PIC CONTROLLED ROBOTIC DEVICE DRIVE SYSTEM

By

NUR AISHA WASIR HALIM

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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CERTIFICATION OF APPROVAL

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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.

NUR AISHA WASIR HALIM

ABSTRACT

The Final Year Project course is designed for students to perform research; design and development work in each discipline, to produce practical solutions. It provides opportunity for students to use the tools and techniques of problem-solving by engagement of the project. Under proper guidance of supervisor, the students will shape the direction in the field of interest as a preparation for approaching their desired career path in the near future, as well as gain better understanding of the responsibilities they have to shoulder when they undertake future projects. The objective of this project is to produce a storage/delivery autonomous robot which will operate in a production plant. The Scope of Study will cover areas of research done to fulfill design requirements of project with objective and its functionality. The areas of design requirements will include movement mechanism, electronic circuits, and programming. These subareas are developed and integrated for implementation of the workable robot. The project is divided into two phases; 1) intensive design research and 2) implementation and construction. Methodology and Project Work of this project is done by implementing a lot of research not only on the Internet but also literature review on scholars that have completed similar robotic design. The weekly Log Book and Progress Report is also compiled and summarized to present the author's progress so far. Consultation with supervisor and other FYP students had also aid in objective of completing the author's FYP. The author has also included flow chart of activities planned throughout the semester to ensure maximum progress of her FYP. The research taken with the methodology mentioned allows the author to fulfill progress of design requirements planned in completion of the robot with reference to the scope of study for the project. Progress and modification made throughout project are discussed in detail, to reflect objective of project. Future improvisation and recommendations are also suggested at the end for further research.

ACKNOWLEDGEMENTS

First and foremost the author would like to take this opportunity to express her appreciation to all the parties that is involved in making Final Year Project (FYP) a success. The undergoing of this project would have not been possible without the assistance and guidance of certain individuals and organization whose contributions have helped in its completion.

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CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

A robot is an artificial or virtual agent, which in the physical form gives the appearance of being alive. The artificial form (the physical agent) is an electro-mechanical or bio-mechanical device or group of devices that can perform autonomous or pre-programmed tasks while interacting with its surrounding environment using sensors. A telerobot may act under the direct control of a human, such as the robotic arm on a space shuttle, or autonomously under the control of a programmed computer. Robots may be used to perform tasks that are too dangerous or difficult for humans, such as radioactive waste clean-up, or may be used to automate mindless repetitive tasks that should be performed with more precision by a robot than by a human, such as automobile production.

Most importantly, robotics technology has offer aid to humans with various daily activities in both industrial and domestic applications. Manual human labor is replaced vigorously in heavy industries with long termed investment robotics that offer high precision workmanship with little error on the production line. Robotic technology is currently advancing to embed artificial intelligence to almost do anything a human requires in daily life from a pet dog robot to military surveillance robots.

1.2 PROBLEM STATEMENT

On a daily basis, there is a need to deliver load to its required drop off locations; i.e. to drop mails in respective destinations boxes in a post office, arrange stock in a supermarket, or even deliver printed documents from a LAN printer to its source/user. The robot has to be able to recognize the drop off location identification on these blocks collected at pick up point and later deliver them at their respective drop off points accurately without human supervision.

Either domestic or industrial use, the robot will be able to reduce human labor on tedious repetitive task (delivery and storage). However, cost seems to be a setback when dealing with robotics/automated systems, especially domestic or small scale usage. The success of designing an inexpensive delivery/storage autonomous robot would allow not only industrial users but home users too to utilize the autonomous delivery robot to ease repetitive storing task.

This has given the author the opportunity to design an inexpensive, free of human supervision delivery autonomous robot, for industrial use on a production plant. The autonomous robot will be able to pick up loads from a conveyor belt, and store the loads at its respective storage areas. With this, some of the criteria set for the mobile delivery robot are as the following. Also these criteria are used as a guide to outline the project objective.

1. The robot must not go out of the given scope of work area.
2. The robot must deliver/store all loads from pick up point/conveyor belt to its respective storage areas.
3. The robot must be able to avoid collision of obstacles along its pathway.
4. The robot must be cost effective and affordable.

1.3 OBJECTIVE

The objective of this project is to design and construct a robot which would be able to aid a production plant in industrial usage. The robot will deliver loads from a conveyor belt to multiple storage areas on a predetermined path within scope of work area. At the same time the robot will be able to detect obstacles and avoid collision along its pathway. Cost is to be minimize to achieve minimal expenses throughout project. Along with cost effectiveness, the implementation of the PIC microcontroller or PLC controller is favored. The PIC microcontroller is used, which is cost effective and easy to implement which in hope will arise the interest of university students in further development and implementation of robots as university projects or simply a personal hobby.

The first semester of the FYP is used up for preliminary research and the second half is used for actual design and construction while modifications are done along the way to improve initial design. Programming and integrating systems is also done during the second half of the semester to complete robot as a whole.

There are a few objectives need to be achieved by the end of project completion. The objective will be stated clearly as to make sure the success of the project implemented. The objectives of this project are as the following section.

1.3.1 To design a simple structure and movement mechanism for the robot

The design of the structure and movement mechanism of the robot is to be simple yet effective for easy troubleshooting purpose. The simple mechanism can also reduce the complexity of the programming of the robot and reduce cost.

1.3.2 To set up the boundaries of the working area of the robot

Setting up the boundaries of work area is essential for the robot in order to be able to meet its objective; which is to pick up load from a conveyor belt and deliver them to their respective drop off points on a predetermined path. Robot moving out of the specified boundaries would cause downtime and incur extra human labor cost to redo task.

1.3.3 To be able to avoid obstacle collision

The robot is desired to be able to take proactive measures of avoiding collision of obstacles along its path. Failure to do so will damage the robots body and the robot stagnant on that position due to the obstacle blocking its way thus, causing the objective of the robot unmet.

1.4 SCOPE OF STUDY

The scope of study can be divided into three subsections. In which interdependency and coordination between all three subsections must be developed to produce a functioning mobile robot.

1.4.1 Controllers and Programming

Controllers are the brain of the robot. There are various choices of controllers to choose from. However, the cost is a heavy factor for this project. Therefore, PIC microcontroller has been chosen to enable the robot to be cost effective where the programming language required for this controller is C Programming.

1.4.2 Electrical Circuits

Suitable sensors are needed for collision avoidance system. Also other electrical circuitry is required for proper navigation along its determined path, and proper function of mechanical devices and to supply regulated and stable power for the robot.

1.4.3 Robotic Movement and Mechanism

Motors and actuators are the "muscles" of the robot. Proper motors need to be selected for desired output and tasks. Three types of motors have been identified for the robot; Continuous Motors, Stepper Motors and Servo Motors.

1.5 THE RELEVANCY OF THE PROJECT

Robotics being an important creation with the evolution of technology offers great assistance to mankind in automation activities as briefed in the Background Study. This FYP offers the author a great exposure in technical application and design, in completion of her Electrical and Electronic Engineering Degree majoring in Instrumentation. With much guidance from Supervisor, the project allows the author to spark up her creative ideas to build an autonomous robot that can offer benefits to the society in various ways from daily chores at homes to delivering/store keeping tasks in a production line in a factory. The author's project will also allow a ground base for future undergraduates to further improve the function and design of the autonomous robot without going through much tedious basic 101 researches on building an autonomous robot.

1.6 FEASIBILITY OF THE PROJECT

The project is considered feasible based on the time given and also the abundance of information on robotic systems, which are available through the Internet as well as the resources from the library. With assistance of the supervisor and other undergraduates, completion study of the autonomous robot within the given time frame is made possible. Proper planning and methodology is applied to ensure success in completion of the author's FYP with reference of the Scope of Study outlined.

The first half of the project period was used to concentrate more on research and basic structure of the robot such as the structure, mechanism and power source. The second half semester in June 2007 of the project will be concentrated on the implementation of research done to complete the FYP within objectives stated. This includes building the structure, gripping and locomotion design, as well as pre-programmed recognition of path to deliver the blocks to its required destination. As completion of the robot is done, the author will make room for modification and alternation to original design based on the first semester's research in case of improvement or complication of any kind.

CHAPTER 2
LITERATURE REVIEW

2.1 OVERVIEW

Robots may include feedback driven connection between sense and action, not under direct human control. Responses may take form of electromagnetic motor or actuators (effectors) which may control arm, open or close grips. Control and feedback is provided by computer program which can be either external or internally inside the robot itself.

There are two basic ways of using effectors, in which the first, to move the robot around (locomotion) and the second, to move other object around (manipulation). The distinction divides the robotics into two mostly separate categories: mobile robots (moving) and manipulator robotics (grabbing).

2.2 HISTORY

The idea of artificial people dates back as the ancient legend of Cadmus, who sowed dragon teeth that turned into soldiers, and the myth of Pygmalion, whose statue of Galatea came to life. According to classical mythology, the deformed god of metalwork, Hephaestus, created mechanical servants, ranging from intelligent golden hand maidens to utilitarian three legged tables that could move about under their own power. [7]

Czech writer Karel Capek introduced the word "ROBOT" in his play RUR (Rossums's Universal Robots) in 1921, Robot in Czech comes from the word "robota" which means "compulsory labor". The earliest ideas that could be related to robotic is in 350B.C. by the Greek Mathematician, Archytas. He created a mechanical bird he called "The Pigeon" which was propelled by steam. [7]

The first recorded design of a humanoid robot was done by Leonardo da Vinci (1495). Da Vinci's notebook contained detailed drawing for a mechanical knight that was apparently able to sit up, wave its arms and move its head and jaw.

The first known functioning robot was created in 1783 by Jaques de Vaucanson, who made an android that played the flute. Many considered the first robot in the modern sense to be a teleoperated boat, similar to a modern ROV (Remote Operated Vehicle), designed by Nikola Tesla and demonstrated at an 1898 exhibition in Madison Square Garden. In the thirties, Westinghouse made a humanoid robot known as Electro, which was exhibited at the 1939 and 1940 World's Fairs. The first electronic autonomous robot was created by Grey Walter at Bristol University England in 1948. [8]

2.3 TYPES OF ROBOTS

Generally, the types of robots are divided into two categories in which:

1. Manipular robotics: Robots stationed in one location and able to move other objects such as the robotic arm for material sorting process.

2. Mobile robotics: Robots which are able to move about.

2.3.1 Industrial Robots (Manipulator robotics)

Typical industrial robots do jobs that are difficult, dangerous or which high repetition. They lift heavy objects, cut and shape fabricated parts, paint, chemical handling and perform assembly and inspection work. These robots are able to perform quality of work due to fatigue or weariness and they are able to operate for long hours. Industrial robots used in the market include:

Cartesian robot/Gantry robot

Used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding. The robot is normally mounted on a tract on the operation floor. The Cartesian robot is the familiar of x, y, and z axes of the machine tool.

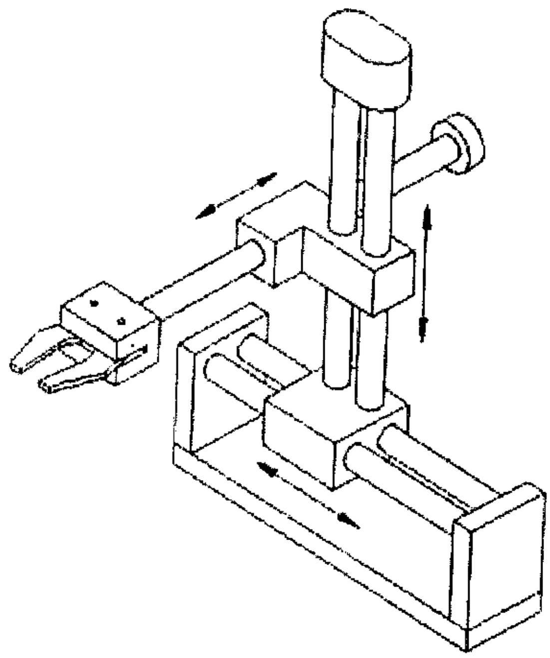

Figure 2.1: Diagram of a Cartesian robot (XYZ Robot).

Cylindrical robot

Normally used for assembly operations, handling at machine tools, spot welding and handling at die-casting machines. It is a robot whose axes form a cylindrical coordinate system. The movement of the joints of a cylindrical robot generates a work shape of a cylinder.

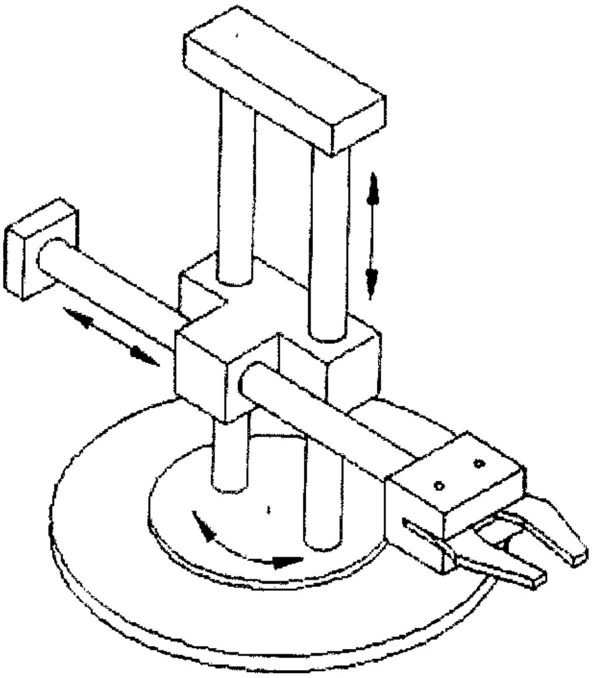

Figure 2.2: Diagram of a cylindrical robot.

Spherical robot

It is able to handle machine tools, spot welding, die-casting, gas welding, and arc welding. It is a robot whose axes for a polar coordinate system.

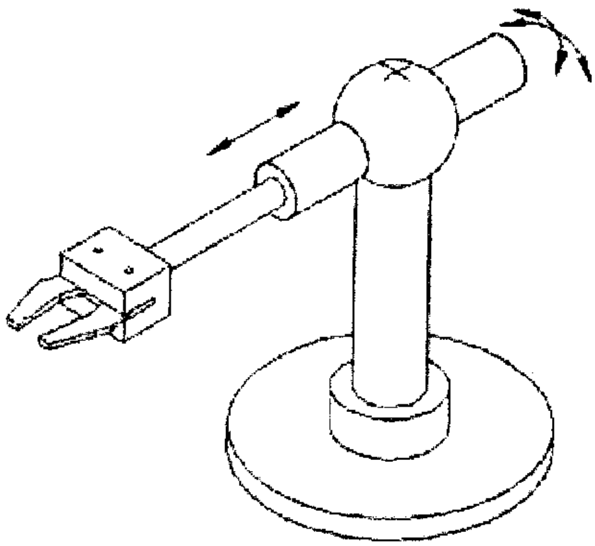

Figure 2.3: Diagram of a spherical robot.

SCARA robot

Popular for pick and place work, application of sealant, assembly operations and handling machine tools. A robot which has two parallel rotary joints to provide compliance in a plane. The name SCARA means Selective Compliance Assembly Robot Arm which was introduces in the late 1970 as a robot ideally suited for assembly task. One of the main reasons this robot excels is because of the Compliance feature it offers. "Compliance" is a robotic term what means that the robot or tooling is ca[able of adjusting to accommodate misalignment. [3]

Articulated robot

A robot which resembles a robotic arm, used for assembly operations, die-casting, fettling machines, gas welding, arc welding, and spray painting. It is a robot whose arm has at least three rotary joints.

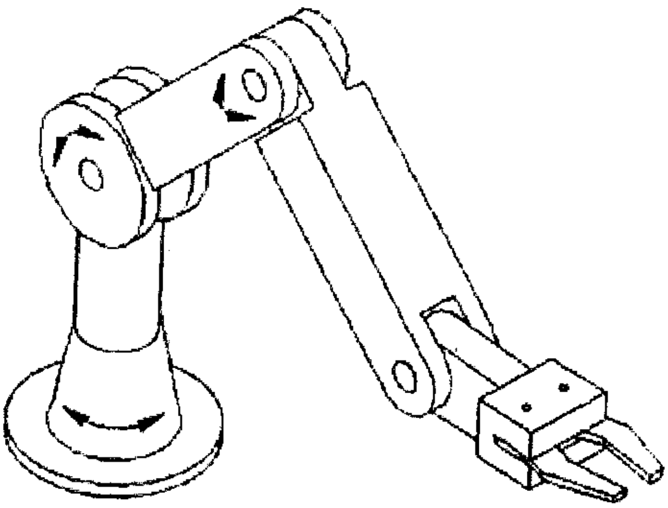

Figure 2.4: Diagram of an articulated robot.

2.3.2 Mobile Robots

The other types of robots used are the mobile robots. These robots unlike the industrial robots are able to move from one position to another. Such ability allows the robots to be used in various fields such as:

Replace human labor for long and tedious work (agriculture)

Farmers drive over a slow tractor for miles every year on the same ground. The slow speed and gentle land allow robot navigation techniques to be applied to this environment. Demeter, an automatic robot harvester, is a model for commercializing mobile robotics technology. The Demeter harvester contains controllers, positioners, safeguards, and task software specialized to the needs of commercial agriculture.

Investigation of hazardous and dangerous environments

The Pioneer robot is a remote reconnaissance system, used to perform structural analysis of the Chornobyl Unit 4 reactor building. It is a teleoperated mobile robot for deploying sensor and sampling payloads, a mapper for creating photorealistic 3D models of the building interior, equipped with tools for cutting and retrieving samples of structural materials thus, providing an alternative to replace humans from entering hazardous environments. [7]

Dante II, an eight-legged, tethered, robot descended into the active crater of Mt. Spurr, an Alaskan volcano 90 miles west of Anchorage. The robot's mission was to walk anonymously over rough terrain in harsh environment and determine the amount of carbon dioxide, hydrogen sulfide, and sulfur dioxide exists in the steamy gas emanating from fumaroles in the crater. With Dante II, many volcanologists are saved from having to enter the craters of the active volcanoes. [7]

Underwater exploration

Robotic underwater rovers are used to explore and gather information about many facets of our marine environment. Project Jeremy, is collaboration between NASA and Santa Clara University. An underwater telepresence remotely operated vehicle (TROV) was sent by scientist into the freezing Arctic Ocean waters to investigate the remains of a whaling fleet list in 1871. The TROV was cable operated, which carried power and instructions down to the robot and the robot returned video images. The TROV can also collect artifacts and gather information about the water conditions. [7]

Space robots

ROV is used for outer space terrain exploration. An ROV can be of different forms, such as an unmanned spacecraft that remains in flight, or a rover that can move over terrain once it has landed one of the best known ROV's is the Sojourner rover that was deployed by the Mars Pathfinder spacecraft. [7]

2.4 BUILDING THE BLOCKS OF ROBOTS AND AUTOMATION

Robots and automation is made up of various building blocks, in which are interdependent to each other for the successful implementation and function of the robot. Failure in one of these building blocks would affect the overall process of the automation. [3] The building blocks of a robot consist:

1. Controllers
2. Sensors and Transducers
3. Analyzers
4. Actuators
5. Drives

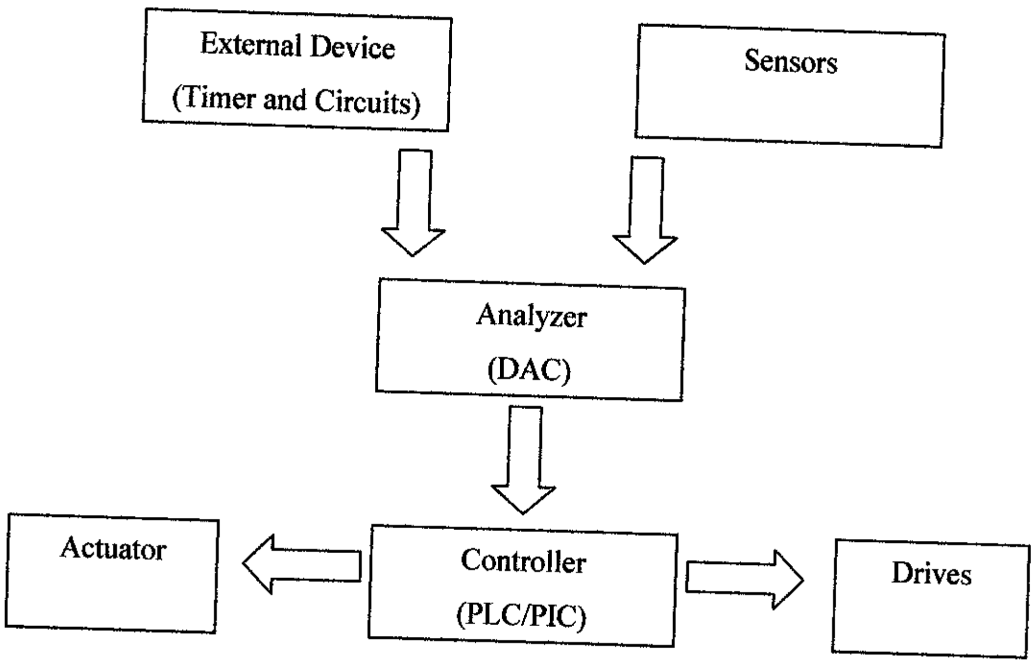

Figure 2.5: Building block components of robot and automation.

2.4.1 Controllers

These devices are known as the "brain" of the robot. It is able to define any action taken or to be performed according to the program set by the programmer. The controllers' purposes are to monitor the coordination of the system such that a desired behavior is achieved when an input is received.

Most common controllers used to control a robot are the PLC (Programmable Logic Controllers; normally used in large scale industries), Microcontrollers (such as the Programmable Input Controllers (PIC)). Data and information will be inputted to the controllers, processed according to the program defined and executed via the outputs.

2.4.2 Sensors and Transducers

They are devices that generates output signal for the purpose of sensing a physical phenomenon. The most familiar sensor of all is a manual switch. The switch is the link between a robot and a person who desires the robot to be turned on or off. Limit switch is another type of mechanical switch. Unlike the manual switch, the input for a limit switch comes the mechanism itself and is not controlled by the user. Limit switched can be used to limit the travel of a robot arm on any of it axes and motion. When the limit is reached, the circuit is opened that removes power from the axis of motion either directly or via the robot controller.

Another type of sensors is those that do not require physical contact. These proximity sensors are capable of sensing the presence of nearby objects without touching it. The proximity switches are such as infrared sensors (uses infrared light detect the presence of an object, not affected by ambient light), photoelectric sensors (uses light to detect presence of object, affected by ambient light) and the ultrasonic sensors (uses sounds for detection, sound bounces back when hits solid barrier and detected by the transducers).

2.4.3 Analyzers

The functions of analyzers are to register and analyze the output signals produced by sensors or devices. Analyzers for sensors may be of ADC (analogue to digital converter) in which is to convert data produced by the sensors to digital binary data understood by the robot.

2.4.4 Actuators

Once a real world condition is sensed and analyzed, something may be needed to be done. Actuators perform direct physical action for a particular process. The difference between actuators and drives is that actuators are limited to short linear discreet motion. Actuators may include solenoid and cylinders.

Cylinders are popular for pneumatic types and may be used in robots such as the gripper. The rod in the valve of the cylinder would extend when the air is pumped into the cylinder. The extended rod may be used as a switch to activate another push button, or just for mechanical joint extension used by pneumatic robot arms.

2.4.5 Drives

Like actuators, drives take some action upon the process at the command of the controller or to other analyzer. The difference between actuator and drives is that actuators are used to affect a short, complete, discrete motion (usually linear) and drives executes more continuous movements typically motors. Motors are the muscle of the robot; weather to move other objects or to move the robot itself. There are several types of motor normally used by robots, which are the stepper motors, DC continuous motors and the servo motors. Detailed discussions of these motors are explained later chapters.

2.5 CONTROLLERS

2.5.1 Programmable Logic Controller (PLC)

The PLC is a digitally operating electronic apparatus which uses a programmable memory for the internal storage of instructions by implementing specific functions such as logic sequencing, timing, counting, and arithmetic to control, through digital or analogue input/output modules.

2.5.2 Programmable Input Controller (PIC)

The PIC microchips are used for embedded designs. The Microcontroller is able to perform various functions according to the user programming codes (Assembly Language/C Programming). The microcontroller is able to perform task which is once difficult to be implemented on normal logic circuit.

Table 2.1: Comparison between wired logic, PLC and PIC controllers.

	Wired Logic	PLC	PIC
Control Device (Hardware)	Specific purpose	General purpose	Specific purpose but programmable
Control Scale	Small and medium	Medium and large	Small sale is likely to succeed
Change or Addition of Specification	Difficult	Easy	Moderate (depends on the programming skills of the user)
Delivery Period	Several days	Almost immediate	Almost immediate

Maintenance	Difficult	Easy	Moderate
Reliability	Depend on design and manufacturer	Very high	Not able to withstand industrial environment
Economic Efficiency	Advantage on small scale operation	Advantage on small, medium and large scale operation	Cheap

2.6 ROBOTICS FUNDAMENTAL ON LOCOMOTION

2.6.1 Fundamental of Robotic Mechanical System

Rolling robots are under the autonomous mobile robot category. The focus is on robots meant for tasks on horizontal surface, in which their platforms undergo planar motion, which simplifies their kinematics. Rolling robots are basically of two kids, depending on whether they are supplied with conventional or omni-directional wheels. Robots with conventional wheels have two degrees of freedom motion while robots with omni-directional wheels are capable of three degrees of freedom motion which increase their maneuverability substantially.

2.6.2 Robots with Conventional Wheel

These robot have only two degrees of freedom, therefore, they only need two actuators. The example below is taken from *Fundamentals of Robotic Mechanical Systems (Theory, Methods and Algorithms) written by Jorge Angeles.* The coaxial wheels are coupled to the chassis and revolute of axes passing through points 0_1 and 0_2. [5]

The orientation of the steering wheel is defined by ψ, is controlled by the second actuator. The design has a few drawbacks:

1. Two motors serving two essentially different task requires different operational characteristics, in which both may not be available from the same manufacturer.
2. Power motor requires velocity control, steering motor for position control therefore giving rise to two independent control systems that may end up by operating in uncoordinated fashion.
3. Differential gear train increase cost, weight and bring out inherent backlash of gears.

2.6.3 Differential Wheels vs. Caster Wheel Mobile Robot

Differential drive robots have more advantage over caster wheel type and tricycle type robots. Relative to the global coordinate system, the robot can be position anywhere specified by two coordinates of x and y and pointed in any direction specified by a third coordinate, angle θ. [4]

Robots with caster wheels however, the degree of freedom of the robot is limited to two parameters; the steering angle, α and the total distance it travels, S. Therefore, the robot's orientation and position are coupled. The robot must move forward or backward in order to turn. The robot cannot go directly from one position/orientation to another. The robot must follow some path and would be complicated with the presence of obstacle.

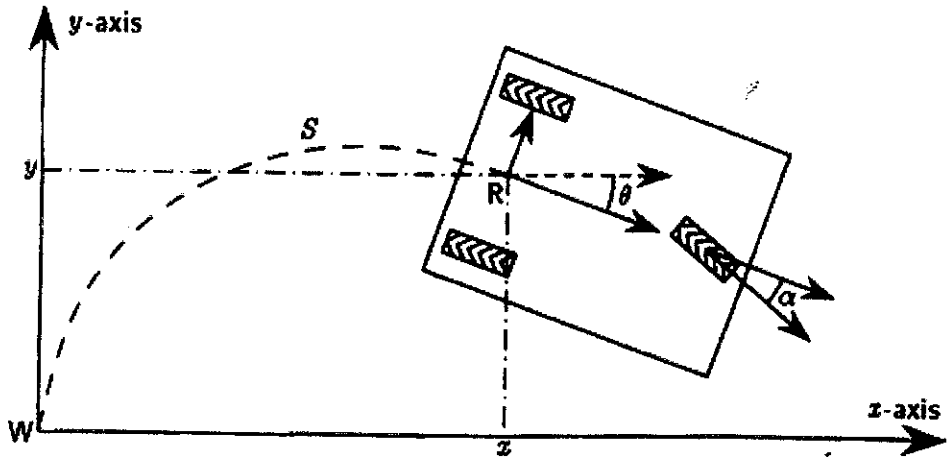

Figure 2.6: Kinematics of a caster wheel drive mobile robot.

As shown in Figure 2.7, the differential drive robot has more flexibility in reaching the desired position and orientation. The caster wheel drive requires turning forward and backward motions in order to reach desired position and orientation. The differential drive method is therefore chosen for this robot as it is easier to implement and the amount of flexibility is much more as compared to the mobile robot with caster wheel drive.

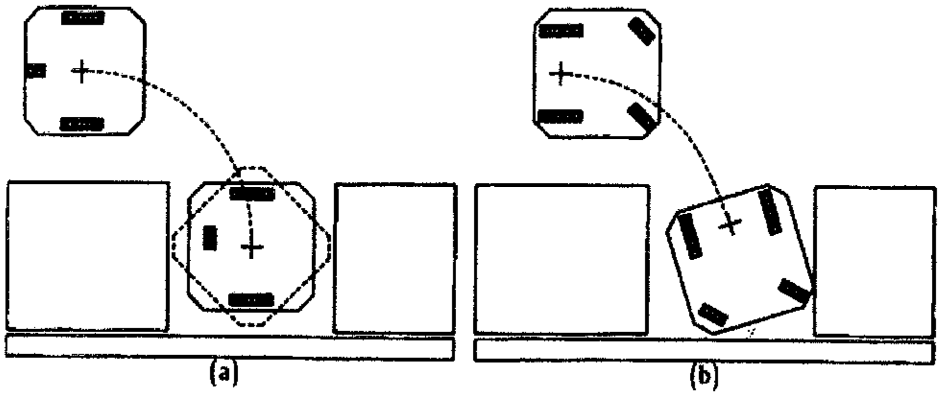

Figure 2.7: Comparison of (a) differential drive and (b) caster wheel drive kinematics using parallel parking example.

2.7 MECHANICAL DRIVES

2.7.1 Choosing the Right Motor for the Job

Motors are the muscle of robots, when attached to a set of wheels, robots are used as legs. When attaching a motor to a lever, they serve the purpose as a shoulder joint to move up and down. There are many types of motors:

DC motor: The common motor normally used to drive continuously in one direction. It only stops when the power supply is removed.

Stepper motor: Application of power causes the shaft to rotate a few degrees and then stop. Continuous rotation of the shaft requires the power to be pulsed to the motor.

Servo Motor: Strong motors normally used as joints for robots. It can only move 180 degrees in direction.

2.7.2 Motor Specification

Voltage

All motors are rated by their operating voltage. Small hobby motors usually range from 1.5 V to 12 V. Most motors can be operated satisfactorily at voltages higher or lower than that specified. However, most motor is likely to operate 50 percent of the specified rating. Running a motor continuously at more than 30 or 40 percent of its rated voltage is not recommended. The windings will overheat which may cause permanent damage.

Current Draw

It is the amount of current (amp or milliamps) in which the motor requires from the power supply. Current draw however, increases with load. A point is reached when the motor does all the work it can perform, and no more current will flow through it. The shaft stops rotating; the motor has stalled. Therefore, when building a robot, the load (weight) must be including under consideration.

Speed

The rotational speed of a motor is given in revolution per minute (rpm). The speed of the motor could be increased or decreased using 2 methods; building a bigger motor (impractical) or add gear reduction.

The speed always decreases when going from small to large gear.
The speed always increases when going from large to small gear.

Therefore, if there is a need to reduce the speed of motor from 5000 rpm to 50 rpm, the speed reduction would require a reduction ration of 100:1. This would require a drive gear of 10 teeth and a driven gear of 1000 teeth.

