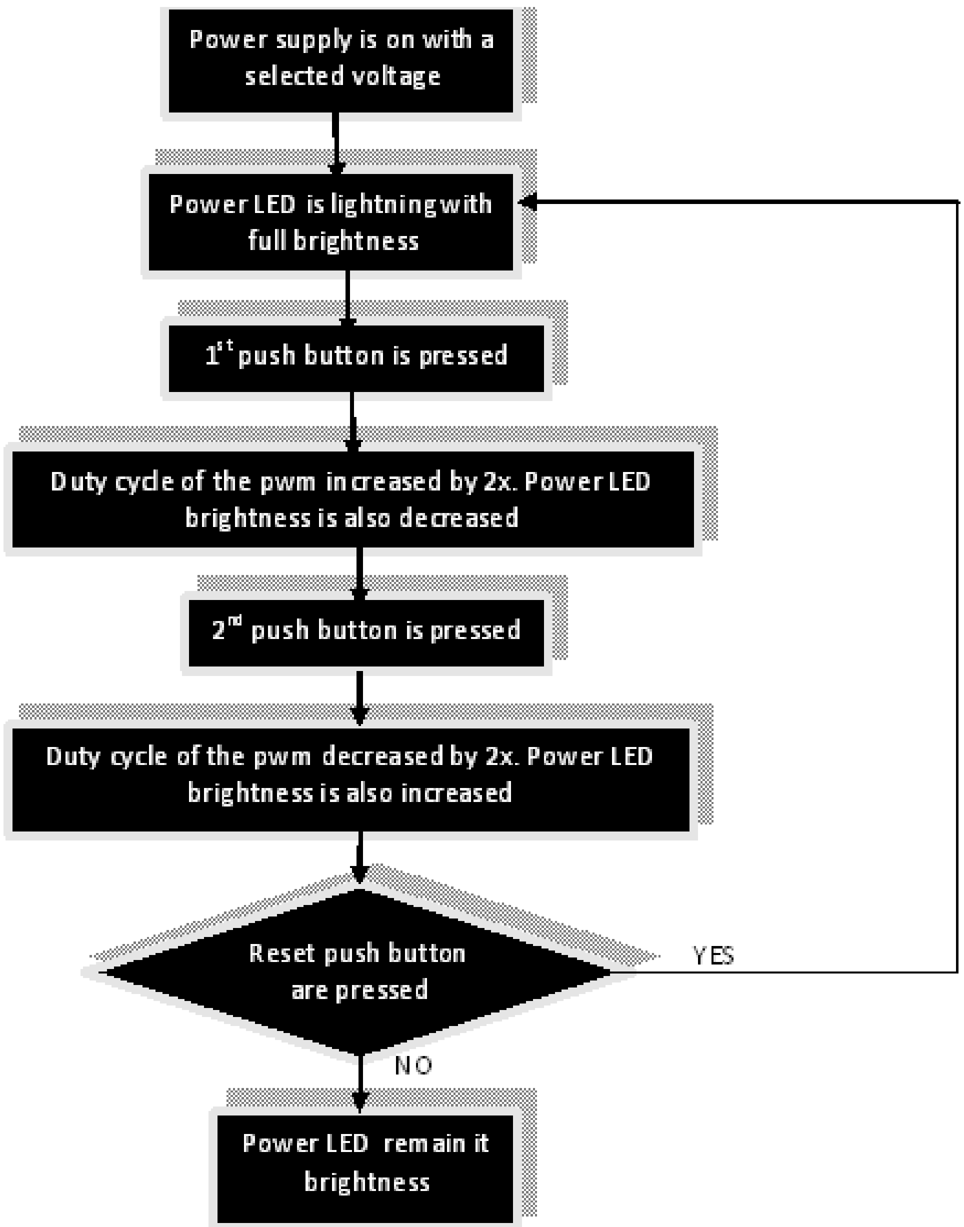


Figure 3.11: programmer device configuration

3.4 Project flowchart



3.5 Printed Circuit Board Design

Protel DXP 2004:

To design the printed circuit board layout, software called DXP 2004 was used. The publisher of the software is Altium. It can be use to design a layout for a PCB including this software will automatically do a track routing for us. There are several steps to do it:

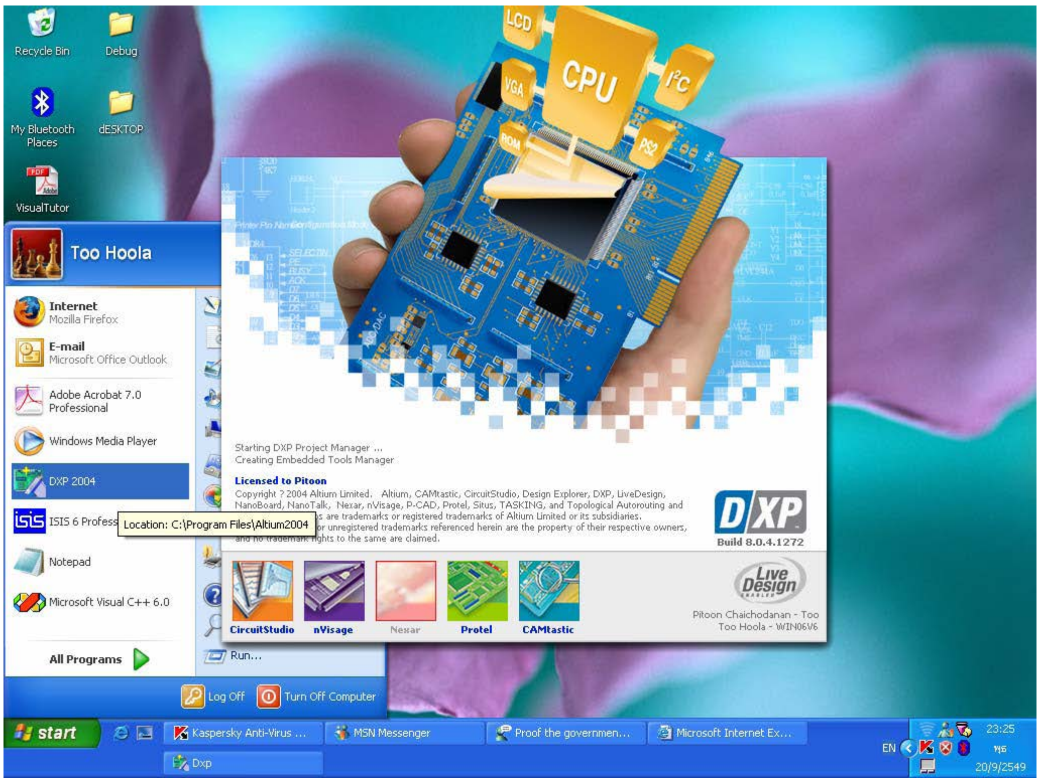


Figure 3.12: Start with Altium DXP 2004

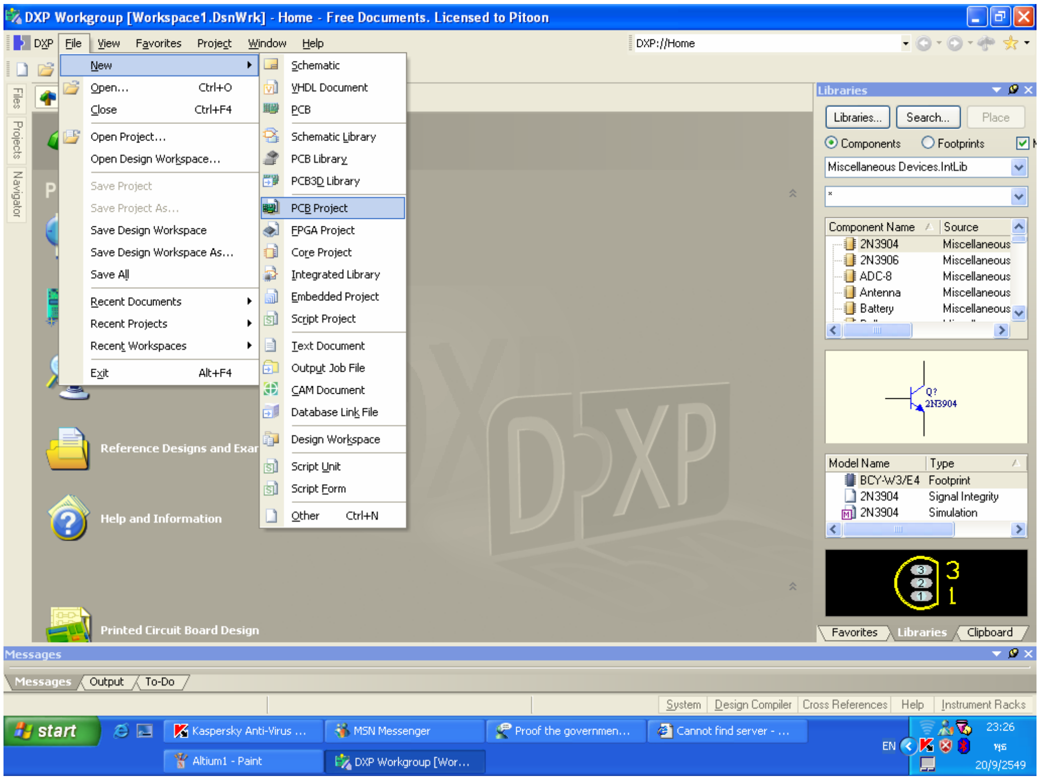


Figure 3.13: Create the PCB Project

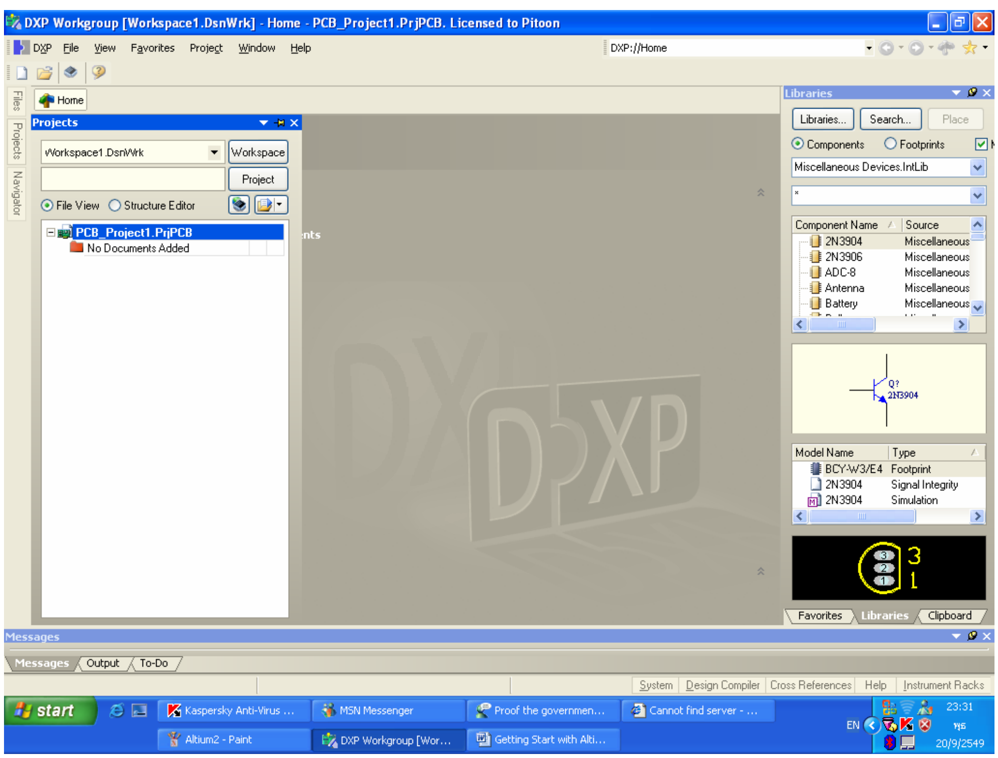


Figure 3.14: Blank Project

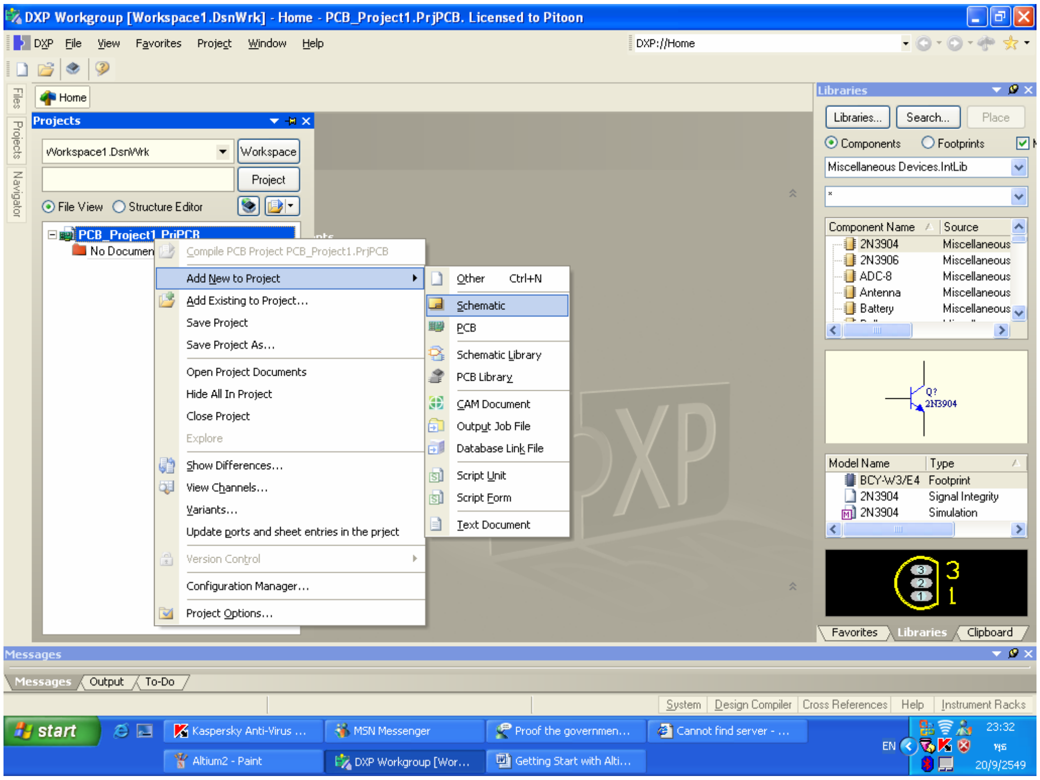


Figure 3.15: Adding Schematic to the Project

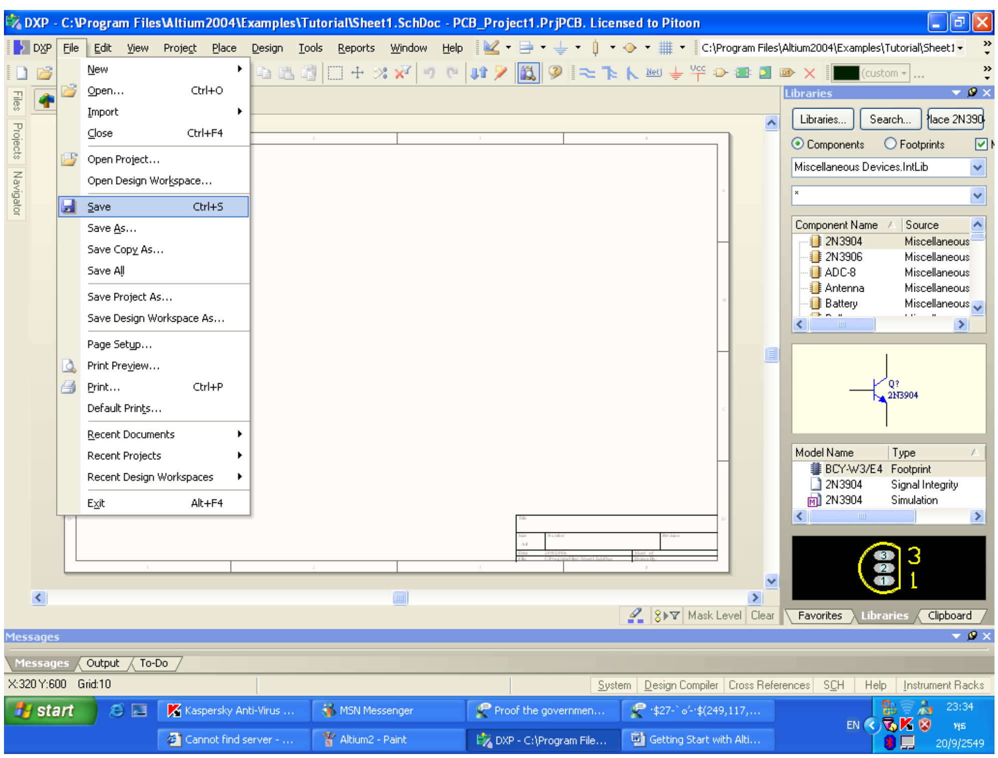


Figure 3.16: Save for Safe

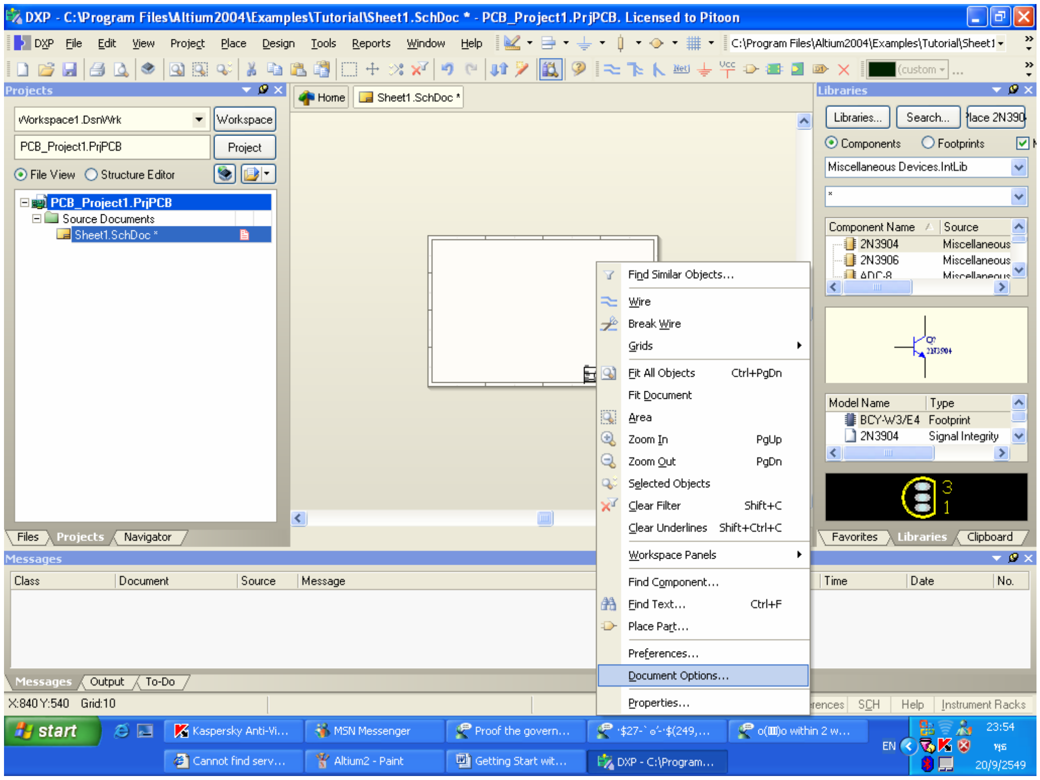


Figure 3.17: Resize Sheet Size

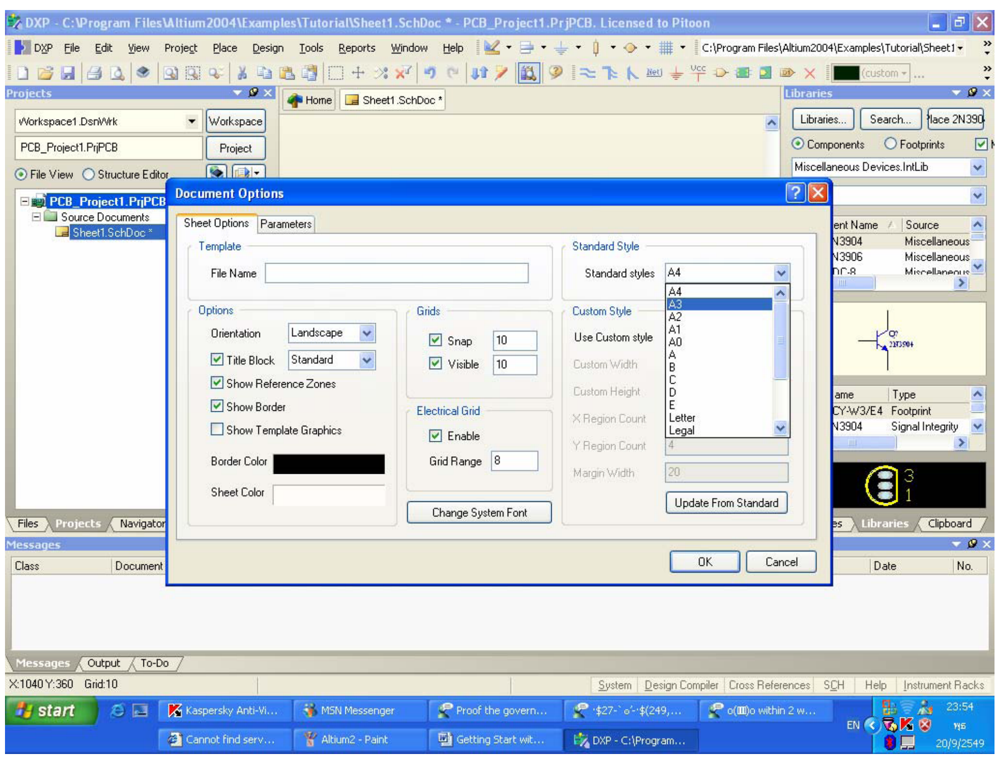


Figure 3.18: Select Sheet Size

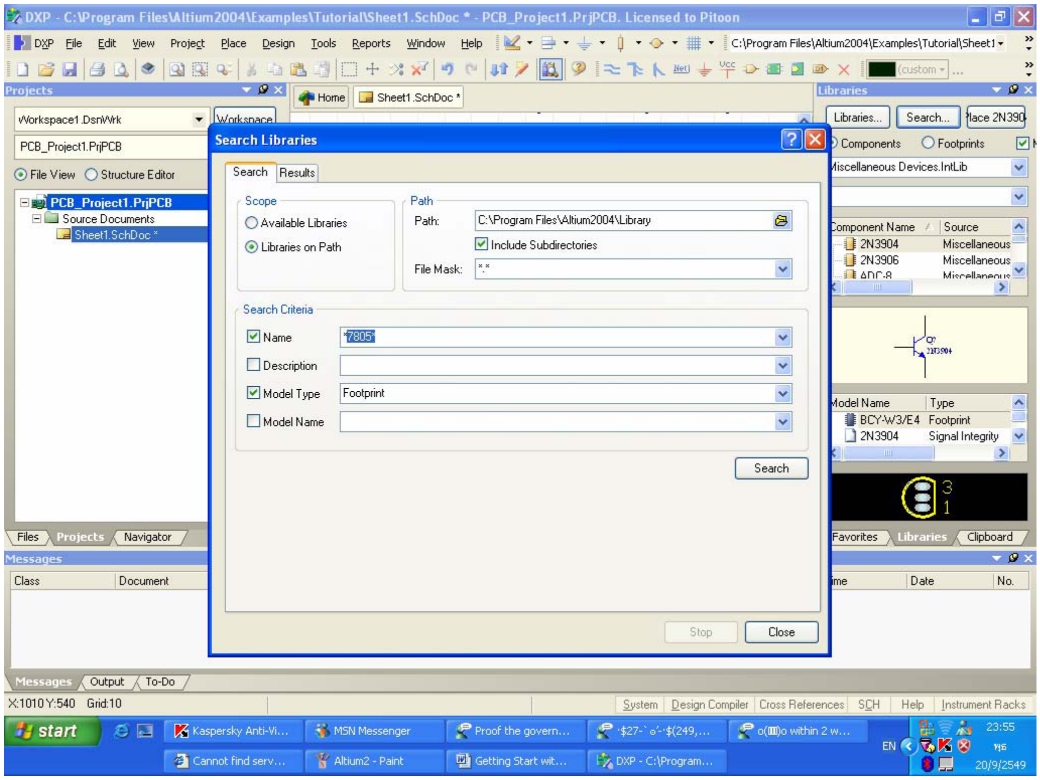


Figure 3.19: Finding the Component

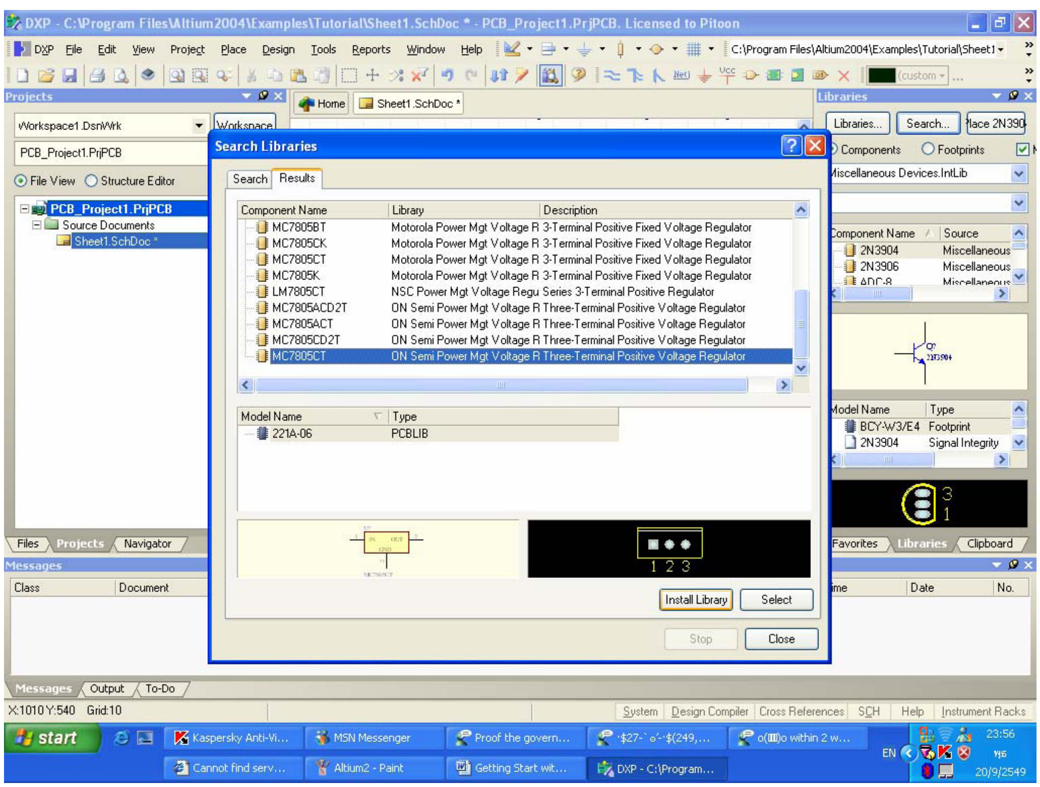


Figure 3.20: Adding components to Project

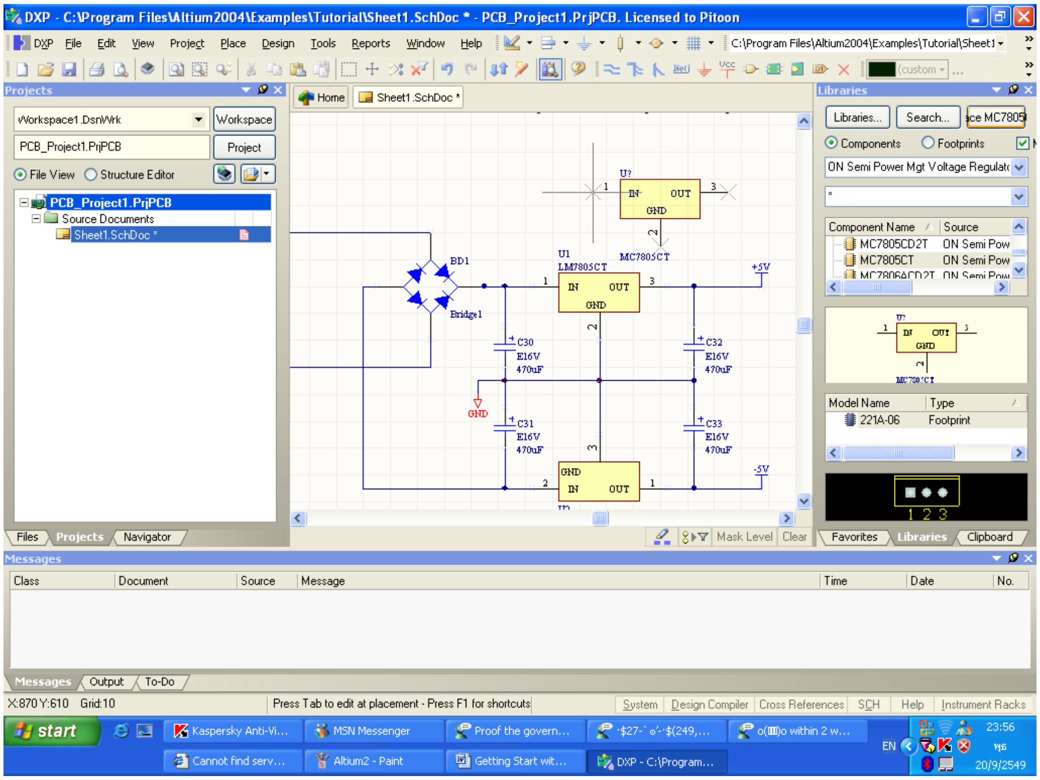


Figure 3.21: Drawing schematic

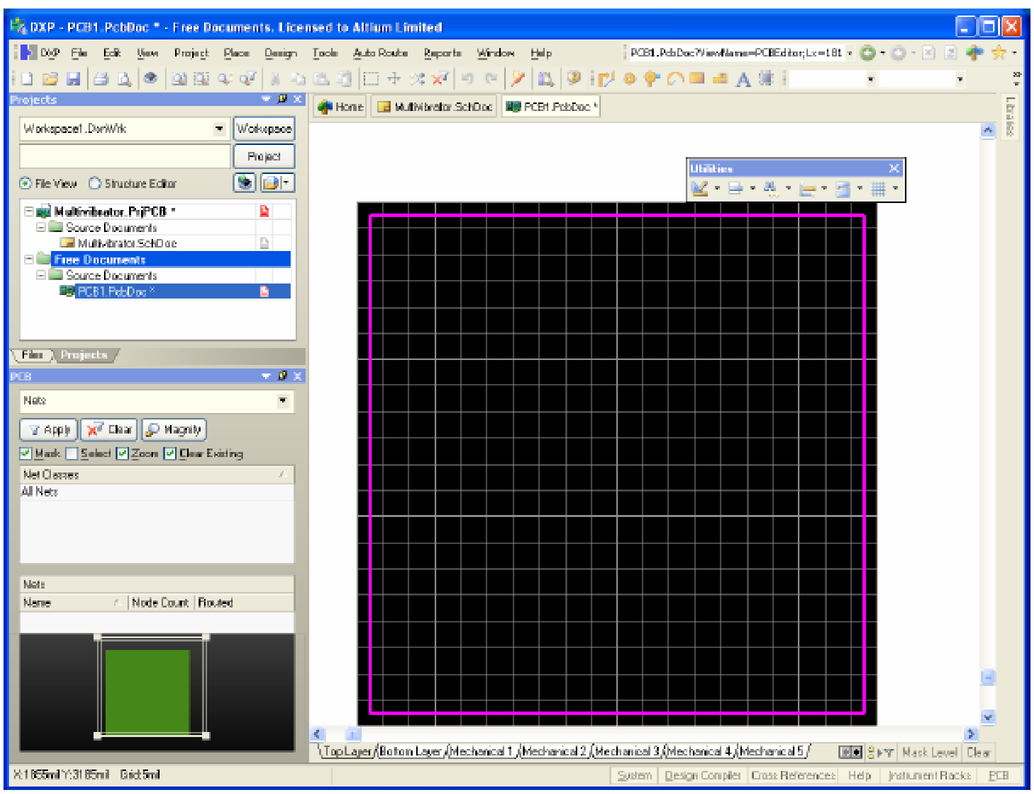


Figure 3.22: Export schematic to PCB Board Wizard

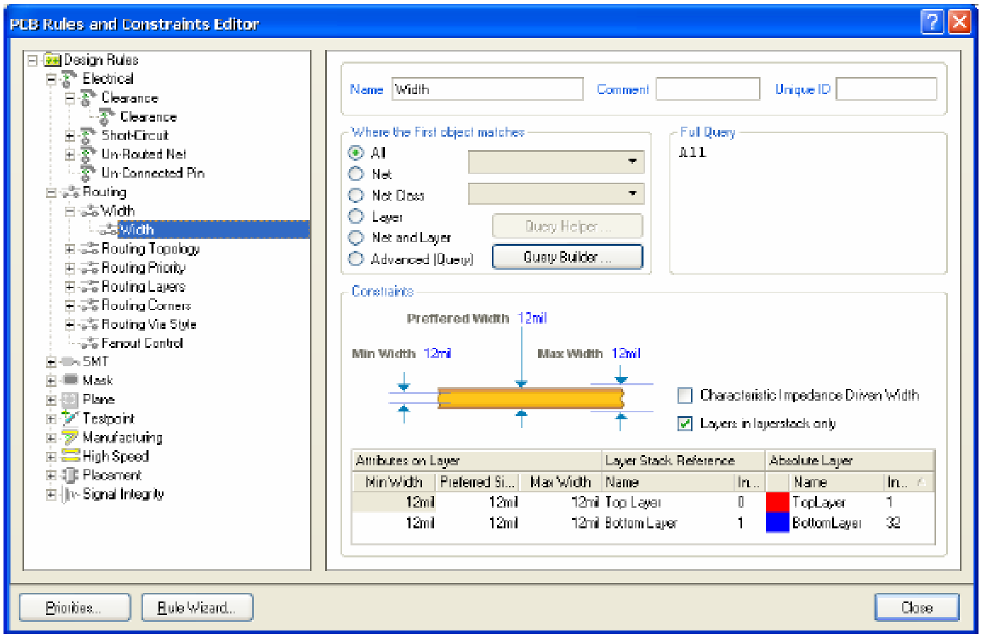


Figure 3.23: Setting PCB rules

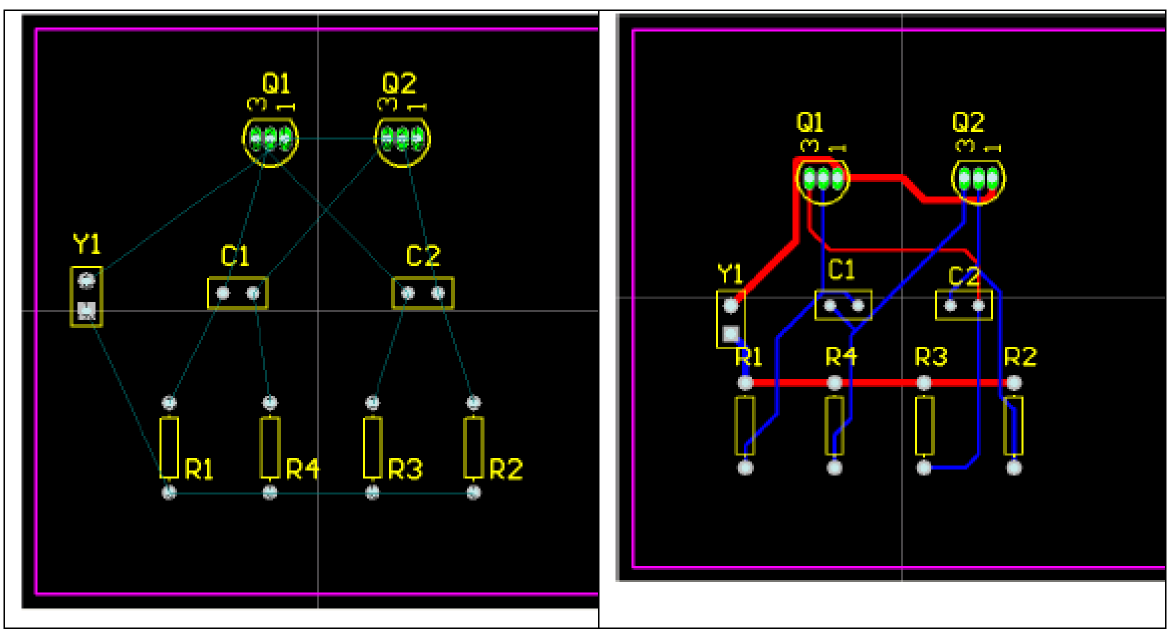


Figure 3.24: PCB routing

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter described and discussed both experimental and simulation result related to the buck-boost power LED driver in generating PWM signal by adjusting its duty cycle input that will be controlling the MOSFET gate. This chapter is divided into two parts: simulation of the buck-boost converter using P-Spice and the hardware implementation of buck-boost converter and the designed driver using the printed circuit board.

