PHOTOVOLTAIC CHARGE CONTROLLER

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor Degree of Electrical Engineering (Electronics)

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MAY, 2009

"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Electronics)"

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Signature : ______________________________

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Date : 4 MAY 2009

Specially dedicated to my beloved family

To My Beloved Mother and Dad, My Lovely Sisters & My Sweet Brothers

Mohd Bin Tahar
Wan Kembang Binti Wan Ngah

Dzul Fadli Bin Mohd
Dzul Awatif Bin Mohd
Noor Syafiqa Amira Bt. Mohd
Dzul Haziq Bin Mohd
Noor Huwaida Adeeba Bt. Mohd
Muhammad Aqif Ikhwan Bin Mohd

And those people who have guided and inspired me throughout my journey of education

Thanks for everything…

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my supervisor, Mr Mohd Shawal Bin Jadin, for encouragement, guidance, critics, friendship, advice, information and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Malaysia Pahang (UMP) for funding my degree study. Librarians at UMP also deserve special thanks for their assistance in supplying the relevant literatures and guiding me in using e-journal.

My sincere appreciation also extends to all my colleagues, and others who have provided assistance at various occasions especially to Marliyani bte Omar. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members especially my mother and dad for their moral support, advice and understanding me.

Thank you.

Noor Juwaina Ayuni Bt. Mohd

ABSTRACT

Photovoltaic or in short term PV is one of the renewable energy resources that recently has become broader in nowadays technology. The demand or future work is looking for high efficiency, more reliable and economical price PV charge controller which is come in portable size has become very popular in PV system. In general, PV system consists of a PV array, charge controller, rechargeable battery and dc load. PV charge controller is very important in PV system. In this project, a PV Charge Controller is designed based on microcontroller (PIC 16F877A) which reduced complexity in the number of electronic components and increased monitoring and regulative functions. This project used dc-dc buck converter circuit which has been simulated using software of OrCAD PSPICE. Pulse width modulation (PWM) will be implemented on a PIC 16F877A to control duty cycle, voltage and current in the PV system and is programmed using software of Microcode Studio. Liquid Crystal Display (LCD) is used to display the voltage and current from rechargeable battery. The benefit of this project is an improvement of efficiency depend on duty cycle and voltage change.

ABSTRAK

Voltan cahaya atau singkatannya PV adalah salah satu daripada sumber tenaga yang dapat diperbaharui yang baru-baru ini menjadi semakin meluas dalam teknologi pada masa kini. Permintaan atau projek di masa hadapan bagi pengawal cas elektrik PV adalah dalam keluaran yang lebih efisien, boleh dipercayai kegunaannya dan harga yang berpatutan dalam bentuk yang mudah dibawa semakin popular dalam sistem PV. Secara umumnya, sistem PV mengandungi susunan PV, pengawal cas elektrik, bateri cas semula dan beban arus elektrik terus. Pengawal tenaga elektrik sangat berguna dalam system PV. Di dalam projek ini, pengawal cas elektrik photovoltaic direka berdasarkan pengawal terbenam (PIC 16F877A) di mana ia mengurangkan kekompleksan dalam penggunaan jumlah komponen elektronik dan meningkatkan pengawasan dan fungsi pengaturan. Projek ini menggunakan litar *"dc-dc buck converter"* yang telah dihasilkan menggunakan perisian *"OrCAD PSPICE"*. Nadi keluasan modulasi (PWM) akan dilaksanakan menggunakan PIC 16F877A untuk mengawasi kitaran duti, voltan dan arus aliran elekrik dalam system photovoltaic dan seterusnya diprogramkan menggunakan perisian *"MicroCode Studio"*. Paparan cecair Kristal (LCD) pula digunakan untuk mempamerkan bacaan voltan dan arus aliran elektrik daripada bateri caj semula. Kelebihan projek ini adalah peningkatan kecekapan yang bergantung kepada kitaran duti dan perubahan voltan.

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LIST OF SYMBOLS

D	Duty Cycle
f	Frequency
V	Voltage/Potential difference
L	Inductance
R	Resistance
C	Capacitance
I	Current
T	Time

LIST OF ABBREVIATIONS

D.C.	Direct Current
ADC	Analog to Digital converter
PWM	Pulse Width Modulation
PV	Photovoltaic
IC	Integrated Circuit
ICD	Circuit Debugging
IDE	Integrated Development Environmental
LCD	Liquid Crystal Display
DIP	Dual Inline Package
L.E.D	Light Emitting Diode
PIC	Programmable Interface Controller
RISC	Reduced Instruction Set Computing
OSC	Oscillation
ESR	Equivalent Series Resistance
CCM	Continues Current Mode

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Photovoltaic or in short term PV is one of the renewable energy resources that recently has become broader in nowadays technology. PV has many benefits especially in environmental, economic and social. In general, a PV system consists of a PV array which converts sunlight to direct-current electricity, a control system which regulates battery charging and operation of the load, energy storage in the form of secondary batteries and loads or appliances. A charge controller is one of functional and reliable major components in PV systems. A good, solid and reliable PV charge controller is a key component of any PV battery charging system to achieve low cost and the benefit that user can get from it. The main function of a charge controller in a PV system is to regulate the voltage and current from PV solar panels into a rechargeable battery. The minimum function of a PV charge controller is to disconnect the array when the battery is fully charged and keep the battery fully charged without damage. A charge controller is important to prevent battery overcharging, excessive discharging, reverse current flow at night and to protect the life of the batteries in a PV system. A power electronics circuit is used in a PV charge controller to get highest efficiency, availability and reliability. The use of power electronics circuits such as various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology as power conditioning circuitry to provide a desired current to charge battery effectively.

1.2 OBJECTIVES

(i) To design Photovoltaic (PV) Charge Controller by using PIC microcontroller type.

(ii) To monitor voltage and current as the input of the rechargeable battery and display on the Liquid Crystal Display (LCD).

1.3 SCOPE OF PROJECT

(i) The PV charge controller that designed in this project will be implement PIC microcontroller in it.

(ii) This project concentrates on DC-DC Converter.

(iii) This project will use PIC microcontroller to control the voltage and current at certain values that have been set which are act as input of the rechargeable battery and displays all the results of voltage, current, power and percentage remaining rechargeable battery on the LCD.

1.4 PROBLEM STATEMENT

Most of the PV charge controller nowadays just uses LED to indicate the operating status of the rechargeable battery. It is hard to know the values of the rechargeable battery that have been used such as voltage, current and others. Besides most of PV charge controller is expensive depends on the total cost of PV system that has been used.

1.5 THESIS OVERVIEW

This Photovoltaic Charge Controller final thesis is arranged into following chapter:

Chapter 1: Basically is an introduction of the project. In this chapter, provides the background of the project, objectives, scope of the project, problem statement, and also the thesis outline.

Chapter 2: Focuses on literature reviews of this project based on journals and other references.

Chapter 3: Mainly focused on methodologies for the development of Photovoltaic Charge Controller. Details on the progress of the project are explained in this chapter.

Chapter 4: Presents the results obtained and the limitation of the project. All discussions are concentrating on the result and performance of Photovoltaic Charge Controller.

Chapter 5: Concludes overall about the project. Obstacle faces and future recommendation are also discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Photovoltaic Charge Controller

A charge controller is needed in photovoltaic system to safely charge sealed lead acid battery. The most basic function of a charge controller is to prevent battery overcharging. If battery is allowed to routinely overcharge, their life expectancy will be dramatically reduced. A charge controller will sense the battery voltage, and reduce or stop the charging current when the voltage gets high enough. This is especially important with sealed lead acid battery where we cannot replace the water that is lost during overcharging. Unlike Wind or Hydro System charge controller, PV charge controller can open the circuit when the battery is full without any harm to the modules. Most PV charge controller simply opens or restricts the circuit between the battery and PV array when the voltage rises to a set point. Then, as the battery absorbs the excess electrons and voltage begins dropping, the controller will turn back on. Some charge controllers have these voltage points factory-preset and non adjustable, other controllers can be adjustable. [1]

2.2 Photovoltaic

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sun energy (sunlight or sun ultra violet radiation) directly into electricity. Due to the growing demand for clean sources of energy, the manufacture of solar cells and PV arrays has expanded dramatically in recent years.[2] PV production has been doubling every two years, increasing by an average of 48 percent each year since 2002, making it the world's fastest-growing energy technology.[3] At the end of 2008, according to preliminary data, cumulative global installations reached 15,200 megawatts.[4] PV is best known as a method for generating electric power by using solar cells packaged in PV modules, often electrically connected in multiples as solar PV arrays to convert energy from the sun into electricity. The term PV denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all PV devices are some type of photodiode. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. The first practical application of PV was to power orbiting satellites and other spacecraft, but today the majority of PV modules are used for grid connected power generation.

Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When more power is required than a single cell can deliver, cells are electrically connected together to form photovoltaic modules, or solar panels. A single module is enough to power an emergency telephone, but for a house or a power plant the modules must be arranged in arrays. Although the selling price of modules is still too high to compete with grid electricity in most places, significant financial incentives in Japan and then Germany and Italy triggered a huge growth in demand, followed quickly by production. Perhaps not unexpectedly, a significant market has emerged in off-grid locations for solar-power-charged storage-battery based solutions. These often provide the only electricity available. [5] The EPIA/Greenpeace Advanced Scenario shows that by the year 2030, PV systems could be generating approximately 1,864 GW of electricity around the world. This means that, assuming a serious commitment is made to energy efficiency, enough solar power would be produced globally in twenty-five years' time to satisfy the electricity needs of almost 14% of the world's population. [6]

2.3 DC-DC Converters

There are various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology are used in PV charge controller. Since solar panels are only capable of producing a DC voltage, the DC-DC converter becomes quite useful by providing the flexibility to adjust the DC voltage or current at any point in the circuit. DC-DC converters are often preferred in modern electronics since they are smaller, lightweight, provide a high quality output, and more efficient. [7]

2.3.1 Buck (Step-Down) Converter

Regarding this project, several reviews were made. One of the researches made is about buck converter topology which is one of many topologies that were used in PV charge controller development. A buck converter is called a step-down DC to DC converter because the output voltage is less than the input. 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. A buck converter can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating. Most buck converters are designed for continuous-current mode operation compared to the discontinuous-current mode operation. The continuous-current mode operation is characterized by inductor current remains positive throughout the switching period. Conversely, the discontinuous-current mode operation is characterized by inductor current returning to zero during each period. The Figure 2.1 shows the basic of buck converter topology circuit. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

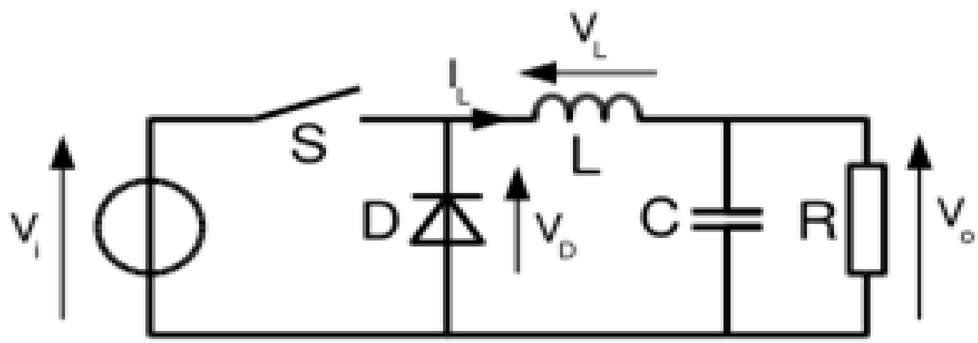

Figure 2.1: A basic buck converter topology circuit

2.3.2 Basic Operation of Buck Converter

<u>Method 1: During ON state</u>

Refer on Figure 2.2, when the switch is in ON state, diode become as reversed biased and the inductor will deliver current and switch conducts inductor current. With the voltage (Vin -Vo) across the inductor, the current rises linearly (current changes, ΔiL). The current through the inductor increase, as the source voltage would be greater then the output voltage and capacitor current may be in either direction depending on the inductor current and load current. When the current in inductor increase, the energy stored also increased. In this state, the inductor acquires energy. Capacitor will provides smooth out of inductor current changes into a stable voltage at output voltage and it's big enough such that V out doesn't change significantly during one switching cycle.

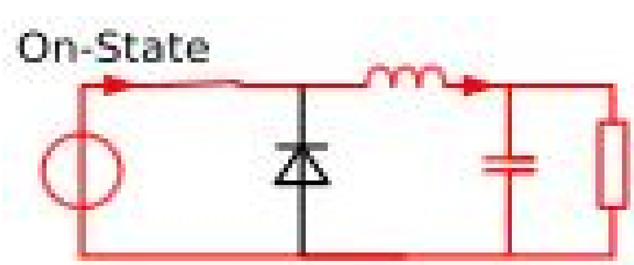

Figure 2.2: Equivalent circuit for switch closed

Method 2: During OFF state

As can see in Figure 2.3, when the switch is in OFF state, the diode is ON and the inductor will maintains current to load. Because of inductive energy storage, iL will continues to flow. While inductor releases current storage, it will flow to the load and provides voltage to the circuit. The diode is forward biased. The current flow through the diode which is inductor voltage is equal with negative output voltage.

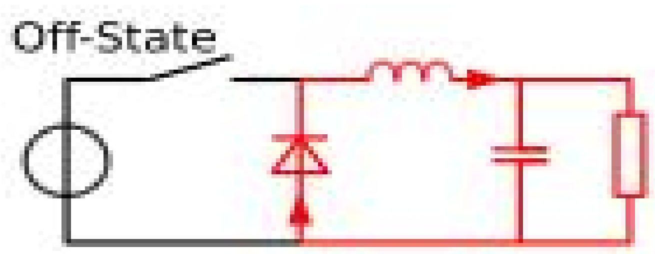

Figure 2.3: Equivalent circuit for switch open

2.4 PIC 16F877A Microcontroller

2.4.1 An overview

The **PIC** (Programmable Interface Controller) line of microcontrollers was originally developed by the semiconductor division of General Instruments Inc (Figure 2.2). The first PIC's were a major improvement over existing microcontroller because they were a programmable, high output current, input/output controller built around a RISC (Reduced Instruction Set Code) architecture. The first PICs ran efficiently at one instruction per internal clock cycle, and the clock cycle was derived from the oscillator divided by 4. Early PICs could run with a high oscillator frequency of 20 MHz. This made them relatively fast for an 8-bit microcontroller, but their main feature was 20 mA of source and sink current capability on each I/O (Input/Output) pin. Typical micros of the time were advertising high I/O currents of only 1 milliampere (mA) source and 1.6 mA sink. [8]

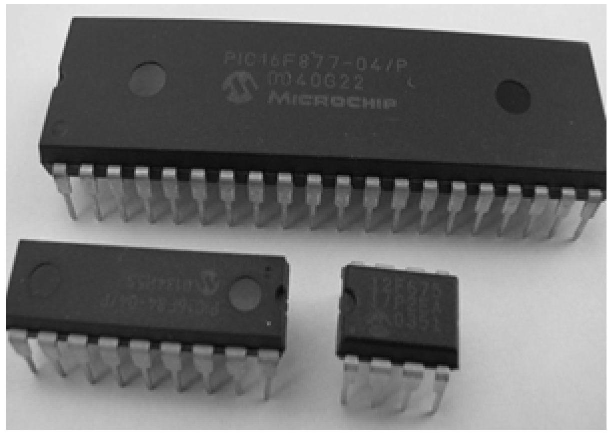

Figure 2.4: Types of PIC Microcontroller

2.4.2 PIC 16F877A Microcontroller Implementation

Regarding this project, several reviews were made. PIC 16F877A microcontroller is selected to monitor voltage and current in PV charge controller. PIC 16F877A is general purpose microprocessor which has additional parts that allow them to control external devices. Basically, a microcontroller executes a user program which is loaded in its program memory. PIC16F877A is a small piece of semiconductor integrated circuits (IC). The package type of these integrated circuits is DIP (Dual Inline Package) package. 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. PIC 16F877A include on-chip PWM units and has two which has a selectable on-time and period. The duty cycle is the ratio of the on-time to the period while the modulating frequency is the inverse of the period.

2.5 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) controls adjusts the duty ratio of the switches as the input changes to produce a constant output voltage. The DC voltage is converted to a square-wave signal, alternating between fully on and zero. By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. In nowadays implementation, many microcontrollers already include on-chip PWM controllers, making implementation easy. In a nutshell, PWM is a way of digitally encoding analog signal levels. PWM control can be used in two ways: voltage-mode and current-mode. In voltage-mode control the output voltage increases and decreases as the duty ratio increases and decreases. The output voltage is sensed and used for feedback. If it has two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach full charge. Then it will drop the voltage lower to sustain a "finish" or "trickle" charge. Two-stage regulating is important for a system that may experience many days or weeks of excess energy (or little use of energy). It maintains a full charge but minimizes water loss and stress. The voltages at which the controller changes the charge rate are called set points. When determining the ideal set points, there is some compromise between charging quickly before the sun goes down, and mildly overcharging the battery. The determination of set points depends on the anticipated pattern of use, the type of battery, and to some extent, the experience and philosophy of the system designer or operator. [9]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains about hardware development such as equipments, procedures and method design for the photovoltaic (PV) charge controller. The relevant information is gathered through literature review from previous chapter. This chapter also will cover about designing the buck converter, software interface, part by part circuits and complete circuit. Before looking at the details of all methods below, it is best to begin with brief review of the system design.

3.2 Hardware Development

3.2.1 System Design

The photovoltaic (PV) charge controller was designed to protect the rechargeable battery. To design this PV charge controller, it consists of seven parts where the first part is a buck converter circuit, second part is a microcontroller circuit, third part is a driver circuit, four part is rechargeable battery, five part is voltage sensor, six part is current sensor and seven part is liquid crystal display, LCD.

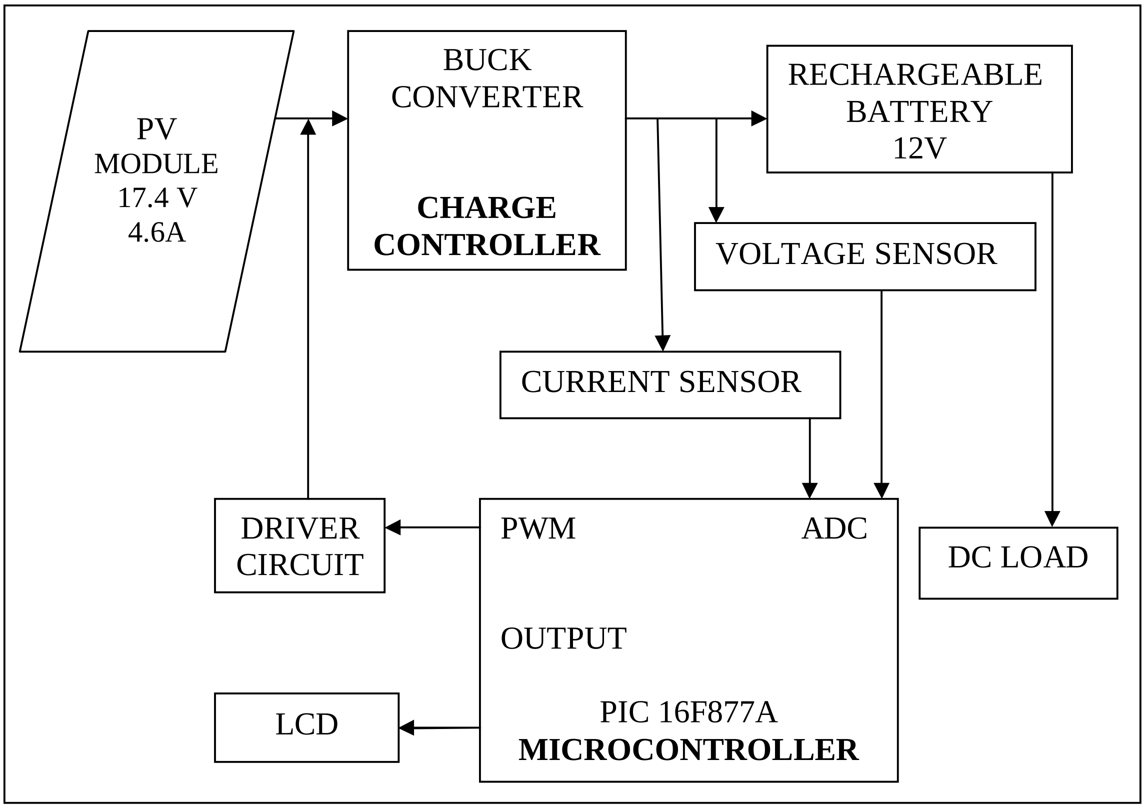

Figure 3.1: System design of Photovoltaic Charge Controller

3.2.2 Buck Converter Circuit Design

For the first part is a buck converter circuit, this circuit is needed in PV charge controller to control charging voltage from PV module to rechargeable battery. The circuit included parts of Buck components such as controllable switch (IRFP150N), diode (1N4148), inductor and capacitor, and load resistor. Some of the designs criteria as show as follow:

i. POWER MOSFET (IRFP150N)

As illustrate in Figure 3.2, this power MOSFET has limitations operation in terms of voltage, current and power dissipation. The power absorbed by the gate drive circuitry should not significantly affect the overall efficiency. The power MOSFET current rating is related with the heat dissipated in the devices. This rating will be take in consideration for designing appropriate circuit to protect power MOSFET against high voltage and current, thus cause heat generation. While considering protection of power MOSFET against over voltage, a distinction has to be made between slowly varying over voltage and short time surge. It is about 100Vdc the minimum rating of drain to source breakdown voltage. Gate voltage must be 15-20V higher than the drain voltage. Being a high side switch, such gate voltage would have to be higher than the rail voltage, which is frequently the higher voltage available in the system. Refer APPENDIX D for details specification. The datasheet provided by manufacturers are given in order to ensure the devices neither connected in the specified limits nor exceeded.

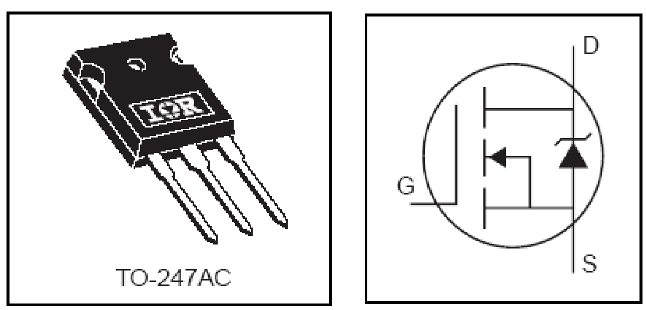

Figure 3.2: IRFP50N terminal pin configuration

ii. Capacitor

Except refer to capacitor value and rating of voltage use in system, the capacitor also supposed to be choose with minimum loss because switched power regulators are usually used in high current-performance power supplies. Loss occurs because of its internal series resistance and inductance. Commonly capacitors for switched regulators are chosen based on the equivalent series resistance (ESR).

iii. Inductor

The function on inductor is to store energy and the value is selected to maintain a continuous current mode (CCM) operation as a rated of load (5.6 Ω) is decided for this Buck converter. In CCM, current flow continuously in inductor during the entire switching cycle and output inductance selected to limit the peak to peak ripple current flowing. The factors to be considered in selecting the inductor are its peak to peak ripple current (CCM), maximum dc or peak current (not overheat) and maximum operating frequency (maximum core loss is not exceeded, resulting in overheating or saturation).

Design of buck converter circuit will consider as continuous current operation mode, CCM. The choice of switching frequency and inductance will affect the continuous current in buck converter design. Just for simple overview about buck converter, as the switching frequency increase, it can reduce the size of inductor in order to produce CCM and reduce capacitor size to limit output ripple in buck converter design.

Here the calculations method and formulas used in order to determine the values of the required components in Buck converter design. This buck converter circuit is needed to produce an output voltage of 12Vdc from an input of 17.4Vdc.

Step 1: Determine the duty cycle, D to obtain required output voltage.

$$D = \frac{Vo}{Vd} \tag{3.1}$$

Where:

D = Duty cycle

Vo = Voltage output

Vd = Voltage input

$$D = \frac{12V}{17.4V}$$

$$D = 0.7$$

$$\%D = 70\%$$

Step 2: Select a particular switching frequency (f) and device

Before Buck converter circuit is design, the pulse width modulation (PWM) frequency should be determined. Basically, if the frequency increases, the efficiency of the Buck converter also increases. Thus to choose a suitable PWM frequency for the Buck converter, both of power consumption and the efficiency of the system need to be consider.

First, we should determine the whole system timing characteristics. The design of Buck converter input voltage should able to be decrease to 70% of its maximum value. Thus, the component at hand is POWER MOSFET IRFP150N for the switching element, IR2109 for the driver and PIC16F877A for the PWM controller. The rise time, tr, the fall time, tf, the minimum on-time, ton (min) and the minimum off-time, toff(min) can be found in the datasheet. Table 3.1 lists the rise and fall times and Table 3.2 lists the on and off times of each components.

Table 3.1: Rise and Fall Time

Bil	**Component**	**tr(ns)**	**tf(ns)**
1	IRFP150N	56	40
2	IR2109	150	50

Table 3.2: Minimum On and Off Time

Bil	Component	tr(ns)	tf(ns)
1	IRFP150N	11	45
2	IR2109	750	200

Referring to Table 1, the slowest tr and tf of the components are 150ns and 50ns respectively. Referring Table 2, it can be seen that both the slowest ton (min) and toff(min) of all components is at MOSFET driver. With the information, the frequency range for the de vice can be determined. A summary of data that we obtained are as follows:

(a) D (min) = 10%

(b) D (max) = 70%

(c) tr (slowest) = 150ns

(d) tf (slowest) = 50ns

(e) ton (min) = 750ns

(f) toff(min) = 200ns

Insert this data in the equation 3.2:

$$\frac{4(1-\text{Dmax})}{3(\text{tr}(\text{slowest})+\text{tf}(\text{slowest}))+4\text{toff}(\text{min})} \leq \text{fswitch} \leq \frac{4(\text{Dmin})}{\text{tr}(\text{slowest})+\text{tf}(\text{slowest})+4\text{ton}(\text{min})} \ldots(3.2)$$

$$\frac{4(1-0.7)}{3(150\text{ns}+50\text{ns})+4(200\text{ns})} \leq \text{fswitch} \leq \frac{4(0.1)}{150\text{ns}+50\text{ns}+4(750\text{ns})}$$

$$\frac{1.2}{1400\text{ns}} \leq \text{fswitch} \leq \frac{0.4}{3200\text{ns}}$$

$$857.142\text{kHz} \leq \text{fswitch} \leq 125\text{kHz}$$

Based on the calculation frequency range, the lowest switching frequency is about 125 kHz and the maximum is about up to 857.14 kHz. Thus the switching frequency is set to be 250 kHz. This minimum value is selected in order to minimize power use in Buck converter.

Step 3: Determine minimum inductor, L_{min} size. The switching frequency and inductor size selected for CCM is f = 25 kHz with load resistor, RL=5.6Ω/10W

$$Lmin = \left(\frac{1-D}{2f}\right)R \tag{3.3}$$

Where:

Lmin = Minimum inductor

D = Duty cycle

f = Frequency

R = Resistor

$$Lmin = \left(\frac{1-0.7}{2(250kHz)}\right)5.6\Omega$$

$$Lmin = \left(\frac{0.3}{500kHz}\right)5.6\Omega$$

$$Lmin = 3.36uH$$

Step 4: To ensure CCM let inductor be 25% greater than minimum inductor value

$$L = 1.25Lmin \tag{3.4}$$

$$L = 1.25(3.36uH)$$

$$L = 4.2uH$$

Step 5: The average current and the change in current

$$I_L = \frac{Vo}{R} \tag{3.5}$$

$$I_L = 5A$$

$$\Delta i_L = \frac{Vd - VO}{L}(DT) \tag{3.6}$$

$$\Delta i_L = \frac{17.4V - 12V}{4.2uH}(0.7)\left(\frac{1}{250kHz}\right)$$

$$\Delta i_L = 3.6A$$

Step 6: The maximum inductor current

$$Imax = I_L + \frac{\Delta i_L}{2} \tag{3.7}$$

$$Imax = 5A + \frac{3.6A}{2}$$

$$Imax = 5A + 1.8A$$

$$Imax = 6.8A$$

Step 7: The minimum inductor current

$$Imin = I_L - \frac{\Delta i_L}{2} \tag{3.8}$$

$$Imin = 5A - \frac{3.6A}{2}$$

$$Imin = 5A - 1.8A$$

$$Imin = 3.2A$$

Step 8: The capacitor if output ripple not exceed 2%

$$C = \frac{1 - D}{8L\left(\frac{\Delta Vo}{Vo}\right)f^2} \tag{3.9}$$

Where:

L = Inductor

D = Duty cycle

f = Frequency

$$\frac{\Delta Vo}{Vo} = \text{Ripple factor}$$

$$C = \frac{1 - 0.7}{8(4.2uH)(0.02)\left(250kHz^2\right)}$$

$$C = \frac{0.3}{42k}$$

$$C = 7.2uF$$

Figure 3.3 shows the basic construction of buck converter circuit using software OrCAD PSPICE based on calculations.

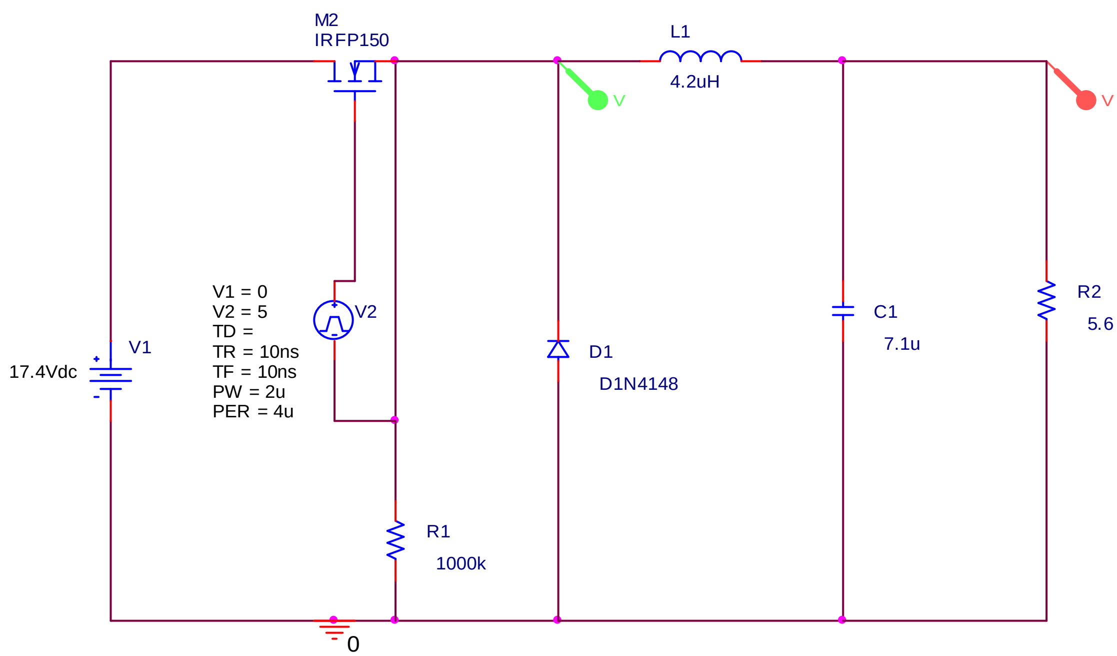

Figure 3.3: OrCAD PSPICE Schematic of Buck Converter.

Once the above schematic is designed, the simulation can be run. Figure 3.4 and 3.5 shows the waveforms generated by PSPICE simulation of the buck converter circuit. The waveform in Figure 3.3 shows the output voltage rising to 12V. We can also see the voltage across the diode during the switch off time is near -3 volts and during the switch on time is near the input voltage. The waveform in Figure 3.4 shows the converter is operating in the continuous conduction mode with an average operating current of about 5A and a peak in-rush current of about 15A.

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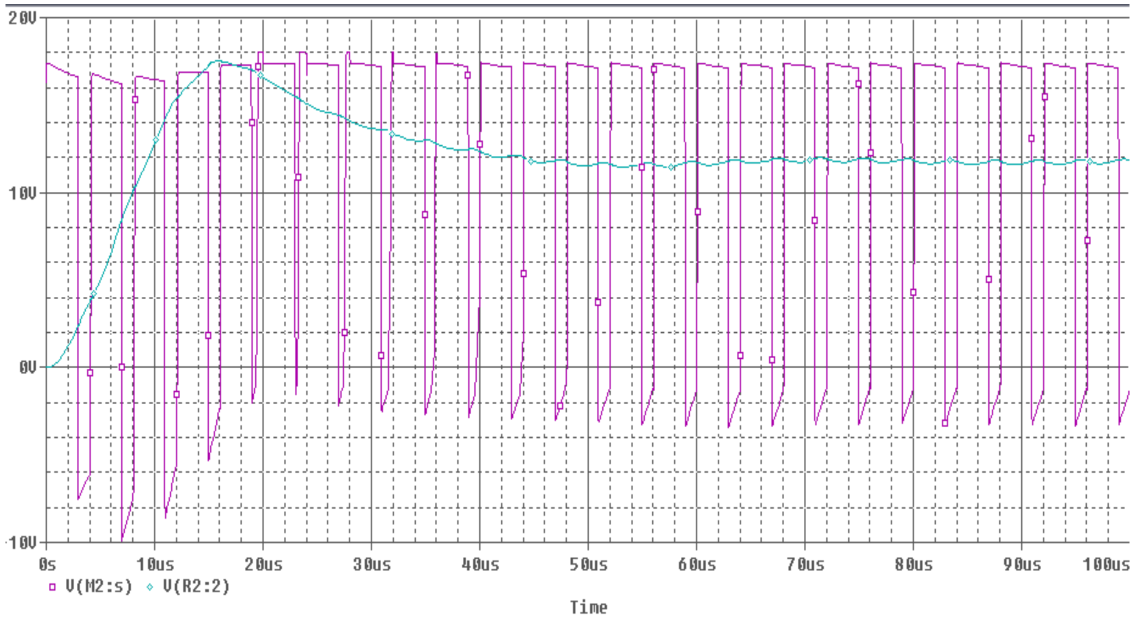

Figure 3.4: PSPICE simulation for V_{in} = 17.4 V; V_{out} = 12 V; D = 0.7

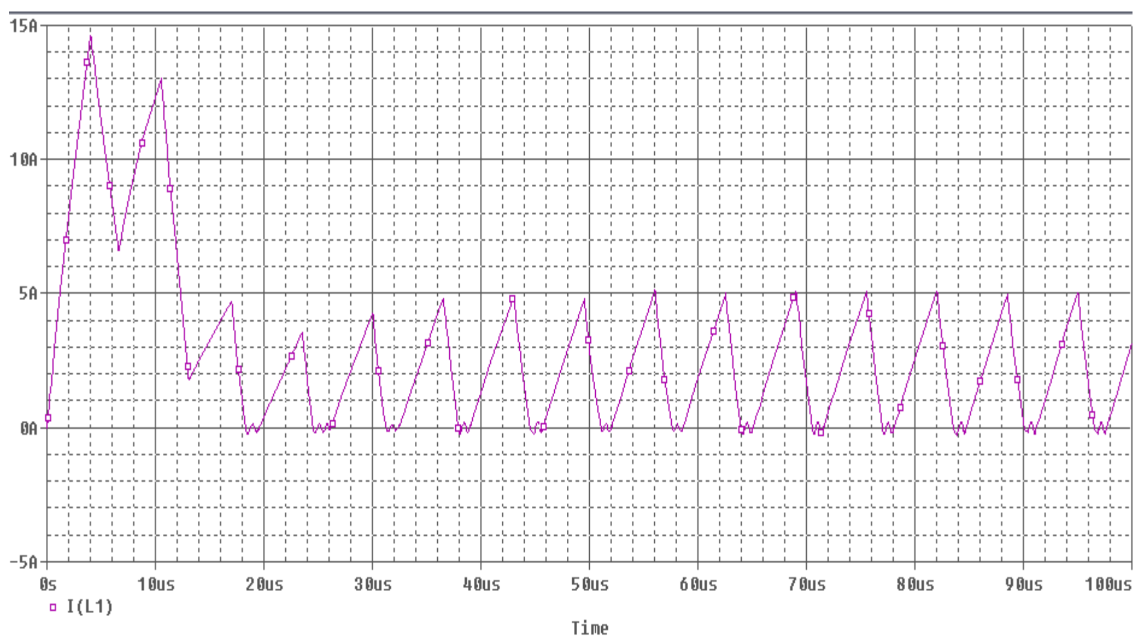

Figure 3.5: PSPICE simulation for i_L = 5A

3.2.3 PIC 16F877A Circuit Design

The second part is a microcontroller circuit. PIC 16F877A microcontroller is used in this PV charge controller to control POWER MOSFET switching duty cycle on the buck converter circuit. PIC 16F877A has 40 pins. This microcontroller offers the advantages which are very easy to be assembled, can be reprogrammed and erased up to 10,000 times and also an economical price. Therefore it is very good for new product development phase. Figure 3.6 show 40 pin PDIP of PIC 16F877A microcontroller.

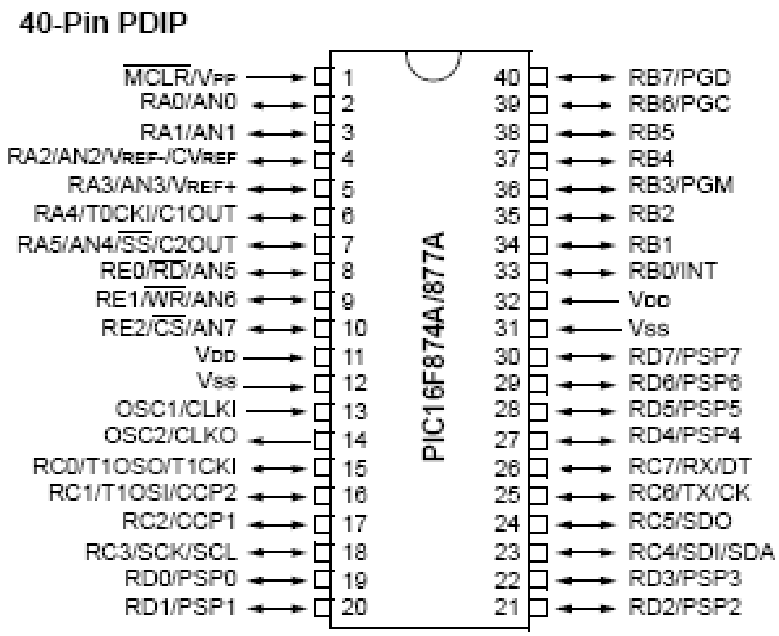

Figure 3.6: 40-Pin PDIP Diagram of PIC 16F887A

Before generate PWM signal from PIC16F877A, there are several circuits that is compulsory for the system to function well. It were included the power supply, clock circuit, and reset circuit. Power supply circuit (Figure 3.7) is needed in the basic PIC16F877A circuitry because 7805 regulator need to regulate the voltage supply of (>6V to 12V) so that the suitable voltage supply will drop at the PIC16F877A Vdd pin12 and make the PIC to functioned.