2.7.3 Torque

Torque is the angular force that a motor can deliver at a certain distance from the shaft. A 5 oz-in of torque with a distance of 1 inch away from the shaft of the motor, it is strong enough to pull up a weight of 5 ounces using a pulley. Metric units normally specify torque in terms of Newton-meters (Nm). [4]

$$1N = 1\frac{kg - m}{sec^2} = 0.225lb$$

Electrical power is converted to mechanical power in motor. The relationship involves power (in watts) and energy (in joules). Power is the rate of energy used. Therefore, power is represented by

$$1Watt = 1\frac{Joule}{sec}$$

The electrical power supplied to the motor, Pe, equals the voltage, V, across the motor's terminal multiply with the current, I, through the motor. Current measured in the unit of amperes is the amount of charge passing through a conductor per second: [4]

$$P_e = VI$$

$$1\,Ampere = 1\,\frac{Coulomb}{sec}$$

$$1\,Watt = 1\,Volt\ \times Ampere = 1\,Volt\ \times \frac{Coulomb}{sec}$$

Mechanical power, Pm, equals the torque, T, output by the shaft multiplied with its angular speed, ω (torque is taken in Newton Meters):

$$P_e\ = T\omega$$

$$\frac{2\pi rad}{sec} = 1\,\frac{rev}{sec}$$

$$1Watt = 1\,\frac{Nm}{sec}$$

Since power is energy per unit time, this shows that one joule energy can be expressed in two ways; either as 1 Newton meter or 1 Coulomb Volt. This is just reaffirming the fact that energy is energy whether it comes from mechanical origin or electrical origin. [4] The motor is just a transducer transforming energy to one form from another.

$$1\,\mathrm{J} = 1\,Nm$$

$$1\,\mathrm{J} = 1\,CV$$

2.7.4 Motor Model

The relationship describing the electrical power to mechanical power in permanent DC motor was described previously. The mechanical output power (due to the losses from friction, wind, heating in the coils) will be some fraction of the electrical input power. [4] The percentage is given as efficiency, η where:

$$P_m =\ \eta P_e$$

The rotor coil is essentially an inductor with a resistance R. When rotor is turning, the commutator segment sliding past the brushes create an alternating current in the armature winding. A changing current, $\frac{di}{dt}$ through an inductor induces a voltage across it:

$$v = L\frac{di}{dt}$$

Where L is the proportionality constant called the inductance. As the motor turns, voltage is inducted and opposes the applied voltage. The faster the motor turns, the more the current switches direction, this the larger the inducted voltage becomes. Thus, it tends to limit the current through the resistor R.

When current fails, the less flux is created around the conductor, and the torque also falls. Therefore, when speed increases, the torque decreases.

The rotating motor can be modeled by the induced voltage, e (back electromagnetic force) and the winding resistance R. The applied voltage is related to the back-emf and current:

$$V = IR + e$$

When motor is not rotating, e = 0V and the current through the motor is equal to the motor applied drive voltage divided by the resistance. The current required to start the motor from zero speed is called the starting current/stall current, Is.

$$I_s = \frac{V}{R}$$

When the rotor is rotating, e increases proportionally with the speed of the armature;

$$e = k_e\omega$$

When k_e is called the back-emf constant, the applied voltage is then related to the current and the armature speed by:

$$V = IR + k_e\omega$$

The negative feedback provided by the back-emf causes the motor to settle to a steady state operating point of speed and torque as determined by the load and the applied voltage. The torque increases linearly with current with proportionally constant k_t (torque constant):

$$T = k_t I$$

Solving for I and plugging into the equation above:

$$V = \frac{TR}{k_t} + k_e\omega$$

k_t is actually equal k_e. This can be seen from the fact that the mechanical power output by the shaft will be the electrical power input, minus the I^2R losses due to heating in the resistor:

$$P_m = P_e - I^2R$$

$$T\omega = VI - I^2R$$

Replacing the equation from T and V

$$k_tI\omega = (IR + k_e\omega)I^2R$$

gives,

$$k_t = k_e = k$$

The applied voltage is then related to the torque and speed by constant k:

$$V = \frac{TR}{k} + k\omega$$

The speed-torque relationship is linear with the negative slope:

$$\omega = -\frac{R}{k^2}T + \frac{V}{k}$$

2.7.5 Determining the amount of power needed for the motor

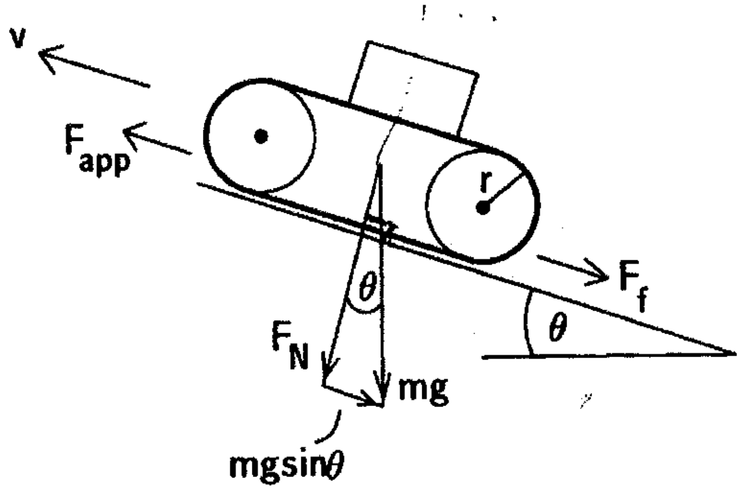

Figure 2.8: Free body diagram of a mobile robot and the forces as the vehicle climbs a hill.

Assuming that the mobile vehicle is a different drive mechanism (two motors) and need to climb a ramp of angle θ at a constant velocity v. The free-body diagram makes explicit the force acting on the vehicle. [4]

Since the vehicle moves at a constant velocity, there is no net force on the car:

$$F = ma$$

Since the acceleration a, is 0 (the car moves at a constant velocity), the net force F must be 0. Thus, the applied force F_{app}, from the wheels acting in the direction up the hill must balance the force down the hill resisting that force. The resisting forces are the friction force and the force that is the component of the vehicle's weight acting in the direction down the hill. [4]

$$F_{app} = F_f + F_w$$

Where F_f is the coefficient of friction, μ multiplied with the normal force, FN:

$$F_f = \mu F_N = \mu mg\ cos\theta$$

F_w is the mg sin θ (where mg, mass multiplied with acceleration due to gravity is the weight of the robot)

$$F_{app} = \mu mg\ cos\theta + mg\ sin\theta$$

The power required from the motor is the product of the force that needs to be applied by the wheels times the velocity, v the robot travel up the hill.

$$P_m = F_{app}v$$

The torque and speed requirement of each motor can be calculated from:

$$\frac{P}{2} = T\omega$$

$$\omega = \frac{v}{r}$$

2.7.6 *Robot Locomotion with DC motors*

Most robot designs use two identical motor to spin two wheels. These wheels provide forward and backward momentum, as well as left and right steering. Stopping one motor, would allow the robot to change direction. Reversing both motors in relative to one another, robot turns by spinning on its wheel axis. This would cause sharp right and left turns.

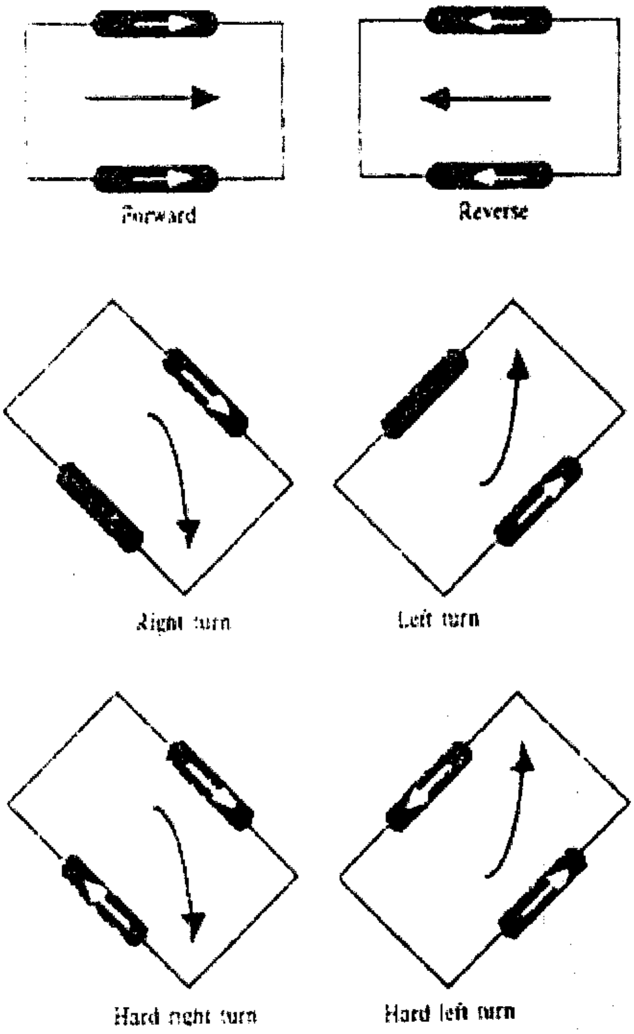

Figure 2.9: Direction of mobile robot with differential drive locomotion.

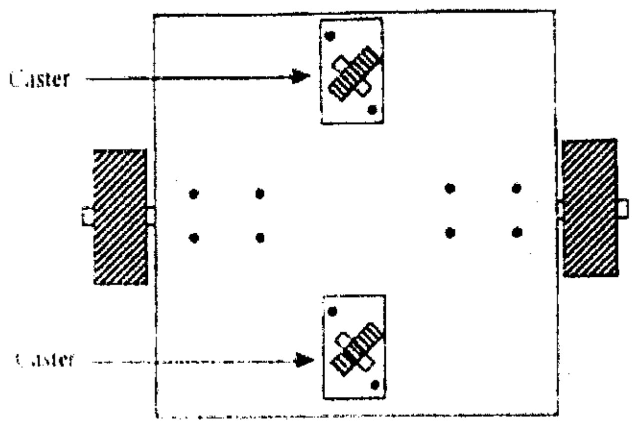

Figure 2.10: A two wheeled differential drive mobile robot with caster installed.

Method for calculating travel speed of the robot:

1. Divide the rpm speed of the motor by 60. The result is the revolutions of the motor per second (rps). Example: A 100 rpm motor runs at 1.66 rps.
2. Multiply the diameter of the drive wheel by pi (π = 3.124). Example: A 5 cm diameter wheel would have a circumference of about 15.71 cm.
3. Multiply the speed of the motor (rps) with the circumference of the wheel. The result would be the number of centimeters covered by the wheel in one second.
4. The heavier the robot, the slower the motor will turn (depending on the torque).

2.7.7 Robot Locomotion with Stepper Motors

Stepper Motors

DC motors are cheap and able to deliver a lot of torque for their size. However, the common dc motor is rather imprecise because there is no servo feedback mechanism or tachometer. It is impossible to command the motor to turn exactly a specified number of revolutions and also fraction of a revolution. Stepper motors are dc motors with slight difference: instead of being powered by a continuous flow of current, as with regular dc motors, they are driven by pulses of electricity. Each pulse drives the shaft of the motor a little bit. The more pulse that is fed to the motor, the more the shaft turns. [8]

Inside a stepper motor

A four phase stepper motor is really two motors switched together. Each motor is composed two windings. Wire connects to each of the four windings of the motor pair, so there are eight wires coming from the motor. The common from the windings are often ganged together, which reduces the wire count to five or six instead of eight.

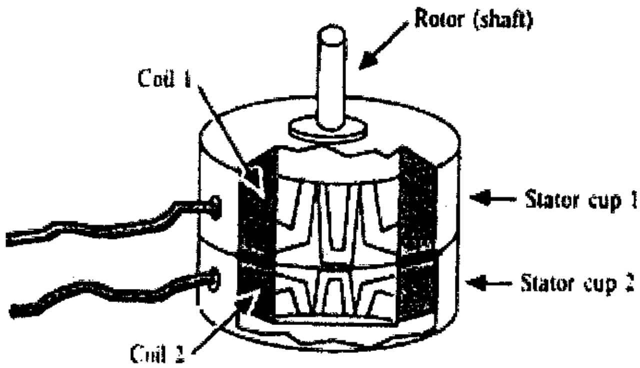

Figure 2.11: Illustration of a Stepper motor and components that make up a stepper motor.

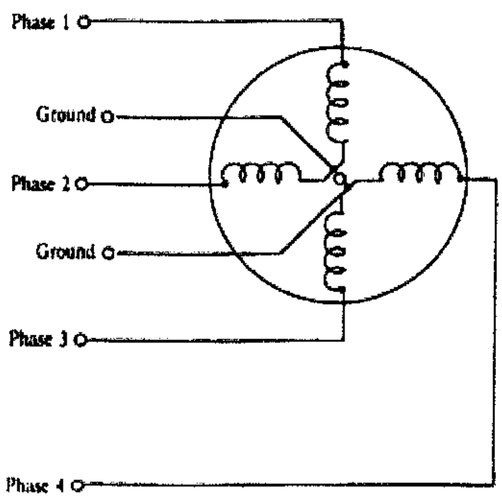

Figure 2.12: Schematic diagram of the Stepper motor.

Wave Step Sequence

The motor shaft turns a fraction of a revolution each time a winding is energized. For the shaft to turn properly the winding must be energized in wave step sequence

(energized wires 1, 2, 3 and 4)

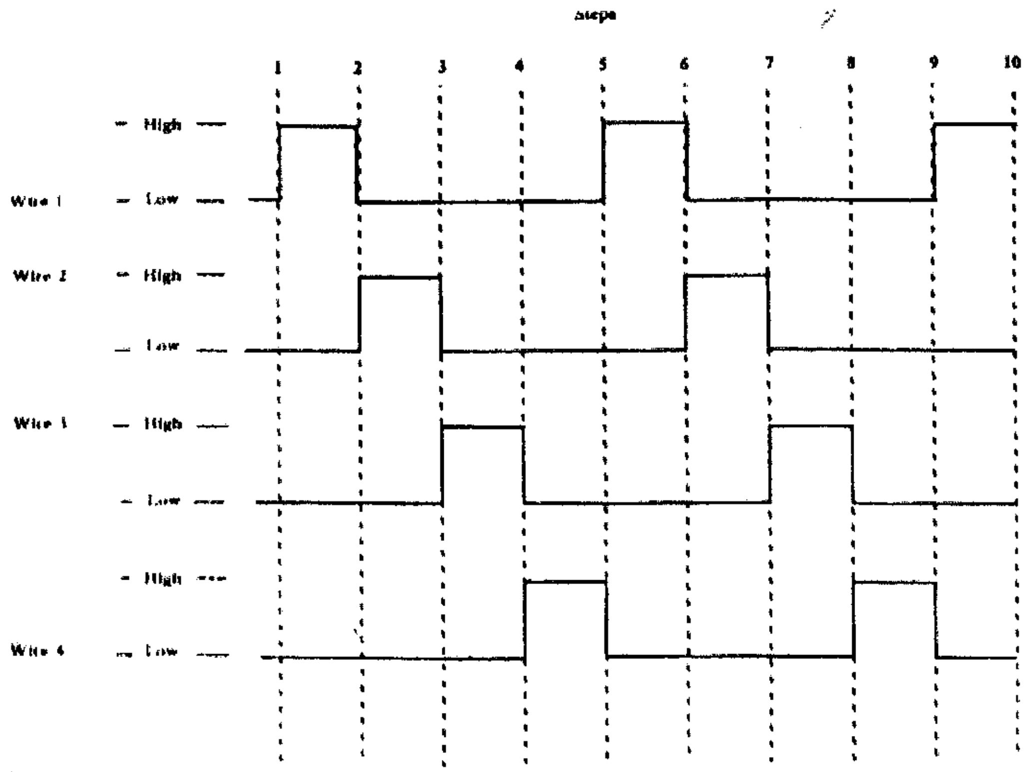

Figure 2.13: Basic wave-step actuation sequence of four-phase stepper motor.

Double-On / Double-Off Sequence

Wave step sequence is the basic actuation technique for a four-phase motor. A better approach would require actuating two winding at one in both-on/ both-off sequence increasing the driving power of the motor. This provides greater shaft rotation precision. Other varieties of stepper motors would require actuating in different ways.

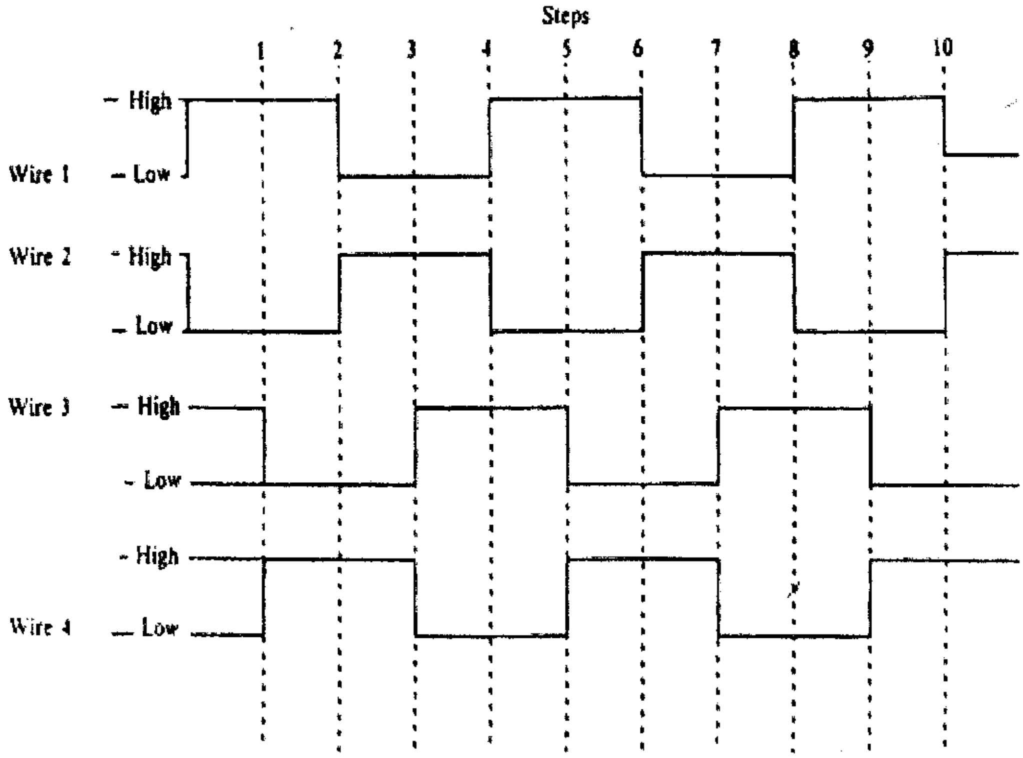

Figure 2.14: The double-on/double-off actuation sequence of four-phase stepper motor.

2.7.8 Stepper Motor Specification

Stepper Phasing

A four-phase stepper requires a sequence of four pulses applied to its various winding for proper rotation. Most stepper are at least 2 phase, however majority are 4 phase and six phase. Usually the more phases in a motor, the more accurate they are.

Step Angle

Stepper motors vary in the amount of the rotation the shaft turns each time a winding is energized. The amount of rotation is called "step angle" and can vary from as small as 0.9 degrees (1.8 degree is more common) to 90 degrees. The step angle determines the number of steps per revolution. A stepper with a 1.8 degree step angle must be pulsed 200 times for the shaft to turn one complete revolution. A stepper with a 7.5 degree step angle instead must be pulsed 48 times for one revolution.

Pulse Rate

The smaller the step angle, the more accurate the motor. But stepper motor has an upper limit to the number pulses they can accept per second. Heavy duty steppers usually have a maximum pulse rate of 200 to 300 steps per second providing 60 to 100 rpm. Small steppers can accept 1000 or more pulses per second but they do not provide much torque and are not suitable as driving or steering motors.

An interesting point to note is that stepper motor cannot be motivated to run at their top speed immediately from a dead stop. Applying too many pulses directly from a battery causes the motor to freeze up. To achieve top speed, the motor must be gradually accelerated. In terms of human motion, the acceleration can be quite swift. The speed can be 1/3 for the first milliseconds, 2/3 on the next 50 to 75 milliseconds and full speed later on.

Running Torque

Steppers may not be able to deliver as much torque as dc motors for the same size and weight. In comparison, a typical 12 volt medium sized stepper motor may have torque of 25 oz-inches. The same 12 volt medium sized standard dc motor may have running torque three or four times more.

Steppers are at their optimum performance when turning slowly. With stepper, the slower the motor revolves, the higher the torque. DC motor however, is opposite from this situation, in which the higher the speed, the better the torque.

Braking Effect

Actuation of one of the winding in a stepper motor advances the shaft. Continuous input of current to the winding and the motor would not turn anymore. The shaft would be locked as if the breaks were applied on to them.

2.7.9 Servo Motor Application for Robot Arm

A Servo is a small device that has an output shaft. This 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. In practice, servos are used in radio controlled airplanes to position control surfaces like the elevators and rudders. They are also used in radio controlled cars, puppets, and of course, robots.

Figure 2.15: A servo.

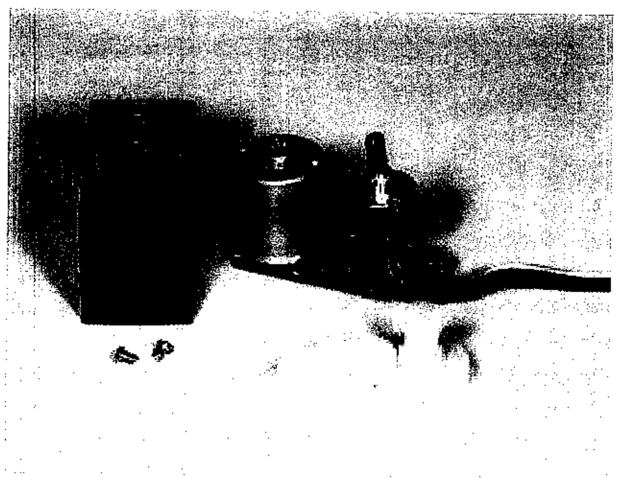

Figure 2.16: A dissembled servo.

The servo motor has some control circuits and a potentiometer (a variable resistor, also known as pot) that is connected to the output shaft. In the Figure 2.16, the pot can be seen on the right side of the circuit board. This pot allows the control circuitry to 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 of travelling somewhere around 180 degrees. Usually, it is somewhere in the 210 degree range, but it varies by manufacturer. A normal servo is used to control an angular motion of between 0 and 180 degrees. A normal servo is mechanically not capable of turning any farther due to a mechanical stop built on to the main output gear.

The amount of power applied to the motor is proportional to the distance it needs to travel. So, if the shaft needs to turn a large distance, the motor will run at full speed. If it needs to turn only a small amount, the motor will run at a slower speed. This is called proportional control.

The control wire is used to communicate the angle. The angle is determined by 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, for example, 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 degress. If the pulse is longer than 1.5ms, the shaft turns closer to 180 degress.

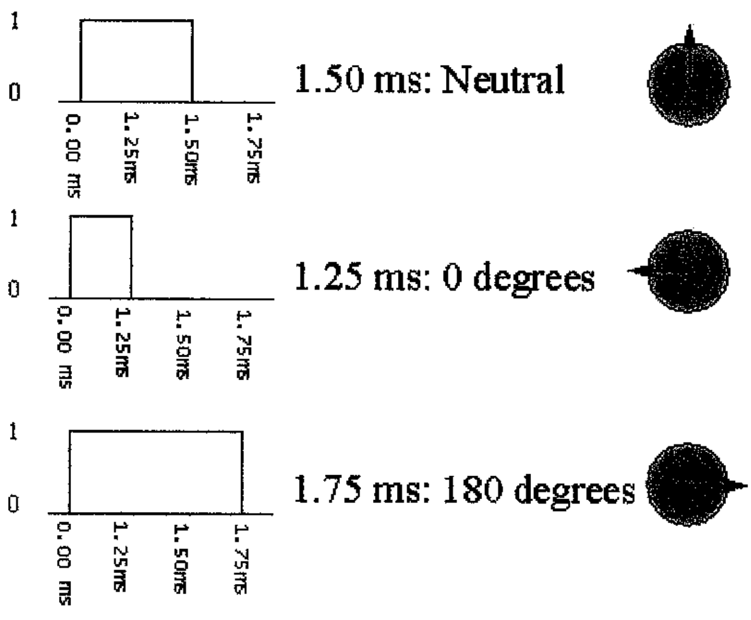

Figure 2.17: Angle of output shaft dictated by duration of the pulse.

As seen in the picture, the duration of the pulse dictates the angle of the output shaft (shown as the green circle with the arrow). Note that the times here are illustrative and the actual timings depend on the motor manufacturer. The principle, however, is the same.

2.8 ELECTRONIC CIRCUITS

2.8.1 Collision Avoidance and Detection

There are two different types of detection system. Collision Detection is a form of Passive detection, where the robot only changes direction after it has collided into an obstacle along its path. Collision Avoidance however, is more towards an Active detection system. The system would detect an obstacle from a defined distance (dependant of sensitivity of the sensors), and changes course of direction before collision.

Infrared light

Light may always travel in a straight line but it bounces off nearly everything. This is advantageous to build an infrared collision detection system. The circuit below in Figure 2.18 is an example on how the infrared LED and phototransistors can be mounted on the top of the robot for the purpose of detecting obstacle like a wall or an object in its path. The set point adjustment, R2, Provides means to increase or decrease sensitivity of the circuit. Increase in sensitivity would allow the robot to be able to detect objects future away. The circuit recommended below has an effective range of 6 inches.

Objects reflect light in different ways. Light bounces better on white colored surfaces compared to black. The phototransistor must also be blocked from direct light of the LED, as seen in Figure 2.18.

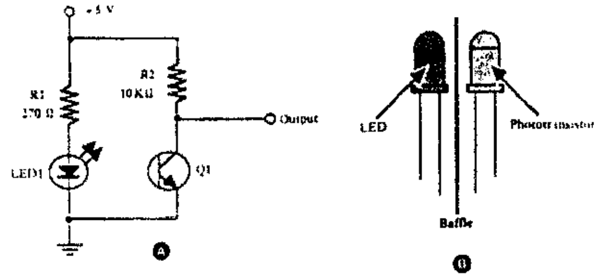

Figure 2.18: (A) Proximity detector using infrared light circuit diagram and (B) LED/Phototransistor Placement.

Ultrasonic Sound

Sound can be used to detect the proximity of objects in much the same as for infrared light. Ultrasonic sound is transmitted from a transducer, is reflected by a nearby object, and then received by another transducer. The advantage of using sound is that it is not sensitive to objects of different color and light reflective properties. However, there are materials that reflect sound better than others, and some even absorb sound completely. In comparison, proximity detection with sound is more fool proof.

The circuit below provides a practical circuit for building ultrasonic proximity detector. A stream of 40 kHz pulses is produced by a 555 timer wired up as an astable multivibrator. The output of the 555 provides more than enough power for the transducer. A piece of foam between the transducers is needed to eliminate direct interference between the two.

The advantage of using ultrasonic is that it is particular about the frequency of sound. Specifically, it is desired to limit the sensitivity of the circuit to 40 kHz, the same as the output of the transmitter. A 567 tone decoder IC is connected to the output of the 741 amp.

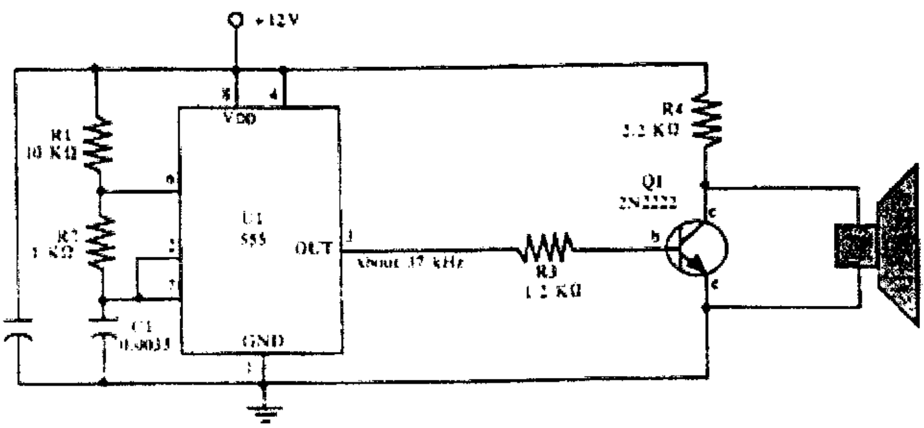

Figure 2.19: Schematic of 40 kHz ultrasonic transmitter.

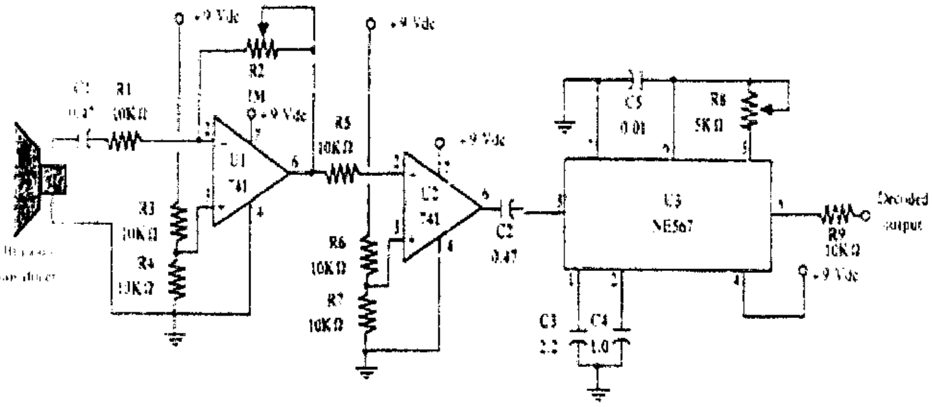

Figure 2.20: Schematic for an ultrasonic receiver and tone decoder.

2.8.2 Direction Control

Relay Control

This method is slightly old fashioned compared to the other alternatives. However, they are less expensive than the other methods, easier to implement and takes up less space. The relay may wear out in time (after a few hundred thousand switching.)

This direction control system however, does produce a centre-off position, in which the motor receive no power and does not move. The diagram below shows a simple motor switching circuit. Input to the relay would trigger both the motor to operate.

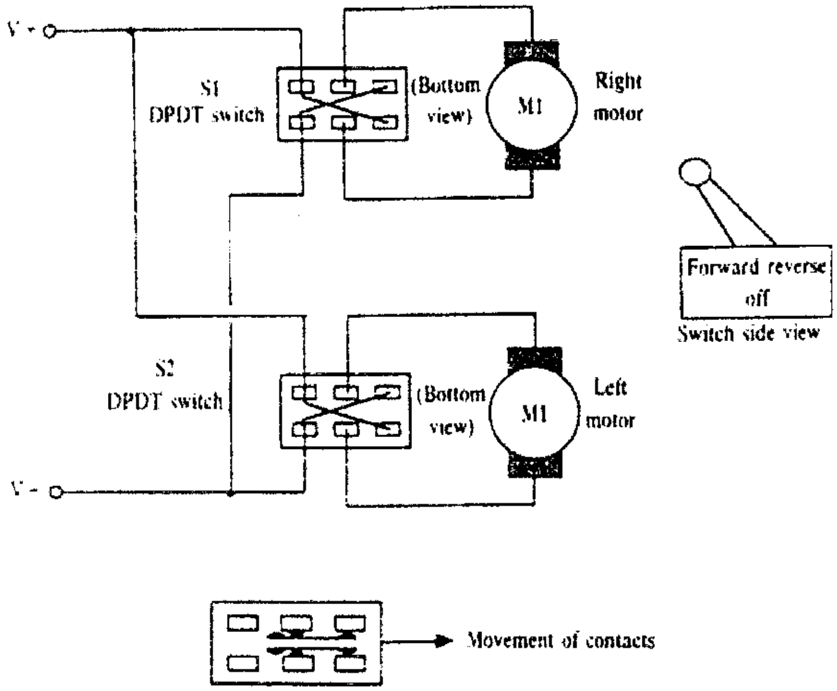

Figure 2.21: A relay controlled motor circuit.

Transistor

Transistors provide true solid state control of motors. The motor is connected so that when one transistor is switched on, the shaft turns clockwise. When the other transistor turns on, the shaft turns counter-clockwise. When both transistors are off, the motor does not turn. The amount of voltage required depends on the voltage the motor requires. However, for this motor control, both motors cannot be turned on at the same time. Doing so will cause damage to the transistors.

Resistors used to bias the base of each transistor are necessary to prevent the transistors from pulling excessive current from the gate controlling it (computer port, microcontroller or logic gates.) Without resistors; the gate would overheat and be destroyed. The actual value of the resistor depends on the voltage and current draw of the motor, as well as the characteristics of the transistors used.

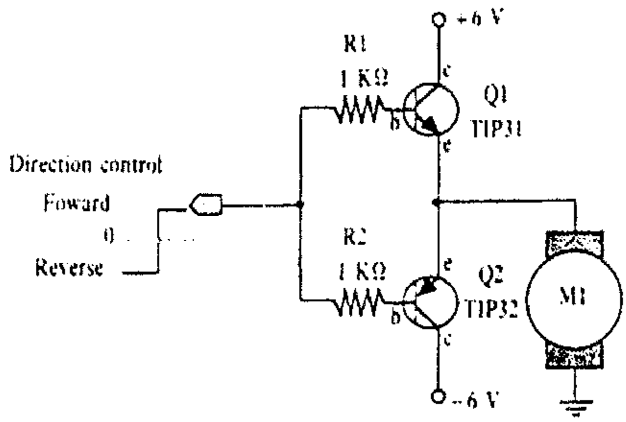

Figure 2.22: A transistor controlled motor circuit.

