

**IMPLEMENTATION OF MICROCONTROLLER
TO THE CONTROL OF AN AGV**

By

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FINAL PROJECT REPORT

**Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)**

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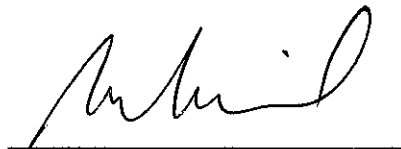
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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
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(Electrical & Electronics Engineering)

Approved:



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June 2008

CERTIFICATION OF ORIGINALITY

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



Mohamad Lokman Bin Mohamad Rafiuddin

ABSTRACT

This work describes the designing and the implementation of microcontroller to the control of an AGV. AGV is an acronym for Automatic Guided Vehicle and it's apparently become more demanding nowadays especially in the manufacturing industry due to its ability to self guided the transportation process. The main hardware components consist of the microcontroller board, the sensor, the voltage regulator and the motor driver circuits. The task of interfacing the hardware and the programming of the software is challenging. The microcontroller will act as brain of the AGV to control the action that should be taken by the AGV while moving under pre-defined pathways. Basically, the sensors which are located at the front and both sides of the AGV will sense the existence of black line at the bottom of the AGV. The sensor provides the input signal to the microcontroller. The microcontroller will process the input obtained and provide the appropriate instruction to the output to control the motion of two motors. The output would results in the AGV to change the direction of movement either to the right or left or may remain in the same direction depending on the microcontroller's decision. Several experiments and tests also have been conducted to verify the operation of the circuits. The AGV prototype is successfully designed, assembled, built and tested.

ACKNOWLEDGEMENTS

The author would like to take this opportunity to thank all parties involved in making the Final Year Project (FYP) successfully performed and become a great educational session. Deepest gratitude goes to UNIVERSITI TEKNOLOGI PETRONAS's Final Year Project Committee and Electrical and Electronics Engineering Department, Staff for the support and patience in providing quality education and guidance.

The author would like to thank the following fellows for their respective professionalism and contribution to the program.

- *Assoc. Prof. Dr. Nordin Saad*, Project Supervisor.
- *Dr. Nor Hisham Hamid*, Head of Department of Electrical & Electronics Engineering Department.
- *All Lecturers*, Electrical & Electronics Engineering Department.
- *All Technicians and Staff*, Electrical & Electronics Engineering Department.
- *All the Colleague of University Technology PETRONAS (UTP)*.
- All staffs of University Technology PETRONAS (UTP).

Heartfelt appreciation goes to lecturers and UTP staff, which have spend time to provide additional support and advice throughout the Final Year Project until this project has been selected and present the department in Engineering Design Exhibition (EDX) 21 on April 2008 and achieve the EDX 21 bronze medal.

Not forgetting, to the family members that always give the morale support to accomplish the project in the best efforts so that project would be one of the unforgettable projects in UTP. Besides, appreciation as well goes to the friends and housemate in UTP, who have in one-way or another, contributed to the project success. Thank you.

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LIST OF ABBREVIATIONS

FYP	Final Year Project
AGV	Automatic Guided Vehicle
PIC	Peripheral Interface Controller
LED	Light Emitting Diode
IRR	Infrared Receiver
DC	Direct Current
PCB	Printed Circuit Board

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Theoretically, an Automatic Guided Vehicle (AGV) is self propelled or driverless vehicle that guided along defined pathways and controlled by a controller. It was used in many applications especially for material handling system in manufacturing industry. In material handling system, the AGV almost similar to the mobile robot that capable to move the material from one point to another point with navigation of sensor [1]. Basically, the AGV system consists of 3 stages which are sensing stage, processing stage and motion stage as described below:



Figure 1: Automatic Guided Vehicle Stages

During the sensing stage, the sensors which locate at the front bottom of the vehicle will act as the detector to detect the line pathway at bottom of the vehicle. Its functions are to guide the vehicle throughout the predefined pathways and provide the inputs to the processing stage. The processing stage is the main stage of the AGV System since its consist of microcontroller elements which function is to process the input from the sensing stage before come out with appropriate result either it would affect the motion of the vehicle or not. That's why the processing stage also called the brain of the AGV System since it will control all the operation of the AGV System especially the motion of the motor. Lastly, the motion stage which will get the instructions from the

microcontroller and act based on the given instruction either the direction should be changed or not. If any direction changes needed, the motor will act accordingly either to be reverse or forward in order to change the motion of the direction.

1.2 Problem Statement

Nowadays, world have been changed from manual mode operation to the automatic based operations. This change not only affects our life style at home but also affects the operations system in an industry. The industry demands for electronics system due to several factors: more accuracy, less cost, less human error and human dependency, and safety. Referring to the material handling system in manufacturing industry, the industry aims for the accuracy in term of time and the process. In term of time, the industry demands for the system which able to ensure 'On-Time Material Delivery' while for the process the system able to deliver the material from the store to the production line in exact location [2].

In terms of the costing, it is costly to have a system which uses a lot of manpower due to company need to pay for salary, allowance, compensation and benefits. However, by using the electronics system, the company may reduce number of labor required and thus costs for the material handling labor can be drastically reduced. Electronics system also provide less human dependency and thus will minimize the human error since in most cases, product damages caused by the operators during the transportation process between store and production line due to lack of alertness, careless and material was carried not in an appropriate ways. However in AGV system, the material will carried on the specified ways with certain speed. Therefore, this provides more careful operation on the material and ensures the products safety [3].

1.3 Objective and Scope of Study

As discussed earlier, there are several problem that may caused by the manual material handling system which are not accurate, costly, human error and safety. Therefore, the objective of the Automatic Guided Vehicle (AGV) was to eliminate this entire problem that occurs in the material handling system in the industry.

The objectives are further described as the following:

i. Safety

- To provide a safe system which include safe working operation and product safe from damages during material handling operation. Safe working operation is refer to the operator safe from injuries such MSD (musculoskeletal disorders) due to force and repetition since using the AGV System the material was carried by the AGV. Besides that, the product also safe from damages which may caused by the human error such as careless, crashes, scratches and material was carried not in an appropriate ways

ii. Minimize Error

- Since the AGV system has been controlled by the electronics system, it is less human dependency. Therefore it's definitely will eliminate human error such as crashes, material damage due to carry in various position and wrong delivery.

iii. Accuracy

- To make sure the material handling system was accurate in term of time and processes. Therefore, it must be able to provide the 'On-Time Material Delivery' as well as material able to be delivered from one point to another point.

iv. Cost Effective

- To ensure the AGV system could provide a low cost operation of the material handling system by reducing the production cost due to high number of material handling labors and material damages.

The scope of the project involve research on the subject matters such as application of the sensor, sensor operations and circuitry, microcontroller devices availability and functionality, and output element operations. Interestingly, it also includes designing the whole system circuitry, programming and hardware setup and interfacing of the prototype.

CHAPTER 2

LITERATURE REVIEW

As mentioned in the Chapter 1, the research element in this project is based on Automatic Guide Vehicle (AGV) System. Therefore, it is necessity to be familiar with certain application of the software and hardware since in order to accomplish the projects, the operation and functionality of software and hardware and how they are working must fully understood. Besides that, it is very important to be able to manipulate the software and hardware accordingly to assure a working prototype could be accomplished. The hardware and software applied in this project will be further discussed in this section:

2.1 Power Supply Module

The Power Supply Module is the soul of the electronics circuitry since every electronics circuit requires a power supply to power up the components of the circuitry. The required power can be provided by a battery, or otherwise by the main voltage which then reduced to the required voltage level before used in the circuit. The standard power supply voltage in digital electronic circuits is +5V and most of the microcontroller as well operates at this voltage level.

Therefore, the +9V power supply need to be converted to +5V in order to operates the microcontroller. This can be achieved by using the voltage regulator to step the voltage down to the +5V. In addition, this module also providing circuit protection against incorrect setup and voltage spikes.

2.2 Voltage Regulator Module

Voltage regulators are used to produce a stable power supply voltage (+Vs) from a higher (varying) d.c. voltage. They can also be used to limit the current supplied. Some electronic systems require a voltage supply which is quite stable. Voltage regulators have an input voltage which can vary quite widely. They convert this into a stable output voltage [4].

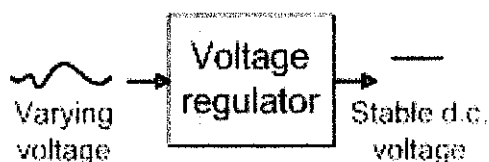


Figure 2: Voltage Regulator Operations [4]

For example, the widely used LM7805 voltage regulators produce an output voltage which is close to 5V (within the range 4.75V to 5.25V). They will accept input voltages that vary anywhere in the range 7.5V to 35V. Voltage regulators include protection to prevent the current drawn from the input voltage source exceeding these limits. This can be useful, for example in preventing excessive current being drawn from rechargeable batteries and also protects against accidental reverse connection of the input voltage source [4].

As stated in PICbasic Project by Dogan [5], a voltage regulator circuit is used to convert the +9V voltage to +5V, independent of the current drawn from the supply. A basic voltage regulator circuit consists of a regulator integrated circuit and filter capacitor. Figure 3 shows the low-cost voltage regulator circuit using IC type voltage regulator, the LM7805 (see Figure 4 and Figure 5), with two filter capacitors. LM7805 is a 3-pin IC with a maximum current capacity is 1A [6]. The input pins of the LM7805 need to be connected to the +V terminal of the battery in parallel with a 0.33 μ F capacitor while the ground pin is connected to the -V terminal of the battery. The third pin which provides the + 5V output

will be connected to the microcontroller and other devices such as motor, H – Bridge Driver Motor and sensor.

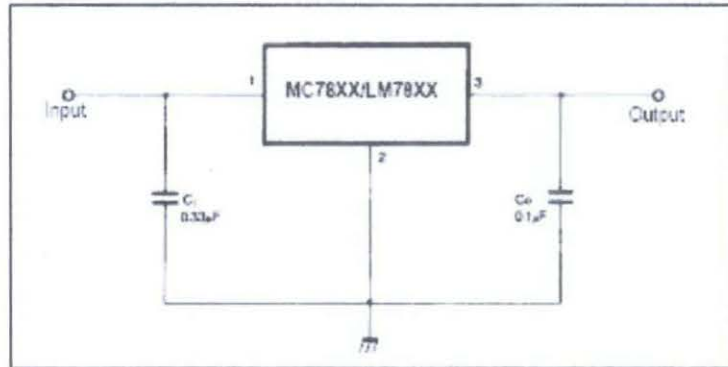


Figure 3: Circuit Diagram of the Voltage Regulator [6]

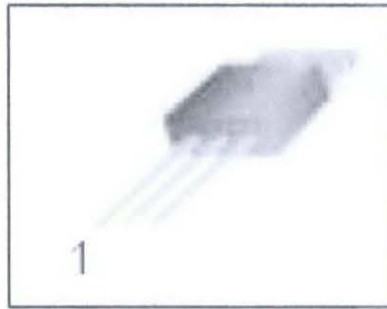


Figure 4: LM7805 Voltage Regulator [6]

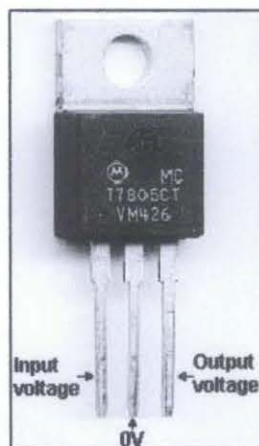


Figure 5: LM7805 Pin Configuration [5]

2.3 Microcontroller Module

A microcontroller is single-chip computer consisting of CPU (central processing unit), data and program memory, serial and parallel I/O (input/output), timers, external and internal interrupts, all integrated into a single chip that is very cheap in the market. Most microcontrollers operate with the standard logic voltage of +5V. Since the project will be using the +9V battery, a voltage regulator is needed to reduce the voltage to +5V to operate the microcontroller [5].

Intelligence of the robot lies in the complex and lengthy algorithm applied in the microcontroller. It is not easy to implement such algorithm if there is no good support from the programming side. In PIC Microcontroller Project Book by Iovine J. [7] has listed down the advantages of using microcontroller such as microcontroller is widely used due to inexpensive and capable to work as the brain of the robot. Apart from that, microcontroller is capable to store and run the program. Microcontroller also has the ability to perform math and logic function, which allow it to understand the sophisticated logic and electronics circuits. Book of 'PIC Microcontroller for beginners, too!' [8] stated that microcontroller have memories which functions to store data, hence the microcontroller is the component that makes the robot intelligent. It's also capable to accept high level programming language such as C.

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology. Its derived from the PIC1650 which originally developed by General Instrument's Microelectronics Division. The name PIC was originally an acronym for "Programmable Intelligent Computer". However, PIC is generally regarded that stands for Peripheral Interface Controller [9]. PICs privilege are their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability [10].

In this project, the microcontroller will receive inputs signal from the infrared receiver and user switch. The output of the microcontroller will be sent to the motor drive to control the motion of direction of the AGV. The microcontroller will act as the brain of the system and it is programmed on MicroC using C language. The entire algorithm and the operation of the AGV will be programmed inside this microcontroller. The microcontroller that used for this project is PIC 16F877.

PIC16F877 is one of the most popular PIC microcontrollers. It's consist of 40 pin device and offers 8k x 14 words Flash Program Memory, 368 bytes RAM and 256 bytes EEPROM. There are 33 I/O pins where each pin can source or sink 25 mA current. Additionally, the device contains of 3 timers and a watchdog timer with internal oscillator [11]. Further features of the PIC16F877 have been simplified in the Table 1 below:

Table 1: Microcontroller Features of PIC16F877 [11]

Key Features PICmicro™ Mid-Range Reference Manual (DS33023)	PIC16F877
Operating Frequency	DC - 20 MHz
FLASH Program Memory (14-bit words)	8K
RAM Data Memory (bytes)	368
EEPROM Data Memory (bytes)	256
Interrupts Capability	14 Source
I/O Ports	Ports A,B,C,D,E
I/O Pins	33
Timers	3
Capture/Compare/PWM modules	2
Operating Voltage Range	2.0V to 5.5V
High Sink / Source Current	25 mA

Table 2: Microcontroller PIC16F877 Pin Description [11]

Pin	Description	Pin	Description
1	MCLR – Master clear	40	RB7 – PORT B bit 7
2	RA0 – PORT A bit 0	39	RB6 – PORT B bit 6
3	RA1 – PORT A bit 1	38	RB5 – PORT B bit 5
4	RA2 – PORT A bit 2	37	RB4 – PORT B bit 4
5	RA3 – PORT A bit 3	36	RB3 – PORT B bit 3
6	RA4/T0CK1 – PORTA bit 4/ Counter clk	35	RB2 – PORT B bit 2
7	RA5 – PORT A bit 5	34	RB1 – PORT B bit 1
8	RE0 – PORT E bit 0	33	RB0/INT – PORT B bit 0
9	RE1 – PORT E bit 1	32	Vdd - + V supply
10	RE2 – PORT E bit 2	31	Vss – Gnd
11	Vdd - + V supply	30	RD7 – PORT D bit 7
12	Vss – Gnd	29	RD6 – PORT D bit 6
13	OSC1 / CLK IN	28	RD5 – PORT D bit 5
14	OSC2 / CLK OUT	27	RD4 – PORT D bit 4
15	RC0 – PORT C bit 0	26	RC7 – PORT C bit 7
16	RC1 – PORT C bit 1	25	RC6 – PORT C bit 6
17	RC2 – PORT C bit 2	24	RC5 – PORT C bit 5
18	RC3 – PORT C bit 3	23	RC4 – PORT C bit 4
19	RD0 – PORT D bit 0	22	RD3 – PORT D bit 3
20	RD1 – PORT D bit 1	21	RD2 – PORT D bit 2

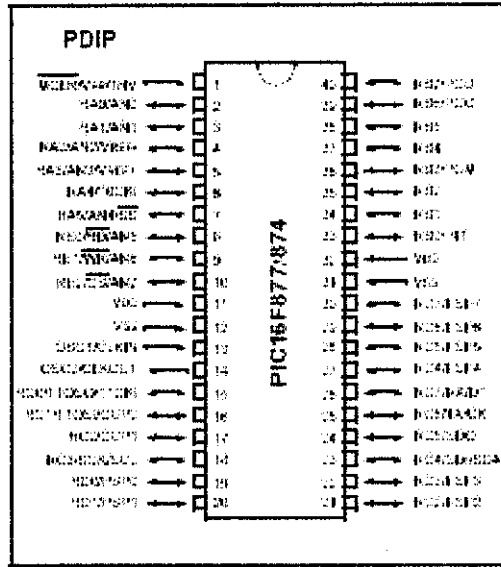


Figure 6: Microcontroller PIC16F877 Pin Configuration [9]

2.4 Motor Drive Module

A Motor Drive is an electronic circuit which enables DC electric motors to be run forwards or backwards. These circuits are often used in robotics and available in form of integrated circuits, or can be built from separate components. The Motor Drive also known as H-bridge which term "H-bridge" is derived from the typical graphical representation of such a circuit [12].

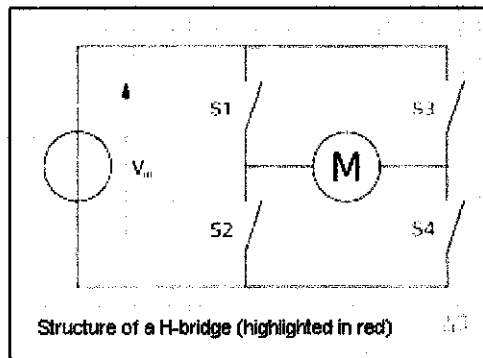


Figure 7: Structure of H-bridge Circuit [12]

This consists of a minimum of four mechanical or solid-state switches, such as two NPN and two PNP transistors. One NPN and one PNP transistor are activated at a time [13]. When the switches S1 and S4 (according to figure 7) are closed (S2 and S3 are open) a positive voltage will be applied across the motor, causes forward operation of the motor. By opening S1 and S4 switches (closing S2 and S3 switches), the voltage is reversed, allowing reverse operation of the motor [12].

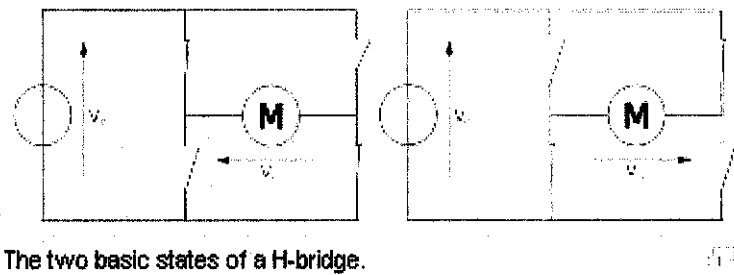


Figure 8: Two Basic States of H-bridge [12]

Using the nomenclature above, the switches S1 and S2 should never be closed at the same time, as this would cause a short circuit on the input voltage source. The same applies to the switches S3 and S4. This condition is known as shoot-through [12].