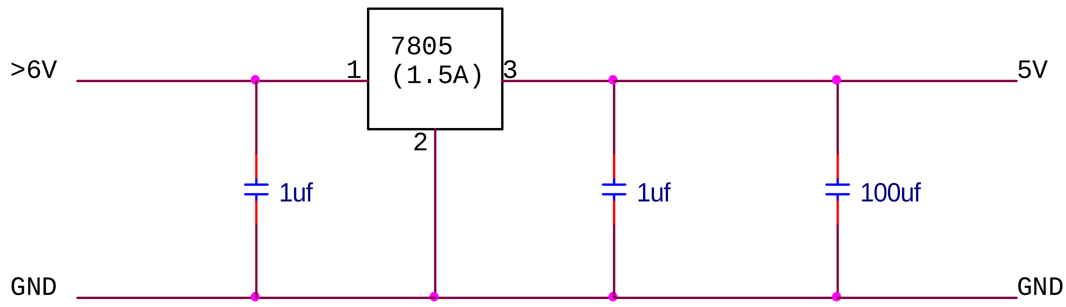

Figure 3.7: PIC 16F877A power supply circuit

A simple RC circuit (Figure 3.8) is used to produce action-synchronizing clock pulses. 20-MHz resonator is used for the operation clock oscillation by PIC 16F877A. The precision of this oscillation frequency doesn't influence the precision of the clock. The precision of the clock is decided by the precision of the frequency which is inputted to pin13 (OSC1) and pin14 (OSC2).

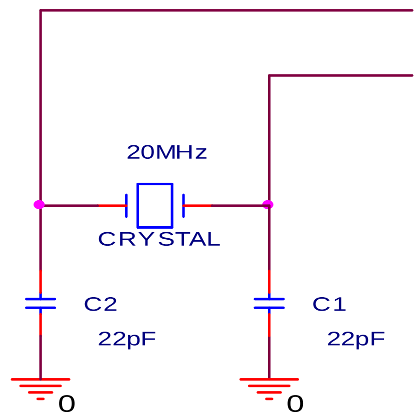

Figure 3.8: PIC 16F877A clock circuit

Meanwhile, the reset circuit (Figure 3.9) is used so that the program from a known state. It will be reset when the Master Clear (/MCLR) pin is connected to the 0V supply (ground). The PIC has internal circuits to perform this function at power on and the simplest design involve merely connecting the /MCLR pin directly to the positive voltage supply through a resistor to the positive voltage supply. When the power supply is connected, the voltage rise too slowly then this reset function may not work. By having a capacitor, at switch on, the capacitor will discharges. The PIC will be held reset until the voltage /MCLR is above threshold value.

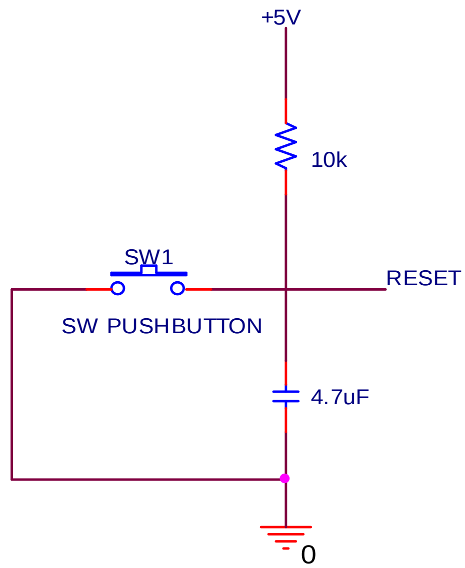

Figure 3.9: PIC 16F877A reset circuit

Since the PWM for Buck converter is sourced by PIC 16F877A in order to maintain the output voltage, the PWM function pin at port RB6 (bit 7 of PORTB) is set to be PWM output and it connecting to IN pin in the IR2109 half bridge driver.

3.2.4 Driver Circuit Design

The third part is a driver circuit. This circuit is really important in this PV charge controller in order to amplify and translate the PWM signal from PIC 16F877A microcontroller to trigger POWER MOSFET (IRFP150N) gate and the high output, HO. HO of driver circuit is connected to the MOSFET IRFP150N gates through resistor and switching diode (IN4148) that is oriented to bypass the resistor during turn-off, to ensure that MOSFET IRFP150N in one leg are fully off by the time another leg is turn on. The resistance is used value 20 Ω which allow a maximum gate turn-on current on the high side. Figure 3.10 show the MOSFET driver circuit.

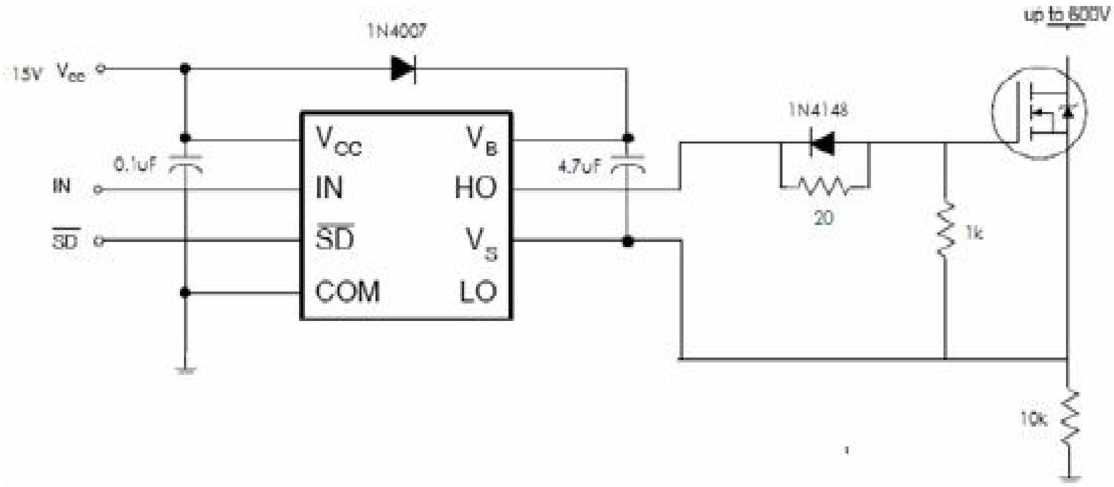

Figure 3.10: Circuit connection for IR2109 half-bridge

Basically, the driver circuit is receives controlled duty cycle signals from the PIC microcontroller at IN pin. The duty cycle signal from microcontroller is small in range about 0Vdc up to 5Vdc maximum. This duty cycle signal received then used for control the power MOSFET switching to the Buck converter. If the output voltage of Buck converter is higher, then the driver will drive a small duty cycle to POWER MOSFET and vise versa. Refer details about high –side driver operation in result discussion.

3.2.4 Rechargeable Battery

The four part is rechargeable battery. This rechargeable battery will be used in PV charge controller is 12V Sealed Lead Acid battery which is stored electrical energy in chemical form to operates dc load at night or bad weather and also requires lower maintenances, has longer life and gives better performance compared to normal battery.

3.2.6 Voltage Sensor Circuit Design

The five part is voltage sensor. This voltage sensor is used in PV charge controller to detect the voltage from rechargeable battery. First of all, the components in the strip board need to be supplied by 5V output. So the voltage sensor is designed to have 5V output by using supply from 12V rechargeable battery which is fed to port RA1 (bit 2 of PORTA). Here is the calculations method and formulas used in order to determine the values of the required components in voltage sensor circuit design. Figure 3.11 show the construction of voltage sensor circuit using software OrCAD PSPICE based on calculations.

$$Vo = \left(\frac{R_2}{R_1 + R_2}\right)Vin \tag{3.10}$$

Let R_1 = 1kiloohm

$$12V = \left(\frac{1k\Omega}{1k\Omega + R_2}\right)5V$$

$$5k\Omega + 5R_2 = 12R_2$$

$$5k\Omega = 7R_2$$

$$R_2 = 714.29\Omega$$

The standard value of resistor is used in this voltage sensor circuit is 715 ohm.

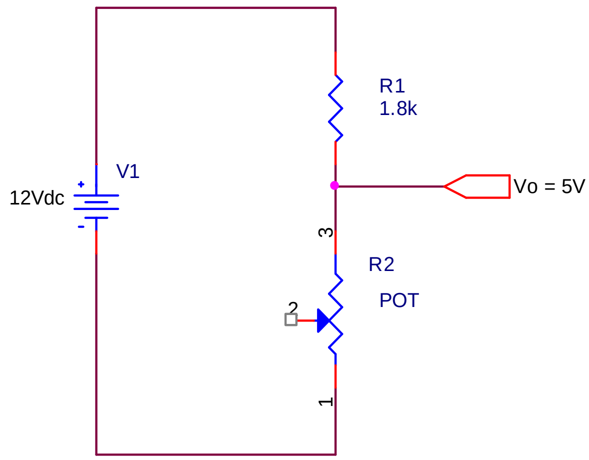

Figure 3.11: OrCAD PSPICE Schematic of Voltage Sensor.

3.2.7 Current Sensor

The six part is current sensor. The current sensor is used in PV charge controller to read the current from rechargeable battery. The current sensor used is LEM HX05-P/SP2.

3.2.8 Liquid Crystal Display (LCD)

The seven part is liquid crystal display (LCD). This LCD will be used in PV charge controller to display the operating status of rechargeable battery, output voltage, current value and also duty cycle of PWM from PIC 16F877A microcontroller. LCD is used in this project is 2X16 VCM162A. Table 3.3 shows the description connection of LCD.

Table 3.3: The description connection of LCD

Pin No	Symbol	Description
1	VSS	Ground terminal of module
2	VDD	Supply terminal of module
3	VO	Power supply for Liquid Crystal Drive
4	RS	Register Select: RS = 0 …. Instruction Register RS = 1 …. Data Register
5	R/W	Read/Write: High = Read Low = Write
6	E	Enable
7-14	D0 to D7	Bi-directional Data Bus. Data Transfer is performed once, thru D0 to D7, in the case of interface data length is 8-bits.
15	(BL -)	LED power supply terminals
`16	(BL +)	LED power supply terminals

As defined in the following structure, Table 3.4 show the pin connection from PIC16F877A microcontroller to the LCD pin while Figure 3.12 show the schematic of LCD circuit using software Proteus 7 Professional.

Table 3.4: The pin connection from PIC 16F877A to the LCD pin

Pin From PIC 16F877A	Pin From LCD
RB0	DB4
RB1	DB5
RB2	DB6
RB3	RB7
RB4	E
RB5	RS

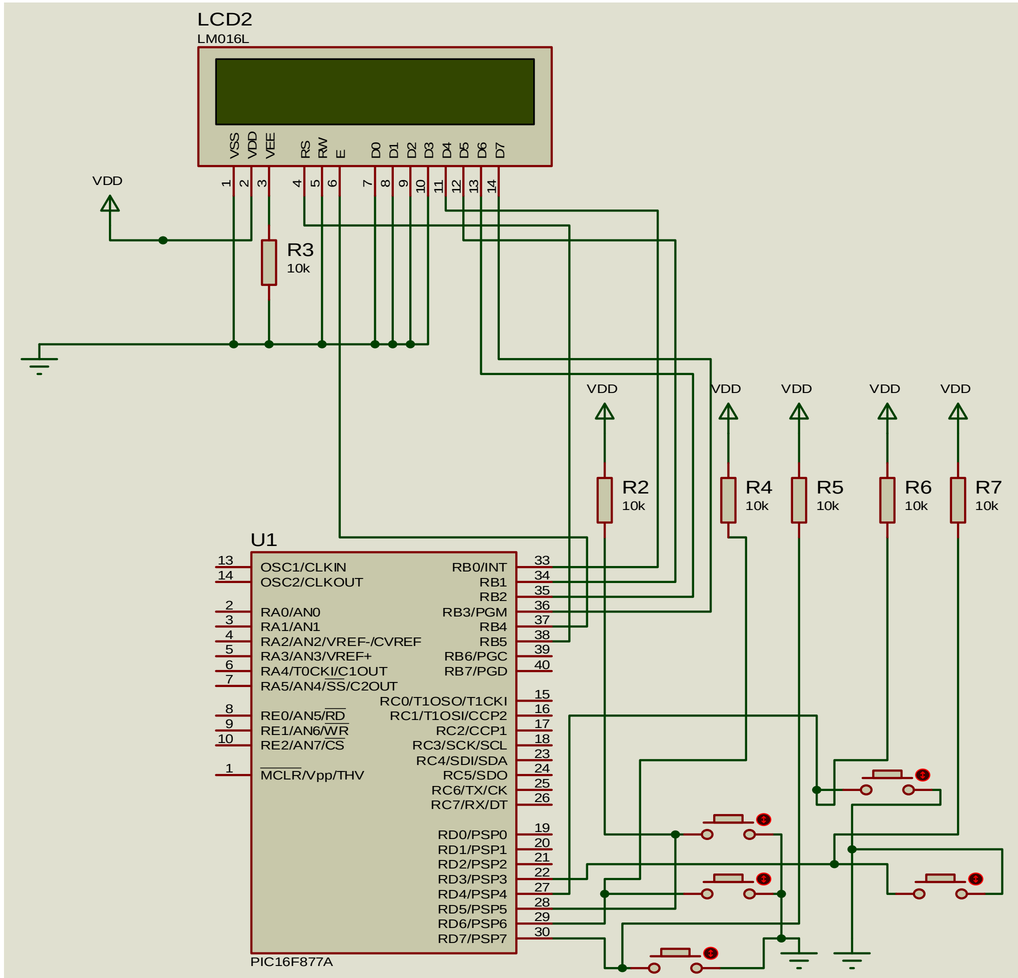

Figure 3.12: Schematic of LCD circuit with push button switches.

3.3 Software Implementation

3.3.1 PICBASIC PRO (PBP)

PICBASIC PRO allows us to use assembly language code mixed together with our BASIC code. The PICBASIC PRO Compiler (or PBP) makes it even quicker and easier to program Microchip Technology's powerful PICmicro microcontrollers (MCUs). The English-like BASIC language is much easier to read and write than the quirky Microchip assembly language. PBP Compiler produce code that can be programmed into a wide variety of PICmicro microcontroller which having from 8 until 84 pins and various on-chip features including A/D converters, hardware timers and serial ports. The PBP Compiler files are compressed into the self-extracting file on the included disk. They must be uncompressed before use. In general, PICBASIC language provides understood language, a widely standardized language and very productive language. Features like bit manipulation, bit field manipulation, direct memory addressing, and the ability to manipulate function addresses pointers have included in PICBASIC language. In other words, PICBASIC language is the only popular high level language that can be conveniently used for a microcontroller device such as for PIC 16F877A microcontroller to perform specific task in Photovoltaic (PV) Charge Controller. PIC 16F877A device contain between 64 and 1024 bytes of non-volatile data memory that can be used to store program and data and others parameters even when the power is turned off.

3.3.2 MicroCode Studio (PBP Compiler)

MicroCode Studio is one of the PBP Compiler that available for the Microchip PIC Controllers which is in this project, PIC 16F877A. MicroCode Studio is a powerful, visual Integrated Development Environment (IDE) with In Circuit Debugging (ICD) capability designed specifically for PICBASIC PRO™ compiler that allows users to build projects, add source code files to the projects, set compiler options for the objects and compile projects into executable program files. MicroCode Studio has its own database to track the properties of each Microchip PIC Microcontroller that it supports which is in this project is the PIC 16F877A. The data base can be update through Device Editor Menu item and new devices may be added or change the entries for a device for a special application. MicroCode Studio now includes EasyHID Wizard, a free code generation tool that enables a user to quickly implement bi-directional communication between an embedded PIC™ microcontroller and a PC. The compiler, assembler and programmer options is easy to setup. Compilation and assembler errors can easily be identified and corrected using the error results window. Just click on a compilation error and MicroCode Studio will automatically take to the error line. MicroCode Studio even comes with a serial communications window, allowing the debugging and view serial output from your microcontroller. Each line of source code is animated in the main editor window, showing which program line is currently being executed by the host microcontroller. User also can even toggle multiple breakpoints and step through your PICBASIC PRO™ code line by line. Figure 3.12 show the example programming which is written in Microcode Studio.

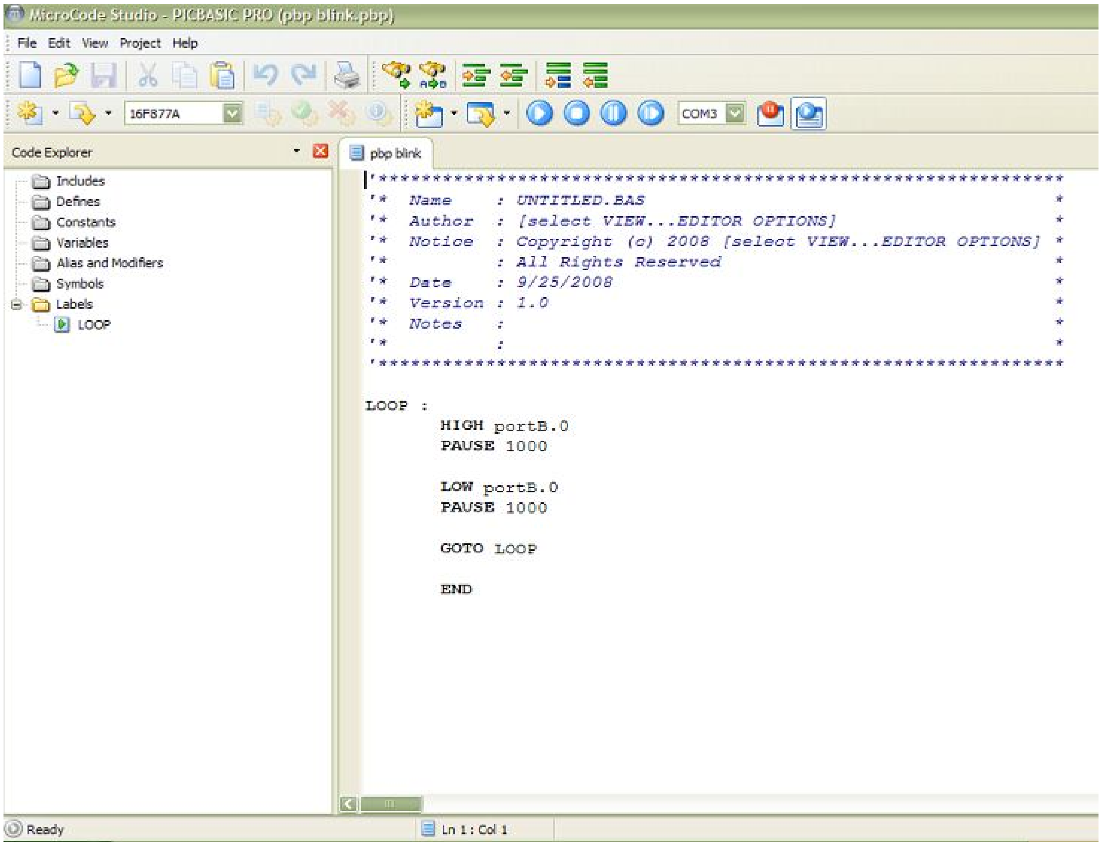

Figure 3.13: MicroCode Studio Screenshots

3.3.3 UP00A PIC USB Programmer

UP00A PIC USB Programmer is driven and powered from a single USB port on any personal computer. UP00A PIC USB Programmer allows programming of PIC microcontrollers in DIP, PLCC or surface mount packages on the programmer pin demo board which available for 8, 18, 28 and 40 pin of PIC microcontrollers. UP00A PIC USB Programmer also included easy-to-understand tutorials software that allows users to learn at their own pace. Refer APPENDIX for detail specification. Figure 3.13 show the hardware of UP00A PIC USB Programmer.

Figure 3.14: UP00A PIC USB Programmmer

3.3.4 Programming the PIC 16F877A Microcontroller

It is really important to check either the program is working or not. The easiest way to find it out is trying and testing the code again and again using UP00A PIC USB Programmer. It does take a long time to develop a program that really satisfies the project objective and scope. The flash memory technology of the PIC 16F877A microcontroller permits the microcontroller to be programmed, erase and programmed again repeatedly and it saves us more time to construct ideal program.

3.3.5 Photovoltaic Charge Controller System Operational Flow

The overall operation of the whole system is simplified and indicated by the flowchart in Figure 3.11 as shown below.

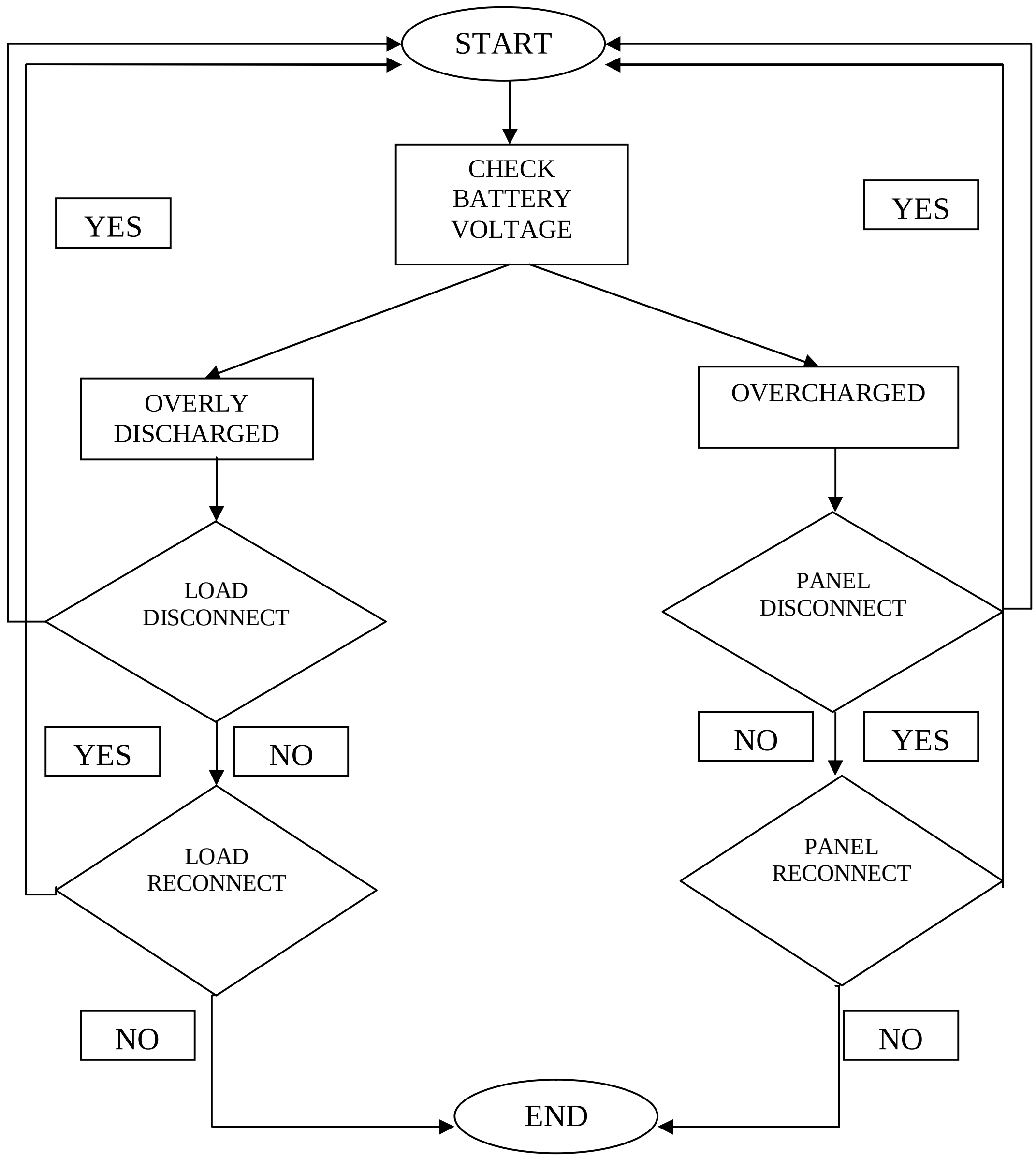

Figure 3.15: Flow chart of the whole system

From the flow chart above, the PV charge controller algorithm is being summarized. Everyday charging cycle of rechargeable battery is based on photovoltaic energy and maintained by using PWM techniques. First check the battery voltage. If battery is overly discharged (below than 11.2V) then the load is disconnect. After that, loop to start to check the battery voltage is more than 11.2V. Then check if load is really disconnected. If load is disconnected, check if reconnection voltage of the load criteria is met which is equal to 12V. If criteria are met reconnect the load then loop to check the battery voltage. If battery is overcharged (more than 13.2V) then the panel is disconnect. After that, loop to check the battery voltage is reaches voltage limit (13.2V). Then check if panel is really disconnected. If panel is disconnected, check if reconnection voltage of the panel criteria is met. If criteria are met reconnect the panel then loop to start to check the battery voltage.

CHAPTER 4

RESULT & DISCUSSION

4.1 INTRODUCTION

In this chapter, all results of hardware testing and circuit troubleshooting of the PV charge controller will be discussed. All discussions will focus on the result obtained and performance of the project.

4.2 PIC 16F877A Microcontroller Circuit

Before complete PIC 16F877A microcontroller circuit is implementing on driver circuit, the constructed PIC 16F877A microcontroller circuit needs to be check first. There are two steps to check PIC 16F877A microcontroller circuit is function properly. Figure 4.1 shows the complete PIC 16F877A microcontroller circuit.

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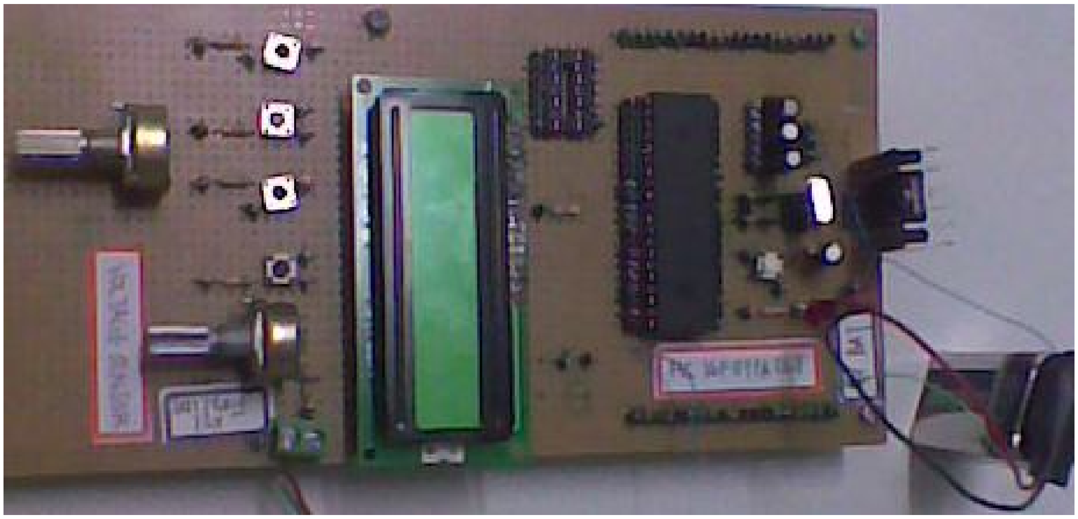

Figure 4.1: The complete PIC 16F877A microcontroller circuit.

Step 1: Check the voltage supply, Vdd at pin 11 of PIC 16F877A

The voltage drop at pin 11 of PIC 16F877A microcontroller will be measured by using digital multimeter and the result is 5V. This value ensured that the PIC 16F877A microcontroller is well function and this value also were produced by the regulating voltage supply through the power supply circuitry mentioned in Chapter 3. Figure 4.2 show the value of voltage drop is measured by digital multimeter.

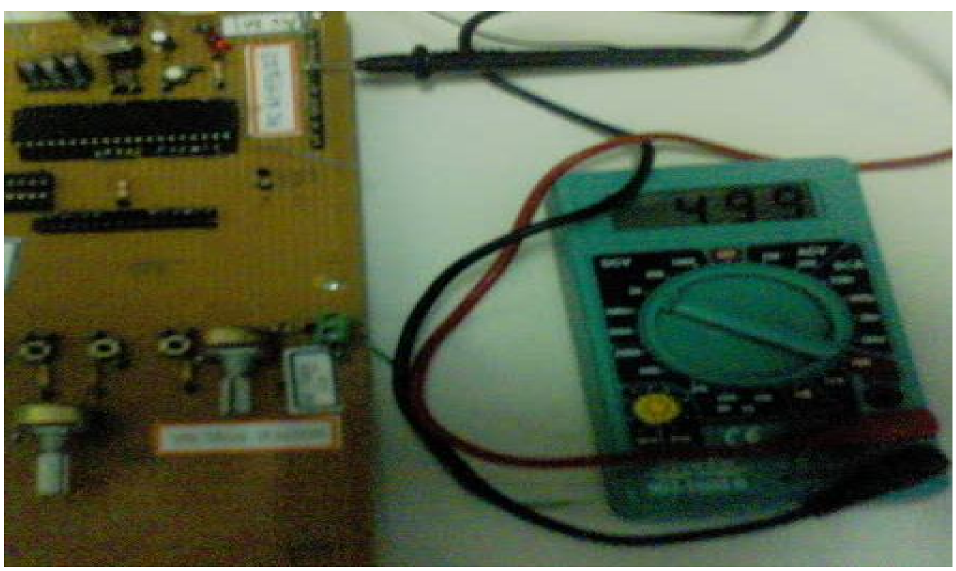

Figure 4.2: The digital multimeter show the value of voltage drop near to 5V.

Step 2: Led is ON

A red LED is connect to port RA2 (bit 3 of PORTA) of a PIC 16F877A microcontroller and then write a program to continuously flash the red LED with 1s intervals. When a red LED is ON, it shows the PIC 16F877A microcontroller is function properly. Figure 4.3 show the red LED is ON from PIC 16F877A microcontroller circuit.

Figure 4.3: The red LED is ON.

After checking the status function of PIC 16F877A microcontroller circuit, we can move on to test the pulse width modulation (PWM) which is signal by PIC 16F877A microcontroller.

4.2.1 Pulse Width Modulation (PWM)

The pulse width modulation (PWM) is required in PV charge controller for control switching frequency in order to obtain the desired output voltage. The controlled duty cycle from PIC 16F877A microcontroller enter to high side MOSFET driver before control POWER MOSFET gate terminal for switching scheme. The switching frequency required for this Buck converter is about 250 kHz. The selection of switching frequency can refer to component determination in chapter three together with simple microcontroller program use to generate desired PWM. From previous calculation in equation 3.2, PWM used to determine the duty cycle, D ratio between inputs to output of Buck converter. The desire duty cycle for switching scheme is about 70% by operating on CCM mode. There are two methods to control duty cycle. First method using variable resistor or potentiometer and second method using switches which is connected to 4 pin of PORTB of PIC 16F877A microcontroller. Figure 4.4 show the duty cycle of PWM from PIC 16F877A microcontroller to meet the project requirement.

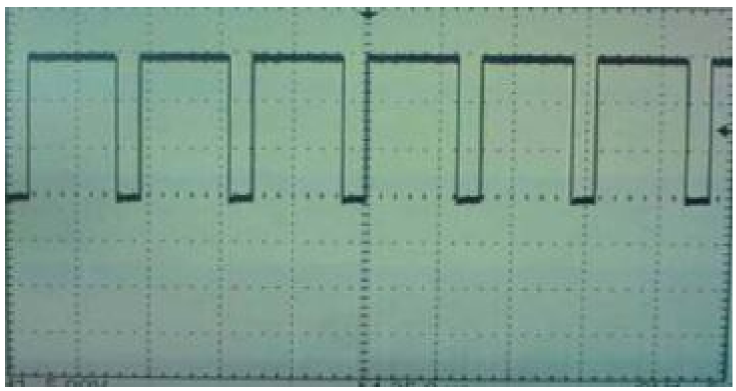

Figure 4.4: Duty cycle 70% of PWM output waveform from PIC 16F877A

4.2.2 Discussion

4.2.2.1 PIC 16F877A microcontroller circuit

Make sure the connection of power supply circuit, clock circuit and reset circuit is connected properly to PIC 16F877A microcontroller to ensure this circuit functions appropriately.

4.2.2.2 Pulse Width Modulation (PWM)

Make sure duty cycle of PWM which is generated by PIC 16F877A microcontroller for buck converter circuit is not less or more than range assigned because it will affect the buck converter circuit to function inappropriately. The chance of buck converter circuit to damage is high due to rating of component determination based on duty cycle calculation are not supported.

4.3 Driver Circuit

Before the complete circuit of MOSFET driver is applies on Buck converter, the constructed driver circuit needs to test first. There are 2 steps to test this driver circuit. First step without POWER MOSFET at high output (HO) of MOSFET driver while second step with POWER MOSFET at source (S) pin of it. This step is really important to perform because to ensure the output from MOSFET driver is function in order to control switching frequency of POWER MOSFET on buck converter. Figure 4.5 shows the complete driver circuit.

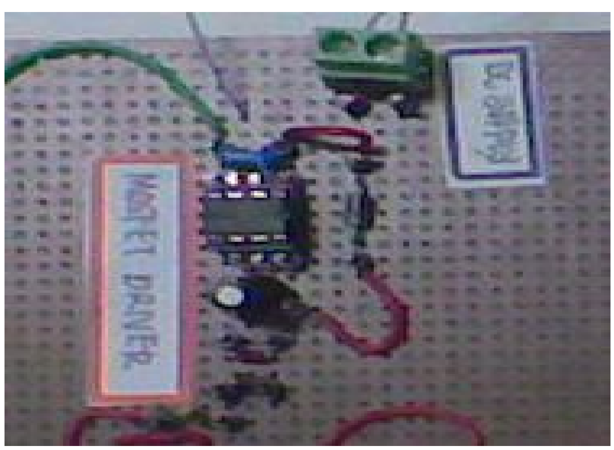

Figure 4.5: The complete MOSFET driver circuit.

4.3.1 MOSFET Driver Circuit without POWER MOSFET Output

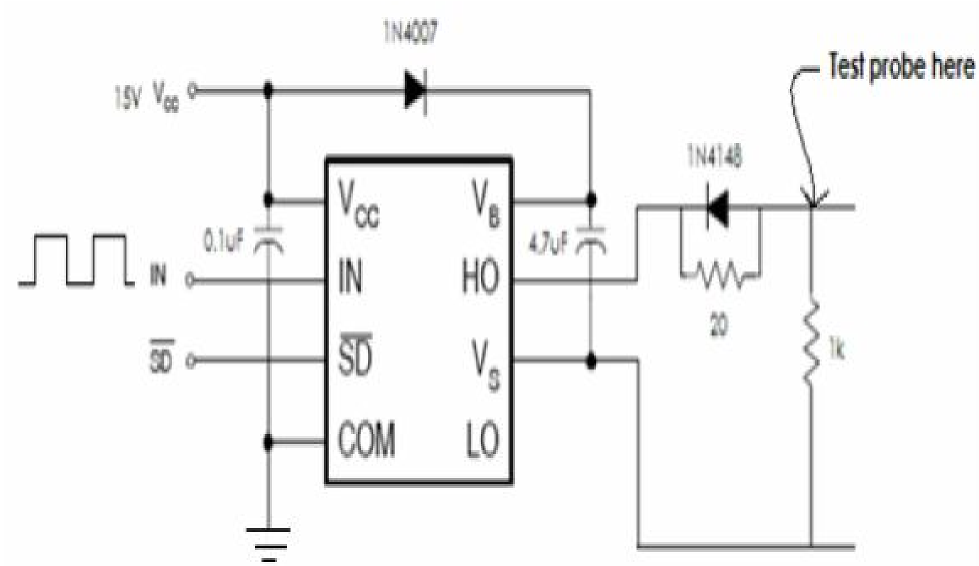

Figure 4.6: The test probe at HO pin of MOSFET driver.

Figure 4.6 show the probe point to test and measure is placed while another probe point is tab to the Vs pin. The output point is test by varied the duty cycle coming from PIC 16F877A at IN pin of MOSFET driver. Figure 4.7 show the result of duty cycle at oscilloscope.

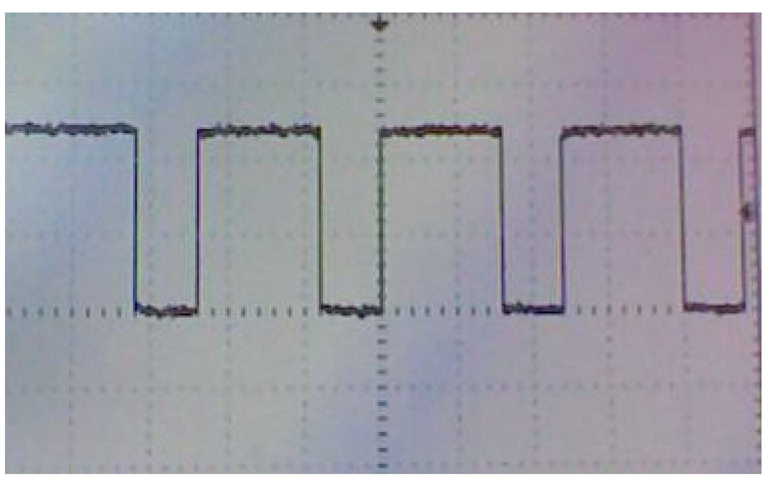

Figure 4.7: The output waveforms of HO MOSFET driver with D = 70%.

4.3.2 MOSFET Driver Circuit with POWER MOSFET Output

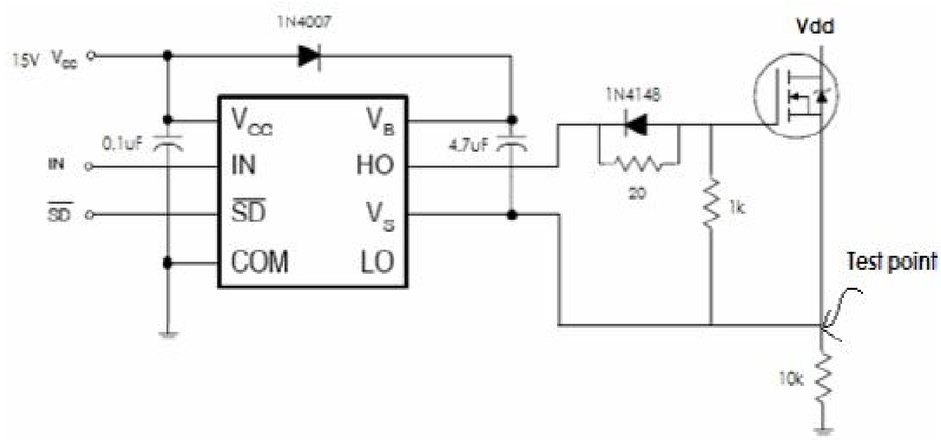

Figure 4.8: The test point at POWER MOSFET switching output

Figure 4.8 show the joint of gate terminal of POWER MOSFET with HO of MOSFET driver, the need of voltage supply at drain voltage, Vdd of POWER MOSFET terminal and the place of probe point to test and measure. The high output, HO pin is act as a PWM signal for the POWER MOSFET. The output result at probe point is get by varied the Vdd which is coming from POWER MOSFET terminal. Figure 4.9 show the result of Vdd output at oscilloscope.