The diagram below shows the "H" network which is wired such a way that only two resistors are on at a time. When transistor 1 and 4 are activated, the motor turns in one direction. When transistor 2 and 3 are on, the motor spins the other way. When all transistors are off, the motor remains still.

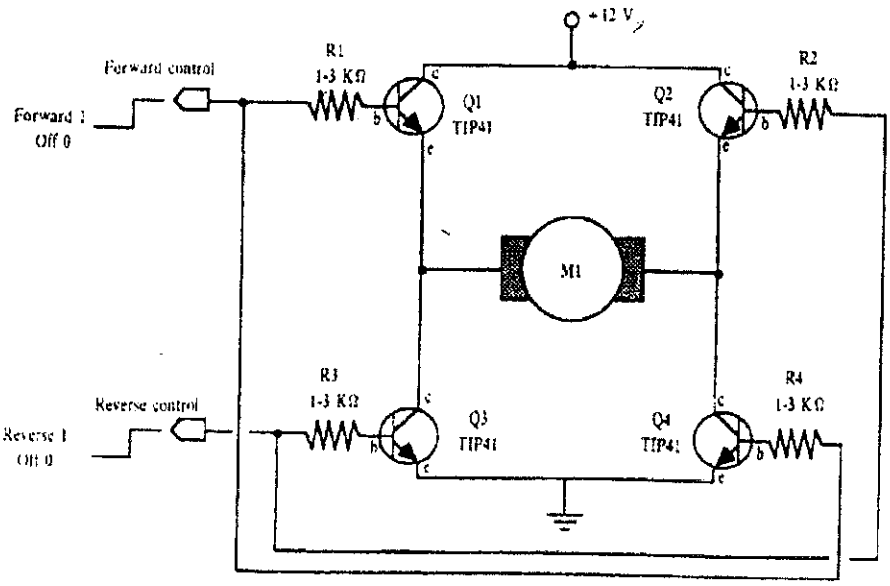

Figure 2.23: An H-bridge motor control circuit.

There is a special type of transistor, which is the power MOSFET (Metal Oxide Semiconductor Field Transistor.) The power MOSFET is able to handle higher current and voltage to drive the motors without worrying about burning and frying the component.

The diagram below uses power MOSFET to drive the motor system. The circuit is controlled by a NAND CMOS gate for positive action control. [8]

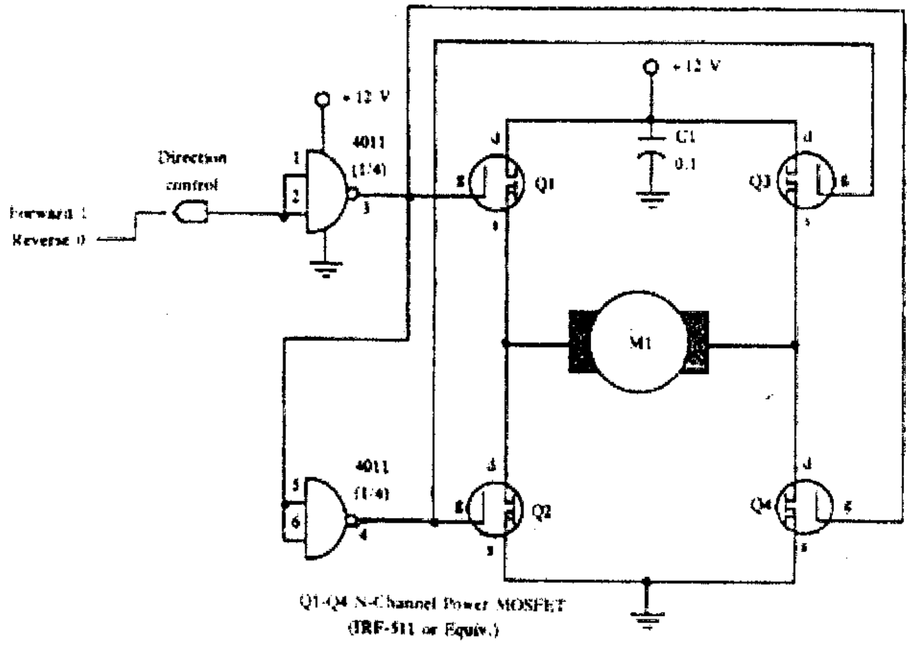

Figure 2.24: Diagram of power MOSFET and H-bridge motor control circuit using power MOSFET.

2.8.3 Location Tracking on Work Area

Wheel Encoder Design

One of the simplest forms of position measurement where the position of a robot is determined based on measurements of the distance traveled by each wheel of the robot. This information, when combined with knowledge of the robot's physical properties (i.e. its kinematics) allows one to deduce the current position and heading.

The process of measuring the rotation of the wheel of a robot is an example of odometer, and a sensor capable of such measurements is the digital optical encoder or, simply, encoder.

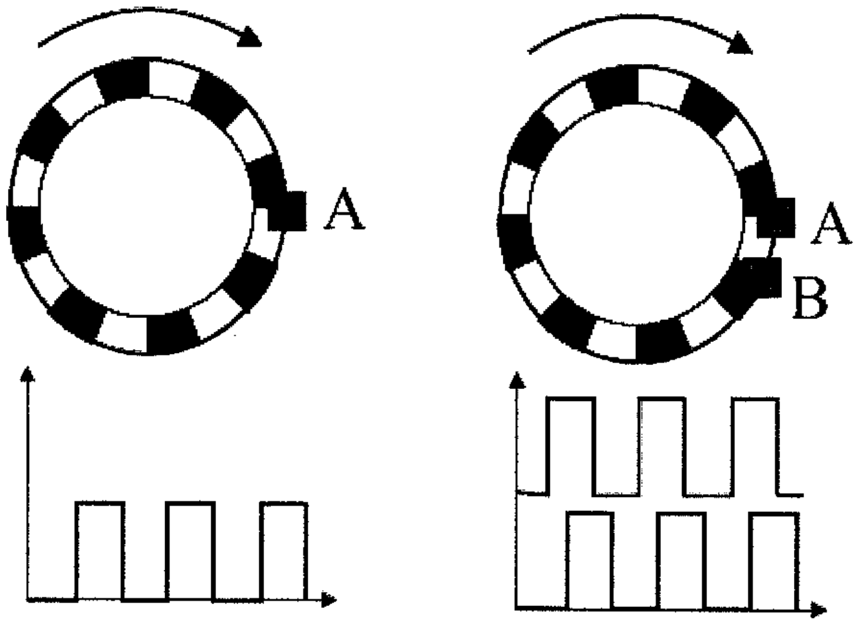

Figure 2.25: Encoder with single and two detectors.

Essentially, an encoder is a disc made of glass or plastic, with shaded regions that regularly interrupt a light beam. In Figure 2.25, the left panel shows a simple encoder, with a single detector (A), which measures the interruptions of a light beam, producing the curve shown below the encoder. In the right panel, two detectors are used, making it possible to determine also the direction of rotation.

By counting the number of interruptions, the rotation of the wheel can be deduced, as shown in the left panel of Figure 2.25. However, in order to determine also the direction of rotation, a second detector, placed at a quarter of a cycle out of phase with the first detector, is needed (such an arrangement is called quadrature encoding, and is shown in the right panel of Figure 2.25).

Line Tracking Implementation

The line tracking is an implementation of three infrareds to detect a white/black line on a contrasting surface. The infrared light operates the same way as of the collision avoidance and detection system, where the object here is merely a white line ideally on a darker surface. The concept of light being reflected on a lighter surface as to of a darker surface is used into implementation for the line tracking design. Also highlighted, the white line on work area ideally needs to be off same width. Below is a line tracker circuitry. The line tracking circuitry will make use of three IR emitters on the white line. The theory behind line tracking is actually pretty simple. An infrared LED is paired with an infrared detector (Figure 2.18). The LED is illuminated and directed to the surface where the line is to be detected. The detector is biased on and fed into a comparator to clean up the signal. In order to keep the electronics as simple as possible a 74HC14 Schmidt-trigger hex inverter will replace the comparator circuitry. The very high input impedance, built in hysteresis and low parts count makes the CMOS version an excellent alternative. The outputs go low when the LED/IR Detector pair is positioned over a black surface and high when positioned over a white surface. If the center sensor sees the line, go forward. If the left sensor sees the line, turn left. If the right sensor sees the line, turn right. Part of the programming should allow the robot to remember which sensor saw the line last and continue to make corrections in order to negotiate turns where the line will be out of the sensors view for a limited amount of time.

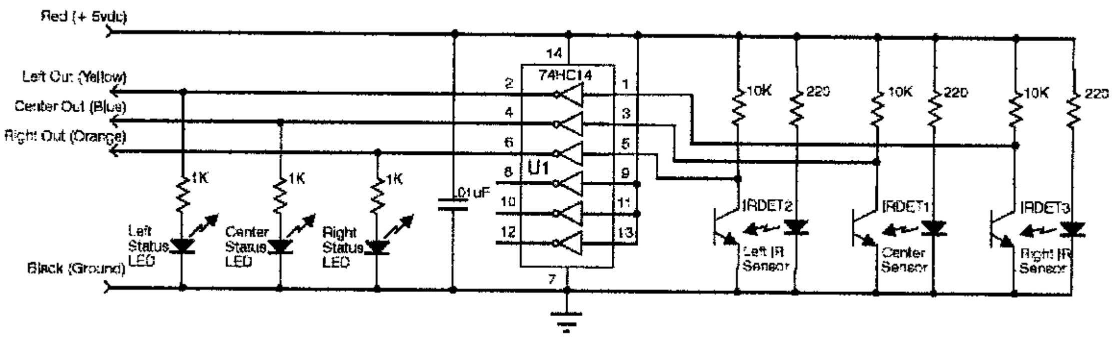

Figure 2.26: Line tracking circuitry.

2.8.4 Power Regulation

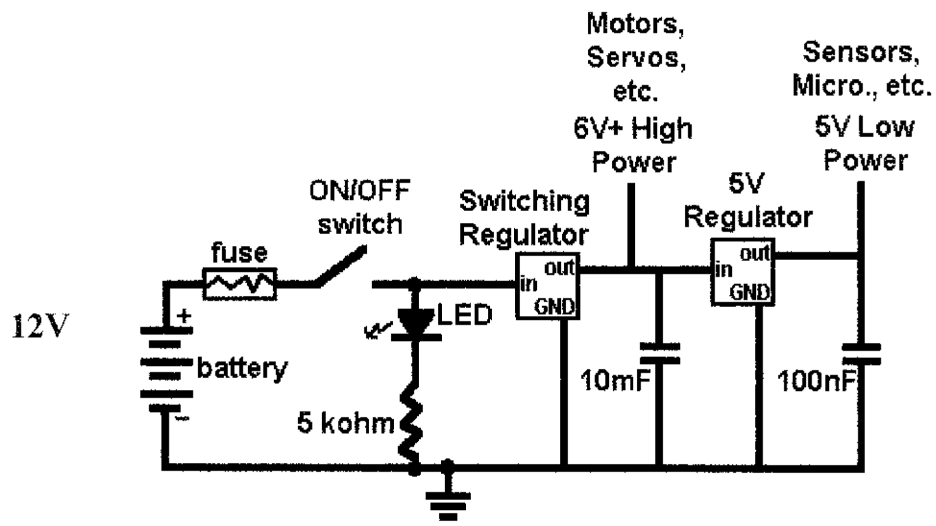

Figure 2.27: Power Regulation Circuitry.

A power regulator circuit shown in Figure 2.27 basically ensures control of the robots' power source. A power regulation circuit must do the following for the robot.

1) **Regulate at a set voltage.**

For efficiency, optimally it would be best to use a power source closest (yet slightly above) the desired voltage input required. However this is rarely easy or even feasible. For a start, different electronics require different voltages. A microcontroller will require 5V, motors perhaps 12V, a voltage amplifier perhaps both 20V and -20V. Batteries are never at a constant voltage. A 6V battery will be at around 7V when fully charged, and can drop to 3 to 4V when drained.

2) **Supply a minimum required amount of power.**

The sum required power of all the robot components needs to be below the amount the power circuit can supply. If power drops even for a fraction of a second below what the robot requires, things like the microcontroller could reset, or sensors would give bad readings, or motors won't work very well.

3) **Allow for additional features/requirements, such as short circuit protection, regeneration, negative voltages, and noise protection.**

   If something bad goes wrong with the batteries, things like acid chemical spilling, dangerous fires and burnout could happen. The power regulation circuit needs to account for this, by implementing fuses. One problem the circuit might have is high frequency noise (bad). High frequency noise can result from common things such as el-cheapo and/or old motors (the brushes have bad connections), RF interference, and telepathic aliens. To correct for this, use another capacitor but of a much smaller farad rating.

2.8.5 Data Acquisition of Drop-off Point

The robot will be able to identify the path to be traveled to arrive and drop off point by information tagged on to the block itself. Research has been conducted to determine best system for path and destination information recognition. The robot will basically be preprogrammed of the path for various destination data tagged on the blocks. Research done is to determine best system for path and destination information recognition. Below are comments on some of the possible data acquisition systems that were proposed to implement this are as of the following.

Bar code

- Embedding information in a sequence of bars representing 1's and 0's.
- Can represent a lot of destinations.
- Require a bar code design program and a bar code scanner, which might incur a lot of cost.

Character recognition

- Items are labeled with characters, alphabets or numbers.
- The robot is to recognize these identification data visually as an image.
- Need of a web cam or digital video surveillance system to identify character.
- Needs a very complicated algorithm especially dealing with digital signal processing

Color Coding

- Use different color representation for each destination.
- Represent different colors with different voltage levels.
- Use of photo sensors can represent up to two different colors, which are costly and there is more than two destinations.
- To represent more than two destinations, a web cam may be used, however again requires complex programming for pixel recognition of colors.

CHAPTER 3
METHODOLOGY OF PROJECT WORK

3.1 PROCEDURE IDENTIFICATION

The process flow of the project will be done based on the simple flow, which is then applied throughout the project. Refer to the Gantt Chart (APPENDIX A) to see the schedule of work progress.

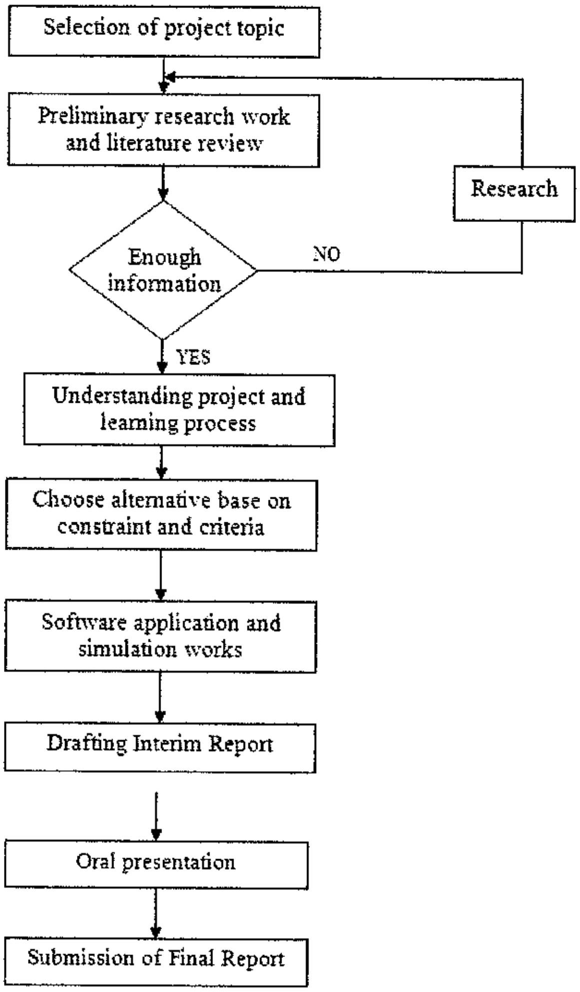

Figure 3.1: Process Flow for FYP.

The first step that should be taken into consideration is to select the project topic and thus conduct preliminary researches and literature review through the available source such as using the Internet or textbooks. As the information is available, it is very crucial for the author to undergo learning process, as robotics is not a familiar area to her. From the data gathered, the alternatives will then be layered out and the best alternatives will be chosen based on constraint and criteria.

The next step would be to transfer or apply the information gathered by using related software or doing some stimulation pertaining to the project. The following step is the drafting of Interim Report, which has to be submitted before the oral presentation through the end of this semester. The final process is the submission of final report of all the activities conducted for the project flow the whole semester.

3.2 TOOLS REQUIRED

Below in Table 3.1 are the expected tools and parts needed for completion of the autonomous robot. These tools are obtainable for use from UTP workshop and the software required is downloadable from the Internet for free. The materials such as wood and aluminum are to be purchased or recycled from previous undergraduate projects and electrical and electronic components can be borrowed from the UTP electronics store or purchased from electronics stores outside of UTP. It is also a requirement to fabricate all circuits as PCB, which can be done in the UTP PCB lab with supervision of the lab technologist.

Table 3.1: Parts and tools need for the project

No	Parts	Material or Components	Tool
1.	Structure	1. Metal	1. Drill 2. Welding
2.	Mobility and Movement	1. DC motor with gears(x2) 2. Casters(x2) 3. Nuts and screws 4. Plastic wheels coupled(x2)	1. Screw drivers 2. Pliers
3.	Power distribution	1. Batteries(12V) 2. Connectors & Wires 3. Ribbon Cable	1. Solder and flux 2. Multimeter 3. Screw drivers
4.	Sensors	1. Ultrasonic 2. Infrared 3. Electronic Components	1. Simulation software (Multisim or Pspice) 2. Breadboard 3. Solder and flux 4. Multimeter 5. Oscilloscope
5.	Microprocessors	1. PIC Controller 16F877 2. PIC Programmer Board 3. PIC 16F877 Target Boards	1. Breadboard 2. Electronics components 3. Oscilloscope 4. PIC programming software 5. Connectors

3.3 PROJECT WORK

Below in Figure 3.2 is a flow chart describing the project methodology step-by-step in more detail, including literature reviews, fabrication of robot, and troubleshooting and modification.

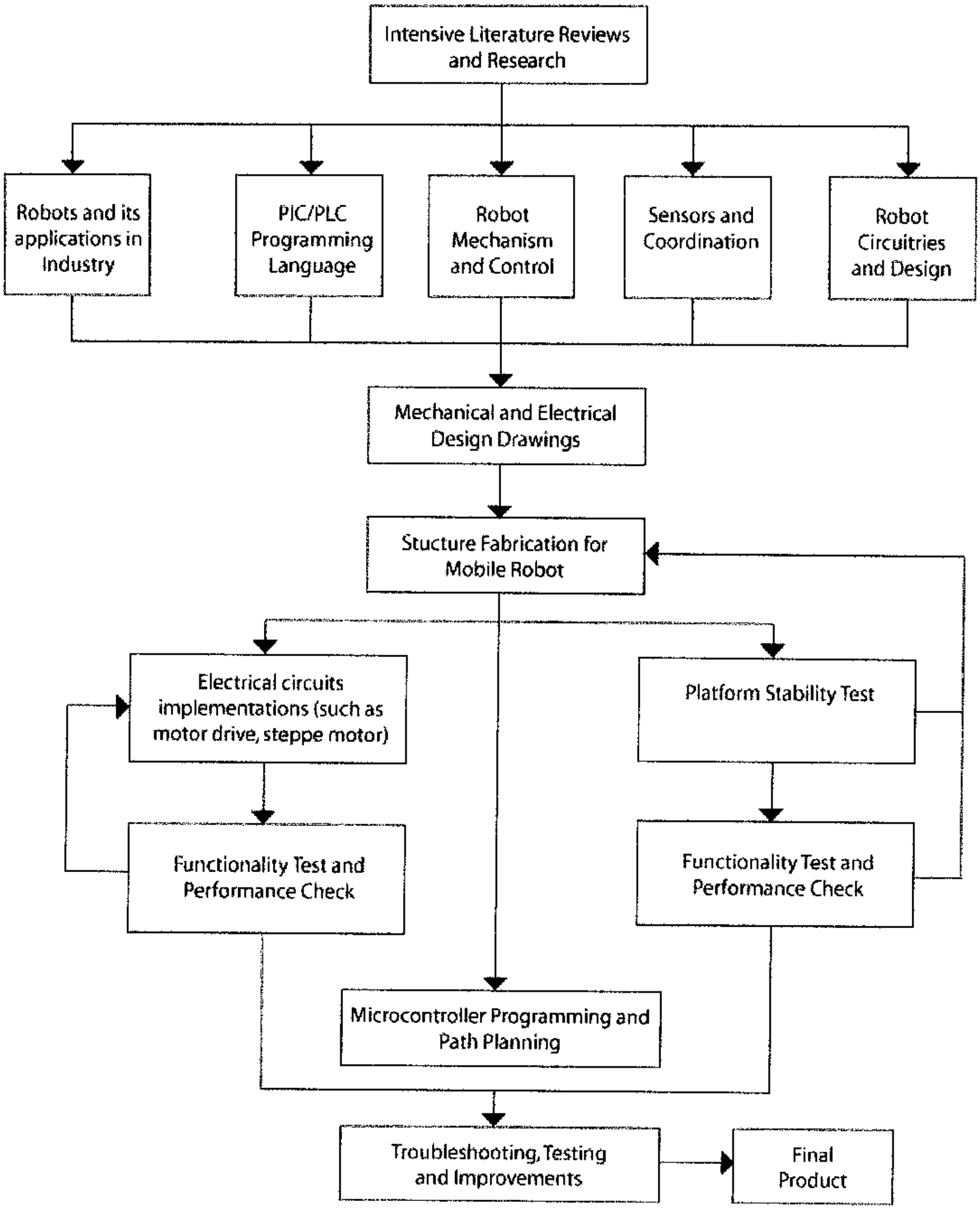

Figure 3.2: Project Methodology Flow Chart.

3.3.1 Literature Reviews

Intensive literature reviews has been done on mobile robot fabrication. Resources from related books, internet and online journals have been accessed. The reviews are crucial to identify the method, tools and equipments that are needed for implementation of the robot. The literature reviews cover five important areas which are:

1. Robots and its application in the industry
   - The technology of robots used in various industries and the level of technologies for each of the robots in its job application.
2. PIC Programming language
   - Learning the programming language (C++) which is used to program the microcontroller selected for this robot design, which is the Programmable Input Controller (PIC) chip.
3. Robot Mechanism and Control
   - Mechanical Trajectory and dynamics calculation has been done to indentify the type of locomotion to be used, the torque of the motor needed and mechanisms that would be implemented to the design.
4. Sensors and Coordination
   - Identify the best suited sensor for the obstacle avoidance of the robot as well as path planning needed for covering the area of land that needs to be covered.
5. Robot Circuitries and Designs
   - Electrical circuits such as stepper motors and driver circuits for controls of the mobility of the robot.

3.3.2 Mechanical and Electrical Designs

The mechanical structures are drawn out which includes the details in which the real robot would resemble. The electrical designs are done for simulation to test the theory and check the sufficiency of voltage and current supplied to the circuitry.

3.3.3 Structure Fabrication for mobile robot

The wheels are mounted to the robot base. The stepper motor is coupled to robots neck for gripper implementation. Electrical implementations are carried out parallel to the construction of the robot.

3.3.4 Microcontroller Programming and Path Planning

The microcontroller is the 'brain' of the robot. Programming is needed to be done in order to control the movement and path planning for the robot. The microcontroller is implemented on the robot once the robot is completed.

3.3.5 Troubleshooting and testing

Troubleshooting is needed to ensure a functioning robot is produced at the end of the project period.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 THE OVERALL DESIGN

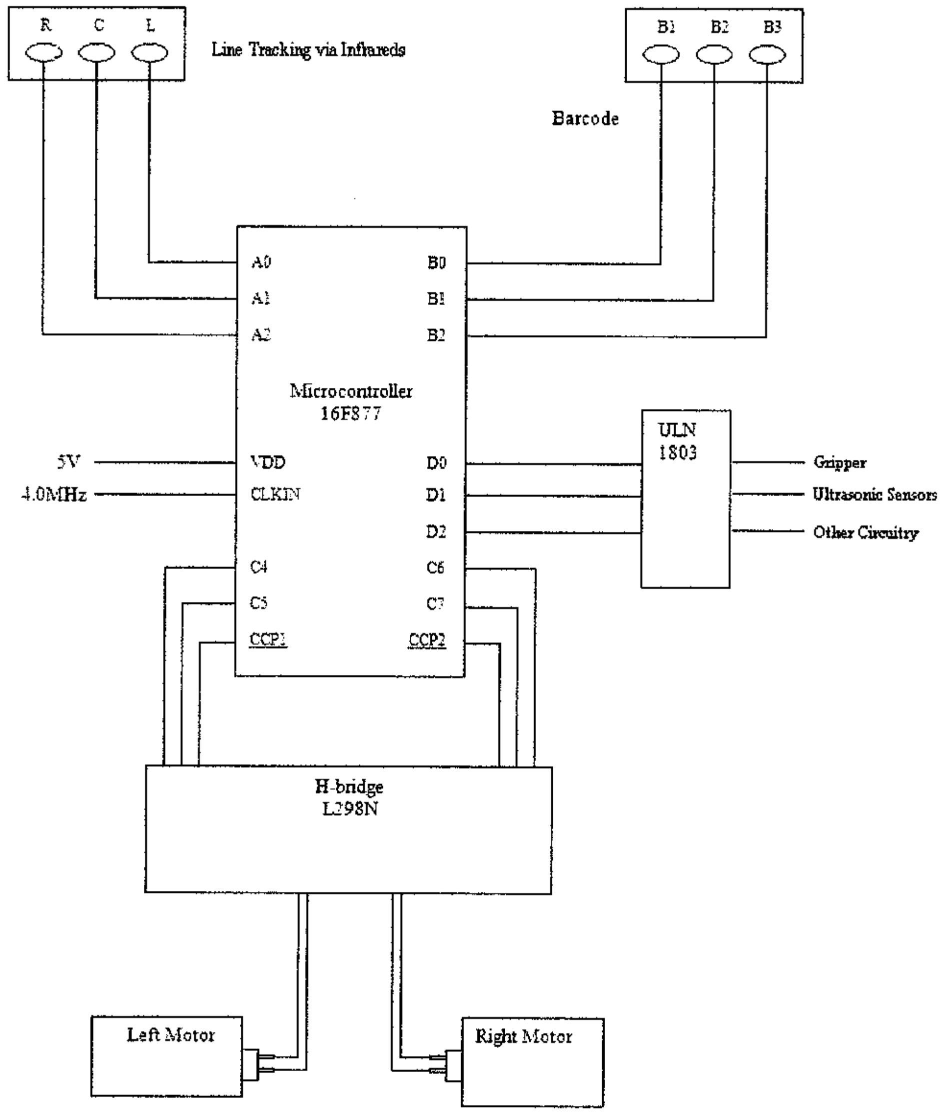

Figure 4.1: Overview of the robot circuitries with the microcontroller.

4.1.1 Component Functions and Interaction

With the reference to the Block Diagram shown in Figure 4.1, the functions of the components are described below:

PIC 16F877 Microcontroller

The overall process of the robot is determined by this chip. The chip receives inputs from the sensors and processes it to execute appropriate instructions according to the program written by the programmer. The controller also controls the drives such as the DC motor according to the path planning codes written.

DC Motors

The DC motors are used to move the robot about. The motor has sufficient amount of torque in order to successfully move the whole structure.

Line Tracker

The line tracker implementing infrared are essential for movement from point to point of the robot. The line tracker is design to follow white lines over work area to get around. The implementation of line tracker over wheel encoder will be discussed later on.

Ultrasonic Receiver / Transmitter

The ultrasonic sensor is essential for the obstacle avoidance feature in this robot. When an obstacle is detected along the predetermined path of the robot, a signal would be sent to the microcontroller by the ultrasonic sensors. The obstacle avoidance program would then be executed to avoid any collision of the robot.

Stepper Motor Translator

Stepper motors require certain combination of pulsing in order to move. The stepper is implemented here for gripper control design.

4.2 MECHANISM

The design of the autonomous robot requires its functionality as a delivering robot which collects blocks from pick up point and delivers them at its respective drop off point. These blocks will be design as a cube of 7cm x 7cm x 7cm, made of high-density polystyrene to reduce weight constraint, hence torque required when picking up the blocks.

The robot will be able to identify the path to be traveled to arrive at drop off point by information tagged on to the block itself. Research has been conducted to determine best system for path and destination information recognition. The robot will basically be preprogrammed of the path for various destination data tagged on the blocks. Research done is to determine best system for path and destination information recognition. Some of the possible data acquisition systems that were proposed in chapter 2.8.5 are as of the following.

1. Bar code
2. Character recognition
3. Color Coding

Therefore, the author had proposed a simple bar code method to aid the robot in destination recognition process, as further complex digital data processing of the character and color recognition is not preferred. The barcode scanner in this case is made of two infrareds (BS1 and BS2) to interpret the information embedded onto the barcode. The barcode itself therefore represented by two lines (L1 and L2), given black or white state to represent 0 and 1 respectively. BS1 will be aligned to perform recognition on half of the barcode, L1 and BS2 on L2. As shown in Figure 4.2, the two infrareds will be placed far away from each other, and the L1 and L2 will also be represented by a big area (instead of thin lines) of black or white to prevent position inaccuracy while robot place itself for pick up. The state of each BS1 and BS2 will be fed into the input of the microprocessor.

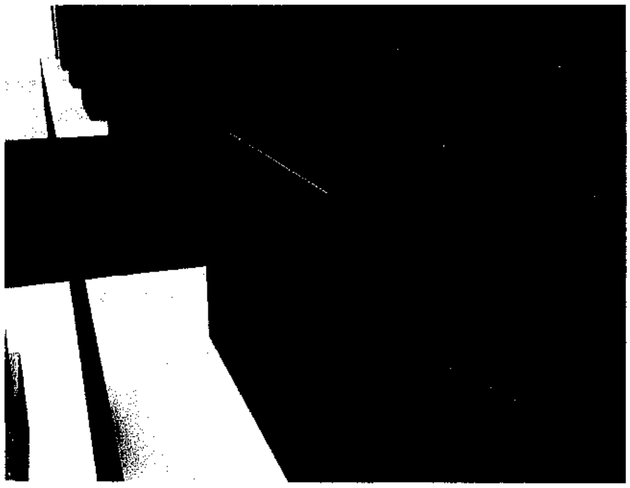

Figure 4.2: Bar code recognition method.

The layout of the pickup point, paths, and destinations are shown in Figure 4.3. A is the starting point and C, D and E are drop off points while W, X, Y and Z are junctions. B is conveyor belt with a random time of blocks arrival at pick up point. Therefore, the autonomous robot will only have to return to the conveyor belt at the same position it picks up the last block after delivery. The conveyor belt should too be installed with sensors, to stop moving, once a block is in position for pick up to avoid overloading. If load is not placed on the conveyor belt, the autonomous robot will be on standby until the user switches it off.