For this project, the servo motor used with a motor driver. The L293 driver were suggested to be used to drive the 5V dc motor either to be forward or reverse operation due to it's similarity with servo motor driver. Two enable inputs are provided to enable or disable the motor independently of the input signals [14]. These two inputs are droved by the signal from the microcontroller as to enable the changes of the AGV direction.

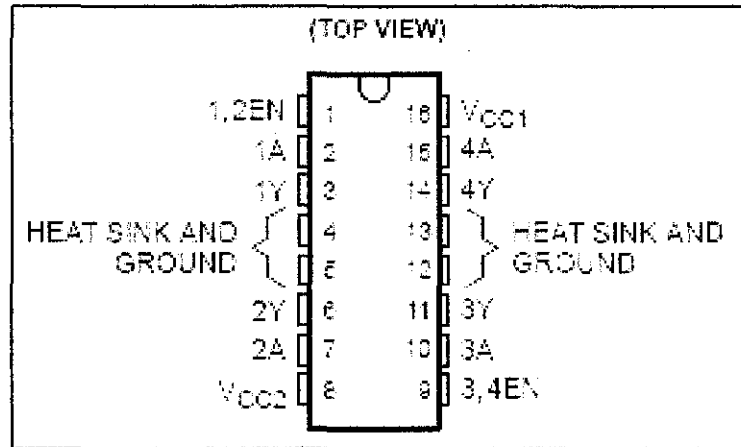


Figure 9: L293 Pin Connections [14]

The input pins of 1,2EN, 1A and 2A needs to be connected to the microcontroller as it's provide the input which to drive the operations of the dc motor. The pin of 1,2EN is used as to enable the pins input 1A and 2A. The output pins of 1Y and 2Y needs to be connected to the dc motor since its will control the operations of the dc motor either to be forward or reverse. Furthermore, the pin of Vcc will connect to the +5V terminal while the pin of Ground connected to the ground. As provided in L293 Function Table below, the drivers are enabled in pairs by 1,2EN. When enable input is high, the drivers will enable the outputs. Then, if 1A is high while 2A is low, the motor will rotate counterclockwise & vice versa [14].

Table 3: L293 Function Table [14]

(each driver)

INPUTS‡		OUTPUT
A	EN	Y
H	H	H
L	H	L
X	L	Z

H = high-level, L = low-level,

X = irrelevant, Z = high-impedance (off)

‡ In the thermal shutdown mode, the output is in the high-impedance state regardless of the input levels.

Figure 10 shows the circuit diagram of the dc motor control using IC type H-bridge, the L293. Its can provide currents up to 1 A at voltages from 4.5 V to 36 V and designed to operate in temperature from 0 oC to 70 oC [14].

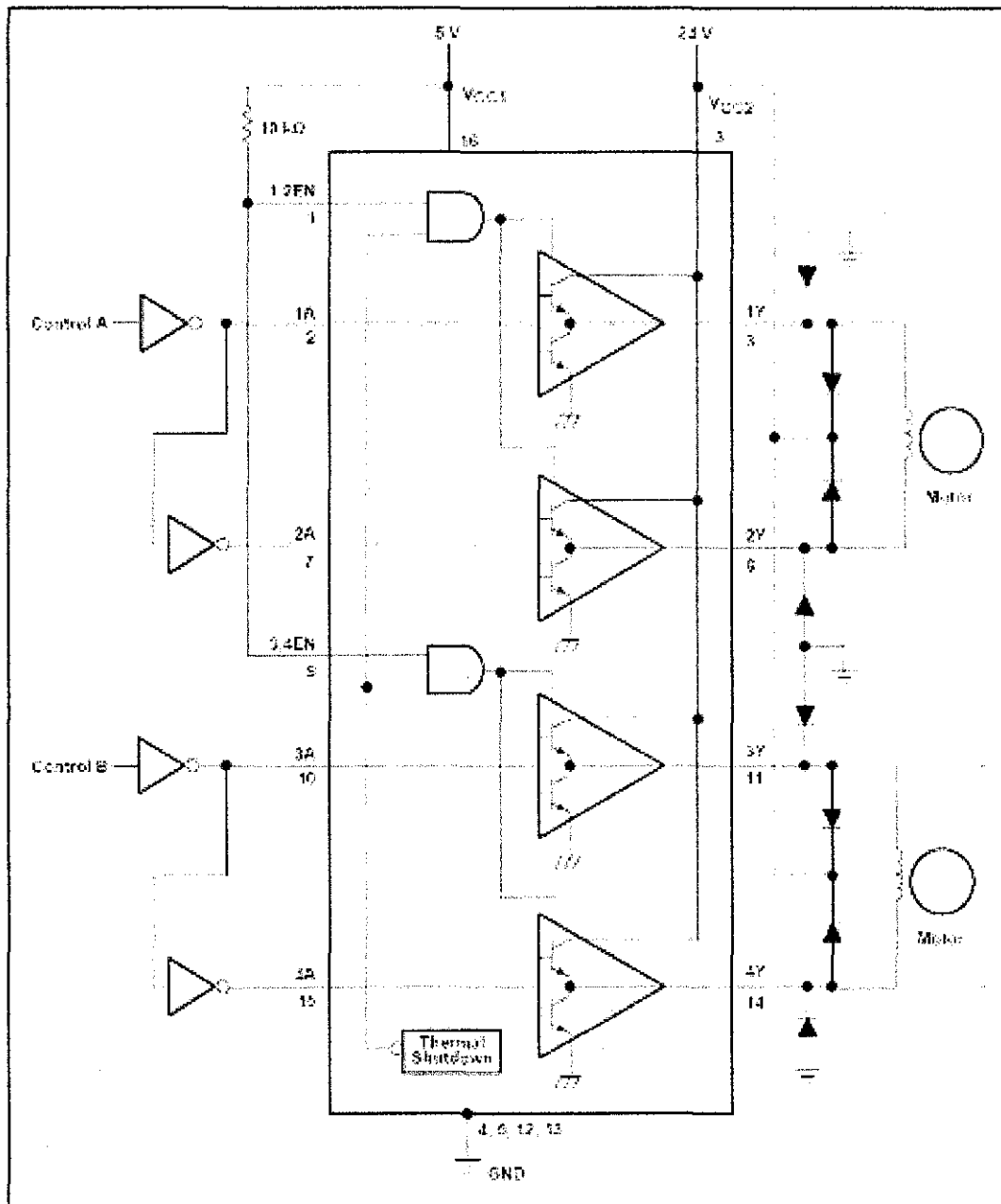


Figure 10: Circuit Diagram of the DC Motor Control [14]

2.5 DC Motor Module



Figure 11: Two Poles DC Motor Operations [15]

A DC motor is an internally commutated which designed to be run with existence of DC power source. When the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn toward the right, causing rotation. When a current passes through the coil wound around a soft iron core, the side of the positive pole is acted upon by an upwards force, while the other side is acted upon by a downward force [15].

According to Fleming's left hand rule, the forces cause a turning effect on the coil, making it rotate. To make the motor rotate in a constant direction, "direct current" commutators make the current reverse in direction every half a cycle thus causing the motor to rotate in the same direction [15].

The problem facing by the motor shown above is when the plane of the coil is parallel to the magnetic field; i.e. the torque is ZERO-when the rotor poles or displaced 90 degrees from the stator poles. The motor would not be able to start in this position, but the coil can continue to rotate by inertia. However, unlike the demonstration motor above, DC motors are commonly designed with more than two poles which are able to start at any position, and do not have any position where current can flow without producing electromotive power [15].

2.6 Servo Motor Module

Servos are consists of DC Motor with built in gearing and feedback control loop circuitry using motor driver [16]. The DC Motor output shaft can be positioned to specific angular positions by sending the servo a coded signal. As long as the coded signal exists on the input line, the servo will maintain the angular position of the shaft. As the coded signal changes, the angular position of the shaft changes [17].

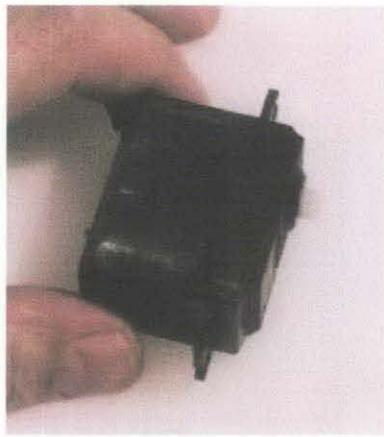


Figure 12: Futaba S-148 Servo [17]

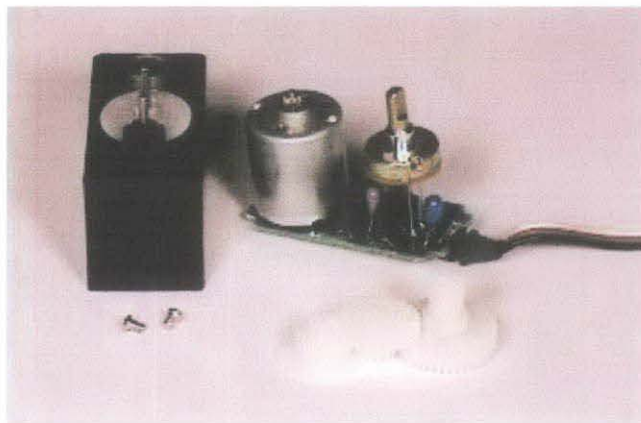


Figure 13: The Disassembled Servo [17]

The output shaft can be controlled due to its connected to the control circuit and a potentiometer (a variable resistor, a.k.a. pot). The control circuit will monitor the current angle of the servo motor. If the shaft is at the correct angle, then the motor shuts off. If the circuit finds that the angle is not correct, it will turn the motor the correct direction until the angle is correct. The output shaft of the servo is capable to travel around 180 degrees, however it varies by manufacturer. A normal servo is used to control an angular motion between 0 and 180 degrees. It is mechanically not capable of turning any farther due to a mechanical stop built on to the main output gear [17].

The angle can be controlled by determine the duration of a pulse that is applied to the control wire. This is called Pulse Coded Modulation. The servo expects to see a pulse every 20 milliseconds (.02 seconds). The length of the pulse will determine how far the motor turns. A 1.5 millisecond pulse will make the motor turn to the 90 degree position (often called the neutral position). If the pulse is shorter than 1.5 ms, then the motor will turn the shaft to closer to 0 degrees. If the pulse is longer than 1.5ms, the shaft turns closer to 180 degrees. The relationship between pulse duration and servo angle is illustrated below [17]:

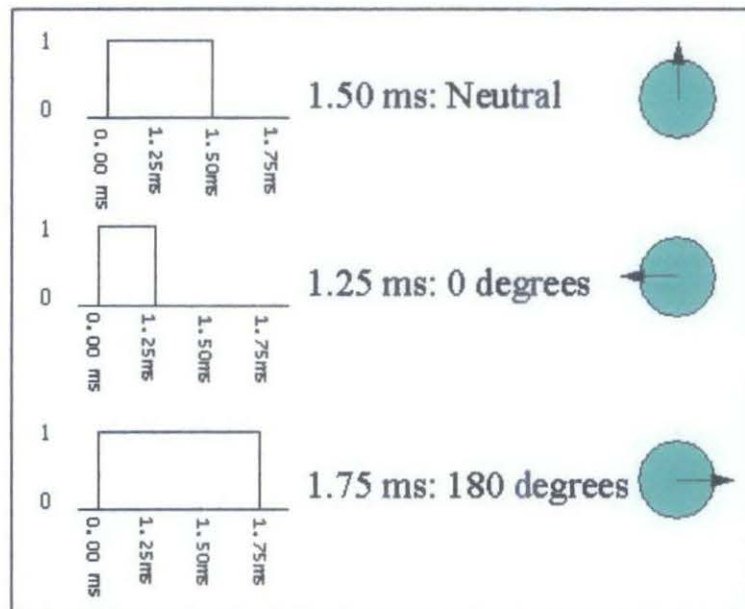


Figure 14: The Pulse Duration And Servo Angle Relationship [17]

Servos can operate under a range of voltages from 4.8V to 6V. The reason for this standard range is because most microcontrollers and RC receivers operate near this voltage even though the DC motors have higher torque at higher voltages [16].

For the wiring, the servos normally consists of three wires which are black or brown for ground, red for power (~4.8-6V) and Yellow, Orange, or White for signal wire (3-5V). The signal wire is use to command the servo by send an ordinary logic square wave to the servo at a specific wave length. Then, the servo goes to a particular angle (or velocity) [16].

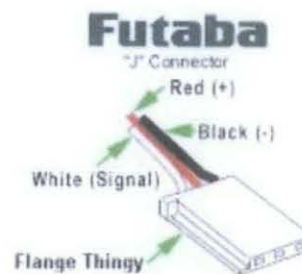


Figure 15: The Servo Motor Wiring [16]

2.7 Transmitter or Emitter Module

An emitter is a device used to emit any signal, beacon, light, odor, liquid, fragrance, or any other type of signal. It is also called a dripper and is a device used in drip irrigation. An emitter may refer to an infrared LED which used to emulate a remote control [18]. Generally emitted infrared radiation across a spectrum of wavelengths, but only a specific region of the spectrum is of interest because sensors are usually designed only to collect radiation within a specific bandwidth [19].

A light-emitting diode (LED) is a semiconductor diode that emits incoherent narrow-spectrum light when electrically biased in the forward direction of the p-n junction. This effect is a form of electroluminescence [20].

Like a normal diode, an LED consists of a chip of semiconducting material impregnated, or *doped*, with impurities to create a *p-n junction*. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction [20]. The diode will restrict the directional flow of charge carriers. Essentially, a diode allows an electric current to flow in one direction, but blocks it in the opposite direction. Thus, the circuits that require current flow in only one direction typically include one or more diodes in the circuit design [21].

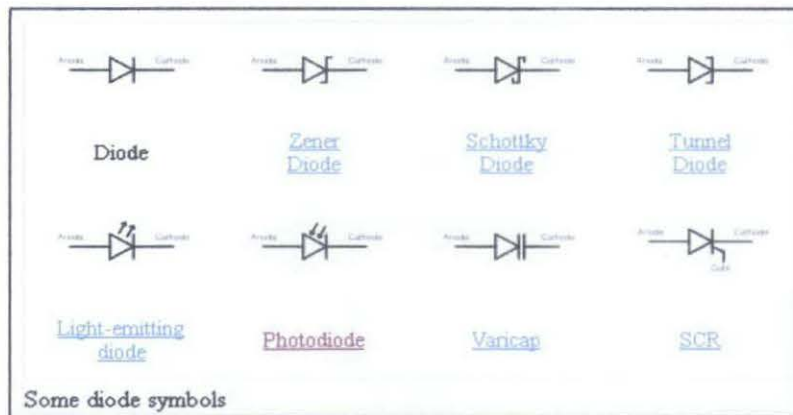


Figure 16: Types of Semiconductor Diodes with Its Symbols [21]

There are several types of junction diodes, which either emphasizes a different physical aspects of a diode such as geometric scaling and doping level: Normal (p-n) diodes which operate as described above, usually made of doped silicon or, more rarely, germanium. The vast majority of all diodes are the p-n diodes found in CMOS integrated circuits, which include 2 diodes per pin and many other internal diodes [21].

2.8 Receiver Module

A photodiode is a semiconductor diode that functions as a photodetector. Photodiodes are packaged with either a window or optical fibre connection, in order to let in the light to the sensitive part of the device. Most photodiodes will look like similar to a Light Emitting Diode. They will have two leads, or wires, coming from the bottom. The shorter end of the two is the cathode, while the longer end is the anode. Electrons will pass from the anode to the cathode, basically following the arrow [22].

A photodiode is a p-n junction structure. When a photon of sufficient energy strikes the diode, it excites an electron thereby creating a mobile electron and a positively charged electron hole. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in field of the depletion region, producing a photocurrent [22].

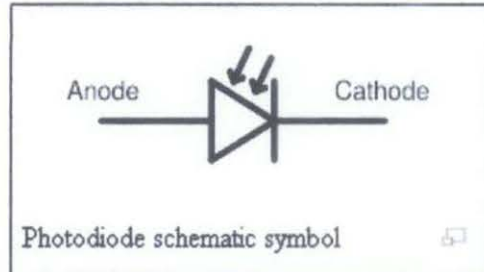


Figure 17: Photodiode Schematic Symbol [22]

An infrared detector is a photodetector that reacts to infrared (IR) radiation. Incident IR photons can cause electronic excitations. In photoconductive detectors, the resistivity of the detector element is monitored. Photovoltaic detectors contain a p-n junction on which photoelectric current appears upon illumination [23].

2.9 PIC Programmer Module

Devices called "programmers" are traditionally used to get program code into the target PIC [10]. In computer hardware, the term programmer refers to a hardware device that configures programmable non-volatile circuits such as EEPROM or programmable logic circuits. In the early days of computing, before terminal and graphical display devices, a programmer was a device used to configure a program for a computer. It usually consisted of switches and LEDs, where instructions had to be entered one by one by setting the switches in a series of "on" and "off" positions. The positions of the switches corresponded to computer instructions, similar to how assembly language is used today. Such hardware programmers are almost never seen or used today [24].

Nowadays, there are many programmers for PIC microcontrollers ranging from the extremely simple designs which rely on ICSP (In Circuit Serial Programming) to allow direct download of code from a host computer, to intelligent programmers that can verify the device at several supply voltages. Many of these complex programmers use a pre-programmed PIC themselves to send the programming commands to the PIC that is to be programmed [10].

These are some common programmer types:

1. Simple serial port ICSP programmers
 - These generally rely on driving the PIC's V_{ss} line negative to get the necessary voltage differences from programming. Hence they are compact and cheap but great care is needed if using them for in circuit programming [10].
2. Simple parallel port ICSP programmers
 - Simple to understand but often have much higher part counts and generally require external power supplies [10].
3. Intelligent programmers

- o Generally faster and more reliable (especially on laptops which tend to have idiosyncrasies in the way they implement their ports) but far more complex to build (in particular they tend to use a PIC in the programmer which must itself be programmed somehow) [10].

For this project, CYTRON SK40A which provided by Cytron Enterprise will be used as the PIC Programmer. SK40A have onboard voltage regulator, 7805 which will provide stable 5V output to PIC and other application. However, the maximum current of this regulator is only1A, thus if higher current is needed, an additional voltage regulator is required. SK40A is ready with a protection diode to avoid damage to circuit if the Power Input polarity is connected wrongly. Once power is connected to Power Input, Power On LED will light up. If the LED does not light after power is connected, it might be caused by wrong polarity of power or no power from battery. SK40A also capable to accept the input voltage that range from 7V to 30V [25].