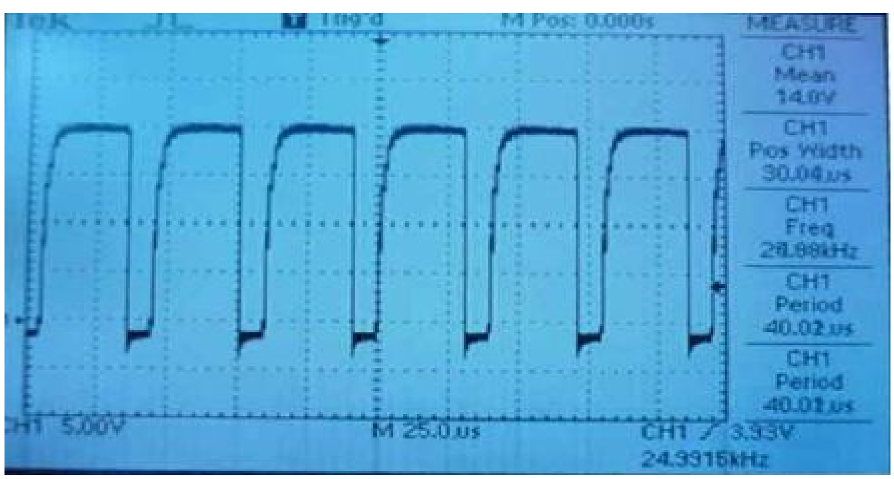

Figure 4.9: The output waveforms of HO MOSFET driver with Vdd = 14V.

4.3.3 Discussion of Driver Circuit

During construct the driver circuit, there is a major problem especially when construct high side driver circuit. The wrong connection of high side ground caused the signal from PIC 16F877A not read by MOSFET driver. This circuit is an important part because to ensure the output from MOSFET driver is well function as triggered switching function of POWER MOSFET. So make sure the connection of high side MOSFET driver in right connection.

4.4 Buck Converter Circuit

Now the buck converter circuit construction can be test after all parts for PWM of PIC 16F877A microcontroller and driver circuit is tested and verifies. In this circuit, the output voltage will be measured. Figure 4.10 show the complete buck converter circuit while Table 4.1 shows the testing data for Buck converter circuit construction which is applied the range of duty cycle ratio.

Figure 4.10: The complete buck converter circuit

Table 4.1: The output voltage from buck converter

Vdd (V)	Duty Cycle (%D)	Vout (mV)	Frequency (kHz)
10	50.00	1.82	215.25
11	52.04	2.92	220.49
12	57.07	3.10	225.08
13	57.50	4.02	230.00
14	58.59	5.27	235.17
15	62.06	6.42	240.51
16	69.75	7.53	245.45
17.4	70.00	8.90	250.00

4.4.1 Discussion of Buck Converter Circuit

From the Table 4.1, it show the maximum input supply voltage, Vdd can varied is about 17.4Vdc and the output voltage of buck converter circuit is about 8.90mVdc at desired 70% of duty cycle. Basically to design of Buck converter is achieved but it not meets the requirement of to produce 12Vdc output voltage. As we can see on duty cycle ratio in Table 4.1, the increasing range of duty ratio may cause the higher ratio of output voltage of buck converter circuit. The buck converter circuit may in risk and possibility malfunction if this range of duty cycle constantly use. The buck circuit has face with many problems especially due to rating of components selection so to get the right rating of components selection, the try error method is applied. To avoid an over voltage or over current flow through the Buck converter system, the best way is to use variable power supply unit to perform the step down dc-to-dc converter system.

4.5 Voltage Sensor Circuit

Before the complete voltage sensor circuit is implementing on PIC 16F877A microcontroller, the voltage sensor circuit is test to make sure the output voltage from voltage sensor circuit is fixed 5V. This value will be measured by using digital multimeter. Figure 4.11 show the complete voltage sensor circuit.

Figure 4.11: The complete voltage sensor circuit

4.5.1 Discussion of Voltage Sensor Circuit

The voltage output from voltage sensor circuit is fixed 5V after have been tested. This show the voltage sensor circuit is well function. Then, the output voltage of voltage sensor circuit is sent to port RA0 (bit 1 of PORT A) on PIC 16F877A microcontroller to control the voltage output from rechargeable battery.

4.6 Liquid Crystal Display (LCD) Circuit

Before the liquid crystal display (LCD) display the information of duty cycle and voltage and current from rechargeable battery to the user, LCD circuit is check to make sure it can be display. The LCD circuit is tune with potentiometer 10kilooh to get the contrast of the display which is in function of the voltage on the LCD pin. After the LCD circuit is checked, the command is given to PIC 16F877A microcontroller in order to display the information on the LCD. Figure 4.12 show the complete circuit of LCD circuit while Figure 4.13 show the information of duty cycle on the LCD.

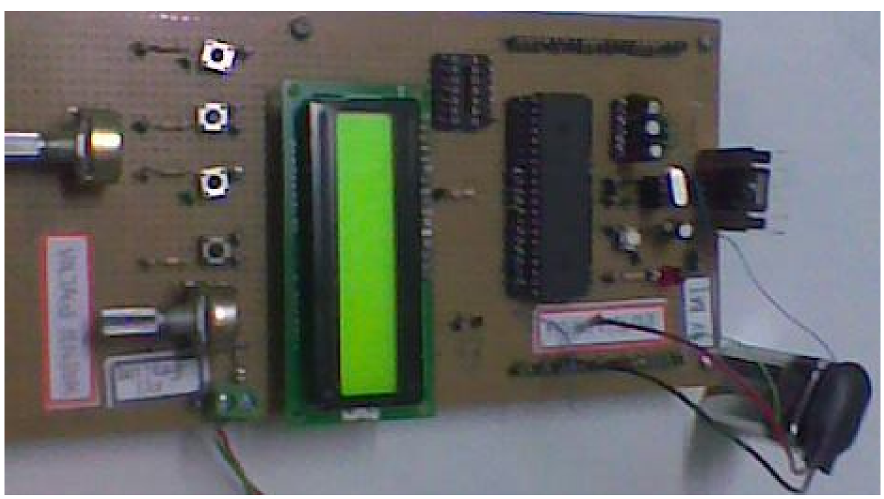

Figure 4.12: The complete circuit of LCD circuit

Figure 4.13: The information of duty cycle on the LCD

4.6.1 Discussion of LCD Circuit

From the Figure 4.13, we can see only information of duty cycle is displayed while information of voltage and current of rechargeable battery cannot be display. This happen due to unstable board because of lots of changing variations like voltage changing. The importance of achieving a high order of stability still remains a significant problem at the end of the day and the final circuit exhibits a high degree of stability. It is recommended in the solution that LCD circuit will need to orderly adjusted the be preset the potentiometers due to changes variation by using analysis method when configuring the effect of ranges in potentiometer and the contact connections related to external circuit

CHAPTER 5

CONCLUSION AND FUTURE DEVELOPMENT

5.1 INTRODUCTION

This chapter discuss about the conclusion and project development in the future. This project has two major parts which is hardware description and software implementation. Both topics integrate with each other to develop Photovoltaic (PV) Charge Controller as a working product that can be applied to perform effective PV system.

5.2 CONCLUSION

As a conclusion, there are five chapters which are introduction, literature review, methodology, result and discussion, and conclusion and future development that has been discuss in this thesis for the development of PV Charge Controller project. At the end of this project, the implementation of this project with PIC 16F877A microcontroller was successful since the main objective has been achieved but with certain limit of the buck converter system. The design of Buck converter is to step down input voltage from 17.4Vdc to 12Vdc. But unfortunately, after circuit constructs and testing, the Buck converter has been to step down output voltage about 8.90mVdc only. Basically, the main reason of why system only able to step down about 8.90mVdc of voltage output is because due to ratings of components selection are not supported in terms of large flow of current through the circuit. The noise like higher switching frequency is one of causes and affects that produced higher current and carried it through the components. Besides, the LCD only can display the information of duty cycle to the users due to unstable board.

5.3 FUTURE DEVELOPMENT

For the future development, it is better to combine this project with maximum power-point tracking (MPPT) to get a maximum efficiency output. More or less for the Photovoltaic (PV) Charge Controller construction, using Printed Circuit Board (PCB) will be much likely saving the risk of stability. By having PCB in PV Charge Controller construction, the probability of gaining high stability is positive. Fuse also is installed in the load to prevent PCB from short circuit or overload current. Besides, PCB makes the circuit become smaller and looks compact, this way, will increasing the thought to make this PV Charge Controller becomes a portable device. In addition, for future design, student should be exposed with several of types of microcontroller for well-use programming language in the system for firmware and hardware implementation.

5.4 COSTING AND COMMERLIZATION

At a time of reduced budget resulting in many electrical appliances need to used, one way to increase efficiency and productivity of photovoltaic system is by using Photovoltaic (PV) Charge Controller. Total estimation cost to build the PV Charge Controller is about RM94.07; see APPENDIX B for details price and components items. This project can be commercialized due to several reasons which are:

i) The selling prices will be lower than RM 100.00

ii) Portable PV charge controller

iii) Small in size and weight

iv) High efficiency

Based on the reasons, this project actually quite simple compare to other similar project concept (PV Charge Controller) available in marketplace. Thus, it is impossible to compete with another advance project readily available but this PV Charge Controller would be the best portable PV system that people want most.

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APPENDICES

APPENDIX A

Programming Language

```
'****************************************************************
'*  Name    : CONTROLLER.BAS                                    *
'*  Author  : [select VIEW...EDITOR OPTIONS]                    *
'*  Notice  : Copyright (c) 2009 [select VIEW...EDITOR OPTIONS] *
'*          : All Rights Reserved                               *
'*  Date    : 4/7/2009                                          *
'*  Version : 1.0                                               *
'*  Notes   :                                                   *
'*          :                                                   *
'****************************************************************

' Display Microcontroller pin
' DB4 RB0    -0
' DB5 RB1    -0
' DB6 RB2    -0
' RB7 RB3    -0
' E RB4      -0
' RS RB5     -1
' RB6 -PWM OUTPUT
' rangeH button RD4
' rangeL button RD5
' cycleH button RD6
' cycleL button RD7

START:
DEFINE LCD_DREG PORTB          ' LCD Data bits on PORTB
DEFINE LCD_DBIT 0          ' PORTB starting address
DEFINE LCD_RSREG PORTB         ' LCD RS bit on PORTB
DEFINE LCD_RSBIT 5         ' LCD RS bit address
DEFINE LCD_EREG PORTB          ' LCD E bit on PORTB
DEFINE LCD_EBIT 4          ' LCD E bit address
DEFINE LCD_BITS 4          ' LCD in 4-bit mode
DEFINE LCD_LINES 2         ' LCD has 2 rows

DEFINE ADC_BITS 10         'A/D NUMBER OF BITS
DEFINE ADC_CLOCK    3   'USE A/D INTERNAL RC CLOCK
DEFINE ADC_SAMPLEUS  50        'SET SAMPLING TIME IN uS

'VARIABLES

RES VAR WORD               'A/D CONVERTER RESULT
VOLTS1 VAR WORD
VOLTS2 VAR WORD
PWMCYC VAR BYTE
CYC VAR BYTE
DELAY VAR BYTE
```

```
DUTY VAR WORD
DISP VAR BYTE
PLO VAR WORD 'PULS_LOW
PHI VAR WORD 'PULS_HIGH
PWIDTH VAR WORD 'ADD TWO RESULT (PULS_LOW+PULS_HIGH)

'CONSTANS

CONV1 CON 19                '5000/256=19.53,THIS IS THE DECIMAL PART
CONV2 CON 626               'THIS IS THE FRACTIONAL PART


TRISA.0=1                   'RA0(AN0) IS INPUT
TRISB = %00100000
TRISD = %11111000

Symbol CYCLEL = PORTD.5         ' How many cycle in PWM
Symbol CYCLEH = PORTD.4         ' PWMcycle from 0 to 255 : will determine
dutycycle
Symbol RANGEL = PORTD.7         ' How many cycle in PWM
Symbol RANGEH = PORTD.6         ' PWMcycle from 0 to 255 : will determine
dutycycle
SYMBOL BTN    = PORTD.3

OPTION_REG = $05 ' Set prescaler = 64

ON INTERRUPT GOTO ISR           ' ISR routine
INTCON = $A0                    ' Enable TMR0 interrupt and global interrupts
ADCON1=0                        'MAKE AN0 TO AN4 AS ANALOG INPUTS,
                                'MAKE REFERRENCE VOLTAGE=VDD
pause 500                       ' Wait 0.5sec for LCD to initialize
LCDOUT $FE,1                    ' Clear LCD

DEFAULT:
PWMCYC=179
CYC=20
rangeL=1
cycleL=1
rangeH=0
cycleH=1
disp=1
PWM PORTB.6,PWMCYC,CYC          ' Send a XX% duty cycle PWM signal out PB1 for
XX cycle

MAIN:
```

```
DUTY=(PWMCYC*100)/255
IF DUTY=100 THEN DUTY=0
PWM PORTB.6,PWMCYC,CYC      ' Send a XX% duty cycle PWM signal out PB1 for
XX cycles
GOSUB DISPLAY
GOSUB PRESS

DUTY=(PWMCYC*100)/255
IF DUTY=100 THEN DUTY=0

GOTO MAIN

PRESS:
if CYCLEH=0 THEN
   CYC=CYC+1
   IF CYC=100 then cyc=0
   GOSUB debounce
endif

if RANGEH=0 THEN
   PWMCYC=PWMCYC+1
   IF PWMCYC=255 then PWMCYC=0
   GOSUB debounce
endif
if CYCLEL=0 THEN
   CYC=CYC-1
   IF CYC=100 then cyc=0
   GOSUB debounce
endif

if RANGEL=0 THEN
   PWMCYC=PWMCYC-1
   IF PWMCYC=255 then PWMCYC=0
   GOSUB debounce
endif

if BTN=1 THEN AGAIN
        ADCIN 0,RES               'READ CHANNEL 0 DATA
       VOLTS1=RES*CONV1       'MULTIPLY BY 53
       VOLTS2=RES*CONV2
       VOLTS2=VOLTS2/100
       VOLTS1=VOLTS1+VOLTS2
       LCDOUT $FE,2,"VDC=",DEC4 VOLTS1  'DISPLAY RESULT
       GOTO MAIN
        pause 1000
        gosub debounce
```

```
endif

RETURN

DEBOUNCE:
FOR Delay = 1 To 100
Pause 1 ' Delay 1ms inside a loop. This way,
NEXT Delay ' timer interrupts are not stopped
DISP = 1 ' Set display flag to 1
RETURN

DISABLE
ISR:
IF cycleL=1 THEN NoUpdate
if rangeL=1 then noupdate
IF cycleH=1 THEN NoUpdate
if rangeH=1 then noupdate
if BTN=1    then Noupdate
disp=1

NoUpdate:
INTCON.2 = 0 ' Re-enable TMR0 interrupts
Resume
ENABLE ' Re-enable interrupts
end

DISPLAY:
IF DISP=1 THEN
LCDOut $fe, 2
'LCDOUT  "L",DEC3 plo ,"H",DEC3 phi
LCDOUT "DUTY CYCLE:", DEC2 DUTY ,"%"
LCDOut $fe, $C0
LCDOUT  "CYC:",DEC3 cyc ," PWM:",DEC3 pwmcyc
disp=0
ENDIF
RETURN
end
```

APPENDIX B

List of Components

NO.	ITEMS	Quantity	Price per Unit	Price (RM)
1.	PIC16F877A + BASE	1	22.00	22.00
2.	LM 7805 Voltage Regulator	1	1.00	1.00
3.	Crystal 20Mhz	1	2.00	2.00
4.	Heat Sink (Silver)	1	0.40	0.40
5.	Resistor 10kΩ	5	0.05	0.25
6.	Resistor 1.8k Ω	1	0.05	0.05
7.	Resistor 1kΩ	1	0.05	0.05
8.	Resistor 330Ω	1	0.05	0.05
9.	Resistor 20 Ω	1	0.05	0.05
10.	Resistor 5.6 Ω/10W	1	1.00	1.00
11.	Switch	5	0.60	3.00
12.	Capacitor 100 μF	1	4.50	4.50
13.	Capacitor 22pF	2	0.06	0.12
14.	Capacitor 10μF	1	0.06	0.06
15.	Capacitor 4.7 μF	2	0.06	0.12
16.	Capacitor 1μF	2	0.06	0.12
17.	Capacitor 0.1 μF (Ceramic)	1	0.30	0.30
18.	LED	1	0.20	0.20
19.	Potentiometer 10kΩ	1	2.50	2.50
20.	Potentiometer 25kΩ	1	2.50	2.50
21.	Power MOSFET IRFP150N	1	4.00	4.00
22.	MOSFET Driver IR2109	1	2.00	2.00
23.	Inductor 10 μH	1	5.00	5.00
24.	Diode 1N4148	2	0.10	0.20
25.	Diode 1N4005	1	0.20	0.20
26.	Liquid Crsytal Display	1	30.00	30.00
27.	Connector	4	0.60	2.40
28.	Independent Board	2	8.00	8.00
29.	Stand-off pillar	10	0.20	2.00
			TOTAL	**RM 94.07**

APPENDIX C

PIC 16F877A Datasheet

MICROCHIP

PIC16F87XA

28/40/44-Pin Enhanced Flash Microcontrollers

Devices Included in this Data Sheet:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

High-Performance RISC CPU:

- Only 35 single-word instructions to learn
- All single-cycle instructions except for program branches, which are two-cycle
- Operating speed: DC – 20 MHz clock input
  DC – 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during Sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I^{2}C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) – 8 bits wide with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Analog Features:

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)
- Brown-out Reset (BOR)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (VREF) module
  - Programmable input multiplexing from device inputs and internal voltage reference
  - Comparator outputs are externally accessible

Special Microcontroller Features:

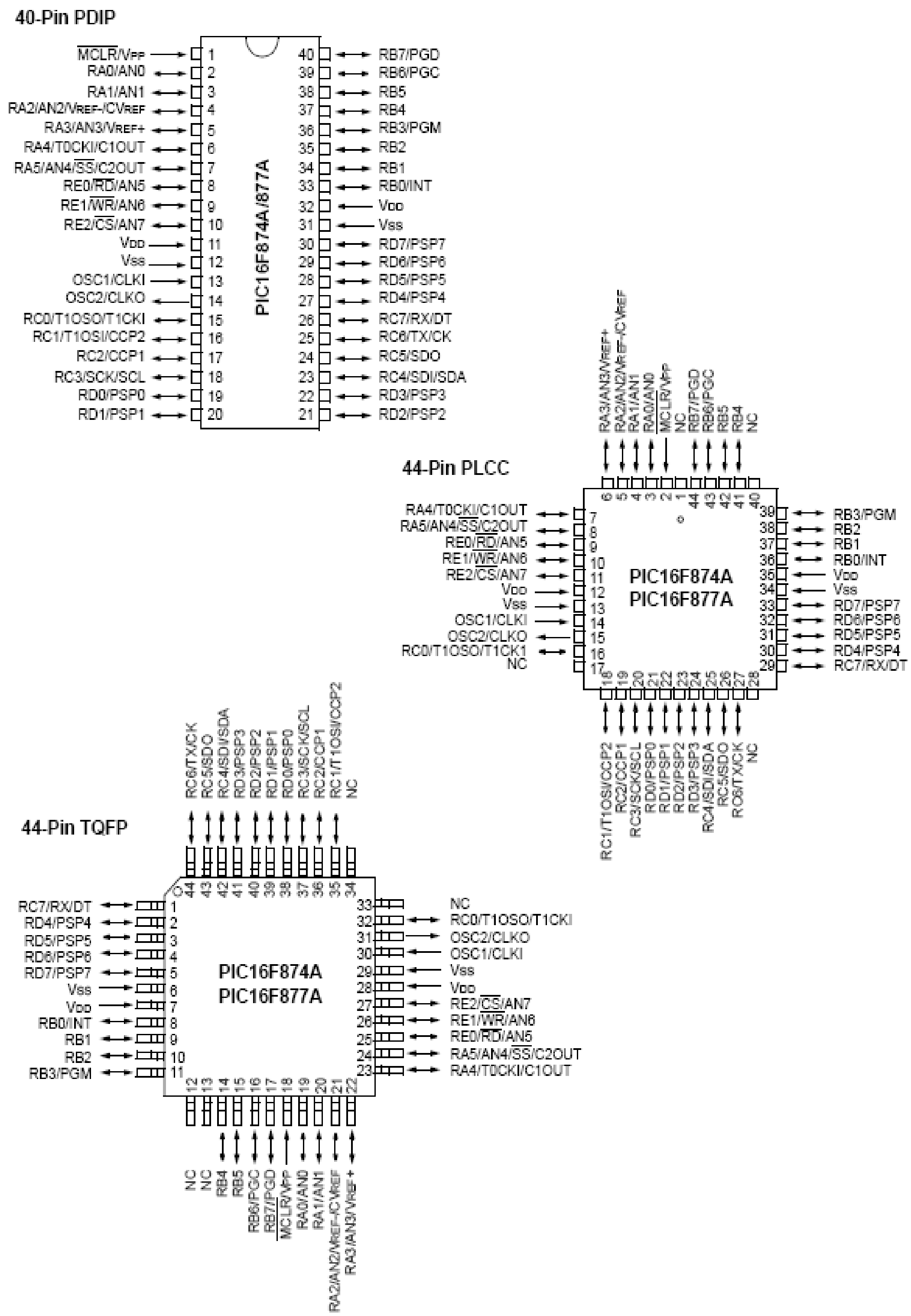
- 100,000 erase/write cycle Enhanced Flash program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Data EEPROM Retention > 40 years
- Self-reprogrammable under software control
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Single-supply 5V In-Circuit Serial Programming
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving Sleep mode
- Selectable oscillator options
- In-Circuit Debug (ICD) via two pins

CMOS Technology:

- Low-power, high-speed Flash/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Commercial and Industrial temperature ranges
- Low-power consumption

Device	Program Memory		Data SRAM (Bytes)	EEPROM (Bytes)	I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8/16-bit	Comparators
	Bytes	# Single Word Instructions						SPI	Master I^{2}C			
PIC16F873A	7.2K	4096	192	128	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F874A	7.2K	4096	192	128	33	8	2	Yes	Yes	Yes	2/1	2
PIC16F876A	14.3K	8192	368	256	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F877A	14.3K	8192	368	256	33	8	2	Yes	Yes	Yes	2/1	2

Pin Diagrams (Continued)



1.0 DEVICE OVERVIEW

This document contains device specific information about the following devices:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

PIC16F873A/876A devices are available only in 28-pin packages, while PIC16F874A/877A devices are available in 40-pin and 44-pin packages. All devices in the PIC16F87XA family share common architecture with the following differences:

- The PIC16F873A and PIC16F874A have one-half of the total on-chip memory of the PIC16F876A and PIC16F877A
- The 28-pin devices have three I/O ports, while the 40/44-pin devices have five
- The 28-pin devices have fourteen interrupts, while the 40/44-pin devices have fifteen
- The 28-pin devices have five A/D input channels, while the 40/44-pin devices have eight
- The Parallel Slave Port is implemented only on the 40/44-pin devices

The available features are summarized in Table 1-1. Block diagrams of the PIC16F873A/876A and PIC16F874A/877A devices are provided in Figure 1-1 and Figure 1-2, respectively. The pinouts for these device families are listed in Table 1-2 and Table 1-3.

Additional information may be found in the PICmicro® Mid-Range 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.

TABLE 1-1: PIC16F87XA DEVICE FEATURES

Key Features	PIC16F873A	PIC16F874A	PIC16F876A	PIC16F877A
Operating Frequency	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
Flash Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory (bytes)	128	128	256	256
Interrupts	14	15	14	15
I/O Ports	Ports A, B, C	Ports A, B, C, D, E	Ports A, B, C	Ports A, B, C, D, E
Timers	3	3	3	3
Capture/Compare/PWM modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Analog Comparators	2	2	2	2
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions
Packages	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN

8.0 CAPTURE/COMPARE/PWM MODULES

Each Capture/Compare/PWM (CCP) module contains a 16-bit register which can operate as a:

- 16-bit Capture register
- 16-bit Compare register
- PWM Master/Slave Duty Cycle register

Both the CCP1 and CCP2 modules are identical in operation, with the exception being the operation of the special event trigger. Table 8-1 and Table 8-2 show the resources and interactions of the CCP module(s). In the following sections, the operation of a CCP module is described with respect to CCP1. CCP2 operates the same as CCP1 except where noted.

CCP1 Module:

Capture/Compare/PWM Register 1 (CCPR1) is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). The CCP1CON register controls the operation of CCP1. The special event trigger is generated by a compare match and will reset Timer1.

CCP2 Module:

Capture/Compare/PWM Register 2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2. The special event trigger is generated by a compare match and will reset Timer1 and start an A/D conversion (if the A/D module is enabled).

Additional information on CCP modules is available in the PICmicro® Mid-Range MCU Family Reference Manual (DS33023) and in application note *AN594, "Using the CCP Module(s)"* (DS00594).

TABLE 8-1: CCP MODE – TIMER RESOURCES REQUIRED

CCP Mode	Timer Resource
Capture	Timer1
Compare	Timer1
PWM	Timer2

TABLE 8-2: INTERACTION OF TWO CCP MODULES

CCPx Mode	CCPy Mode	Interaction
Capture	Capture	Same TMR1 time base
Capture	Compare	The compare should be configured for the special event trigger which clears TMR1
Compare	Compare	The compare(s) should be configured for the special event trigger which clears TMR1
PWM	PWM	The PWMs will have the same frequency and update rate (TMR2 interrupt)
PWM	Capture	None
PWM	Compare	None

11.0 ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the 40/44-pin devices.

The conversion of an analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of VDD, VSS, RA2 or RA3.

The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D clock must be derived from the A/D's internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADCON0 register, shown in Register 11-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 11-2, configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

Additional information on using the A/D module can be found in the PICmicro® Mid-Range MCU Family Reference Manual (DS33023).

REGISTER 11-1: ADCON0 REGISTER (ADDRESS 1Fh)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit 7							bit 0

bit 7-6 **ADCS1:ADCS0:** A/D Conversion Clock Select bits (ADCON0 bits in **bold**)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	**00**	FOSC/2
0	**01**	FOSC/8
0	**10**	FOSC/32
0	**11**	FRC (clock derived from the internal A/D RC oscillator)
1	**00**	FOSC/4
1	**01**	FOSC/16
1	**10**	FOSC/64
1	**11**	FRC (clock derived from the internal A/D RC oscillator)

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits

000 = Channel 0 (AN0)
001 = Channel 1 (AN1)
010 = Channel 2 (AN2)
011 = Channel 3 (AN3)
100 = Channel 4 (AN4)
101 = Channel 5 (AN5)
110 = Channel 6 (AN6)
111 = Channel 7 (AN7)

Note: The PIC16F873A/876A devices only implement A/D channels 0 through 4; the unimplemented selections are reserved. Do not select any unimplemented channels with these devices.

bit 2 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit

When ADON = 1:
1 = A/D conversion in progress (setting this bit starts the A/D conversion which is automatically cleared by hardware when the A/D conversion is complete)
0 = A/D conversion not in progress

bit 1 **Unimplemented:** Read as '0'

bit 0 **ADON:** A/D On bit

1 = A/D converter module is powered up
0 = A/D converter module is shut-off and consumes no operating current

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 D

IRFP150N POWER MOSFET Datasheet

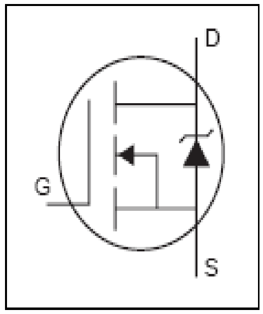
International
IOR Rectifier

PD- 91503C

IRFP150N

HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 100V

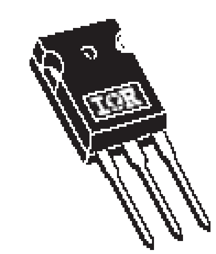
$R_{DS(on)}$ = 0.036Ω

I_D = 42A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 package because of its isolated mounting hole.



TO-247AC

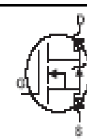
Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	42	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	30	
I_{DM}	Pulsed Drain Current ① ⑤	140	
P_D @T_C = 25°C	Power Dissipation	160	W
	Linear Derating Factor	1.1	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy② ⑤	420	mJ
I_{AR}	Avalanche Current①⑤	22	A
E_{AR}	Repetitive Avalanche Energy①	16	mJ
dv/dt	Peak Diode Recovery dv/dt ③ ⑤	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

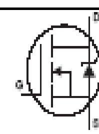
Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.95	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{\theta JA}$	Junction-to-Ambient	—	40	

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	—	—	V	V_{GS} = 0V, I_D = 250μA
$\Delta V_{(BR)DSS}/\Delta T_J$	Breakdown Voltage Temp. Coefficient	—	0.11	—	V/°C	Reference to 25°C, I_D = 1mA⑤
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.036	W	V_{GS} = 10V, I_D = 23A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS} = V_{GS}, I_D = 250μA
g_{fs}	Forward Transconductance	14	—	—	S	V_{DS} = 25V, I_D = 22A⑤
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	μA	V_{DS} = 100V, V_{GS} = 0V
		—	—	250		V_{DS} = 80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	—	—	110	nC	I_D = 22A
Q_{gs}	Gate-to-Source Charge	—	—	15		V_{DS} = 80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	58		V_{GS} = 10V, See Fig. 6 and 13 ④⑤
$t_{d(on)}$	Turn-On Delay Time	—	11	—	ns	V_{DD} = 50V
t_r	Rise Time	—	56	—		I_D = 22A
$t_{d(off)}$	Turn-Off Delay Time	—	45	—		R_G = 3.6W
t_f	Fall Time	—	40	—		R_D = 2.9W, See Fig. 10 ④⑤
L_D	Internal Drain Inductance	—	5.0	—	nH	Between lead, 6mm (0.25in.) 
L_S	Internal Source Inductance	—	13	—		from package and center of die contact
C_{iss}	Input Capacitance	—	1900	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	450	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	230	—		f = 1.0MHz, See Fig. 5⑤

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	42	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①⑤	—	—	140		
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S =23A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	180	270	ns	T_J = 25°C, I_F = 22A
Q_{rr}	Reverse RecoveryCharge	—	1.2	1.8	μC	di/dt = 100A/μs ④ ⑤
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② Starting T_J = 25°C, L = 1.7mH R_G = 25W, I_{AS} = 22A. (See Figure 12)

③ I_{SD} £ 22A, di/dt £ 180A/μs, V_{DD} £ $V_{(BR)DSS}$, T_J £ 175°C

④ Pulse width £ 300μs; duty cycle £ 2%.

⑤ Uses IRF1310N data and test conditions

APPENDIX E

1N4148 Diode Datasheet

Fast Switching Diodes

Features

- Silicon Epitaxial Planar Diodes
- Electrically equivalent diodes: 1N4148 - 1N914
  1N4448 - 1N914B

Applications

Extreme fast switches

Mechanical Data

Case: DO-35 Glass Case

Weight: approx. 125 mg

Packaging Codes/Options:

TR / 10 k per 13 " reel (52 mm tape), 50 k/box

TAP / 10 k per Ammopack (52 mm tape), 50 k/box

Parts Table

Part	Type differentiation	Ordering code	Remarks
1N4148	V_{RRM} = 100 V, V_F @ I_F 10 mA = 1 V	1N4148-TAP or 1N4148-TR	Ammopack / Tape and Reel
1N4448	V_{RRM} = 100 V, V_F @ I_F 100 mA = 1 V	1N4448-TAP or 1N4448-TR	Ammopack / Tape and Reel

Absolute Maximum Ratings

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Repetitive peak reverse voltage		V_{RRM}	100	V
Reverse voltage		V_R	75	V
Peak forward surge current	t_p = 1 µs	I_{FSM}	2	A
Repetitive peak forward current		I_{FRM}	500	mA
Forward current		I_F	300	mA
Average forward current	V_R = 0	I_{FAV}	150	mA
Power dissipation	l = 4 mm, T_L = 45 °C	P_V	440	mW
	l = 4 mm, T_L ≤ 25 °C	P_V	500	mW

Thermal Characteristics

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Junction ambient	l = 4 mm, T_L = constant	R_{thJA}	350	K/W
Junction temperature		T_j	200	°C
Storage temperature range		T_{stg}	- 65 to + 200	°C

APPENDIX F

LM7805 Voltage Regulator Datasheet

National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

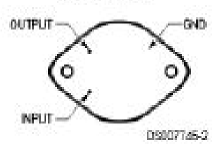
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

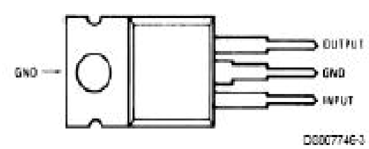
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage				5V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
V_N	Output Noise Voltage	T_A =25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)		V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

$0°C \leq T_J \leq 125°C$ unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	$T_j = 25°C$		2.1			1.5			1.2		A
	Peak Output Current	$T_j = 25°C$		2.4			2.4			2.4		A
	Average TC of V_{OUT}	$0°C \leq T_j \leq +125°C$, $I_O = 5$ mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_j = 25°C$, $I_O \leq 1A$		7.5		14.6			17.7			V

Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \leq 10$ ms, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

APPENDIX G

IR2109 Half-Bridge Driver Datasheet

International IOR Rectifier

Data Sheet No. PD60163-U

IR2109(4) (S) & (PbF)

HALF-BRIDGE DRIVER

Features

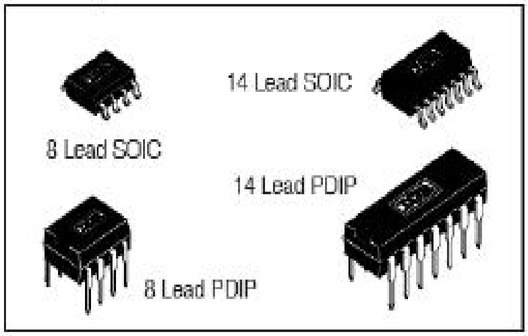
- Floating channel designed for bootstrap operation
  Fully operational to +600V
  Tolerant to negative transient voltage
  dV/dt immune
- Gate drive supply range from 10 to 20V
- Undervoltage lockout for both channels
- 3.3V, 5V and 15V input logic compatible
- Cross-conduction prevention logic
- Matched propagation delay for both channels
- High side output in phase with IN input
- Logic and power ground +/- 5V offset.
- Internal 540ns dead-time, and programmable up to 5us with one external R_{DT} resistor (IR21094)
- Lower di/dt gate driver for better noise immunity
- Shut down input turns off both channels.
- Available in Lead-Free

Product Summary

V_{OFFSET}	600V max.
I_{O}+/-	120 mA / 250 mA
V_{OUT}	10 - 20V
$t_{on/off}$ (typ.)	750 & 200 ns
Dead Time	540 ns

(programmable up to 5uS for IR21094)

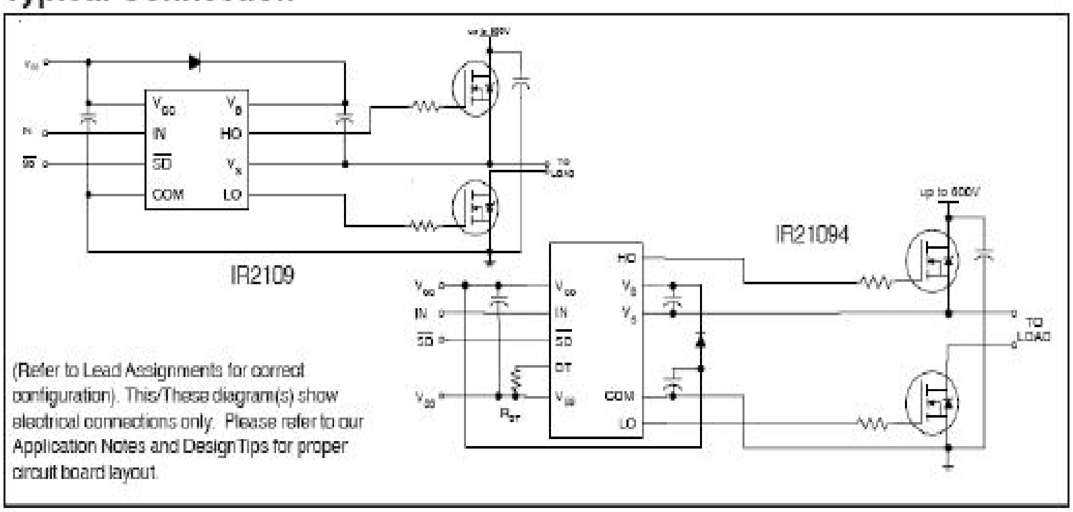
Packages



Description

The IR2109(4)(S) are high voltage, high speed power MOSFET and IGBT drivers with dependent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. The logic input is compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts.

Typical Connection



Absolute Maximum Ratings

Absolute maximum ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

Symbol	Definition		Min.	Max.	Units
V_B	High side floating absolute voltage		-0.3	625	V
V_S	High side floating supply offset voltage		V_B - 25	V_B + 0.3	
V_{HO}	High side floating output voltage		V_S - 0.3	V_B + 0.3	
V_{CC}	Low side and logic fixed supply voltage		-0.3	25	
V_{LO}	Low side output voltage		-0.3	V_{CC} + 0.3	
DT	Programmable dead-time pin voltage (IR21094 only)		V_{SS} - 0.3	V_{CC} + 0.3	
V_{IN}	Logic input voltage (IN & $\overline{SD}$)		V_{SS} - 0.3	V_{CC} + 0.3	
V_{SS}	Logic ground (IR21094/IR21894 only)		V_{CC} - 25	V_{CC} + 0.3	
dV_S/dt	Allowable offset supply voltage transient		—	50	V/ns
P_D	Package power dissipation @ $T_A \leq +25°C$	(8 Lead PDIP)	—	1.0	W
		(8 Lead SOIC)	—	0.625	
		(14 lead PDIP)	—	1.6	
		(14 lead SOIC)	—	1.0	
Rth_{JA}	Thermal resistance, junction to ambient	(8 Lead PDIP)	—	125	°C/W
		(8 Lead SOIC)	—	200	
		(14 lead PDIP)	—	75	
		(14 lead SOIC)	—	120	
T_J	Junction temperature		—	150	°C
T_S	Storage temperature		-50	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

Recommended Operating Conditions

The input/output logic timing diagram is shown in figure 1. For proper operation the device should be used within the recommended conditions. The V_S and V_{SS} offset rating are tested with all supplies biased at 15V differential.