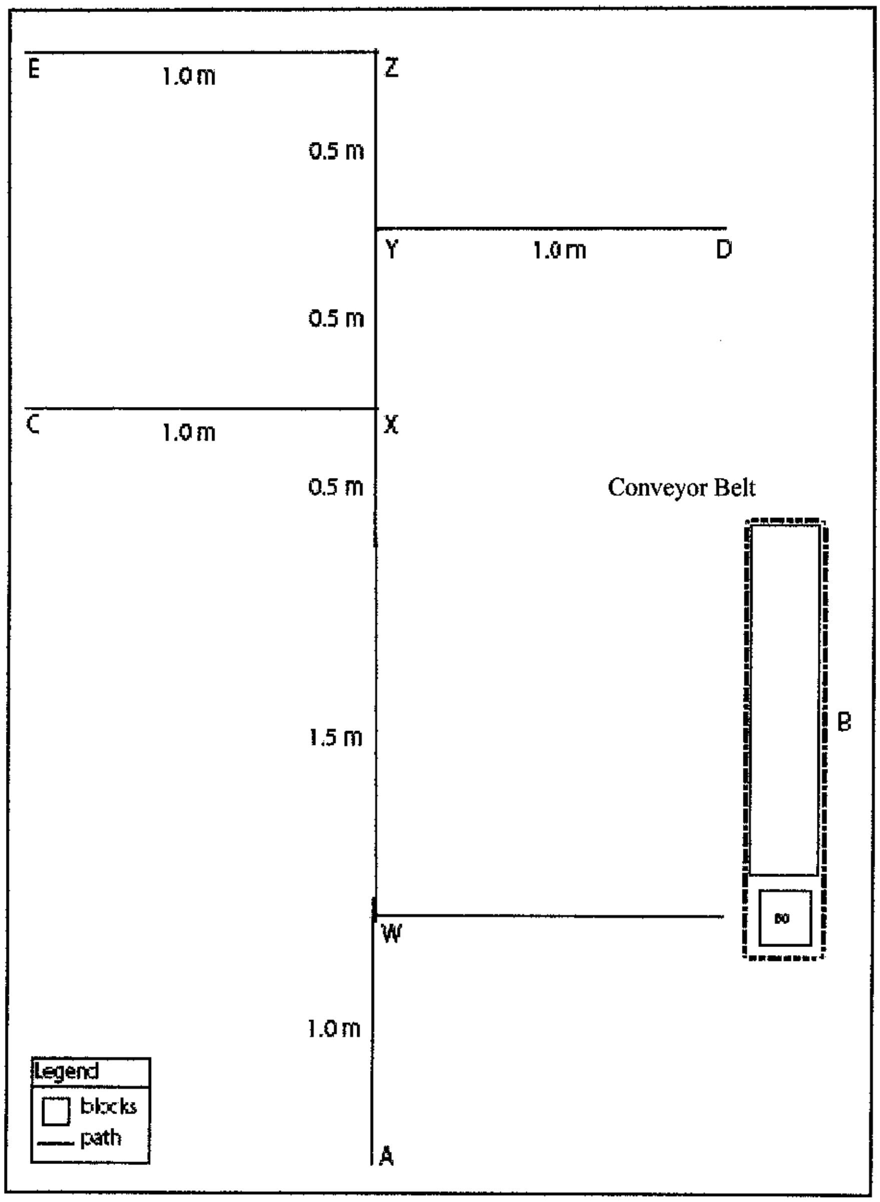

Figure 4.3: Layout of prototype destination area.

A flowchart of the robot mechanism with reference of the path layout is provided in Figure 4.4. The autonomous robot will be switched on by the user at point A and requires no supervision from this point onwards. The robot will move to junction W, and turn right in to B to pick up the first block. Note that the blocks would be assigned with random destination information tagged onto it. Now, for instance this first blocks destination is E. The robot will move back to junction W and travel down the WXYZ path for 5m and turn left at junction Z and drop the block of at E. The robot will also be able to sense any obstacle in its way and stop. It will then provide alarm via buzzer to demand that its path be clear with assumption that this obstacle is a human being. If the obstacle still exists after 10 seconds (obstacle cannot remove itself from path; i.e. concrete object) the robot will alert user to remove the obstacle in its way by a longer duration (continuous) alarm.

From Figure 4.3, there are three destinations to deliver the items from the storage area B. The two lines of barcode, L1 and L2 will be able to represent four (2^n, where n (number of input) =2) destinations with 1's and 0's combination as shown in Table 4.1.

Table 4.1: Destination representation by barcode.

B1	**B2**	**Destination**
0(black)	0(black)	C
0(black)	1(white)	D
1(white)	0(black)	E
1(white)	1(white)	Not Implemented

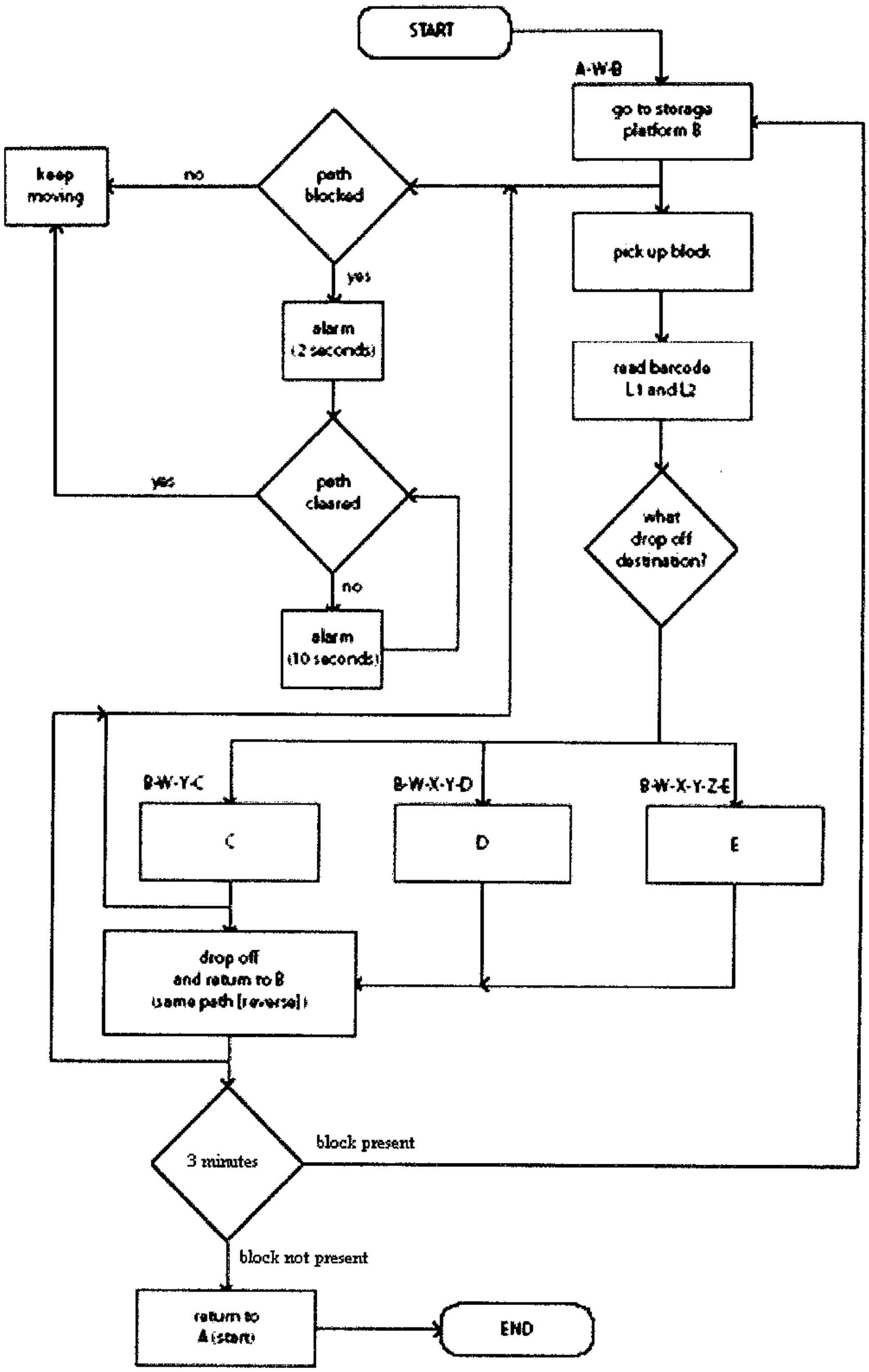

Figure 4.4: Flowchart of robot mechanism.

4.3 STRUCTURE AND DESIGN

The figures below show the dimension of the autonomous robot physical design, which includes the gripper, design. Figure 4.5, 4.6, and 4.7 are respectively side, front and top view of the autonomous robot while Figure 4.8 is a 3D projection of the robot. The author had decided to use both plywood and aluminum in design of the autonomous robot to ensure minimal expenditure trough out completion of the project. The author had decided on using large wheels for large wheels provide low torque but high velocity of locomotion.

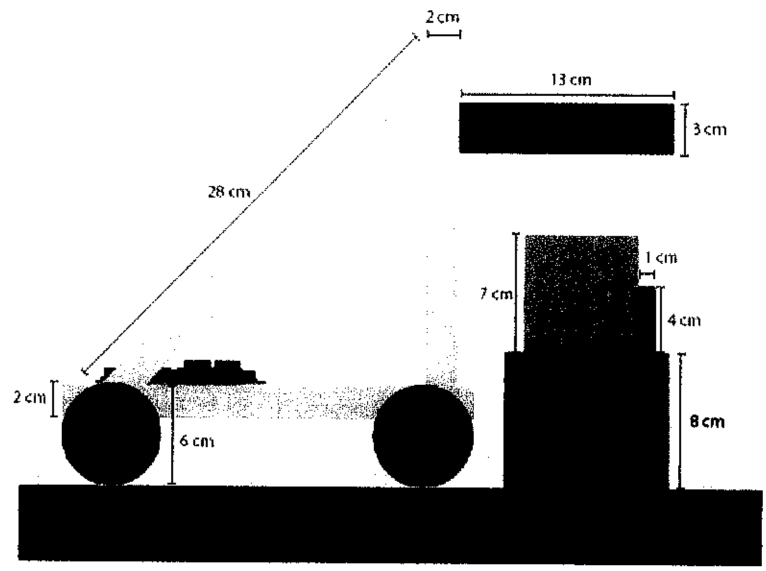

Figure 4.5: Side view of the autonomous robot model.

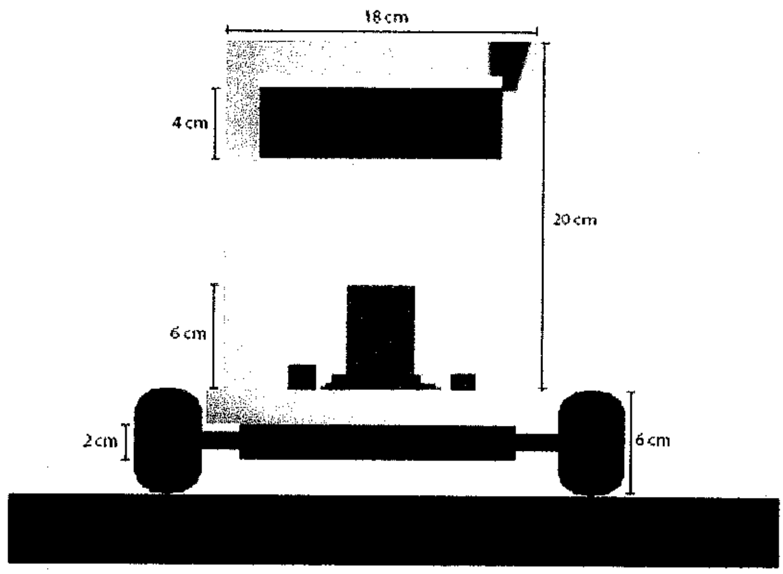

Figure 4.6: Front view of the autonomous robot model.

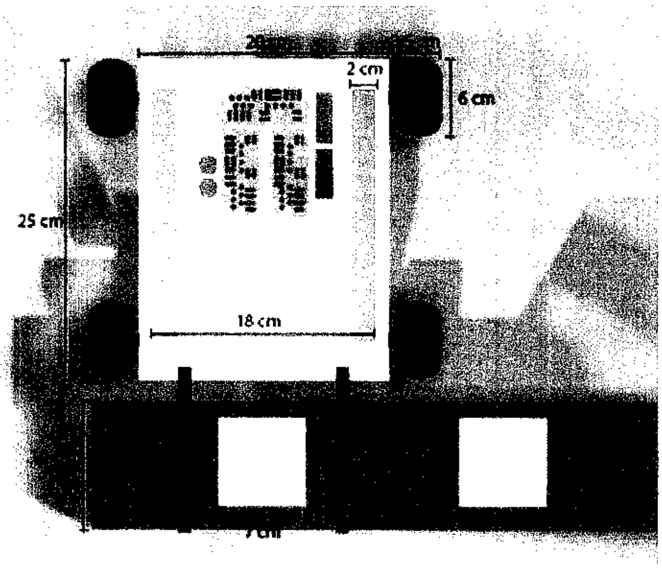

Figure 4.7: Top view of the autonomous robot model.

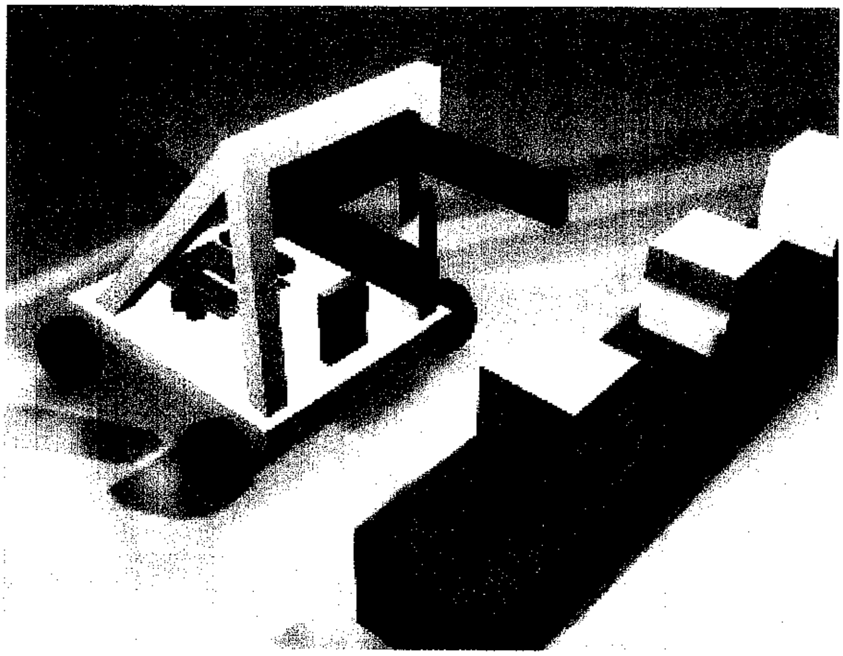

Figure 4.8: 3D projection of the autonomous robot model.

The following are photos of the constructed chassis of the robot made of aluminum bars.

Figure 4.9: Side profile of chassis design.

Figure 4.10: Top profile of chassis design.

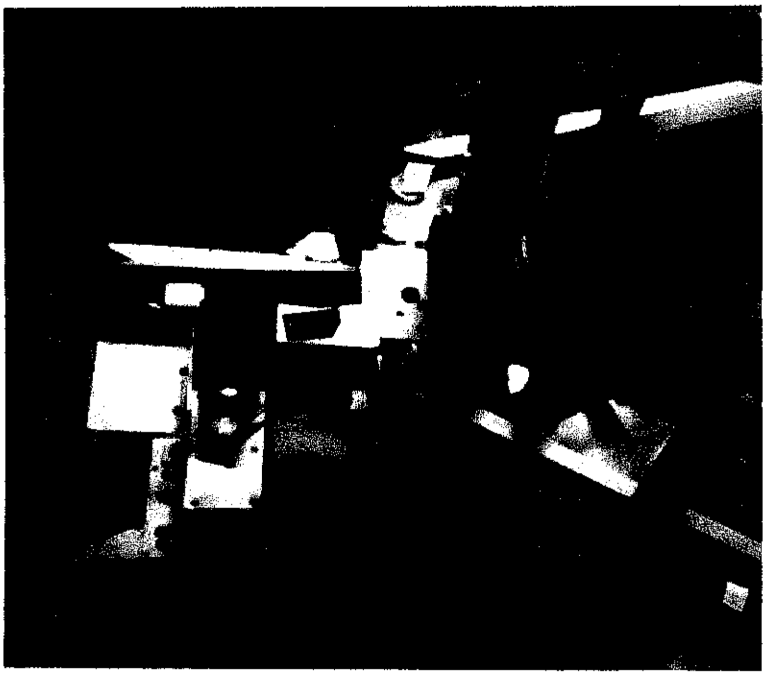

Figure 4.11: 3D projection of constructed chassis.

To mount any type of motor to the chassis, it is required to use an L shaped bracket. For a DC motor, all that is needed to do is take a sheet of aluminum, drill two holes in two of the corners, drill two more holes on the other half to match the motor screw holes, and then bend the entire piece in a 90 degree angle. In Figure 4.12 a U shaped piece of aluminum, is cut to size, and the appropriate holes are drilled to attach it to the white HDPE chassis. Two motorized wheels will be placed on the robot, one on either side. The movement commands to the motors by either using a motor driver or H-bridge.

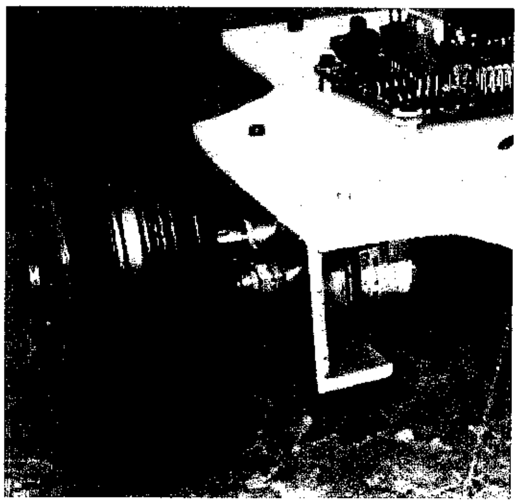

Figure 4.12: Mounting motor to wheels.

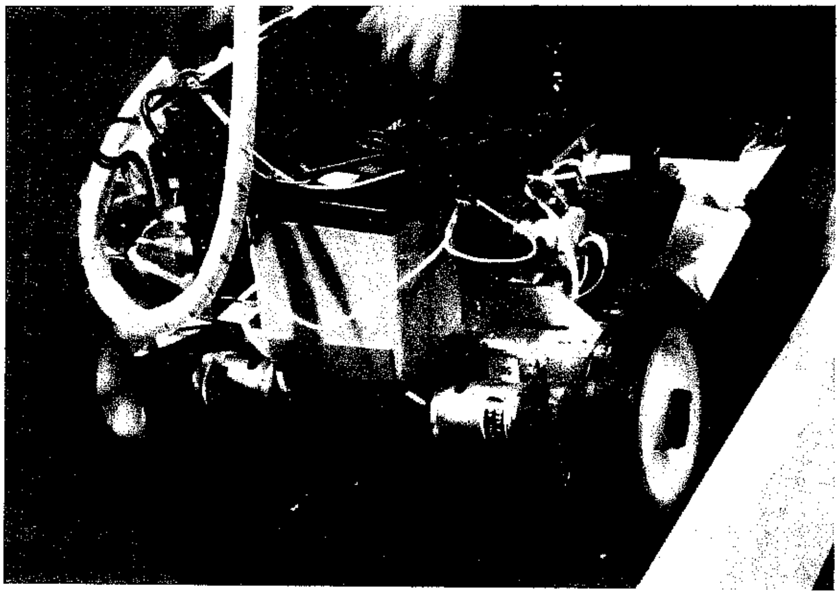

Figure 4.13: Constructed chassis of robot, with installed gears and wheel mounting.

4.4 CONTROL METHODS

The most important of DC motor control techniques is the H-Bridge. After the H-Bridge is hooked up to the motor, to determine the wheel velocity/position an encoder is implemented. The H-Bridge is the link between digital circuitry and mechanical action. The computer sends out binary commands, and high-powered actuators perform required actions. Most often H-bridges are used to control rotational direction of DC motors. In Figure 4.14 is an H-bridge circuitry used to control the DC motors.

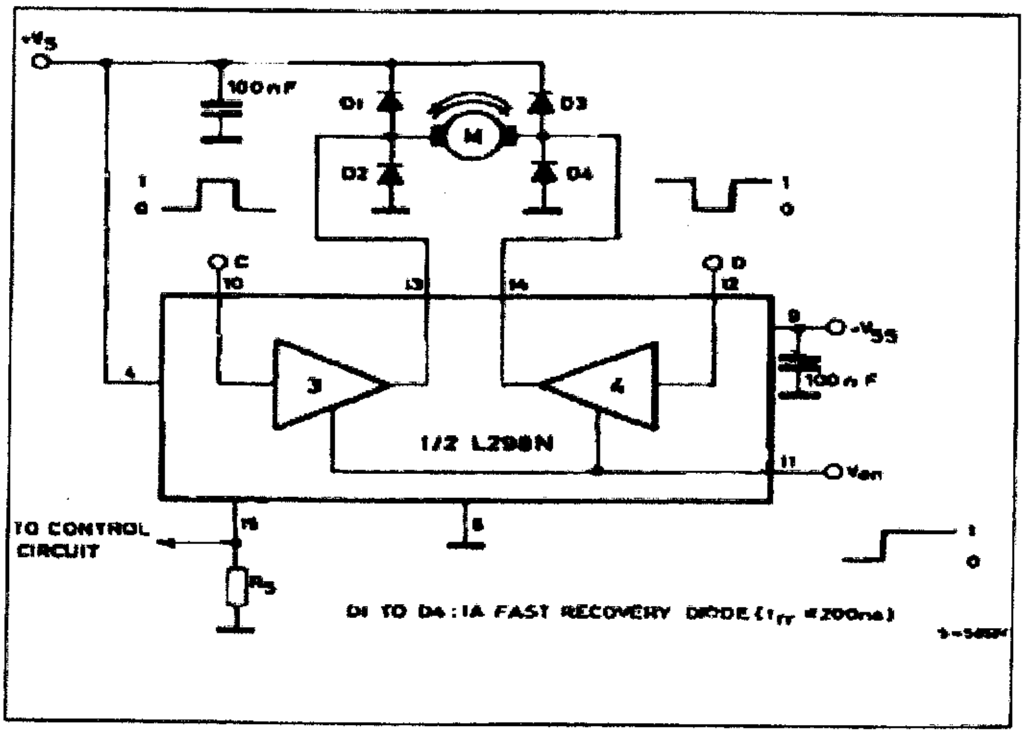

Figure 4.14: H-bridge circuitry used to control the DC motors.

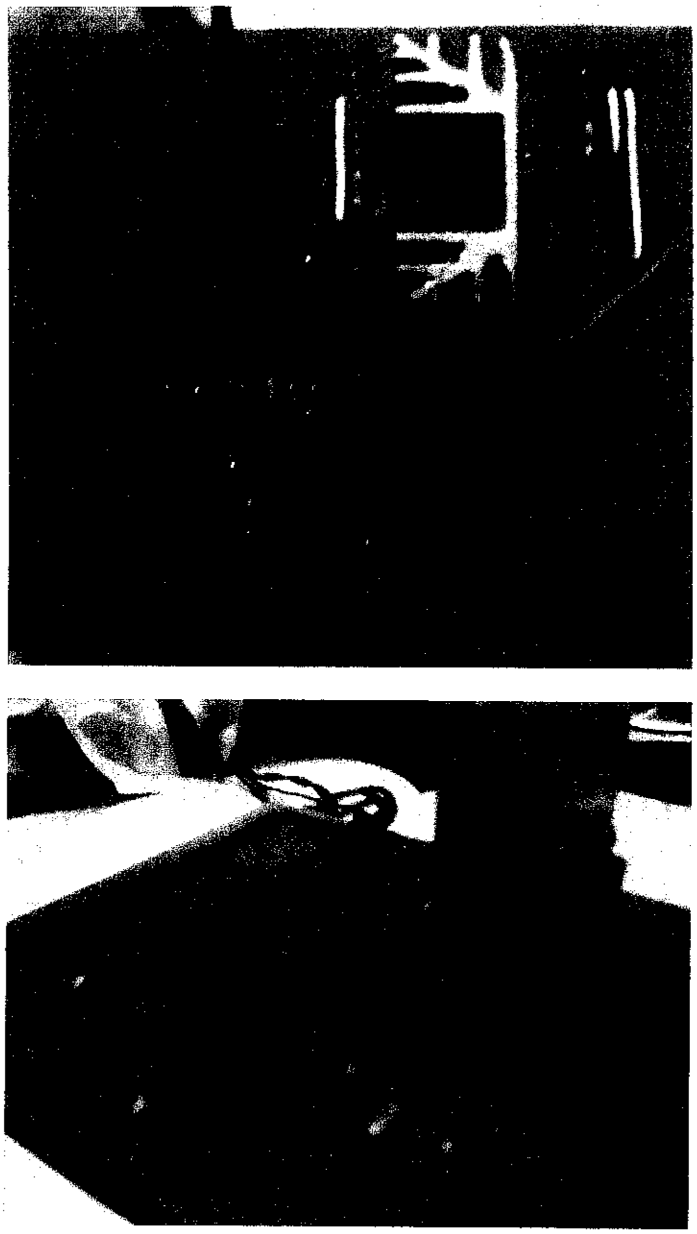

Figure 4.15: H-bridge circuitry for DC motor control and interfacing with microcontroller.

4.5 POWER REGULATION

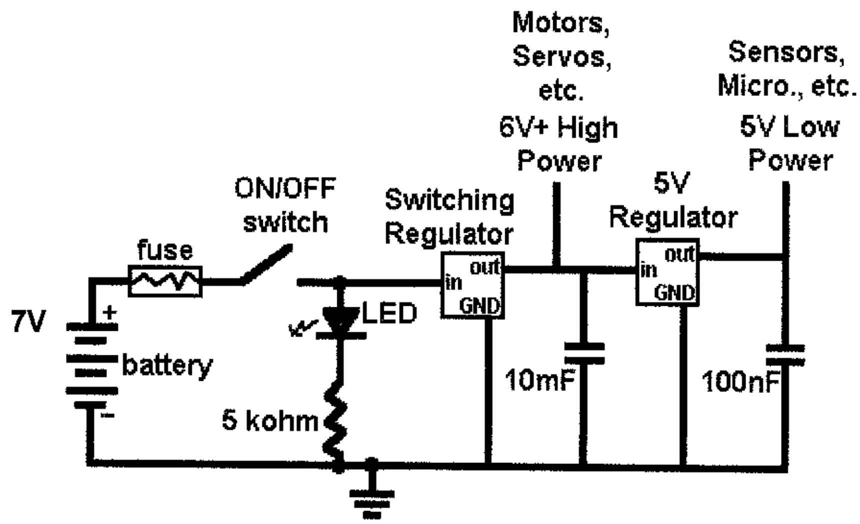

Figure 4.16: Power Regulation Circuitry.

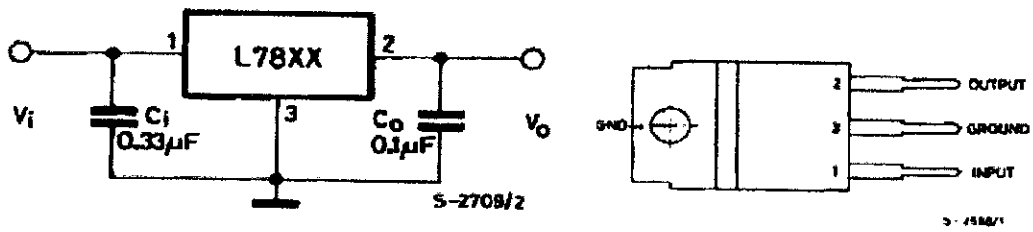

Figure 4.17: The pin layout and application diagram of the L78xx Voltage Regulator.

A power regulator circuit shown in Figure 4.16 basically ensures control of the robots' power source. A power regulation circuit must do the following for the robot.

1) Regulate at a set voltage.

2) Supply a minimum required amount of power.

3) Allow for additional features/requirements, such as short circuit protection, regeneration, negative voltages, and noise protection.

This power regulation circuitry is to provide other circuitry or sensors with the required voltage. From the 12V battery, this voltage regulation circuitry allows us to tap onto 5V via L7805 and 6V via L7806. Both the input and output shares a common ground as seen in Figure 4.17. The chip is also easily heated up and there would be some power loss to the environment. Therefore, to ensure the safety of the chip, heat-sinks are attached to the chip for heat dissipation. The voltage regulators are soldered on a veraboard and equipped with heat sink.

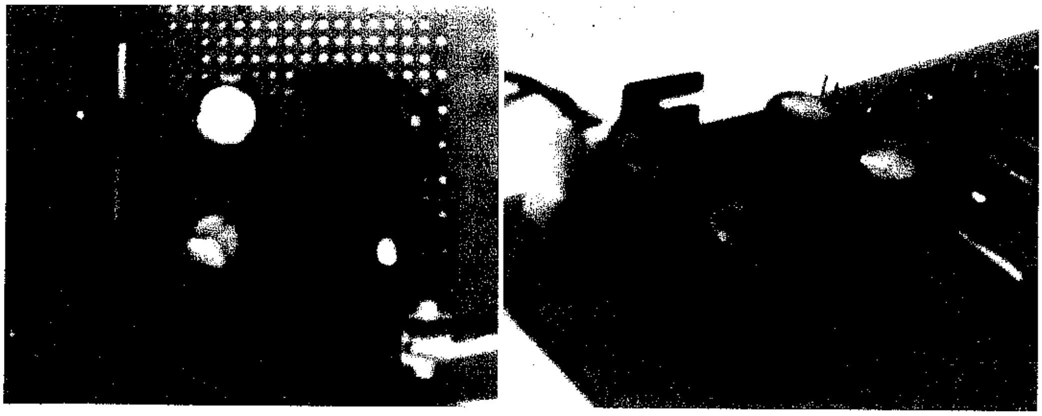

Figure 4.18: Voltage Regulation Circuit with L7806 and L7805 mounted onto heat sinks.

4.6 COLLISION AVOIDANCE SYSTEM

4.6.1 Ultrasonic Receiver and Switching Circuit

The circuit has been designed based on the schematics shared on the internet by the electronic hobby kit webpage. The design circuit in Figure 4.19 allows the relay switch to activate when the receiver detects ultrasonic waves.

The circuit works based on the ultrasonic transducer when sensing ultrasonic signals. It converts it to electrical input with the same frequency. The purposes of transistors T3 and T4 are to amplify the signal (as they are supplied by 9V voltage source). The amplified signals are then rectified and filtered. The filtered DC voltage is fed to the inverting input of the op-amp IC-2. The non-inverting pin is connected to a variable DC voltage in which the threshold value of ultrasonic signal received can be manipulated. The output of op-amp is used to bias transistor T5 which will then bias the transistor T6. T6 can then activate the relay to control other equipment or connected to the microcontroller.

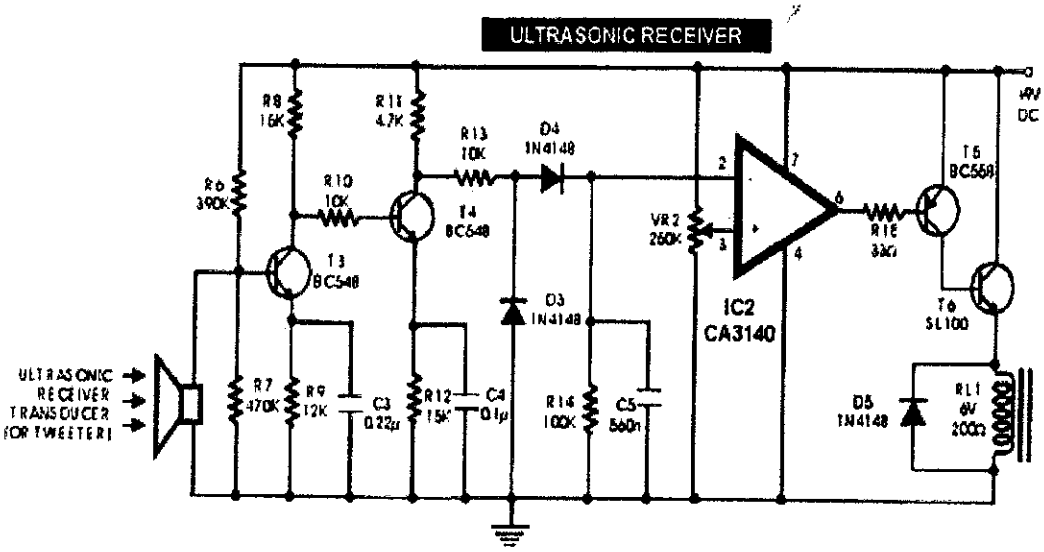

Figure 4.19: Schematic of ultrasonic receiver.

The circuit was tested through simulation on the Electronic Workbench software and the simulated result was compared to the final product when built. The simulation results are vital for troubleshooting the actual circuit.