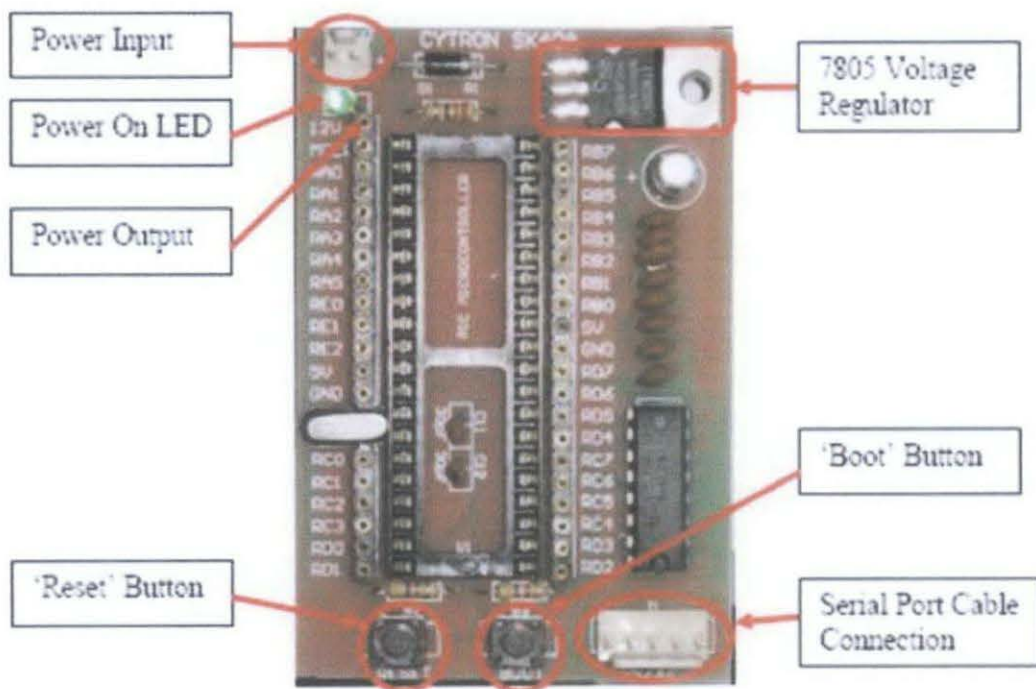


Figure 18: CYTRON SK40A PIC Programmer [25]

SK40A also provided with bootloader capability to ease the process of loading program further save development time and cost. However, a few pin have been used for bootloader function. Pins that involved are [25]:

- MCLR, used as reset and connected to 'Reset' Button
- RB0, used as 'Boot' button and is pulled up through a 4.7K Ω resistor to 5V
- RC7, used as Receiver Diode (RxD) and connected to MAX232
- RC6, used as Transmitter Diode (TxD) and connected to MAX232
- RD2, used a RTS and connected to MAX232
- RD3, used a CTS and connected to MAX232

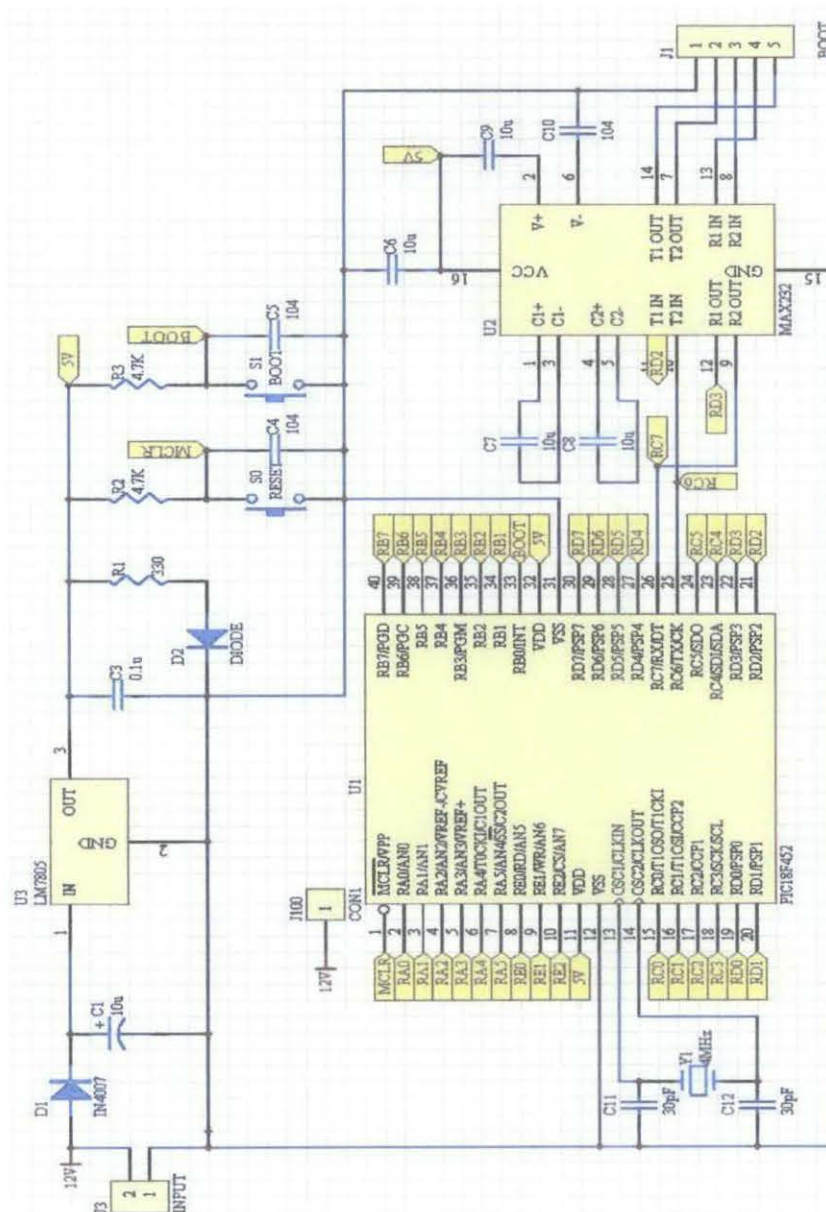


Figure 19: Schematic Diagram of SK40A PIC Programmer [25]

CHAPTER 3

METHODOLOGY

3.1 Project Flow Diagram

Figure 20 shows the project flow diagram of the step undertaken in the design and construction process that have been evolved during this project work.

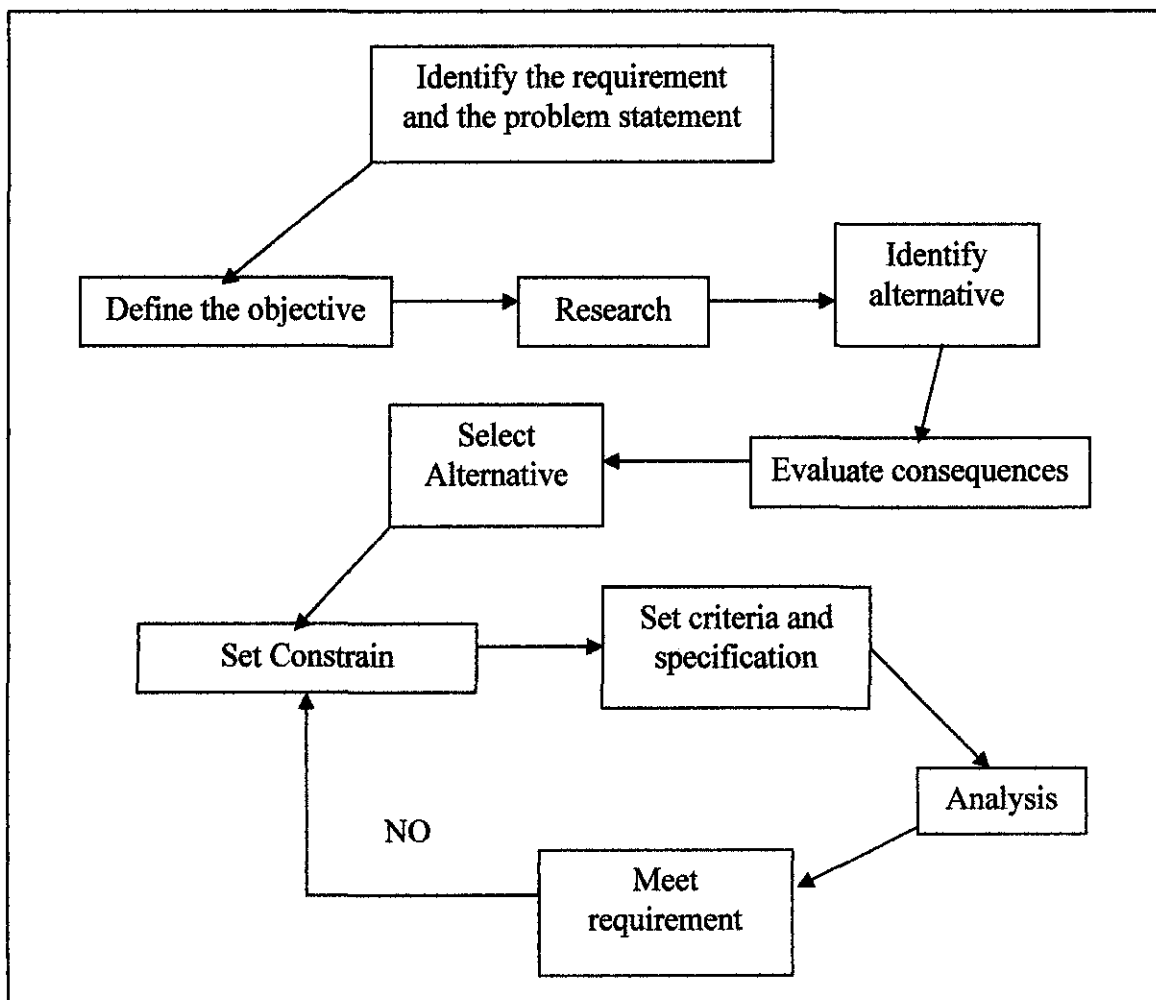


Figure 20: Project Flow Diagram

Firstly, the project requirement and the problem statement are identified. From that, the researches have been made on the topic matters throughout journal, internet, books, and articles in order to understand the concept of the AGV system. Then, the objective of the project had defined as well as the scope of study.

Next, further researches have been conducted to find the possible alternatives of hardware and software to accomplish the project. The concerns here are needed to identify type of sensor, type of microcontroller and developing the program and hardware setup. Therefore, it is very important to fully understand how the hardware and software used will be operates. Throughout the discussion, some useful advices had obtained regarding on how the system possibly done and how to approach the suitable project design.

Follows that is to select the most ideal alternative among others which means need to consider and select one item from the other alternatives. Thus, the aspects that need to be considered are the price, its function and effectiveness. This is also very important aspect because the consequences from the other alternatives need to be considered carefully so that the next step will be working smoothly

After having the most ideal alternative, it is necessary to set the criteria and its specification based on the project requirement. Then, some lab researches need to be done in order to analyze and compare between the theoretical function and actual function. Since the infrared will be used as the sensor, so some tests need to be taken in the actual situations so that the current that will be transmitted to the microcontroller can be finalized. If the results meet the requirement of the project, thus the project research can be finalized in the report. Otherwise, needs to set its criteria and specification again and analyzed back until it meets the project requirement.

3.2 Automatic Guided Vehicle (AGV) System Layout

Throughout studies that have been done as discussed earlier, the author had come out with the following system design for the Automatic Guided Vehicle (AGV) System. The system consists of three stages which are sensing stage, processing stage and motion stage as discussed in Background of Study Section have been illustrated into the following layout:

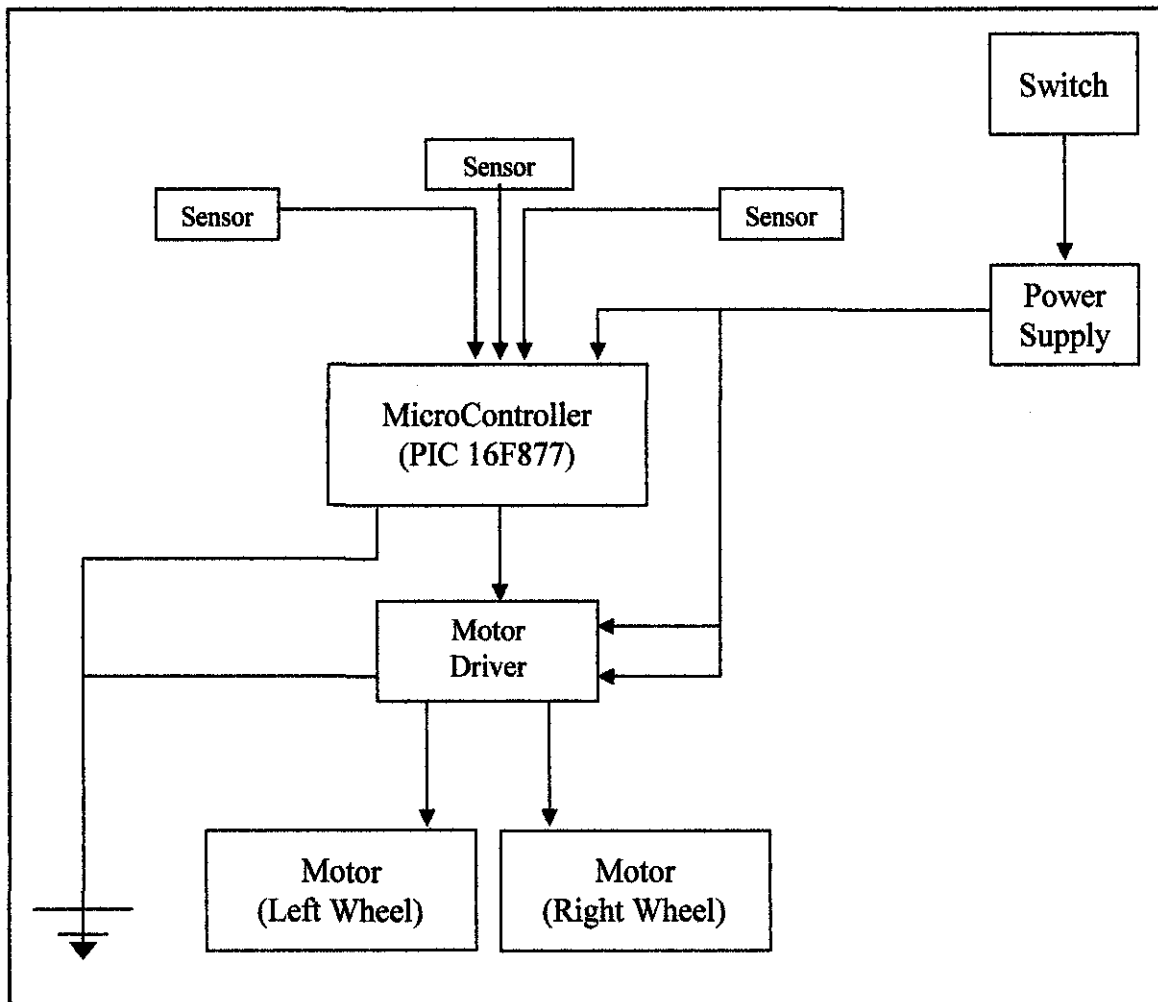


Figure 21: Automatic Guided Vehicle (AGV) System Layout

In addition, the H-Bridge Motor Driver have been introduced as motor driver so that the power supply could be divert to motor once its receive signal from the microcontroller.

3.3 Tools Required

There are several devices and software are required to be used or built in order to attain the objective of the project which to establish a prototype of Automatic Guided Vehicle (AGV). The hardware and software used were briefly explained below.

3.3.1 Hardware

- Transmitter and Receiver sensor

The sensor will be made by using Printed Circuit Board (PCB) and it will be using the Infrared Transmitter (IRT) and Infrared Receiver (IRR).

- PIC Microcontroller

The PIC used for this project is PIC16F877 which have processing frequency up to 20 MHz and flash memory size 8K bytes.

- Voltage Regulator

The voltage regulator will be used to convert the input voltage to the +5V output voltage which is applied by most of the circuits components.

- Motor Driver

Its uses to control the operation of the motor either forward or reverse operations.

- Servo Motor Motor

The servo motor is used to drive the wheel of the AGV.

- Rechargeable Battery

The rechargeable battery is used to provide the power supply to power up the components of the AGV System.

3.3.2 Software

- PSpice and Multisim 7
For schematic drawing and circuit simulation.
- MicroC using High-Level Language C
For programming the PIC microcontroller using C language.
- Eagle Layout Editor
For schematic drawing and Gerber files creation.

3.4 Full List of Component Used

Table 4: Details List of Component with Quantiy

Component	Quantity
Power Supply (9 V Rechargeable Battery)	1
Push Button	2
Voltage Regulator, LM7805	2
Crystal Oscillator, 20M Hz	1
Microcontroller, 16F877	1
Infrared Pair (Transmitter & Receiver)	3
Servo Motor	2
Capacitor	
- 10 uF	2
- 0.1 uF	2
- 22 pF	2
Resistor	
- 220 ohm	8
- 4.7k ohm	5
Trimmer (Variable Resistor), 10k ohm	3
Comparator, LM339	2
Light Emitting Diode, LED	5

3.5 Initial Program Flowchart

As stated in Structured Programming Approach Using C by Behrouz and Gilberg [11], a program is a set of step-by-step instructions that directs the computer to do the desired tasks and produce the results. There are 6 process step involve in order to do a programming for the system. The steps are as follows;

1. Analyze the Problem
2. Develop an Algorithm
3. Document the Program
4. Write Code for the Program
5. Run the Program
6. Test the Results

Hence, a programmer must know what information will go into the software, how it will process the information, and what will the result is. All software must work with these three concepts to be successful:

- **Input:** Information that comes from an external source and enters into the software to be processed.
- **Processing:** Manages information according to a piece of software's logic. Processing is what the software does to the input it receives.
- **Output:** The information that software produces after input have been processed. Output can appears on a computer screen, or printout, or can be records in a database.

Therefore, a logic flowchart has been produced for this project after analyzing the problems. For initial program flowchart, please refer to the figure below. The next steps that will be taken are producing the pseudo code, algorithm, document the program, write the code and test the program. After that, the code produced will be programmed into the PIC 16F877 before it can be implemented to the whole system.