Symbol	Definition	Min.	Max.	Units
VB	High side floating supply absolute voltage	V_S + 10	V_S + 20	V
V_S	High side floating supply offset voltage	Note 1	600	
V_{HO}	High side floating output voltage	V_S	V_B	
V_{CC}	Low side and logic fixed supply voltage	10	20	
V_{LO}	Low side output voltage	0	V_{CC}	
V_{IN}	Logic input voltage (IN & $\overline{SD}$)	V_{SS}	V_{CC}	
DT	Programmable dead-time pin voltage (IR21094 only)	V_{SS}	V_{CC}	
V_{SS}	Logic ground (IR21094 only)	-5	5	
T_A	Ambient temperature	-40	125	°C

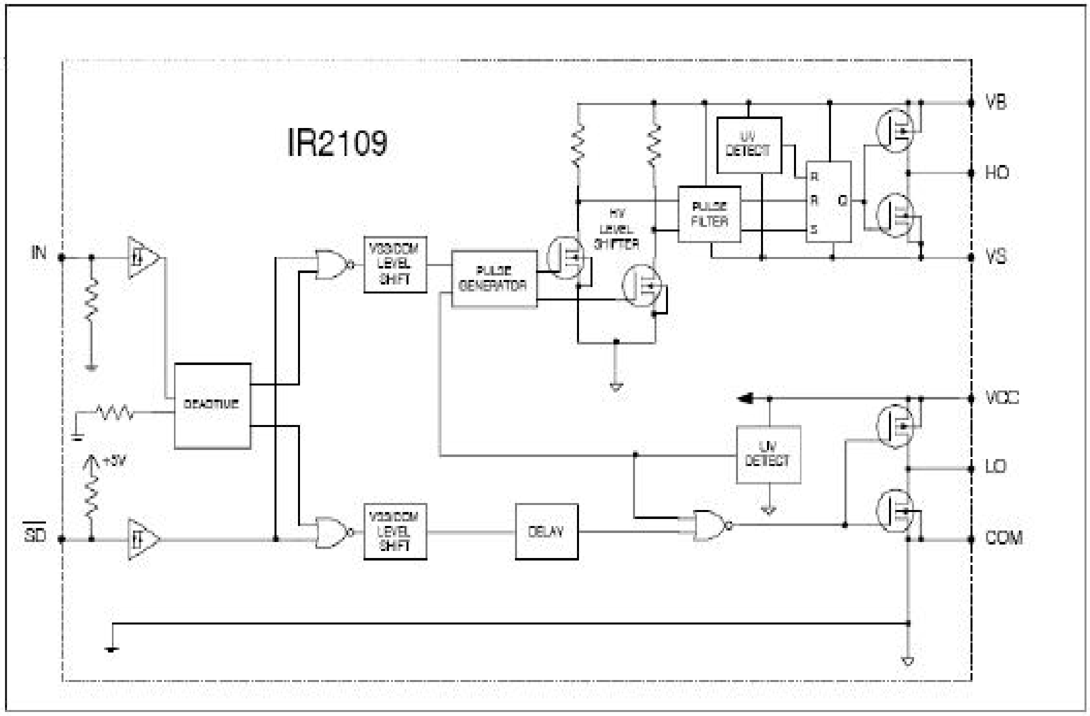
Note 1: Logic operational for V_S of -5 to +600V. Logic state held for V_S of -5V to $-V_{BS}$. (Please refer to the Design Tip DT97-3 for more details).

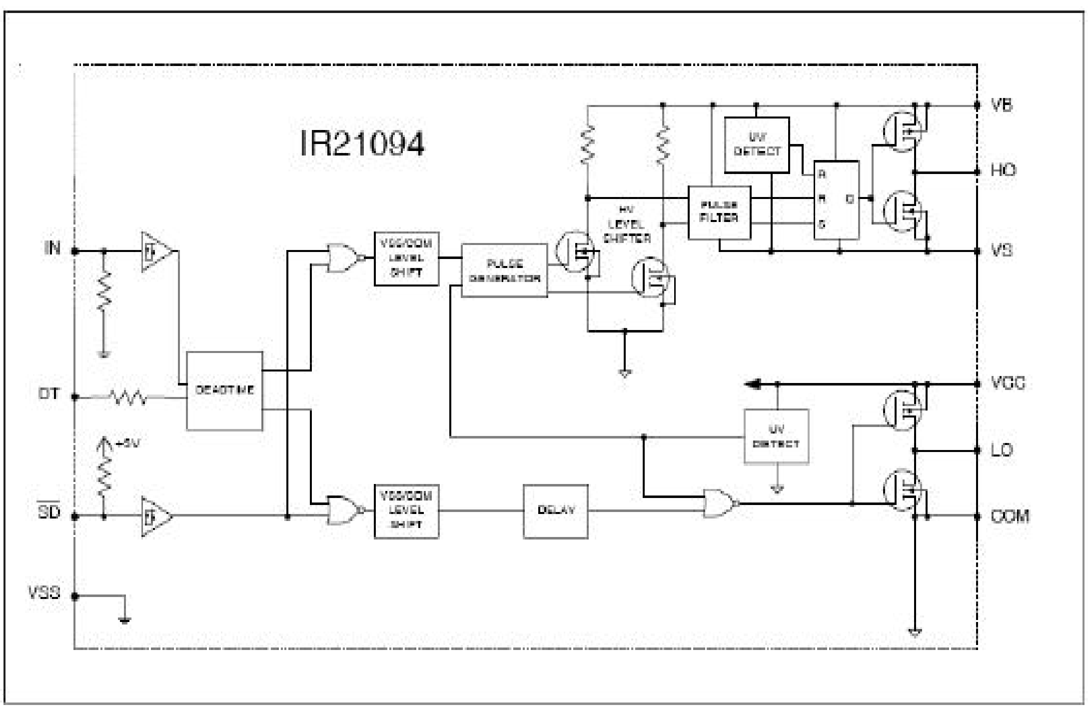
Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 15V, V_{SS} = COM, C_L = 1000 pF, T_A = 25°C, DT = VSS unless otherwise specified.

Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
t_{on}	Turn-on propagation delay	—	750	950	nsec	V_S = 0V
t_{off}	Turn-off propagation delay	—	200	280		V_S = 0V or 600V
t_{sd}	Shut-down propagation delay	—	200	280		
MT	Delay matching, HS & LS turn-on/off	—	0	70		
t_r	Turn-on rise time	—	150	220		V_S = 0V
t_f	Turn-off fall time	—	50	80		V_S = 0V
DT	Deadtime: LO turn-off to HO turn-on(DT_{LO-HO}) &	400	540	680		RDT= 0
	HO turn-off to LO turn-on (DT_{HO-LO})	4	5	6	usec	RDT = 200k (IR21094)
MDT	Deadtime matching = DT_{LO-HO} - DT_{HO-LO}	—	0	60	nsec	RDT=0
		—	0	600		RDT = 200k (IR21094)

Functional Block Diagrams

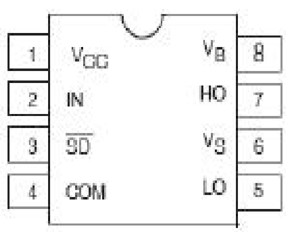




Lead Definitions

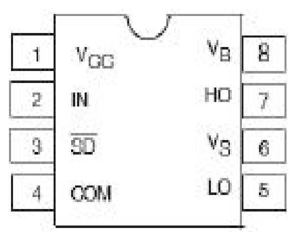
Symbol	Description
IN	Logic input for high and low side gate driver outputs (HO and LO), in phase with HO (referenced to COM for IR2109 and VSS for IR21094)
$\overline{SD}$	Logic input for shutdown (referenced to COM for IR2109 and VSS for IR21094)
DT	Programmable dead-time lead, referenced to VSS. (IR21094 only)
VSS	Logic Ground (21094 only)
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side and logic fixed supply
LO	Low side gate drive output
COM	Low side return

Lead Assignments



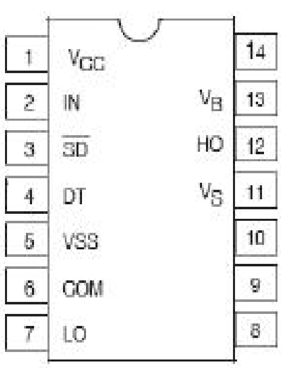
8 Lead PDIP

IR2109



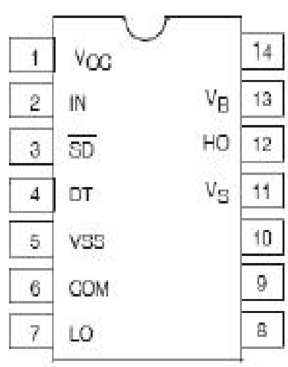
8 Lead SOIC

IR2109S



14 Lead PDIP

IR21094



14 Lead SOIC

IR21094S

APPENDIX H

Potentiometer Datasheet

Model P160
16mm Rotary Potentiometer
Conductive Plastic Element
100,000 Cycle Life
Metal shaft / Bushing
Multi – Ganged available
RoHS Compliant

MODEL STYLES	
Side Adjust , Solder Lugs	P160KNP
Side Adjust , PC pins	P160KN
Side Adjust , PC Pins, Long pins	P160KN2
Rear Adjust, PC pins	P160KNPD

ELECTRICAL[1]	
Resistance Range, Ohms	500-1M
Standard Resistance Tolerance	± 20%
Residual Resistance	20 ohms max.
Power rating Input Voltage, maximum	200 Vac max.
Power Rated, Watts	0.2W- B taper, 0.1W-others
Dielectric Strength	500Vac, I minute
Insulation Resistance, Minimum	100M ohms at 250Vdc
Sliding Noise	100mV max.
Actual Electrical Travel, Nominal	260°

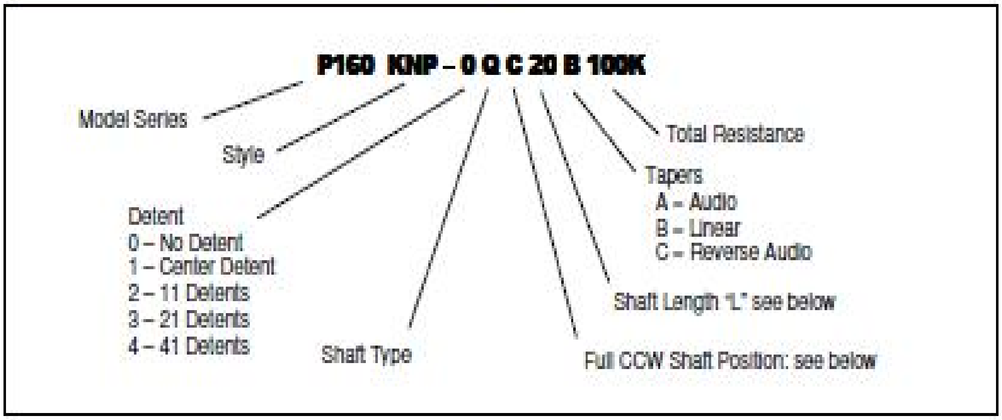
MECHANICAL	
Total Mechanical Travel	300°± 10°
Static Stop Strength	90 oz-in
Rotational Torque, Maximum	2.5 oz-in

ENVIRONMENTAL	
Operating Temperature Range	-20°C to +70°C
Rotational Life	100,000 cycles

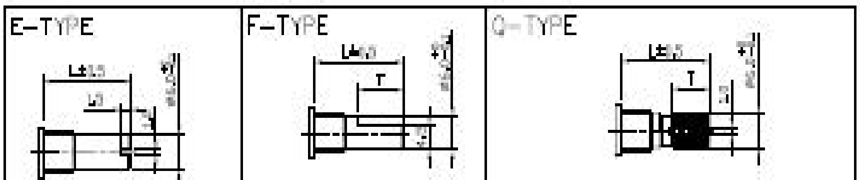
[1] *Specifications subject to change without notice.*

Model P160

ORDERING INFORMATION[2]



Shaft Types



E-Type:

L	10	15	20	25	30	35	40

F-Type:

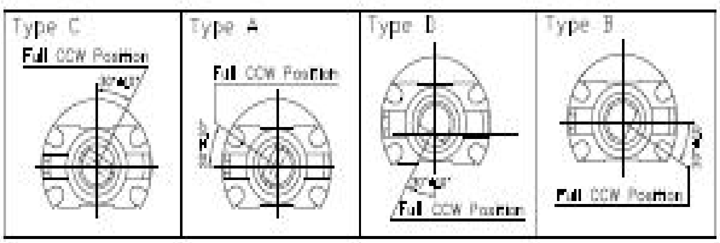
L	15	18	20	25	30	35
T	7	10	12	12	12	12

Q-Type:

L	10	12	13	14	15	17	20	25	30	35	45
T	2.5	4.5	4	5	6	8	10	12	12	12	12

Shaft Position (F-Type Shaft)

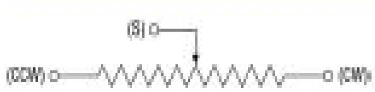
Dashed lines on Type "C" and Type "A" shows position of adjustment slot for E-Type and Q-Type shafts



STANDARD RESISTANCE VALUES, OHMS

500	1K	2K	5K	10K	20K	50K	100K	200K	500K	1MEG

CIRCUIT DIAGRAM



APPENDIX I

UP00A USB PIC Programmer Datasheet

4. HARDWARE (Programmer)

Connecting the Programmer to the Computer

Use the USB Cable provided.

Connect one side of the cable to the programmer and the other side to the USB port of the computer.

Plugging the Microcontroller

40-pin Microcontroller

- Plug in the microcontroller at the socket (indicated on the board) and **push forward the toggle switch** as shown.

5. SOFTWARE INSTALLATION

Before UP00A PIC USB programmer can be used, the driver must be installed (1st time User).

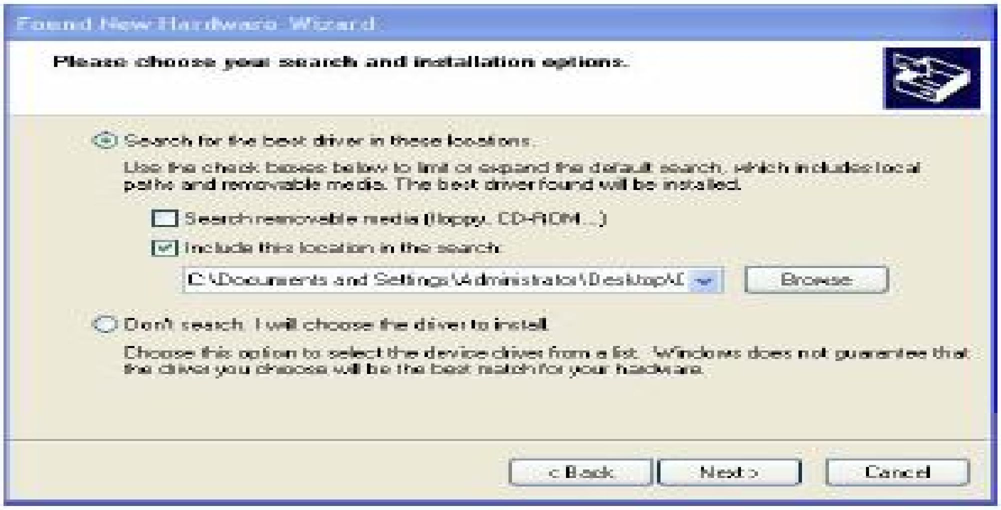
1. Copy "Cytron Prgrammer" folder from the CD to your PC.

2. Plug one end of the USB cable to the USB Programmer and the other end to the PC's USB port. You will see the 'loading' red light illuminates.

3. The window will now show "Found New Hardware".

4. Choose to "Install from a list of specific location (Advanced)" when the "Wizard" window appear.

5. Click *Browse* and browse to "USB Driver" folder in "Cytron Programmer" folder that you copied. Click *Next* to proceed the installation.



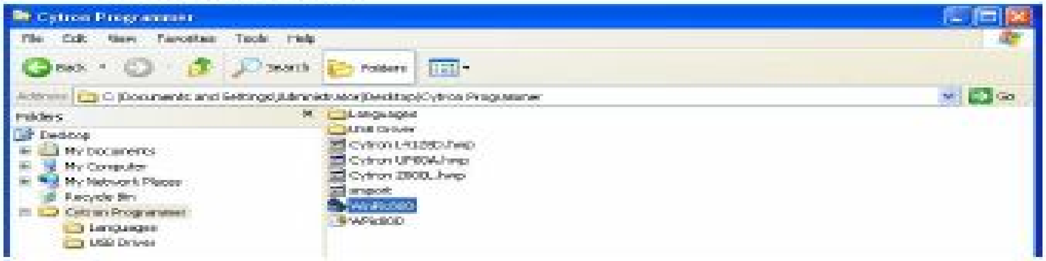
6. If the window as figure below pops up, click *Continue Anyway*.

7. When installation is complete, click *Finish*.

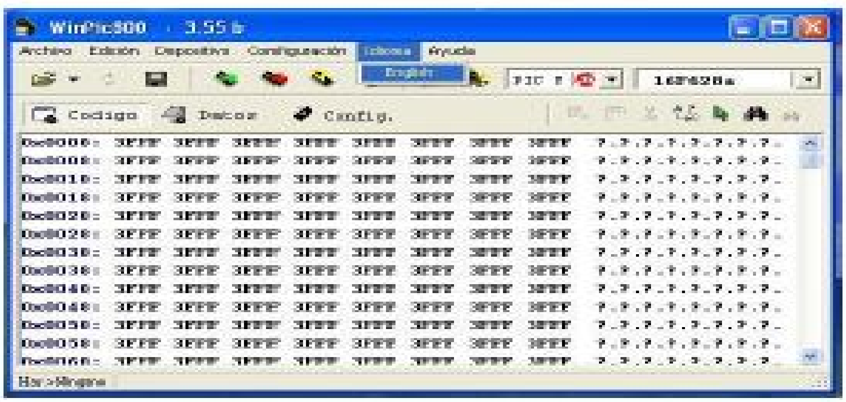
8. Once the installation of driver is completed, the "ready" green light will illuminate.

9. After driver installation, USB programmer is ready to be used with WinPic800. This software is a freeware, thus Cytron will not be responsible for any upgrade or issue found with this software.

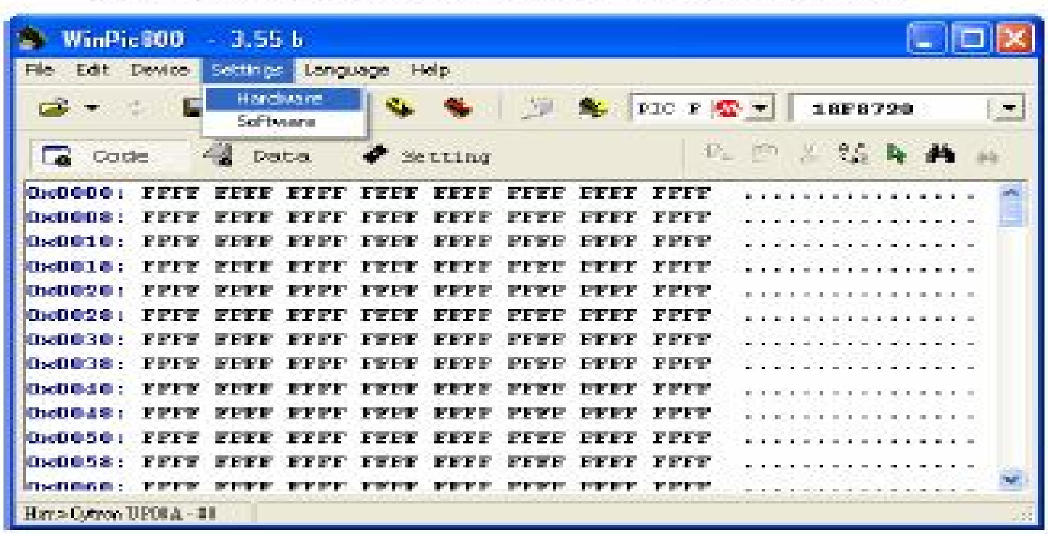
10. The application or .exe file is included in "Cytron Programmer" folder, please open WinPic800.exe as shown.



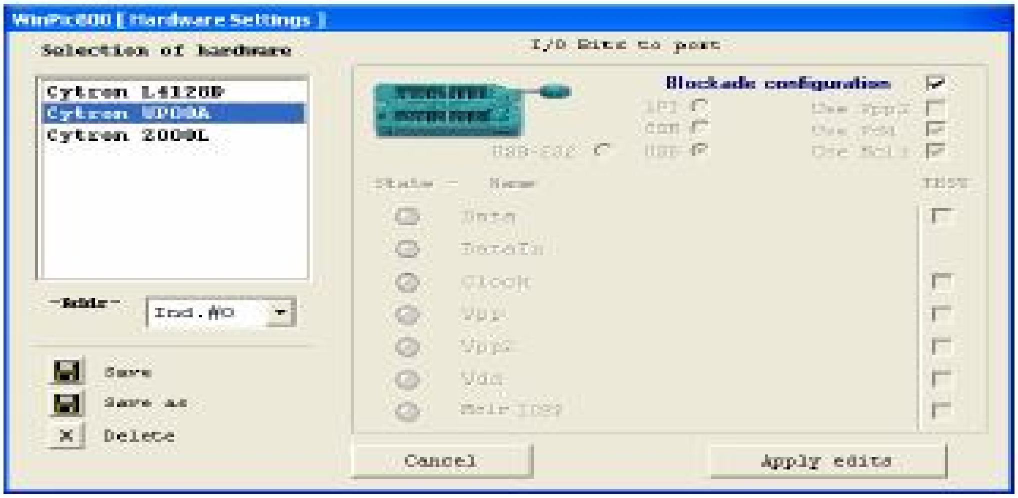
11. By default, the software is in other language, click *OK* when the window below pops up and then change the language to English (One time configuration).



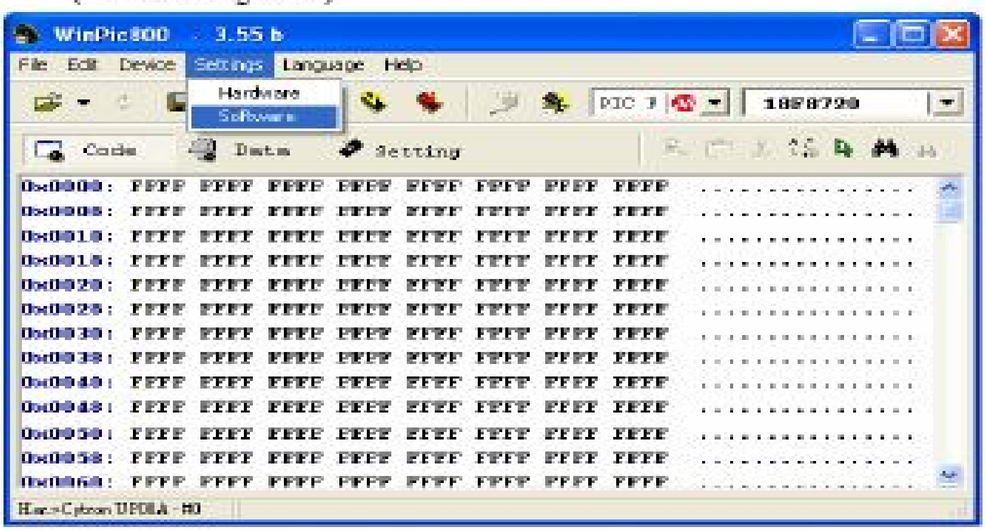
12. Correct hardware must be chosen (one time configuration) because WinPic800 support more than one programmer. Go to "Settings", choose *Hardware*.



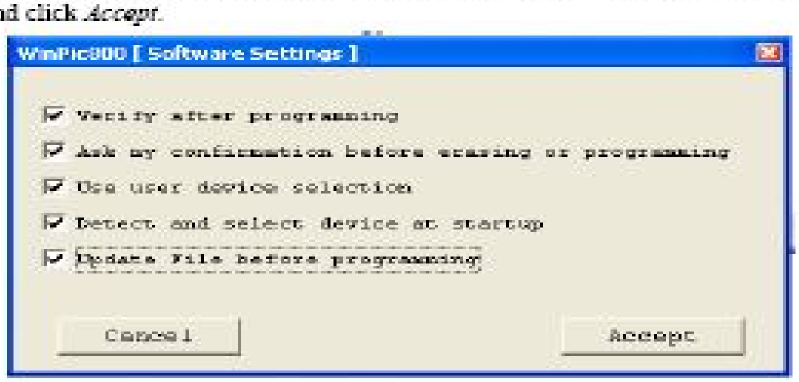
13. A "WinPic800 (Hardware Settings)" window will appear. Choose "Cytron UP00A" under "Selection of hardware". Click *Apply edits* to close this window.



14. Next is to configure software settings. Please go to "Settings" and choose *Software* (one time configuration).

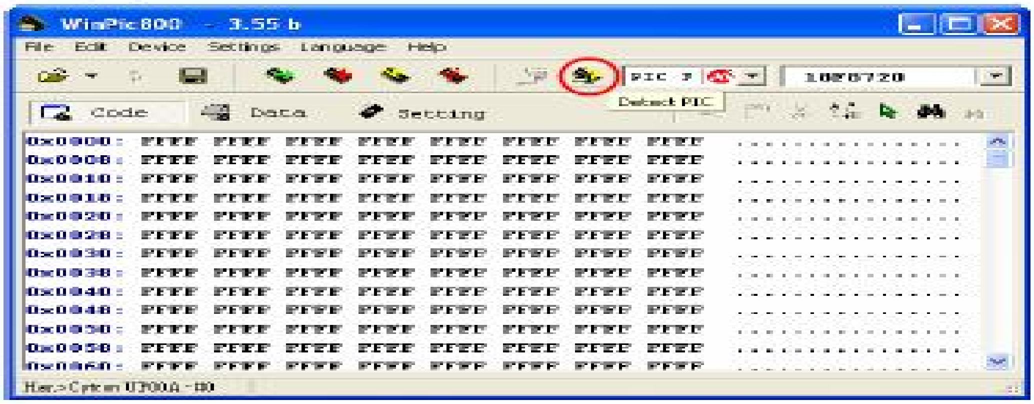


15. A "WinPic800 (Software Settings)" window will appear. Tick the selection as shown and click *Accept*.

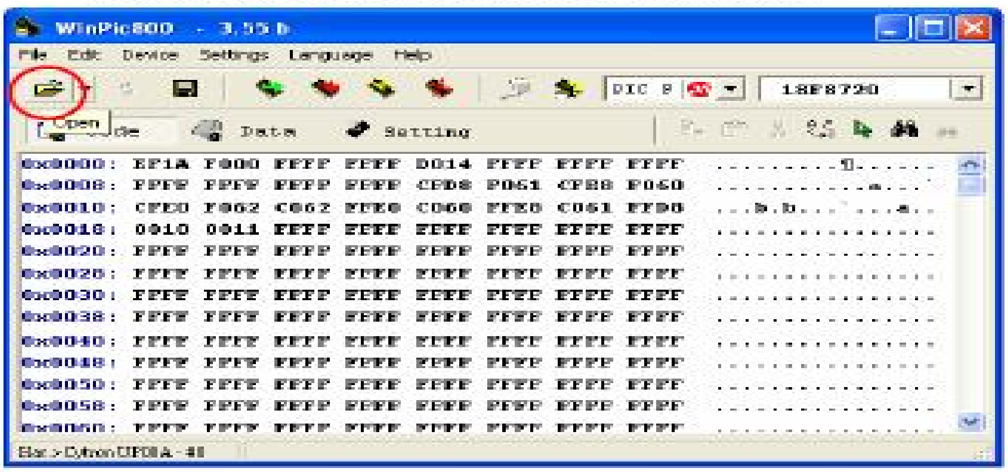


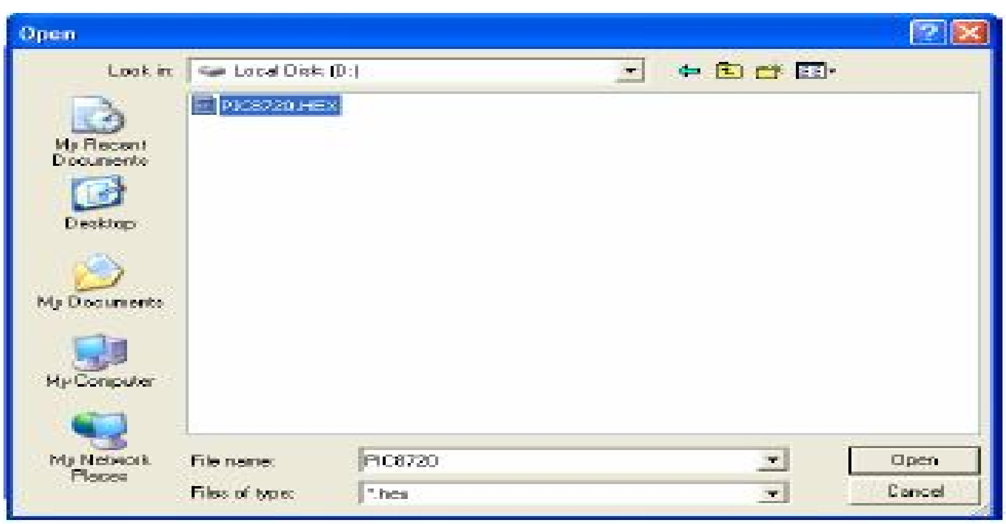
6. HOW TO PROGRAM THE PIC MICROCONTROLLER

1. Now WinPic800 is ready to program the PIC. This programmer is able to detect the PIC. By clicking the icon shown, the programmer will detect the type of PIC on the programmer.

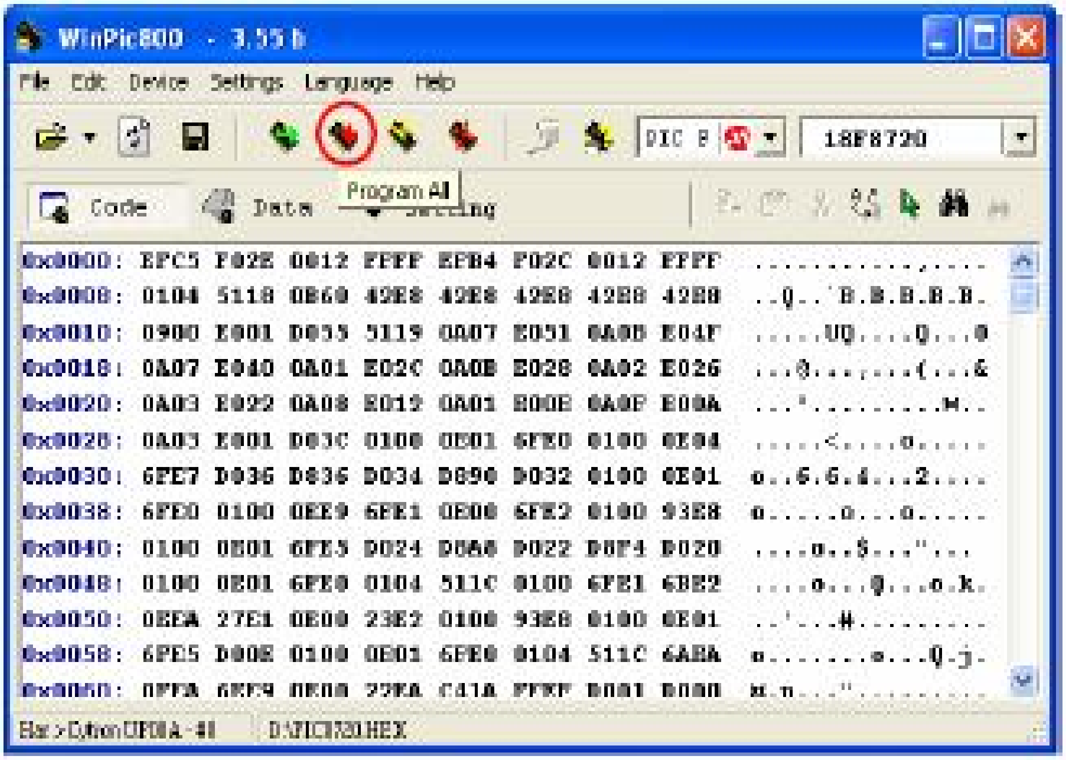


2. To write Hex code to PIC we must first open the hex file. By clicking the icon shown, a browse window will appear, open the hex file by clicking the file.

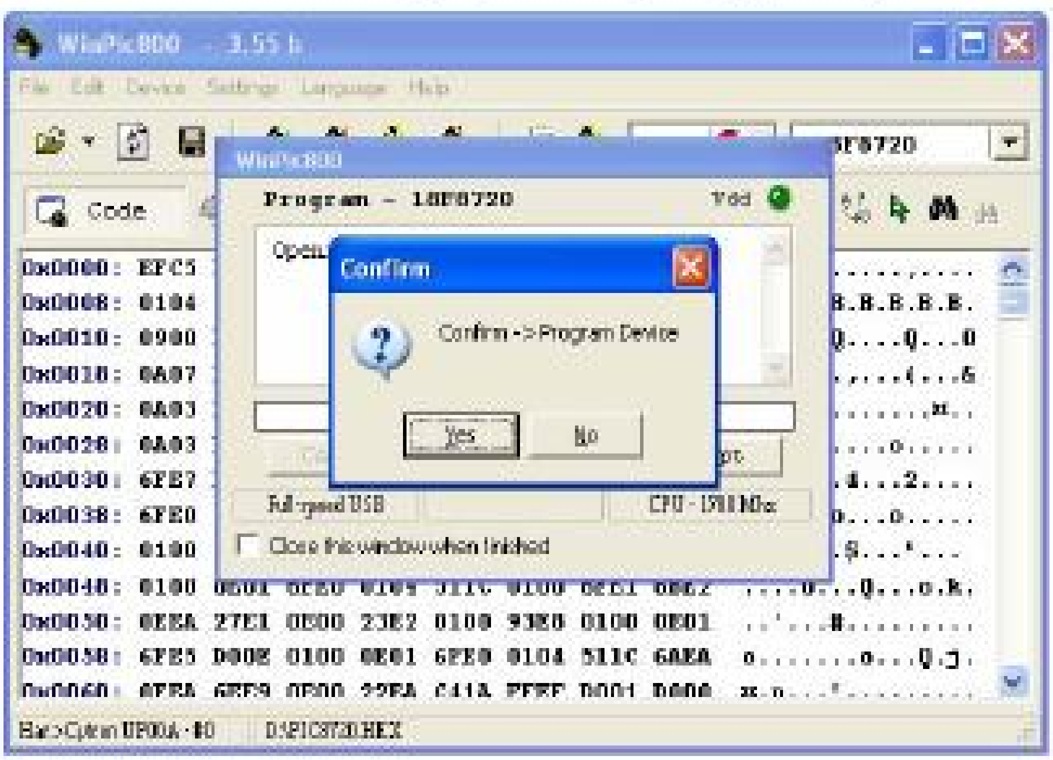


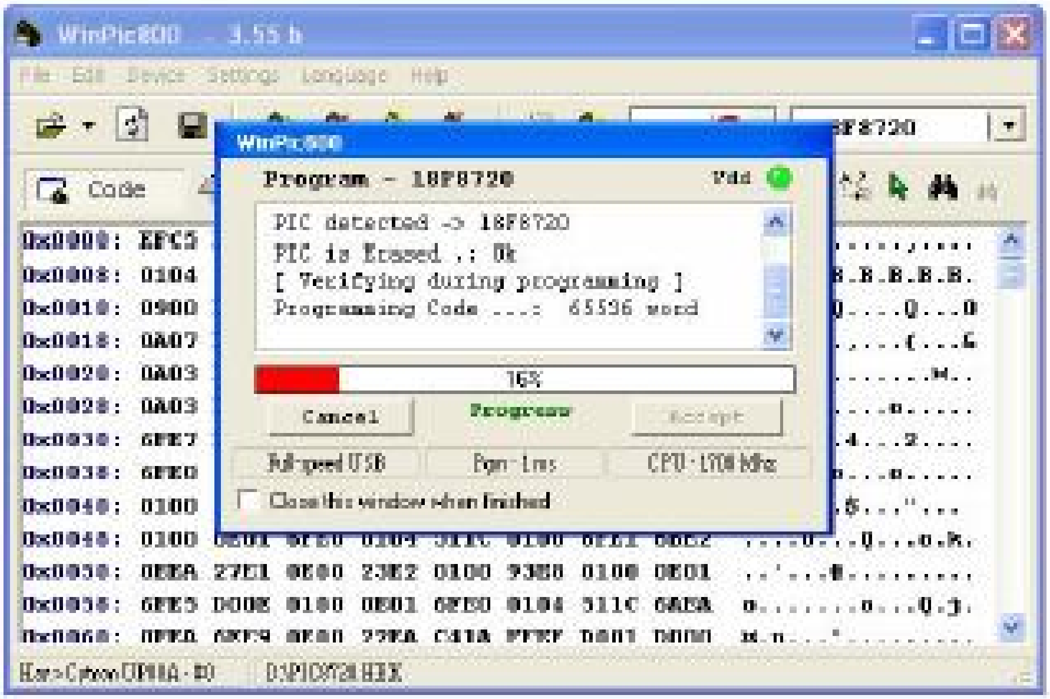


3. Program the file to PIC by clicking the icon shown.

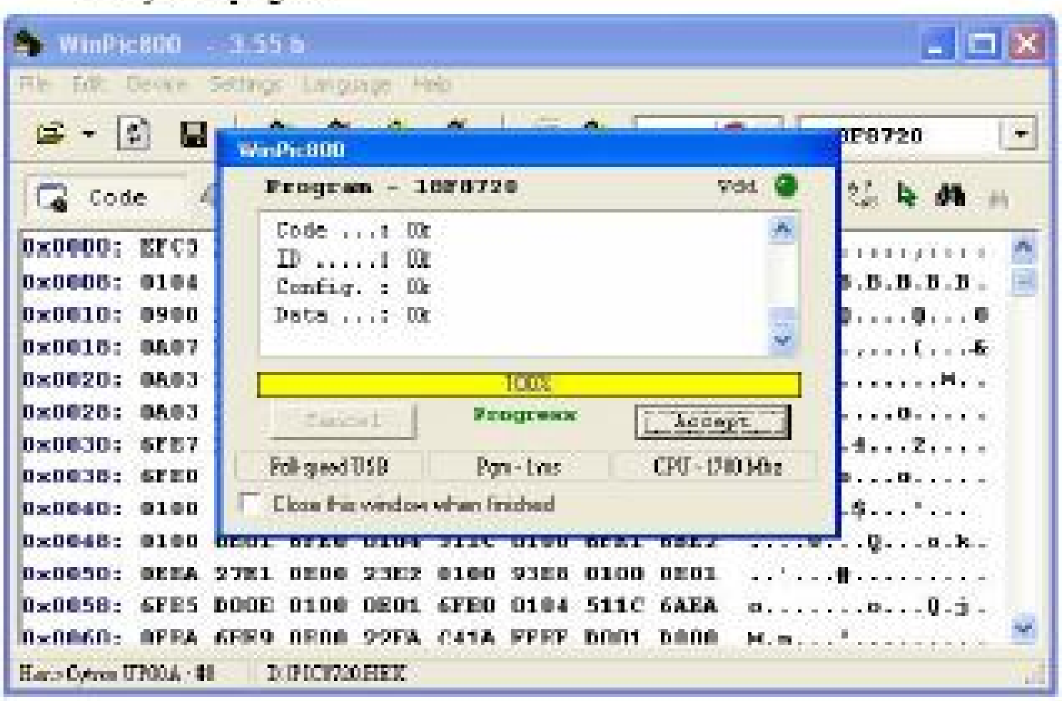


4. A confirmation window will appear, click *Yes* to proceed programming PIC.





5. When it is completed, the window will show the status. Click *Accept* and the PIC is ready to be plug out.



6. To disconnect UP00A, simply plug the USB out. No extra configuration or setting needed. Same applied when plug-in for the 2[nd] time, installation of driver is not required.