Hardware result showed that the buck-boost power LED driver will be producing a certain amount of current that light the power LED to its full brightness and then the current can be dimming by pressing the push button a couple of times so we can control the brightness of the power LED. We also get a PWM signal at the gate of the MOSFET produced by the PIC microcontroller. The duty cycle of PWM signal are the one that controlling the switching speed of the MOSFET and the amount of current that will enter the power LED and the duty cycle are controlled by the push button.

The simulation result was carried out on a fixed frequency of 250 kHz and fixed voltage supply of 9V. During the simulation, the duty cycle is the one that we controlled and see the simulation result. On the other hand, the PIC was programmed to give the user the advantage to change the duty cycle and the current flow through the power LED.

4.2 Printed Circuit Board

The printed circuit board were designed using the Protel 2004 software and this method were choose instead of using the wire board because of its advantage for us to troubleshoot the hardware and also making the soldering work much easier.

The works in designing the buck-boost power LED driver using the printed circuit board are divided into three parts. The first part is to draw it schematic design using the software and the entire component needed in designing it were available in the Protel 2004 library. This designing process must be done carefully because any mistake at the footprint of the component will make the foot of the component related could be soldered.

The second part is to compile the schematic design and making the printed circuit board layout. This layout will be design whether we want to use a double layer board or single layer board. The third part is to drill the board and make a route to the board according to layout design. We can use neither machine nor acid to make the route of the board but using the machine is much easier and efficient.

4.2.1 Buck-Boost Power LED driver controller Schematic Design

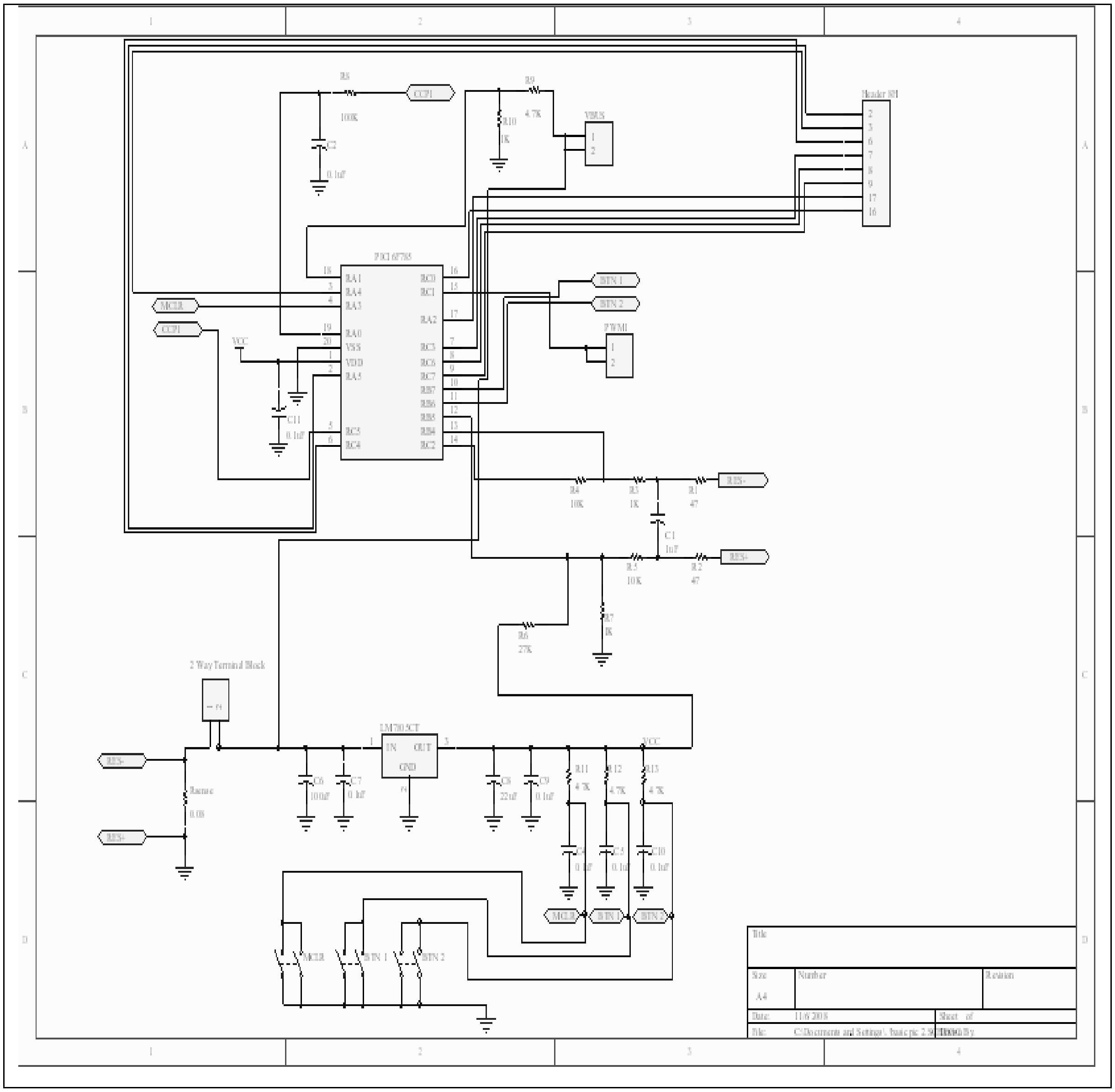


Figure 4.1: Setting PCB rules

4.2.2 Buck-Boost Power LED driver Layout Design

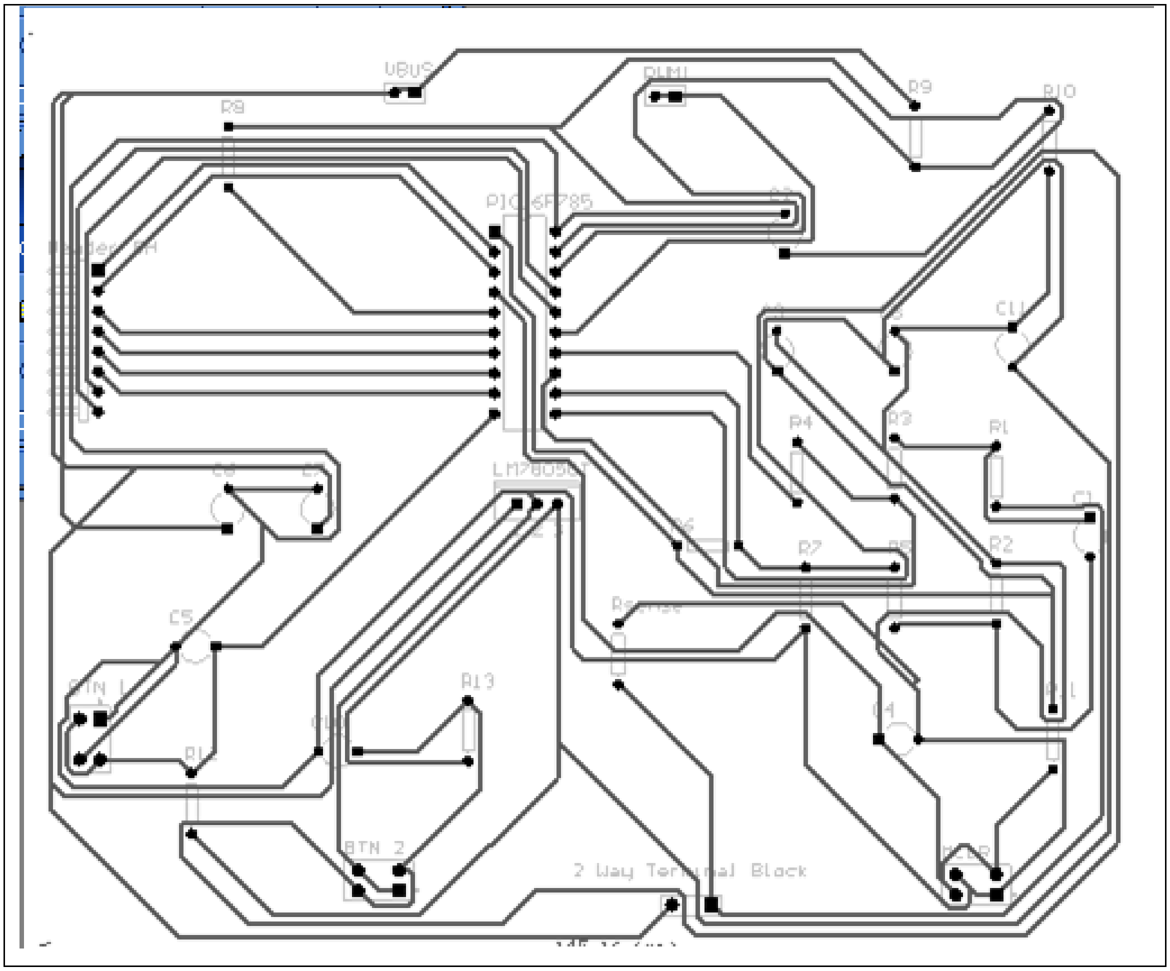


Figure 4.2: Setting PCB rules

4.2.3 Buck-Boost Converter Schematic Design

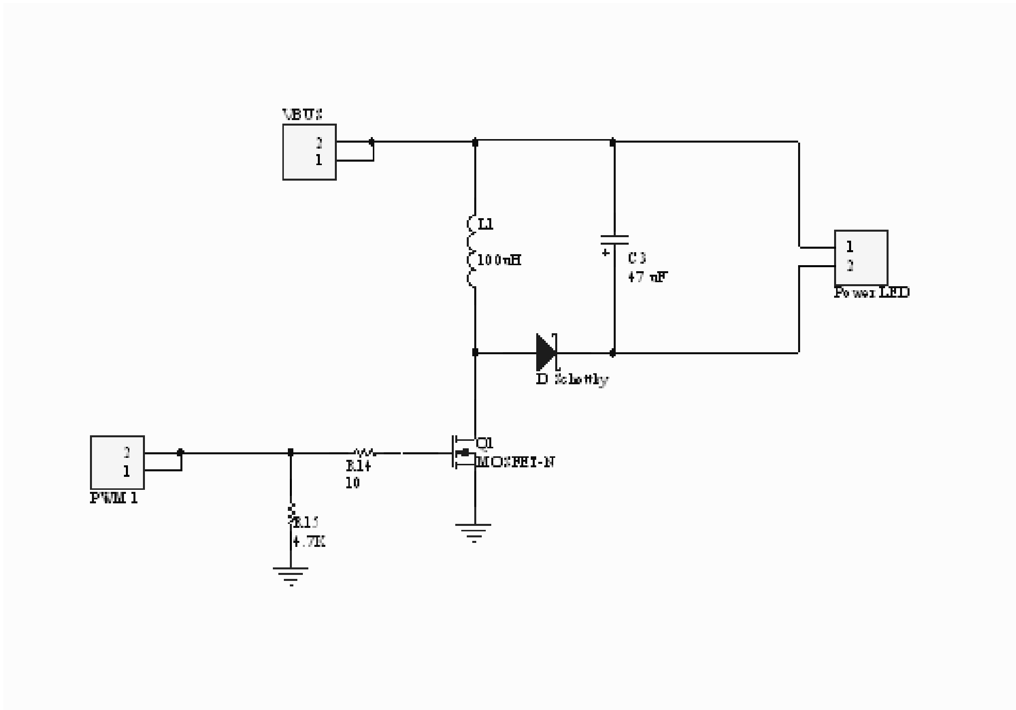


Figure 4.3: Setting PCB rules

4.2.4 Buck-Boost Converter Layout Design

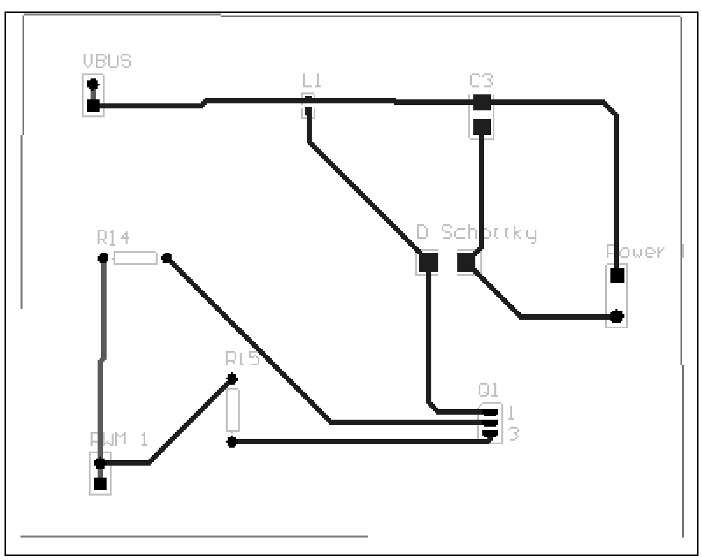


Figure 4.4: Setting PCB rules

4.3 Buck-Boost Power LED driver Board

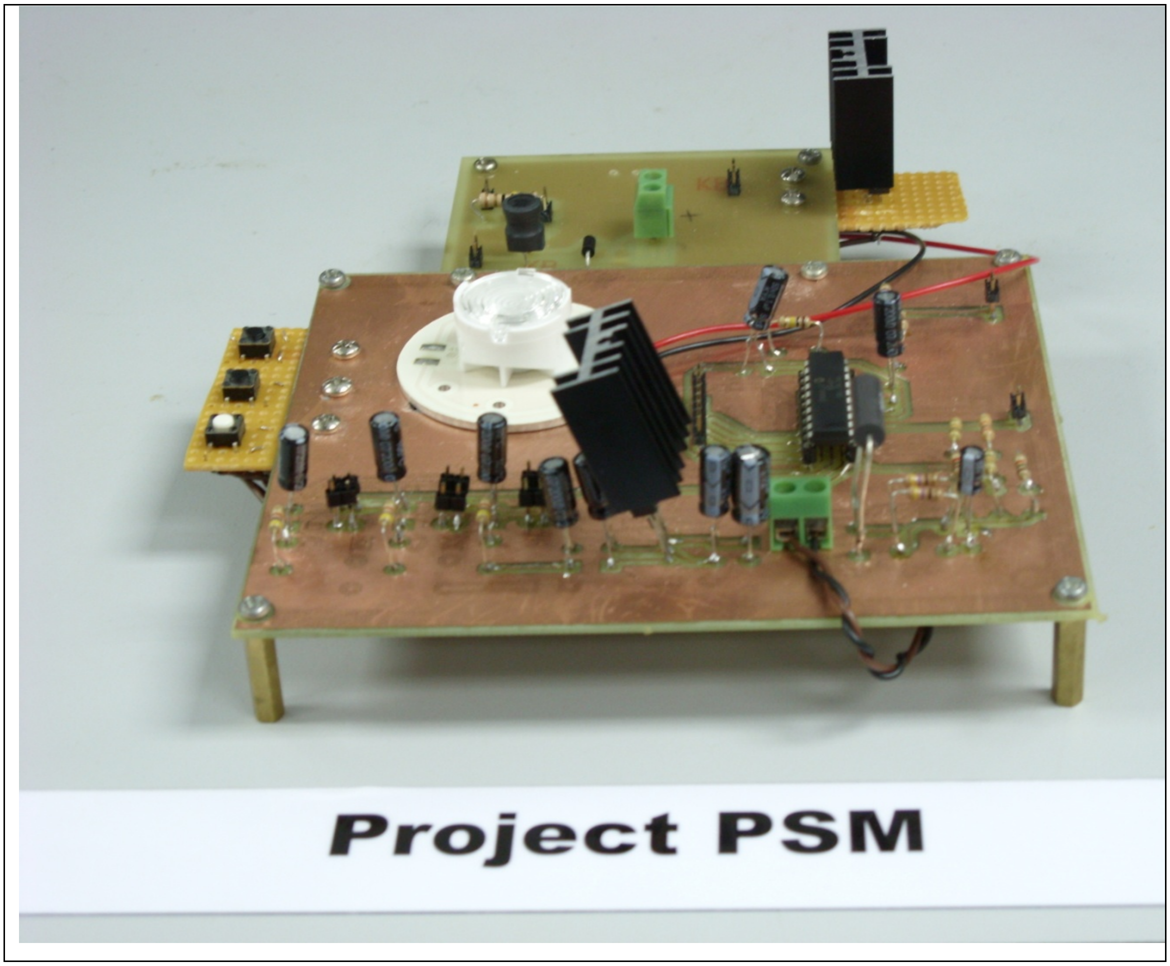


Figure 4.5: Buck-Boost Power LED driver Board

4.4 Simulation Configuration Description

The Pspice/Orcad was chosen because we deal with some digital IC such as voltage regulator, operational amplifier and comparator in generating the PWM pulse and also power switch such as MOSFET in driving the buck-boost circuit. As a result, it is better if it simulated using the Pspice. Furthermore, we have to ensure that we will get the desired result using the capacitor, inductor and also Schottky diode that were chosen.