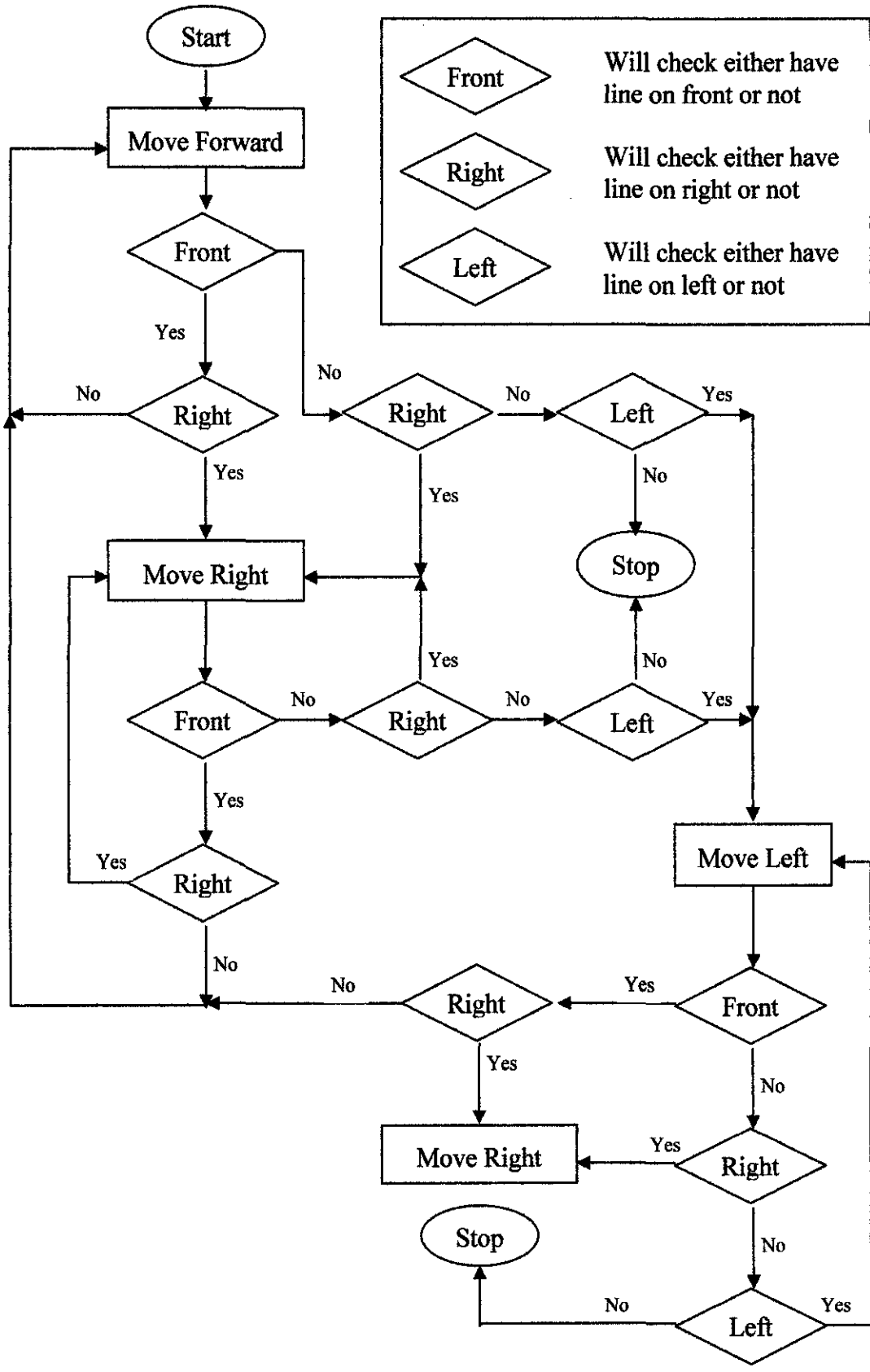


Figure 22: Initial Program Flowchart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Infrared Sensor Design

In the previous semester (Final Year Project 1), background work have been performed that include design the project flow diagram, identify the functionality of AGV as well designing the system layout of the AGV. Besides that, the problem statements as well as the objectives of the project have been determined to identify the scope of the project works as discussed in Chapter 1.

During the FYP 1 as well, the application of the hardware and software have been studied and familiarized since in order to accomplish the projects, the operations and the functionality of the hardware and software and how they are working needs to be understood. Thus, some researches have been performed on the hardware required include transmitter and receiver which used for the sensing operations, H-bridge motor which used as the motor driver, the motor itself and the voltage regulators.

The transmitter and the receiver can be interpreted as the first stage of the AGV System since it will sense the obstacle around the AGV, then provide the input to the microcontroller so that an appropriate action can be executed. Therefore, the researches have been done through the transmitter and the receiver in order to understand the type of the sensor as well as the functionality and the sensing operation of the sensor. After understanding the sensing operation of the sensor, the types of the sensor have been selected as infrared transmitter and the photodiode receiver. Then, the circuitry of the sensor which consist of infrared transmitter, photodiode receiver, light emitting diode (LED) and the comparator have been developed and designed.

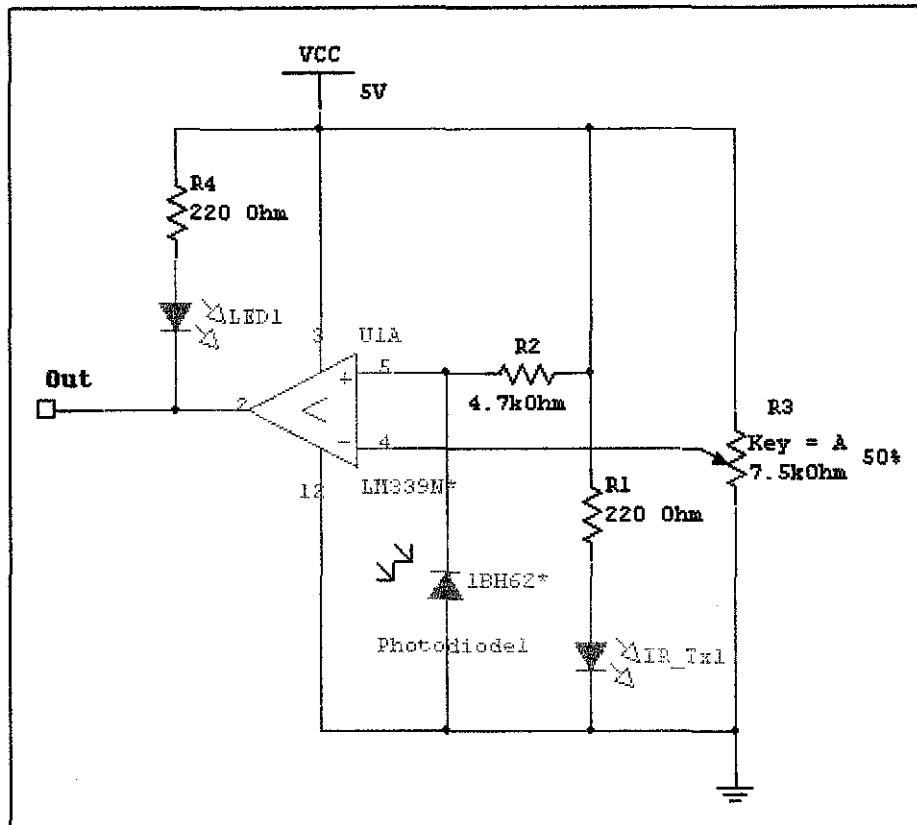


Figure 23: Schematic Diagram of the Infrared Sensor

In this project, three similar infrared sensors which are Left Sensor, Front Sensor and Right Sensor were used and indicated based on the position of sensor on the AGV. For left sensor indicates that it's for detecting the line at the left side of AGV while for front sensor to guide the path way of AGV and the right sensor to sense the line at the right side of the AGV.

In the designed sensor circuitries that have been developed, the sensor consists of infrared transmitter, photodiode receiver, light emitting diode (LED) and the comparator. The comparator is used to ensure that the stable voltage could be supplied to the microcontroller once the signal been detected by the photodiode receiver. As in sensor schematic diagram previously, the output (indicate as Out terminal) of comparator will go Low or +0V after photodiode receiver receive the infrared signal and goes High or +5V when no signal received at the receiver. This will be indicated by the LED which will

glows after the infrared signal sensed. The figure below shown the LED have been turn light, thus indicate the photodiode receiver had receive the signal from the transmitter.

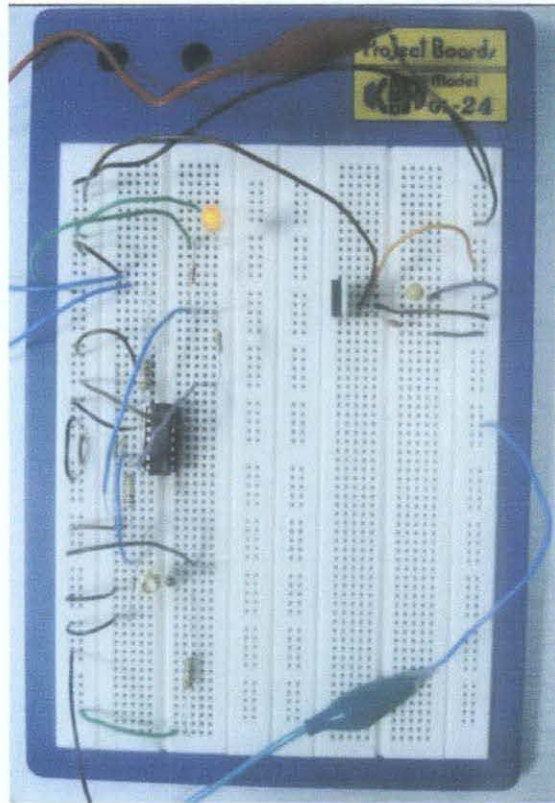


Figure 24: The Circuitry Model of the Sensor

4.2 Voltage Regulator Circuitry Design and Hardware Setup

In order to obtain a stable 5V voltage supply for the circuit component such as microcontroller and the comparator, a voltage regulator LM7805 have been used. From the studied performed on the voltage regulators, the functionality of the voltage regulators is to produce a stable power supply voltage (+Vs) from a higher (varying) d.c. voltage. Usually, the voltage regulators input can vary quite widely in the range from 7.5V to 35V. Besides that, its also be used to limit the current supplied by the power supply, thus providing protection to prevent the current drawn from the input voltage source exceeding these limits.

In this project, the circuitry for the voltage regulator has been designed using P-Spice Schematic. The circuit is designed to drop the voltage from 12VDC to 5VDC with 0.01 μ F and 0.33 μ F capacitors are connected in parallel and will be acting as low pass filters. The figure follow shows the circuit that had designed using P-Spice Schematic.

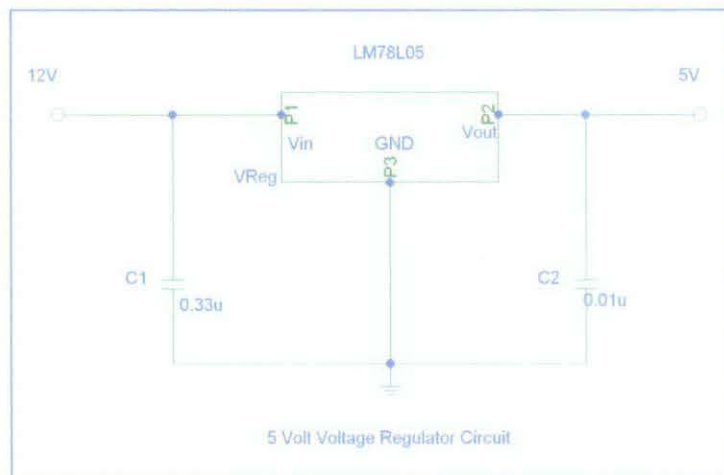


Figure 25: The Schematic Diagram of Voltage Regulator

Once after the schematic diagram designed, the circuitry of the voltage regulator application has been constructed using a breadboard as illustrated in the diagram follows;

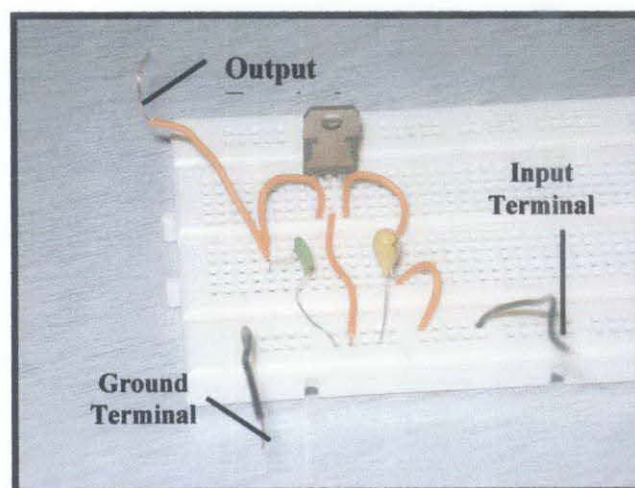


Figure 26: Voltage Regulator Circuit Diagram

4.3 Voltage Regulator Experimentation

An experiment has been conducted in order to test the voltage regulator circuit by using 12Vdc car battery as the input. The experimentation was performed to investigate the capability of the voltage regulator either capable to produce 5Vdc as required or not. Type of voltage regulator used in this experiment is LM7805. In the experiment, firstly the car battery voltage was measured by using a digital multimeter and the reading obtained is 12.2 Vdc as in figure below:

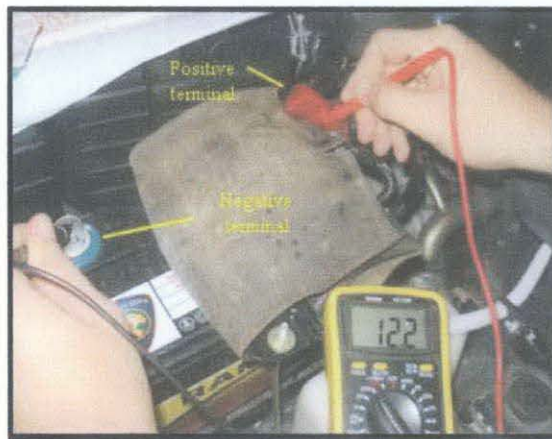


Figure 27: The Initial Voltage of Car Battery

After that the power supply circuit is connected to the car battery and measurement has been taken at the output terminal of the power supply circuit. The output voltage obtained is 5.0 Vdc which as required by the project prototype.

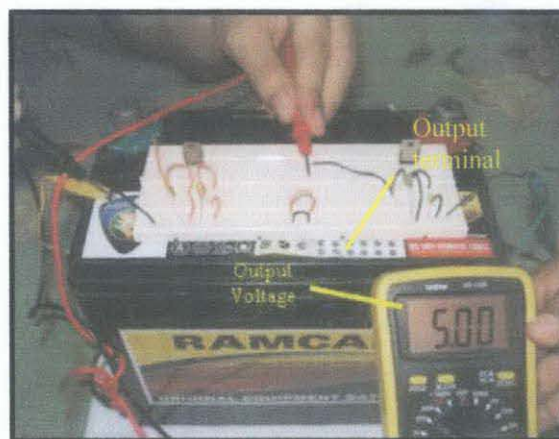


Figure 28: The Output Voltage of Voltage Regulator Circuit

4.4 PCB Design

After the functionality of the sensor circuit has been confirmed, the Printed Circuit Board (PCB) of the circuitry has been developed. In order to produce PCB, the schematic diagrams of the circuit have been redesigned using Eagle 4.13 software so that a Gerber file can be created as below:

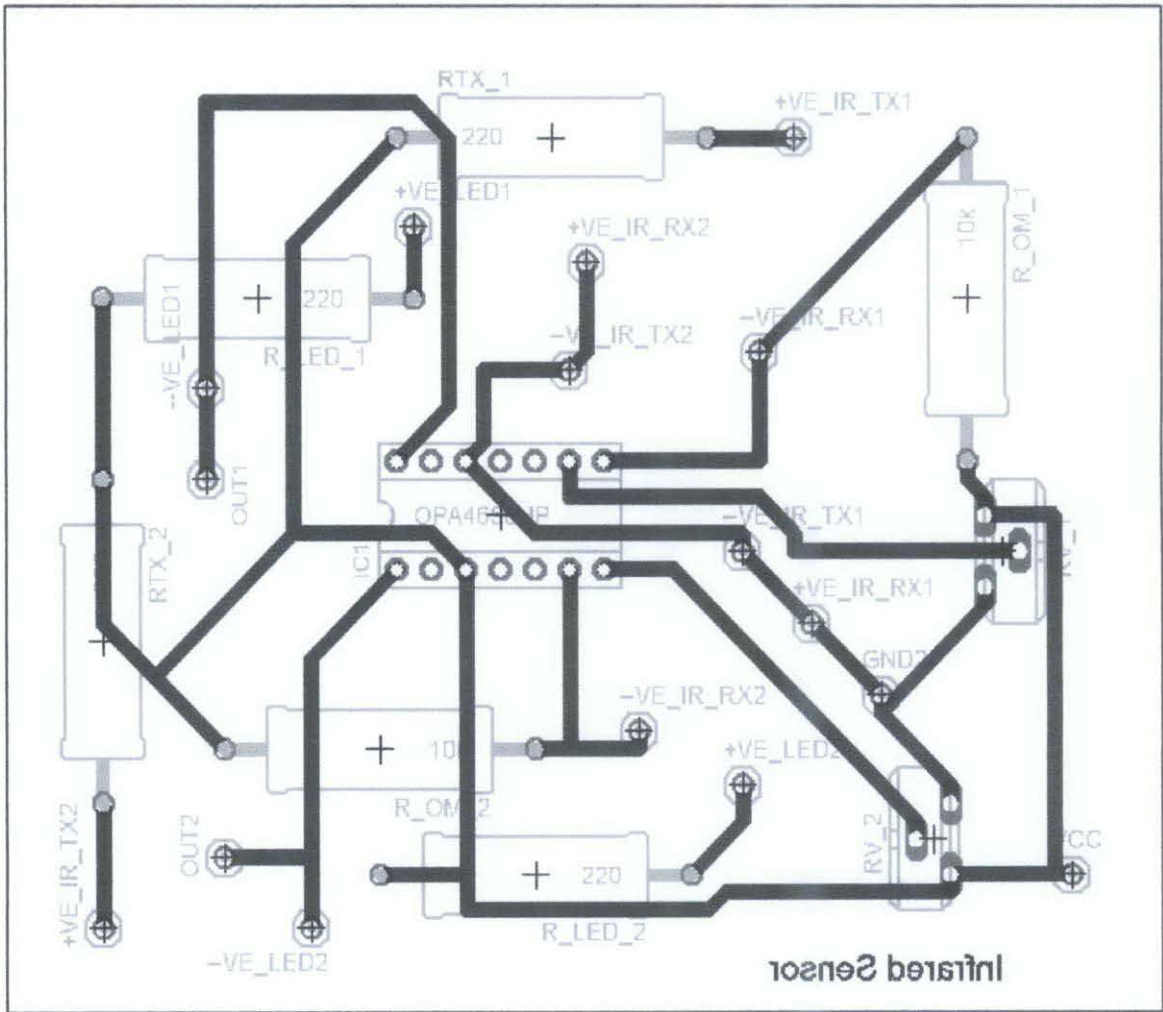


Figure 29: Gerber File of the Infrared Sensor

After the Gerber Files have been created, the files were used to idealize the actual circuit on the Printed Circuit Board. The complete PCBs with soldered components are as followed:

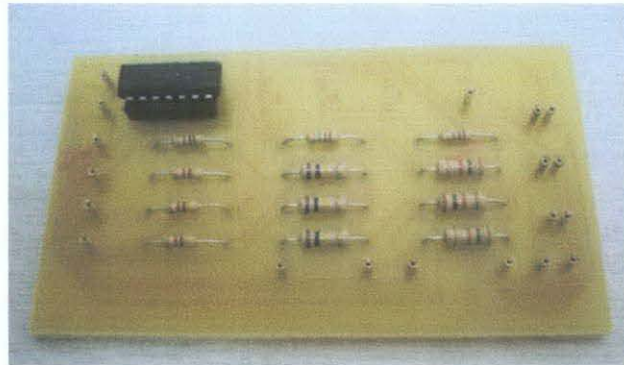


Figure 30: Printed Circuit Board (PCB) of the Sensor

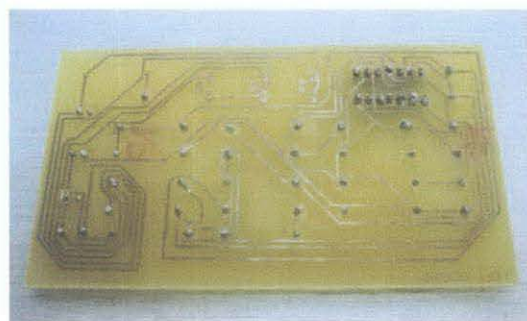


Figure 31: Back Side of Printed Circuit Board (PCB)

4.5 Main System of AGV

As discussed earlier, the input signal from the infrared sensor will be processed by the Microcontroller, PIC 16F877 to control the servo motor. In order for microcontroller to be able to process the signal, a main circuit which contains the microcontroller is required. Thus, new circuits have been developed for the AGV which consist of microcontroller, crystal oscillator, downloader port, input and output terminal.