PHOTOVOLTAIC CHARGE CONTROLLER

NOOR JUWAINA AYUNI BT. MOHD

UNIVERSITI MALAYSIA PAHANG

PHOTOVOLTAIC CHARGE CONTROLLER

NOOR JUWAINA AYUNI BT. MOHD

This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor Degree of Electrical Engineering (Electronics)

Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang

MAY, 2009

"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering (Electronics)"

Signature : ______________________

Name : MOHD SHAWAL BIN JADIN

Date : 1 MAY 2009

Signature : ______________________________

Author : NOOR JUWAINA AYUNI BT. MOHD

Date : 4 MAY 2009

Specially dedicated to my beloved family

To My Beloved Mother and Dad, My Lovely Sisters & My Sweet Brothers

Mohd Bin Tahar
Wan Kembang Binti Wan Ngah

Dzul Fadli Bin Mohd
Dzul Awatif Bin Mohd
Noor Syafiqa Amira Bt. Mohd
Dzul Haziq Bin Mohd
Noor Huwaida Adeeba Bt. Mohd
Muhammad Aqif Ikhwan Bin Mohd

And those people who have guided and inspired me throughout my journey of education

Thanks for everything…

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my supervisor, Mr Mohd Shawal Bin Jadin, for encouragement, guidance, critics, friendship, advice, information and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Malaysia Pahang (UMP) for funding my degree study. Librarians at UMP also deserve special thanks for their assistance in supplying the relevant literatures and guiding me in using e-journal.

My sincere appreciation also extends to all my colleagues, and others who have provided assistance at various occasions especially to Marliyani bte Omar. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members especially my mother and dad for their moral support, advice and understanding me.

Thank you.

Noor Juwaina Ayuni Bt. Mohd

ABSTRACT

Photovoltaic or in short term PV is one of the renewable energy resources that recently has become broader in nowadays technology. The demand or future work is looking for high efficiency, more reliable and economical price PV charge controller which is come in portable size has become very popular in PV system. In general, PV system consists of a PV array, charge controller, rechargeable battery and dc load. PV charge controller is very important in PV system. In this project, a PV Charge Controller is designed based on microcontroller (PIC 16F877A) which reduced complexity in the number of electronic components and increased monitoring and regulative functions. This project used dc-dc buck converter circuit which has been simulated using software of OrCAD PSPICE. Pulse width modulation (PWM) will be implemented on a PIC 16F877A to control duty cycle, voltage and current in the PV system and is programmed using software of Microcode Studio. Liquid Crystal Display (LCD) is used to display the voltage and current from rechargeable battery. The benefit of this project is an improvement of efficiency depend on duty cycle and voltage change.

ABSTRAK

Voltan cahaya atau singkatannya PV adalah salah satu daripada sumber tenaga yang dapat diperbaharui yang baru-baru ini menjadi semakin meluas dalam teknologi pada masa kini. Permintaan atau projek di masa hadapan bagi pengawal cas elektrik PV adalah dalam keluaran yang lebih efisien, boleh dipercayai kegunaannya dan harga yang berpatutan dalam bentuk yang mudah dibawa semakin popular dalam sistem PV. Secara umumnya, sistem PV mengandungi susunan PV, pengawal cas elektrik, bateri cas semula dan beban arus elektrik terus. Pengawal tenaga elektrik sangat berguna dalam system PV. Di dalam projek ini, pengawal cas elektrik photovoltaic direka berdasarkan pengawal terbenam (PIC 16F877A) di mana ia mengurangkan kekompleksan dalam penggunaan jumlah komponen elektronik dan meningkatkan pengawasan dan fungsi pengaturan. Projek ini menggunakan litar *"dc-dc buck converter"* yang telah dihasilkan menggunakan perisian *"OrCAD PSPICE"*. Nadi keluasan modulasi (PWM) akan dilaksanakan menggunakan PIC 16F877A untuk mengawasi kitaran duti, voltan dan arus aliran elekrik dalam system photovoltaic dan seterusnya diprogramkan menggunakan perisian *"MicroCode Studio"*. Paparan cecair Kristal (LCD) pula digunakan untuk mempamerkan bacaan voltan dan arus aliran elektrik daripada bateri caj semula. Kelebihan projek ini adalah peningkatan kecekapan yang bergantung kepada kitaran duti dan perubahan voltan.

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LIST OF SYMBOLS

D	Duty Cycle
f	Frequency
V	Voltage/Potential difference
L	Inductance
R	Resistance
C	Capacitance
I	Current
T	Time

LIST OF ABBREVIATIONS

D.C.	Direct Current
ADC	Analog to Digital converter
PWM	Pulse Width Modulation
PV	Photovoltaic
IC	Integrated Circuit
ICD	Circuit Debugging
IDE	Integrated Development Environmental
LCD	Liquid Crystal Display
DIP	Dual Inline Package
L.E.D	Light Emitting Diode
PIC	Programmable Interface Controller
RISC	Reduced Instruction Set Computing
OSC	Oscillation
ESR	Equivalent Series Resistance
CCM	Continues Current Mode

LIST OF APPENDIXES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Photovoltaic or in short term PV is one of the renewable energy resources that recently has become broader in nowadays technology. PV has many benefits especially in environmental, economic and social. In general, a PV system consists of a PV array which converts sunlight to direct-current electricity, a control system which regulates battery charging and operation of the load, energy storage in the form of secondary batteries and loads or appliances. A charge controller is one of functional and reliable major components in PV systems. A good, solid and reliable PV charge controller is a key component of any PV battery charging system to achieve low cost and the benefit that user can get from it. The main function of a charge controller in a PV system is to regulate the voltage and current from PV solar panels into a rechargeable battery. The minimum function of a PV charge controller is to disconnect the array when the battery is fully charged and keep the battery fully charged without damage. A charge controller is important to prevent battery overcharging, excessive discharging, reverse current flow at night and to protect the life of the batteries in a PV system. A power electronics circuit is used in a PV charge controller to get highest efficiency, availability and reliability. The use of power electronics circuits such as various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology as power conditioning circuitry to provide a desired current to charge battery effectively.

1.2 OBJECTIVES

(i) To design Photovoltaic (PV) Charge Controller by using PIC microcontroller type.

(ii) To monitor voltage and current as the input of the rechargeable battery and display on the Liquid Crystal Display (LCD).

1.3 SCOPE OF PROJECT

(i) The PV charge controller that designed in this project will be implement PIC microcontroller in it.

(ii) This project concentrates on DC-DC Converter.

(iii) This project will use PIC microcontroller to control the voltage and current at certain values that have been set which are act as input of the rechargeable battery and displays all the results of voltage, current, power and percentage remaining rechargeable battery on the LCD.

1.4 PROBLEM STATEMENT

Most of the PV charge controller nowadays just uses LED to indicate the operating status of the rechargeable battery. It is hard to know the values of the rechargeable battery that have been used such as voltage, current and others. Besides most of PV charge controller is expensive depends on the total cost of PV system that has been used.

1.5 THESIS OVERVIEW

This Photovoltaic Charge Controller final thesis is arranged into following chapter:

Chapter 1: Basically is an introduction of the project. In this chapter, provides the background of the project, objectives, scope of the project, problem statement, and also the thesis outline.

Chapter 2: Focuses on literature reviews of this project based on journals and other references.

Chapter 3: Mainly focused on methodologies for the development of Photovoltaic Charge Controller. Details on the progress of the project are explained in this chapter.

Chapter 4: Presents the results obtained and the limitation of the project. All discussions are concentrating on the result and performance of Photovoltaic Charge Controller.

Chapter 5: Concludes overall about the project. Obstacle faces and future recommendation are also discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Photovoltaic Charge Controller

A charge controller is needed in photovoltaic system to safely charge sealed lead acid battery. The most basic function of a charge controller is to prevent battery overcharging. If battery is allowed to routinely overcharge, their life expectancy will be dramatically reduced. A charge controller will sense the battery voltage, and reduce or stop the charging current when the voltage gets high enough. This is especially important with sealed lead acid battery where we cannot replace the water that is lost during overcharging. Unlike Wind or Hydro System charge controller, PV charge controller can open the circuit when the battery is full without any harm to the modules. Most PV charge controller simply opens or restricts the circuit between the battery and PV array when the voltage rises to a set point. Then, as the battery absorbs the excess electrons and voltage begins dropping, the controller will turn back on. Some charge controllers have these voltage points factory-preset and non adjustable, other controllers can be adjustable. [1]

2.2 Photovoltaic

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sun energy (sunlight or sun ultra violet radiation) directly into electricity. Due to the growing demand for clean sources of energy, the manufacture of solar cells and PV arrays has expanded dramatically in recent years.[2] PV production has been doubling every two years, increasing by an average of 48 percent each year since 2002, making it the world's fastest-growing energy technology.[3] At the end of 2008, according to preliminary data, cumulative global installations reached 15,200 megawatts.[4] PV is best known as a method for generating electric power by using solar cells packaged in PV modules, often electrically connected in multiples as solar PV arrays to convert energy from the sun into electricity. The term PV denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all PV devices are some type of photodiode. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. The first practical application of PV was to power orbiting satellites and other spacecraft, but today the majority of PV modules are used for grid connected power generation.

Cells require protection from the environment and are usually packaged tightly behind a glass sheet. When more power is required than a single cell can deliver, cells are electrically connected together to form photovoltaic modules, or solar panels. A single module is enough to power an emergency telephone, but for a house or a power plant the modules must be arranged in arrays. Although the selling price of modules is still too high to compete with grid electricity in most places, significant financial incentives in Japan and then Germany and Italy triggered a huge growth in demand, followed quickly by production. Perhaps not unexpectedly, a significant market has emerged in off-grid locations for solar-power-charged storage-battery based solutions. These often provide the only electricity available. [5] The EPIA/Greenpeace Advanced Scenario shows that by the year 2030, PV systems could be generating approximately 1,864 GW of electricity around the world. This means that, assuming a serious commitment is made to energy efficiency, enough solar power would be produced globally in twenty-five years' time to satisfy the electricity needs of almost 14% of the world's population. [6]

2.3 DC-DC Converters

There are various dc to dc converters topologies like buck converter, boost converter, buck-boost converter and others converter topology are used in PV charge controller. Since solar panels are only capable of producing a DC voltage, the DC-DC converter becomes quite useful by providing the flexibility to adjust the DC voltage or current at any point in the circuit. DC-DC converters are often preferred in modern electronics since they are smaller, lightweight, provide a high quality output, and more efficient. [7]

2.3.1 Buck (Step-Down) Converter

Regarding this project, several reviews were made. One of the researches made is about buck converter topology which is one of many topologies that were used in PV charge controller development. A buck converter is called a step-down DC to DC converter because the output voltage is less than the input. 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. A buck converter can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating. Most buck converters are designed for continuous-current mode operation compared to the discontinuous-current mode operation. The continuous-current mode operation is characterized by inductor current remains positive throughout the switching period. Conversely, the discontinuous-current mode operation is characterized by inductor current returning to zero during each period. The Figure 2.1 shows the basic of buck converter topology circuit. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

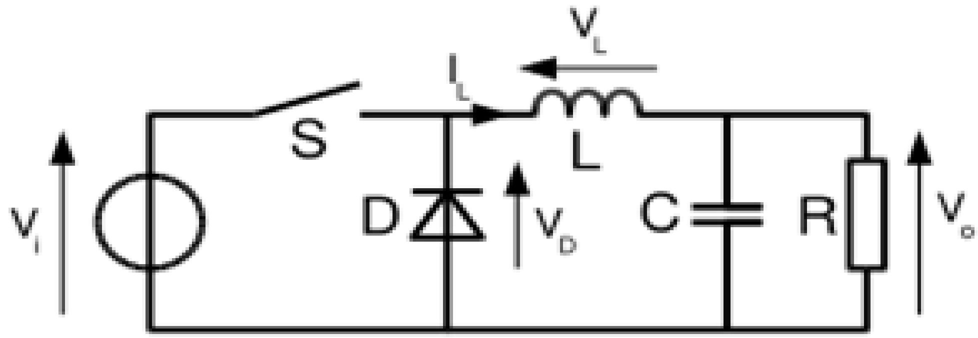

Figure 2.1: A basic buck converter topology circuit

2.3.2 Basic Operation of Buck Converter

Method 1: During ON state

Refer on Figure 2.2, when the switch is in ON state, diode become as reversed biased and the inductor will deliver current and switch conducts inductor current. With the voltage (Vin -Vo) across the inductor, the current rises linearly (current changes, ΔiL). The current through the inductor increase, as the source voltage would be greater then the output voltage and capacitor current may be in either direction depending on the inductor current and load current. When the current in inductor increase, the energy stored also increased. In this state, the inductor acquires energy. Capacitor will provides smooth out of inductor current changes into a stable voltage at output voltage and it's big enough such that V out doesn't change significantly during one switching cycle.

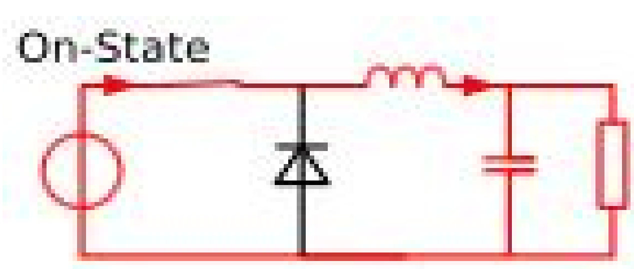

Figure 2.2: Equivalent circuit for switch closed

Method 2: During OFF state

As can see in Figure 2.3, when the switch is in OFF state, the diode is ON and the inductor will maintains current to load. Because of inductive energy storage, iL will continues to flow. While inductor releases current storage, it will flow to the load and provides voltage to the circuit. The diode is forward biased. The current flow through the diode which is inductor voltage is equal with negative output voltage.

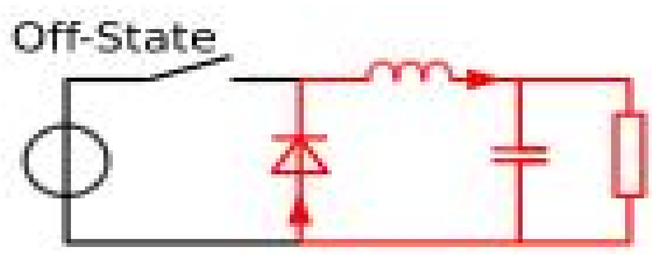

Figure 2.3: Equivalent circuit for switch open

2.4 PIC 16F877A Microcontroller

2.4.1 An overview

The **PIC** (Programmable Interface Controller) line of microcontrollers was originally developed by the semiconductor division of General Instruments Inc (Figure 2.2). The first PIC's were a major improvement over existing microcontroller because they were a programmable, high output current, input/output controller built around a RISC (Reduced Instruction Set Code) architecture. The first PICs ran efficiently at one instruction per internal clock cycle, and the clock cycle was derived from the oscillator divided by 4. Early PICs could run with a high oscillator frequency of 20 MHz. This made them relatively fast for an 8-bit microcontroller, but their main feature was 20 mA of source and sink current capability on each I/O (Input/Output) pin. Typical micros of the time were advertising high I/O currents of only 1 milliampere (mA) source and 1.6 mA sink. [8]

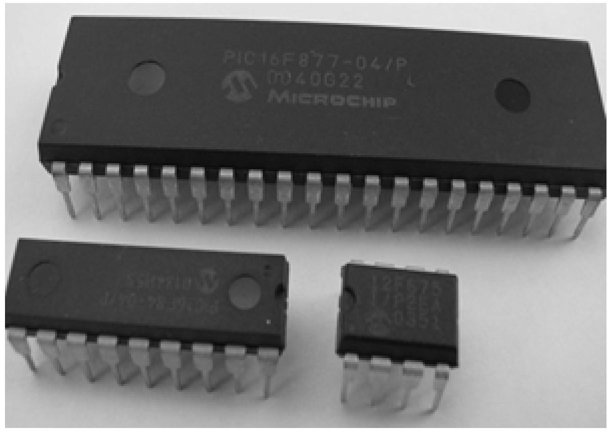

Figure 2.4: Types of PIC Microcontroller

2.4.2 PIC 16F877A Microcontroller Implementation

Regarding this project, several reviews were made. PIC 16F877A microcontroller is selected to monitor voltage and current in PV charge controller. PIC 16F877A is general purpose microprocessor which has additional parts that allow them to control external devices. Basically, a microcontroller executes a user program which is loaded in its program memory. PIC16F877A is a small piece of semiconductor integrated circuits (IC). The package type of these integrated circuits is DIP (Dual Inline Package) package. 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. PIC 16F877A include on-chip PWM units and has two which has a selectable on-time and period. The duty cycle is the ratio of the on-time to the period while the modulating frequency is the inverse of the period.

2.5 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) controls adjusts the duty ratio of the switches as the input changes to produce a constant output voltage. The DC voltage is converted to a square-wave signal, alternating between fully on and zero. By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. In nowadays implementation, many microcontrollers already include on-chip PWM controllers, making implementation easy. In a nutshell, PWM is a way of digitally encoding analog signal levels. PWM control can be used in two ways: voltage-mode and current-mode. In voltage-mode control the output voltage increases and decreases as the duty ratio increases and decreases. The output voltage is sensed and used for feedback. If it has two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach full charge. Then it will drop the voltage lower to sustain a "finish" or "trickle" charge. Two-stage regulating is important for a system that may experience many days or weeks of excess energy (or little use of energy). It maintains a full charge but minimizes water loss and stress. The voltages at which the controller changes the charge rate are called set points. When determining the ideal set points, there is some compromise between charging quickly before the sun goes down, and mildly overcharging the battery. The determination of set points depends on the anticipated pattern of use, the type of battery, and to some extent, the experience and philosophy of the system designer or operator. [9]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains about hardware development such as equipments, procedures and method design for the photovoltaic (PV) charge controller. The relevant information is gathered through literature review from previous chapter. This chapter also will cover about designing the buck converter, software interface, part by part circuits and complete circuit. Before looking at the details of all methods below, it is best to begin with brief review of the system design.

3.2 Hardware Development

3.2.1 System Design

The photovoltaic (PV) charge controller was designed to protect the rechargeable battery. To design this PV charge controller, it consists of seven parts where the first part is a buck converter circuit, second part is a microcontroller circuit, third part is a driver circuit, four part is rechargeable battery, five part is voltage sensor, six part is current sensor and seven part is liquid crystal display, LCD.

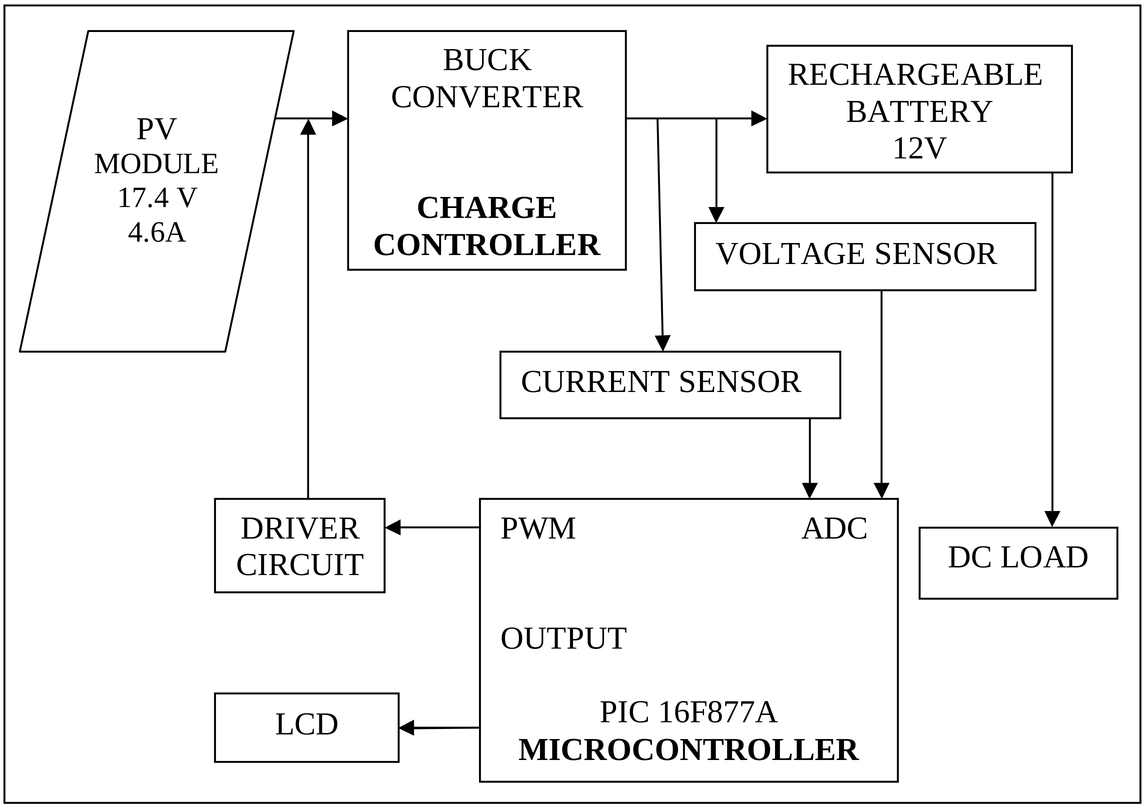

Figure 3.1: System design of Photovoltaic Charge Controller

3.2.2 Buck Converter Circuit Design

For the first part is a buck converter circuit, this circuit is needed in PV charge controller to control charging voltage from PV module to rechargeable battery. The circuit included parts of Buck components such as controllable switch (IRFP150N), diode (1N4148), inductor and capacitor, and load resistor. Some of the designs criteria as show as follow:

i. POWER MOSFET (IRFP150N)

As illustrate in Figure 3.2, this power MOSFET has limitations operation in terms of voltage, current and power dissipation. The power absorbed by the gate drive circuitry should not significantly affect the overall efficiency. The power MOSFET current rating is related with the heat dissipated in the devices. This rating will be take in consideration for designing appropriate circuit to protect power MOSFET against high voltage and current, thus cause heat generation. While considering protection of power MOSFET against over voltage, a distinction has to be made between slowly varying over voltage and short time surge. It is about 100Vdc the minimum rating of drain to source breakdown voltage. Gate voltage must be 15-20V higher than the drain voltage. Being a high side switch, such gate voltage would have to be higher than the rail voltage, which is frequently the higher voltage available in the system. Refer APPENDIX D for details specification. The datasheet provided by manufacturers are given in order to ensure the devices neither connected in the specified limits nor exceeded.

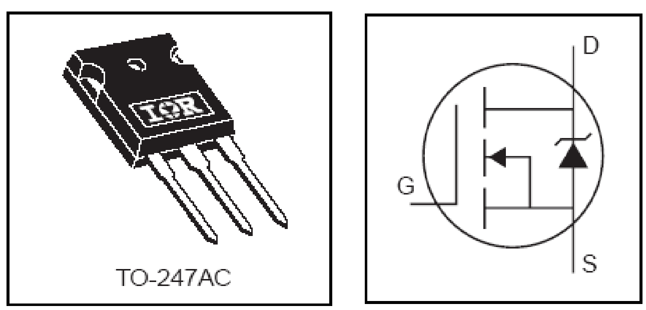

Figure 3.2: IRFP50N terminal pin configuration

ii. Capacitor

Except refer to capacitor value and rating of voltage use in system, the capacitor also supposed to be choose with minimum loss because switched power regulators are usually used in high current-performance power supplies. Loss occurs because of its internal series resistance and inductance. Commonly capacitors for switched regulators are chosen based on the equivalent series resistance (ESR).

iii. Inductor

The function on inductor is to store energy and the value is selected to maintain a continuous current mode (CCM) operation as a rated of load (5.6 Ω) is decided for this Buck converter. In CCM, current flow continuously in inductor during the entire switching cycle and output inductance selected to limit the peak to peak ripple current flowing. The factors to be considered in selecting the inductor are its peak to peak ripple current (CCM), maximum dc or peak current (not overheat) and maximum operating frequency (maximum core loss is not exceeded, resulting in overheating or saturation).

Design of buck converter circuit will consider as continuous current operation mode, CCM. The choice of switching frequency and inductance will affect the continuous current in buck converter design. Just for simple overview about buck converter, as the switching frequency increase, it can reduce the size of inductor in order to produce CCM and reduce capacitor size to limit output ripple in buck converter design.

Here the calculations method and formulas used in order to determine the values of the required components in Buck converter design. This buck converter circuit is needed to produce an output voltage of 12Vdc from an input of 17.4Vdc.

Step 1: Determine the duty cycle, D to obtain required output voltage.

$$D = \frac{Vo}{Vd} \tag{3.1}$$

Where:

D = Duty cycle

Vo = Voltage output

Vd = Voltage input

$$D = \frac{12V}{17.4V}$$

$$D = 0.7$$

$$\%D = 70\%$$

Step 2: Select a particular switching frequency (f) and device

Before Buck converter circuit is design, the pulse width modulation (PWM) frequency should be determined. Basically, if the frequency increases, the efficiency of the Buck converter also increases. Thus to choose a suitable PWM frequency for the Buck converter, both of power consumption and the efficiency of the system need to be consider.

First, we should determine the whole system timing characteristics. The design of Buck converter input voltage should able to be decrease to 70% of its maximum value. Thus, the component at hand is POWER MOSFET IRFP150N for the switching element, IR2109 for the driver and PIC16F877A for the PWM controller. The rise time, tr, the fall time, tf, the minimum on-time, ton (min) and the minimum off-time, toff(min) can be found in the datasheet. Table 3.1 lists the rise and fall times and Table 3.2 lists the on and off times of each components.

Table 3.1: Rise and Fall Time

Bil	Component	tr(ns)	tf(ns)
1	IRFP150N	56	40
2	IR2109	150	50

Table 3.2: Minimum On and Off Time

Bil	Component	tr(ns)	tf(ns)
1	IRFP150N	11	45
2	IR2109	750	200

Referring to Table 1, the slowest tr and tf of the components are 150ns and 50ns respectively. Referring Table 2, it can be seen that both the slowest ton (min) and toff(min) of all components is at MOSFET driver. With the information, the frequency range for the de vice can be determined. A summary of data that we obtained are as follows:

(a) D (min) = 10%

(b) D (max) = 70%

(c) tr (slowest) = 150ns

(d) tf (slowest) = 50ns

(e) ton (min) = 750ns

(f) toff(min) = 200ns

Insert this data in the equation 3.2:

$$\frac{4(1-\text{Dmax})}{3(\text{tr}(\text{slowest})+\text{tf}(\text{slowest}))+4\text{toff}(\text{min})} \le \text{fswitch} \le \frac{4(\text{Dmin})}{\text{tr}(\text{slowest})+\text{tf}(\text{slowest})+4\text{ton}(\text{min})} \ldots(3.2)$$

$$\frac{4(1-0.7)}{3(150\text{ns}+50\text{ns})+4(200\text{ns})} \le \text{fswitch} \le \frac{4(0.1)}{150\text{ns}+50\text{ns}+4(750\text{ns})}$$

$$\frac{1.2}{1400\text{ns}} \le \text{fswitch} \le \frac{0.4}{3200\text{ns}}$$

$$857.142\text{kHz} \le \text{fswitch} \le 125\text{kHz}$$

Based on the calculation frequency range, the lowest switching frequency is about 125 kHz and the maximum is about up to 857.14 kHz. Thus the switching frequency is set to be 250 kHz. This minimum value is selected in order to minimize power use in Buck converter.

Step 3: Determine minimum inductor, L_{min} size. The switching frequency and inductor size selected for CCM is f = 25 kHz with load resistor, RL=5.6Ω/10W

$$Lmin = \left(\frac{1-D}{2f}\right)R \tag{3.3}$$

Where:

Lmin = Minimum inductor

D = Duty cycle

f = Frequency

R = Resistor

$$Lmin = \left(\frac{1-0.7}{2(250kHz)}\right)5.6\Omega$$

$$Lmin = \left(\frac{0.3}{500kHz}\right)5.6\Omega$$

$$Lmin = 3.36uH$$

Step 4: To ensure CCM let inductor be 25% greater than minimum inductor value

$$L = 1.25Lmin \tag{3.4}$$

$$L = 1.25(3.36uH)$$

$$L = 4.2uH$$

Step 5: The average current and the change in current

$$I_L = \frac{Vo}{R} \tag{3.5}$$

$$I_L = 5A$$

$$\Delta i_L = \frac{Vd - VO}{L}(DT) \tag{3.6}$$

$$\Delta i_L = \frac{17.4V - 12V}{4.2uH}(0.7)\left(\frac{1}{250kHz}\right)$$

$$\Delta i_L = 3.6A$$

Step 6: The maximum inductor current

$$Imax = I_L + \frac{\Delta i_L}{2} \tag{3.7}$$

$$Imax = 5A + \frac{3.6A}{2}$$

$$Imax = 5A + 1.8A$$

$$Imax = 6.8A$$

Step 7: The minimum inductor current

$$Imin = I_L - \frac{\Delta i_L}{2} \tag{3.8}$$

$$Imin = 5A - \frac{3.6A}{2}$$

$$Imin = 5A - 1.8A$$

$$Imin = 3.2A$$

Step 8: The capacitor if output ripple not exceed 2%

$$C = \frac{1 - D}{8L\left(\frac{\Delta Vo}{Vo}\right)f^2} \tag{3.9}$$

Where:

L = Inductor

D = Duty cycle

f = Frequency

$$\frac{\Delta Vo}{Vo} = \text{Ripple factor}$$

$$C = \frac{1 - 0.7}{8(4.2uH)(0.02)(250kHz^2)}$$

$$C = \frac{0.3}{42k}$$

$$C = 7.2uF$$

Figure 3.3 shows the basic construction of buck converter circuit using software OrCAD PSPICE based on calculations.

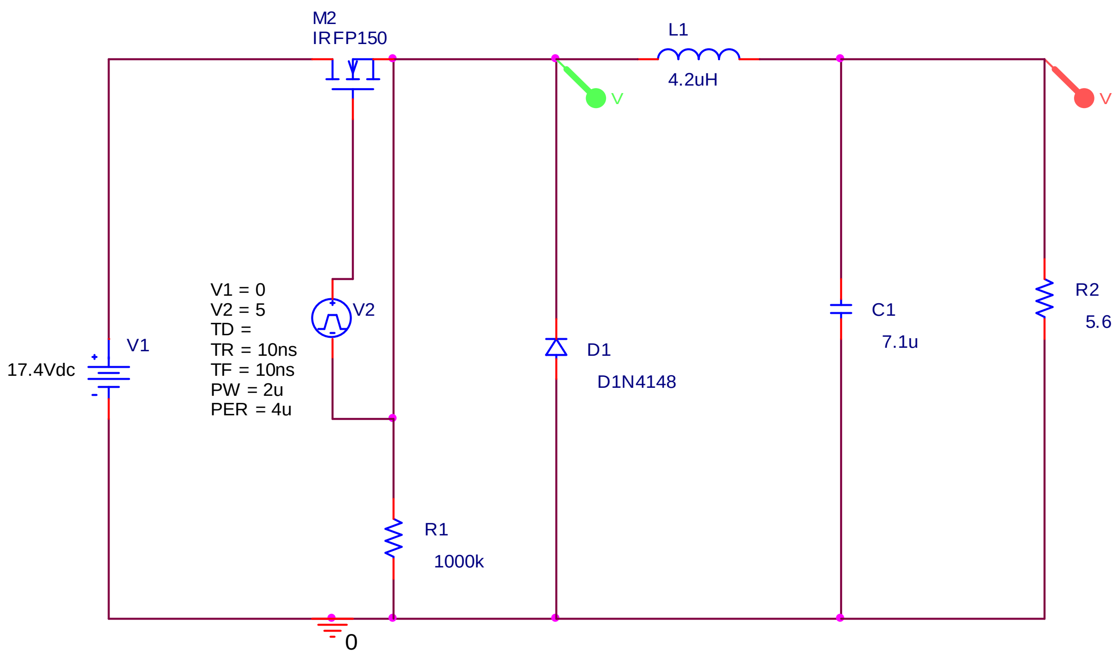

Figure 3.3: OrCAD PSPICE Schematic of Buck Converter.

Once the above schematic is designed, the simulation can be run. Figure 3.4 and 3.5 shows the waveforms generated by PSPICE simulation of the buck converter circuit. The waveform in Figure 3.3 shows the output voltage rising to 12V. We can also see the voltage across the diode during the switch off time is near -3 volts and during the switch on time is near the input voltage. The waveform in Figure 3.4 shows the converter is operating in the continuous conduction mode with an average operating current of about 5A and a peak in-rush current of about 15A.

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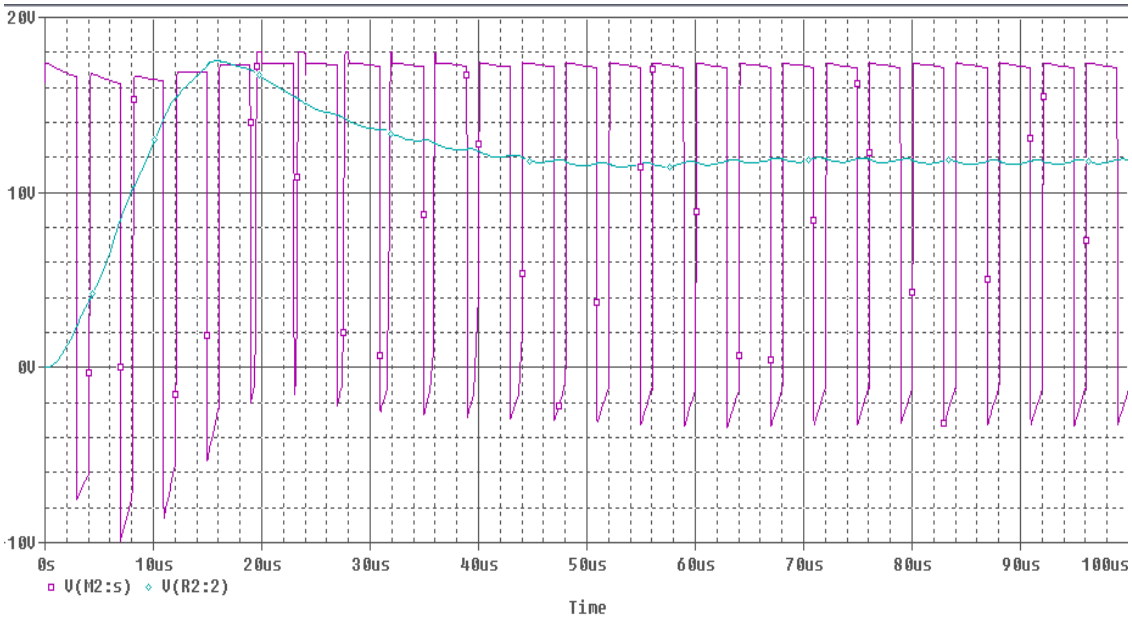

Figure 3.4: PSPICE simulation for V_{in} = 17.4 V; V_{out} = 12 V; D = 0.7

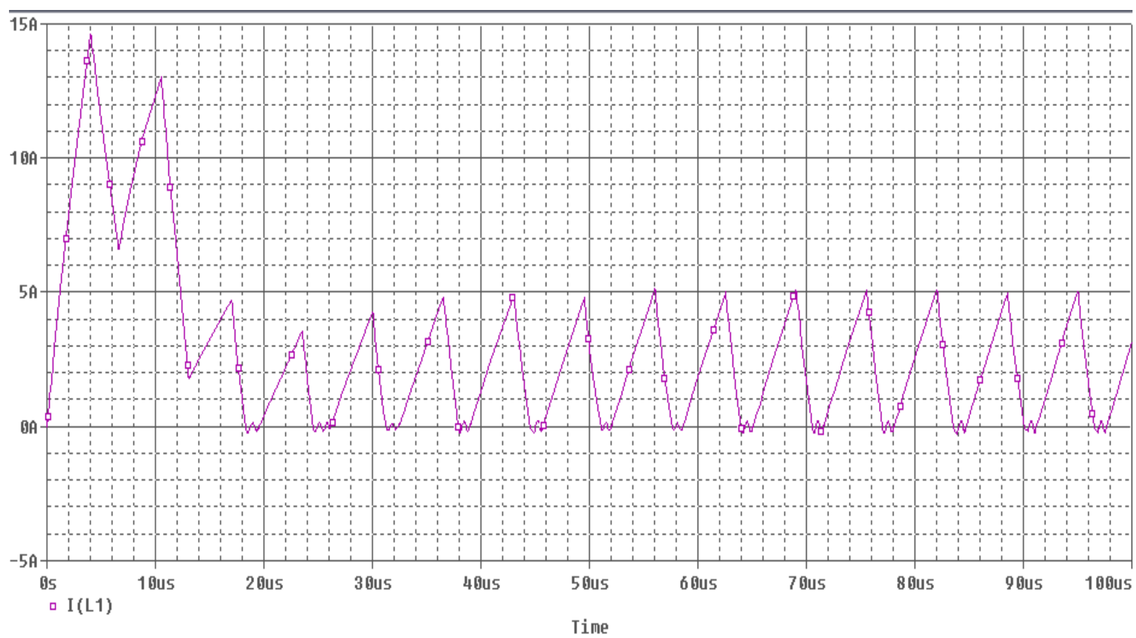

Figure 3.5: PSPICE simulation for i_L = 5A

3.2.3 PIC 16F877A Circuit Design

The second part is a microcontroller circuit. PIC 16F877A microcontroller is used in this PV charge controller to control POWER MOSFET switching duty cycle on the buck converter circuit. PIC 16F877A has 40 pins. This microcontroller offers the advantages which are very easy to be assembled, can be reprogrammed and erased up to 10,000 times and also an economical price. Therefore it is very good for new product development phase. Figure 3.6 show 40 pin PDIP of PIC 16F877A microcontroller.

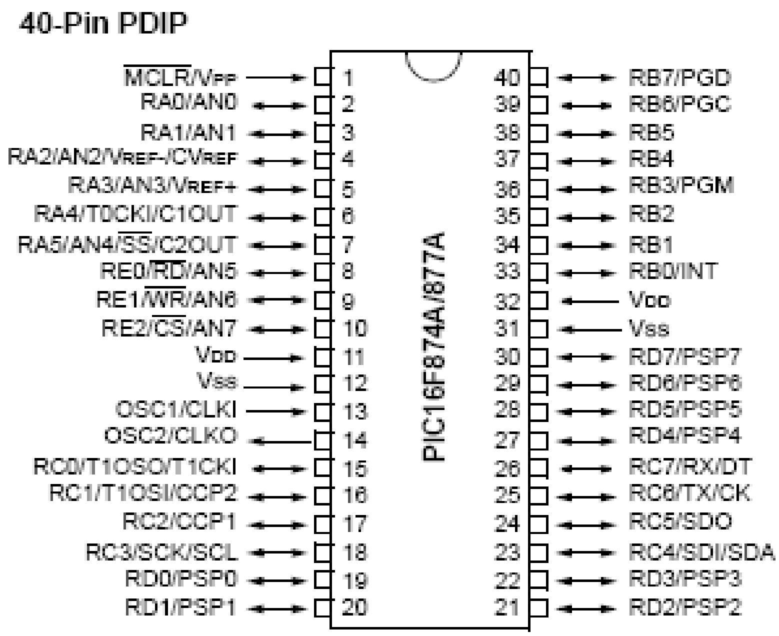

Figure 3.6: 40-Pin PDIP Diagram of PIC 16F887A

Before generate PWM signal from PIC16F877A, there are several circuits that is compulsory for the system to function well. It were included the power supply, clock circuit, and reset circuit. Power supply circuit (Figure 3.7) is needed in the basic PIC16F877A circuitry because 7805 regulator need to regulate the voltage supply of (>6V to 12V) so that the suitable voltage supply will drop at the PIC16F877A Vdd pin12 and make the PIC to functioned.