4.4.1 Schematic Diagram of Buck-Boost converter

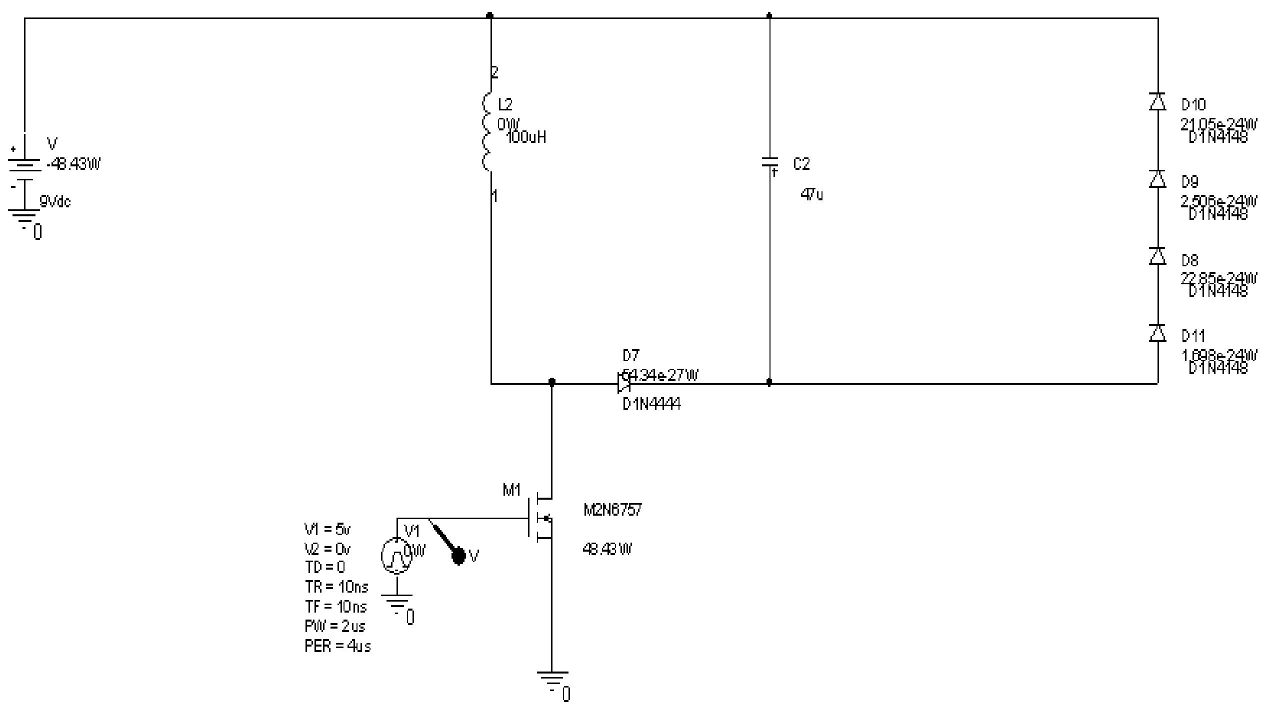


Figure 4.6: Schematic diagram of Buck-Boost

4.4.2 Simulation Result

In the simulation result the dc source was adjusted to be 9V and the Vpulse were 5V. This simulation is to analyze whether the buck-boost converter will increase the input voltage if the duty cycle were bigger than 0.5 and will it decrease if the duty cycle were lower than 0.5.

From this simulation, we control the value of the duty cycle by simply adjusting the pulse width according to this formula:

Duty cycle = Pulse width/period

When we set the duty cycle bigger than 0.5, we'll see that the output voltage will rise up to a certain level and the final value are bigger than the input value and when we set the duty cycle below 0.5, the output voltage will be decrease to a certain amount of level.

4.4.2.1 PWM signal from the Vpulse

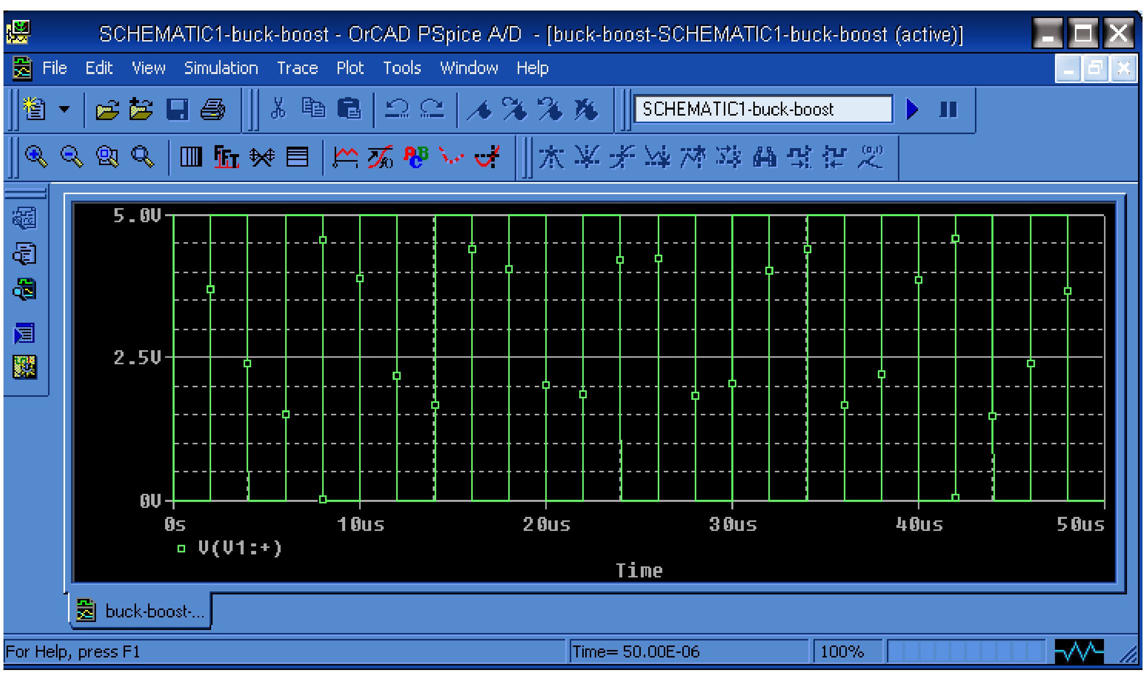


Figure 4.7: PWM signal generated using 5V Vpulse

4.4.2.2 Capacitor current signal

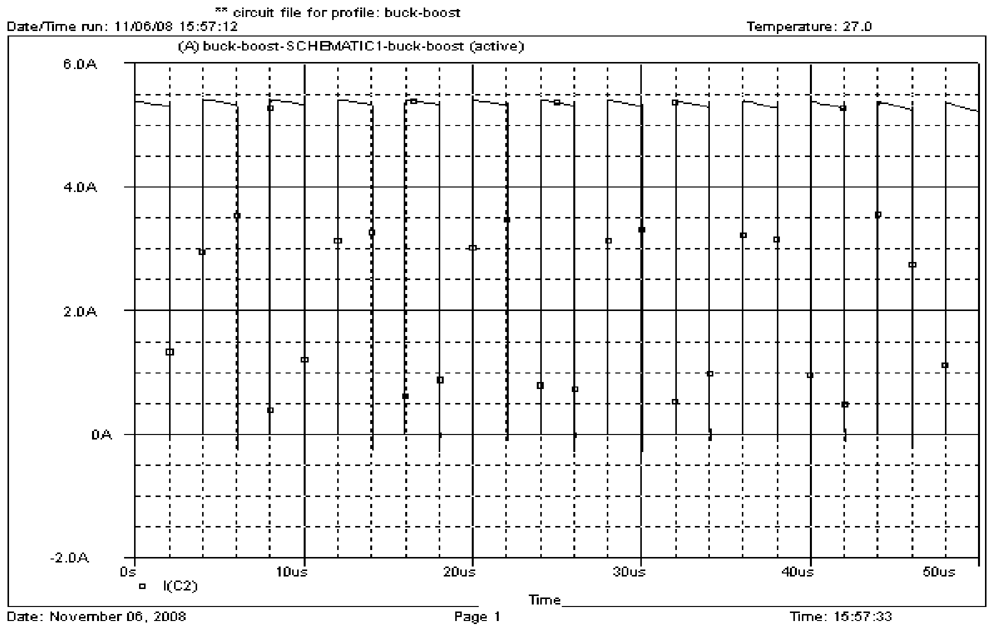


Figure 4.8: Capacitor current signal generated through simulation

4.4.2.3 Inductor Current Signal

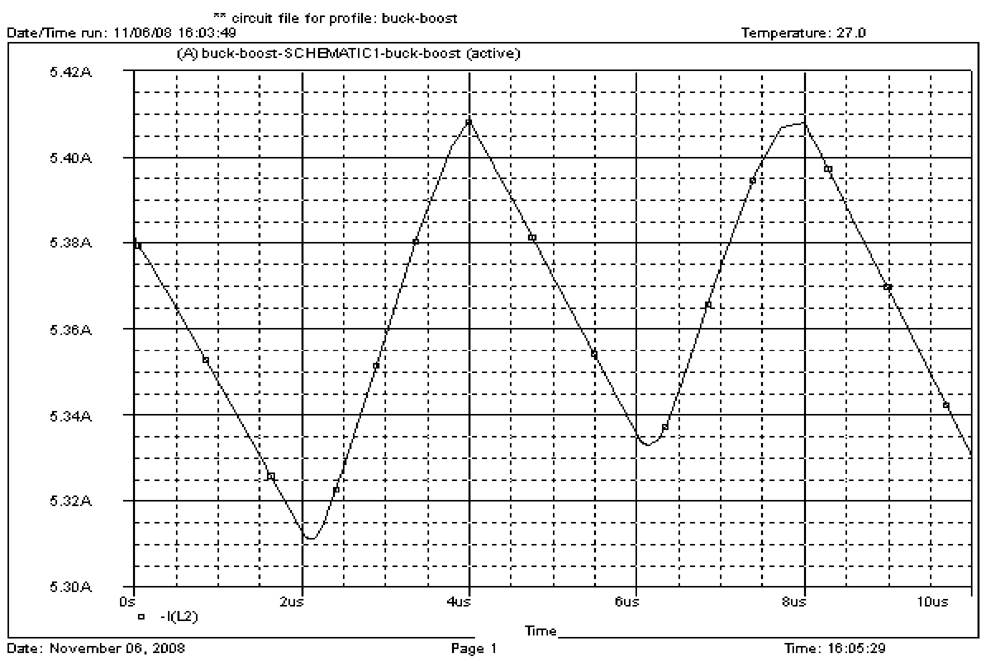


Figure 4.9: Inductor Current Signal generated through simulation

4.4.2.4 Diode current signal

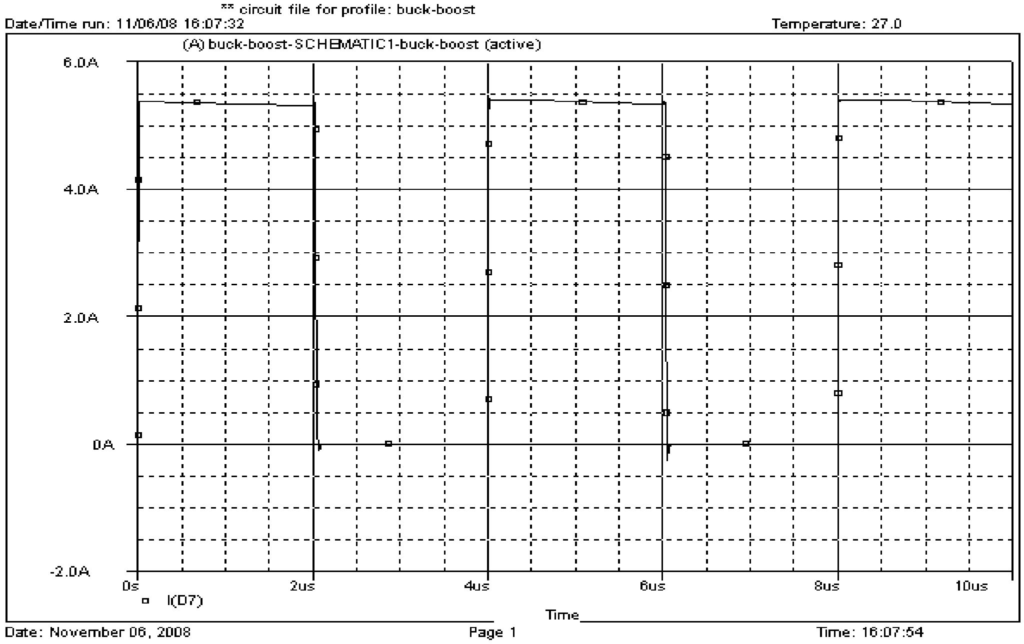


Figure 4.10: Diode Current Signal generated through simulation

4.4.2.5 Output voltage signal

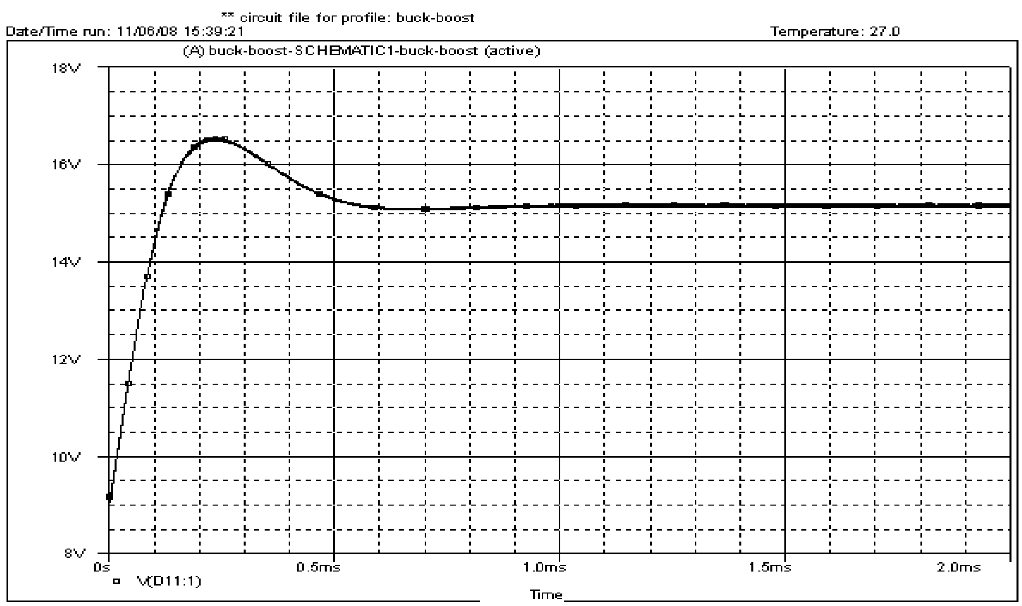


Figure 4.11: Output voltage Signal generated through simulation

4.5 Hardware Implementation Result

4.5.1 PWM signal produced from the Driver

The microcontroller was programmed by using an assembly language to generate PWM signal with a certain amount of duty cycle that can be controlled using the push button. When the power supply is on according to the desired value from 6V to 14V, the power LED will light with full brightness. This application has one reset button and two input buttons that were used control the value of the duty cycle. One button increases the duty cycle of the PWM dimming signal and the other decreases it. A software routine is provided for each button that performs de-bouncing.

When the first push button are pressed, the duty cycle of the signal produce from the driver controller shown in figure 4.1 will increase thus the brightness of the power LED will also be reduced and when the second push button are pressed, the duty cycle of the signal will reduced back to the earlier state and the power LED brightness also will light back to its earlier brightness. If the first push button were pressed again, the duty cycle will be increased again and the power LED brightness will also reduce again and this phenomenon will occur the same way when the second push buttons are pushed where the duty cycle of the signal will reduced back to the earlier state and the power LED brightness also will light back to its earlier brightness.

This calibration will only happen when the push button were pressed three times only and if we want to reset the power LED brightness to the state where it light to its full brightness, we just has to press the clear button.