In this project prototype, the Crystal Oscillator of 20 MHz is used to provide a clock to the microcontroller. The downloader port is required to enable the microcontroller to be downloaded directly from personal computer, pc since it will provide a direct connection to the home pc using PIC Programmer as discussed in Literature Review Section. The input terminals from the Infrared Sensor are indicated as SR-L, SR-M and SR-R while the output terminals to the servo motor are indicated as SW1 and SW2. The schematic diagram for the AGV main system is as below:

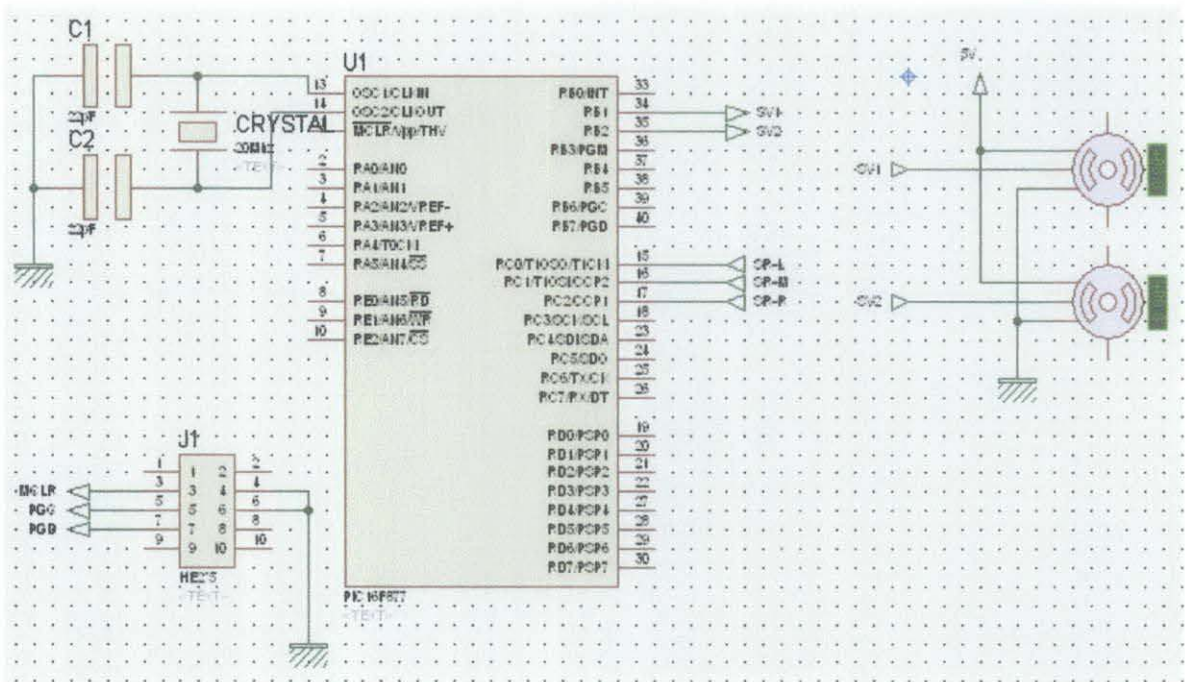


Figure 32: Schematic Diagram of the AGV Main System

4.6 AGV Design using Auto-CAD

Since the final results of the project required establishing a prototype for the AGV, thus the Auto-CAD software was used to design the AGV prototype. The prototype of the designed AGV can be viewed as below:

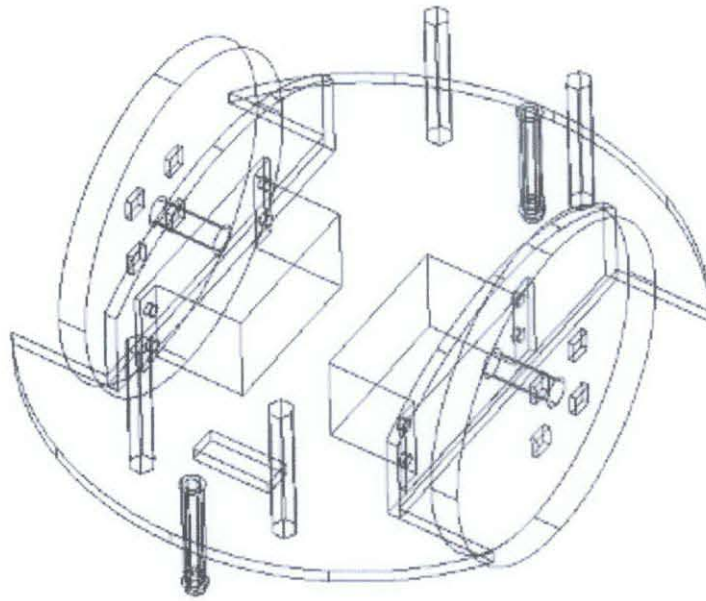


Figure 33: Body Design of AGV Prototype using Auto-CAD

Then, the project proceeds with constructing the actual hardware model of the AGV prototype. The complete set of prototype of the AGV which consist of the body, infrared sensor, servo motor, main circuitry and rechargeable battery is provided in the Figure 34 below:



Figure 34: The Prototype Model of AGV

4.7 System Programming

Based on the program flowchart as in Methodology Section, the C Programming of the AGV operation has been developed using MicroC software. The MicroC software was used to establish the system programming since it's compatible with the PIC application and easy to be programmed. The finalized program that has been developed for the AGV is made available as follows:

```
/*
 * Project: Automatic Guided Vehicle
 * Done by: Mohamad Lokman Bin Mohamad Rafiuddin
 * Description:
   The code shows how the AGV thinking and executed the action after through
   the process.

 * Test configuration:
   MCU:      P16F877A
   Dev.Board:  PICKit 2
   Oscillator:  HS, 20.0000 MHz
   Ext. Modules:  x
   SW:      mikroC v 8.1.0.0
 */

//-----Define I/O-----

#define sensor_center PORTC.F6
#define sensor_right PORTC.F5
#define sensor_left PORTC.F4
#define stop PORTD.F2
#define servo_left PORTB.F4
#define servo_right PORTB.F3
```

```
//-----Function Prototype-----
```

```
void main_init();  
void move_forward();  
void move_right();  
void move_left();  
void move_rev();  
void move_stop();  
void servo_left_on();  
void servo_right_on();
```

```
//-----Main Prog.-----
```

```
void main()  
{  
  int a ;  
  main_init();  
  
  while(1)  
  {  
  
    if((sensor_center == 0)&& (sensor_right == 0)) //detect right curve  
    { while(a <= 50)  
      {a = 0;  
       a++;  
       move_forward();  
      }  
      move_right(); //turn right  
    }  
    else if((sensor_center == 0)&&(sensor_left == 0)) //detect left curve  
    { while(a <= 50)
```

```

    {a = 0;
    a++;
    move_forward();
    }
    move_left();                                //turn left
    }
    else if(( sensor_center == 0)&&(sensor_left == 0 )&& (sensor_right == 0 ))
    { while(a <= 50)
    {a = 0;
    a++;
    move_forward();
    }
    move_right();                                //turn right
    }
    else
    { move_forward();
    }
    }
}

//-----main_init-----
void main_init()
{
    TRISB.F4=0; //servo_left
    TRISB.F3=0; //servo_right
    TRISC.F6=1; //Sensor_center
    TRISC.F5=1; //Sensor_right
    TRISC.F4=1; //Sensor_left
    TRISD.F2=1; //Stop button
}

```

```
//-----move_forward-----
```

```
void move_forward()
```

```
{  
  servo_left_on();  
  servo_right_on();  
}
```

```
//-----move_left-----
```

```
void move_left()
```

```
{  
  servo_right_on();  
  servo_left=1;Delay_ms(1);Delay_us(500); //turn left  
  servo_left=0;Delay_ms(18);Delay_us(500);  
}
```

```
//-----move_right-----
```

```
void move_right()
```

```
{  
  servo_left_on();  
  servo_right=1;Delay_ms(1);Delay_us(500); //turn right  
  servo_right=0;Delay_ms(18);Delay_us(500);  
}
```

```
//-----sv1_on-----
```

```
void servo_right_on()
```

```
{servo_right=1;Delay_ms(1);  
  servo_right=0;Delay_ms(19);  
}
```

```

//-----sv2_on-----
void servo_left_on()
{
  servo_left=1;Delay_ms(1);
  servo_left=0;Delay_ms(19);
}

//-----move_rev-----

void move_rev()
{
  servo_left=1;Delay_ms(2);
  servo_left=0;Delay_ms(18);
  servo_right=1;Delay_ms(2);
  servo_right=0;Delay_ms(18);
}

//-----stop-----

void move_stop()
{
  servo_left=1;Delay_ms(1); Delay_us(500); // servo_left stop
  servo_left=0;Delay_ms(18); Delay_us(500);
  servo_right=1;Delay_ms(1) ; Delay_us(500); //servo_right stop
  servo_right=0;Delay_ms(18); Delay_us(500);
}

```

4.8 Cost Analysis

One of the project objectives was to establish a system that could provide cost effective to the user. The cost for the AGV was evaluated and compared with operation cost in industry with using the Material Handle (MH) person to handle the process of carrying the material from warehouse/store to the production line. The estimation of the production cost of using operator is as follows:

Table 5: Production Cost of using Operator as MH

Subject	
Wage Per Hour	Rm 3.00
Work Hour Per Day	8
Work Days Per Month	30
Wage Per Operator	Rm 720.00

Furthermore, the cost of the production line which using the AGV for the Material Handle (MH) is estimated and tabulated in Table 6 based on industry size of a prototype using trolley as the body kits.

Table 6: Production Cost of using AGV as MH

Subject	Quantity	Price Per Unit	Price
Body Kits (using trolley)	1	Rm 250.00	Rm 250.00
Infrared Sensor	4	Rm 30.00	Rm 120.00
PIC 16F877	1	Rm 40.00	Rm 40.00
Motor	2	Rm 80.00	Rm 160.00
Rechargeable Battery Set	2	Rm 60.00	Rm 120.00
Miscellaneous			Rm 50.00
		Total	Rm 740.00

Even though the production cost of using AGV is slightly higher the production cost of using operators as MH. However, the AGV capable to work effectively in 24 Hour shift non-stop just by replacing the rechargeable battery while for the operator they need to work in 3 shift per day which each shift equivalent to 8 hours. Therefore, the calculation proceeds as follows:

- If working efficiency of 1 AGV = 3 person.
- Then, total cost for 3 operators of Material Handle (MH) per month will be:

$$3 \times \text{Rm } 720 = \text{Rm } 2160.00.$$
- Thus, the production cost savings by using AGV will be Rm 1420 or 65.74%.

4.9 Capacity Analysis

The capacity analysis was done in order to evaluate the amount of capacity that AGV could carry via transportation. Thus, some calculation was performed based on the relationship of Output Power, P_{out} and Load Torque, T_L which is:

$$P_{out} = T_L \omega_L = Fv \quad ; F = mg$$

$$F = P_{out} / v$$

$$m = P_{out} / vg$$

Where F is force and v is velocity while g is gravity acceleration. Therefore, the AGV capacity or mass, m that could be carried is depends on motor output power or AGV velocity. In this case (my project model), the details as below:

Servo Motor Power, $P_{out} = 5$ Watt

Expected velocity, $v = 0.5 \text{ m s}^{-1}$

Mass, $m = 5 / (0.5 \times 9.81) = 1.02$ kg

However, for industrial application, the more powerful motor is suggested to be used so that the output power is higher. Thus, more weight can be carried by the AGV. Hence, the suggested specification for the industrial purpose is as follows:

Motor Voltage = 24 Volt

Motor Power, P_{out} = 100 Watt

Expected velocity, $v = 0.5 m s^{-1}$

Mass, $m = 100 / (0.5 \times 9.81) = 20.39$ kg

Therefore, the maximum capacity that could be carried is up to 20.4 kg if using the motor power of 100 Watt. However, this capacity will be reduced inversely proportional with increasing of AGV velocity, v .

4.10 Advantages and Disadvantages of AGV

a) Advantages of AGV

- No need for rest.
- Not tired and long lasting (reliable).
- Low installation and production cost.
- No need for benefits and compensation (no injury).
- Able to deliver materials accurately to the production line.
- Able to provide 'On Time Material Delivery'.
- Reduce risk of material damages during transportation process.
- Reduce number of labors.

b) Disadvantages of AGV

- Need for re-charged.
- May wear and damaged after long time.
- Need maintenance.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

At the earlier stage of the project development, it is desired that the project could be accomplished. Through a well planned and organized working procedure, the project goals is finally successfully achieved to design and develop the prototype for the Automatic Guided Vehicle (AGV) using a microcontroller.

Since the project is using the infrared sensor and microcontroller chip, thus this make the project more difficult since those components are very sensitive and can cause inconsistent communication between input and output. Therefore, some calculations need to be done earlier in order to get the right value of current and voltage of the system. Besides that, the program need to be tested to ensure the AGV work as programmed.

To make this project marketable, the components and hardware of the prototype was developed from low cost component but with high reliability and well functioning. That's why it is important to do the selection amongst the alternatives so that the project produced will be as economic as possible. Since the project is very significant and related with the industry, thus hopefully this product will be marketable and applicable to the material handling system in industry. Hence, it will be a very useful product since it will make assembly process easier and more convenience.

5.2 Recommendation

For further development of the project, the systems need to be well programmed so that it can be functions well throughout the predefined route. Therefore, the programming skill using C language or Assembly Language is very essential for the next development of the project.

Besides that, the project as well could be equipped with several extra accessories such as wireless camera and vibration sensor. The wireless camera can be use to monitor the AGV operation and were connected with the control room. In addition, the vibration sensor can be installed as to detect any accident or obstacle that block or interfere the AGV movement. Furthermore, the AGV as well can further developed to be installed with speed control devices.

Furthermore, the AGV as well can be improved by using the higher sensitivity infrared sensor or using a built-in set of pair of transmitter and receiver of infrared sensor instead of assembly as one. The improvement also can be performed by using single motor and gears to control the turning of the AGV instead of using two motor for turning since two motor require speed synchronization.

APPENDICES

APPENDIX A

PIC16F87X, MICROCONTROLLER DATASHEET



MICROCHIP

PIC16F87X

28/40-pin 8-Bit CMOS FLASH Microcontrollers

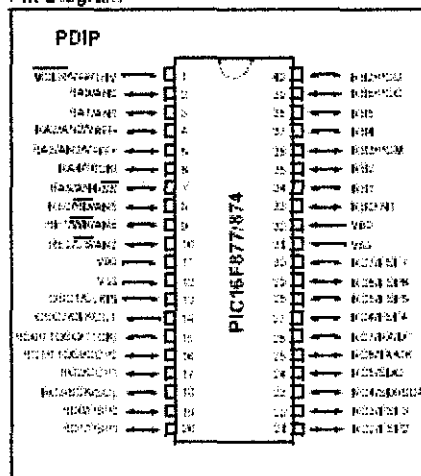
Devices Included in this Data Sheet:

- PIC16F875
- PIC16F876
- PIC16F874
- PIC16F877

Microcontroller Core Features:

- 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 256 x 8 bytes of Data Memory (RAM). Up to 256 x 8 bytes of EEPROM data memory
- Pinout compatible to the PIC16C75B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PURT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
 - < 2 mA typical @ 5V, 4 MHz
 - 20 µA typical @ 3V, 32 kHz
 - < 1 µA typical standby current

Pin Diagram

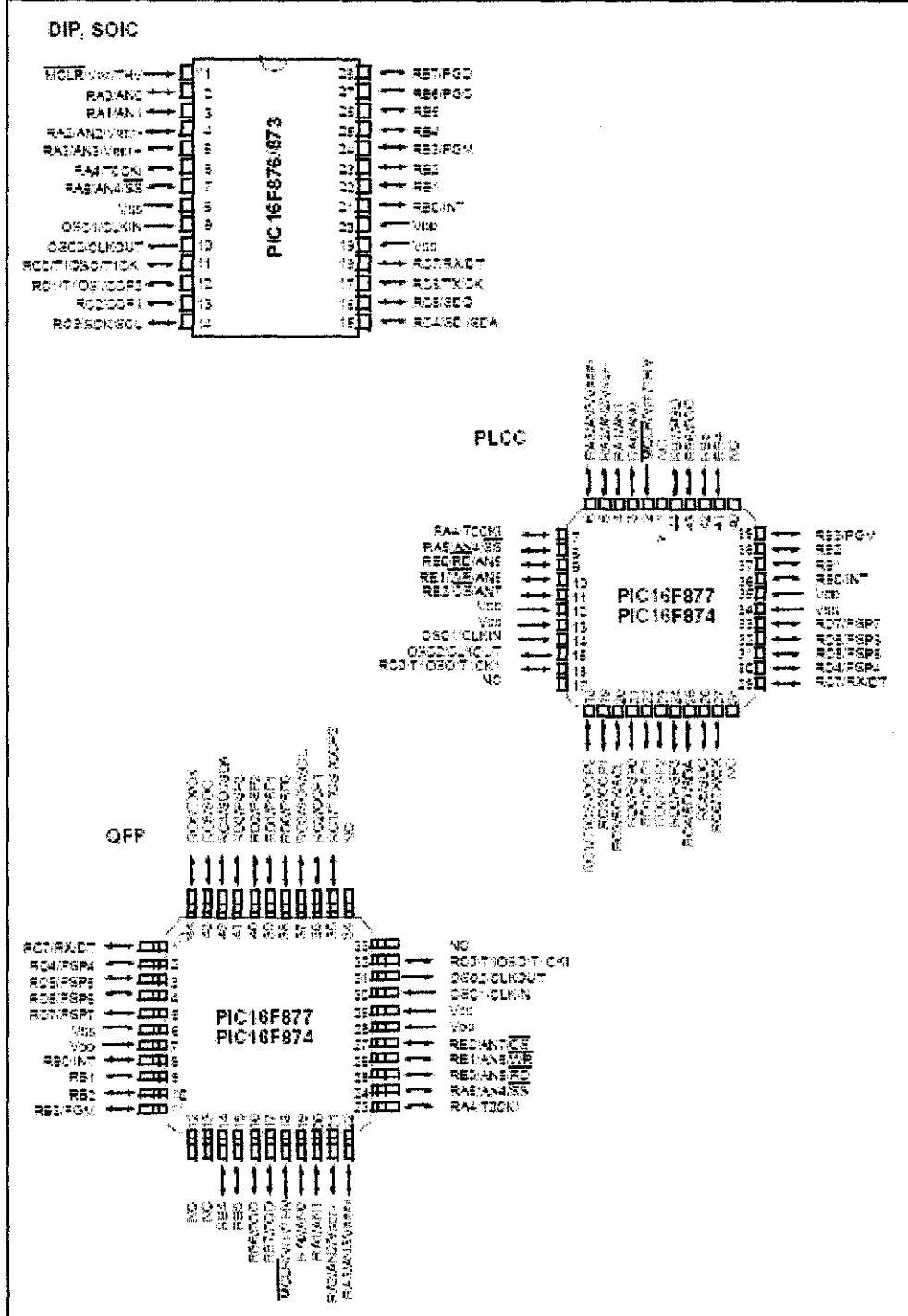


Peripheral Features:

- 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
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master/Slave) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

PIC16F87X

Pin Diagrams



PIC16F87X

Key Features PICmicro™ Mid-Range Reference Manual (DS33023)	PIC16F873	PIC16F874	PIC16F876	PIC16F877
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	385	385
EEPROM Data Memory	128	128	256	256
Interrupts	13	14	13	14
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	5 input channels	5 input channels	5 input channels
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions

PIC16F87X

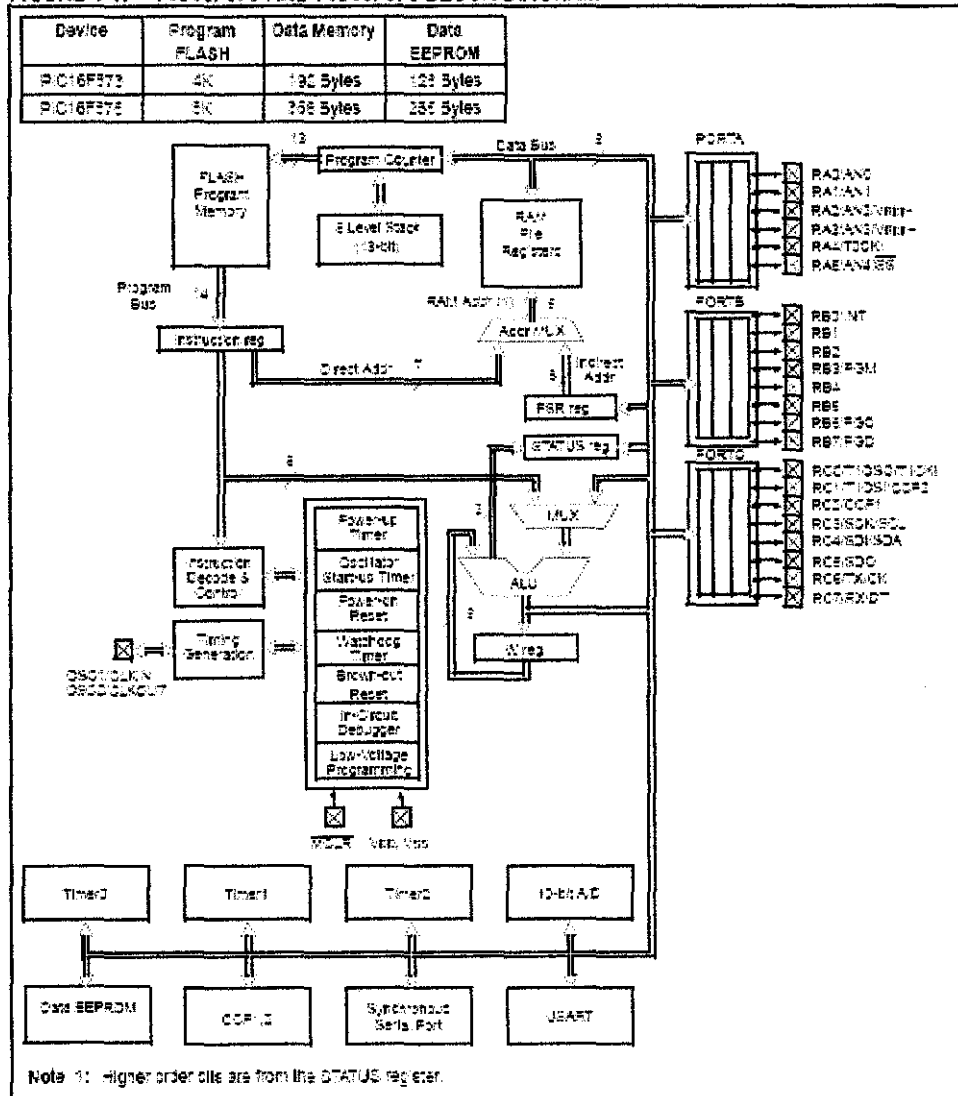
1.0 DEVICE OVERVIEW

This document contains device-specific information. 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 website. 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.

There are four devices (PIC16F873, PIC16F874, PIC16F876 and PIC16F877) covered by this data sheet. The PIC16F876/873 devices come in 28-pin packages and the PIC16F877/874 devices come in 40-pin packages. The 28-pin devices do not have a Parallel Slave Port implemented.

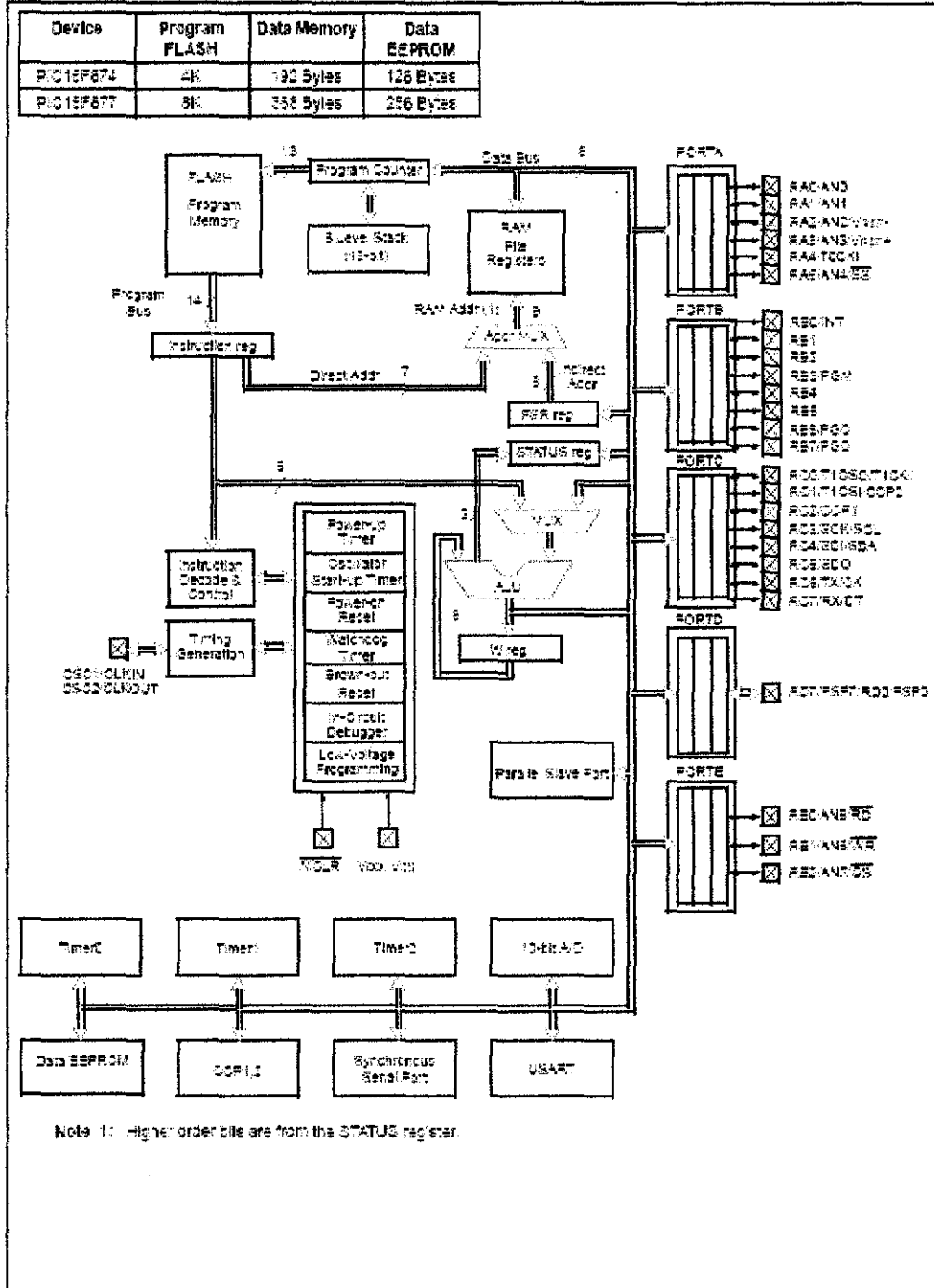
The following two figures are device block diagrams sorted by pin number: 28-pin for Figure 1-1 and 40-pin for Figure 1-2. The 28-pin and 40-pin pinouts are listed in Table 1-1 and Table 1-2, respectively.

FIGURE 1-1: PIC16F873 AND PIC16F876 BLOCK DIAGRAM



PIC16F87X

FIGURE 1-2: PIC16F874 AND PIC16F877 BLOCK DIAGRAM



PIC16F87X

TABLE 1-1: PIC16F873 AND PIC16F876 PINOUT DESCRIPTION

Pin Name	DIP Pin#	SOIC Pin#	NO/P Type	Buffer Type	Description
OSC1/CLKIN	9	9	I	DMCMC/PPI	Oscillator crystal input/external clock source input
OSC2/CLKOUT	10	10	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, the OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate
MCLR/VPP/STV	1	1	IP	OT	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
RAD/AN0	2	2	IO	TTL	PORTA is a bi-directional I/O port. RA0 can also be analog input0
RA1/AN1	3	3	IO	TTL	RA1 can also be analog input1
RA2/AN2/Vref-	4	4	IO	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/Vref+	5	5	IO	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	6	IO	OT	RA4 can also be the clock input to the Timer0 module. Output is open drain type.
RA5/SS/AN4	7	7	IO	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
RB0/INT	21	21	IO	TTL/OT ¹	PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs. RB0 can also be the external interrupt pin.
RB1	22	22	IO	TTL	
RB2	23	23	IO	TTL	
RB3/PGM	24	24	IO	TTL	RB3 can also be the low voltage programming input
RB4	25	25	IO	TTL	interrupt or change pin.
RB5	26	26	IO	TTL	interrupt or change pin.
RB6/PGC	27	27	IO	TTL/OT ²	interrupt or change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	28	28	IO	TTL/OT ²	interrupt or change pin or In-Circuit Debugger pin. Serial programming data.
RC0/T1OSC0/T1CKI	11	11	IO	OT	PORTC is a bi-directional I/O port. RC0 can also be the Timer1 oscillator output or Timer1 clock input.
RC1/T1OSC1/OCF2	12	12	IO	OT	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output
RC2/OCF1	13	13	IO	OT	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/CK0GCL	14	14	IO	OT	RC3 can also be the synchronous serial clock input/output for both SPI and I ² C modes
RC4/SDI/SDA	15	15	IO	OT	RC4 can also be the SPI Data In (SPI mode) or data I/O (I ² C mode).
RC5/SDO	16	16	IO	OT	RC5 can also be the SPI Data Out (SPI mode).
RC6/TXCK	17	17	IO	OT	RC6 can also be the USART Asynchronous Transmitter or Synchronous Clock.
RC7/RXDT	18	18	IO	OT	RC7 can also be the USART Asynchronous Receiver or Synchronous Data.
Vss	8, 19	8, 19	P	—	Ground reference for logic and I/O pins.
Vdd	20	20	P	—	Positive supply for logic and I/O pins.

Legend: I = Input, O = output, IO = Input/output, P = power
 — = Not Used, TTL = TTL input, OT = Schmitt Trigger Input

- Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.
 2: This buffer is a Schmitt Trigger input when used in serial programming mode.
 3: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

PIC16F87X

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	UDIP Type	Buffer Type	Description
OSC1/CLKIN	13	14	32	I	BT/CMOS	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	14	15	31	O	—	Oscillator crystal output. Connects to crystal or resonator in crystal oscillator mode. In RC mode, OSC2 pin outputs CLKOUT which has 1/4 the frequency of OSC1, and denotes the instruction cycle rate.
MCLR/VPP/STV	1	2	19	OP	ST	Master clear/reset, input for programming voltage, input of high voltage level mode control. This pin is an active low reset to the device.
RA0/AN0	2	3	19	IO	TTL	PORTA is a bi-directional I/O port. RA0 can also be analog input 0. RA1 can also be analog input 1. RA2 can also be analog input 2 or negative analog reference voltage. RA3 can also be analog input 3 or positive analog reference voltage. RA4 can also be the clock input to the Timer0 timer counter. Output is open drain type. RA5 can also be analog input 4 or the slave select for the synchronous serial port.
RA1/AN1	3	4	20	IO	TTL	
RA2/AN2/VREF-	4	5	21	IO	TTL	
RA3/AN3/VREF+	5	6	22	IO	TTL	
RA4/T0CKI	6	7	23	IO	ST	
RA5/SSAN4	7	8	24	IO	TTL	
RB0/INT	33	36	9	IO	TTL/CMOS	PORTE is a bi-directional I/O port. PORTE can be software programmed for internal weak pull-up on all inputs. RB0 can also be the external interrupt pin. RB3 can also be the low voltage programming input. Interrupt on change pin. Interrupt on change pin. Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock. Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.
RB1	34	37	9	IO	TTL	
RB2	35	38	10	IO	TTL	
RB3/PGM	36	39	11	IO	TTL	
RB4	37	41	14	IO	TTL	
RB5	39	42	15	IO	TTL	
RB6/PGC	39	43	15	IO	TTL/CMOS	
RB7/PGD	40	44	17	IO	TTL/CMOS	
RC0/T0CK1/CLKIN	16	16	32	IO	ST	PORTC is a bi-directional I/O port. RC0 can also be the Timer0 oscillator output or a Timer0 clock input. RC1 can also be the Timer0 oscillator input or Capture2 input/Compare2 output/PWM2 output. RC2 can also be the Capture1 input/Compare1 output/PWM1 output. RC3 can also be the synchronous serial clock input/output for both SPI and I ² C modes. RC4 can also be the SPI Data In (SPI mode) or data I/O (I ² C mode). RC5 can also be the SPI Data Out (SPI mode). RC6 can also be the USART Asynchronous Transmit or Synchronous Clock. RC7 can also be the USART Asynchronous Receive or Synchronous Data.
RC1/T0CK1/CCP2	16	16	35	IO	ST	
RC2/CCP1	17	19	36	IO	ST	
RC3/CCP2/SCL	18	20	37	IO	ST	
RC4/SPI/SDA	23	25	43	IO	ST	
RC5/SPI/SDO	24	26	43	IO	ST	
RC6/TXCK	25	27	44	IO	ST	
RC7/RXDT	26	29	1	IO	ST	

Legend: I = input, O = output, IO = input/output, F = power, — = Not used, TTL = TTL input, ST = Schmitt Trigger Input

- Note:
- 1: This buffer is a Schmitt Trigger Input when configured as an external interrupt.
 - 2: This buffer is a Schmitt Trigger Input when used in serial programming mode.
 - 3: This buffer is a Schmitt Trigger Input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
 - 4: This buffer is a Schmitt Trigger Input when configured in RC oscillator mode and a CMOS input otherwise.

PIC16F87X

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION (CONTINUED)

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	NOVP Type	Buffer Type	Description
RD0:RCF0	19	21	38	IO	ST-TTL ^{1,2}	PORTC is a bi-directional I/O port or parallel slave port when interfacing to a microprocessor bus.
RD1:RCF1	20	22	39	IO	ST-TTL ^{1,2}	
RD2:RCF2	21	23	40	IO	ST-TTL ^{1,2}	
RD3:RCF3	22	24	41	IO	ST-TTL ^{1,2}	
RD4:RCF4	27	30	2	IO	ST-TTL ^{1,2}	
RD5:RCF5	28	31	3	IO	ST-TTL ^{1,2}	
RD6:RCF6	29	32	4	IO	ST-TTL ^{1,2}	
RD7:RCF7	30	33	5	IO	ST-TTL ^{1,2}	
RE0:RDANS	8	9	25	IO	ST-TTL ^{1,2}	PORTE is a bi-directional I/O port. RE2 can also be read control for the parallel slave port, or analog inputs. RE1 can also be write control for the parallel slave port, or analog inputs. RE2 can also be select control for the parallel slave port, or analog inputs.
RE1:RDANE	9	10	26	IO	ST-TTL ^{1,2}	
RE2:RDANF	10	11	27	IO	ST-TTL ^{1,2}	
Vss	12,31	13,34	6,29	P	—	Ground reference for logic and I/O pins.
Vdd	11,32	12,35	7,28	P	—	Positive supply for logic and I/O pins.
NC	—	1,17,25, 40	12,13, 32,34	—	—	These pins are not internally connected. These pins should be left unconnected.

Legend: I = Input O = output IO = input/output P = power
 — = Not Lead TTL = TTL input ST = Schmitt Trigger Input

- Note: 1: This buffer is a Schmitt Trigger input when configured as an external interrupt.
 2: This buffer is a Schmitt Trigger input when used in serial programming mode.
 3: This buffer is a Schmitt Trigger input when configured as general purpose I/O and a TTL input when used in the Parallel Slave Port mode (for interfacing to a microprocessor bus).
 4: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

APPENDIX B

LM78XX, VOLTAGE REGULATOR DATASHEET

FAIRCHILD
SEMICONDUCTOR®

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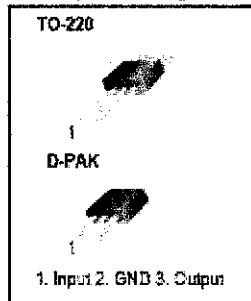
MC78XX/LM78XX/MC78XXA 3-Terminal 1A Positive Voltage Regulator

Features

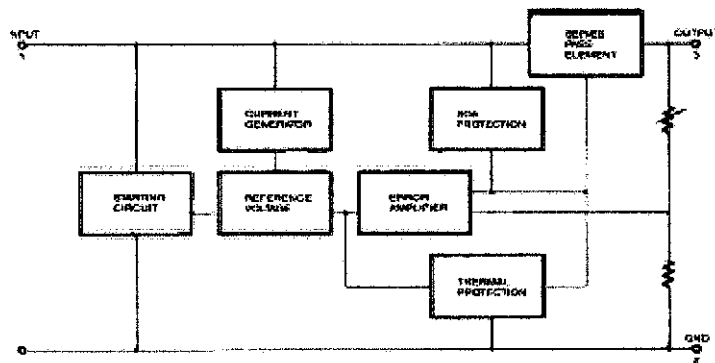
- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The MC78XX/LM78XX/MC78XXA series of three terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.