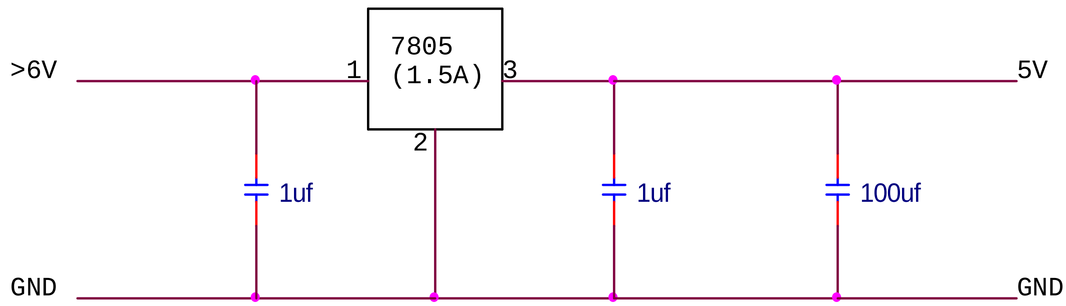

Figure 3.7: PIC 16F877A power supply circuit

A simple RC circuit (Figure 3.8) is used to produce action-synchronizing clock pulses. 20-MHz resonator is used for the operation clock oscillation by PIC 16F877A. The precision of this oscillation frequency doesn't influence the precision of the clock. The precision of the clock is decided by the precision of the frequency which is inputted to pin13 (OSC1) and pin14 (OSC2).

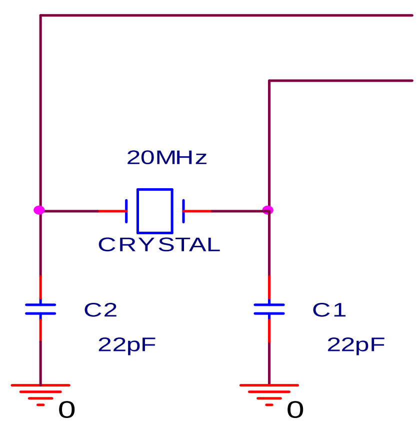

Figure 3.8: PIC 16F877A clock circuit

Meanwhile, the reset circuit (Figure 3.9) is used so that the program from a known state. It will be reset when the Master Clear (/MCLR) pin is connected to the 0V supply (ground). The PIC has internal circuits to perform this function at power on and the simplest design involve merely connecting the /MCLR pin directly to the positive voltage supply through a resistor to the positive voltage supply. When the power supply is connected, the voltage rise too slowly then this reset function may not work. By having a capacitor, at switch on, the capacitor will discharges. The PIC will be held reset until the voltage /MCLR is above threshold value.

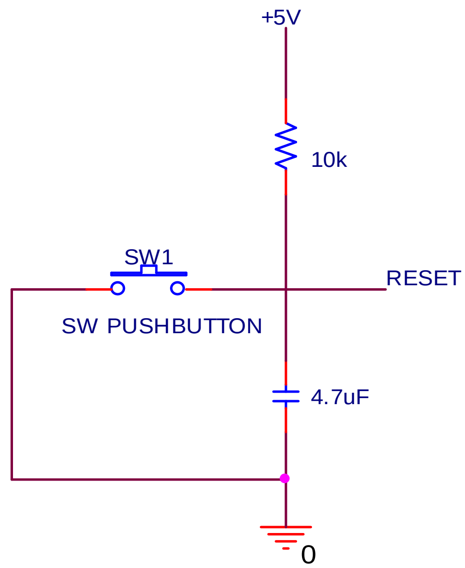

Figure 3.9: PIC 16F877A reset circuit

Since the PWM for Buck converter is sourced by PIC 16F877A in order to maintain the output voltage, the PWM function pin at port RB6 (bit 7 of PORTB) is set to be PWM output and it connecting to IN pin in the IR2109 half bridge driver.

3.2.4 Driver Circuit Design

The third part is a driver circuit. This circuit is really important in this PV charge controller in order to amplify and translate the PWM signal from PIC 16F877A microcontroller to trigger POWER MOSFET (IRFP150N) gate and the high output, HO. HO of driver circuit is connected to the MOSFET IRFP150N gates through resistor and switching diode (IN4148) that is oriented to bypass the resistor during turn-off, to ensure that MOSFET IRFP150N in one leg are fully off by the time another leg is turn on. The resistance is used value 20 Ω which allow a maximum gate turn-on current on the high side. Figure 3.10 show the MOSFET driver circuit.

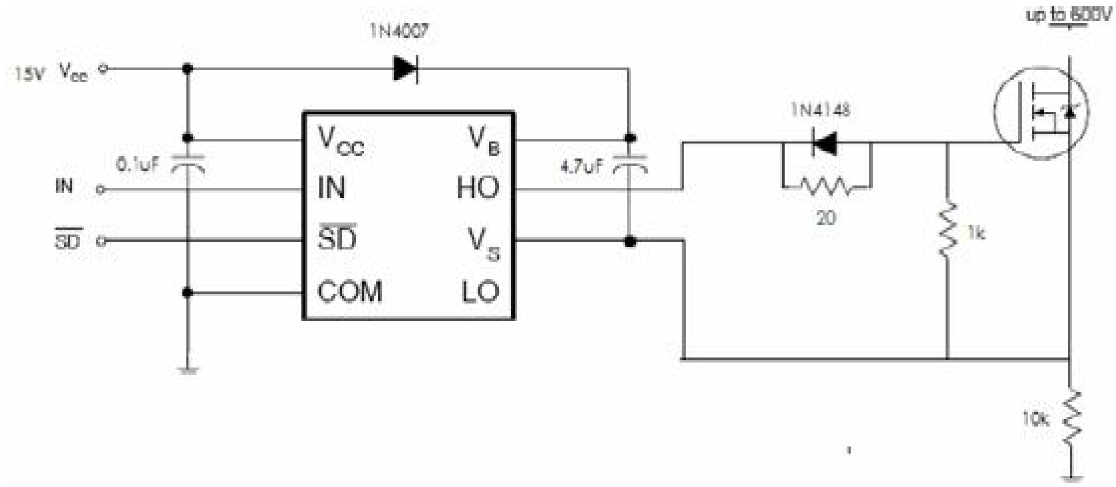

Figure 3.10: Circuit connection for IR2109 half-bridge

Basically, the driver circuit is receives controlled duty cycle signals from the PIC microcontroller at IN pin. The duty cycle signal from microcontroller is small in range about 0Vdc up to 5Vdc maximum. This duty cycle signal received then used for control the power MOSFET switching to the Buck converter. If the output voltage of Buck converter is higher, then the driver will drive a small duty cycle to POWER MOSFET and vise versa. Refer details about high –side driver operation in result discussion.

3.2.4 Rechargeable Battery

The four part is rechargeable battery. This rechargeable battery will be used in PV charge controller is 12V Sealed Lead Acid battery which is stored electrical energy in chemical form to operates dc load at night or bad weather and also requires lower maintenances, has longer life and gives better performance compared to normal battery.

3.2.6 Voltage Sensor Circuit Design

The five part is voltage sensor. This voltage sensor is used in PV charge controller to detect the voltage from rechargeable battery. First of all, the components in the strip board need to be supplied by 5V output. So the voltage sensor is designed to have 5V output by using supply from 12V rechargeable battery which is fed to port RA1 (bit 2 of PORTA). Here is the calculations method and formulas used in order to determine the values of the required components in voltage sensor circuit design. Figure 3.11 show the construction of voltage sensor circuit using software OrCAD PSPICE based on calculations.

$$Vo = \left(\frac{R_2}{R_1 + R_2} \right) Vin \tag{3.10}$$

Let R_1 = 1kiloohm

$$12V = \left(\frac{1k\Omega}{1k\Omega + R_2} \right) 5V$$

$$5k\Omega + 5R_2 = 12R_2$$

$$5k\Omega = 7R_2$$

$$R_2 = 714.29\Omega$$

The standard value of resistor is used in this voltage sensor circuit is 715 ohm.

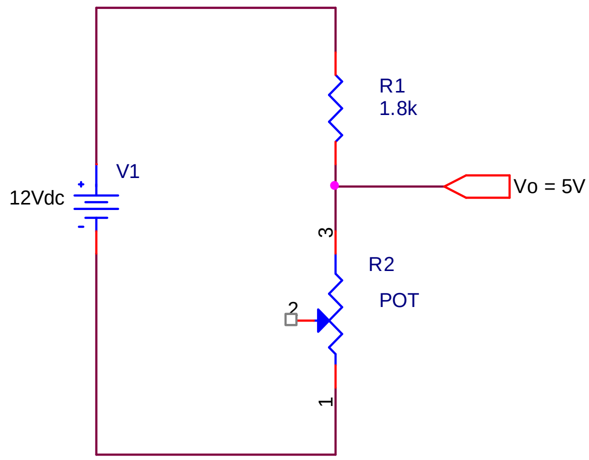

Figure 3.11: OrCAD PSPICE Schematic of Voltage Sensor.

3.2.7 Current Sensor

The six part is current sensor. The current sensor is used in PV charge controller to read the current from rechargeable battery. The current sensor used is LEM HX05-P/SP2.

3.2.8 Liquid Crystal Display (LCD)

The seven part is liquid crystal display (LCD). This LCD will be used in PV charge controller to display the operating status of rechargeable battery, output voltage, current value and also duty cycle of PWM from PIC 16F877A microcontroller. LCD is used in this project is 2X16 VCM162A. Table 3.3 shows the description connection of LCD.

Table 3.3: The description connection of LCD

Pin No	Symbol	Description
1	VSS	Ground terminal of module
2	VDD	Supply terminal of module
3	VO	Power supply for Liquid Crystal Drive
4	RS	Register Select: RS = 0 …. Instruction Register RS = 1 …. Data Register
5	R/W	Read/Write: High = Read Low = Write
6	E	Enable
7-14	D0 to D7	Bi-directional Data Bus. Data Transfer is performed once, thru D0 to D7, in the case of interface data length is 8-bits.
15	(BL -)	LED power supply terminals
`16	(BL +)	LED power supply terminals

As defined in the following structure, Table 3.4 show the pin connection from PIC16F877A microcontroller to the LCD pin while Figure 3.12 show the schematic of LCD circuit using software Proteus 7 Professional.

Table 3.4: The pin connection from PIC 16F877A to the LCD pin

Pin From PIC 16F877A	Pin From LCD
RB0	DB4
RB1	DB5
RB2	DB6
RB3	RB7
RB4	E
RB5	RS

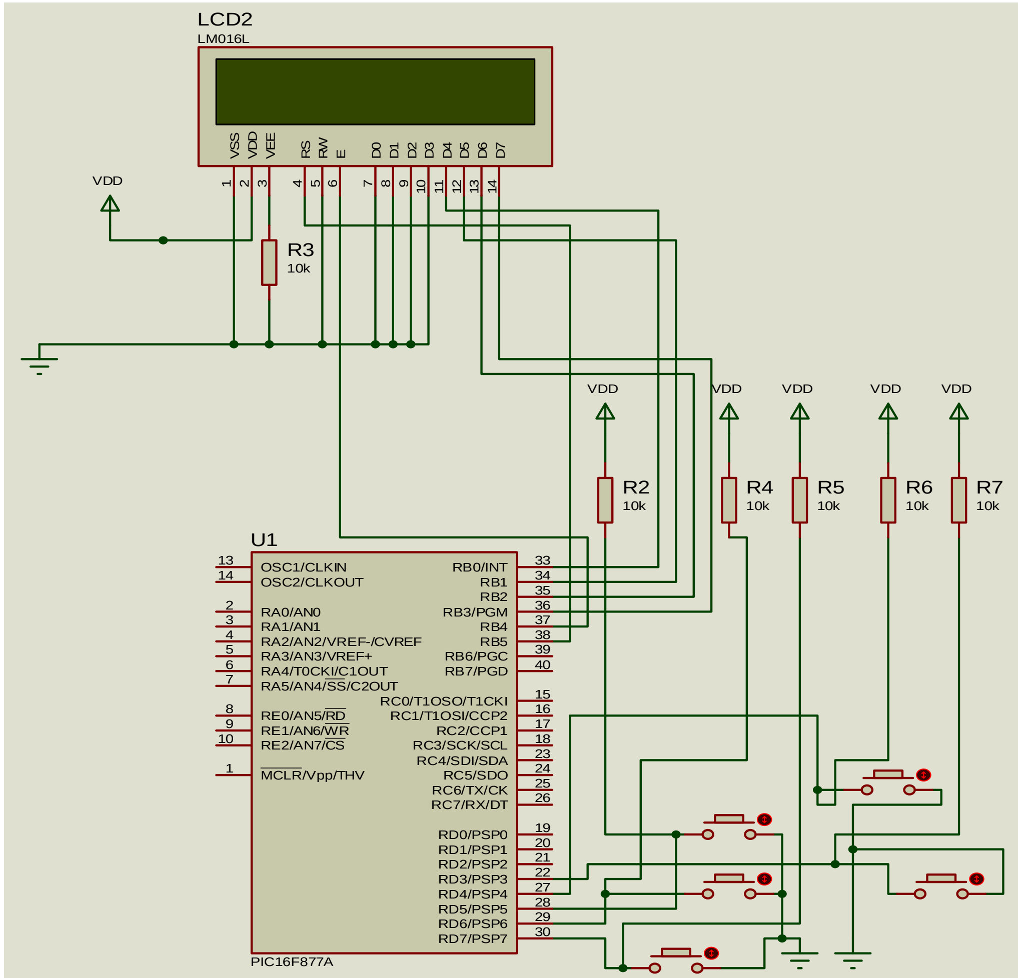

Figure 3.12: Schematic of LCD circuit with push button switches.

3.3 Software Implementation

3.3.1 PICBASIC PRO (PBP)

PICBASIC PRO allows us to use assembly language code mixed together with our BASIC code. The PICBASIC PRO Compiler (or PBP) makes it even quicker and easier to program Microchip Technology's powerful PICmicro microcontrollers (MCUs). The English-like BASIC language is much easier to read and write than the quirky Microchip assembly language. PBP Compiler produce code that can be programmed into a wide variety of PICmicro microcontroller which having from 8 until 84 pins and various on-chip features including A/D converters, hardware timers and serial ports. The PBP Compiler files are compressed into the self-extracting file on the included disk. They must be uncompressed before use. In general, PICBASIC language provides understood language, a widely standardized language and very productive language. Features like bit manipulation, bit field manipulation, direct memory addressing, and the ability to manipulate function addresses pointers have included in PICBASIC language. In other words, PICBASIC language is the only popular high level language that can be conveniently used for a microcontroller device such as for PIC 16F877A microcontroller to perform specific task in Photovoltaic (PV) Charge Controller. PIC 16F877A device contain between 64 and 1024 bytes of non-volatile data memory that can be used to store program and data and others parameters even when the power is turned off.

3.3.2 MicroCode Studio (PBP Compiler)

MicroCode Studio is one of the PBP Compiler that available for the Microchip PIC Controllers which is in this project, PIC 16F877A. MicroCode Studio is a powerful, visual Integrated Development Environment (IDE) with In Circuit Debugging (ICD) capability designed specifically for PICBASIC PRO™ compiler that allows users to build projects, add source code files to the projects, set compiler options for the objects and compile projects into executable program files. MicroCode Studio has its own database to track the properties of each Microchip PIC Microcontroller that it supports which is in this project is the PIC 16F877A. The data base can be update through Device Editor Menu item and new devices may be added or change the entries for a device for a special application. MicroCode Studio now includes EasyHID Wizard, a free code generation tool that enables a user to quickly implement bi-directional communication between an embedded PIC™ microcontroller and a PC. The compiler, assembler and programmer options is easy to setup. Compilation and assembler errors can easily be identified and corrected using the error results window. Just click on a compilation error and MicroCode Studio will automatically take to the error line. MicroCode Studio even comes with a serial communications window, allowing the debugging and view serial output from your microcontroller. Each line of source code is animated in the main editor window, showing which program line is currently being executed by the host microcontroller. User also can even toggle multiple breakpoints and step through your PICBASIC PRO™ code line by line. Figure 3.12 show the example programming which is written in Microcode Studio.

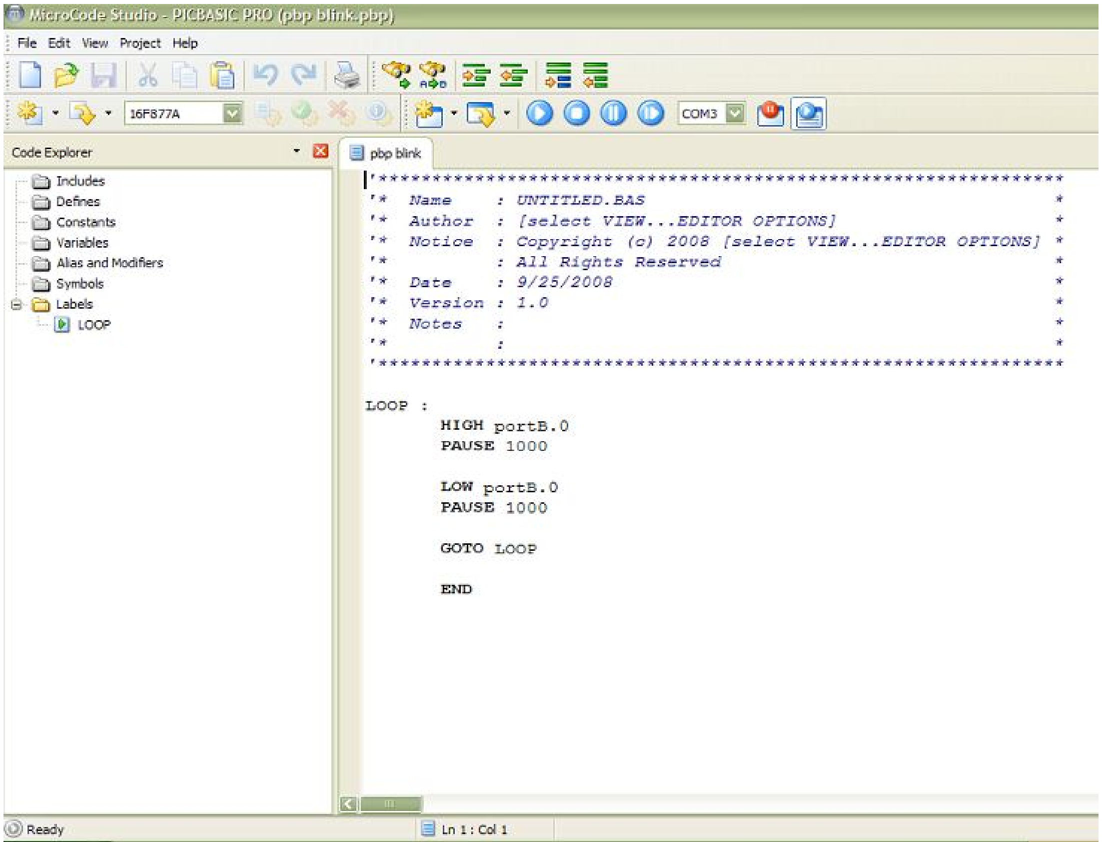

Figure 3.13: MicroCode Studio Screenshots

3.3.3 UP00A PIC USB Programmer

UP00A PIC USB Programmer is driven and powered from a single USB port on any personal computer. UP00A PIC USB Programmer allows programming of PIC microcontrollers in DIP, PLCC or surface mount packages on the programmer pin demo board which available for 8, 18, 28 and 40 pin of PIC microcontrollers. UP00A PIC USB Programmer also included easy-to-understand tutorials software that allows users to learn at their own pace. Refer APPENDIX for detail specification. Figure 3.13 show the hardware of UP00A PIC USB Programmer.

Figure 3.14: UP00A PIC USB Programmmer

3.3.4 Programming the PIC 16F877A Microcontroller

It is really important to check either the program is working or not. The easiest way to find it out is trying and testing the code again and again using UP00A PIC USB Programmer. It does take a long time to develop a program that really satisfies the project objective and scope. The flash memory technology of the PIC 16F877A microcontroller permits the microcontroller to be programmed, erase and programmed again repeatedly and it saves us more time to construct ideal program.

3.3.5 Photovoltaic Charge Controller System Operational Flow

The overall operation of the whole system is simplified and indicated by the flowchart in Figure 3.11 as shown below.

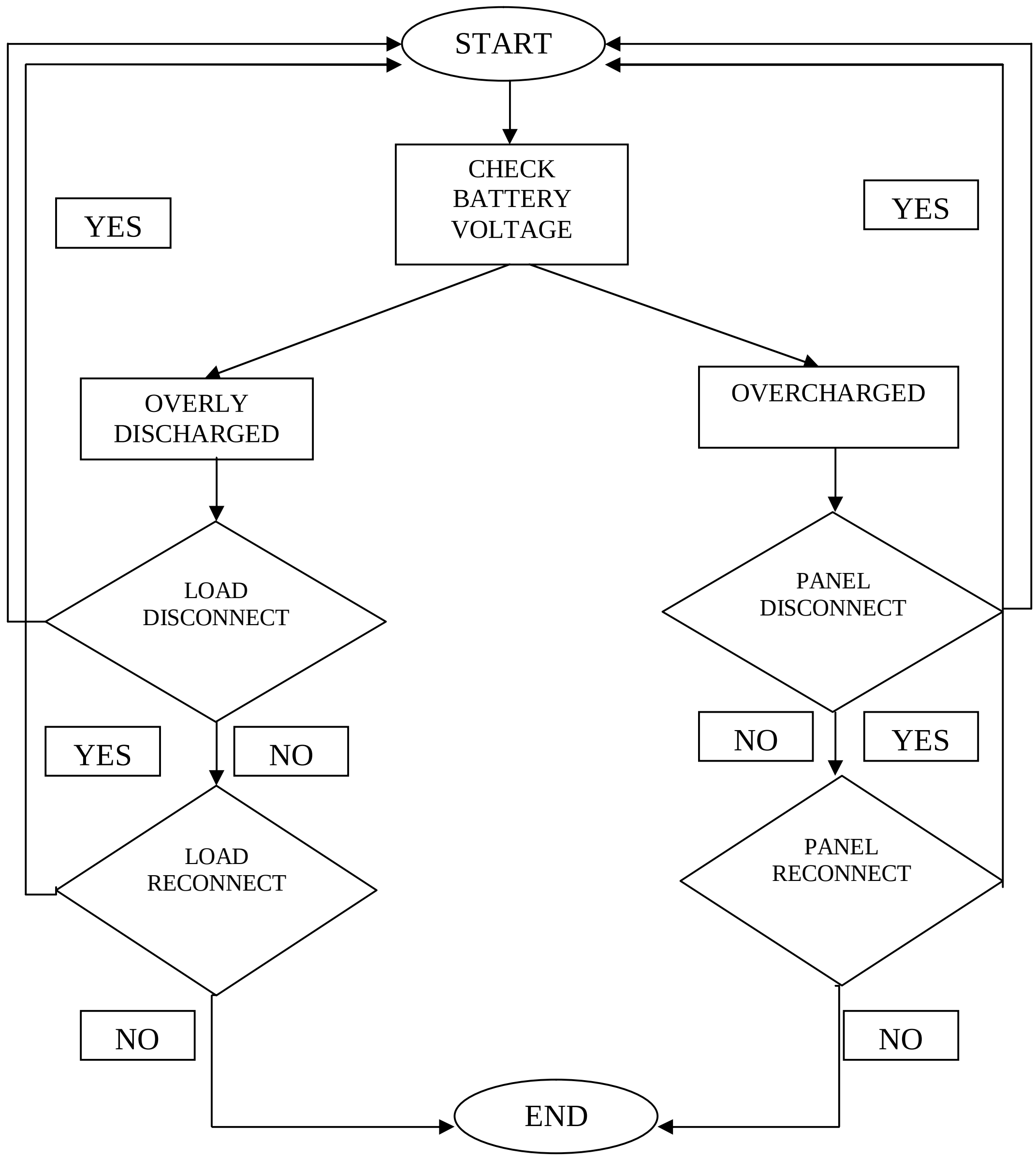

Figure 3.15: Flow chart of the whole system

From the flow chart above, the PV charge controller algorithm is being summarized. Everyday charging cycle of rechargeable battery is based on photovoltaic energy and maintained by using PWM techniques. First check the battery voltage. If battery is overly discharged (below than 11.2V) then the load is disconnect. After that, loop to start to check the battery voltage is more than 11.2V. Then check if load is really disconnected. If load is disconnected, check if reconnection voltage of the load criteria is met which is equal to 12V. If criteria are met reconnect the load then loop to check the battery voltage. If battery is overcharged (more than 13.2V) then the panel is disconnect. After that, loop to check the battery voltage is reaches voltage limit (13.2V). Then check if panel is really disconnected. If panel is disconnected, check if reconnection voltage of the panel criteria is met. If criteria are met reconnect the panel then loop to start to check the battery voltage.

CHAPTER 4

RESULT & DISCUSSION

4.1 INTRODUCTION

In this chapter, all results of hardware testing and circuit troubleshooting of the PV charge controller will be discussed. All discussions will focus on the result obtained and performance of the project.

4.2 PIC 16F877A Microcontroller Circuit

Before complete PIC 16F877A microcontroller circuit is implementing on driver circuit, the constructed PIC 16F877A microcontroller circuit needs to be check first. There are two steps to check PIC 16F877A microcontroller circuit is function properly. Figure 4.1 shows the complete PIC 16F877A microcontroller circuit.

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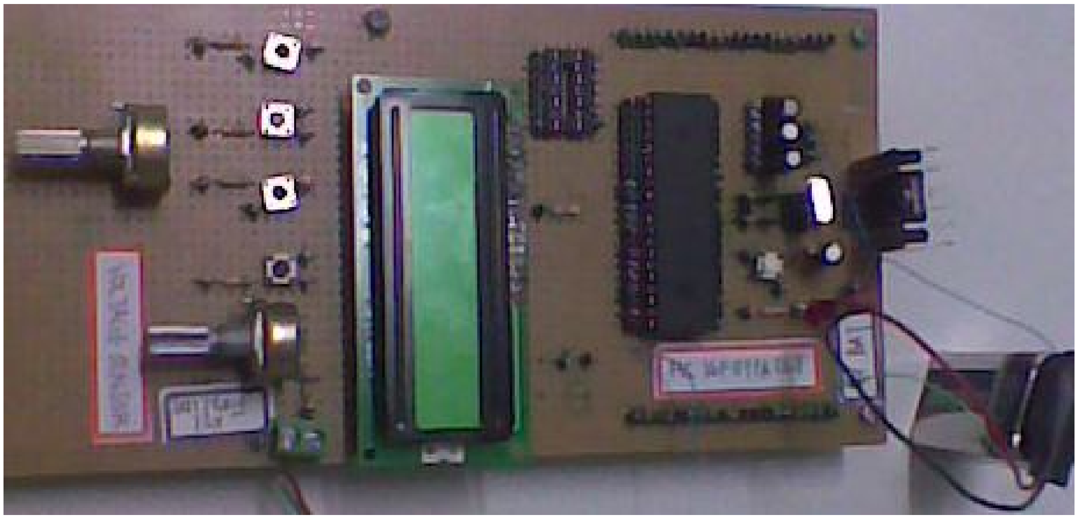

Figure 4.1: The complete PIC 16F877A microcontroller circuit.

Step 1: Check the voltage supply, Vdd at pin 11 of PIC 16F877A

The voltage drop at pin 11 of PIC 16F877A microcontroller will be measured by using digital multimeter and the result is 5V. This value ensured that the PIC 16F877A microcontroller is well function and this value also were produced by the regulating voltage supply through the power supply circuitry mentioned in Chapter 3. Figure 4.2 show the value of voltage drop is measured by digital multimeter.

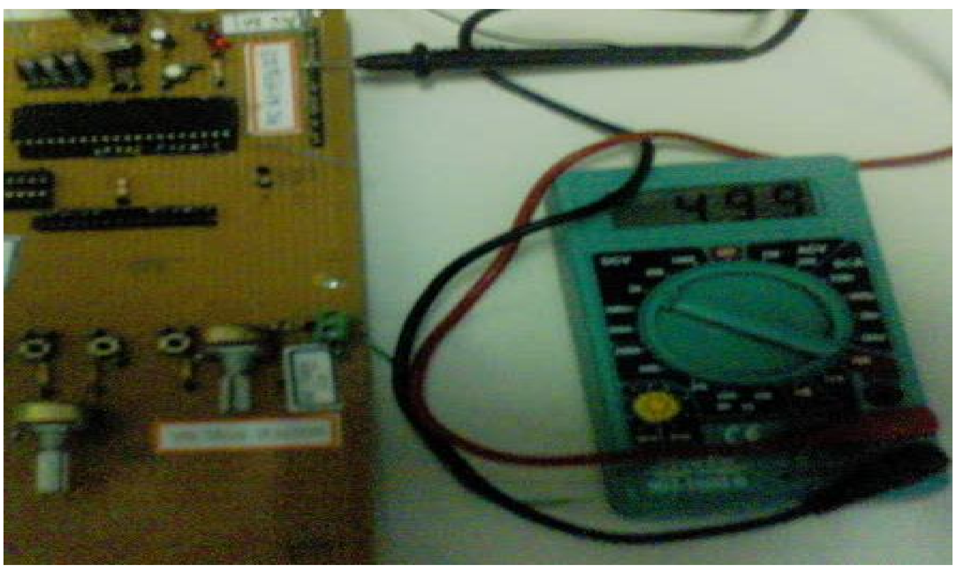

Figure 4.2: The digital multimeter show the value of voltage drop near to 5V.

Step 2: Led is ON

A red LED is connect to port RA2 (bit 3 of PORTA) of a PIC 16F877A microcontroller and then write a program to continuously flash the red LED with 1s intervals. When a red LED is ON, it shows the PIC 16F877A microcontroller is function properly. Figure 4.3 show the red LED is ON from PIC 16F877A microcontroller circuit.

Figure 4.3: The red LED is ON.

After checking the status function of PIC 16F877A microcontroller circuit, we can move on to test the pulse width modulation (PWM) which is signal by PIC 16F877A microcontroller.

4.2.1 Pulse Width Modulation (PWM)

The pulse width modulation (PWM) is required in PV charge controller for control switching frequency in order to obtain the desired output voltage. The controlled duty cycle from PIC 16F877A microcontroller enter to high side MOSFET driver before control POWER MOSFET gate terminal for switching scheme. The switching frequency required for this Buck converter is about 250 kHz. The selection of switching frequency can refer to component determination in chapter three together with simple microcontroller program use to generate desired PWM. From previous calculation in equation 3.2, PWM used to determine the duty cycle, D ratio between inputs to output of Buck converter. The desire duty cycle for switching scheme is about 70% by operating on CCM mode. There are two methods to control duty cycle. First method using variable resistor or potentiometer and second method using switches which is connected to 4 pin of PORTB of PIC 16F877A microcontroller. Figure 4.4 show the duty cycle of PWM from PIC 16F877A microcontroller to meet the project requirement.

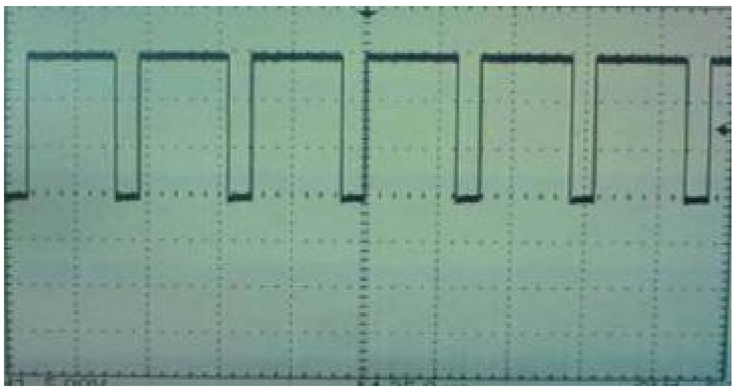

Figure 4.4: Duty cycle 70% of PWM output waveform from PIC 16F877A

4.2.2 Discussion

4.2.2.1 PIC 16F877A microcontroller circuit

Make sure the connection of power supply circuit, clock circuit and reset circuit is connected properly to PIC 16F877A microcontroller to ensure this circuit functions appropriately.

4.2.2.2 Pulse Width Modulation (PWM)

Make sure duty cycle of PWM which is generated by PIC 16F877A microcontroller for buck converter circuit is not less or more than range assigned because it will affect the buck converter circuit to function inappropriately. The chance of buck converter circuit to damage is high due to rating of component determination based on duty cycle calculation are not supported.

4.3 Driver Circuit

Before the complete circuit of MOSFET driver is applies on Buck converter, the constructed driver circuit needs to test first. There are 2 steps to test this driver circuit. First step without POWER MOSFET at high output (HO) of MOSFET driver while second step with POWER MOSFET at source (S) pin of it. This step is really important to perform because to ensure the output from MOSFET driver is function in order to control switching frequency of POWER MOSFET on buck converter. Figure 4.5 shows the complete driver circuit.

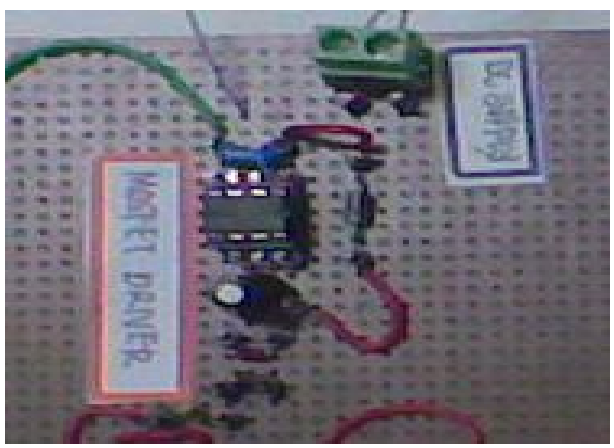

Figure 4.5: The complete MOSFET driver circuit.

4.3.1 MOSFET Driver Circuit without POWER MOSFET Output

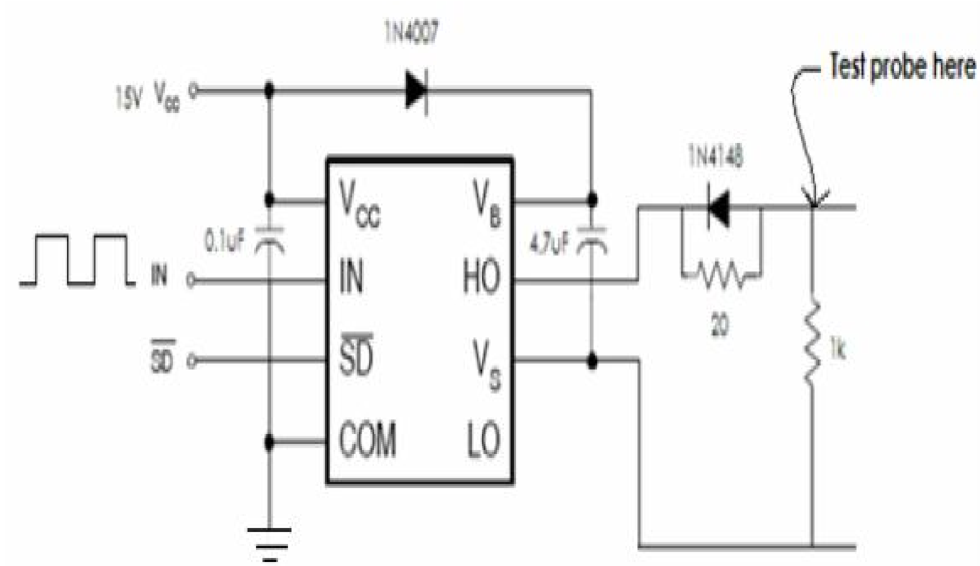

Figure 4.6: The test probe at HO pin of MOSFET driver.

Figure 4.6 show the probe point to test and measure is placed while another probe point is tab to the Vs pin. The output point is test by varied the duty cycle coming from PIC 16F877A at IN pin of MOSFET driver. Figure 4.7 show the result of duty cycle at oscilloscope.

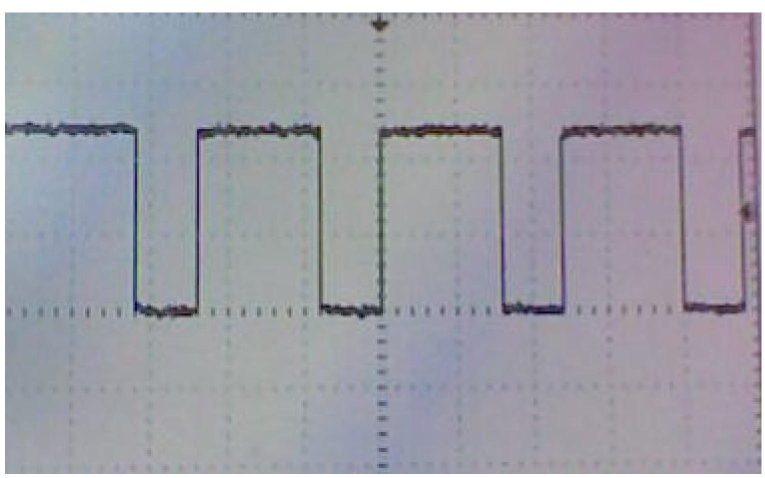

Figure 4.7: The output waveforms of HO MOSFET driver with D = 70%.

4.3.2 MOSFET Driver Circuit with POWER MOSFET Output

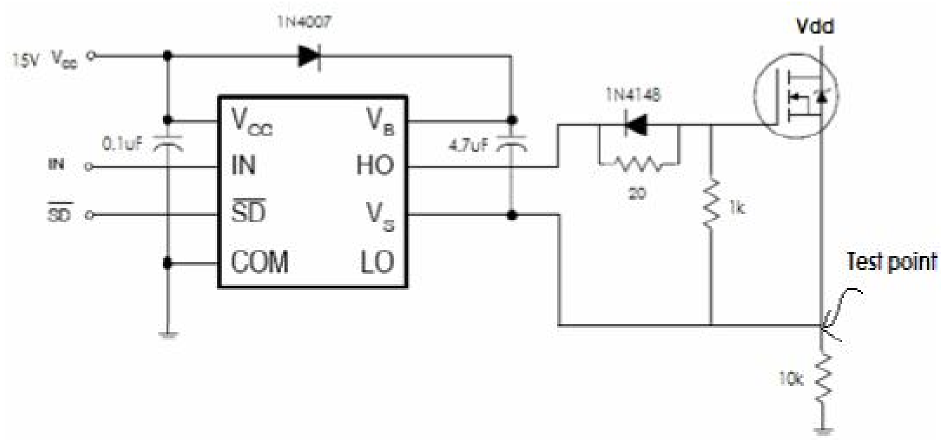

Figure 4.8: The test point at POWER MOSFET switching output

Figure 4.8 show the joint of gate terminal of POWER MOSFET with HO of MOSFET driver, the need of voltage supply at drain voltage, Vdd of POWER MOSFET terminal and the place of probe point to test and measure. The high output, HO pin is act as a PWM signal for the POWER MOSFET. The output result at probe point is get by varied the Vdd which is coming from POWER MOSFET terminal. Figure 4.9 show the result of Vdd output at oscilloscope.