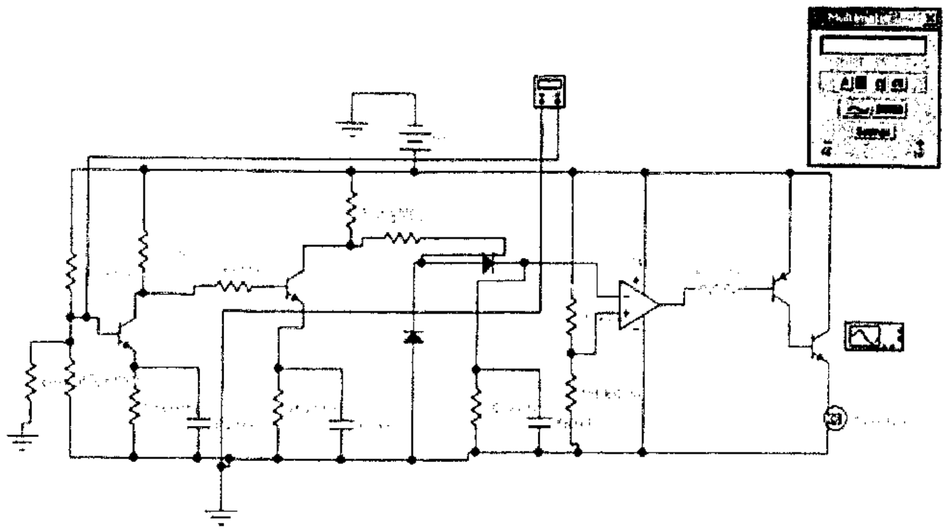

Figure 4.20: Simulation of the ultrasonic receiver on Electronic Workbench.

4.6.2 Ultrasonic Transmitter

The ultrasonic transmitter is constructed using 555 based astable multivibrator. It oscillates at a frequency of 40 to 50 kHz. The transmitter is powered from a 9V or a 12V supply. The value of 4.7k with $\pm$10k (pin 7) and the value of 18k (pin 6) and C1 of 680picoFarad was chosen to generate a 40 kHz to 50 kHz frequency. The accuracy of the frequency is important to be detected efficiently by the receiver. The 40 kHz frequency can be calculated using the formula below.

$$f = \frac{1.44}{(2R_2 + R_1)C_1}$$

$$f = \frac{1.44}{(2 \times 18k + 15k)680pF}$$

$$f = 41.522kHz$$

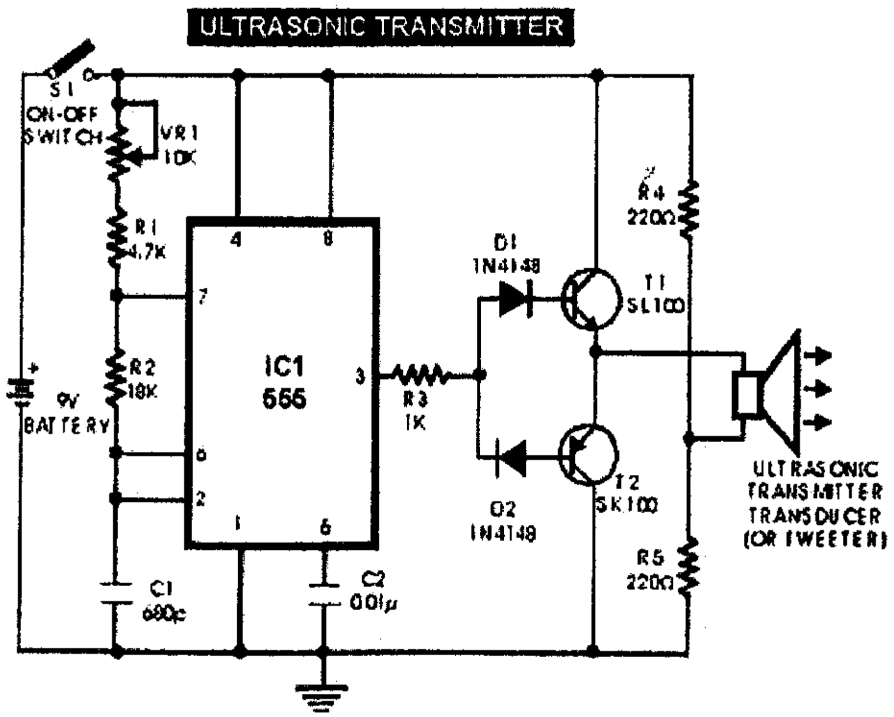

Figure 4.21: Schematic for Ultrasonic Transmitter using NE555 timer.

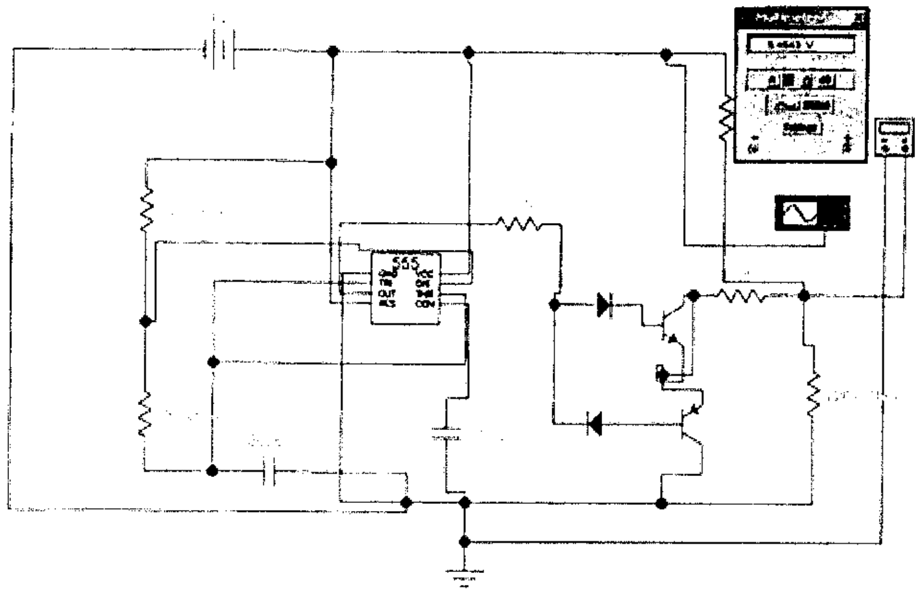

Figure 4.22: Simulation for Ultrasonic Transmitter on Electronic Workbench.

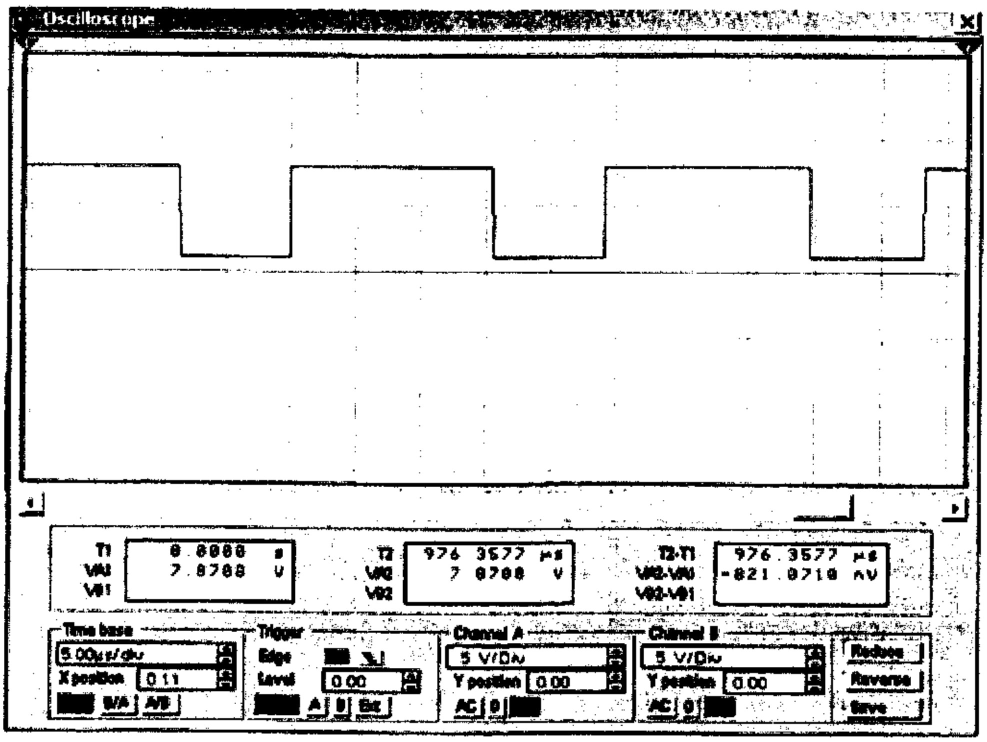

Figure 4.23: Simulation for 40 kHz frequency generation.

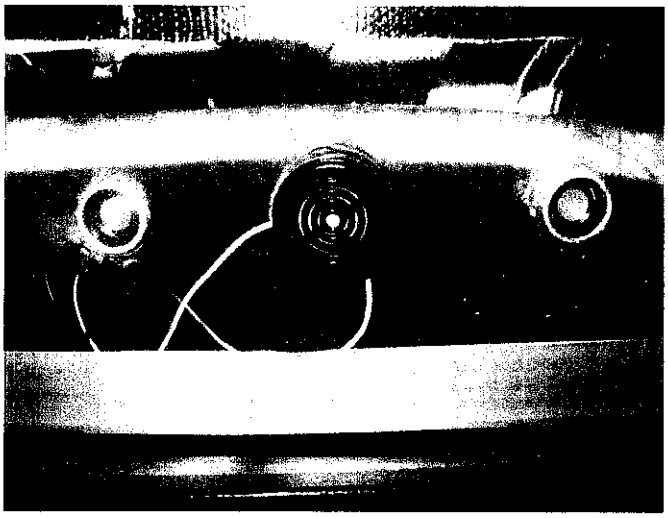

Figure 4.24: Ultrasonic transmitter and receiver.

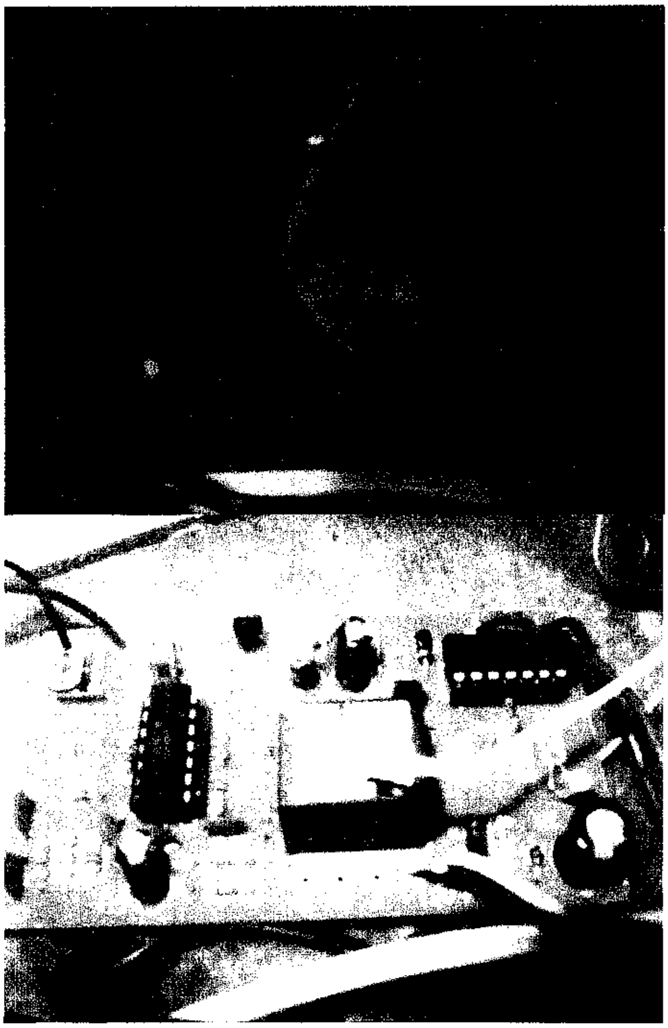

Figure 4.25: Ultrasonic Sensor Circuitry.

4.7 LOCATION TRACKING VIA LINE TRACKING IMPLEMENTATION

The author had proposed to her supervisor to implement line tracking to determine distance and destination paths instead of encoder implementation. This is because at an amateur level of robot building, there is a huge possibility of balancing and alignment problems later on. With line tracking, the robot will be able to travel in a straight line as well determine distance accurately. White lines will be embedded along all the paths on the layout in Figure 4.3 from point A to B and all destinations through all junctions WXYZ. However, the wheel encoder will be look into implementation for future recommendations.

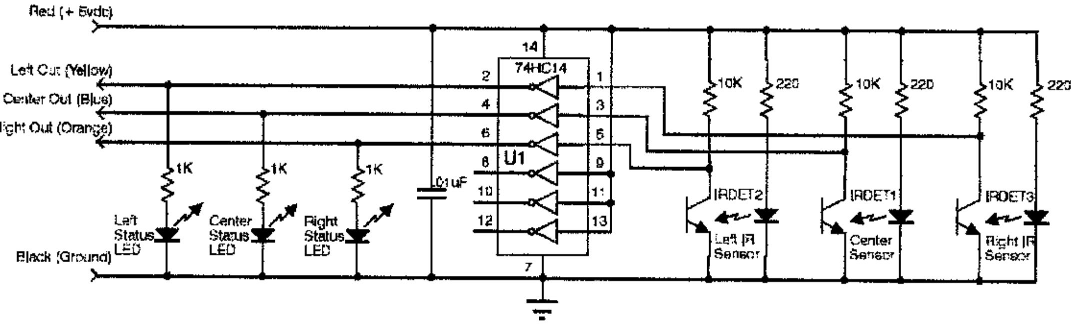

Figure 4.26: Line tracking circuitry.

In Figure 4.26 is the line tracking circuitry to be implemented on the robot. The line tracking circuitry will make use of one IR emitters on each side of the white line and one in the center of the line. These IR emitters are programmed to avoid the white line hence aligning the robots movement to actually follow the white line. At each junction a 0.5m horizontal line would be placed while another IR emitter is placed onto the robot to count the junctions while the robot is moving to its destination. This allows the robot to basically tell where it is on the path layout and also as a guidance to program the robot to arrive at its required drop off destination. Below is the algorithm to be implemented for the line tracking implementation.

However sunlight can flood sensors to the point of being useless. Our sun emits large quantities of light in the infrared spectrum, and although the human eye is blind to it, electronics are not. For obvious reasons the IR emitter/detector circuit is quite sensitive to even the smallest amount of sunlight. So it is important to develop a shield that blocks the light. There have been many variations of this: Cereal boxes, garbage bags, boxes, electrical tape, black felt cloth and duct tape to name a few. The shield must always be flush with the ground, so it has to be flexible too.

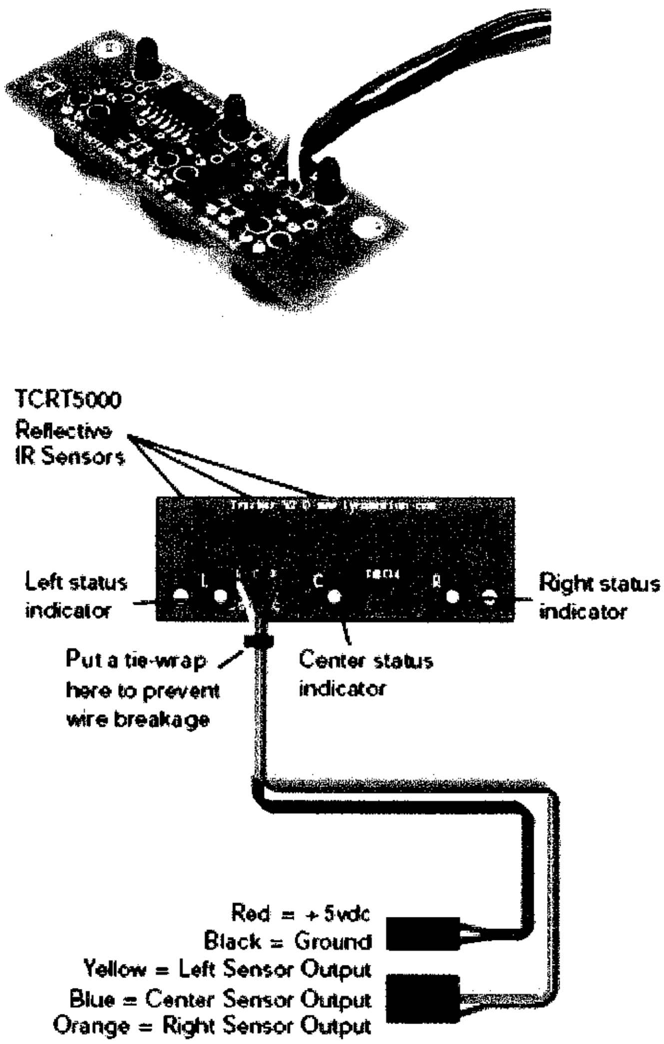

Figure 4.27: Infrared sensors on a line tracking circuitry.

4.8 MICROCONTROLLER

The author had decided to make use of the 16F877 by the manufacturer Microchip. Please find attached in Appendix II the datasheet the microcontroller. The C-programmable 16F877 IC shown in Figure 4.28, features 256 x 8 bytes of EEPROM data memory, self programming, an ICD, 5 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I^2C™) bus and a Universal Asynchronous Receiver Transmitter (USART).

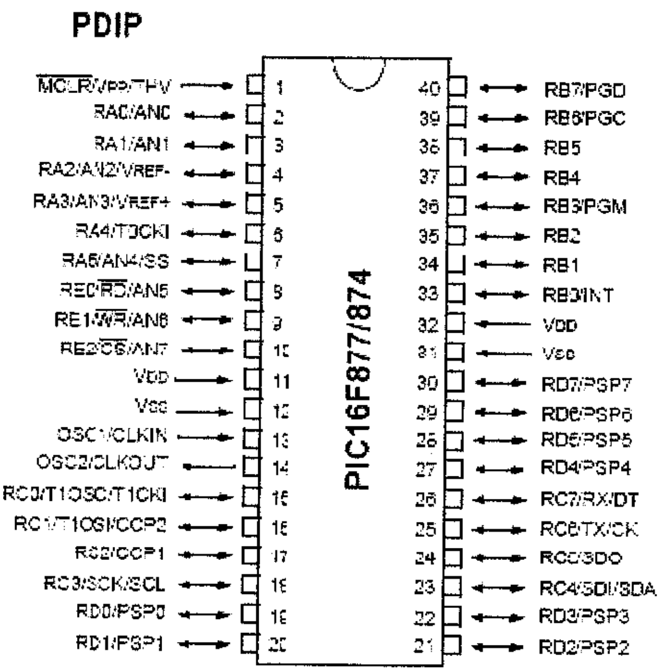

Figure 4.28: The 16F877 IC layout.

A programming board is required to transfer and load the program written in C language on a personal computer onto the chip. The Bumble Bee and PIC compiler was installed on the computer and program written is transferred to the chip through the help of the Serial Cables. The program of the robot, load onto this microcontroller is in APPENDIX B.

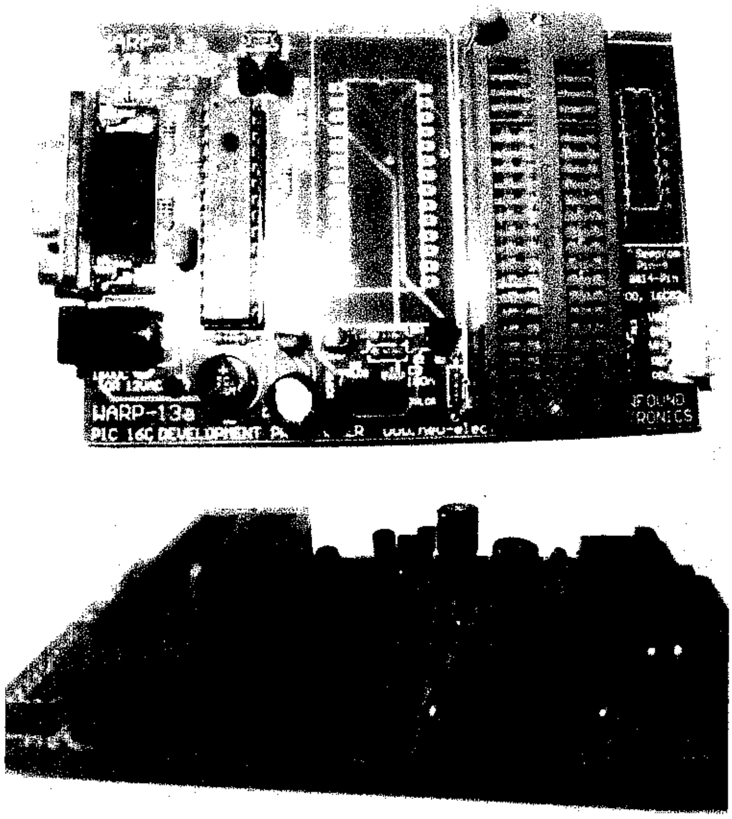

Figure 4.29: Warp 13 programmer board.

An application board is constructed for the 16F873 microcontroller to interface the PIC chip with other drivers such as the H-bridge, and sensors such as the line tracker, barcode data recognition, and obstacle avoidance. An application board is also necessary since, soldering a PIC straight onto a board is not recommended, as heat may destroy the PIC and also to allow flexibility of moving the PIC from the application board to the programmer board. The application board also includes voltage supply, reset switches, a 4.0MHz clock, and input/output sockets for easy installation of sensors and drivers.

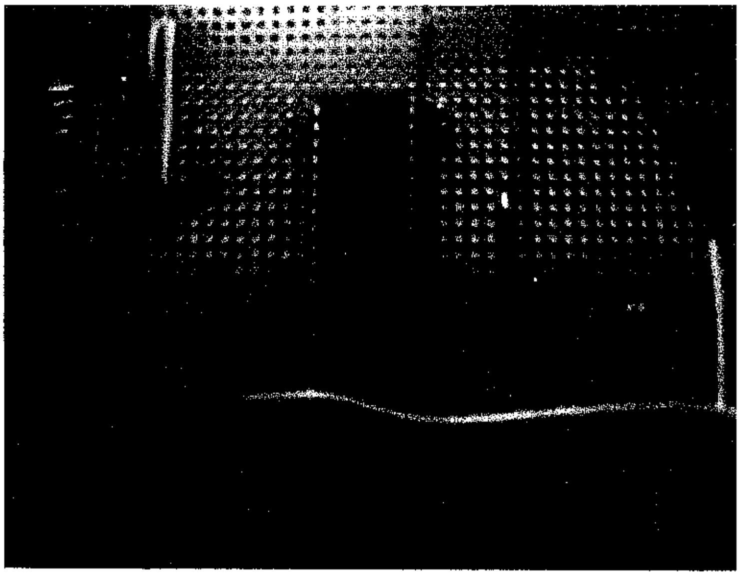

Figure 4.30: Application board, with PIC on its slot, along with a 4.0MHz clock supplied to the PIC and reset switches.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This project needs a very careful study and consistent works. There will be many obstacles that need to be handled and overcome in completing this task. However, with the guidance from the supervisor and other Electrical & Electronics Engineering lecturers, it is hoped that this project can be completed successfully as scheduled. This PIC controlled robot project will be the stepping-stone for the future UTP undergraduates to develop new and better robotics systems. Implementing knowledge gained from the class will be different from the knowledge gain from the hands-on experience. Having all the basics for developing a good robot in house will give strong future on robotics later on.

Below in Figure 5.1 is the summary of the design requirements of the author's autonomous robot.

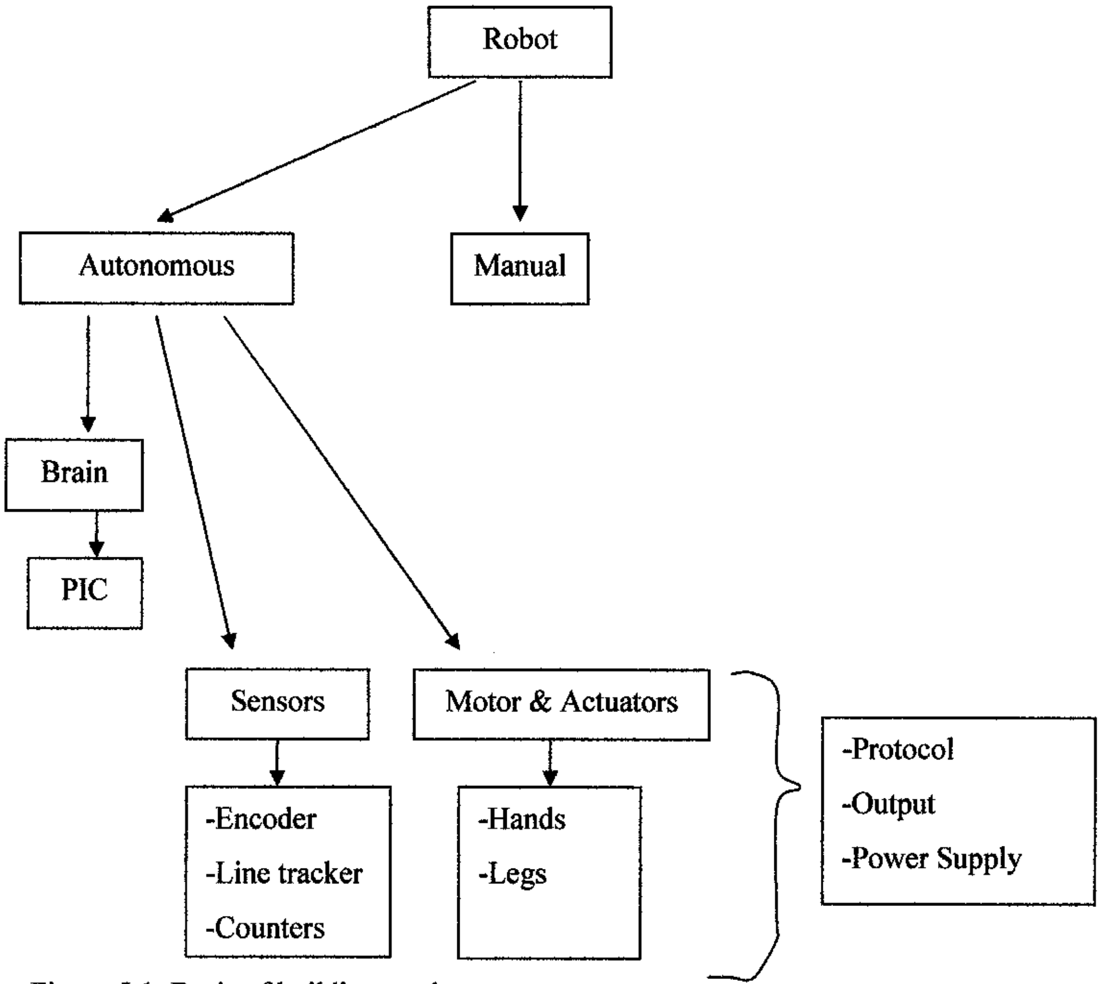

Figure 5.1: Basis of building a robot.

5.2 RECOMMENDATIONS

This semester's research and finding will be a guide to the construction of the author's robot for the next half semester of FYP. However, flexibility is given to the author to proceed with any modification of the original plan to accommodate improvement or complications faced later on during constructions. Some of the recommendations the author plan to look into given no time constraint are as the following.

- ✓ **Implementation of Wheel Encoder Design**

  The current design is to implement line tracking instead of wheel encoder because accuracy of balancing and alignment of the robot is almost impossible at armature level of robot construction. IR emitters are very sensitive to light; imagine an environment with spotlights and light bouncing off the floor. This would cause complication for the line-tracking device to differentiate the white line and surface of the floor. Besides that having grids on a whole floor layout for actual implementation is sight for sore eyes.

- ✓ **More Torque for Pick Up**

  Current design uses high density polystyrene to mold the blocks which is extremely light. However in practical implementation, items for delivery maybe of larger weight. The author plans to further improve this feature by providing more torque for the motors attach for gripping action.

- ✓ **Flexibility to Add On Destinations of Drop Off Point**

  Current design allows a maximum of 4 destinations with L1 and L2 to define destinations. The author plans to allow a flexible feature of more barcode lines to specify more drop-off destinations without requiring much change of programming to the microcontroller.

- ✓ **Voice Activated**

  The current function requires a push button to switch on the robot. It would be definitely an interesting feature to switch on the robot by voice. This will prevent a new user from going through the hassle of reading the operation manual to just allocate a push button to start up the robot.

- ✓ **User Friendly Features**

  The author plans to add on user-friendly features to the robot, since its function to offer a helping hand to human daily activities. Some of the features that would be look into are actual prerecorded voice instruction from the robot instead of alarm/buzzer to request any obstacle to be removed from its path. The author also plans to install a housing for the robot to not only protect the frame and circuitry but also give it a pleasant face or personality.