4.5.2 Software Implementation of LED Dimming Function

In this section, there are a few explanations on how the software or the coding developed. Firstly, the interrupt signal from Timer in the PIC microcontroller is used to implement the PWM dimming function in software. This allows efficient use of hardware and software resources since Timer is already used along with the CCP1 module to generate the current reference level. The system clock is provided by the internal RC oscillator, which is 8 MHz. The system clock is divided by 4 to generate a 2 MHz instruction cycle clock. Timer is clocked by the device instruction clock.

The period register for Timer is set to 0xFF, which provides an interrupt frequency of 2 MHz/256 = 7.8 kHz. A software state machine is used to generate a 100 Hz PWM dimming signal from the Timer interrupt events. A software variable named as the PerCount is used to count the number of Timer interrupts. When PerCount = 78, a new period of the dimming signal is started. At each interrupt event, the value of PerCount is compared to the second variable named as the Duty, to determine when the dimming signal should be turned off. The dimming signal is turned on at the start of each period, unless Duty = 0.

The software generated dimming signal is used to directly control the output of the Two-Phase PWM module. When the dimming signal is on, the PWM output is enabled. When the dimming signal is off, the PWM output is disabled.

4.5.3 Voltage Measurement and Current Reference Calibration

For a typical application, the supply voltage will not change rapidly. For example, you could expect the battery voltage to decay slowly as the battery discharges. For this reason, the supply voltage is only sampled by the ADC once per PWM dimming cycle (100 Hz rate).

The ADC conversion is started one software count period before the LED is to be turned off (Duty – 1). This ensures that the supply voltage is at a stable value after the LED has been energized. If the duty cycle for the PWM dimming is 0, then the ADC conversion is performed at the beginning of the dimming signal period. When the ADC conversion is complete, a new current reference value is read from the lookup table. The lookup value is a duty cycle that is written to the CCP1 module. The software can also do voltage range checks at this time.

4.5.4 PWM signal generated by the driver using 9V DC voltage input

4.5.4.1 When Power LED at its full brightness

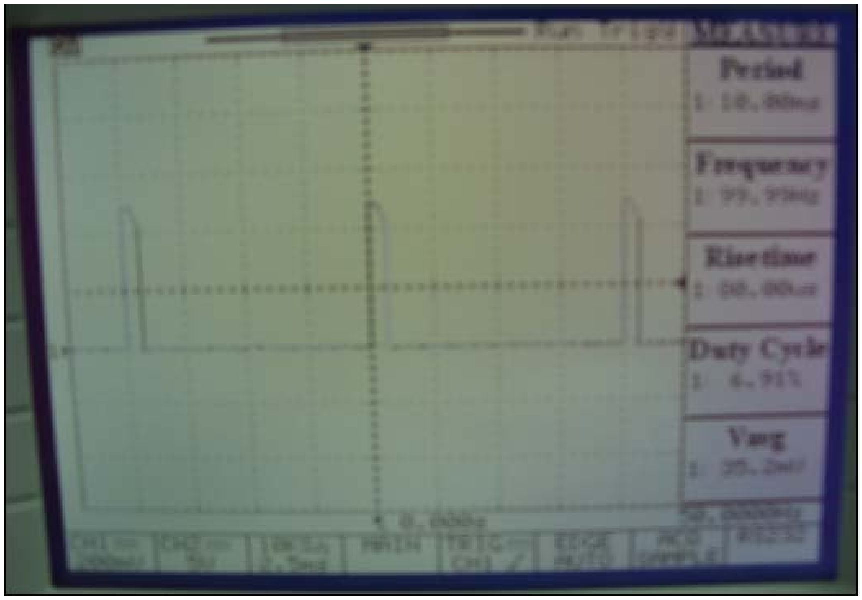


Figure 4.12

Figure 4.12 are showing PWM signal generated at the gate MOSFET when powers LED are light at its full brightness captured using oscilloscope. The duty cycles of the signal are 6.91% and its output voltage are 4.15V.This output voltage value are act accordingly to the buck-boost principle when D<0.5 the circuit will go into buck mode and decrease its input voltage. The output current develop at the buck-boost converter are 325mA and the value of this current are not measured using the oscilloscope but using the ammeter. The ammeter is placed in series with the power LED and then we can measure the current flow through it.

4.5.4.2 When the first push button are pushed for the first time

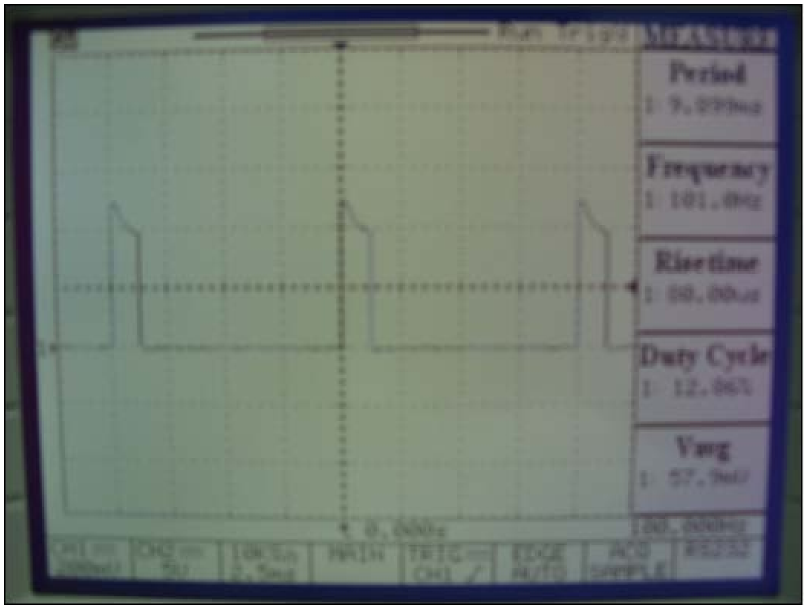


Figure 4.13

Figure 4.13 are showing the PWM signal generated at the gate MOSFET when the first push buttons are pushed for the first time. At this time, the brightness of the power LED is reduced as the duty cycle of the signal is increase two times. The value of the duty cycle now is 12.86% and the output voltage also decreases into 3.24V. The output current measured at the ammeter are 214 mA.

4.5.4.3 When the first push button are pushed for the second time

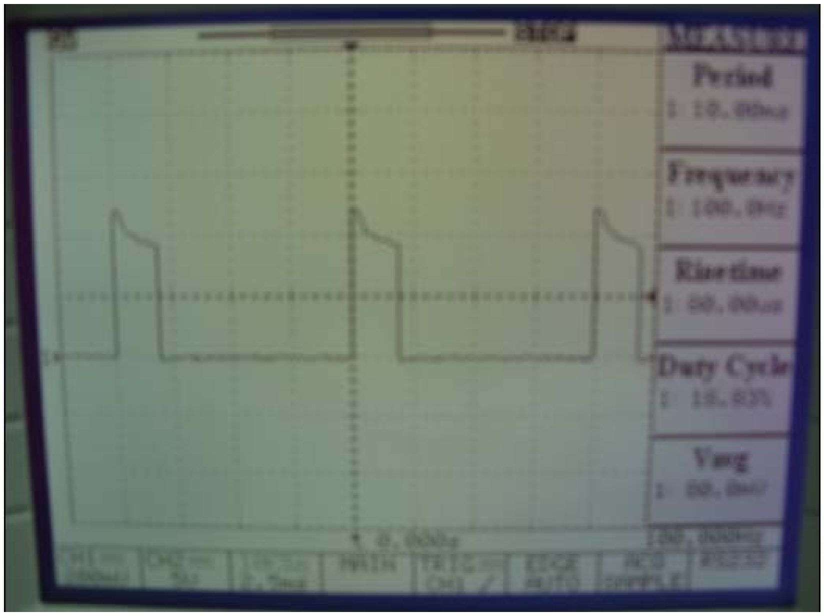


Figure 4.14

Figure 4.14 are showing the PWM signal generated at the gate MOSFET when the first push buttons are pushed for the second time. During this time the brightness of the power LED decrease again and the duty cycle PWM signal are 19.87%. The output voltage also decreases along with the power LED brightness into 2.1 V and the output current is now 105 mA. If we want to restore the power LED brightness into its full brightness, we just have to press the reset button and the PWM signal will go back into the shape at figure 4.12.

4.6 Calculation on Buck-Boost converter

<u>At Vin = 7v</u>

Duty cycle :

Vout = -Vin.$\left(\frac{D}{1-D}\right)$

$$D = \left(\frac{Vout}{Vin}\right) \Big/ \left(\frac{Vout}{Vin} - 1\right)$$

$$D = \left(\frac{-4.5v}{7v}\right) \Big/ \left(\frac{-4.5v}{7v} - 1\right)$$

D = 0.43 @ 43%

Inductor ripples current:

$$\Delta I = \frac{Vin \ \cdot D}{f \cdot L}$$

$$\Delta I = \frac{(7v) \cdot (0.43)}{(250khz) \cdot (100uH)}$$

$$\Delta I = 0.1204$$

Voltage ripple:

$$\Delta Vout = \frac{Iout \cdot D}{f \cdot C}$$

$$\Delta Vout = \frac{(700mA) \cdot (0.43)}{(250khz) \cdot (47uF)}$$

$$\Delta Vout = 0.0256$$

<u>At Vin = 8v</u>

Duty cycle :

Vout = -Vin.$\left(\frac{D}{1-D}\right)$

$$D = \left(\frac{Vout}{Vin}\right) \Big/ \left(\frac{Vout}{Vin} - 1\right)$$

$$D = \left(\frac{-4.5v}{8v}\right) \Big/ \left(\frac{-4.5v}{8v} - 1\right)$$

D = 0.36 @ 36%

Inductor ripples current:

$$I = \frac{Vin \cdot D}{f \cdot L}$$

$$\Delta I = \frac{(8v) \cdot (0.36)}{(250khz) \cdot (100uH)}$$

$$\Delta I = 0.1152$$

Voltage ripple:

$$\Delta Vout = \frac{Iout \cdot D}{f \cdot C}$$

$$\Delta Vout = \frac{(700mA) \cdot (0.36)}{(250khz) \cdot (47uF)}$$

$$\Delta Vout = 0.0214$$

<u>At Vin = 9v</u>

Duty cycle:

Vout = -Vin.$\left(\frac{D}{1-D}\right)$

$$D = \left(\frac{Vout}{Vin}\right) \Big/ \left(\frac{Vout}{Vin} - 1\right)$$

$$D = \left(\frac{-4.5v}{9v}\right) \Big/ \left(\frac{-4.5v}{9v} - 1\right)$$

D = 0.33 @ 33%

Inductor ripples current:

$$\Delta I = \frac{Vin \cdot D}{f \cdot L}$$

$$\Delta I = \frac{(8v) \cdot (0.33)}{(250khz) \cdot (100uH)}$$

$$\Delta I = 0.1056$$

Voltage ripple:

$$\Delta Vout = \frac{Iout \cdot D}{f \cdot C}$$

$$\Delta Vout = \frac{(700mA) \cdot (0.33)}{(250khz) \cdot (47uF)}$$

$$\Delta Vout = 0.0197$$

Efficiency of the power LED were measured using at the dc power supply using 9V voltage input and the input current are 0.2 A

Input power (Pin):

P = VI

= (9.0V)(0.2A)

= 1.8 W

Output power (Pout):

P = VI

= (4.15V)(325mA)

= 1.35 W

Power Efficiency = (Pin/Pout) x 100%

= (1.35W/1.8W) x 100%

= 75%

4.7 List of Component

Table 4.1: List of component

No	Component	Specification	Quantity
1	Capacitor	0.1uF	14
2	Capacitor	1uF	4
3	Capacitor	47uF tantalum capacitor, Low ESR	4
4	Capacitor	100uF	4
5	Capacitor	22uF	4
6	Power LED	3 watt manufactured by CML innovative Technologies	1
7	Diode	Schottky Diode	4
8	Connector	Terminal block	8
9	Inductor	100uH	8
10	Power Switch	BUZ73 MOSFET manufactured by Infineon	4
11	Resistor	47Ω	4
12	Resistor	1KΩ	4
13	Resistor	10KΩ	4
14	Resistor	27KΩ	4
15	Resistor	4.7KΩ	8
16	Resistor	10Ω	4
17	Sensing Resistor	0.08 Ω Manufactured by Vishay Technologies	4
18	Switch	Normally Push Button	6
19	Voltage Regulator	LM7805	3
20	Microcontroller	PIC16F785 manufactured by microchip	4

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The objective of this particular project is to design a system that provide more efficient solution for driving a high power LED by controlling LED forward current using buck-boost converter. To control on and off of the buck-boost converter, power electronic switch such as MOSFET will be used and it's been chosen because of it advantage operating in high frequency along with their low cost. To achieve the objective, the control system or known as the driver has been design and implemented using microcontroller.

In this project, microcontroller PIC16F785 has been used to drive the gate of the MOSFET by hardware implementation of the driver designed along with the buck-boost converter and simulation program run with the satisfactory result was obtained. The hardware of the control system or the driver can only be used to control only one power LED right now but if we want to control more, we have to make further modification in the circuit in order to increase the rating current and voltage to control many loads.

In fact to achieve the above objective, all topology of the dc-dc converter was studied deeply and the entire configuration and the feature of the microcontroller used have been studied thoroughly. Different used in the design were test thoroughly in order for the system to work perfectly and to obtain the output signal. The result of the output waveform has been recorded in the related section and the function of the MOSFET as the buck-boost switching element in switch mode power supply design is understood sufficiently.

In general, the driver design was successful in by controlling LED forward current using buck-boost converter and driving the high power LED. These conclude that buck-boost converter really offer a solution for most of the higher-power lighting applications and in order to control the LED forward current, we must have a fully control of the PWM signal that drive the MOSFET.

5.2 Future Works and Recommendations

After finishing the work, the author would like to forward some suggestion to improve the efficient of the buck-boost LED driver as the future work of this project.

1. PC based Graphical User Interface, or GUI technologies might be useful to be used replacing the push buttons that were used as a switch as now to control the current dimming and the brightness of the power LED.
2. Secondly, I would like to add a LCD screen on the board. The LCD screens are function to display the value of the duty cycle produce from the PIC when the certain amount of input voltage is applied.
3. The third one is to design this driver in smaller size to control traffic light lamp, bollard lighting and many more.

References

[1] A. Torres, J. Garcia, M. Rico Secades, A.J. Calleja, J. Ribas. *Advancing Towards Digital Control for Low Cost High Power LED Drivers*; Industrial Electronics, 2007. ISIE 2007. IEEE International Symposium.

[2] Robert L. Boylestad, Lois Nashelsky. *Electronic Device and Circuit Theory (Ninth Edition)*: Pearson Publishing Company

[3] Buck-Boost Power LED Driver
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[4] DC-DC converter
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[5] Microchip Technology Incorporated: PIC16F785 Datasheet

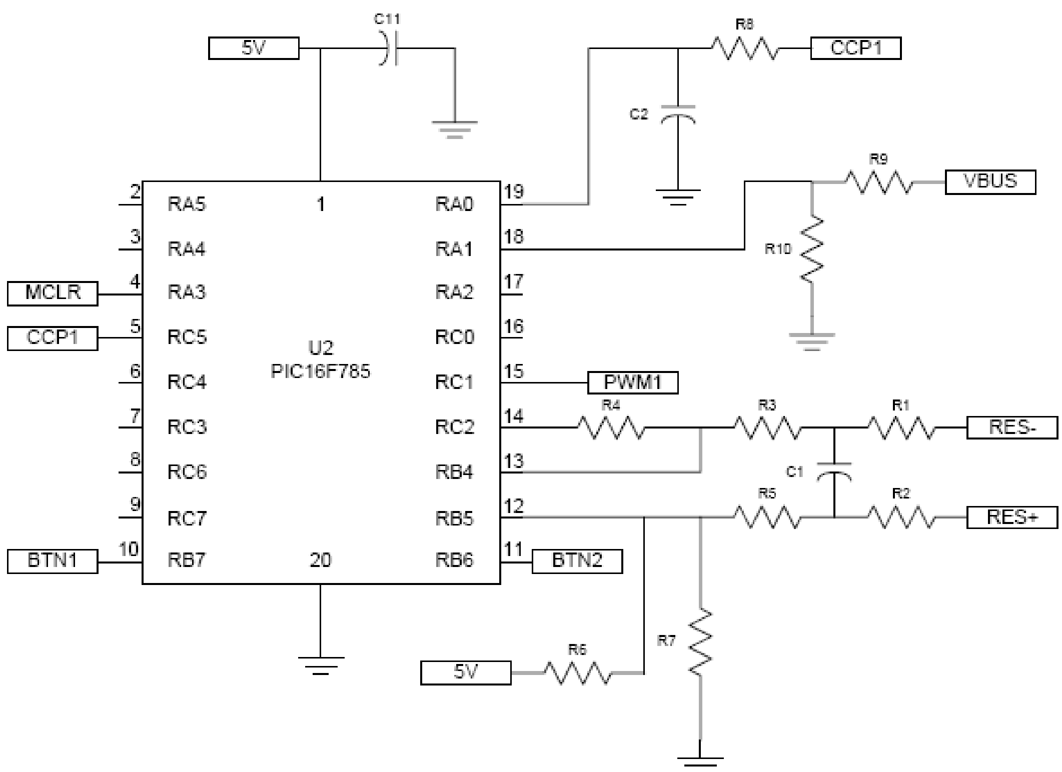
[6] Daniel W. Hart, *Introduction to Power Electronic: Pearson* Publishing Company

[7] LED Backlighting for LCDs Requires Unique Drivers
Available at: http://powerelectronics.com/power_management/led_drivers/led-backlighting-lcd-power-efficiency-0512/