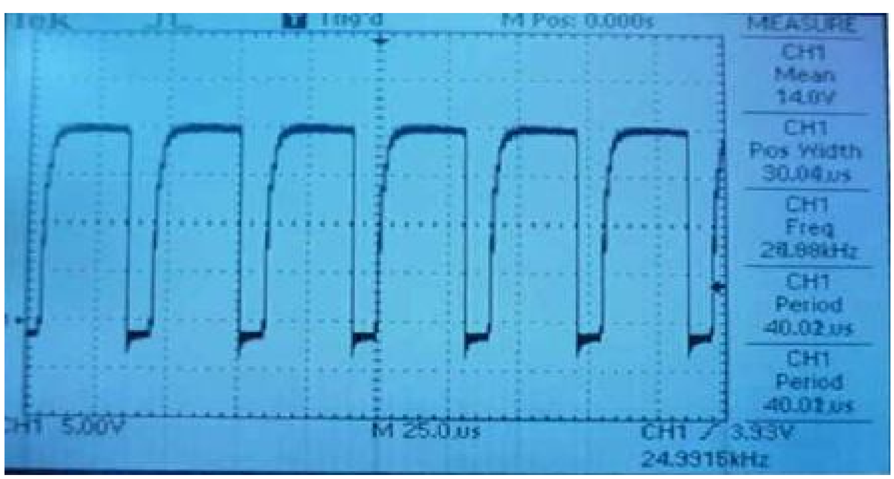

Figure 4.9: The output waveforms of HO MOSFET driver with Vdd = 14V.

4.3.3 Discussion of Driver Circuit

During construct the driver circuit, there is a major problem especially when construct high side driver circuit. The wrong connection of high side ground caused the signal from PIC 16F877A not read by MOSFET driver. This circuit is an important part because to ensure the output from MOSFET driver is well function as triggered switching function of POWER MOSFET. So make sure the connection of high side MOSFET driver in right connection.

4.4 Buck Converter Circuit

Now the buck converter circuit construction can be test after all parts for PWM of PIC 16F877A microcontroller and driver circuit is tested and verifies. In this circuit, the output voltage will be measured. Figure 4.10 show the complete buck converter circuit while Table 4.1 shows the testing data for Buck converter circuit construction which is applied the range of duty cycle ratio.

Figure 4.10: The complete buck converter circuit

Table 4.1: The output voltage from buck converter

Vdd (V)	Duty Cycle (%D)	Vout (mV)	Frequency (kHz)
10	50.00	1.82	215.25
11	52.04	2.92	220.49
12	57.07	3.10	225.08
13	57.50	4.02	230.00
14	58.59	5.27	235.17
15	62.06	6.42	240.51
16	69.75	7.53	245.45
17.4	70.00	8.90	250.00

4.4.1 Discussion of Buck Converter Circuit

From the Table 4.1, it show the maximum input supply voltage, Vdd can varied is about 17.4Vdc and the output voltage of buck converter circuit is about 8.90mVdc at desired 70% of duty cycle. Basically to design of Buck converter is achieved but it not meets the requirement of to produce 12Vdc output voltage. As we can see on duty cycle ratio in Table 4.1, the increasing range of duty ratio may cause the higher ratio of output voltage of buck converter circuit. The buck converter circuit may in risk and possibility malfunction if this range of duty cycle constantly use. The buck circuit has face with many problems especially due to rating of components selection so to get the right rating of components selection, the try error method is applied. To avoid an over voltage or over current flow through the Buck converter system, the best way is to use variable power supply unit to perform the step down dc-to-dc converter system.

4.5 Voltage Sensor Circuit

Before the complete voltage sensor circuit is implementing on PIC 16F877A microcontroller, the voltage sensor circuit is test to make sure the output voltage from voltage sensor circuit is fixed 5V. This value will be measured by using digital multimeter. Figure 4.11 show the complete voltage sensor circuit.

Figure 4.11: The complete voltage sensor circuit

4.5.1 Discussion of Voltage Sensor Circuit

The voltage output from voltage sensor circuit is fixed 5V after have been tested. This show the voltage sensor circuit is well function. Then, the output voltage of voltage sensor circuit is sent to port RA0 (bit 1 of PORT A) on PIC 16F877A microcontroller to control the voltage output from rechargeable battery.

4.6 Liquid Crystal Display (LCD) Circuit

Before the liquid crystal display (LCD) display the information of duty cycle and voltage and current from rechargeable battery to the user, LCD circuit is check to make sure it can be display. The LCD circuit is tune with potentiometer 10kilooh to get the contrast of the display which is in function of the voltage on the LCD pin. After the LCD circuit is checked, the command is given to PIC 16F877A microcontroller in order to display the information on the LCD. Figure 4.12 show the complete circuit of LCD circuit while Figure 4.13 show the information of duty cycle on the LCD.

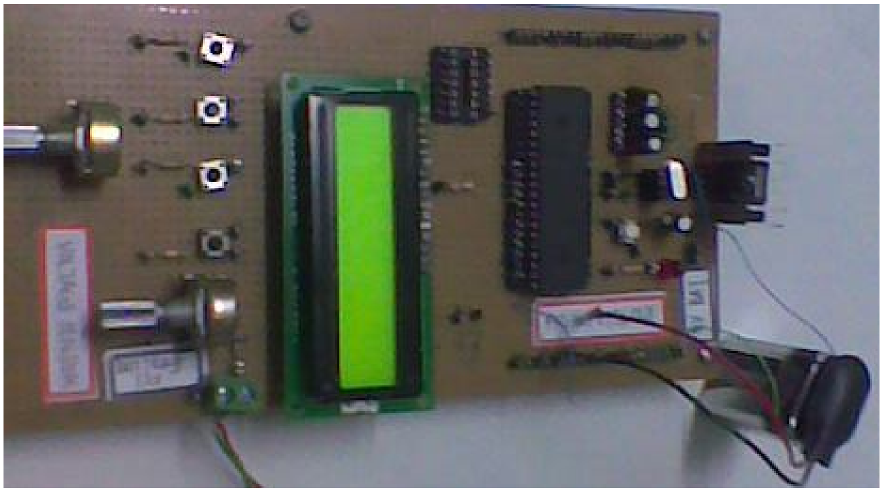

Figure 4.12: The complete circuit of LCD circuit

Figure 4.13: The information of duty cycle on the LCD

4.6.1 Discussion of LCD Circuit

From the Figure 4.13, we can see only information of duty cycle is displayed while information of voltage and current of rechargeable battery cannot be display. This happen due to unstable board because of lots of changing variations like voltage changing. The importance of achieving a high order of stability still remains a significant problem at the end of the day and the final circuit exhibits a high degree of stability. It is recommended in the solution that LCD circuit will need to orderly adjusted the be preset the potentiometers due to changes variation by using analysis method when configuring the effect of ranges in potentiometer and the contact connections related to external circuit

CHAPTER 5

CONCLUSION AND FUTURE DEVELOPMENT

5.1 INTRODUCTION

This chapter discuss about the conclusion and project development in the future. This project has two major parts which is hardware description and software implementation. Both topics integrate with each other to develop Photovoltaic (PV) Charge Controller as a working product that can be applied to perform effective PV system.

5.2 CONCLUSION

As a conclusion, there are five chapters which are introduction, literature review, methodology, result and discussion, and conclusion and future development that has been discuss in this thesis for the development of PV Charge Controller project. At the end of this project, the implementation of this project with PIC 16F877A microcontroller was successful since the main objective has been achieved but with certain limit of the buck converter system. The design of Buck converter is to step down input voltage from 17.4Vdc to 12Vdc. But unfortunately, after circuit constructs and testing, the Buck converter has been to step down output voltage about 8.90mVdc only. Basically, the main reason of why system only able to step down about 8.90mVdc of voltage output is because due to ratings of components selection are not supported in terms of large flow of current through the circuit. The noise like higher switching frequency is one of causes and affects that produced higher current and carried it through the components. Besides, the LCD only can display the information of duty cycle to the users due to unstable board.

5.3 FUTURE DEVELOPMENT

For the future development, it is better to combine this project with maximum power-point tracking (MPPT) to get a maximum efficiency output. More or less for the Photovoltaic (PV) Charge Controller construction, using Printed Circuit Board (PCB) will be much likely saving the risk of stability. By having PCB in PV Charge Controller construction, the probability of gaining high stability is positive. Fuse also is installed in the load to prevent PCB from short circuit or overload current. Besides, PCB makes the circuit become smaller and looks compact, this way, will increasing the thought to make this PV Charge Controller becomes a portable device. In addition, for future design, student should be exposed with several of types of microcontroller for well-use programming language in the system for firmware and hardware implementation.

5.4 COSTING AND COMMERLIZATION

At a time of reduced budget resulting in many electrical appliances need to used, one way to increase efficiency and productivity of photovoltaic system is by using Photovoltaic (PV) Charge Controller. Total estimation cost to build the PV Charge Controller is about RM94.07; see APPENDIX B for details price and components items. This project can be commercialized due to several reasons which are:

i) The selling prices will be lower than RM 100.00

ii) Portable PV charge controller

iii) Small in size and weight

iv) High efficiency

Based on the reasons, this project actually quite simple compare to other similar project concept (PV Charge Controller) available in marketplace. Thus, it is impossible to compete with another advance project readily available but this PV Charge Controller would be the best portable PV system that people want most.

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APPENDICES

APPENDIX A

Programming Language

```
'****************************************************************
'*  Name    : CONTROLLER.BAS                                    *
'*  Author  : [select VIEW...EDITOR OPTIONS]                    *
'*  Notice  : Copyright (c) 2009 [select VIEW...EDITOR OPTIONS] *
'*          : All Rights Reserved                               *
'*  Date    : 4/7/2009                                          *
'*  Version : 1.0                                               *
'*  Notes   :                                                   *
'*          :                                                   *
'****************************************************************

' Display Microcontroller pin
' DB4 RB0    -0
' DB5 RB1    -0
' DB6 RB2    -0
' RB7 RB3    -0
' E RB4      -0
' RS RB5     -1
' RB6 -PWM OUTPUT
' rangeH button RD4
' rangeL button RD5
' cycleH button RD6
' cycleL button RD7

START:
DEFINE LCD_DREG PORTB         ' LCD Data bits on PORTB
DEFINE LCD_DBIT 0         ' PORTB starting address
DEFINE LCD_RSREG PORTB        ' LCD RS bit on PORTB
DEFINE LCD_RSBIT 5        ' LCD RS bit address
DEFINE LCD_EREG PORTB         ' LCD E bit on PORTB
DEFINE LCD_EBIT 4         ' LCD E bit address
DEFINE LCD_BITS 4         ' LCD in 4-bit mode
DEFINE LCD_LINES 2        ' LCD has 2 rows

DEFINE ADC_BITS 10        'A/D NUMBER OF BITS
DEFINE ADC_CLOCK    3  'USE A/D INTERNAL RC CLOCK
DEFINE ADC_SAMPLEUS  50       'SET SAMPLING TIME IN uS

'VARIABLES

RES VAR WORD              'A/D CONVERTER RESULT
VOLTS1 VAR WORD
VOLTS2 VAR WORD
PWMCYC VAR BYTE
CYC VAR BYTE
DELAY VAR BYTE
```

```
DUTY VAR WORD
DISP VAR BYTE
PLO VAR WORD 'PULS_LOW
PHI VAR WORD 'PULS_HIGH
PWIDTH VAR WORD 'ADD TWO RESULT (PULS_LOW+PULS_HIGH)

'CONSTANS

CONV1 CON 19            '5000/256=19.53,THIS IS THE DECIMAL PART
CONV2 CON 626           'THIS IS THE FRACTIONAL PART


TRISA.0=1               'RA0(AN0) IS INPUT
TRISB = %00100000
TRISD = %11111000

Symbol CYCLEL = PORTD.5        ' How many cycle in PWM
Symbol CYCLEH = PORTD.4        ' PWMcycle from 0 to 255 : will determine
dutycycle
Symbol RANGEL = PORTD.7        ' How many cycle in PWM
Symbol RANGEH = PORTD.6        ' PWMcycle from 0 to 255 : will determine
dutycycle
SYMBOL BTN    = PORTD.3

OPTION_REG = $05 ' Set prescaler = 64

ON INTERRUPT GOTO ISR          ' ISR routine
INTCON = $A0                   ' Enable TMR0 interrupt and global interrupts
ADCON1=0                       'MAKE AN0 TO AN4 AS ANALOG INPUTS,
                               'MAKE REFERRENCE VOLTAGE=VDD
pause 500                      ' Wait 0.5sec for LCD to initialize
LCDOUT $FE,1                   ' Clear LCD

DEFAULT:
PWMCYC=179
CYC=20
rangeL=1
cycleL=1
rangeH=0
cycleH=1
disp=1
PWM PORTB.6,PWMCYC,CYC         ' Send a XX% duty cycle PWM signal out PB1 for
XX cycle

MAIN:
```

```
DUTY=(PWMCYC*100)/255
IF DUTY=100 THEN DUTY=0
PWM PORTB.6,PWMCYC,CYC       ' Send a XX% duty cycle PWM signal out PB1 for
XX cycles
GOSUB DISPLAY
GOSUB PRESS

DUTY=(PWMCYC*100)/255
IF DUTY=100 THEN DUTY=0

GOTO MAIN

PRESS:
if CYCLEH=0 THEN
   CYC=CYC+1
   IF CYC=100 then cyc=0
   GOSUB debounce
endif

if RANGEH=0 THEN
   PWMCYC=PWMCYC+1
   IF PWMCYC=255 then PWMCYC=0
   GOSUB debounce
endif
if CYCLEL=0 THEN
   CYC=CYC-1
   IF CYC=100 then cyc=0
   GOSUB debounce
endif

if RANGEL=0 THEN
   PWMCYC=PWMCYC-1
   IF PWMCYC=255 then PWMCYC=0
   GOSUB debounce
endif

if BTN=1 THEN AGAIN
        ADCIN 0,RES              'READ CHANNEL 0 DATA
       VOLTS1=RES*CONV1       'MULTIPLY BY 53
       VOLTS2=RES*CONV2
       VOLTS2=VOLTS2/100
       VOLTS1=VOLTS1+VOLTS2
       LCDOUT $FE,2,"VDC=",DEC4 VOLTS1  'DISPLAY RESULT
       GOTO MAIN
        pause 1000
        gosub debounce
```

```
endif

RETURN

DEBOUNCE:
FOR Delay = 1 To 100
Pause 1 ' Delay 1ms inside a loop. This way,
NEXT Delay ' timer interrupts are not stopped
DISP = 1 ' Set display flag to 1
RETURN

DISABLE
ISR:
IF cycleL=1 THEN NoUpdate
if rangeL=1 then noupdate
IF cycleH=1 THEN NoUpdate
if rangeH=1 then noupdate
if BTN=1    then Noupdate
disp=1

NoUpdate:
INTCON.2 = 0 ' Re-enable TMR0 interrupts
Resume
ENABLE ' Re-enable interrupts
end

DISPLAY:
IF DISP=1 THEN
LCDOut $fe, 2
'LCDOUT  "L",DEC3 plo ,"H",DEC3 phi
LCDOUT "DUTY CYCLE:", DEC2 DUTY ,"%"
LCDOut $fe, $C0
LCDOUT  "CYC:",DEC3 cyc ," PWM:",DEC3 pwmcyc
disp=0
ENDIF
RETURN
end
```

APPENDIX B

List of Components

NO.	ITEMS	Quantity	Price per Unit	Price (RM)
1.	PIC16F877A + BASE	1	22.00	22.00
2.	LM 7805 Voltage Regulator	1	1.00	1.00
3.	Crystal 20Mhz	1	2.00	2.00
4.	Heat Sink (Silver)	1	0.40	0.40
5.	Resistor 10kΩ	5	0.05	0.25
6.	Resistor 1.8k Ω	1	0.05	0.05
7.	Resistor 1kΩ	1	0.05	0.05
8.	Resistor 330Ω	1	0.05	0.05
9.	Resistor 20 Ω	1	0.05	0.05
10.	Resistor 5.6 Ω/10W	1	1.00	1.00
11.	Switch	5	0.60	3.00
12.	Capacitor 100 µF	1	4.50	4.50
13.	Capacitor 22pF	2	0.06	0.12
14.	Capacitor 10µF	1	0.06	0.06
15.	Capacitor 4.7 µF	2	0.06	0.12
16.	Capacitor 1µF	2	0.06	0.12
17.	Capacitor 0.1 µF (Ceramic)	1	0.30	0.30
18.	LED	1	0.20	0.20
19.	Potentiometer 10kΩ	1	2.50	2.50
20.	Potentiometer 25kΩ	1	2.50	2.50
21.	Power MOSFET IRFP150N	1	4.00	4.00
22.	MOSFET Driver IR2109	1	2.00	2.00
23.	Inductor 10 µH	1	5.00	5.00
24.	Diode 1N4148	2	0.10	0.20
25.	Diode 1N4005	1	0.20	0.20
26.	Liquid Crsytal Display	1	30.00	30.00
27.	Connector	4	0.60	2.40
28.	Independent Board	2	8.00	8.00
29.	Stand-off pillar	10	0.20	2.00
			TOTAL	**RM 94.07**

APPENDIX C

PIC 16F877A Datasheet

PIC16F87XA

28/40/44-Pin Enhanced Flash Microcontrollers

Devices Included in this Data Sheet:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

High-Performance RISC CPU:

- Only 35 single-word instructions to learn
- All single-cycle instructions except for program branches, which are two-cycle
- Operating speed: DC – 20 MHz clock input
  DC – 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during Sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I^2C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) – 8 bits wide with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Analog Features:

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)
- Brown-out Reset (BOR)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (V_{REF}) module
  - Programmable input multiplexing from device inputs and internal voltage reference
  - Comparator outputs are externally accessible

Special Microcontroller Features:

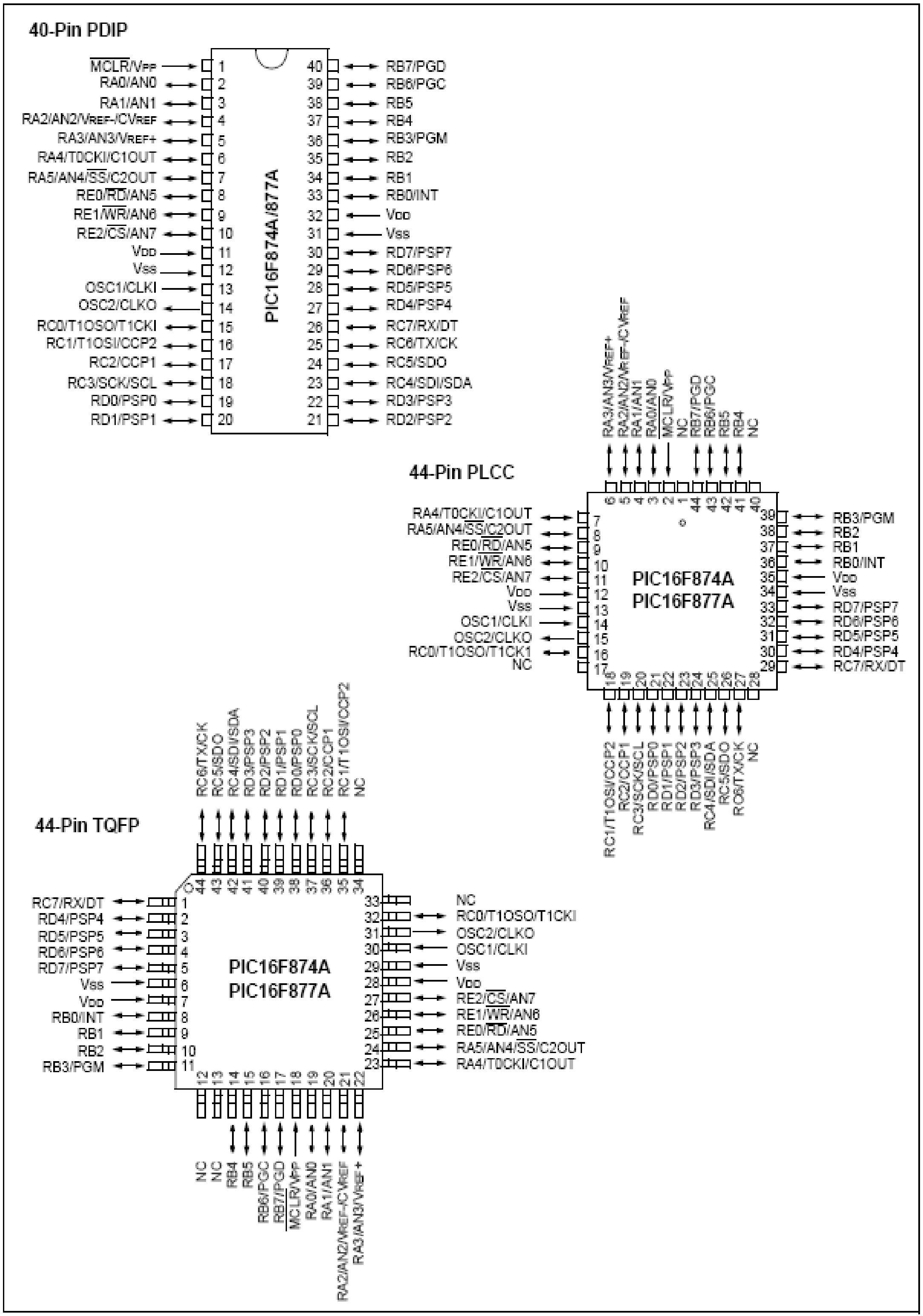
- 100,000 erase/write cycle Enhanced Flash program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Data EEPROM Retention > 40 years
- Self-reprogrammable under software control
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Single-supply 5V In-Circuit Serial Programming
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving Sleep mode
- Selectable oscillator options
- In-Circuit Debug (ICD) via two pins

CMOS Technology:

- Low-power, high-speed Flash/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Commercial and Industrial temperature ranges
- Low-power consumption

Device	Program Memory		Data SRAM (Bytes)	EEPROM (Bytes)	I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8/16-bit	Comparators
	Bytes	# Single Word Instructions						SPI	Master I^2C			
PIC16F873A	7.2K	4096	192	128	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F874A	7.2K	4096	192	128	33	8	2	Yes	Yes	Yes	2/1	2
PIC16F876A	14.3K	8192	368	256	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F877A	14.3K	8192	368	256	33	8	2	Yes	Yes	Yes	2/1	2

Pin Diagrams (Continued)



1.0 DEVICE OVERVIEW

This document contains device specific information about the following devices:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

PIC16F873A/876A devices are available only in 28-pin packages, while PIC16F874A/877A devices are available in 40-pin and 44-pin packages. All devices in the PIC16F87XA family share common architecture with the following differences:

- The PIC16F873A and PIC16F874A have one-half of the total on-chip memory of the PIC16F876A and PIC16F877A
- The 28-pin devices have three I/O ports, while the 40/44-pin devices have five
- The 28-pin devices have fourteen interrupts, while the 40/44-pin devices have fifteen
- The 28-pin devices have five A/D input channels, while the 40/44-pin devices have eight
- The Parallel Slave Port is implemented only on the 40/44-pin devices

The available features are summarized in Table 1-1. Block diagrams of the PIC16F873A/876A and PIC16F874A/877A devices are provided in Figure 1-1 and Figure 1-2, respectively. The pinouts for these device families are listed in Table 1-2 and Table 1-3.

Additional information may be found in the PICmicro® Mid-Range 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.

TABLE 1-1: PIC16F87XA DEVICE FEATURES

Key Features	PIC16F873A	PIC16F874A	PIC16F876A	PIC16F877A
Operating Frequency	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
Flash Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory (bytes)	128	128	256	256
Interrupts	14	15	14	15
I/O Ports	Ports A, B, C	Ports A, B, C, D, E	Ports A, B, C	Ports A, B, C, D, E
Timers	3	3	3	3
Capture/Compare/PWM modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Analog Comparators	2	2	2	2
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions
Packages	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN

8.0 CAPTURE/COMPARE/PWM MODULES

Each Capture/Compare/PWM (CCP) module contains a 16-bit register which can operate as a:

- 16-bit Capture register
- 16-bit Compare register
- PWM Master/Slave Duty Cycle register

Both the CCP1 and CCP2 modules are identical in operation, with the exception being the operation of the special event trigger. Table 8-1 and Table 8-2 show the resources and interactions of the CCP module(s). In the following sections, the operation of a CCP module is described with respect to CCP1. CCP2 operates the same as CCP1 except where noted.

CCP1 Module:

Capture/Compare/PWM Register 1 (CCPR1) is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). The CCP1CON register controls the operation of CCP1. The special event trigger is generated by a compare match and will reset Timer1.

CCP2 Module:

Capture/Compare/PWM Register 2 (CCPR2) is comprised of two 8-bit registers: CCPR2L (low byte) and CCPR2H (high byte). The CCP2CON register controls the operation of CCP2. The special event trigger is generated by a compare match and will reset Timer1 and start an A/D conversion (if the A/D module is enabled).

Additional information on CCP modules is available in the PICmicro® Mid-Range MCU Family Reference Manual (DS33023) and in application note *AN594, "Using the CCP Module(s)"* (DS00594).

TABLE 8-1: CCP MODE – TIMER RESOURCES REQUIRED

CCP Mode	Timer Resource
Capture	Timer1
Compare	Timer1
PWM	Timer2

TABLE 8-2: INTERACTION OF TWO CCP MODULES

CCPx Mode	CCPy Mode	Interaction
Capture	Capture	Same TMR1 time base
Capture	Compare	The compare should be configured for the special event trigger which clears TMR1
Compare	Compare	The compare(s) should be configured for the special event trigger which clears TMR1
PWM	PWM	The PWMs will have the same frequency and update rate (TMR2 interrupt)
PWM	Capture	None
PWM	Compare	None

11.0 ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) Converter module has five inputs for the 28-pin devices and eight for the 40/44-pin devices.

The conversion of an analog input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of VDD, VSS, RA2 or RA3.

The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D clock must be derived from the A/D's internal RC oscillator.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADCON0 register, shown in Register 11-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 11-2, configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

Additional information on using the A/D module can be found in the PICmicro® Mid-Range MCU Family Reference Manual (DS33023).

REGISTER 11-1: ADCON0 REGISTER (ADDRESS 1Fh)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0
ADCS1	ADCS0	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	—	ADON
bit 7							bit 0

bit 7-6 **ADCS1:ADCS0:** A/D Conversion Clock Select bits (ADCON0 bits in **bold**)

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	**00**	FOSC/2
0	**01**	FOSC/8
0	**10**	FOSC/32
0	**11**	FRC (clock derived from the internal A/D RC oscillator)
1	**00**	FOSC/4
1	**01**	FOSC/16
1	**10**	FOSC/64
1	**11**	FRC (clock derived from the internal A/D RC oscillator)

bit 5-3 **CHS2:CHS0:** Analog Channel Select bits

000 = Channel 0 (AN0)
001 = Channel 1 (AN1)
010 = Channel 2 (AN2)
011 = Channel 3 (AN3)
100 = Channel 4 (AN4)
101 = Channel 5 (AN5)
110 = Channel 6 (AN6)
111 = Channel 7 (AN7)

Note: The PIC16F873A/876A devices only implement A/D channels 0 through 4; the unimplemented selections are reserved. Do not select any unimplemented channels with these devices.

bit 2 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit

When ADON = 1:
1 = A/D conversion in progress (setting this bit starts the A/D conversion which is automatically cleared by hardware when the A/D conversion is complete)
0 = A/D conversion not in progress

bit 1 **Unimplemented:** Read as '0'

bit 0 **ADON:** A/D On bit

1 = A/D converter module is powered up
0 = A/D converter module is shut-off and consumes no operating current

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 D

IRFP150N POWER MOSFET Datasheet

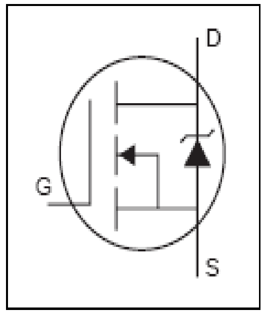
International
IOR Rectifier

PD- 91503C

IRFP150N

HEXFET® Power MOSFET

- Advanced Process Technology
- Dynamic dv/dt Rating
- 175°C Operating Temperature
- Fast Switching
- Fully Avalanche Rated



V_{DSS} = 100V

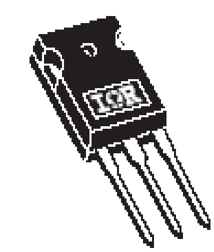
$R_{DS(on)}$ = 0.036Ω

I_D = 42A

Description

Fifth Generation HEXFETs from International Rectifier utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit, combined with the fast switching speed and ruggedized device design that HEXFET Power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications.

The TO-247 package is preferred for commercial-industrial applications where higher power levels preclude the use of TO-220 devices. The TO-247 is similar but superior to the earlier TO-218 package because of its isolated mounting hole.



TO-247AC

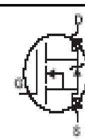
Absolute Maximum Ratings

	Parameter	Max.	Units
I_D @ T_C = 25°C	Continuous Drain Current, V_{GS} @ 10V	42	A
I_D @ T_C = 100°C	Continuous Drain Current, V_{GS} @ 10V	30	
I_{DM}	Pulsed Drain Current ①⑤	140	
P_D @T_C = 25°C	Power Dissipation	160	W
	Linear Derating Factor	1.1	W/°C
V_{GS}	Gate-to-Source Voltage	± 20	V
E_{AS}	Single Pulse Avalanche Energy②⑤	420	mJ
I_{AR}	Avalanche Current①⑤	22	A
E_{AR}	Repetitive Avalanche Energy①	16	mJ
dv/dt	Peak Diode Recovery dv/dt ③⑤	5.0	V/ns
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to + 175	°C
	Soldering Temperature, for 10 seconds	300 (1.6mm from case)	
	Mounting torque, 6-32 or M3 srew	10 lbf•in (1.1N•m)	

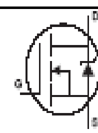
Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	0.95	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface	0.24	—	
$R_{\theta JA}$	Junction-to-Ambient	—	40	

Electrical Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
$V_{(BR)DSS}$	Drain-to-Source Breakdown Voltage	100	—	—	V	V_{GS} = 0V, I_D = 250µA
$DV_{(BR)DSS}/DT_J$	Breakdown Voltage Temp. Coefficient	—	0.11	—	V/°C	Reference to 25°C, I_D = 1mA⑤
$R_{DS(on)}$	Static Drain-to-Source On-Resistance	—	—	0.036	W	V_{GS} = 10V, I_D = 23A ④
$V_{GS(th)}$	Gate Threshold Voltage	2.0	—	4.0	V	V_{DS} = V_{GS}, I_D = 250µA
g_{fs}	Forward Transconductance	14	—	—	S	V_{DS} = 25V, I_D = 22A⑤
I_{DSS}	Drain-to-Source Leakage Current	—	—	25	µA	V_{DS} = 100V, V_{GS} = 0V
		—	—	250		V_{DS} = 80V, V_{GS} = 0V, T_J = 150°C
I_{GSS}	Gate-to-Source Forward Leakage	—	—	100	nA	V_{GS} = 20V
	Gate-to-Source Reverse Leakage	—	—	-100		V_{GS} = -20V
Q_g	Total Gate Charge	—	—	110	nC	I_D = 22A
Q_{gs}	Gate-to-Source Charge	—	—	15		V_{DS} = 80V
Q_{gd}	Gate-to-Drain ("Miller") Charge	—	—	58		V_{GS} = 10V, See Fig. 6 and 13 ④⑤
$t_{d(on)}$	Turn-On Delay Time	—	11	—	ns	V_{DD} = 50V
t_r	Rise Time	—	56	—		I_D = 22A
$t_{d(off)}$	Turn-Off Delay Time	—	45	—		R_G = 3.6W
t_f	Fall Time	—	40	—		R_D = 2.9W, See Fig. 10 ④⑤
L_D	Internal Drain Inductance	—	5.0	—	nH	Between lead, 6mm (0.25in.) from package and center of die contact 
L_S	Internal Source Inductance	—	13	—		
C_{iss}	Input Capacitance	—	1900	—	pF	V_{GS} = 0V
C_{oss}	Output Capacitance	—	450	—		V_{DS} = 25V
C_{rss}	Reverse Transfer Capacitance	—	230	—		f = 1.0MHz, See Fig. 5⑤

Source-Drain Ratings and Characteristics

	Parameter	Min.	Typ.	Max.	Units	Conditions
I_S	Continuous Source Current (Body Diode)	—	—	42	A	MOSFET symbol showing the integral reverse p-n junction diode. 
I_{SM}	Pulsed Source Current (Body Diode) ①⑤	—	—	140		
V_{SD}	Diode Forward Voltage	—	—	1.3	V	T_J = 25°C, I_S =23A, V_{GS} = 0V ④
t_{rr}	Reverse Recovery Time	—	180	270	ns	T_J = 25°C, I_F = 22A
Q_{rr}	Reverse RecoveryCharge	—	1.2	1.8	µC	di/dt = 100A/µs ④ ⑤
t_{on}	Forward Turn-On Time	Intrinsic turn-on time is negligible (turn-on is dominated by L_S+L_D)				

Notes:

① Repetitive rating; pulse width limited by max. junction temperature. (See fig. 11)

② Starting T_J = 25°C, L = 1.7mH R_G = 25W, I_{AS} = 22A. (See Figure 12)

③ I_{SD} £ 22A, di/dt £ 180A/µs, V_{DD} £ $V_{(BR)DSS}$, T_J £ 175°C

④ Pulse width £ 300µs; duty cycle £ 2%.

⑤ Uses IRF1310N data and test conditions

APPENDIX E

1N4148 Diode Datasheet

Fast Switching Diodes

Features

- Silicon Epitaxial Planar Diodes
- Electrically equivalent diodes: 1N4148 - 1N914
  1N4448 - 1N914B

Applications

Extreme fast switches

Mechanical Data

Case: DO-35 Glass Case

Weight: approx. 125 mg

Packaging Codes/Options:

TR / 10 k per 13 " reel (52 mm tape), 50 k/box

TAP / 10 k per Ammopack (52 mm tape), 50 k/box

Parts Table

Part	Type differentiation	Ordering code	Remarks
1N4148	V_{RRM} = 100 V, V_F @ I_F 10 mA = 1 V	1N4148-TAP or 1N4148-TR	Ammopack / Tape and Reel
1N4448	V_{RRM} = 100 V, V_F @ I_F 100 mA = 1 V	1N4448-TAP or 1N4448-TR	Ammopack / Tape and Reel

Absolute Maximum Ratings

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Repetitive peak reverse voltage		V_{RRM}	100	V
Reverse voltage		V_R	75	V
Peak forward surge current	t_p = 1 µs	I_{FSM}	2	A
Repetitive peak forward current		I_{FRM}	500	mA
Forward current		I_F	300	mA
Average forward current	V_R = 0	I_{FAV}	150	mA
Power dissipation	l = 4 mm, T_L = 45 °C	P_V	440	mW
	l = 4 mm, T_L ≤ 25 °C	P_V	500	mW

Thermal Characteristics

T_{amb} = 25 °C, unless otherwise specified

Parameter	Test condition	Symbol	Value	Unit
Junction ambient	l = 4 mm, T_L = constant	R_{thJA}	350	K/W
Junction temperature		T_j	200	°C
Storage temperature range		T_{stg}	- 65 to + 200	°C

APPENDIX F

LM7805 Voltage Regulator Datasheet

National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

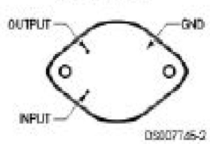
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

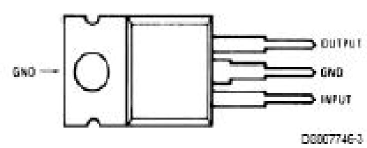
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



Bottom View
Order Number LM7805CK,
LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT,
LM7812CT or LM7815CT
See NS Package Number T03B

Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

		Output Voltage		5V			12V			15V			Units
		Input Voltage (unless otherwise noted)		10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)			V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}	(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 1A	Tj = 25°C			60			120			150	mV
			ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)			V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN}≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN}≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
V_N	Output Noise Voltage	T_A =25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	Tj = 25°C		2.1			1.5			1.2		A
	Peak Output Current	Tj = 25°C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ Tj ≤ +125°C, I_O = 5 mA		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	Tj = 25°C, I_O ≤ 1A		7.5		14.6			17.7			V

Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 μF, and a capacitor across the output of 0.1μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_W ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

APPENDIX G

IR2109 Half-Bridge Driver Datasheet

International
IOR Rectifier

Data Sheet No. PD60163-U

IR2109(4) (S) & (PbF)

HALF-BRIDGE DRIVER

Features

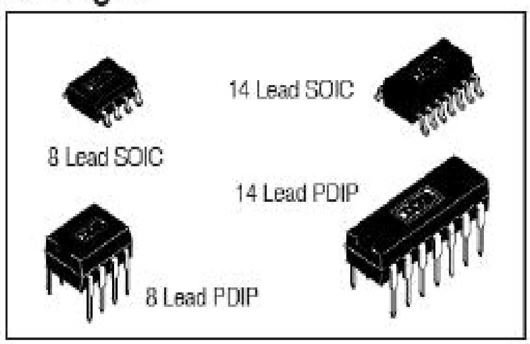
- Floating channel designed for bootstrap operation
  Fully operational to +600V
  Tolerant to negative transient voltage
  dV/dt immune
- Gate drive supply range from 10 to 20V
- Undervoltage lockout for both channels
- 3.3V, 5V and 15V input logic compatible
- Cross-conduction prevention logic
- Matched propagation delay for both channels
- High side output in phase with IN input
- Logic and power ground +/- 5V offset.
- Internal 540ns dead-time, and programmable up to 5us with one external R_{DT} resistor (IR21094)
- Lower di/dt gate driver for better noise immunity
- Shut down input turns off both channels.
- Available in Lead-Free

Product Summary

V_{OFFSET}	600V max.
I_O+/-	120 mA / 250 mA
V_{OUT}	10 - 20V
$t_{on/off}$ (typ.)	750 & 200 ns
Dead Time	540 ns

(programmable up to 5uS for IR21094)

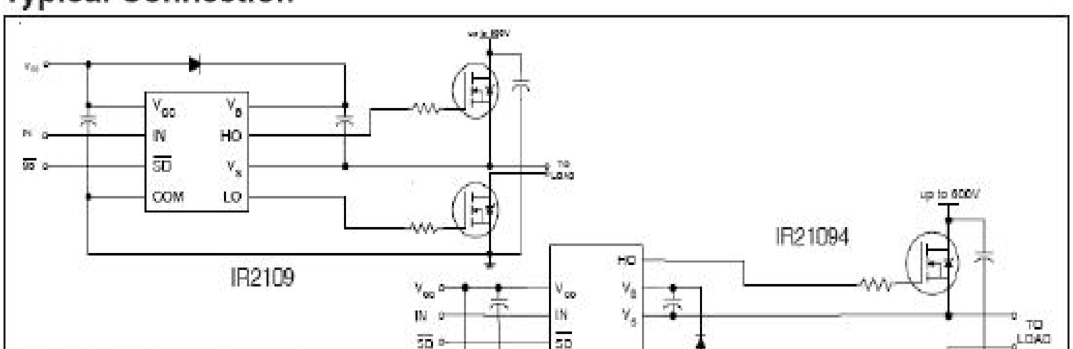
Packages



Description

The IR2109(4)(S) are high voltage, high speed power MOSFET and IGBT drivers with dependent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. The logic input is compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 600 volts.