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APPENDICES

APPENDIX A

GANTT CHART OF PROJECT FLOW

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	Construction of Platform			■	■																		
	-Locomotion																						
	-Line Tracking Implementation																						
2	Submission of Log Book (week 2)			●																			
3	Submission of Log Book (week 3)				●																		
4	Submission of Progress Report I																						
5	Construction of Gripper					■																	
	-Installed with Proximity Sensors																						
	-Install IR for Barcode Function																						
	-Attach Gripper to																						

	Platform																						
6	Submission of Log Book (week 4)																						
7	Fully Functional																						
	-Program Gripper																						
	-Program Barcode																						
	-Program Delivery																						
8	Submission of Log Book (week 5)																						
9	Submission of Log Book (week 6)																						
10	Troubleshooting and Modification																						
11	Submission of Log Book (week 7)																						
12	Submission of Progress Report II																						
13	Submission of Log Book (week 8)																						

APPENDIX B

PROGRAM CODES

```
#include<16f877.h>
#include<stdio.h>

#fuses HS,NOWDT,NOPROTECT,NOPUT,NOBROWNOUT,NOLVP
#use delay (clock=4000000)

#define LTL input(PIN_B7)
#define LTC input(PIN_B6)
#define LTR input(PIN_B5)
#define bar2 input(PIN_C3)
#define bar1 input(PIN_D0)
#define JUNC input(PIN_C2)
// #define bar3 input(PIN_D1)

int junction = 0;
int a=0;
int counter=0;

/*line tracking function*/

void run()
{
   if((LTL == 1 && LTC == 1 && LTR == 1) || (LTL == 0 && LTC == 1 && LTR ==
0)) /*go straight; forward right and left wheel*/
      {
      output_high(PIN_D3);
      output_low(PIN_C4);
      output_high(PIN_C5);
      output_low(PIN_C6);
      }

   else if((LTL == 0 && LTC == 1 && LTR == 1) || (LTL == 0 && LTC == 0 &&
LTR == 1)) /* turn right; stop right wheel and forward left wheel*/
      {
      output_high(PIN_D3);
      output_low(PIN_C4);
```

```
      output_low(PIN_C5);

      output_low(PIN_C6);

      }

   else if((LTL == 1 && LTC == 1 && LTR == 0) || (LTL == 1 && LTC == 0 &&
LTR == 1)) /*turn left; stop left wheel, and forward right wheel*/

      {

      output_low(PIN_D3);

      output_low(PIN_C4);

      output_high(PIN_C5);

      output_low(PIN_C6);

      }


   else /*stop if all 0's*/

      {

      output_low(PIN_D3);

      output_low(PIN_C4);

      output_low(PIN_C5);

      output_low(PIN_C6);

      }

}


/* junction counter*/

void junction_count()

{

   junction++;

}


/*stop locomotion*/

void stop()

{

    output_low(PIN_D3);

    output_low(PIN_C4);

    output_low(PIN_C5);

    output_low(PIN_C6);

}
```

```
/*gripper fucntion*/
void gripper()
{
while(1)
   {
   if(a==1)
      {
      output_high(PIN_A1);  // open gripper for drop off
      delay_us(1600);
      output_low(PIN_A1);
      delay_ms(20);
      }
   else
      {
      output_high(PIN_A1); // close gripper for pick up
      delay_us(700);
      output_low(PIN_A1);
      delay_ms(20);
      }
   }
}

void turn_right() //turn right 90 degrees
{
   output_high(PIN_C5);
   output_low(PIN_C6);
   output_high(PIN_C4);
   output_low(PIN_D3);
   delay_ms(2000);
}

void turn_left() //turn left 90 degrees
{
   output_high(PIN_C6);
```

```
    output_low(PIN_C5);
    output_high(PIN_D3);
    output_low(PIN_C4);
    delay_ms(2000);
}

void turn_right180() //turn right 180 degrees
{
    output_high(PIN_C5);
    output_low(PIN_C6);
    output_high(PIN_C4);
    output_low(PIN_D3);
    delay_ms(4000);
}

void turn_left180() //turn left 180 degrees
{
    output_high(PIN_C6);
    output_low(PIN_C5);
    output_high(PIN_D3);
    output_low(PIN_C4);
    delay_ms(4000);
}

void return_belt()
{
    a=0;
    turn_left180();
    run();
}

void bar_sense()
{
    if(bar1 == 0 && bar2 == 0 ) //drop off point is C
    {
```

```
a=1;
turn_left180();
run();
   if (counter ==1)
   {
   stop();
   turn_right();
   run();
   }
   else if(counter == 2)
   {
   stop();
   turn_left();
   run();
   }
   else if(counter==3)
   {
   stop();
   }
   else if(counter==4)
   {
   stop();
   turn_right();
   run();
   }
   else if(counter==5)
   {
   stop();
   turn_left();
   run();
   }
   else if (counter=6)
   {
   stop();
   counter=0;
```

```
    }
}

else if (bar0 == 0 && bar2 == 1) //drop of point is D
{
a=1;
turn_left180();
run();
    if (counter ==1)
    {
    stop();
    turn_right();
    run();
    }
    else if(counter == 3)
    {
    stop();
    turn_right();
    run();
    }
    else if(counter==4)
    {
    stop();
    a=0;
    turn_left180();
    run();
    }
    else if(counter==5)
    {
    stop();
    turn_left();
    run();
    }
    else if(counter==7)
    {
```

```
    stop();
    turn_left();
    run();
    }
    else if (counter=8)
    {
    stop();
    counter=0;
    }
}

else if (bar1 == 1 && bar2 == 0) //drop off point is E
{
a=1;
turn_left180();
run();
    if (counter ==1)
    {
    stop();
    turn_right();
    run();
    }
    else if(counter == 4)
    {
    stop();
    turn_left();
    run();
    }
    else if(counter==5)
    {
    stop();
    a=0;
    turn_left180();
    run();
    }
```

```
        else if(counter==6)
        {
        stop();
        turn_right();
        run();
        }
        else if(counter==9)
        {
        stop();
        turn_left();
        run();
        }
        else if (counter=10)
        {
        stop();
        counter=0;
        }
    }
    else
    {
    }
}

void main()
{
//setup_ccp1(CCP_PWM); //pwm disabled, speed control disabled
//setup_ccp2(CCP_PWM);
//setup_timer_2(T2_DIV_BY_4, 255, 1);

output_high(PIN_B4); //on buzzer for 2ms
delay_ms(2000);
output_low(PIN_B4);

while(1)
run();
```

```
if (junction==0)
   {
   run();
   }

else if (junction==1)
   {
   stop();
   turn_right();
   run();
   }

else if (junction==2)
   {
   stop();
   barsense();
   }

else if(junction==3)
   {counter++;
   }
else
   {
   }
}
```

APPENDIX C

PIC 16F87X DATASHEET

MICROCHIP

PIC16F87X

28/40-pin 8-Bit CMOS FLASH Microcontrollers

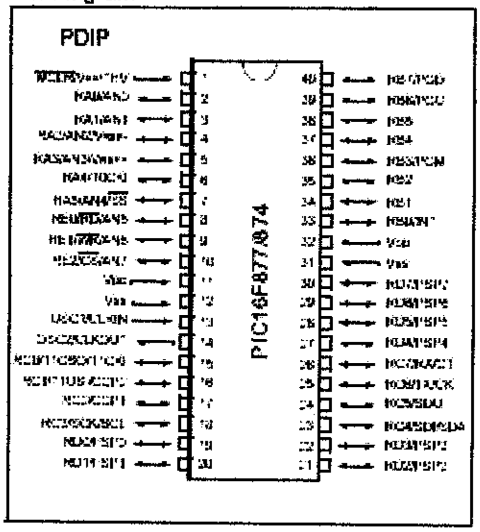
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- 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 368 x 8 bytes of Data Memory (RAM) Up to 256 x 8 bytes of EEPROM data memory
- Pinout compatible to the PIC16C73B/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 (PWRT) 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

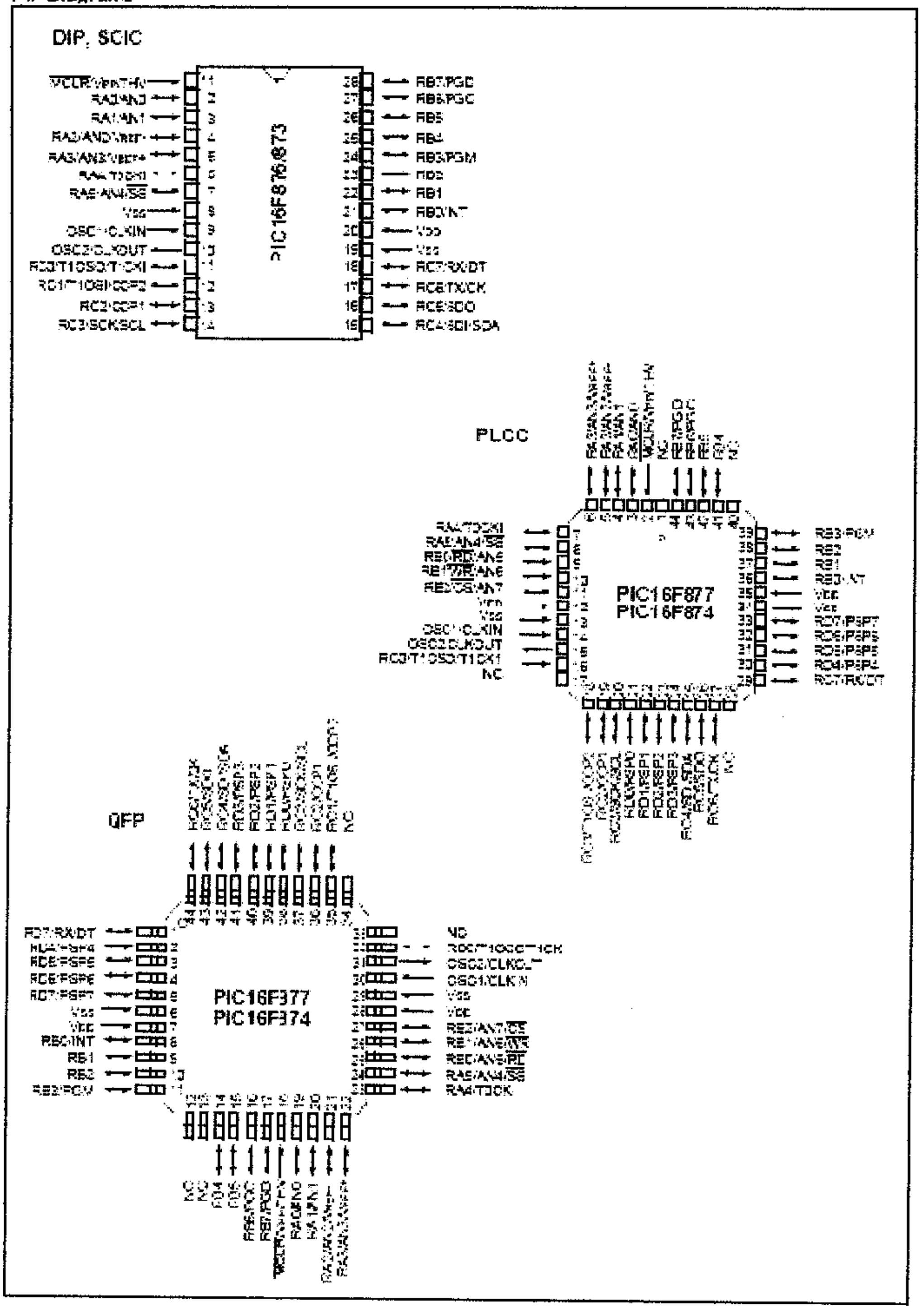
Pin Diagram



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 Mode) 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)

Pin Diagrams



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	368	368
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	8 input channels	5 input channels	8 input channels
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions

1.0 DEVICE OVERVIEW

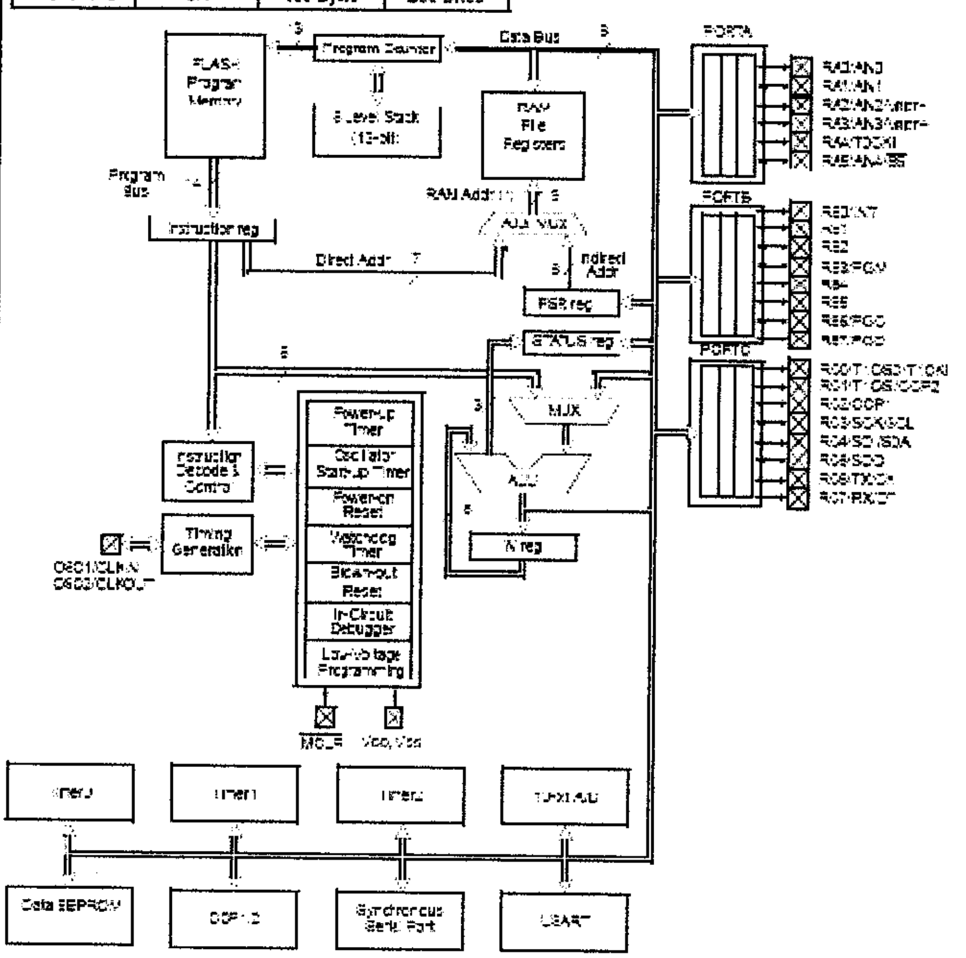
This document contains device-specific information. Additional information may be found in the PICmicro™ Mid-Range Reference Manual, (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip website. The Reference Manual should be considered a complementary 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

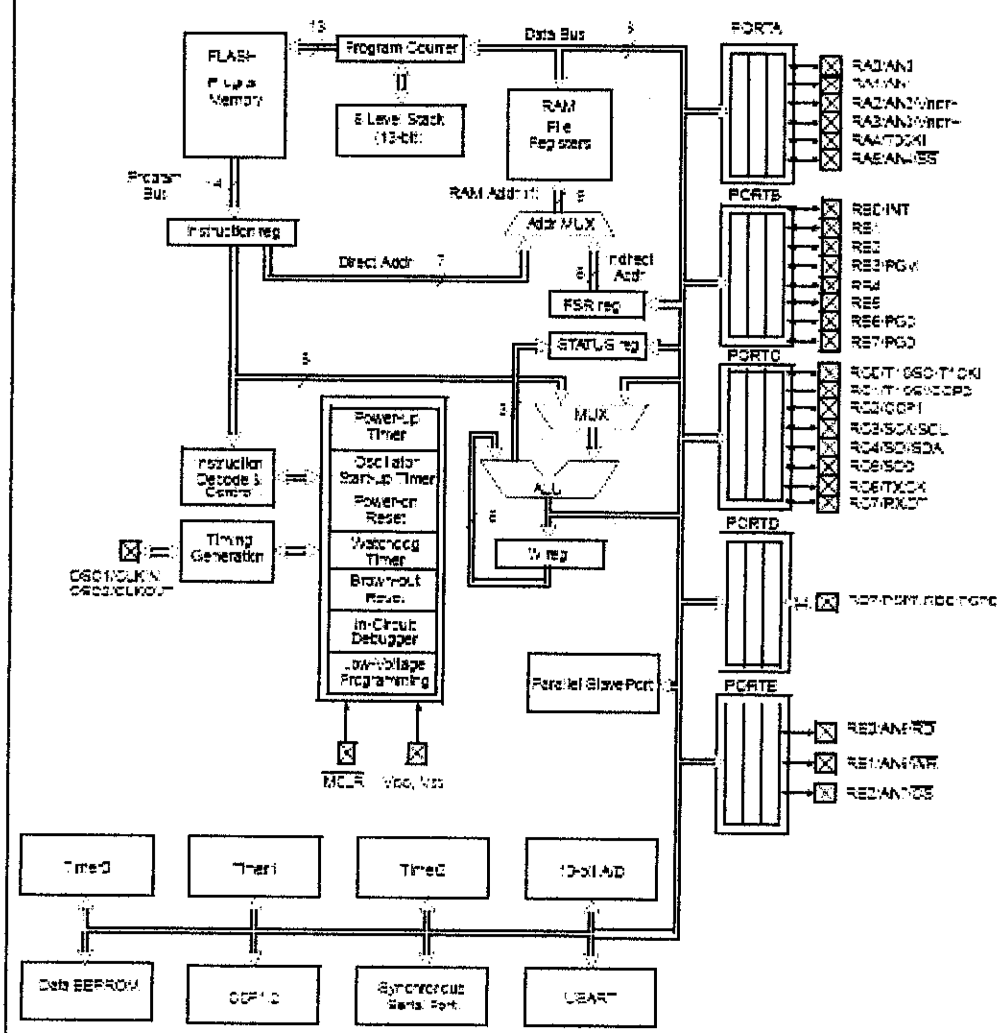
Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

FIGURE 1-2: PIC16F874 AND PIC16F877 BLOCK DIAGRAM

Device	Program FLASH	Data Memory	Data EEPROM
PIC16F874	4K	192 Bytes	128 Bytes
PIC16F877	8K	368 Bytes	256 Bytes



Note 1: Higher order bits are from the STATUS register.

TABLE 1-1: PIC16F873 AND PIC16F876 PINOUT DESCRIPTION

Pin Name	DIP Pin#	SOIC Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	9	9	I	ST/CMOS(3)	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.
$\overline{MCLR}$/VPP/THV	1	1	I/P	ST	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
					PORTA is a bi-directional I/O port.
RA0/AN0	2	2	I/O	TTL	RA0 can also be analog input0
RA1/AN1	3	3	I/O	TTL	RA1 can also be analog input1
RA2/AN2/VREF-	4	4	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/VREF+	5	5	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	6	I/O	ST	RA4 can also be the clock input to the Timer0 module. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	7	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
					PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	21	21	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	22	22	I/O	TTL	
RB2	23	23	I/O	TTL	
RB3/PGM	24	24	I/O	TTL	RB3 can also be the low voltage programming input
RB4	25	25	I/O	TTL	Interrupt on change pin.
RB5	26	26	I/O	TTL	Interrupt on change pin.
RB6/PGC	27	27	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	28	28	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.
					PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	11	11	I/O	ST	RC0 can also be the Timer1 oscillator output or Timer1 clock input.
RC1/T1OSI/CCP2	12	12	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	13	13	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	14	14	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I²C modes.
RC4/SDI/SDA	15	15	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I²C mode).
RC5/SDO	16	16	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	17	17	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	18	18	I/O	ST	RC7 can also be the USART Asynchronous Receive 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 I/O = input/output P = power
— = Not used TTL = TTL input ST = 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.

TABLE 1-2: PIC16F874 AND PIC16F877 PINOUT DESCRIPTION

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	13	14	30		ST/CMOS(4)	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.
$\overline{MCLR}$/VPP/THV	1	2	18	I/P	ST	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1
RA2/AN2/VREF-	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/VREF+	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input
RB4	37	41	14	I/O	TTL	Interrupt on change pin.
RB5	38	42	15	I/O	TTL	Interrupt on change pin.
RB6/PGC	39	43	16	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.
						PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	15	16	32	I/O	ST	RC0 can also be the Timer1 oscillator output or a Timer1 clock input.
RC1/T1OSI/CCP2	16	18	35	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	17	19	36	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	18	20	37	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I^2C modes.
RC4/SDI/SDA	23	25	42	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	24	26	43	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	25	27	44	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	26	29	1	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.

Legend: I = input O = output I/O = input/output P = 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.

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

Pin Name	DIP Pin#	PLCC Pin#	QFP Pin#	I/O/P Type	Buffer Type	Description
						PORTD is a bi-directional I/O port or parallel slave port when interfacing to a microprocessor bus.
RD0/PSP0	19	21	38	I/O	ST/TTL(3)	
RD1/PSP1	20	22	39	I/O	ST/TTL(3)	
RD2/PSP2	21	23	40	I/O	ST/TTL(3)	
RD3/PSP3	22	24	41	I/O	ST/TTL(3)	
RD4/PSP4	27	30	2	I/O	ST/TTL(3)	
RD5/PSP5	28	31	3	I/O	ST/TTL(3)	
RD6/PSP6	29	32	4	I/O	ST/TTL(3)	
RD7/PSP7	30	33	5	I/O	ST/TTL(3)	
						PORTE is a bi-directional I/O port.
RE0/$\overline{RD}$/AN5	8	9	25	I/O	ST/TTL(3)	RE0 can also be read control for the parallel slave port, or analog input5.
RE1/$\overline{WR}$/AN6	9	10	26	I/O	ST/TTL(3)	RE1 can also be write control for the parallel slave port, or analog input6.
RE2/$\overline{CS}$/AN7	10	11	27	I/O	ST/TTL(3)	RE2 can also be select control for the parallel slave port, or analog input7.
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	—	1,17,28,40	12,13,33,34		—	These pins are not internally connected. These pins should be left unconnected.

Legend: I = input O = output I/O = input/output P = 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.

3.0 I/O PORTS

Some pins for these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin.

Additional information on I/O ports may be found in the PICmicro™ Mid-Range Reference Manual, (DS33023).

3.1 PORTA and the TRISA Register

PORTA is a 6-bit wide bi-directional port. The corresponding data direction register is TRISA. Setting a TRISA bit (=1) will make the corresponding PORTA pin an input (i.e., put the corresponding output driver in a hi-impedance mode). Clearing a TRISA bit (=0) will make the corresponding PORTA pin an output (i.e., put the contents of the output latch on the selected pin).

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

Pin RA4 is multiplexed with the Timer0 module clock input to become the RA4/T0CKI pin. The RA4/T0CKI pin is a Schmitt Trigger input and an open drain output. All other PORTA pins have TTL input levels and full CMOS output drivers.

Other PORTA pins are multiplexed with analog inputs and analog VREF input. The operation of each pin is selected by clearing/setting the control bits in the ADCON1 register (A/D Control Register1).

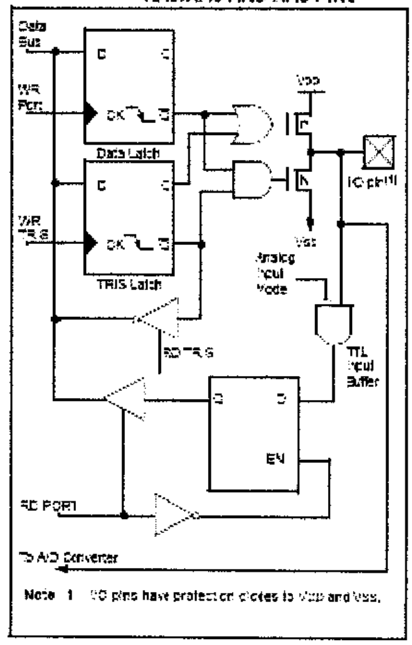
Note:	On a Power-on Reset, these pins are configured as analog inputs and read as '0'.

The TRISA register controls the direction of the RA pins, even when they are being used as analog inputs. The user must ensure the bits in the TRISA register are maintained set when using them as analog inputs.

EXAMPLE 3-1: INITIALIZING PORTA

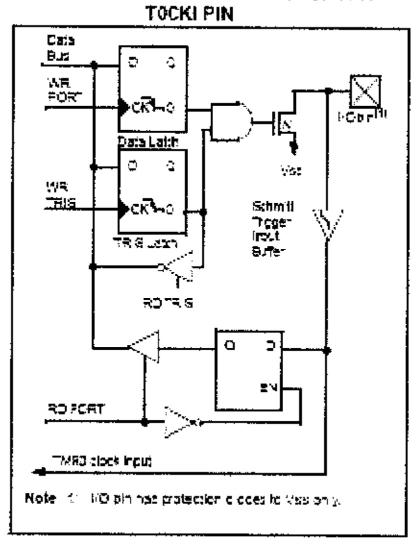
```
BCF     STATUS, RP0   ;
BCF     STATUS, RP1   ; Bank0
CLRF    PORTA         ; Initialize PORTA by
                      ; clearing output
                      ; data latches
BSF     STATUS, RP0   ; Select Bank 1
MOVLW   0x06          ; Configure all pins
MOVWF   ADCON1        ; as digital inputs
MOVLW   0xCF          ; Value used to
                      ; initialize data
                      ; direction
MOVWF   TRISA         ; Set RA<3:0> as inputs
                      ; RA<5:4> as outputs
                      ; TRISA<7:6> are always
                      ; read as '0'.
```

FIGURE 3-1: BLOCK DIAGRAM OF RA3:RA0 AND RA5 PINS



Note 1: I/O pins have protection diodes to VDD and VSS.

FIGURE 3-2: BLOCK DIAGRAM OF RA4/T0CKI PIN



Note 1: I/O pin has protection diodes to VSS only.

TABLE 3-1: PORTA FUNCTIONS

Name	Bit#	Buffer	Function
RA0/AN0	bit0	TTL	Input/output or analog input
RA1/AN1	bit1	TTL	Input/output or analog input
RA2/AN2	bit2	TTL	Input/output or analog input
RA3/AN3/V_{REF}	bit3	TTL	Input/output or analog input or V_{REF}
RA4/T0CKI	bit4	ST	Input/output or external clock input for Timer0 Output is open drain type
RA5/SS/AN4	bit5	TTL	Input/output or slave select input for synchronous serial port or analog input

Legend: TTL = TTL input, ST = Schmitt Trigger input

TABLE 3-2: SUMMARY OF REGISTERS ASSOCIATED WITH PORTA

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
05h	PORTA	—	—	RA5	RA4	RA3	RA2	RA1	RA0	--0x 0000	--0u 0000
85h	TRISA	—	—	PORTA Data Direction Register						--11 1111	--11 1111
9Fh	ADCON1	ADFM	—	—	—	PCFG3	PCFG2	PCFG1	PCFG0	--0- 0000	--0- 0000

Legend: x = unknown, u = unchanged, - = unimplemented locations read as '0'. Shaded cells are not used by PORTA.

Note: When using the SSP module in SPI slave mode and SS enabled, the A/D converter must be set to one of the following modes where PCFG3:PCFG0 = 0100, 0101, 011x, 1101, 1110, 1111.

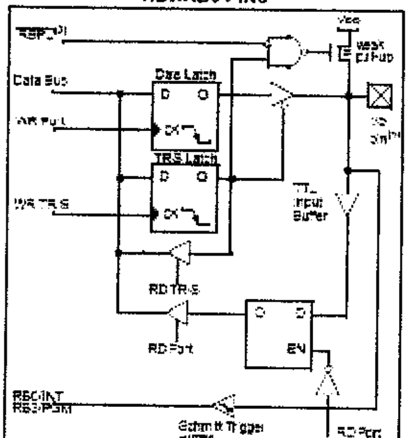
3.2 PORTB and the TRISB Register

PORTB is an 8-bit wide, bi-directional port. The corresponding data direction register is TRISB. Setting a TRISB bit (=1) will make the corresponding PORTB pin an input (i.e., put the corresponding output driver in a hi-impedance mode). Clearing a TRISB bit (=0) will make the corresponding PORTB pin an output (i.e., put the contents of the output latch on the selected pin).

Three pins of PORTB are multiplexed with the Low Voltage Programming function: RB3/PGM, RB6/PGC and RB7/PGD. The alternate functions of these pins are described in the Special Features Section.

Each of the PORTB pins has a weak internal pull-up. A single control bit can turn on all the pull-ups. This is performed by clearing bit RBPU (OPTION_REG<7>). The weak pull-up is automatically turned off when the port pin is configured as an output. The pull-ups are disabled on a Power-on Reset.

FIGURE 3-3: BLOCK DIAGRAM OF RB3:RB0 PINS



Note 1: I/O pins have diode protection to VDD and VSS.
2: To enable weak pull-ups, set the appropriate TRIS bit(s) and clear the RBPU bit (OPTION_REG<7>).

Four of PORTB's pins, RB7:RB4, have an interrupt on change feature. Only pins configured as inputs can cause this interrupt to occur (i.e., any RB7:RB4 pin configured as an output is excluded from the interrupt on change comparison). The input pins (of RB7:RB4) are compared with the old value latched on the last read of PORTB. The "mismatch" outputs of RB7:RB4 are OR'ed together to generate the RB Port Change Interrupt with flag bit RBIF (INTCON<0>).

This interrupt can wake the device from SLEEP. The user, in the interrupt service routine, can clear the interrupt in the following manner:

a) Any read or write of PORTB. This will end the mismatch condition.

b) Clear flag bit RBIF.

A mismatch condition will continue to set flag bit RBIF. Reading PORTB will end the mismatch condition and allow flag bit RBIF to be cleared.

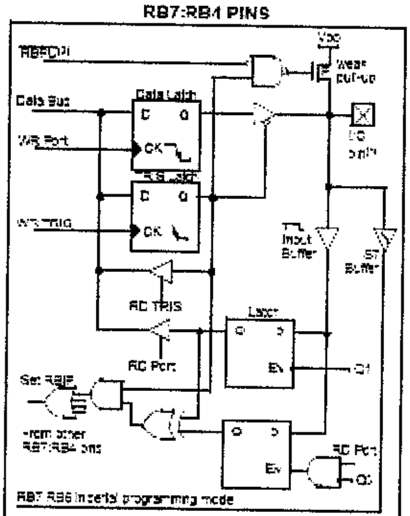
The interrupt on change feature is recommended for wake-up on key depression operation and operations where PORTB is only used for the interrupt on change feature. Polling of PORTB is not recommended while using the interrupt on change feature.

This interrupt on mismatch feature, together with software configureable pull-ups on these four pins, allow easy interface to a keypad and make it possible for wake-up on key-depression. Refer to the Embedded Control Handbook, *"Implementing Wake-Up on Key Stroke"* (AN552).

RB0/INT is an external interrupt input pin and is configured using the INTEDG bit (OPTION_REG<6>).

RB0/INT is discussed in detail in Section 12.10.1.

FIGURE 3-4: BLOCK DIAGRAM OF RB7:RB4 PINS



Note 1: I/O pins have diode protection to VDD and VSS.
2: To enable weak pull-ups, set the appropriate TRIS bit(s) and clear the RBPU bit (OPTION_REG<7>).

Note: When using Low Voltage ICSP Programming (LVP) and the pull-ups on PORTB are enabled, bit 3 in the TRISB register must be cleared to disable the pull-up on RB3 and ensure the proper operation of the device.

TABLE 3-3: PORTB FUNCTIONS

Name	Bit#	Buffer	Function
RB0/INT	bit0	TTL/ST(1)	Input/output pin or external interrupt input. Internal software programmable weak pull-up.
RB1	bit1	TTL	Input/output pin. Internal software programmable weak pull-up.
RB2	bit2	TTL	Input/output pin. Internal software programmable weak pull-up.
RB3/PGM	bit3	TTL	Input/output pin or programming pin in LVP mode. Internal software programmable weak pull-up.
RB4	bit4	TTL	Input/output pin (with interrupt on change). Internal software programmable weak pull-up.
RB5	bit5	TTL	Input/output pin (with interrupt on change). Internal software programmable weak pull-up.
RB6/PGC	bit6	TTL/ST(2)	Input/output pin (with interrupt on change) or In-Circuit Debugger pin. Internal software programmable weak pull-up. Serial programming clock.
RB7/PGD	bit7	TTL/ST(2)	Input/output pin (with interrupt on change) or In-Circuit Debugger pin. Internal software programmable weak pull-up. Serial programming data.

Legend: TTL = TTL input, ST = 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.

TABLE 3-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTB

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
06h, 106h	PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	xxxx xxxx	uuuu uuuu
86h, 186h	TRISB	PORTB Data Direction Register								1111 1111	1111 1111
81h, 181h	OPTION_REG	RBPU	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0	1111 1111	1111 1111

Legend: x = unknown, u = unchanged. Shaded cells are not used by PORTB.

3.3 PORTC and the TRISC Register

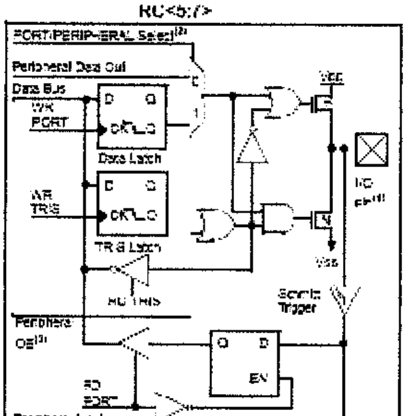
PORTC is an 8-bit wide, bi-directional port. The corresponding data direction register is TRISC. Setting a TRISC bit (=1) will make the corresponding PORTC pin an input (i.e., put the corresponding output driver in a hi-impedance mode). Clearing a TRISC bit (=0) will make the corresponding PORTC pin an output (i.e., put the contents of the output latch on the selected pin).

PORTC is multiplexed with several peripheral functions (Table 3-5). PORTC pins have Schmitt Trigger input buffers.

When the I²C module is enabled, the PORTC (3:4) pins can be configured with normal I²C levels or with SMBUS levels by using the CKE bit (SSPSTAT <6>).

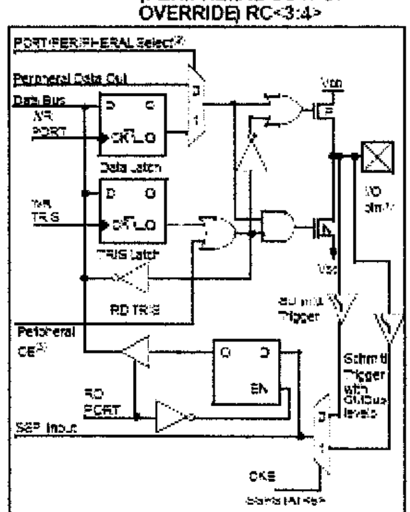
When enabling peripheral functions, care should be taken in defining TRIS bits for each PORTC pin. Some peripherals override the TRIS bit to make a pin an output, while other peripherals override the TRIS bit to make a pin an input. Since the TRIS bit override is in effect while the peripheral is enabled, read-modify-write instructions (BSF, BCF, XORWF) with TRISC as destination should be avoided. The user should refer to the corresponding peripheral section for the correct TRIS bit settings.

FIGURE 3-5: PORTC BLOCK DIAGRAM (PERIPHERAL OUTPUT OVERRIDE) RC<0:2> RC<5:7>



Note 1: I/O pins have diode protection to VDD and VSS.
2: Port/Peripheral select signal selects between port data and peripheral output.
3: Peripheral OE (output enable) is only activated if peripheral select is active.

FIGURE 3-6: PORTC BLOCK DIAGRAM (PERIPHERAL OUTPUT OVERRIDE) RC<3:4>



Note 1: I/O pins have diode protection to VDD and VSS.
2: Port/Peripheral select signal selects between port data and peripheral output.
3: Peripheral OE (output enable) is only activated if peripheral select is active.

TABLE 3-5: PORTC FUNCTIONS

Name	Bit#	Buffer Type	Function
RC0/T1OSO/T1CKI	bit0	ST	Input/output port pin or Timer1 oscillator output/Timer1 clock input
RC1/T1OSI/CCP2	bit1	ST	Input/output port pin or Timer1 oscillator input or Capture2 input/ Compare2 output/PWM2 output
RC2/CCP1	bit2	ST	Input/output port pin or Capture1 input/Compare1 output/PWM1 output
RC3/SCK/SCL	bit3	ST	RC3 can also be the synchronous serial clock for both SPI and I^2C modes.
RC4/SDI/SDA	bit4	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C mode).
RC5/SDO	bit5	ST	Input/output port pin or Synchronous Serial Port data output
RC6/TX/CK	bit6	ST	Input/output port pin or USART Asynchronous Transmit or Synchronous Clock
RC7/RX/DT	bit7	ST	Input/output port pin or USART Asynchronous Receive or Synchronous Data

Legend: ST = Schmitt Trigger input

TABLE 3-6: SUMMARY OF REGISTERS ASSOCIATED WITH PORTC

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
07h	PORTC	RC7	RC6	RC5	RC4	RC3	RC2	RC1	RC0	xxxx xxxx	uuuu uuuu
87h	TRISC	PORTC Data Direction Register								1111 1111	1111 1111

Legend: x = unknown, u = unchanged.