[8] MOSFET
Available at: http://en.wikipedia.org/ wiki/mosfet

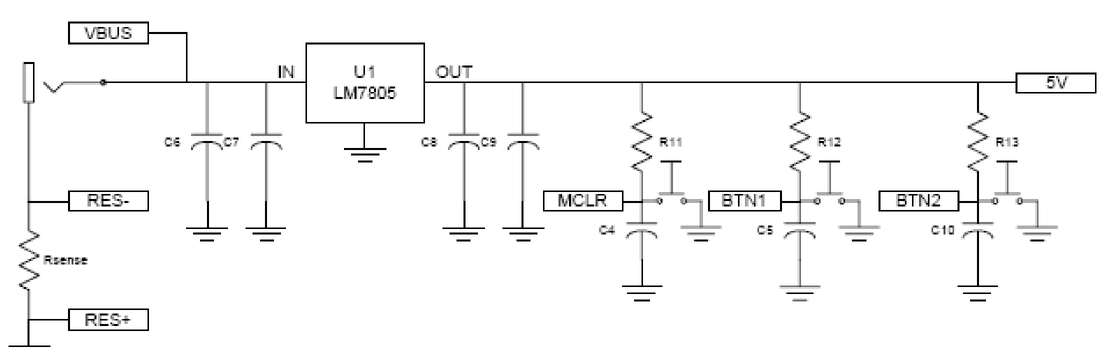
APPENDIX A1

Driver Circuit Schematic Diagram:



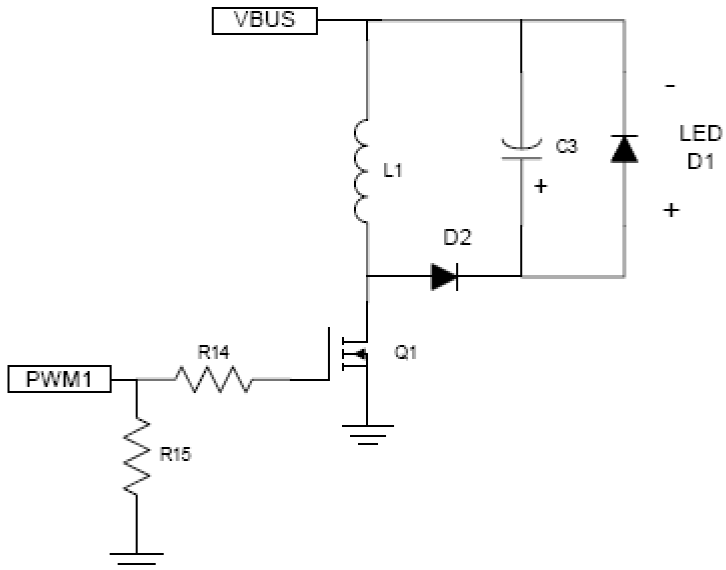
APPENDIX A23

Power Supply Schematic Diagram:



APPENDIX A3

Buck-Boost Converter Schematic Diagram:



APPENDIX B1

PSM 1 Gantz Chart :

NO	ACTIVITIES	JANUARY				FEBRUARY				MARCH			
1	Title selection												
2	Proposal selection												
3	Submit Proposal												
4	Seminar 1												
5	Submit Report												
6	Submit logbook												
7	Component Preparation												

APPENDIX B2

PSM 2 Gantz Chart :

NO	ACTIVITIES	JUN				JULY				AUGUST				SEPTEMBER				OCTOBER			
1	Hardware installation																				
2	Program Design																				
3	Troubleshoot																				
4	Seminar 2 preparation																				
5	Seminar 2																				
6	Thesis preparation																				
7	Submit Thesis																				

APPENDIX C

PIC Microcontroller Program:

```
   list      p=16F785
   #include <p16F785.inc>
   errorlevel  -302


;VARIABLE DEFINITIONS
udata_shr
w_temp          res     1
status_temp     res     1
pclath_temp     res     1
BtnFlags        res     1
Vbus            res     1
Duty            res     1
PerCount        res     1


;bit definitions for 'BtnFlags' register
Btn1Event       equ     0
Btn2Event       equ     1
Btn1Press       equ     2
Btn2Press       equ     3

; Button pins on PORTB
Button1         equ     7
Button2         equ     6


STARTUP     code    0x0
        goto    Main
        nop
        nop
        retfie

PROG1       code

CalibrationTable:
        addwf   PCL
        retlw   .0      ; 0
        retlw   .0      ; 1
        retlw   .0      ; 2
        retlw   .0      ; 3
        retlw   .0      ; 4
```

```
retlw   .0      ; 5
retlw   .0      ; 6
retlw   .0      ; 7
retlw   .0      ; 8
retlw   .0      ; 9
retlw   .0      ; 10
retlw   .0      ; 11
retlw   .0      ; 12
retlw   .0      ; 13
retlw   .0      ; 14
retlw   .0      ; 15
retlw   .0      ; 16
retlw   .0      ; 17
retlw   .0      ; 18
retlw   .0      ; 19
retlw   .0      ; 20
retlw   .0      ; 21
retlw   .0      ; 22
retlw   .0      ; 23
retlw   .0      ; 24
retlw   .0      ; 25
retlw   .132    ; 26  (Vin = 3.0V)
retlw   .133    ; 27
retlw   .134    ; 28
retlw   .135    ; 29
retlw   .136    ; 30
retlw   .136    ; 31
retlw   .137    ; 32
retlw   .138    ; 33
retlw   .138    ; 34    (Vin = 4.0V)
retlw   .139    ; 35
retlw   .139    ; 36
retlw   .140    ; 37
retlw   .140    ; 38
retlw   .141    ; 39
retlw   .141    ; 40
retlw   .142    ; 41
retlw   .142    ; 42
retlw   .143    ; 43    (Vin = 5.0V)
retlw   .143    ; 44
retlw   .143    ; 45
retlw   .144    ; 46
retlw   .144    ; 47
retlw   .144    ; 48
retlw   .145    ; 49
retlw   .145    ; 50
```

```
retlw   .145    ; 51    (Vin = 6.0V)
retlw   .145    ; 52
retlw   .146    ; 53
retlw   .146    ; 54
retlw   .146    ; 55
retlw   .146    ; 56
retlw   .147    ; 57
retlw   .147    ; 58
retlw   .147    ; 59
retlw   .147    ; 60    (Vin = 7.0V)
retlw   .147    ; 61
retlw   .148    ; 62
retlw   .148    ; 63
retlw   .148    ; 64
retlw   .148    ; 65
retlw   .148    ; 66
retlw   .148    ; 67
retlw   .149    ; 68    (Vin = 8.0V)
retlw   .148    ; 69
retlw   .148    ; 70
retlw   .147    ; 71
retlw   .147    ; 72
retlw   .146    ; 73
retlw   .146    ; 74
retlw   .145    ; 75
retlw   .145    ; 76
retlw   .145    ; 77    (Vin = 9.0V)
retlw   .144    ; 78
retlw   .144    ; 79
retlw   .143    ; 80
retlw   .143    ; 81
retlw   .143    ; 82
retlw   .142    ; 83
retlw   .142    ; 84
retlw   .141    ; 85    (Vin = 10.0V)
retlw   .141    ; 86
retlw   .141    ; 87
retlw   .140    ; 88
retlw   .140    ; 89
retlw   .140    ; 90
retlw   .139    ; 91
retlw   .139    ; 92
retlw   .139    ; 93
retlw   .139    ; 94    (Vin = 11.0V)
retlw   .138    ; 95
retlw   .138    ; 96
```

```
retlw   .138    ; 97
retlw   .138    ; 98
retlw   .137    ; 99
retlw   .137    ; 100
retlw   .137    ; 101
retlw   .137    ; 102   (Vin = 12.0V)
retlw   .136    ; 103
retlw   .136    ; 104
retlw   .136    ; 105
retlw   .136    ; 106
retlw   .136    ; 107
retlw   .135    ; 108
retlw   .135    ; 109
retlw   .135    ; 110
retlw   .135    ; 111   (Vin = 13.0V)
retlw   .134    ; 112
retlw   .134    ; 113
retlw   .134    ; 114
retlw   .133    ; 115
retlw   .134    ; 116
retlw   .133    ; 117
retlw   .133    ; 118
retlw   .133    ; 119   (Vin = 14.0V)
retlw   .133    ; 120
retlw   .133    ; 121
retlw   .133    ; 122
retlw   .132    ; 123
retlw   .132    ; 124
retlw   .132    ; 125
retlw   .132    ; 126
retlw   .132    ; 127
retlw   .132    ; 128

;Setup internal oscillator speed
banksel OSCCON
bsf     OSCCON,IRCF0
bsf     OSCCON,IRCF1
bsf     OSCCON,IRCF2

clrf    Vbus
clrf    PerCount

movlw   .5
movwf   Duty

banksel PORTA
```

```
        clrf    PORTA
        clrf    PORTB
        clrf    PORTC

        ; Setup outputs
        banksel TRISA
        bcf     TRISA,5
        bcf     TRISC,1

        ; Setup CCP for PWM mode to make adj. voltage reference.
        call    SetupCCP1

          ; Opamp #2 is used to amplify the current sensing resistor
        call    SetupOpAmp

          ; Comparator #1 is used for PWM shutdown.
        call    SetupComparator

          ; Setup ADC to sample bus voltage
        call    SetupADC

          ; Enable the PWM module
        call    SetupPWM


MainLoop:

WaitTimer2:
        btfss   PIR1,T2IF
        goto    WaitTimer2

        ; If Timer2 has expired, run the following code:
        bcf     PIR1,T2IF
        incf    PerCount

        ; Check to see if there is a period match (78 TMR2 cycles)
        movlw   .78
        subwf   PerCount,W
        btfss   STATUS,Z
        goto    DutyCheck


        ; When the period match occurs, clear the PerCount variable,
        ; Enable the PWM to drive the LED, start a conversion, and
        ; check the buttons.
```

```
PeriodMatch:
        clrf    PerCount

TurnOnLED:
        banksel PWMCON0
        bsf     PWMCON0,PH1EN
        goto    StartConversion

DutyCheck:
        ; Check to see if PerCount = Duty
        ; Turn off PWM output when match occurs.
        movf    Duty,W
        subwf   PerCount,W
        btfss   STATUS,Z
        goto    MainLoop

TurnOffLED:
        banksel PWMCON0
        bcf     PWMCON0,PH1EN
        goto    MainLoop


StartConversion:
        banksel ADCON0
        bsf     ADCON0,GO

        CheckBtn1:
        call    Btn1Handler
        btfss   BtnFlags,Btn1Event
        goto    CheckBtn2
        movlw   .75
        subwf   Duty,W
        btfsc   STATUS,Z
        goto    MaxDuty
        movlw   .5
        addwf   Duty

MaxDuty:
        bcf     BtnFlags,Btn1Event



CheckBtn2:
        call    Btn2Handler
        btfss   BtnFlags,Btn2Event
        goto    CheckADC
```

```
      movlw   .5
      subwf   Duty,W
      btfsc   STATUS,Z
      goto    MinDuty
      movlw   .5
      subwf   Duty

MinDuty:
      bcf     BtnFlags,Btn2Event

CheckADC:
      banksel ADCON0

WaitConversion:
      btfsc   ADCON0,GO
      goto    WaitConversion
      banksel ADRESH
      movf    ADRESH,W
      movwf   Vbus
      SetCurrentRef:
      call    CalibrationTable
      banksel CCPR1L
      movwf   CCPR1L
      goto    MainLoop

Btn1Handler:
      banksel PORTB
      btfsc   PORTB,Button1      ;
      goto    Btn1Release
      bsf     BtnFlags,Btn1Press
      return

Btn1Release:
      btfss   BtnFlags,Btn1Press
      return
      bcf     BtnFlags,Btn1Press
      bsf     BtnFlags,Btn1Event
      return


Btn2Handler:
      banksel PORTB
      btfsc   PORTB,Button2      ;
      goto    Btn2Release
      bsf     BtnFlags,Btn2Press
      return
```

```
Btn2Release:
        btfss   BtnFlags,Btn2Press
        return
        bcf     BtnFlags,Btn2Press
        bsf     BtnFlags,Btn2Event
        return


SetupCCP1:
        banksel TRISC
        bsf     TRISC,5
        movlw   0xFF
        movwf   PR2
        banksel CCP1CON
        movlw   0x0C
        movwf   CCP1CON
        movlw   .0
        movwf   CCPR1L
        bcf     PIR1,TMR2IF
        clrf    TMR2
        bsf     T2CON,TMR2ON

CheckT2Overflow:
        btfss   PIR1,TMR2IF
        goto    CheckT2Overflow
        banksel TRISC
        bcf     TRISC,
        return

SetupPWM
        banksel PWMPH1
        movlw   0x20
        movwf   PWMPH1
        movlw   0x1F        ;value for 250 Khz
        movwf   PWMCLK
        movlw   0x81
        movwf   PWMCON0
        return


SetupADC:
        movlw   0x07
        banksel ANSEL0
        movwf   ANSEL0
        movlw   0x50
```

```
        banksel ADCON1
        movwf   ADCON1
        movlw   0x09
        banksel ADCON0
        movwf   ADCON0
        bsf     ADCON0,GO
        return


SetupComparator:
        movlw   0x9A
        banksel CM1CON0
        movwf   CM1CON0
        return


SetupOpAmp:
        ; Turn on opamp
        banksel OPA1CON
        bsf     OPA2CON,OPAON
        return

    end
```

APPENDIX D

PIC16F785 MCU Datasheet:

MICROCHIP

PIC16F785/HV785

20-Pin Flash-Based 8-Bit CMOS Microcontroller

High-Performance RISC CPU:

- Only 35 instructions to learn:
  - All single-cycle instructions except branches
- Operating speed:
  - DC – 20 MHz oscillator/clock input
  - DC – 200 ns instruction cycle
- Interrupt capability
- 8-level deep hardware stack
- Direct, Indirect and Relative Addressing modes

Special Microcontroller Features:

- Precision Internal Oscillator:
  - Factory calibrated to ±1%
  - Software selectable frequency range of 8 MHz to 32 kHz
  - Software tunable
  - Two-Speed Start-up mode
  - Crystal fail detect for critical applications
  - Clock mode switching during operation for power savings
- Power-Saving Sleep mode
- Wide operating voltage range (2.0V-5.5V)
- Industrial and extended temperature range
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Brown-out Reset (BOR) with software control option
- Enhanced Low-Current Watchdog Timer (WDT) with on-chip oscillator (software selectable nominal 268 seconds with full prescaler) with software enable
- Multiplexed Master Clear with pull-up/input pin
- Programmable code protection
- High-Endurance Flash/EEPROM cell:
  - 100,000 write Flash endurance
  - 1,000,000 write EEPROM endurance
  - Flash/Data EEPROM retention: > 40 years

Low-Power Features:

- Standby Current:
  - 30 nA @ 2.0V, typical
- Operating Current:
  - 8.5 µA @ 32 kHz, 2.0V, typical
  - 100 µA @ 1 MHz, 2.0V, typical
- Watchdog Timer Current:
  - 1 µA @ 2.0V, typical
- Timer1 Oscillator Current:
  - 2 µA @ 32 kHz, 2.0V, typical

Peripheral Features:

- High-speed Comparator module with:
  - Two independent analog comparators
  - Programmable on-chip voltage reference (CV_{REF}) module (% of V_{DD})
  - 1.2V band gap voltage reference
  - Comparator inputs and outputs externally accessible
  - < 40 ns propagation delay
  - 2 mv offset, typical
- Operational Amplifier module with 2 independent op amps:
  - 3 MHz GBWP, typical
  - All I/O pins externally accessible
- Two-Phase Asynchronous Feedback PWM module:
  - Complementary output with programmable dead band delay
  - Infinite resolution analog duty cycle
  - Sync Output/Input for multi-phase PWM
  - $F_{OSC}/2$ maximum PWM frequency
- A/D Converter:
  - 10-bit resolution and 14 channels (2 internal)
- 17 I/O pins and 1 input-only pin:
  - High-current source/sink for direct LED drive
  - Interrupt-on-pin change
  - Individually programmable weak pull-ups
- Timer0: 8-bit timer/counter with 8-bit programmable prescaler
- Enhanced Timer1:
  - 16-bit timer/counter with prescaler
  - External Gate Input mode
  - Option to use OSC1 and OSC2 in LP mode as Timer1 oscillator, if INTOSC mode selected
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Capture, Compare, PWM module:
  - 16-bit Capture, max resolution 12.5 ns
  - Compare, max resolution 200 ns
  - 10-bit PWM with 1 output channel, max frequency 20 kHz
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Shunt Voltage Regulator (PIC16HV785 only)
  - 5 volt regulation
  - 4 mA to 50 mA shunt range

PIC16F785/HV785

Device	Program Memory	Data Memory		I/O	10-bit A/D (ch)	Op Amps	Comparators	CCP	Two-Phase PWM	Timers 8/16-bit	Shunt Reg.
	Flash (words)	SRAM (bytes)	EEPROM (bytes)								
PIC16F785	2048	128	256	17+1	12+2	2	2	1	1	2/1	0
PIC16HV785	2048	128	256	17+1	12+2	2	2	1	1	2/1	1

Dual in Line Pin Diagram

20-pin PDIP, SOIC, SSOP

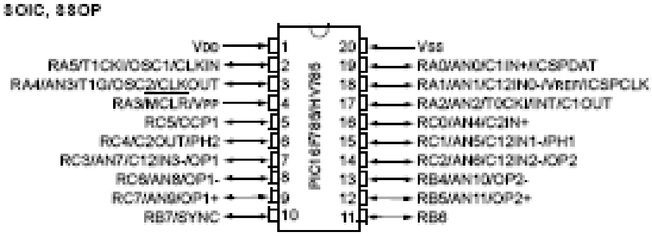


TABLE 1: DUAL IN LINE PIN SUMMARY

I/O	Pin	Analog	Comp.	Op Amps	PWM	Timers	CCP	Interrupt	Pull-ups	Basic
RA0	19	AN0	C1IN+	—	—	—	—	IOC	Y	ICSPDAT
RA1	18	AN1/VREF	C12IN0-	—	—	—	—	IOC	Y	ICSPCLK
RA2	17	AN2	C1OUT	—	—	T0CKI	—	INT/IOC	Y	—
RA3[1]	4	—	—	—	—	—	—	IOC	Y	MCLR/VPP
RA4	3	AN3	—	—	—	T1G	—	IOC	Y	OSC2/CLKOUT
RA5	2	—	—	—	—	T1CKI	—	IOC	Y	OSC1/CLKIN
RB4	13	AN10	—	OP2-	—	—	—	—	—	—
RB5	12	AN11	—	OP2+	—	—	—	—	—	—
RB6[2]	11	—	—	—	—	—	—	—	—	—
RB7	10	—	—	—	SYNC	—	—	—	—	—
RC0	16	AN4	C2IN+	—	—	—	—	—	—	—
RC1	15	AN5	C12IN1-	—	PH1	—	—	—	—	—
RC2	14	AN6	C12IN2-	OP2	—	—	—	—	—	—
RC3	7	AN7	C12IN3-	OP1	—	—	—	—	—	—
RC4	6	—	C2OUT	—	PH2	—	—	—	—	—
RC5	5	—	—	—	—	—	CCP1	—	—	—
RC6	8	AN8	—	OP1-	—	—	—	—	—	—
RC7	9	AN9	—	OP1+	—	—	—	—	—	—
—	1	—	—	—	—	—	—	—	—	VDD
—	20	—	—	—	—	—	—	—	—	VSS

Note 1: Input only.