Typical Connection



(Refer to Lead Assignments for correct configuration). This/These diagram(s) show electrical connections only. Please refer to our Application Notes and DesignTips for proper circuit board layout.

Absolute Maximum Ratings

Absolute maximum ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

Symbol	Definition		Min.	Max.	Units
V_B	High side floating absolute voltage		-0.3	625	V
V_S	High side floating supply offset voltage		V_B - 25	V_B + 0.3	
V_{HO}	High side floating output voltage		V_S - 0.3	V_B + 0.3	
V_{CC}	Low side and logic fixed supply voltage		-0.3	25	
V_{LO}	Low side output voltage		-0.3	V_{CC} + 0.3	
DT	Programmable dead-time pin voltage (IR21094 only)		V_{SS} - 0.3	V_{CC} + 0.3	
V_{IN}	Logic input voltage (IN & $\overline{SD}$)		V_{SS} - 0.3	V_{CC} + 0.3	
V_{SS}	Logic ground (IR21094/IR21894 only)		V_{CC} - 25	V_{CC} + 0.3	
dV_S/dt	Allowable offset supply voltage transient		—	50	V/ns
P_D	Package power dissipation @ $T_A \leq +25°C$	(8 Lead PDIP)	—	1.0	W
		(8 Lead SOIC)	—	0.625	
		(14 lead PDIP)	—	1.6	
		(14 lead SOIC)	—	1.0	
Rth_{JA}	Thermal resistance, junction to ambient	(8 Lead PDIP)	—	125	°C/W
		(8 Lead SOIC)	—	200	
		(14 lead PDIP)	—	75	
		(14 lead SOIC)	—	120	
T_J	Junction temperature		—	150	°C
T_S	Storage temperature		-50	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

Recommended Operating Conditions

The input/output logic timing diagram is shown in figure 1. For proper operation the device should be used within the recommended conditions. The V_S and V_{SS} offset rating are tested with all supplies biased at 15V differential.

Symbol	Definition	Min.	Max.	Units
VB	High side floating supply absolute voltage	$V_S + 10$	$V_S + 20$	V
V_S	High side floating supply offset voltage	Note 1	600	
V_{HO}	High side floating output voltage	V_S	V_B	
V_{CC}	Low side and logic fixed supply voltage	10	20	
V_{LO}	Low side output voltage	0	V_{CC}	
V_{IN}	Logic input voltage (IN & $\overline{SD}$)	V_{SS}	V_{CC}	
DT	Programmable dead-time pin voltage (IR21094 only)	V_{SS}	V_{CC}	
V_{SS}	Logic ground (IR21094 only)	-5	5	
T_A	Ambient temperature	-40	125	°C

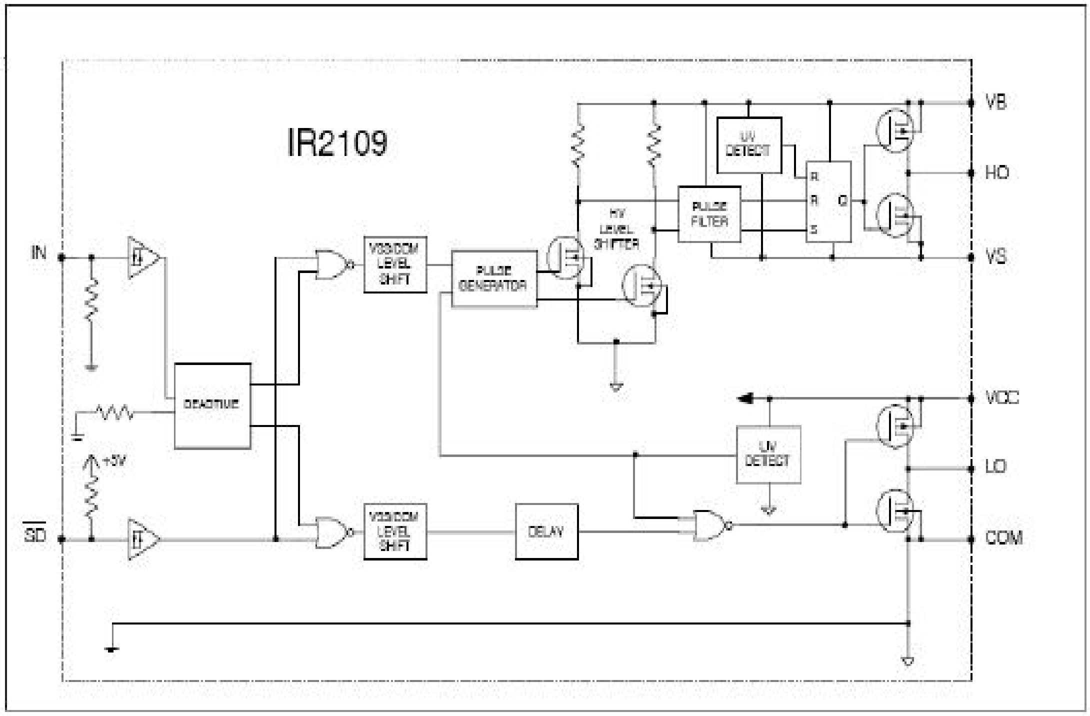
Note 1: Logic operational for V_S of -5 to +600V. Logic state held for V_S of -5V to $-V_{BS}$. (Please refer to the Design Tip DT97-3 for more details).

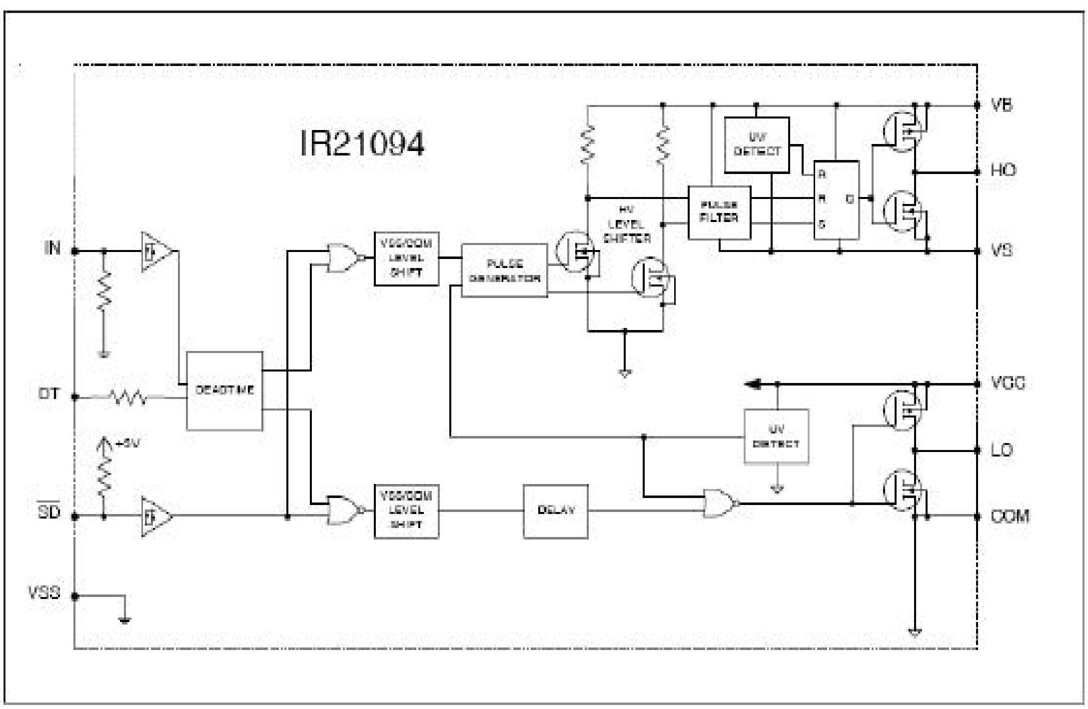
Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 15V, V_{SS} = COM, C_L = 1000 pF, T_A = 25°C, DT = VSS unless otherwise specified.

Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
t_{on}	Turn-on propagation delay	—	750	950	nsec	V_S = 0V
t_{off}	Turn-off propagation delay	—	200	280		V_S = 0V or 600V
t_{sd}	Shut-down propagation delay	—	200	280		
MT	Delay matching, HS & LS turn-on/off	—	0	70		
t_r	Turn-on rise time	—	150	220		V_S = 0V
t_f	Turn-off fall time	—	50	80		V_S = 0V
DT	Deadtime: LO turn-off to HO turn-on(DT_{LO-HO}) & HO turn-off to LO turn-on (DT_{HO-LO})	400	540	680		RDT= 0
		4	5	6	usec	RDT = 200k (IR21094)
MDT	Deadtime matching = $DT_{LO-HO} - DT_{HO-LO}$	—	0	60	nsec	RDT=0
		—	0	600		RDT = 200k (IR21094)

Functional Block Diagrams

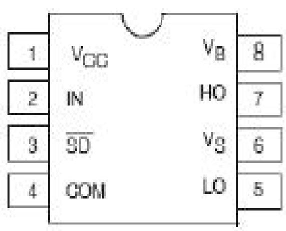




Lead Definitions

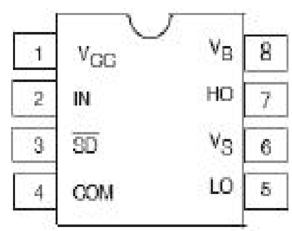
Symbol	Description
IN	Logic input for high and low side gate driver outputs (HO and LO), in phase with HO (referenced to COM for IR2109 and VSS for IR21094)
$\overline{SD}$	Logic input for shutdown (referenced to COM for IR2109 and VSS for IR21094)
DT	Programmable dead-time lead, referenced to VSS. (IR21094 only)
VSS	Logic Ground (21094 only)
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side and logic fixed supply
LO	Low side gate drive output
COM	Low side return

Lead Assignments



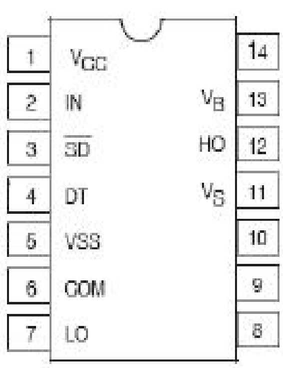
8 Lead PDIP

IR2109



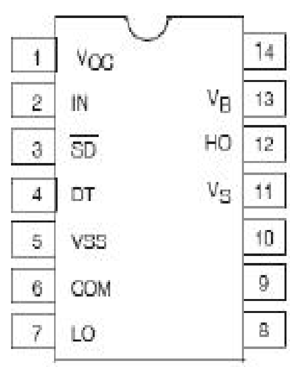
8 Lead SOIC

IR2109S



14 Lead PDIP

IR21094



14 Lead SOIC

IR21094S

APPENDIX H

Potentiometer Datasheet

Model P160
16mm Rotary Potentiometer
Conductive Plastic Element
100,000 Cycle Life
Metal shaft / Bushing
Multi – Ganged available
RoHS Compliant

MODEL STYLES	
Side Adjust , Solder Lugs	P160KNP
Side Adjust , PC pins	P160KN
Side Adjust , PC Pins, Long pins	P160KN2
Rear Adjust, PC pins	P160KNPD

ELECTRICAL[1]	
Resistance Range, Ohms	500-1M
Standard Resistance Tolerance	± 20%
Residual Resistance	20 ohms max.
Power rating Input Voltage, maximum	200 Vac max.
Power Rated, Watts	0.2W- B taper, 0.1W-others
Dielectric Strength	500Vac, I minute
Insulation Resistance, Minimum	100M ohms at 250Vdc
Sliding Noise	100mV max.
Actual Electrical Travel, Nominal	260°

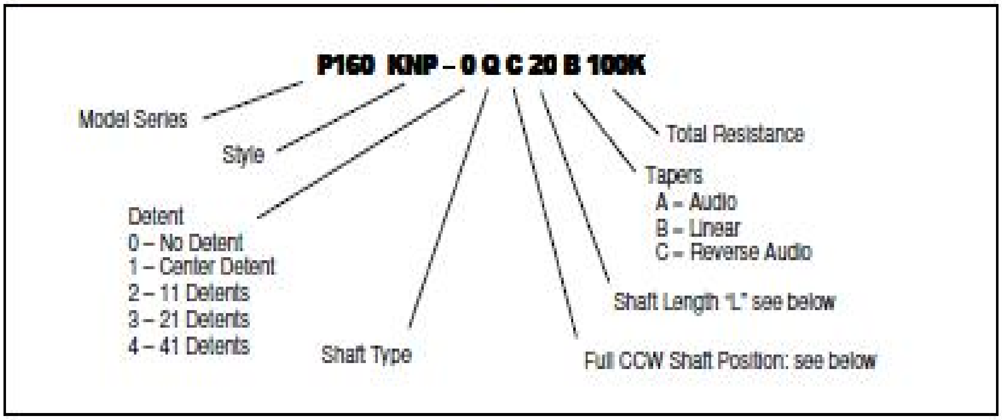
MECHANICAL	
Total Mechanical Travel	300°± 10°
Static Stop Strength	90 oz-in
Rotational Torque, Maximum	2.5 oz-in

ENVIRONMENTAL	
Operating Temperature Range	-20°C to +70°C
Rotational Life	100,000 cycles

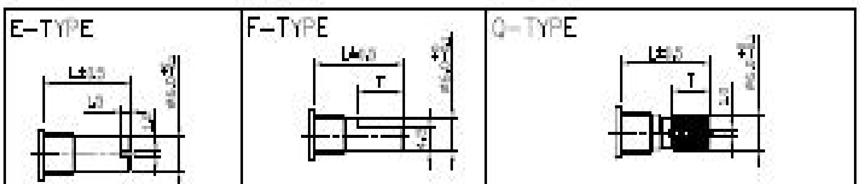
[1] *Specifications subject to change without notice.*

Model P160

ORDERING INFORMATION[2]



Shaft Types



E-Type:

L	10	15	20	25	30	35	40

F-Type:

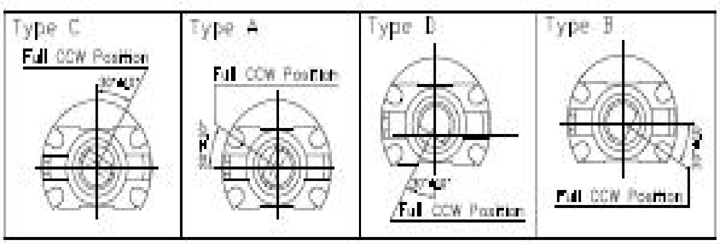
L	15	18	20	25	30	35
T	7	10	12	12	12	12

Q-Type:

L	10	12	13	14	15	17	20	25	30	35	45
T	2.5	4.5	4	5	6	8	10	12	12	12	12

Shaft Position (F-Type Shaft)

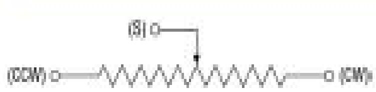
Dashed lines on Type "C" and Type "A" shows position of adjustment slot for E-Type and Q-Type shafts



STANDARD RESISTANCE VALUES, OHMS

500	1K	2K	5K	10K	20K	50K	100K	200K	500K	1MEG

CIRCUIT DIAGRAM



APPENDIX I

UP00A USB PIC Programmer Datasheet

4. HARDWARE (Programmer)

Connecting the Programmer to the Computer

Use the USB Cable provided.

Connect one side of the cable to the programmer and the other side to the USB port of the computer.

Plugging the Microcontroller

40-pin Microcontroller

- Plug in the microcontroller at the socket (indicated on the board) and **push forward the toggle switch** as shown.

5. SOFTWARE INSTALLATION

Before UP00A PIC USB programmer can be used, the driver must be installed (1st time User).

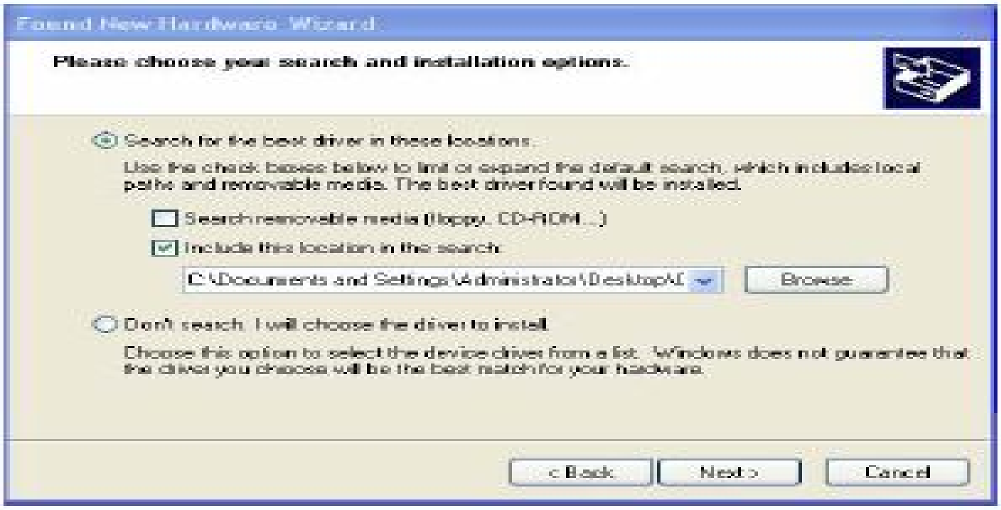
1. Copy "Cytron Prgrammer" folder from the CD to your PC.

2. Plug one end of the USB cable to the USB Programmer and the other end to the PC's USB port. You will see the 'loading' red light illuminates.

3. The window will now show "Found New Hardware".

4. Choose to "Install from a list of specific location (Advanced)" when the "Wizard" window appear.

5. Click *Browse* and browse to "USB Driver" folder in "Cytron Programmer" folder that you copied. Click *Next* to proceed the installation.



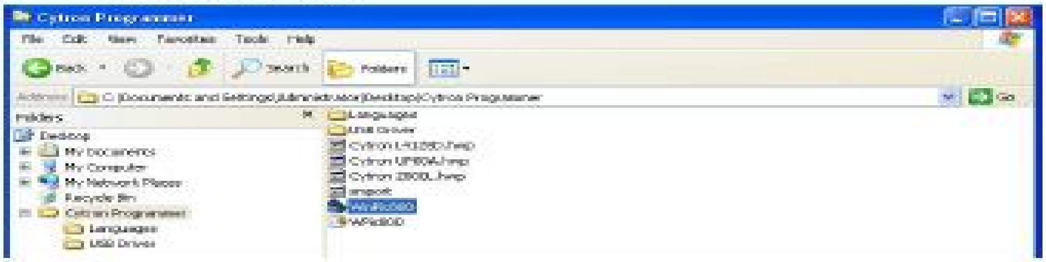
6. If the window as figure below pops up, click *Continue Anyway*.

7. When installation is complete, click *Finish*.

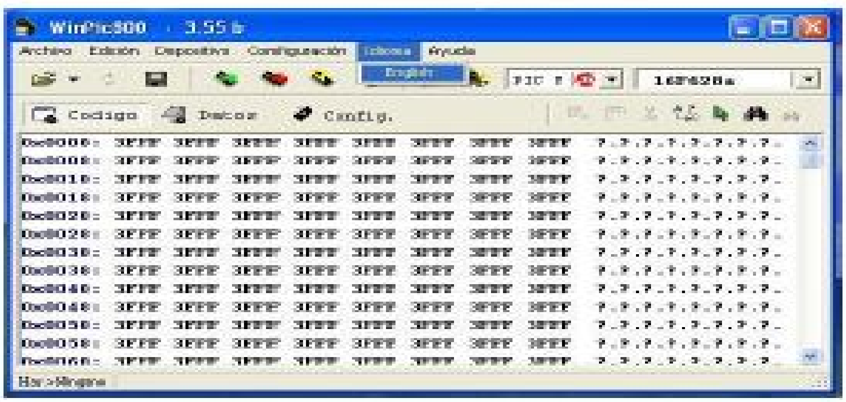
8. Once the installation of driver is completed, the "ready" green light will illuminate.

9. After driver installation, USB programmer is ready to be used with WinPic800. This software is a freeware, thus Cytron will not be responsible for any upgrade or issue found with this software.

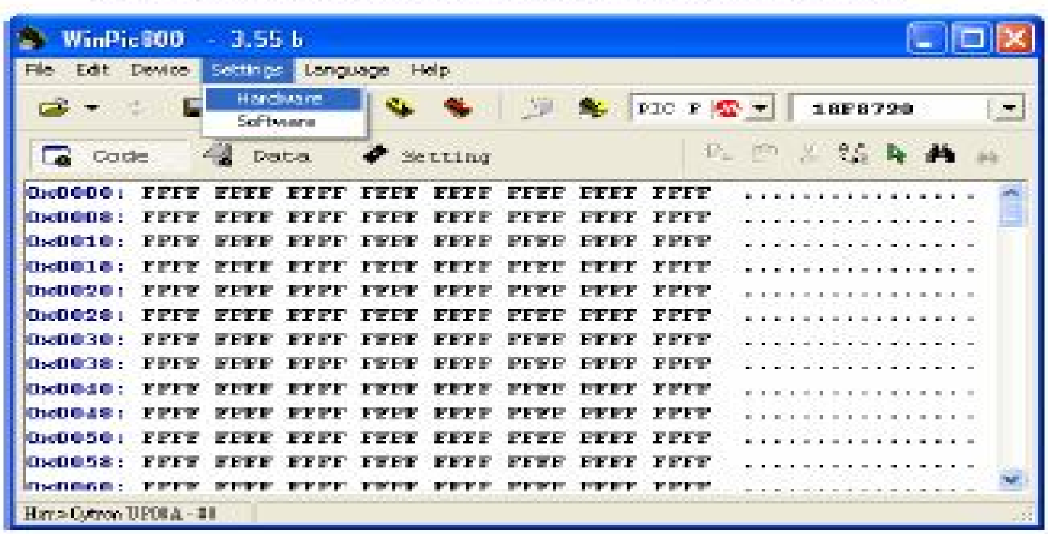
10. The application or .exe file is included in "Cytron Programmer" folder, please open WinPic800.exe as shown.



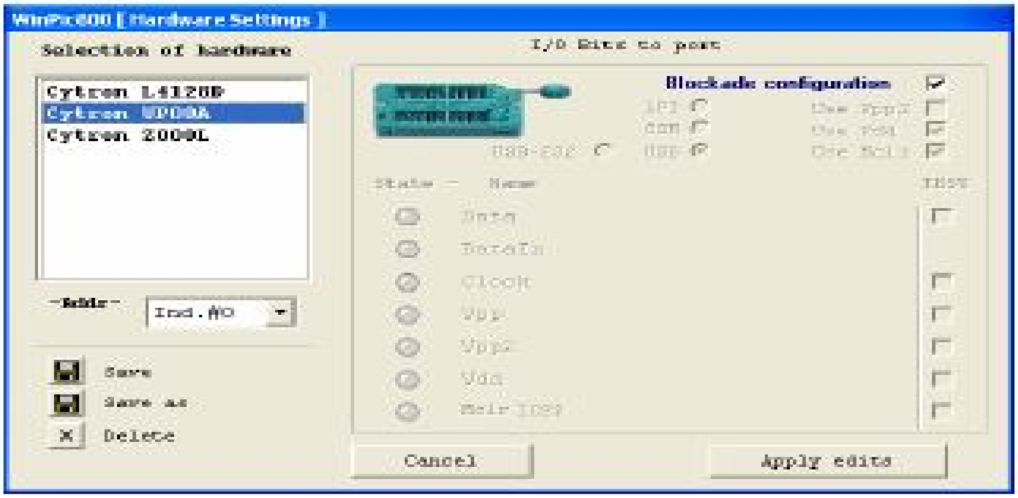
11. By default, the software is in other language, click *OK* when the window below pops up and then change the language to English (One time configuration).



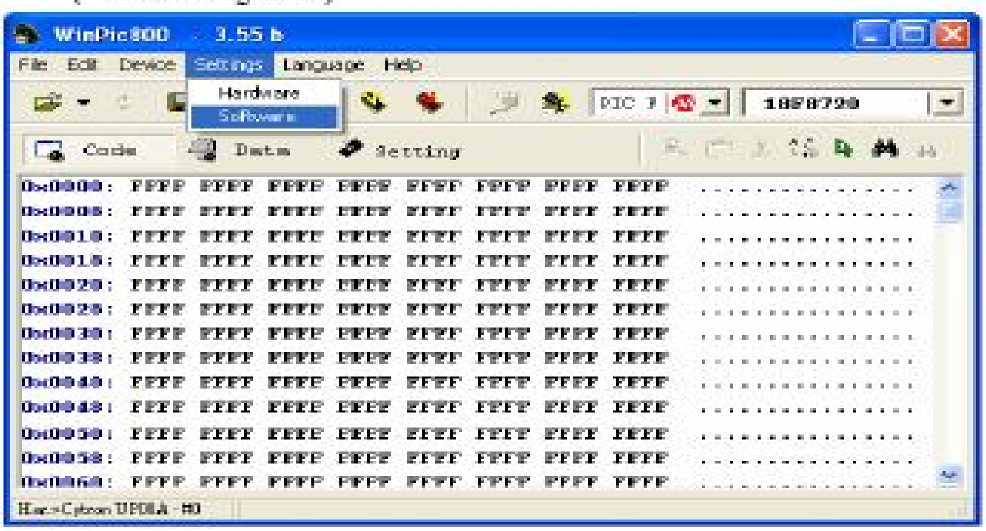
12. Correct hardware must be chosen (one time configuration) because WinPic800 support more than one programmer. Go to "Settings", choose *Hardware*.



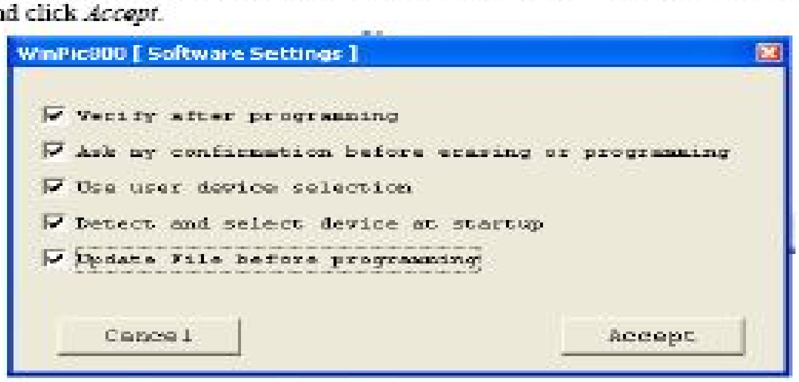
13. A "WinPic800 (Hardware Settings)" window will appear. Choose "Cytron UP00A" under "Selection of hardware". Click *Apply edits* to close this window.



14. Next is to configure software settings. Please go to "Settings" and choose *Software* (one time configuration).

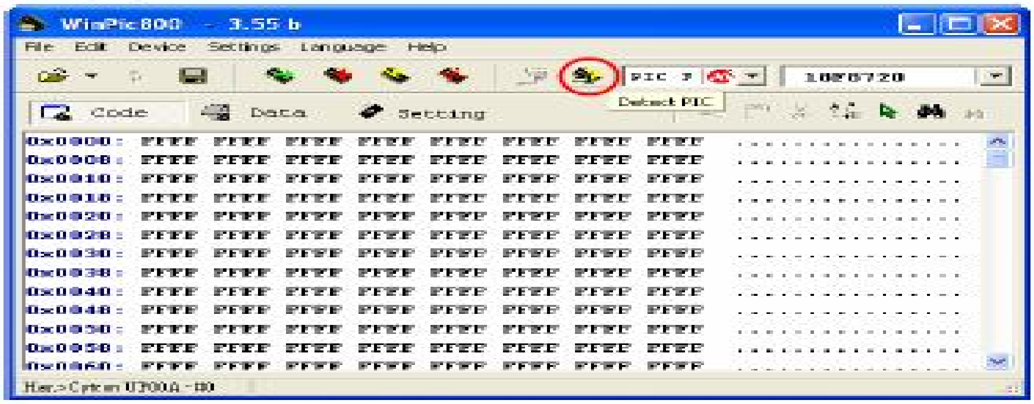


15. A "WinPic800 (Software Settings)" window will appear. Tick the selection as shown and click *Accept*.

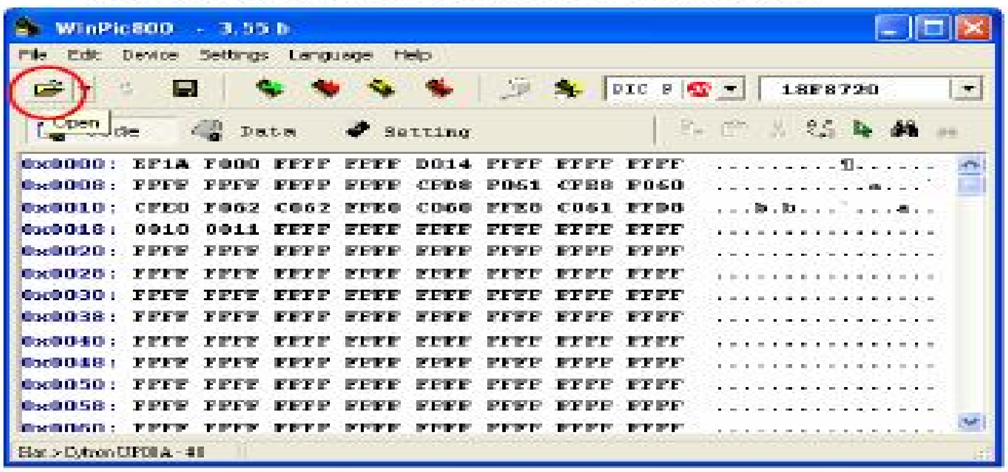


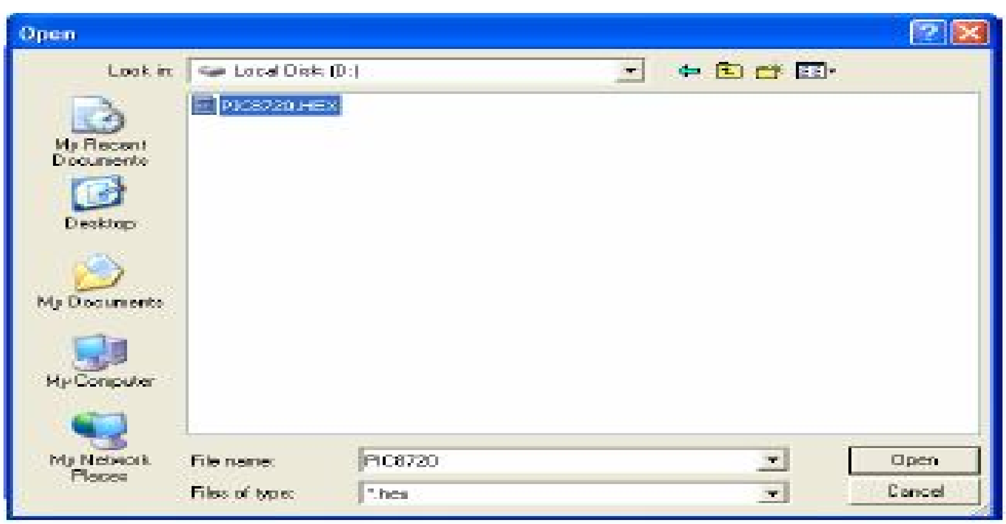
6. HOW TO PROGRAM THE PIC MICROCONTROLLER

1. Now WinPic800 is ready to program the PIC. This programmer is able to detect the PIC. By clicking the icon shown, the programmer will detect the type of PIC on the programmer.

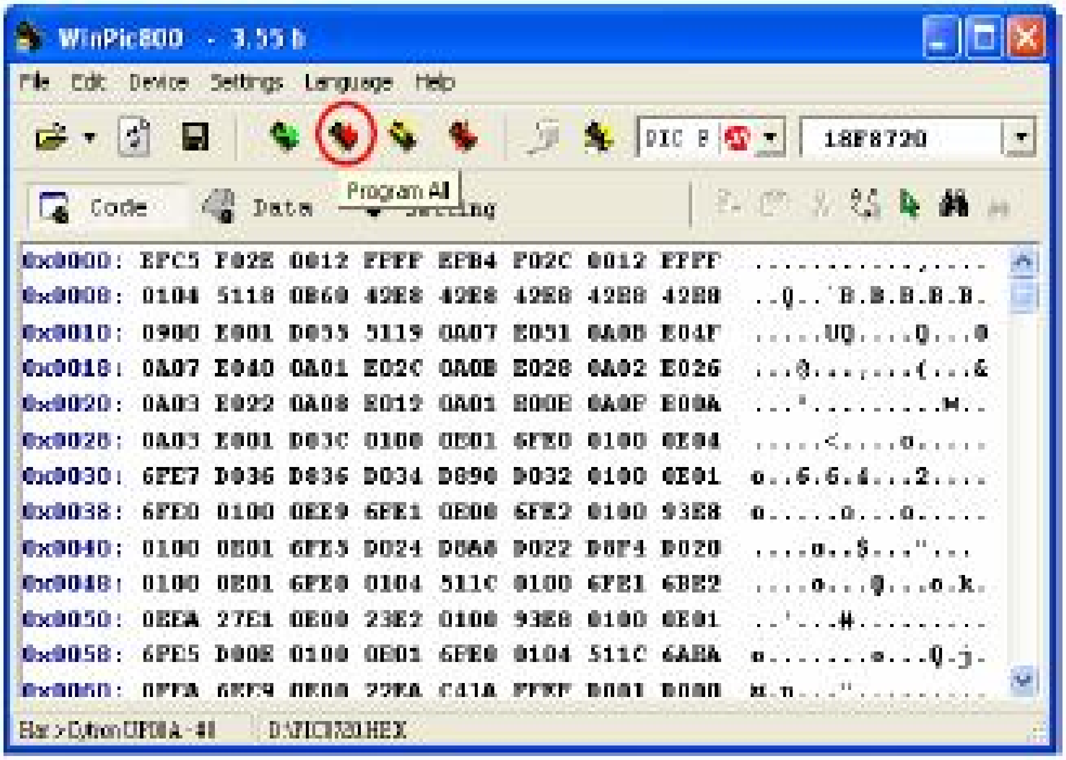


2. To write Hex code to PIC we must first open the hex file. By clicking the icon shown, a browse window will appear, open the hex file by clicking the file.

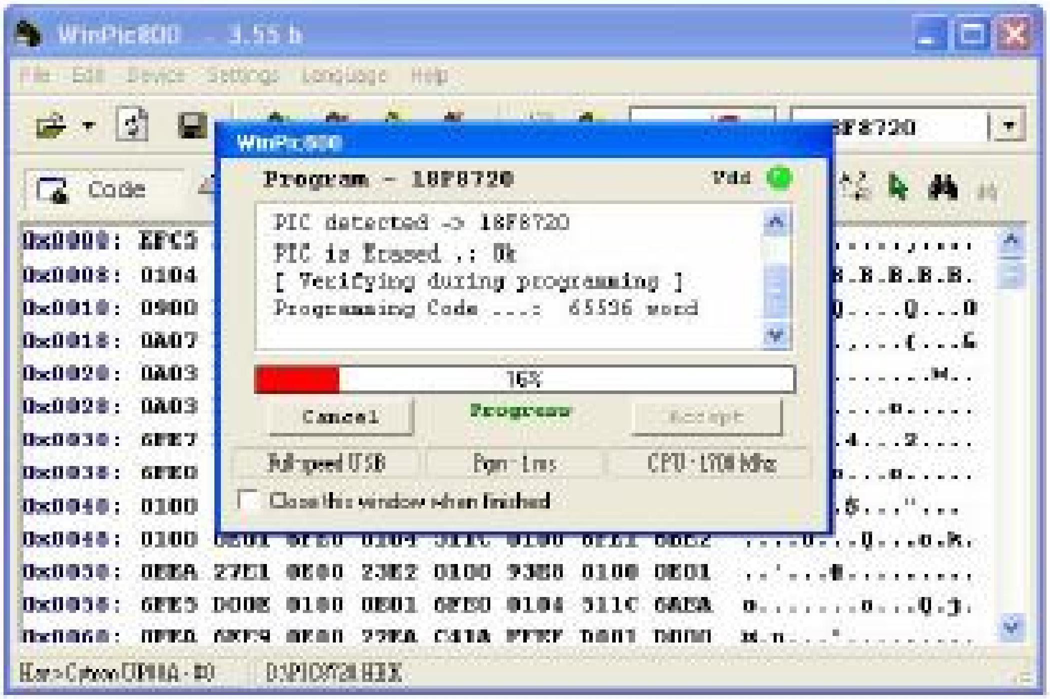




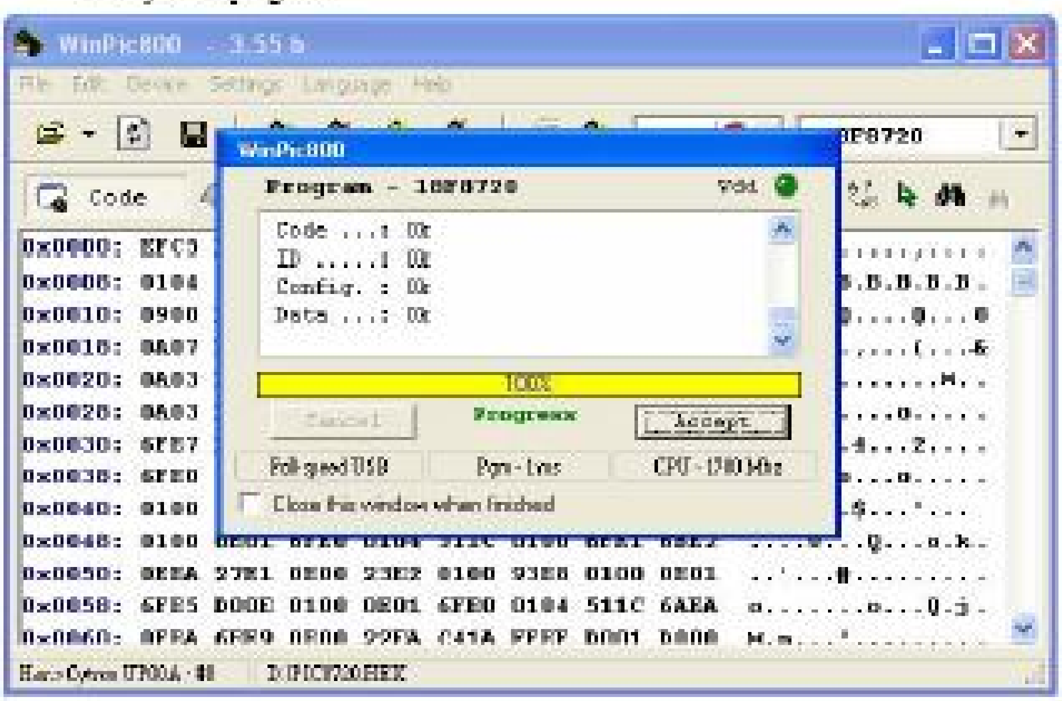
3. Program the file to PIC by clicking the icon shown.



4. A confirmation window will appear, click *Yes* to proceed programming PIC.



5. When it is completed, the window will show the status. Click *Accept* and the PIC is ready to be plug out.



6. To disconnect UP00A, simply plug the USB out. No extra configuration or setting needed. Same applied when plug-in for the 2nd time, installation of driver is not required.