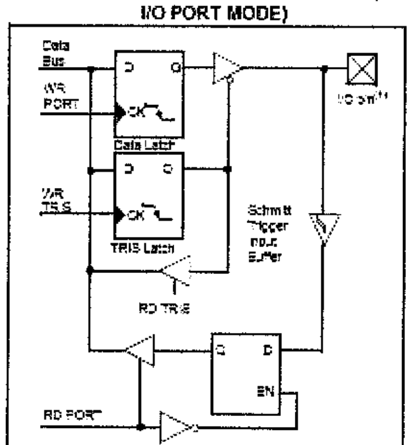
3.4 PORTD and TRISD Registers

This section is not applicable to the PIC16F873 or PIC16F876.

PORTD is an 8-bit port with Schmitt Trigger input buffers. Each pin is individually configurable as an input or output.

PORTD can be configured as an 8-bit wide microprocessor port (parallel slave port) by setting control bit PSPMODE (TRISE<4>). In this mode, the input buffers are TTL.

FIGURE 3-7: PORTD BLOCK DIAGRAM (IN I/O PORT MODE)



Note 1: I/O pins have protection diodes to VDD and VSS.

TABLE 3-7: PORTD FUNCTIONS

Name	Bit#	Buffer Type	Function
RD0/PSP0	bit0	ST/TTL(1)	Input/output port pin or parallel slave port bit0
RD1/PSP1	bit1	ST/TTL(1)	Input/output port pin or parallel slave port bit1
RD2/PSP2	bit2	ST/TTL(1)	Input/output port pin or parallel slave port bit2
RD3/PSP3	bit3	ST/TTL(1)	Input/output port pin or parallel slave port bit3
RD4/PSP4	bit4	ST/TTL(1)	Input/output port pin or parallel slave port bit4
RD5/PSP5	bit5	ST/TTL(1)	Input/output port pin or parallel slave port bit5
RD6/PSP6	bit6	ST/TTL(1)	Input/output port pin or parallel slave port bit6
RD7/PSP7	bit7	ST/TTL(1)	Input/output port pin or parallel slave port bit7

Legend: ST = Schmitt Trigger input TTL = TTL input

Note 1: Input buffers are Schmitt Triggers when in I/O mode and TTL buffer when in Parallel Slave Port Mode.

TABLE 3-8: SUMMARY OF REGISTERS ASSOCIATED WITH PORTD

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
08h	PORTD	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD0	xxxx xxxx	uuuu uuuu
88h	TRISD	PORTD Data Direction Register								1111 1111	1111 1111
89h	TRISE	IBF	OBF	IBOV	PSPMODE	—	PORTE Data Direction Bits			0000 -111	0000 -111

Legend: x = unknown, u = unchanged, - = unimplemented read as '0'. Shaded cells are not used by PORTD.

3.5 PORTE and TRISE Register

This section is not applicable to the PIC16F873 or PIC16F876.

PORTE has three pins, RE0/$\overline{RD}$/AN5, RE1/$\overline{WR}$/AN6 and RE2/$\overline{CS}$/AN7, which are individually configurable as inputs or outputs. These pins have Schmitt Trigger input buffers.

I/O PORTE becomes control inputs for the microprocessor port when bit PSPMODE (TRISE<4>) is set. In this mode, the user must make sure that the TRISE<2:0> bits are set (pins are configured as digital inputs). Ensure ADCON1 is configured for digital I/O. In this mode, the input buffers are TTL.

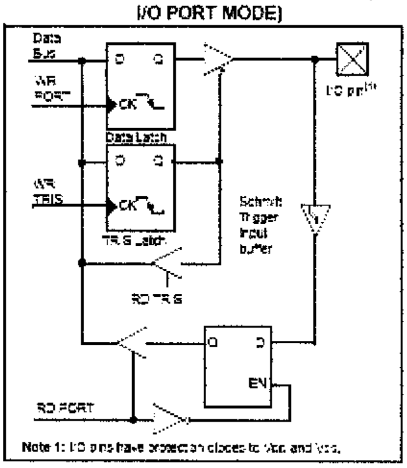
Register 3-1 shows the TRISE register, which also controls the parallel slave port operation.

PORTE pins are multiplexed with analog inputs. When selected as an analog input, these pins will read as '0's.

TRISE controls the direction of the RE pins, even when they are being used as analog inputs. The user must make sure to keep the pins configured as inputs when using them as analog inputs.

Note:	On a Power-on Reset, these pins are configured as analog inputs.

FIGURE 3-8: PORTE BLOCK DIAGRAM (IN I/O PORT MODE)



Note 1: I/O pins have protection diodes to VDD and VSS.

REGISTER 3-1: TRISE REGISTER (ADDRESS 89h)

R-0	R-0	R/W-0	R/W-0	U-0	R/W-1	R/W-1	R/W-1
IBF	OBF	IBOV	PSPMODE	—	bit2	bit1	bit0
bit7							bit0

R = Readable bit
W = Writable bit
U = Unimplemented bit, read as '0'
- n= Value at POR reset

Parallel Slave Port Status/Control Bits

bit 7: **IBF**: Input Buffer Full Status bit
1 = A word has been received and is waiting to be read by the CPU
0 = No word has been received

bit 6: **OBF**: Output Buffer Full Status bit
1 = The output buffer still holds a previously written word
0 = The output buffer has been read

bit 5: **IBOV**: Input Buffer Overflow Detect bit (in microprocessor mode)
1 = A write occurred when a previously input word has not been read (must be cleared in software)
0 = No overflow occurred

bit 4: **PSPMODE**: Parallel Slave Port Mode Select bit
1 = Parallel slave port mode
0 = General purpose I/O mode

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

PORTE Data Direction Bits

bit 2: **Bit2**: Direction Control bit for pin RE2/$\overline{CS}$/AN7
1 = Input
0 = Output

bit 1: **Bit1**: Direction Control bit for pin RE1/$\overline{WR}$/AN6
1 = Input
0 = Output

bit 0: **Bit0**: Direction Control bit for pin RE0/$\overline{RD}$/AN5
1 = Input
0 = Output

TABLE 3-9: PORTE FUNCTIONS

Name	Bit#	Buffer Type	Function
RE0/$\overline{RD}$/AN5	bit0	ST/TTL[1]	Input/output port pin or read control input in parallel slave port mode or analog input: $\overline{RD}$ 1 = Not a read operation 0 = Read operation. Reads PORTD register (if chip selected)
RE1/$\overline{WR}$/AN6	bit1	ST/TTL[1]	Input/output port pin or write control input in parallel slave port mode or analog input: $\overline{WR}$ 1 = Not a write operation 0 = Write operation. Writes PORTD register (if chip selected)
RE2/$\overline{CS}$/AN7	bit2	ST/TTL[1]	Input/output port pin or chip select control input in parallel slave port mode or analog input: $\overline{CS}$ 1 = Device is not selected 0 = Device is selected

Legend: ST = Schmitt Trigger input TTL = TTL input

Note 1: Input buffers are Schmitt Triggers when in I/O mode and TTL buffers when in Parallel Slave Port Mode.

TABLE 3-10: SUMMARY OF REGISTERS ASSOCIATED WITH PORTE

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
09h	PORTE	—	—	—	—	—	RE2	RE1	RE0	---- -xxx	---- -uuu
89h	TRISE	IBF	OBF	IBOV	PSPMODE	—	PORTE Data Direction Bits			0000 -111	0000 -111
9Fh	ADCON1	ADFM	—	—	—	PCFG3	PCFG2	PCFG1	PCFG0	--0- 0000	--0- 0000

Legend: x = unknown, u = unchanged, - = unimplemented read as '0'. Shaded cells are not used by PORTE.

5.2 Using Timer0 with an External Clock

When no prescaler is used, the external clock input is the same as the prescaler output. The synchronization of T0CKI with the internal phase clocks is accomplished by sampling the prescaler output on the Q2 and Q4 cycles of the internal phase clocks. Therefore, it is necessary for T0CKI to be high for at least 2Tosc (and a small RC delay of 20 ns) and low for at least 2Tosc (and a small RC delay of 20 ns). Refer to the electrical specification of the desired device.

5.3 Prescaler

There is only one prescaler available, which is mutually exclusively shared between the Timer0 module and the watchdog timer. A prescaler assignment for the Timer0 module means that there is no prescaler for the watchdog timer, and vice-versa. This prescaler is not readable or writable (see Figure 5-1).

The PSA and PS2:PS0 bits (OPTION_REG<3:0>) determine the prescaler assignment and prescale ratio.

When assigned to the Timer0 module, all instructions writing to the TMR0 register (e.g. CLRF 1, MOVWF 1, BSF 1,x....etc.) will clear the prescaler. When assigned to WDT, a CLRWDT instruction will clear the prescaler along with the Watchdog Timer. The prescaler is not readable or writable.

Note: Writing to TMR0, when the prescaler is assigned to Timer0 will clear the prescaler count, but will not change the prescaler assignment.

REGISTER 5-1: OPTION_REG REGISTER

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
RBPU	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0
bit 7							bit 0

R = Readable bit
W = Writable bit
U = Unimplemented bit, read as '0'
- n = Value at POR reset

bit 7: **RBPU**

bit 6: **INTEDG**

bit 5: **T0CS**: TMR0 Clock Source Select bit
1 = Transition on T0CKI pin
0 = Internal instruction cycle clock (CLKOUT)

bit 4: **T0SE**: TMR0 Source Edge Select bit
1 = Increment on high-to-low transition on T0CKI pin
0 = Increment on low-to-high transition on T0CKI pin

bit 3: **PSA**: Prescaler Assignment bit
1 = Prescaler is assigned to the WDT
0 = Prescaler is assigned to the Timer0 module

bit 2-0: **PS2:PS0**: Prescaler Rate Select bits

Bit Value	TMR0 Rate	WDT Rate
000	1 : 2	1 : 1
001	1 : 4	1 : 2
010	1 : 8	1 : 4
011	1 : 16	1 : 8
100	1 : 32	1 : 16
101	1 : 64	1 : 32
110	1 : 128	1 : 64
111	1 : 256	1 : 128

Note: To avoid an unintended device RESET, the instruction sequence shown in the PICmicro™ Mid-Range MCU Family Reference Manual (DS33023) must be executed when changing the prescaler assignment from Timer0 to the WDT. This sequence must be followed even if the WDT is disabled.

TABLE 5-1: REGISTERS ASSOCIATED WITH TIMER0

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on: POR, BOR	Value on all other resets
01h,101h	TMR0	Timer0 module's register								xxxx xxxx	uuuu uuuu
0Bh,8Bh, 10Bh,18Bh	INTCON	GIE	PEIE	T0IE	INTE	RBIE	T0IF	INTF	RBIF	0000 000x	0000 000u
81h,181h	OPTION_REG	$\overline{RBPU}$	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0	1111 1111	1111 1111

Legend: x = unknown, u = unchanged, - = unimplemented locations read as '0'. Shaded cells are not used by Timer0.

APPENDIX D

L78XX VOLTAGE REGULATOR DATASHEET

FAIRCHILD
SEMICONDUCTOR

www.fairchildsemi.com

KA78XX/KA78XXA

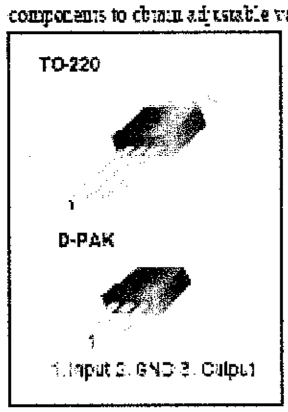
3-Terminal 1A Positive Voltage Regulator

Features

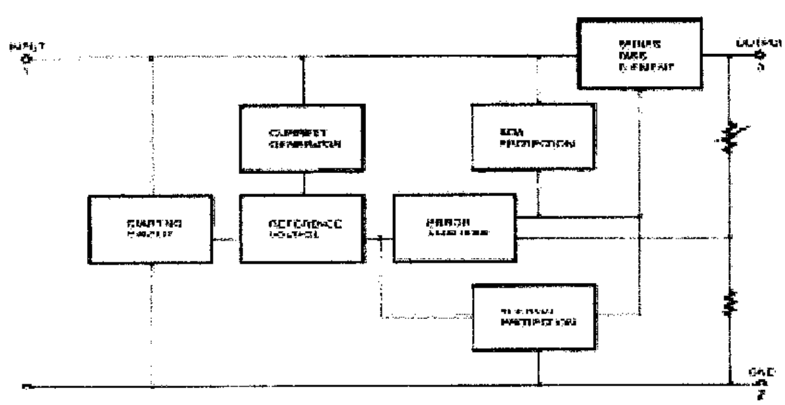
- Output Current up to 1A
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V
- Thermal Overload Protection
- Short Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The KA78XX/KA78XXA series of three-terminal positive regulator 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 Digram



Rev. 1.0.0

Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (KA78XX/A/R)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics (KA7805/KA7805R)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =10V, C_I= 0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7805 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	μV/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 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °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.

Electrical Characteristics (KA7806/KA7806R)

(Refer to test circuit, $0°C < T_J < 125°C$, I_O = 500mA, V_I = 11V, C_I = 0.33μF, C_O = 0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7806 Min.	KA7806 Typ.	KA7806 Max.	Unit
Output Voltage	V_O	T_J = +25°C		5.75	6.0	6.25	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W, V_I = 8.0V to 21V		5.7	6.0	6.3	
Line Regulation (Note1)	Regline	T_J = +25°C	V_I = 8V to 25V	-	5	120	mV
			V_I = 9V to 13V	-	1.5	60	
Load Regulation (Note1)	Regload	T_J = +25°C	I_O = 5mA to 1.5A	-	9	120	mV
			I_O = 250mA to 750mA	-	3	60	
Quiescent Current	I_Q	T_J = +25°C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8V to 25V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A = +25°C		-	45	-	μV/Vo
Ripple Rejection	RR	f = 120Hz, V_I = 9V to 19V		59	75	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J = +25°C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	19	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A = +25°C		-	250	-	mA
Peak Current	I_{PK}	T_J = +25°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.

Electrical Characteristics (KA7808/KA7808R)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =14V, C_I= 0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7808 Min.	KA7808 Typ.	KA7808 Max.	Unit
Output Voltage	V_O	T_J =+25 °C		7.7	8.0	8.3	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 10.5V to 23V		7.6	8.0	8.4	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 10.5V to 25V	-	5.0	160	mV
			V_I = 11.5V to 17V	-	2.0	80	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5.0mA to 1.5A	-	10	160	mV
			I_O= 250mA to 750mA	-	5.0	80	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.05	0.5	mA
		V_I = 10.5A to 25V		-	0.5	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-0.8	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	52	-	μV/V_O
Ripple Rejection	RR	f = 120Hz, V_I= 11.5V to 21.5V		56	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °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.

Electrical Characteristics (KA7809/KA7809R)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =16V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7809 Min.	KA7809 Typ.	KA7809 Max.	Unit
Output Voltage	V_O	T_J =+25 °C		8.65	9	9.35	V
		5.0mA≤ I_O ≤1.0A, P_O ≤15W V_I= 11.5V to 24V		8.6	9	9.4	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_I = 11.5V to 25V	-	6	180	mV
			V_I = 12V to 17V	-	2	90	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5mA to 1.5A	-	12	180	mV
			I_O = 250mA to 750mA	-	4	90	
Quiescent Current	I_Q	T_J=+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 11.5V to 26V		-	-	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f= 10Hz to 100KHz T_A=+25 °C		-	58	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 13V to 23V		56	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J= +25 °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.

Electrical Characteristics (KA7810)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =16V, C_I= 0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7810 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		9.6	10	10.4	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 12.5V to 25V		9.5	10	10.5	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 12.5V to 25V	-	10	200	mV
			V_I = 13V to 25V	-	3	100	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	12	200	mV
			I_O = 250mA to 750mA	-	4	400	
Quiescent Current	I_Q	T_J =+25 °C		-	5.1	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 12.5V to 29V		-	-	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/°C
Output Noise Voltage	V_N	f= 10Hz to 100KHz T_A=+25 °C		-	58	-	μV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 13V to 23V		56	71	-	dB
Dropout Voltage	VDrop	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	rO	f = 1KHz		-	17	-	mΩ
Short Circuit Current	ISC	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	IPK	T_J =+25 °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.

Electrical Characteristics (KA7812/KA7812R)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =19V, C_I= 0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7812/KA7812R Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		11.5	12	12.5	V
		5.0mA ≤ I_O ≤1.0A, P_O≤15W V_I = 14.5V to 27V		11.4	12	12.6	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 14.5V to 30V	-	10	240	mV
			V_I = 16V to 22V	-	3.0	120	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	11	240	mV
			I_O = 250mA to 750mA	-	5.0	120	
Quiescent Current	I_Q	T_J =+25 °C		-	5.1	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.1	0.5	mA
		V_I = 14.5V to 30V		-	0.5	1.0	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	76	-	μV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 15V to 25V		55	71	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	18	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J = +25 °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.

Electrical Characteristics (KA7815)

(Refer to test circuit ,0°C < TJ < 125°C, IO = 500mA, VI =23V, CI= 0.33µF, CO=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7815 Min.	Typ.	Max.	Unit
Output Voltage	VO	TJ =+25 °C		14.4	15	15.6	V
		5.0mA ≤ IO≤1.0A, PO≤15W VI = 17.5V to 30V		14.25	15	15.75	
Line Regulation (Note1)	Regline	TJ =+25 °C	VI = 17.5V to 30V	-	11	300	mV
			VI = 20V to 26V	-	3	150	
Load Regulation (Note1)	Regload	TJ =+25 °C	IO = 5mA to 1.5A	-	12	300	mV
			IO = 250mA to 750mA	-	4	150	
Quiescent Current	IQ	TJ =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔIQ	IO = 5mA to 1.0A		-	-	0.5	mA
		VI = 17.5V to 30V		-	-	1.0	
Output Voltage Drift	ΔVO/ΔT	IO = 5mA		-	-1	-	mV/°C
Output Noise Voltage	VN	f = 10Hz to 100KHz, TA =+25 °C		-	90	-	µV/Vo
Ripple Rejection	RR	f = 120Hz VI = 18.5V to 28.5V		54	70	-	dB
Dropout Voltage	VDrop	IO = 1A, TJ=+25 °C		-	2	-	V
Output Resistance	rO	f = 1KHz		-	19	-	mΩ
Short Circuit Current	ISC	VI = 35V, TA=+25 °C		-	250	-	mA
Peak Current	IPK	TJ =+25 °C		-	2.2	-	A

Note:

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

Electrical Characteristics (KA7818)

(Refer to test circuit ,0°C < T_J < 125°C, I_O = 500mA, V_I =27V, C_I= 0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7818			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		17.3	18	18.7	V
		5.0mA ≤ I_O ≤1.0A, P_O ≤15W V_I = 21V to 33V		17.1	18	18.9	
Line Regulation (Note1)	Regline	T_J =+25 °C	V_I = 21V to 33V	-	15	360	mV
			V_I = 24V to 30V	-	5	180	
Load Regulation (Note1)	Regload	T_J =+25 °C	I_O = 5mA to 1.5A	-	15	360	mV
			I_O = 250mA to 750mA	-	5.0	180	
Quiescent Current	I_Q	T_J =+25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	-	0.5	mA
		V_I = 21V to 33V		-	-	1	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A =+25 °C		-	110	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 22V to 32V		53	69	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J=+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	22	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A=+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J =+25 °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.

Electrical Characteristics (KA7824)

(Refer to test circuit, 0°C < T_J < 125°C, I_O = 500mA, V_I = 33V, C_I = 0.33µF, C_O = 0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		KA7824 Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J = +25 °C		23	24	25	V
		5.0mA ≤ I_O ≤ 1.0A, P_O ≤ 15W V_I = 27V to 38V		22.8	24	25.25	
Line Regulation (Note1)	Regline	T_J = +25 °C	V_I = 27V to 38V	-	17	480	mV
			V_I = 30V to 36V	-	6	240	
Load Regulation (Note1)	Regload	T_J = +25 °C	I_O = 5mA to 1.5A	-	15	480	mV
			I_O = 250mA to 750mA	-	5.0	240	
Quiescent Current	I_Q	T_J = +25 °C		-	5.2	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.1	0.5	mA
		V_I = 27V to 38V		-	0.5	1	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O = 5mA		-	-1.5	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A = +25 °C			60		µV/Vo
Ripple Rejection	RR	f = 120Hz V_I = 28V to 38V		50	67		dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J = +25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	28	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A = +25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J = +25 °C		-	2.2	-	A

Note:

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

Electrical Characteristics (KA7805A)

(Refer to the test circuits. 0°C < T_J < +125°C, I_O =1A, V_I = 10V, C_I=0.33μF, C_O=0.1μF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		4.9	5	5.1	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = 7.5V to 20V		4.8	5	5.2	
Line Regulation (Note1)	Regline	V_I = 7.5V to 25V I_O = 500mA		-	5	50	mV
		V_I = 8V to 12V		-	3	50	
		T_J =+25 °C	V_I= 7.3V to 20V	-	5	50	
			V_I= 8V to 12V	-	1.5	25	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	9	100	
		I_O = 250mA to 750mA		-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	6.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 8 V to 25V, I_O = 500mA		-	-	0.8	
		V_I = 7.5V to 20V, T_J =+25 °C		-	-	0.8	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-0.5	-	mV/°C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	μV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 8V to 18V		-	68	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J= +25 °C		-	2.2	-	A

Note:

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

Electrical Characteristics (KA7806A)

(Refer to the test circuits. 0°C < T_J < +125°C, I_O =1A, V_I = 11V, C_I=0.33µF, C_O=0.1µF, unless otherwise specified)

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Output Voltage	V_O	T_J =+25 °C		5.88	6	6.12	V
		I_O = 5mA to 1A, P_O ≤ 15W V_I = 8.6V to 21V		5.76	6	6.24	
Line Regulation (Note1)	Regline	V_I= 8.6V to 25V I_O = 500mA		-	5	60	mV
		V_I= 9V to 13V		-	3	60	
		T_J =+25 °C	V_I= 8.3V to 21V	-	5	60	
			V_I= 9V to 13V	-	1.5	30	
Load Regulation (Note1)	Regload	T_J =+25 °C I_O = 5mA to 1.5A		-	9	100	mV
		I_O = 5mA to 1A		-	4	100	
		I_O = 250mA to 750mA		-	5.0	50	
Quiescent Current	I_Q	T_J =+25 °C		-	4.3	6.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1A		-	-	0.5	mA
		V_I = 9V to 25V, I_O = 500mA		-	-	0.8	
		V_I= 8.5V to 21V, T_J =+25 °C		-	-	0.5	
Output Voltage Drift	$\Delta V/\Delta T$	I_O = 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz T_A =+25 °C		-	10	-	µV/Vo
Ripple Rejection	RR	f = 120Hz, I_O = 500mA V_I = 9V to 19V		-	65	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	r_O	f = 1KHz		-	17	-	mΩ
Short Circuit Current	I_{SC}	V_I= 35V, T_A =+25 °C		-	250	-	mA
Peak Current	I_{PK}	T_J=+25 °C		-	2.2	-	A

Note:

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

Typical Perfomance Characteristics

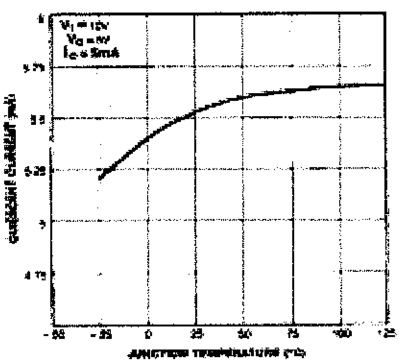


Figure 1. Quiescent Current

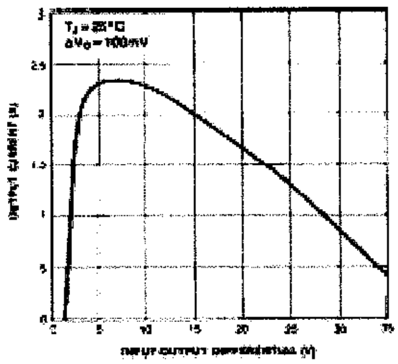


Figure 2. Peak Output Current

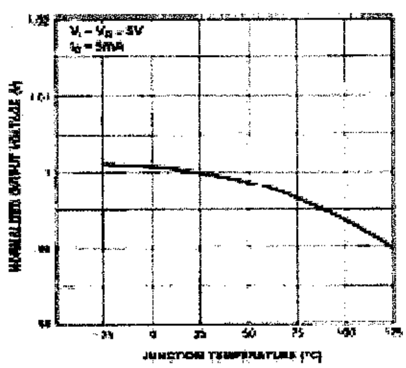


Figure 3. Output Voltage

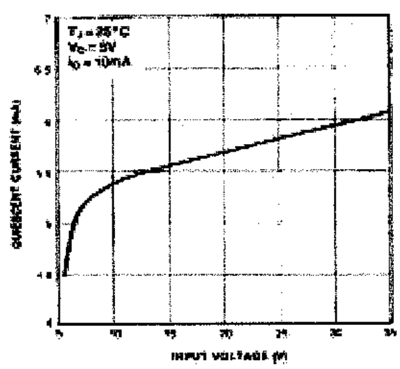


Figure 4. Quiescent Current

Typical Applications

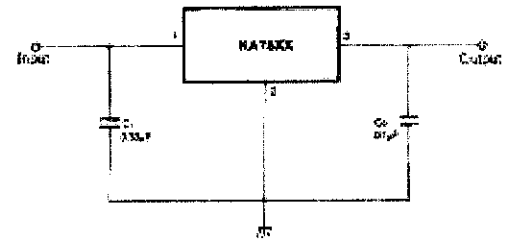


Figure 5. DC Parameters

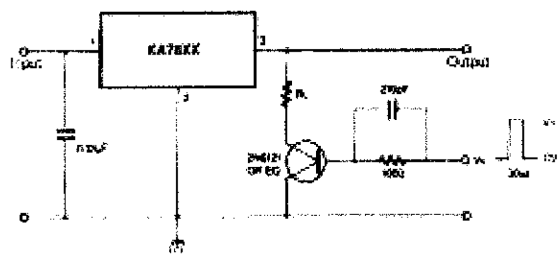


Figure 6. Load Regulation

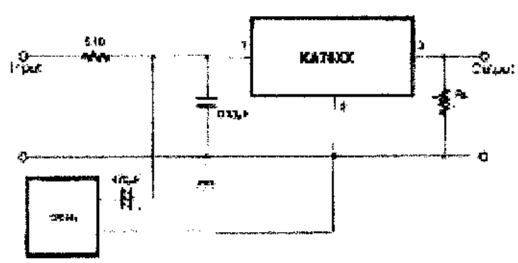


Figure 7. Ripple Rejection

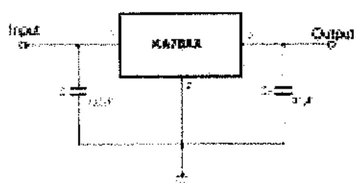
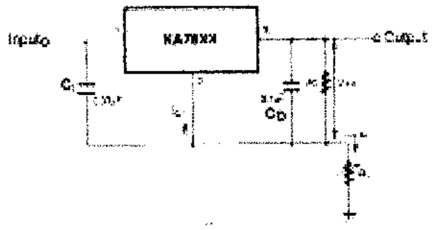


Figure 8. Fixed Output Regulator



$I_O = \frac{V_{XX}}{R_1} + I_Q$

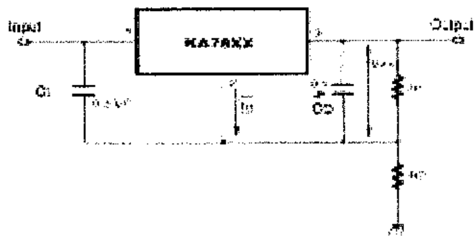
Figure 9. Constant Current Regulator

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) C_I is required if regulator is located an appreciable distance from power Supply filter.

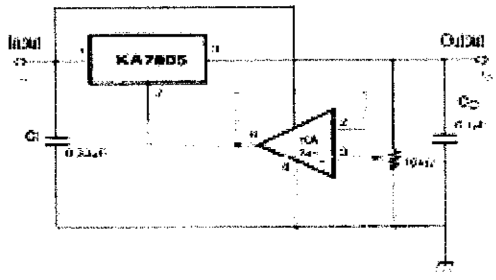
(3) C_O improves stability and transient response.