Internal Block Diagram



Rev. 1.0.1

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Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for $V_O = 5V$ to $18V$) (for $V_O = 24V$)	V_i	35	V
	V_i	40	V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	$^{\circ}C/W$
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	$^{\circ}C/W$
Operating Temperature Range	T_{OPR}	$0 \sim +125$	$^{\circ}C$
Storage Temperature Range	T_{STG}	$-85 \sim +150$	$^{\circ}C$

Electrical Characteristics (MC7805/LM7805)

(Refer to test circuit, $0^{\circ}C < T_J < 125^{\circ}C$, $I_O = 500mA$, $V_i = 10V$, $C_i = 0.33\mu F$, $C_O = 0.1\mu F$, unless otherwise specified.)

Parameter	Symbol	Conditions	MC7805/LM7805			Unit	
			Min.	Typ.	Max.		
Output Voltage	V_O	$T_J = +25^{\circ}C$	4.9	5.0	5.2	V	
		$5.0mA \leq I_O \leq 1.0A$, $P_O \leq 15W$ $V_i = 7V$ to $20V$	4.75	5.0	5.25		
Line Regulation (Note 1)	Regline	$T_J = +25^{\circ}C$	$V_O = 7V$ to $25V$	-	4.0	100	mV
			$V_i = 8V$ to $12V$	-	1.6	50	
Load Regulation (Note 1)	Regload	$T_J = +25^{\circ}C$	$I_O = 5.0mA$ to $1.5A$	-	8	100	mV
			$I_O = 250mA$ to $750mA$	-	4	50	
Quiescent Current	I_Q	$T_J = +25^{\circ}C$	-	5.0	8.0	mA	
Quiescent Current Change	ΔI_Q	$I_O = 5mA$ to $1.0A$	-	0.03	0.6	mA	
		$V_i = 7V$ to $25V$	-	0.3	1.3		
Output Voltage Drift	$\Delta V_O / \Delta T$	$I_O = 5mA$	-	-0.8	-	$mV/^{\circ}C$	
Output Noise Voltage	V_N	$f = 10Hz$ to $100kHz$, $T_A = +25^{\circ}C$	-	42	-	$\mu V/V_O$	
Ripple Rejection	RR	$f = 120Hz$ $V_O = 8V$ to $18V$	62	73	-	dB	
Dropout Voltage	V_{Drop}	$I_O = 1A$, $T_J = +25^{\circ}C$	-	2	-	V	
Output Resistance	r_O	$f = 1kHz$	-	15	-	$m\Omega$	
Short Circuit Current	I_{SC}	$V_i = 35V$, $T_A = +25^{\circ}C$	-	230	-	mA	
Peak Current	I_{PK}	$T_J = +25^{\circ}C$	-	2.2	-	A	

Note:

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.

Typical Applications

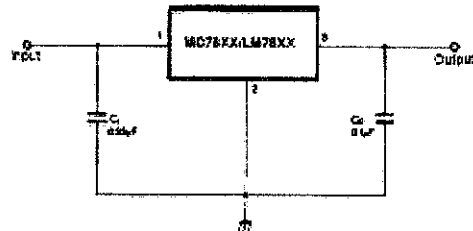


Figure 5. DC Parameters

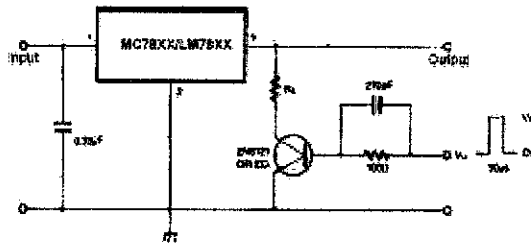


Figure 6. Load Regulation

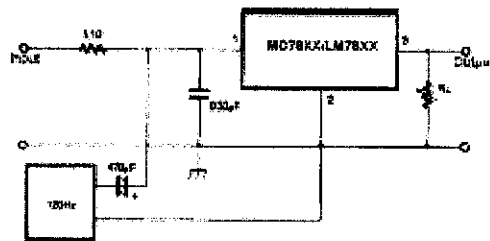


Figure 7. Ripple Rejection

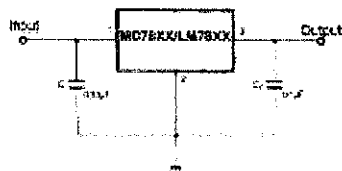
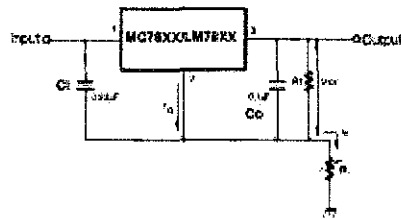


Figure 8. Fixed Output Regulator

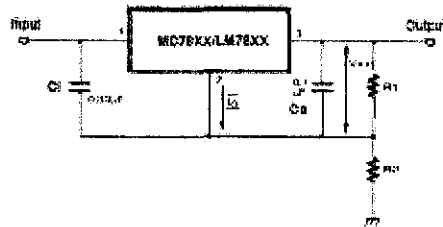


$$I = \frac{V_{XX}}{R_L}$$

Figure 9. Constant Current Regulator

Notes:

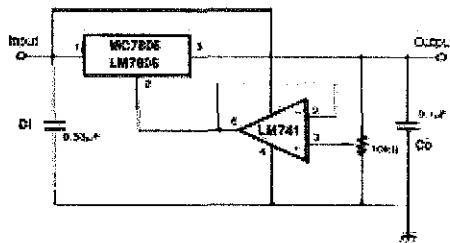
- (1) To specify an output voltage, substitute voltage value for "XX." A common ground is required between the input and the Output voltage. The input voltage must remain typically 2.0V above the output voltage even during the low point on the input ripple voltage.
- (2) C1 is required if regulator is located an appreciable distance from power supply filter.
- (3) C0 improves stability and transient response.



$$I_q \approx 510 \mu A$$

$$V_O = V_{XX}(1 + R_2/R_1) + I_q R_2$$

Figure 10. Circuit for Increasing Output Voltage



$$I_q \approx 510 \mu A$$

$$V_O = V_{XX}(1 + R_2/R_1) + I_q R_2$$

Figure 11. Adjustable Output Regulator (7 to 30V)

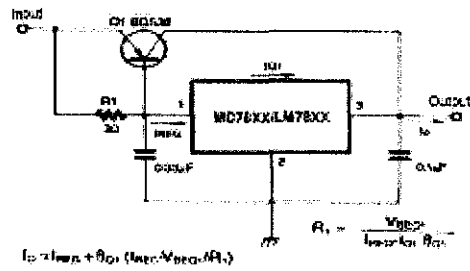


Figure 12. High Current Voltage Regulator

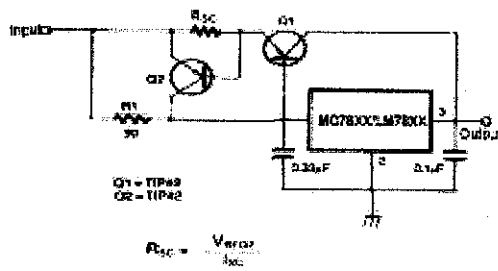


Figure 13. High Output Current with Short Circuit Protection

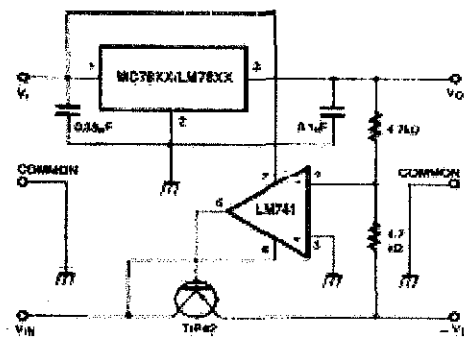


Figure 14. Tracking Voltage Regulator

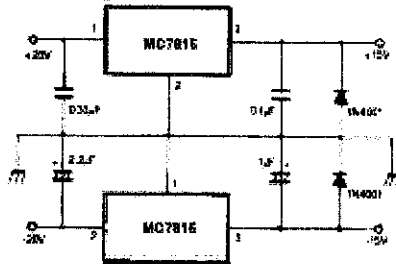


Figure 15. Split Power Supply ($\pm 15V-1A$)

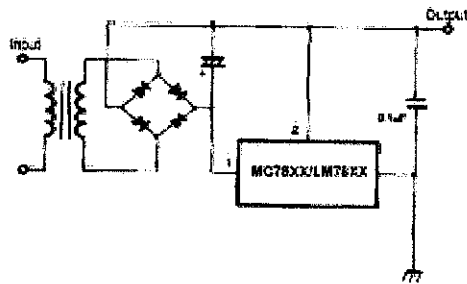


Figure 16. Negative Output Voltage Circuit

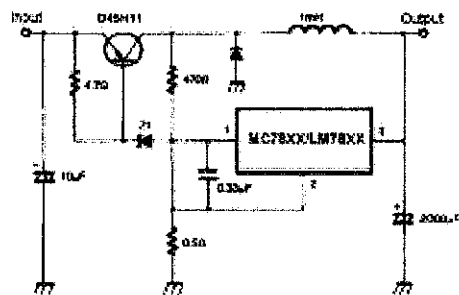


Figure 17. Switching Regulator

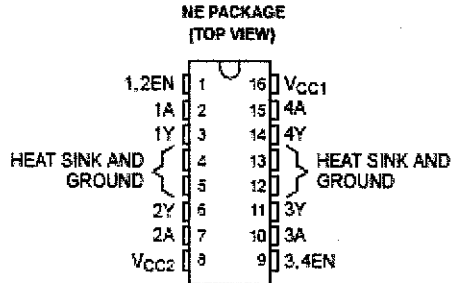
APPENDIX C

L293, MOTOR DRIVER DATASHEET

L293 QUADRUPLE HALF-H DRIVER

SLRS005 - SEPTEMBER 1986 - REVISED MAY 1990

- 1-A Output Current Capability Per Driver
- Pulsed Current 2-A Driver
- Wide Supply Voltage Range: 4.5 V to 36 V
- Separate Input-Logic Supply
- NE Package Designed for Heat Sinking
- Thermal Shutdown
- Internal ESD Protection
- High-Noise-Immunity Inputs
- Functional Replacement for SGS L293



description

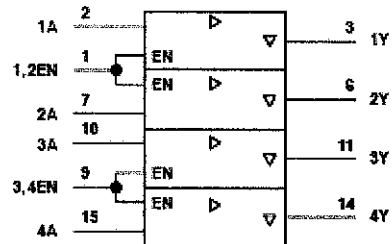
The L293 is a quadruple high-current half-H driver designed to provide bidirectional drive currents of up to 1 A at voltages from 4.5 V to 36 V. It is designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

All inputs are TTL compatible. Each output is a complete totem-pole drive circuit with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled and their outputs are active and in phase with their inputs. When the enable input is low, those drivers are disabled and their outputs are off and in a high-impedance state. With the proper data inputs, each pair of drivers form a full-H (or bridge) reversible drive suitable for solenoid or motor applications.

External high-speed output clamp diodes should be used for inductive transient suppression. A V_{CC1} terminal, separate from V_{CC2} , is provided for the logic inputs to minimize device power dissipation.

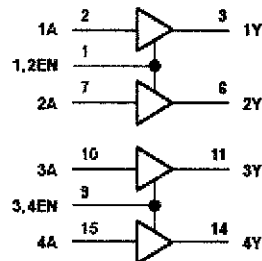
The L293 is designed for operation from 0°C to 70°C.

logic symbol†



† This symbol is in accordance with ANSI/IEEE Std 91-1984 and IEC publication 617-12.

logic diagram



FUNCTION TABLE
(each driver)

INPUTS‡		OUTPUT
A	EN	Y
H	H	H
L	H	L
X	L	Z

H = high-level, L = low-level,
 X = irrelevant, Z = high-impedance (off)
 ‡ In the thermal shutdown mode, the output is in the high-impedance state regardless of the input levels.

PRODUCTION DATA Information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

**TEXAS
INSTRUMENTS**

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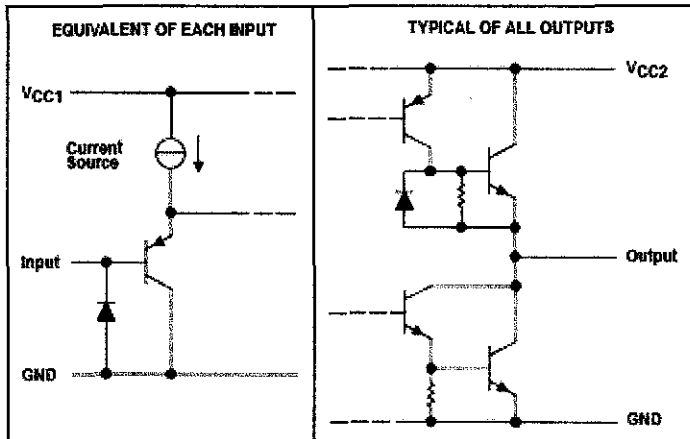
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L293
QUADRUPLE HALF-H DRIVER

SLR8005 - SEPTEMBER 1986 - REVISED MAY 1990

schematics of inputs and outputs



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{CC1} (see Note 1)	36 V
Output supply voltage range, V_{CC2}	36 V
Input voltage range, V_I	7 V
Output voltage range, V_O	-3 V to $V_{CC2} + 3$ V
Peak output current, I_O (nonrepetitive, $t \leq 5$ ms)	± 2 A
Continuous output current, I_O	± 1 A
Continuous total dissipation at (or below) 25°C free-air temperature (see Notes 2 and 3)	2075 mW
Continuous total dissipation at 80°C case temperature (see Note 3)	5000 mW
Operating case or virtual junction temperature range, T_A	-40°C to 150°C
Storage temperature range, T_{stg}	-85°C to 150°C
Lead temperature 1.6 mm (1/16 inch) from case for 10 seconds	280°C

- NOTES: 1. All voltage values are with respect to the network ground terminal.
 2. For operation above 25°C free-air temperature, derate linearly at the rate of 16.6 mW/°C.
 3. For operation above 25°C case temperature, derate linearly at the rate of 71.4 mW/°C. Due to variations in individual device electrical characteristics and thermal resistance, the built-in thermal overload protection may be activated at power levels slightly above or below the rated dissipation.

recommended operating conditions

		MIN	MAX	UNIT
Logic supply voltage, V_{CC1}		4.5	7	V
Output supply voltage, V_{CC2}		36		V
High-level input voltage, V_{IH}	$V_{CC1} \leq 7$ V	2.3		V
	$V_{CC1} \geq 7$ V	2.3	7	
Low-level output voltage, V_{OL}		-0.3†	1.5	V
Operating free-air temperature, T_A		B	70	°C

† The algebraic convention, in which the least positive (most negative) designated minimum, is used in this data sheet for logic voltage levels.



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L293 QUADRUPLE HALF-H DRIVER

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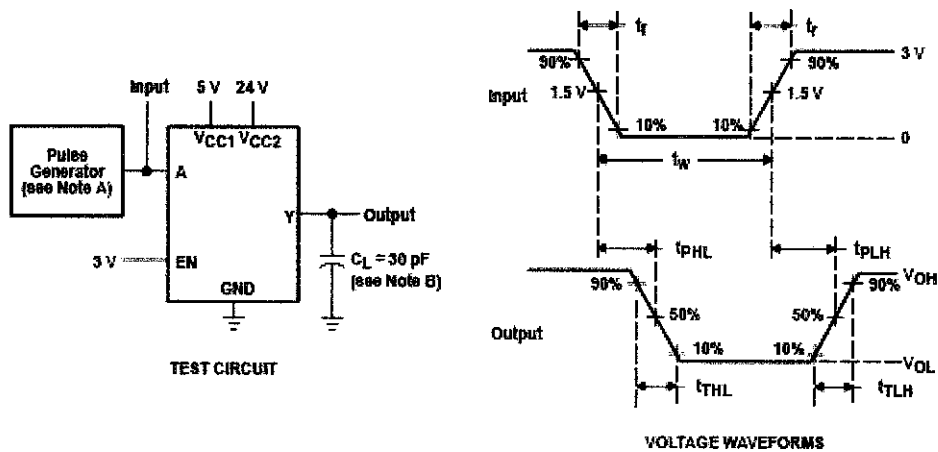
electrical characteristics, $V_{CC1} = 5\text{ V}$, $V_{CC2} = 24\text{ V}$, $T_A = 25^\circ\text{C}$

PARAMETER	TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{OH} High-level output voltage	$I_{OH} = -1\text{ A}$		$V_{CC2} - 1.5$	$V_{CC2} - 1.4$		V
V_{OL} Low-level output voltage	$I_{OL} = 1\text{ A}$			1.2	1.8	V
I_{IH} High-level input current	A	$V_I = 7\text{ V}$		0.2	10D	μA
	EN			0.2	± 10	
I_{IL} Low-level input current	A	$V_I = 0$		-3	-10	μA
	EN			-2	-10D	
I_{CC1} Logic supply current	$I_O = 0$	All outputs at high level		13	22	mA
		All outputs at low level		35	60	
		All outputs at high impedance		8	24	
I_{CC2} Output supply current	$I_O = 0$	All outputs at high level		14	24	mA
		All outputs at low level		2	6	
		All outputs at high impedance		2	4	

switching characteristics, $V_{CC1} = 5\text{ V}$, $V_{CC2} = 24\text{ V}$, $T_A = 25^\circ\text{C}$

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{PLH} Propagation delay time, low-to-high-level output from A input	$C_L = 30\text{ pF}$. See Figure 1		300		ns
t_{PHL} Propagation delay time, high-to-low-level output from A input			400		ns
t_{TLH} Transition time, low-to-high-level output			350		ns
t_{THL} Transition time, high-to-low-level output			350		ns

PARAMETER MEASUREMENT INFORMATION



- NOTES: A. The pulse generator has the following characteristics: $t_r \leq 10\text{ ns}$, $t_f \leq 10\text{ ns}$, $t_w = 10\text{ }\mu\text{s}$, PRR = 5 KHZ, $Z_0 = 50\text{ }\Omega$.
 B. C_L includes probe and jig capacitance.