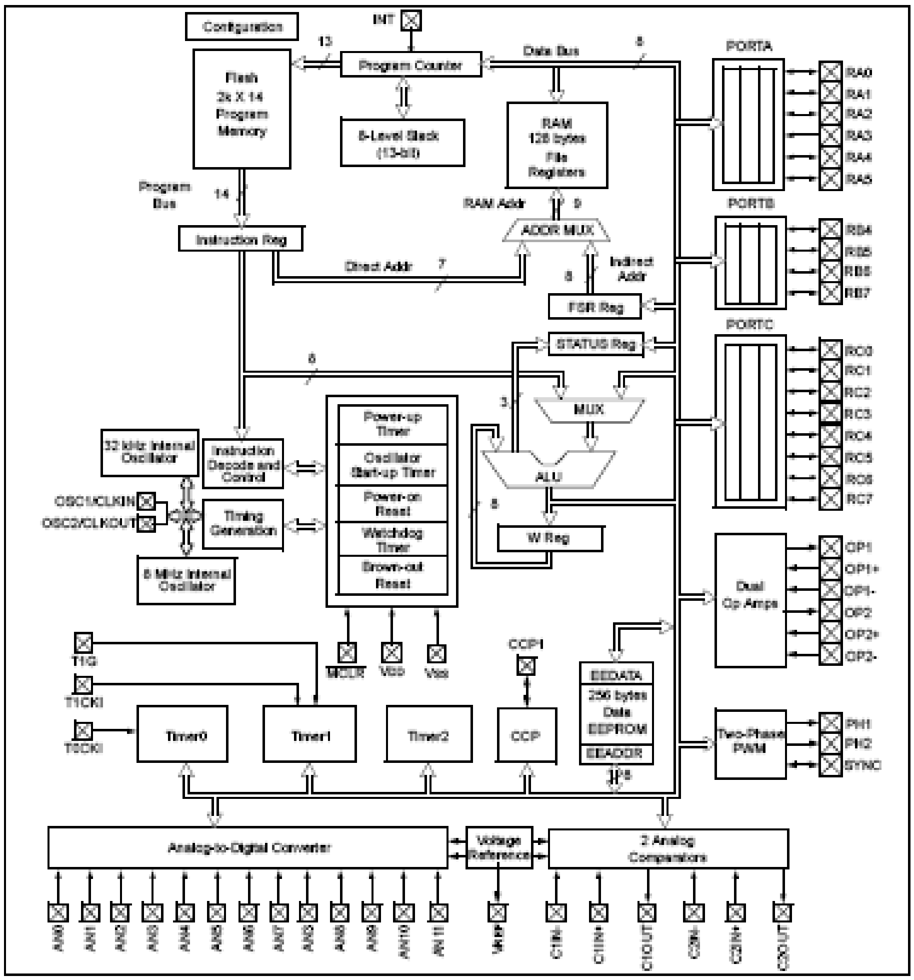
2: Open drain.

1.0 DEVICE OVERVIEW

This document contains device specific information for the PIC16F785/HV785. Additional information may be found in the "*PICmicro® Mid-Range MCU Family Reference Manual*" (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip web site. The Reference Manual should be considered a complementary document to this Data Sheet and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

The PIC16F785/HV785 is covered by this Data Sheet. It is available in 20-pin PDIP, SOIC, SSOP and QFN packages. Figure 1-1 shows a block diagram of the PIC16F785/HV785 device. Table 1-1 shows the pinout description.

FIGURE 1-1: PIC16F785/HV785 BLOCK DIAGRAM



PIC16F785/HV785

TABLE 1-1: PIC16F785/HV785 PINOUT DESCRIPTION

Name	Function	Input Type	Output Type	Description
RA0/AN0/C1IN+/ICSPDAT	RA0	TTL	CMOS	PORTA I/O with prog. pull-up and interrupt-on-change
	AN0	AN	—	A/D Channel 0 input
	C1IN+	AN	—	Comparator 1 non-inverting input
	ICSPDAT	ST	CMOS	Serial Programming Data I/O
RA1/AN1/C12IN0-/VREF/ ICSPCLK	RA1	TTL	CMOS	PORTA I/O with prog. pull-up and interrupt-on-change
	AN1	AN	—	A/D Channel 1 input
	C12IN0-	AN	—	Comparator 1 and 2 inverting input
	VREF	AN	AN	External Voltage Reference for A/D, buffered reference output
	ICSPCLK	ST	—	Serial Programming Clock
RA2/AN2/T0CKI/INT/C1OUT	RA2	ST	CMOS	PORTA I/O with prog. pull-up and interrupt-on-change
	AN2	AN	—	A/D Channel 2 input
	T0CKI	ST	—	Timer0 clock input
	INT	ST	—	External interrupt
	C1OUT	—	CMOS	Comparator 1 output
RA3/MCLR/Vpp	RA3	TTL	—	PORTA input with prog. pull-up and interrupt-on-change
	MCLR	ST	—	Master Clear with internal pull-up
	VPP	HV	—	Programming voltage
RA4/AN3/T1G/OSC2/ CLKOUT	RA4	TTL	CMOS	PORTA I/O with prog. pull-up and interrupt-on-change
	AN3	AN	—	A/D Channel 3 input
	T1G	ST	—	Timer1 gate
	OSC2	—	XTAL	Crystal/Resonator
	CLKOUT	—	CMOS	FOSC/4 output
RA5/T1CKI/OSC1/CLKIN	RA5	TTL	CMOS	PORTA I/O with prog. pull-up and interrupt-on-change
	T1CKI	ST	—	Timer1 clock
	OSC1	XTAL	—	Crystal/Resonator
	CLKIN	ST	—	External clock input/RC oscillator connection
RB4/AN10/OP2-	RB4	TTL	CMOS	PORTB I/O
	AN10	AN	—	A/D Channel 10 input
	OP2-	—	AN	Op Amp 2 inverting input
RB5/AN11/OP2+	RB5	TTL	CMOS	PORTB I/O
	AN11	AN	—	A/D Channel 11 input
	OP2+	—	AN	Op Amp 2 non-inverting input
RB6	RB6	TTL	OD	PORTB I/O. Open drain output
RB7/SYNC	RB7	TTL	CMOS	PORTB I/O
	SYNC	ST	CMOS	Master PWM Sync output or slave PWM Sync input
RC0/AN4/C2IN+	RC0	TTL	CMOS	PORTC I/O
	AN4	AN	—	A/D Channel 4 input
	C2IN+	AN	—	Comparator 2 non-inverting input

Legend: TTL = TTL input buffer, ST = Schmitt Trigger input buffer, AN = Analog, OD = Open Drain output, HV = High Voltage

2.3 PCL and PCLATH

The Program Counter (PC) specifies the address of the instruction to fetch for execution. The program counter is 13 bits wide. The low byte is called the PCL register. The PCL register is readable and writable. The high byte of the PC (PC<12:8>) is called the PCH register. This register contains PC<12:8> bits which are not directly readable or writable. All updates to the PCH register goes through the PCLATH register.

On any Reset, the PC is cleared. Figure 2-3 shows the two situations for loading the PC. The upper example of Figure 2-3 shows how the PC is loaded on a write to PCL (PCLATH<4:0> → PCH). The lower example of Figure 2-3 shows how the PC is loaded during a CALL or GOTO instruction (PCLATH<4:3> → PCH).

2.3.1 MODIFYING PCL

Executing any instruction with the PCL register as the destination simultaneously causes the Program Counter PC<12:8> bits (PCH) to be replaced by the contents of the PCLATH register. This allows the entire contents of the program counter to be changed by writing the desired upper 5 bits to the PCLATH register. When the lower 8 bits are written to the PCL register, all 13 bits of the program counter will change to the values contained in the PCLATH register and those being written to the PCL register.

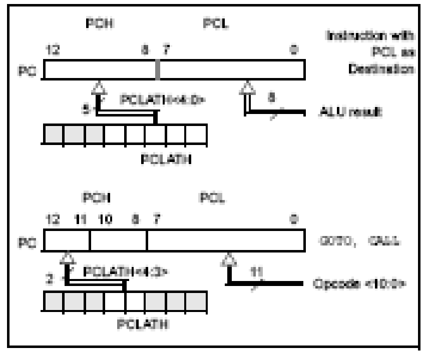
A computed GOTO is accomplished by adding an offset to the program counter (ADDWF PCL). Care should be exercised when jumping into a look-up table or program branch table (computed GOTO) by modifying the PCL register. Assuming that PCLATH is set to the table start address, if the table length is greater than 255 instructions or if the lower 8 bits of the memory address rolls over from 0xFF to 0x00 in the middle of the table, then PCLATH must be incremented for each address rollover that occurs between the table beginning and the target location within the table.

For more information refer to Application Note AN556, "*Implementing a Table Read*" (DS00556).

2.3.2 PROGRAM MEMORY PAGING

The CALL and GOTO instructions provide 11 bits of address to allow branching within any 2K program memory page. When using a CALL or GOTO instruction, the Most Significant bits of the address are provided by PCLATH<4:3> (page select bits). When using a CALL or GOTO instruction, the user must ensure that the page select bits are programmed so that the desired destination program memory page is addressed. When the CALL instruction (or interrupt) is executed, the entire 13-bit PC return address is PUSHed onto the stack. Therefore, manipulation of the PCLATH<3> bit is not required for the RETURN or RETFIE instructions (which POPs the address from the stack).

FIGURE 2-3: LOADING OF PC IN DIFFERENT SITUATIONS



2.3.3 STACK

The PIC16F785/HV785 family has an 8-level deep x 13-bit wide hardware stack (see Figure 2-1). The stack space is not part of either program or data space and the Stack Pointer is not readable or writable. The PC is PUSHed onto the stack when a CALL instruction is executed or an interrupt causes a branch. The stack is POPed in the event of a RETURN, RETLW or RETFIE instruction execution. PCLATH is not affected by a PUSH or POP operation.

The stack operates as a circular buffer. This means that after the stack has been PUSHed eight times, the ninth PUSH overwrites the value that was stored from the first PUSH. The tenth PUSH overwrites the second PUSH (and so on).

Note 1:	There are no Status bits to indicate stack overflow or stack underflow conditions.
2:	There are no instructions/mnemonics called PUSH or POP. These are actions that occur from the execution of the CALL, RETURN, RETLW and RETFIE instructions or the vectoring to an interrupt address.

3.0 CLOCK SOURCES

3.1 Overview

The PIC16F785/HV785 has a wide variety of clock sources and selection features to allow it to be used in a wide range of applications while maximizing performance and minimizing power consumption. Figure 3-1 illustrates a block diagram of the PIC16F785/HV785 clock sources.

Clock sources can be configured from external oscillators, quartz crystal resonators, ceramic resonators and Resistor-Capacitor (RC) circuits. In addition, the system clock source can be configured from one of two internal oscillators, with a choice of speeds selectable via software. Additional clock features include:

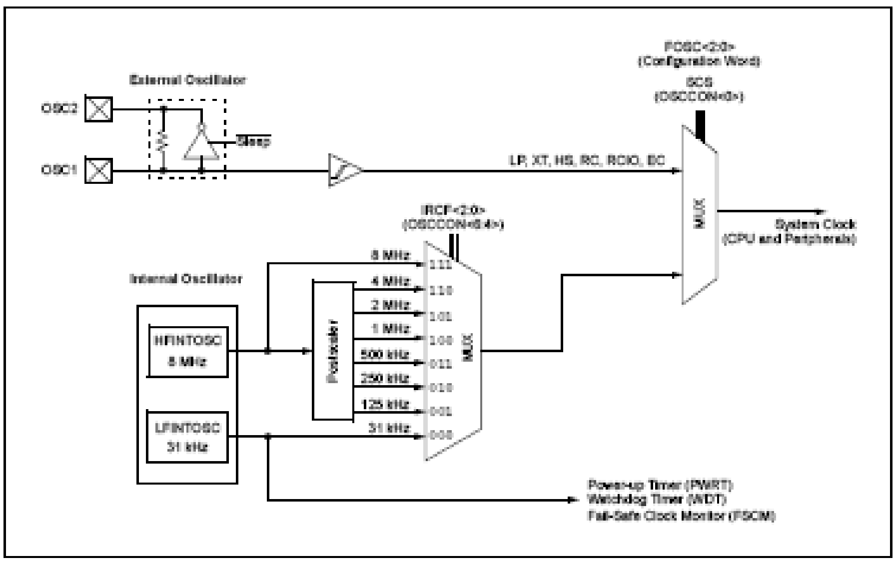
- Selectable system clock source between external or internal via software.
- Two-Speed Clock Start-up mode, which minimizes latency between external oscillator start-up and code execution.
- Fail-Safe Clock Monitor (FSCM) designed to detect a failure of the external clock source (LP, XT, HS, EC or RC modes) and switch to the internal oscillator.

The PIC16F785/HV785 can be configured in one of eight clock modes.

1. EC – External clock with I/O on RA4.
2. LP – 32.768 kHz Watch Crystal or Ceramic Resonator Oscillator mode.
3. XT – Medium Gain Crystal or Ceramic Resonator Oscillator mode.
4. HS – High Gain Crystal or Ceramic Resonator mode.
5. RC – External Resistor-Capacitor (RC) with FOSC/4 output on RA4
6. RCIO – External Resistor-Capacitor with I/O on RA4.
7. INTOSC – Internal Oscillator with FOSC/4 output on RA4 and I/O on RA5.
8. INTOSCIO – Internal Oscillator with I/O on RA4 and RA5.

Clock Source modes are configured by the FOSC<2:0> bits in the Configuration Word (see **Section 15.0 "Special Features of the CPU"**). Once the PIC16F785/HV785 is programmed and the Clock Source mode configured, it cannot be changed in the software.

FIGURE 3-1: PIC16F785/HV785 CLOCK SOURCE BLOCK DIAGRAM



3.2 Clock Source Modes

Clock Source modes can be classified as external or internal.

- External Clock modes rely on external circuitry for the clock source. Examples are oscillator modules (EC mode), quartz crystal resonators or ceramic resonators (LP, XT, and HS modes) and resistor-capacitor (RC mode) circuits.
- Internal clock sources are contained internally within the PIC16F785/HV785. The PIC16F785/HV785 has two internal oscillators; the 8 MHz High-frequency Internal Oscillator (HFINTOSC) and 31 kHz Low-frequency Internal Oscillator (LFINTOSC).

The system clock can be selected between external or internal clock sources via the System Clock Selection (SCS) bit (see **Section 3.5 "Clock Switching"**).

3.3 External Clock Modes

3.3.1 OSCILLATOR START-UP TIMER (OST)

When the PIC16F785/HV785 is configured for any of the Crystal Oscillator modes (LP, XT or HS), the Oscillator Start-up Timer (OST) is enabled, which extends the Reset period to allow the oscillator additional time to stabilize. The OST counts 1024 clock periods present on the OSC1 pin following a Power-on Reset (POR), a wake from Sleep, or when the Power-up Timer (PWRT) has expired (if the PWRT is enabled). During this time, the program counter does not increment and program execution is suspended. The OST ensures that the oscillator circuit, using a quartz crystal resonator or ceramic resonator, has started and is providing a stable system clock to the PIC16F785/HV785. Table 3-1 shows examples where the oscillator delay is invoked.

In order to minimize latency between external oscillator start-up and code execution, the Two-Speed Clock Start-up mode can be selected (see **Section 3.6 "Two-Speed Clock Start-up Mode"**).