Figure 1. Test Circuit and Voltage Waveforms

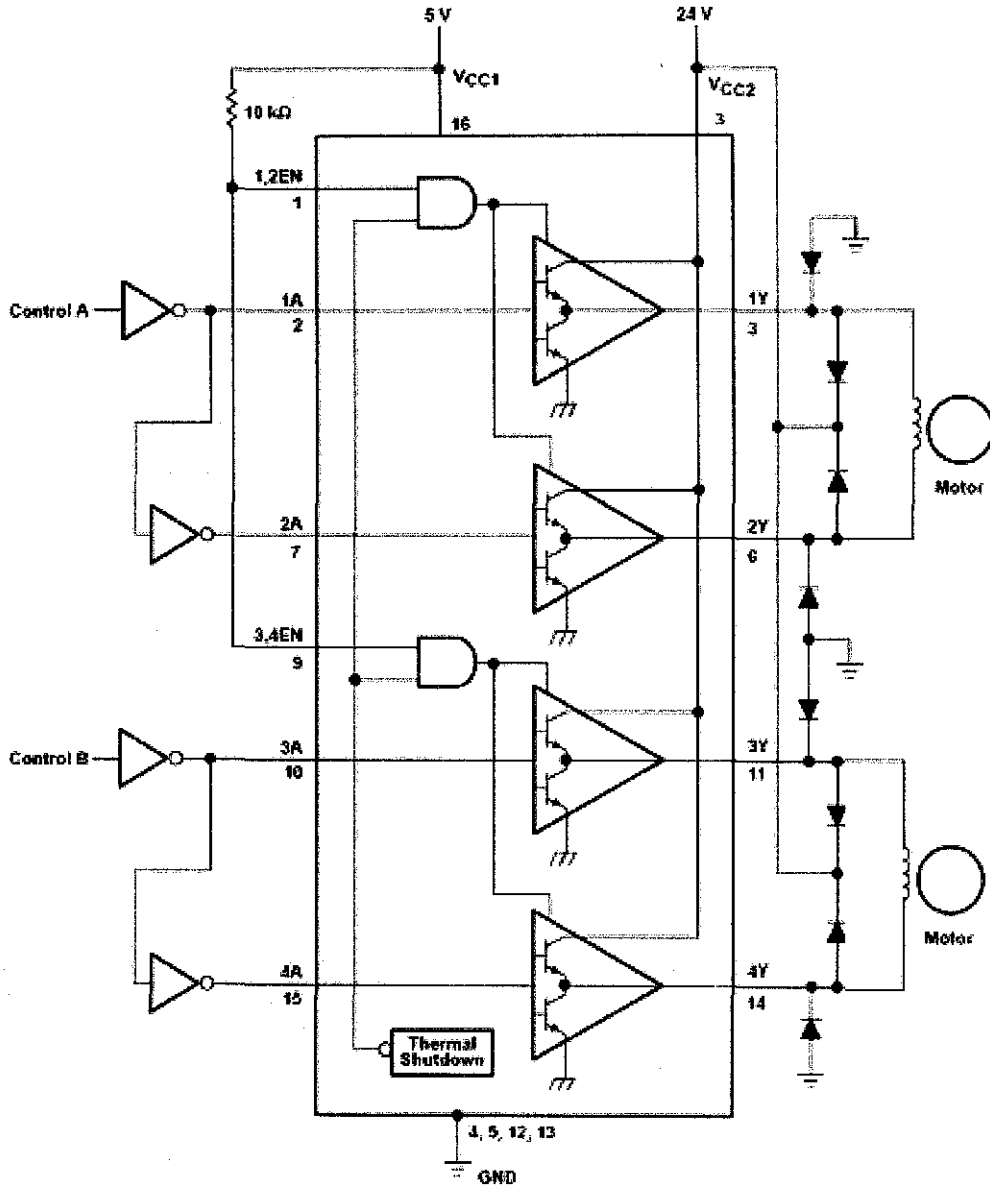


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L293
QUADRUPLE HALF-H DRIVER

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APPLICATION INFORMATION



TEXAS
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APPENDIX D

LM339, COMPARATOR DATASHEET

LM339, LM239, LM2901, LM2901V, NCV2901, MC3302

Single Supply Quad Comparators

These comparators are designed for use in level detection, low-level sensing and memory applications in consumer, automotive, and industrial electronic applications.

Features

- Pb-Free Packages are Available*
- Single or Split Supply Operation
- Low Input Bias Current: 25 nA (Typ)
- Low Input Offset Current: ± 5.0 nA (Typ)
- Low Input Offset Voltage
- Input Common Mode Voltage Range to GND
- Low Output Saturation Voltage: 130 mV (Typ) @ 4.0 mA
- TTL and CMOS Compatible
- ESD Clamps on the Inputs Increase Reliability without Affecting Device Operation



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**SOIC-14
D SUFFIX
CASE 751A**

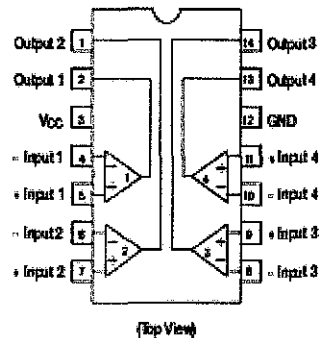


**PDIP-14
N, P SUFFIX
CASE 646**



**TSOP-14
DTB SUFFIX
CASE 948G**

PIN CONNECTIONS



ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 7 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 6 of this data sheet.

*For additional information on our Pb-Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

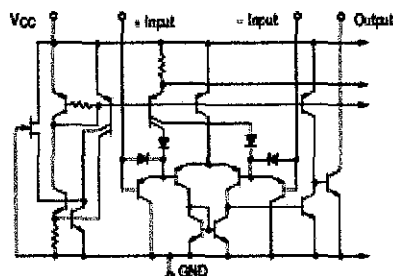
LM339, LM239, LM2901, LM2901V, NCV2901, MC3302

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Supply Voltage LM239/LM339/LM2901, V MC3302	V_{CC}	+36 or ± 18 +30 or ± 15	Vdc
Input Differential Voltage Range LM239/LM339/LM2901, V MC3302	V_{ICR}	36 30	Vdc
Input Common Mode Voltage Range	V_{ICMR}	-0.3 to V_{CC}	Vdc
Output Short Circuit to Ground (Note 1)	I_{SC}	Continuous	
Power Dissipation @ $T_A = 25^\circ\text{C}$ Plastic Package Derate above 25°C	P_D $1/\theta_{JA}$	1.0 3.0	W mW/°C
Junction Temperature	T_J	150	°C
Operating Ambient Temperature Range LM239 MC3302 LM2901 LM2901V, NCV2901 LM339	T_A	-25 to +85 -40 to +85 -40 to +105 -40 to +125 0 to +70	°C
Storage Temperature Range	T_{STG}	-65 to +150	°C
ESD Protection at any Pin Human Body Model Machine Model	V_{ESD}	2000 200	V

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

- The maximum output current may be as high as 20 mA, independent of the magnitude of V_{CC} . Output short circuits to V_{CC} can cause excessive heating and eventual destruction.



NOTE: Diagram shown is for 1 comparator.

Figure 1. Circuit Schematic

LM339, LM239, LM2901, LM2901V, NCV2901, MC3302

ELECTRICAL CHARACTERISTICS ($V_{CC} = +5.0$ Vdc, $T_A = +25^\circ\text{C}$, unless otherwise noted)

Characteristic	Symbol	LM239/339			LM2901/2901V NCV2901			MC3302			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage (Note 3)	V_{IO}	-	± 2.0	± 5.0	-	± 2.0	± 7.0	-	± 3.0	± 2.0	mVdc
Input Bias Current (Notes 3, 4) (Output in Analog Range)	I_{IB}	-	25	250	-	25	250	-	25	500	nA
Input Offset Current (Note 3)	I_{IO}	-	± 5.0	± 50	-	± 5.0	± 50	-	± 3.0	± 100	nA
Input Common Mode Voltage Range	V_{ICMR}	0	-	$V_{CC} - 1.5$	0	-	$V_{CC} - 1.5$	0	-	$V_{CC} - 1.5$	V
Supply Current $R_L = \infty$ (For All Comparators) $R_L = \infty, V_{CC} = 3.0$ Vdc	I_{CC}	-	0.8 1.0	2.0 2.5	-	0.8 1.0	2.0 2.5	-	0.8 1.0	2.0 2.5	mA
Voltage Gain $R_L \geq 15$ k Ω , $V_{CC} = 15$ Vdc	A_{VOL}	50	200	-	25	100	-	25	100	-	V/mV
Large Signal Response Time $V_i =$ TTL Logic Swing, $V_{ref} = 1.4$ Vdc, $V_{RL} = 5.0$ Vdc, $R_L = 5.1$ k Ω	-	-	300	-	-	300	-	-	300	-	ns
Response Time (Note 5) $V_{RL} = 5.0$ Vdc, $R_L = 5.1$ k Ω	-	-	1.3	-	-	1.3	-	-	1.3	-	μs
Output Sink Current $V_i(-) \geq +1.0$ Vdc, $V_i(+)=0$, $V_O \leq 1.5$ Vdc	I_{sINK}	6.0	16	-	6.0	16	-	6.0	16	-	mA
Saturation Voltage $V_i(-) \geq +1.0$ Vdc, $V_i(+)=0$, $I_{sINK} \leq 4.0$ mA	V_{sat}	-	130	400	-	130	400	-	130	500	mV
Output Leakage Current $V_i(+)\geq +1.0$ Vdc, $V_i(-)=0$, $V_O = +5.0$ Vdc	I_{OL}	-	0.1	-	-	0.1	-	-	0.1	-	nA

- (LM239) $T_{low} = -25^\circ\text{C}$, $T_{high} = +65^\circ\text{C}$
(LM339) $T_{low} = 0^\circ\text{C}$, $T_{high} = +70^\circ\text{C}$
(MC3302) $T_{low} = -40^\circ\text{C}$, $T_{high} = +85^\circ\text{C}$
(LM2901) $T_{low} = -45^\circ\text{C}$, $T_{high} = +105^\circ\text{C}$
(LM2901V & NCV2901) $T_{low} = -40^\circ\text{C}$, $T_{high} = +125^\circ\text{C}$
NCV2901 is qualified for automotive use.
- At the output switch point, $V_O = 1.4$ Vdc, $R_S \leq 100 \Omega$, 5.0 Vdc $\leq V_{CC} \leq 3.0$ Vdc, with the inputs over the full common mode range (0 Vdc to $V_{CC} - 1.5$ Vdc).
- The bias current flows out of the inputs due to the PNP input stage. This current is virtually constant, independent of the output state.
- The response time specified is for a 100 mV input step with 5.0 mV overdrive. For larger signals, 300 ns is typical.

LM339, LM239, LM2901, LM2901V, NCV2901, MC3302

PERFORMANCE CHARACTERISTICS ($V_{CC} = +5.0$ Vdc, $T_A = T_{low}$ to T_{high} [Note 6])

Characteristic	Symbol	LM239/339			LM2901/2901V/ NCV2901			MC3302			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage (Note 7)	V_{IO}	-	-	±9.0	-	-	±15	-	-	±40	mVdc
Input Bias Current (Notes 7, 8) (Output in Analog Range)	I_B	-	-	400	-	-	500	-	-	1000	nA
Input Offset Current (Note 7)	I_{IO}	-	-	±150	-	-	±200	-	-	±300	nA
Input Common Mode Voltage Range	V_{ICMR}	0	-	$V_{CC} - 2.0$	0	-	$V_{CC} - 2.0$	0	-	$V_{CC} - 2.0$	V
Saturation Voltage $V_i(-) \geq +1.0$ Vdc, $V_i(+)=0$, $I_{sat} \leq 4.0$ mA	V_{sat}	-	-	700	-	-	700	-	-	700	mV
Output Leakage Current $V_i(+)\geq +1.0$ Vdc, $V_i(-)=0$, $V_O = 30$ Vdc	I_{OL}	-	-	1.0	-	-	1.0	-	-	1.0	µA
Differential Input Voltage All $V_i \geq 0$ Vdc	V_{ID}	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	Vdc

6. (LM239) $T_{low} = -25^\circ\text{C}$, $T_{high} = +85^\circ\text{C}$
 (LM339) $T_{low} = 0^\circ\text{C}$, $T_{high} = +70^\circ\text{C}$
 (MC3302) $T_{low} = -40^\circ\text{C}$, $T_{high} = +85^\circ\text{C}$
 (LM2901) $T_{low} = -40^\circ\text{C}$, $T_{high} = +185^\circ\text{C}$
 (LM2901V & NCV2901) $T_{low} = -40^\circ\text{C}$, $T_{high} = +125^\circ\text{C}$
 NCV2901 is qualified for automotive use.
7. At the output switch point, $V_O \approx 1.4$ Vdc, $R_S \leq 100\ \Omega$, 5.0 Vdc $\leq V_{CC} \leq 30$ Vdc, with the inputs over the full common mode range (0 Vdc to $V_{CC} - 1.5$ Vdc).
8. The bias current flows out of the inputs due to the PNP input stage. This current is virtually constant, independent of the output state.
9. The response time specified is for a 100 mV input step with 5.0 mV overdrive. For larger signals, 300 ns is typical.

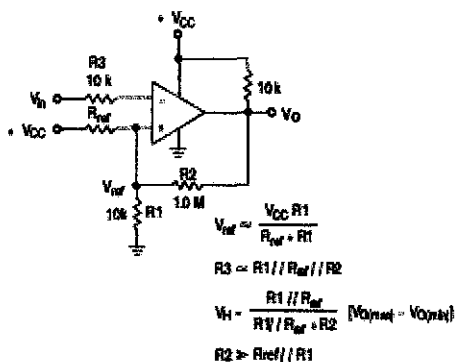


Figure 2. Inverting Comparator with Hysteresis

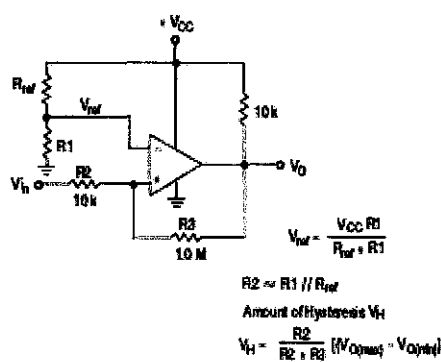


Figure 3. Noninverting Comparator with Hysteresis

LM239, LM2901, LM2901V, NCV2901, MC3302

Typical Characteristics

($V_{CC} = 15\text{ Vdc}$, $T_A = +25^\circ\text{C}$ (each comparator) unless otherwise noted.)

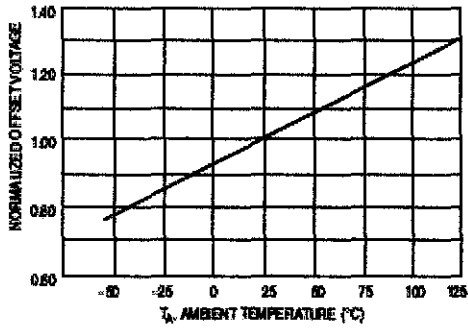


Figure 4. Normalized Input Offset Voltage

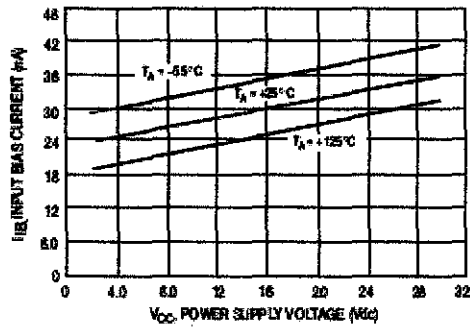


Figure 5. Input Bias Current

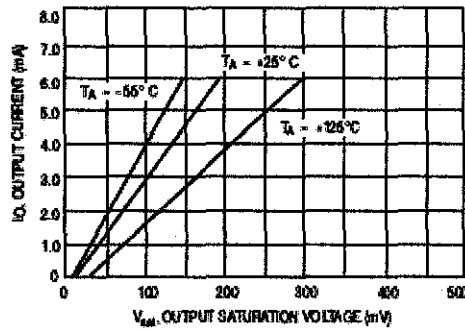
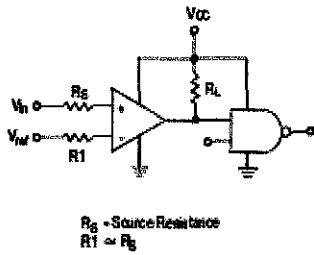


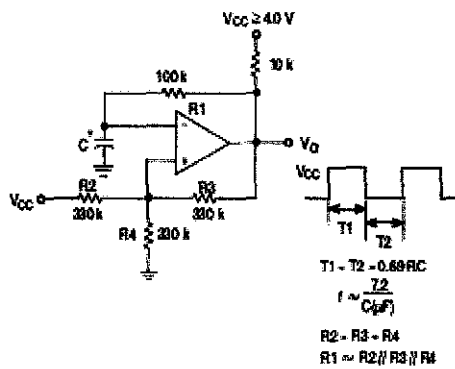
Figure 6. Output Sink Current versus Output Saturation Voltage



R_S - Source Resistance
 $R_1 \approx R_S$

Logic	Device	V_{CC} (V)	R_L (k Ω)
CMOS	1/4 MC14001	+15	100
TTL	1/4 MC7400	+5.0	10

Figure 7. Driving Logic



$T_1 - T_2 = 0.69RC$
 $f \approx \frac{T_2}{C(\mu\text{F})}$
 $R_2 - R_3 - R_4$
 $R_1 \approx R_2 // R_3 // R_4$

Figure 8. Squarewave Oscillator

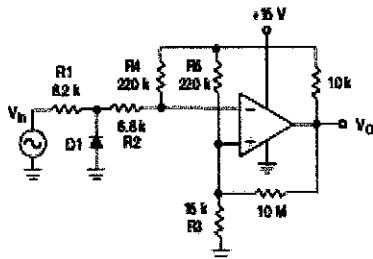
LM339, LM239, LM2901, LM2901V, NCV2901, MC3302

APPLICATIONS INFORMATION

These quad comparators feature high gain, wide bandwidth characteristics. This gives the device oscillation tendencies if the outputs are capacitively coupled to the inputs via stray capacitance. This oscillation manifests itself during output transitions (V_{OL} to V_{OH}). To alleviate this situation input resistors $< 10\text{ k}\Omega$ should be used. The

addition of positive feedback ($< 10\text{ mV}$) is also recommended. It is good design practice to ground all unused input pins.

Differential input voltages may be larger than supply voltages without damaging the comparator's inputs. Voltages more negative than -300 mV should not be used.

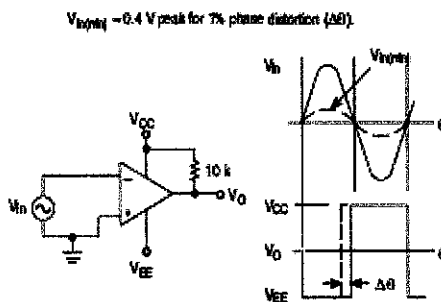


D1 prevents input from going negative by more than 0.6V.

$$R1 + R2 = R3$$

$$R3 \leq \frac{R5}{10} \text{ for small error in zero crossing}$$

Figure 9. Zero Crossing Detector (Single Supply)



$V_{in(pk)} = 0.4\text{ V}$ peak for 7% phase distortion ($\Delta\theta$).

Figure 10. Zero Crossing Detector (Split Supplies)