TABLE 3-1: OSCILLATOR DELAY EXAMPLES

Switch From	Switch To	Frequency	Oscillator Delay	Comments
Sleep/POR	INTRC INTOSC	31 kHz 125 kHz-8 MHz	5 µs-10 µs (approx.) CPU Start-up(1)	Following a wake-up from Sleep mode or POR, CPU start-up is invoked to allow the CPU to become ready for code execution.
Sleep	EC, RC	DC – 20 MHz		
LFINTOSC (31 kHz)	EC, RC	DC – 20 MHz		
Sleep/POR	LP, XT, HS	31 kHz-20 MHz	1024 Clock Cycles (OST)	
LFINTOSC (31 kHz)	INTOSC	125 kHz-8 MHz	1 µs (approx.)	

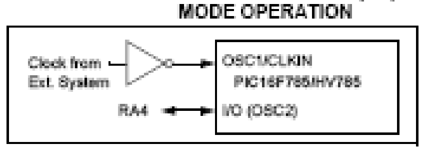
Note 1: The 5 µs-10 µs start-up delay is based on a 1 MHz System Clock.

3.3.2 EC MODE

The External Clock (EC) mode allows an externally generated logic level as the system clock source. When operating in this mode, an external clock source is connected to OSC1 pin and the RA4 pin is available for general purpose I/O. Figure 3-2 shows the pin connections for EC mode.

The Oscillator Start-up Timer (OST) is disabled when EC mode is selected. Therefore, there is no delay in operation after a Power-on Reset (POR) or wake-up from Sleep. Because the PIC16F785/HV785 design is fully static, stopping the external clock input will have the effect of halting the device while leaving all data intact. Upon restarting the external clock, the device will resume operation as if no time had elapsed.

FIGURE 3-2: EXTERNAL CLOCK (EC) MODE OPERATION



4.3 PORTB and TRISB Registers

PORTB is a 4-bit wide, bidirectional port. The corresponding data direction register is TRISB (Register 4-6). Setting a TRISB bit (= 1) will make the corresponding PORTB pin an input (i.e., put the corresponding output driver in a High-impedance mode). Clearing a TRISB bit (= 0) will make the corresponding PORTB pin an output (i.e., put the contents of the output latch on the selected pin). Example 4-2 shows how to initialize PORTB.

Reading the PORTB register (Register 4-5) reads the status of the pins, whereas writing to it will write to the port latch. All write operations are read-modify-write operations. Therefore, a write to a port implies that the port pins are read, this value is modified and then written to the port data latch.

Pin RB6 is an open drain output. All other PORTB pins have full CMOS output drivers.

The TRISB register controls the direction of the PORTB pins, even when they are being used as analog inputs. The user must ensure the bits in the TRISB register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'.

> **Note:** The ANSEL1 (93h) register must be initialized to configure an analog channel as a digital input. Pins configured as analog inputs will read '0'.

EXAMPLE 4-2: INITIALIZING PORTB

```
BCF     STATUS,RP0    ;Bank 0
BCF     STATUS,RP1    ;
CLRF    PORTB         ;Init PORTB
BSF     STATUS,RP0    ;Bank 1
BCF     ANSEL1,2      ;digital I/O - RB4
BCF     ANSEL1,3      ;digital I/O - RB5
MOVLW   30h           ;Set RB<5,4> as inputs
MOVWF   TRISB         ;and set RB<7,6>
                      ;as outputs
BCF     STATUS,RP0    ;Bank 0
```

REGISTER 4-5: PORTB: PORTB REGISTER (ADDRESS: 06h, 106h)

R/W-x	R/W-x	R/W-x(1)	R/W-x(1)	U-0	U-0	U-0	U-0
RB7	RB6	RB5	RB4	—	—	—	—
bit 7							bit 0

bit 7-4 **RB<7:4>**: PORTB General Purpose I/O Pin bits
1 = Port pin is greater than V_{IH}
0 = Port pin is less than V_{IL}

bit 3-0 **Unimplemented**: Read as '0'

Note 1: Data latches are unknown after a POR, but each port bit reads '0' when the corresponding analog select bit is '1' (see Register 12-2 on page 82).

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

REGISTER 4-6: TRISB: PORTB TRI-STATE REGISTER (ADDRESS: 86h, 186h)

R/W-1	R/W-1	R/W-1	R/W-1	U-0	U-0	U-0	U-0
TRISB7	TRISB6	TRISB5	TRISB4	—	—	—	—
bit 7							bit 0

bit 7-4 **TRISB<7:4>**: PORTB Tri-State Control bits
1 = PORTB pin configured as an input (tri-stated)
0 = PORTB pin configured as an output

bit 3-0 **Unimplemented**: Read as '0'

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

4.4 PORTC and TRISC Registers

PORTC is an 8-bit wide, bidirectional port. The corresponding data direction register is TRISC (Register 4-8). Setting a TRISC bit (= 1) will make the corresponding PORTC pin an input (i.e., put the corresponding output driver in a High-impedance mode). Clearing a TRISC bit (= 0) will make the corresponding PORTC pin an output (i.e., put the contents of the output latch on the selected pin). Example 4-3 shows how to initialize PORTC.

Reading the PORTC register (Register 4-7) reads the status of the pins, whereas writing to it will write to the port latch. All write operations are read-modify-write operations. Therefore, a write to a port implies that the port pins are read, this value is modified and then written to the port data latch.

The TRISC register controls the direction of the PORTC pins, even when they are being used as analog inputs. The user must ensure the bits in the TRISC register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'.

When RC4 or RC5 is configured as an op amp output, the corresponding RC4 or RC5 digital output driver will automatically be disabled regardless of the TRISC<4> or TRISC<5> value.

> **Note:** The ANSEL0 (91h) and ANSEL1 (93h) registers must be initialized to configure an analog channel as a digital input. Pins configured as analog inputs will read '0'.

EXAMPLE 4-3: INITIALIZING PORTC

```
BCF    STATUS,RP0    ;Bank 0
BCF    STATUS,RP1
CLRF   PORTC         ;Init PORTC
BSF    STATUS,RP0    ;Bank 1
CLRF   ANSEL0        ;digital I/O
CLRF   ANSEL1        ;digital I/O
MOVLW  0Ch           ;Set RC<3,2> as inputs
MOVWF  TRISC         ; and set RC<5,4,1,0>
                     ; as outputs
BCF    STATUS,RP0    ;Bank 0
```

REGISTER 4-7: PORTC: PORTC REGISTER (ADDRESS: 07h, 107h)

R/W-x[1]	R/W-x[1]	R/W-x	R/W-x	R/W-x[1]	R/W-x[1]	R/W-x[1]	R/W-x[1]
RC7	RC6	RC5	RC4	RC3	RC2	RC1	RC0
bit 7							bit 0

bit 7-0 **RC<7:0>**: PORTC General Purpose I/O Pin bits
1 = Port pin is greater than V_{IH}
0 = Port pin is less than V_{IL}

Note 1: Data latches are unknown after a POR, but each port bit reads '0' when the corresponding analog select bit is '1' (see Registers 12-1 and 12-2 on page 82).

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

REGISTER 4-8: TRISC: PORTC TRI-STATE REGISTER (ADDRESS: 87h, 187h)

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
TRISC7	TRISC6	TRISC5	TRISC4	TRISC3	TRISC2	TRISC1	TRISC0
bit 7							bit 0

bit 7-0 **TRISC<7:0>**: PORTC Tri-State Control bits
1 = PORTC pin configured as an input (tri-stated)
0 = PORTC pin configured as an output

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

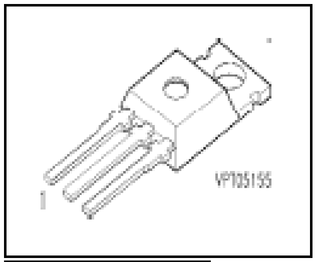
APPENDIX E

MOSFET BUZ73 Datasheet:

SIPMOS ® Power Transistor

BUZ 73

- N channel
- Enhancement mode
- Avalanche-rated
- Pb-free lead plating; RoHS compliant



Pin 1	Pin 2	Pin 3
G	D	S

Type	V_{DS}	I_D	$R_{DS(on)}$	Package	Ordering Code
BUZ 73	200 V	7 A	0.4 Ω	PG-TO-220 AB	C67078-S1317-A2

Maximum Ratings

Parameter	Symbol	Values	Unit
Continuous drain current T_C = 28 °C	I_D	7	A
Pulsed drain current T_C = 25 °C	I_{Dpuls}	28	
Avalanche current,limited by T_{jmax}	I_{AR}	7	
Avalanche energy,periodic limited by T_{jmax}	E_{AR}	6.5	mJ
Avalanche energy, single pulse I_D = 7 A, V_{DD} = 50 V, R_{GS} = 25 Ω L = 3.67 mH, T_j = 25 °C	E_{AS}	120	
Gate source voltage	V_{GS}	± 20	V
Power dissipation T_C = 25 °C	P_{tot}	40	W
Operating temperature	T_j	-55 ... + 150	°C
Storage temperature	T_{stg}	-55 ... + 150	
Thermal resistance, chip case	R_{thJC}	≤ 3.1	K/W
Thermal resistance, chip to ambient	R_{thJA}	75	
DIN humidity category, DIN 40 040		E	
IEC climatic category, DIN IEC 68-1		55 / 150 / 56	

Electrical Characteristics, at T_j = 25°C, unless otherwise specified

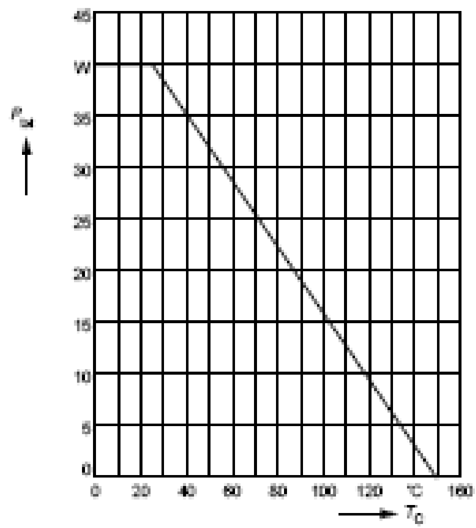
Parameter	Symbol	Values			Unit
		min.	typ.	max.	
Static Characteristics					
Drain- source breakdown voltage V_{GS} = 0 V, I_D = 0.25 mA, T_j = 25 °C	$V_{(BR)DSS}$	200	-	-	V
Gate threshold voltage V_{GS}=$V_{DS,}$ I_D = 1 mA	$V_{GS(th)}$	2.1	3	4	
Zero gate voltage drain current V_{DS} = 200 V, V_{GS} = 0 V, T_j = 25 °C V_{DS} = 200 V, V_{GS} = 0 V, T_j = 125 °C	I_{DSS}	- -	0.1 10	1 100	µA
Gate-source leakage current V_{GS} = 20 V, V_{DS} = 0 V	I_{GSS}	-	10	100	nA
Drain-Source on-resistance V_{GS} = 10 V, I_D = 4.5 A	$R_{DS(on)}$	-	0.3	0.4	Ω

Electrical Characteristics, at T_j = 25°C, unless otherwise specified

Parameter	Symbol	Values			Unit
		min.	typ.	max.	
Dynamic Characteristics					
Transconductance $V_{DS} \geq 2 \cdot I_D \cdot R_{DS(on)max}$, I_D = 4.5 A	g_{fs}	3	4.2	-	S
Input capacitance V_{GS} = 0 V, V_{DS} = 25 V, f = 1 MHz	C_{iss}	-	400	530	pF
Output capacitance V_{GS} = 0 V, V_{DS} = 25 V, f = 1 MHz	C_{oss}	-	85	130	
Reverse transfer capacitance V_{GS} = 0 V, V_{DS} = 25 V, f = 1 MHz	C_{rss}	-	45	70	
Turn-on delay time V_{DD} = 30 V, V_{GS} = 10 V, I_D = 3 A R_{GS} = 50 Ω	$t_{d(on)}$	-	10	15	ns
Rise time V_{DD} = 30 V, V_{GS} = 10 V, I_D = 3 A R_{GS} = 50 Ω	t_r	-	40	60	
Turn-off delay time V_{DD} = 30 V, V_{GS} = 10 V, I_D = 3 A R_{GS} = 50 Ω	$t_{d(off)}$	-	55	75	
Fall time V_{DD} = 30 V, V_{GS} = 10 V, I_D = 3 A R_{GS} = 50 Ω	t_f	-	30	40	

Power dissipation

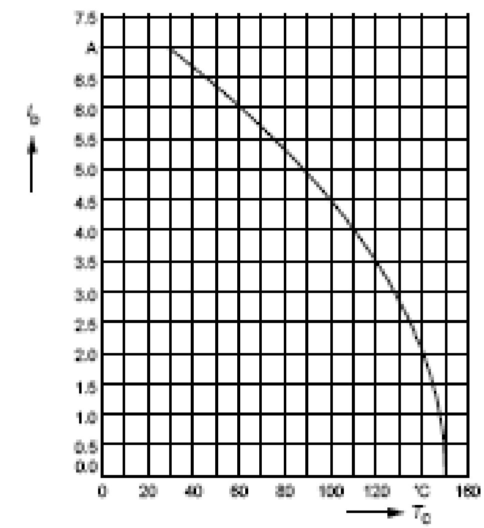
$P_{tot} = f(T_C)$



Drain current

$I_D = f(T_C)$

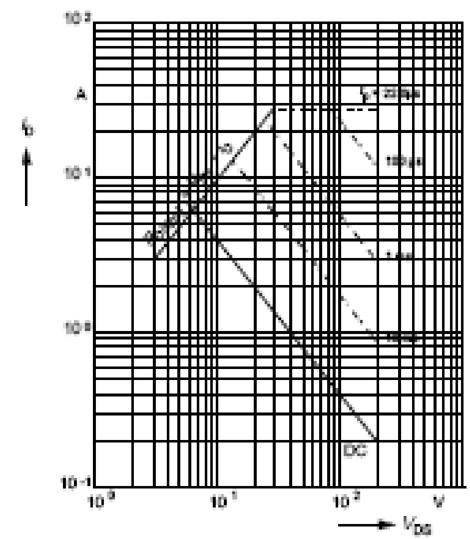
parameter: $V_{GS} \geq 10$ V



Safe operating area

$I_D = f(V_{DS})$

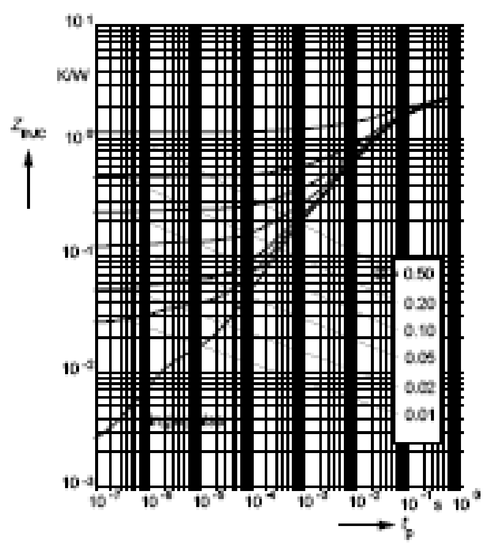
parameter: $D = 0.01$, $T_C = 25$°C



Transient thermal impedance

$Z_{th\ JC} = f(t_p)$

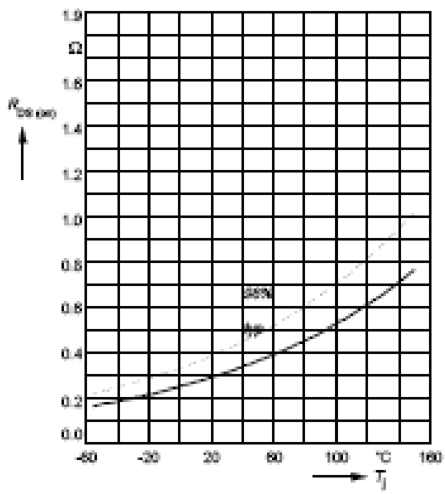
parameter: $D = t_p / T$



Drain-source on-resistance

$R_{DS\,(on)} = f(T_j)$

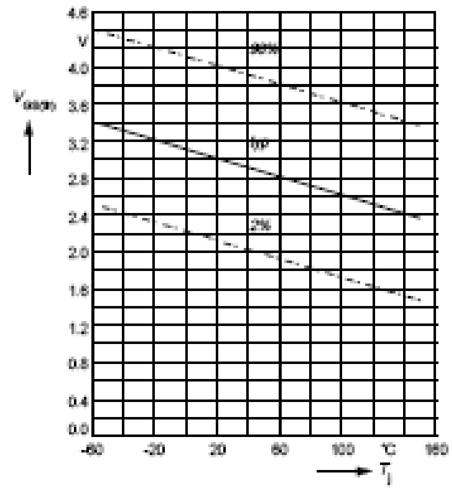
parameter: I_D = 4.5 A, V_{GS} = 10 V



Gate threshold voltage

$V_{GS\,(th)} = f(T_j)$

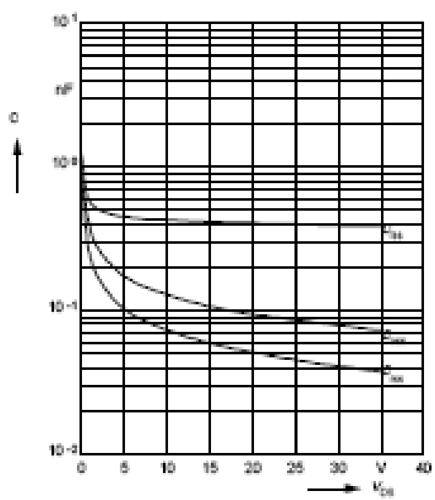
parameter: V_{GS} = V_{DS}, I_D = 1 mA



Typ. capacitances

$C = f(V_{DS})$

parameter: V_{GS} = 0V, f = 1MHz



Forward characteristics of reverse diode

$I_F = f(V_{SD})$

parameter: T_j, t_p = 80 µs