$I_{R1} \geq 5 I_Q$

$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$

Figure 10. Circuit for Increasing Output Voltage



$I_{R1} \geq 5\ I_Q$

$V_O = V_{XX}(1+R_2/R_1)+I_QR_2$

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

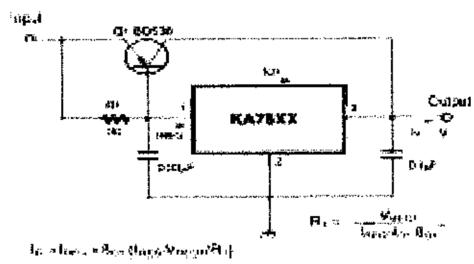


Figure 12. High Current Voltage Regulator

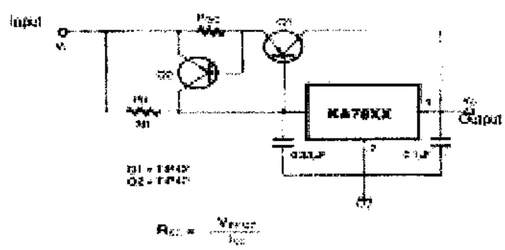


Figure 13. High Output Current with Short Circuit Protection

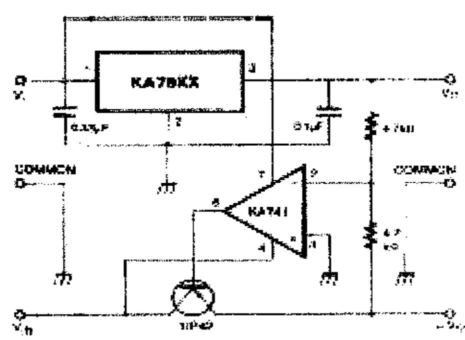
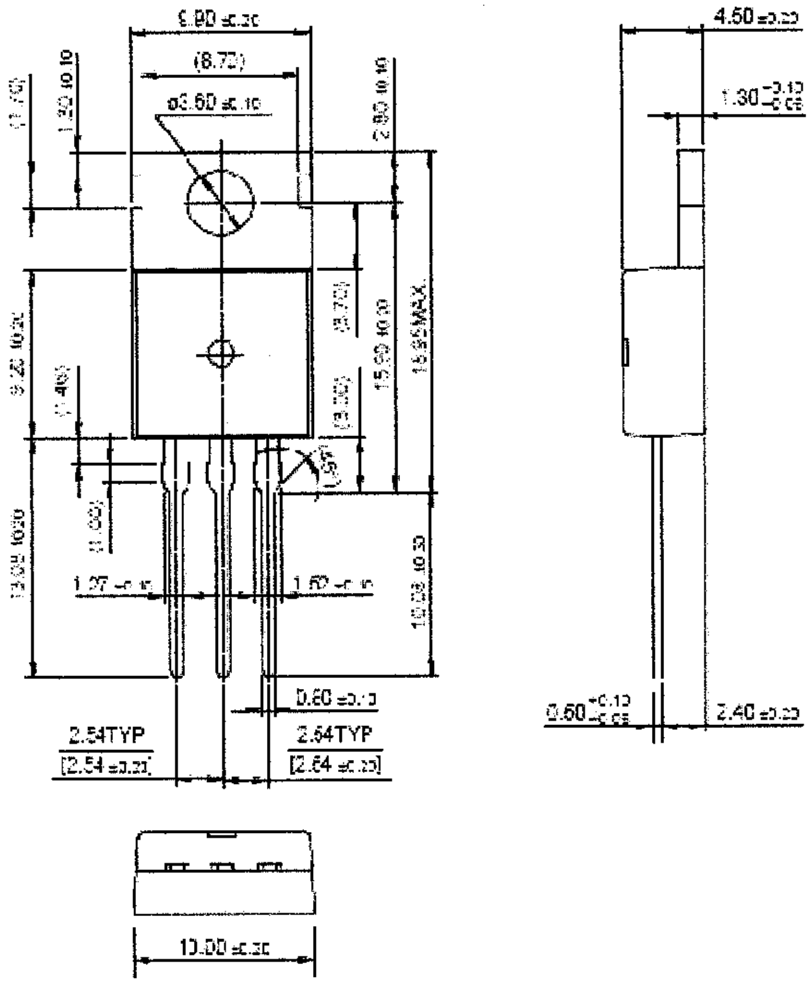


Figure 14. Tracking Voltage Regulator

Mechanical Dimensions

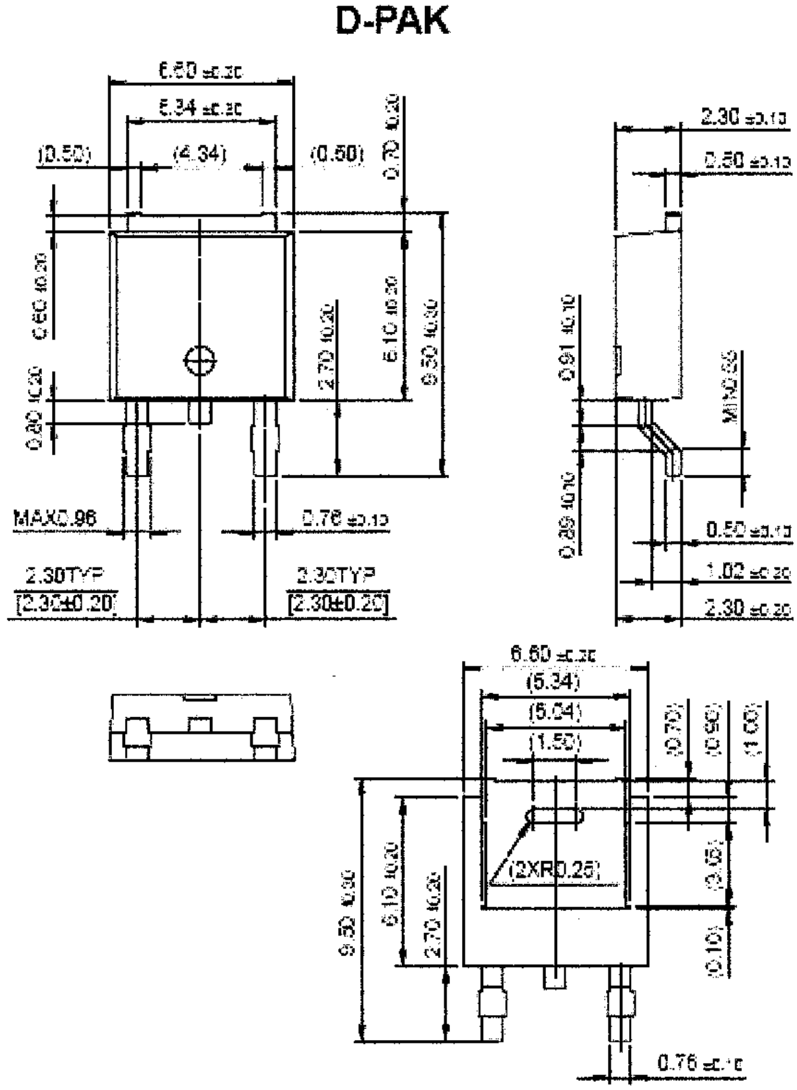
Package

TO-220



Mechancal Dimensions (Continued)

Package



Ordering Information

Product Number	Output Voltage Tolerance	Package	Operating Temperature
KA7805 / KA7806	±4%	TO-220	0 ~ + 125°C
KA7808 / KA7809			
KA7810			
KA7812 / KA7815			
KA7818 / KA7824			
KA7805A / KA7806A	±2%		
KA7808A / KA7809A			
KA7810A / KA7812A			
KA7815A / KA7818A			
KA7824A			
KA7805R / KA7806R	±4%	D-PAK	
KA7808R / KA7809R			
KA7812R			

APPENDIX E

L298N H-BRIDGE DRIVER DATASHEET

DUAL FULL-BRIDGE DRIVER

- OPERATING SUPPLY VOLTAGE UP TO 46 V
- TOTAL DC CURRENT UP TO 4 A
- LOW SATURATION VOLTAGE
- OVERTEMPERATURE PROTECTION
- LOGICAL "0" INPUT VOLTAGE UP TO 1.5 V (HIGH NOISE IMMUNITY)

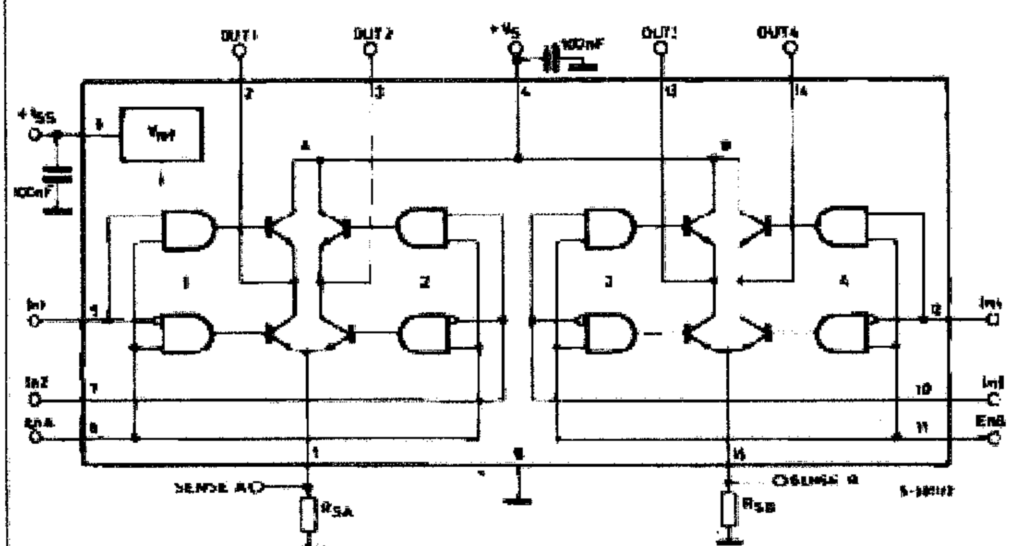
Multiwatt15 PowerSO20

ORDERING NUMBERS : L298N (Multiwatt Vert.)
L298HN (Multiwatt Horiz.)
L298P (PowerSO20)

DESCRIPTION

The L298 is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage.

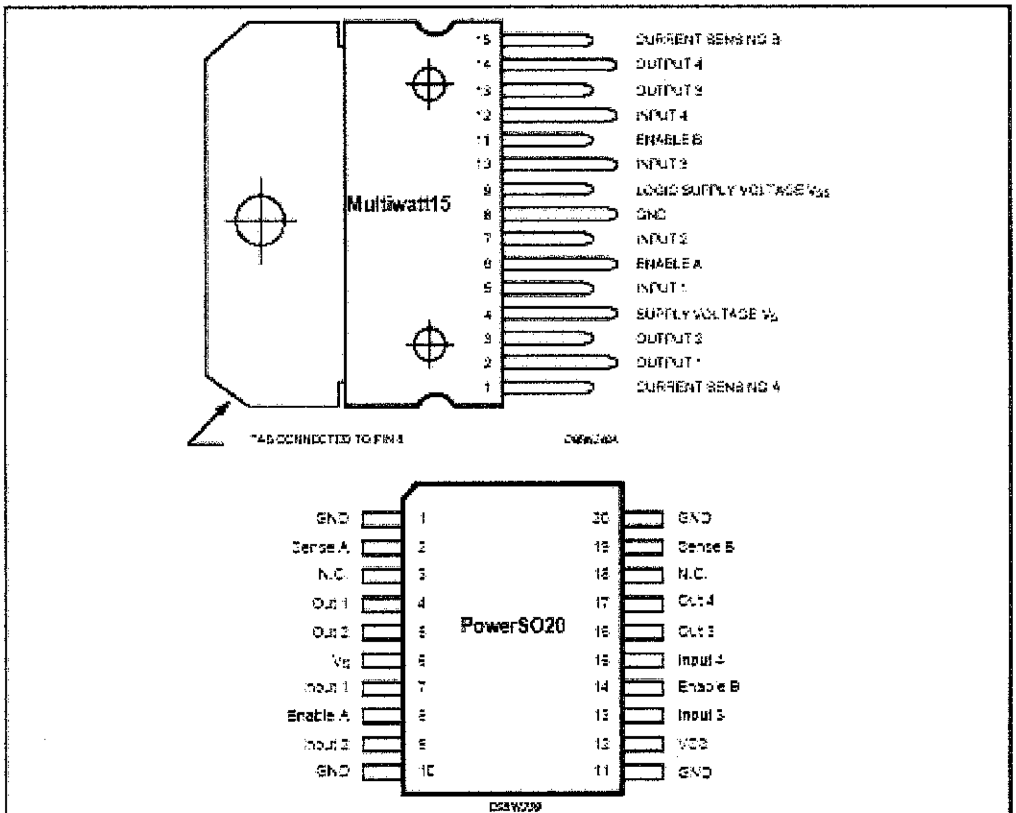
BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_S	Power Supply	50	V
V_{SS}	Logic Supply Voltage	7	V
V_I,V_{en}	Input and Enable Voltage	–0.3 to 7	V
I_O	Peak Output Current (each Channel) – Non Repetitive (t = 100µs) –Repetitive (80% on –20% off; t_{on} = 10ms) –DC Operation	 3 2.5 2	 A A A
V_{sens}	Sensing Voltage	–1 to 2.3	V
P_{tot}	Total Power Dissipation (T_{case} = 75°C)	25	W
T_{op}	Junction Operating Temperature	–25 to 130	°C
T_{stg}, T_j	Storage and Junction Temperature	–40 to 150	°C

PIN CONNECTIONS (top view)



THERMAL DATA

Symbol	Parameter		PowerSO20	Multiwatt15	Unit
$R_{th\ j\text{-}case}$	Thermal Resistance Junction-case	Max.	–	3	°C/W
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-ambient	Max.	13 (*)	35	°C/W

(*) Mounted on aluminum substrate

PIN FUNCTIONS (refer to the block diagram)

MW.15	PowerSO	Name	Function
1;15	2;19	Sense A; Sense B	Between this pin and ground is connected the sense resistor to control the current of the load.
2;3	4;5	Out 1; Out 2	Outputs of the Bridge A; the current that flows through the load connected between these two pins is monitored at pin 1.
4	6	V_S	Supply Voltage for the Power Output Stages. A non-inductive 100nF capacitor must be connected between this pin and ground.
5;7	7;9	Input 1; Input 2	TTL Compatible Inputs of the Bridge A.
6;11	8;14	Enable A; Enable B	TTL Compatible Enable Input: the L state disables the bridge A (enable A) and/or the bridge B (enable B).
8	1,10,11,20	GND	Ground.
9	12	VSS	Supply Voltage for the Logic Blocks. A100nF capacitor must be connected between this pin and ground.
10; 12	13;15	Input 3; Input 4	TTL Compatible Inputs of the Bridge B.
13; 14	16;17	Out 3; Out 4	Outputs of the Bridge B. The current that flows through the load connected between these two pins is monitored at pin 15.
–	3;18	N.C.	Not Connected

ELECTRICAL CHARACTERISTICS (V_S = 42V; V_{SS} = 5V, T_j = 25°C; unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
V_S	Supply Voltage (pin 4)	Operative Condition	V_{IH} +2.5		46	V
V_{SS}	Logic Supply Voltage (pin 9)		4.5	5	7	V
I_S	Quiescent Supply Current (pin 4)	V_{en} = H; I_L = 0 V_i = L V_i = H		13 50	22 70	mA mA
		V_{en} = L V_i = X			4	mA
I_{SS}	Quiescent Current from V_{SS} (pin 9)	V_{en} = H; I_L = 0 V_i = L V_i = H		24 7	36 12	mA mA
		V_{en} = L V_i = X			6	mA
V_{iL}	Input Low Voltage (pins 5, 7, 10, 12)		–0.3		1.5	V
V_{iH}	Input High Voltage (pins 5, 7, 10, 12)		2.3		VSS	V
I_{iL}	Low Voltage Input Current (pins 5, 7, 10, 12)	V_i = L			–10	µA
I_{iH}	High Voltage Input Current (pins 5, 7, 10, 12)	Vi = H ≤ V_{SS} –0.6V		30	100	µA
V_{en} = L	Enable Low Voltage (pins 6, 11)		–0.3		1.5	V
V_{en} = H	Enable High Voltage (pins 6, 11)		2.3		V_{SS}	V
I_{en} = L	Low Voltage Enable Current (pins 6, 11)	V_{en} = L			–10	µA
I_{en} = H	High Voltage Enable Current (pins 6, 11)	V_{en} = H ≤ V_{SS} –0.6V		30	100	µA
$V_{CEsat(H)}$	Source Saturation Voltage	I_L = 1A I_L = 2A	0.95	1.35 2	1.7 2.7	V V
$V_{CEsat(L)}$	Sink Saturation Voltage	I_L = 1A (5) I_L = 2A (5)	0.85	1.2 1.7	1.6 2.3	V V
V_{CEsat}	Total Drop	I_L = 1A (5) I_L = 2A (5)	1.80		3.2 4.9	V V
V_{sens}	Sensing Voltage (pins 1, 15)		–1 (1)		2	V

ELECTRICAL CHARACTERISTICS (continued)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
T_1 (V_i)	Source Current Turn-off Delay	0.5 V_i to 0.9 I_L (2); (4)		1.5		µs
T_2 (V_i)	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		0.2		µs
T_3 (V_i)	Source Current Turn-on Delay	0.5 V_i to 0.1 I_L (2); (4)		2		µs
T_4 (V_i)	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.7		µs
T_5 (V_i)	Sink Current Turn-off Delay	0.5 V_i to 0.9 I_L (3); (4)		0.7		µs
T_6 (V_i)	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.25		µs
T_7 (V_i)	Sink Current Turn-on Delay	0.5 V_i to 0.9 I_L (3); (4)		1.6		µs
T_8 (V_i)	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.2		µs
f_c (V_i)	Commutation Frequency	I_L = 2A		25	40	KHz
T_1 (V_{en})	Source Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (2); (4)		3		µs
T_2 (V_{en})	Source Current Fall Time	0.9 I_L to 0.1 I_L (2); (4)		1		µs
T_3 (V_{en})	Source Current Turn-on Delay	0.5 V_{en} to 0.1 I_L (2); (4)		0.3		µs
T_4 (V_{en})	Source Current Rise Time	0.1 I_L to 0.9 I_L (2); (4)		0.4		µs
T_5 (V_{en})	Sink Current Turn-off Delay	0.5 V_{en} to 0.9 I_L (3); (4)		2.2		µs
T_6 (V_{en})	Sink Current Fall Time	0.9 I_L to 0.1 I_L (3); (4)		0.35		µs
T_7 (V_{en})	Sink Current Turn-on Delay	0.5 V_{en} to 0.9 I_L (3); (4)		0.25		µs
T_8 (V_{en})	Sink Current Rise Time	0.1 I_L to 0.9 I_L (3); (4)		0.1		µs

1) 1) Sensing voltage can be –1 V for t ≤ 50 µsec; in steady state V_{sens} min ≥ –0.5 V.
2) See fig. 2.
3) See fig. 4.
4) The load must be a pure resistor.

Figure 1 : Typical Saturation Voltage vs. Output Current.

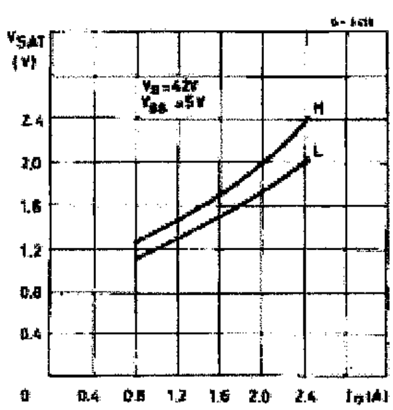
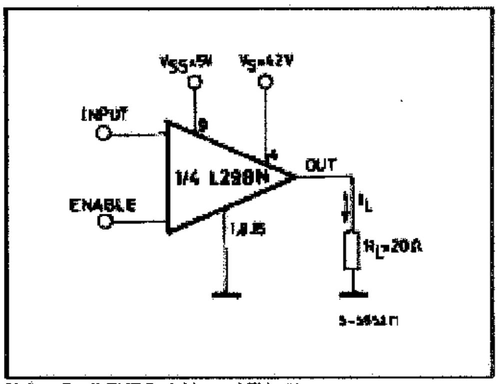


Figure 2 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = H

Figure 3 : Source Current Delay Times vs. Input or Enable Switching.

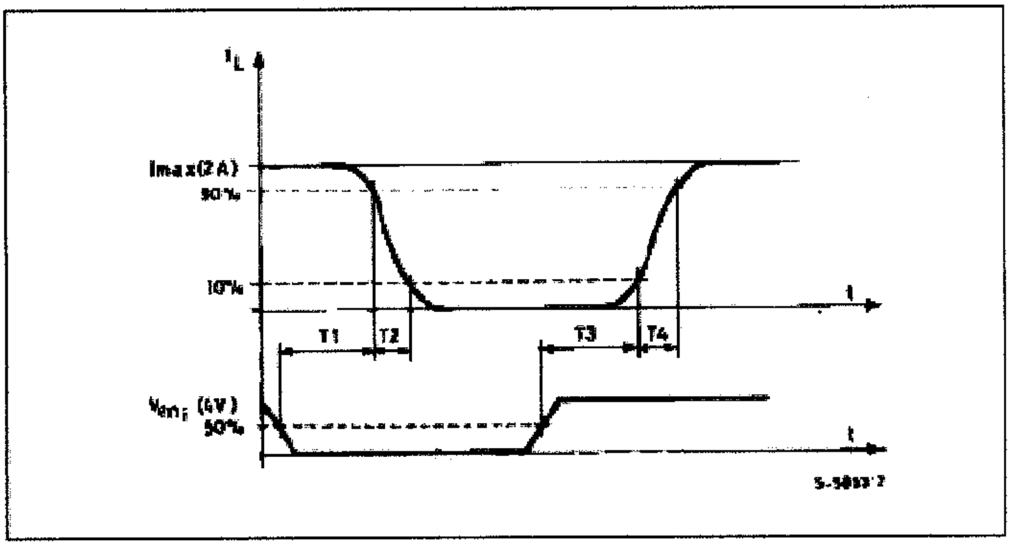
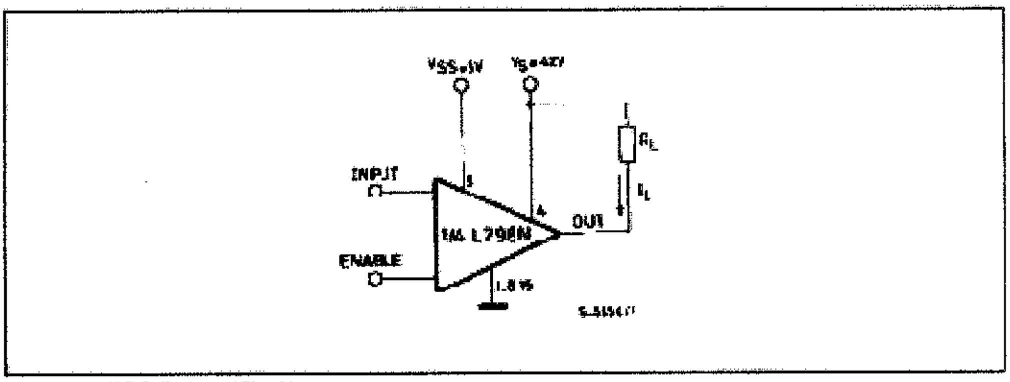


Figure 4 : Switching Times Test Circuits.



Note : For INPUT Switching, set EN = H
For ENABLE Switching, set IN = L

Figure 5 : Sink Current Delay Times vs. Input 0 V Enable Switching.

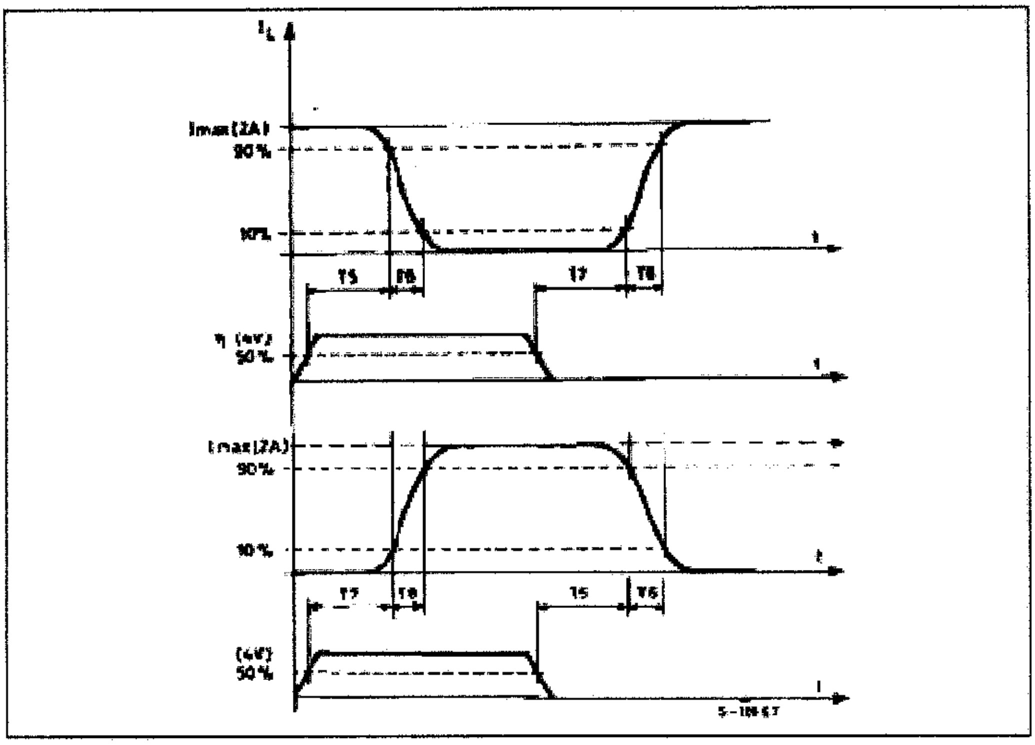
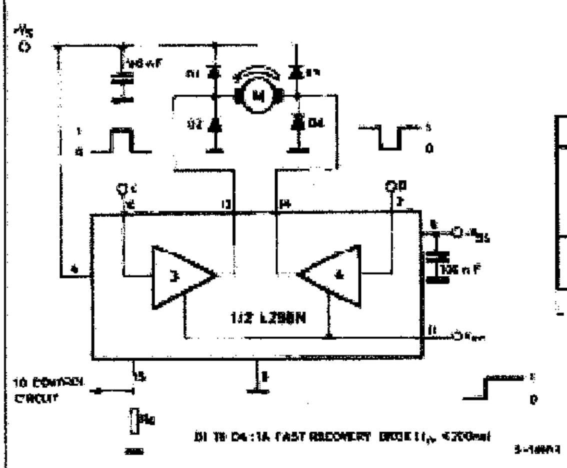


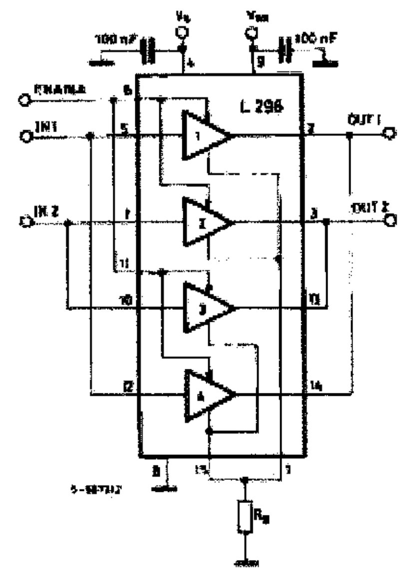
Figure 6 : Bidirectional DC Motor Control.



Inputs		Function
V_{en} = H	C = H ; D = L	Forward
	C = L ; D = H	Reverse
	C = D	Fast Motor Stop
V_{en} = L	C = X ; D = X	Free Running Motor Stop

L = Low H = High X = Don't care

Figure 7 : For higher currents, outputs can be paralleled. Take care to parallel channel 1 with channel 4 and channel 2 with channel 3.



APPLICATION INFORMATION (Refer to the block diagram)

1.1. POWER OUTPUT STAGE

The L298 integrates two power output stages (A ; B). The power output stage is a bridge configuration and its outputs can drive an inductive load in common or differenzial mode, depending on the state of the inputs. The current that flows through the load comes out from the bridge at the sense output : an external resistor (R_{SA} ; R_{SB}.) allows to detect the intensity of this current.

1.2. INPUT STAGE

Each bridge is driven by means of four gates the input of which are In1 ; In2 ; EnA and In3 ; In4 ; EnB. The In inputs set the bridge state when The En input is high ; a low state of the En input inhibits the bridge. All the inputs are TTL compatible.

2. SUGGESTIONS

A non inductive capacitor, usually of 100 nF, must be foreseen between both Vs and Vss, to ground, as near as possible to GND pin. When the large capacitor of the power supply is too far from the IC, a second smaller one must be foreseen near the L298.

The sense resistor, not of a wire wound type, must be grounded near the negative pole of Vs that must be near the GND pin of the I.C.

Each input must be connected to the source of the driving signals by means of a very short path.

Turn-On and Turn-Off : Before to Turn-ON the Supply Voltage and before to Turn it OFF, the Enable input must be driven to the Low state.

3. APPLICATIONS

Fig 6 shows a bidirectional DC motor control Schematic Diagram for which only one bridge is needed. The external bridge of diodes D1 to D4 is made by four fast recovery elements ($t_{rr} \leq 200$ nsec) that must be chosen of a VF as low as possible at the worst case of the load current.

The sense output voltage can be used to control the current amplitude by chopping the inputs, or to provide overcurrent protection by switching low the enable input.

The brake function (Fast motor stop) requires that the Absolute Maximum Rating of 2 Amps must never be overcome.

When the repetitive peak current needed from the load is higher than 2 Amps, a paralleled configuration can be chosen (See Fig.7).

An external bridge of diodes are required when inductive loads are driven and when the inputs of the IC are chopped ; Shottky diodes would be preferred.

This solution can drive until 3 Amps In DC operation and until 3.5 Amps of a repetitive peak current.

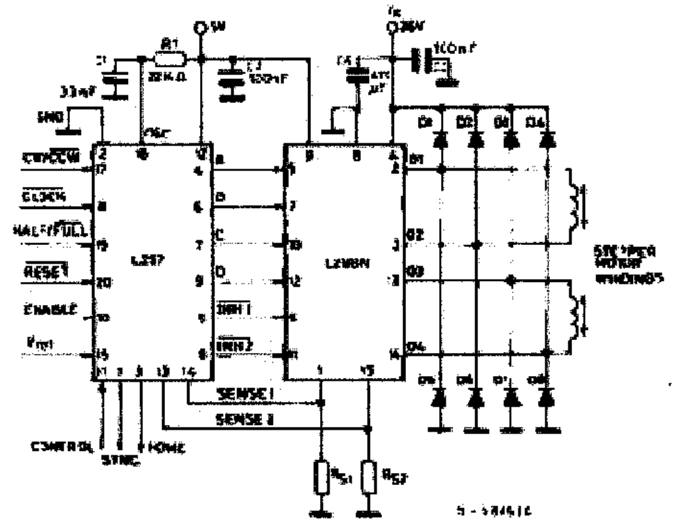
On Fig 8 it is shown the driving of a two phase bipolar stepper motor : the needed signals to drive the inputs of the L298 are generated, in this example, from the IC L297.

Fig 9 shows an example of P.C.B. designed for the application of Fig 8.

Fig 10 shows a second two phase bipolar stepper motor control circuit where the current is controlled by the I.C. L6506.

Figure 8 : Two Phase Bipolar Stepper Motor Circuit.

This circuit drives bipolar stepper motors with winding currents up to 2 A. The diodes are fast 2 A types.

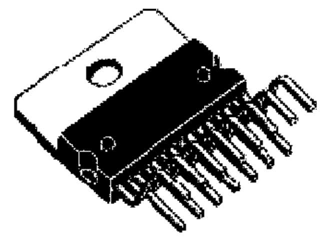


$R_{S1} = R_{S2} = 0.5\,\Omega$

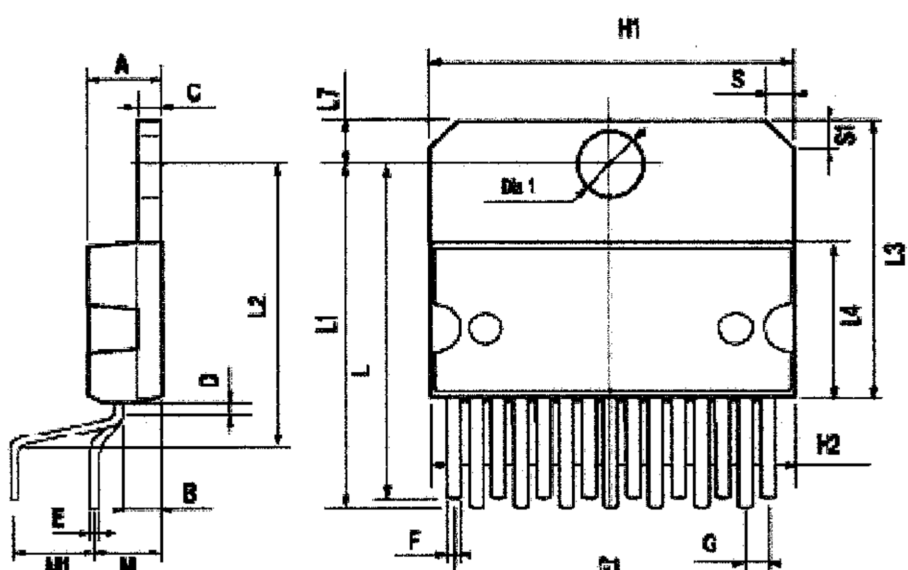
D1 to D8 = 2 A Fast diodes { $V_F \leq 1.2$ V @ I = 2 A; trr ≤ 200 ns

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			5			0.197
B			2.65			0.104
C			1.6			0.063
D		1			0.039	
E	0.49		0.55	0.019		0.022
F	0.66		0.75	0.026		0.030
G	1.02	1.27	1.52	0.040	0.050	0.060
G1	17.53	17.78	18.03	0.690	0.700	0.710
H1	19.6			0.772		
H2			20.2			0.795
L	21.9	22.2	22.5	0.862	0.874	0.886
L1	21.7	22.1	22.5	0.854	0.870	0.886
L2	17.65		18.1	0.695		0.713
L3	17.25	17.5	17.75	0.679	0.689	0.699
L4	10.3	10.7	10.9	0.406	0.421	0.429
L7	2.65		2.9	0.104		0.114
M	4.25	4.55	4.85	0.167	0.179	0.191
M1	4.63	5.08	5.53	0.182	0.200	0.218
S	1.9		2.6	0.075		0.102
S1	1.9		2.6	0.075		0.102
Dia1	3.65		3.85	0.144		0.152

OUTLINE AND MECHANICAL DATA



Multiwatt15 V



APPENDIX F

TCRT5000 OPTICAL SENSOR DATASHEET

Reflective Optical Sensor with Transistor Output

Description

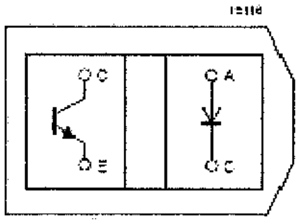
The TCRT5000(L) has a compact construction where the emitting-light source and the detector are arranged in the same direction to sense the presence of an object by using the reflective IR beam from the object. The operating wavelength is 950 nm. The detector consists of a phototransistor.

94 8412

Applications

- Position sensor for shaft encoder
- Detection of reflective material such as paper, IBM cards, magnetic tapes etc.
- Limit switch for mechanical motions in VCR
- General purpose – wherever the space is limited

15116



Top view

Features

- Snap-in construction for PCB mounting
- Package height: 7 mm
- Plastic polycarbonate housing construction which prevents crosstalk
- L = long leads
- Current Transfer Ratio (CTR) of typical 10%

Order Instruction

Ordering Code	Sensing Distance	Remarks
TCRT5000	12 mm	Leads (2.5 mm)
TCRT5000(L)	12 mm	Long leads (15 mm)

Absolute Maximum Ratings

Input (Emitter)

Parameter	Test Conditions	Symbol	Value	Unit
Reverse voltage		V_R	5	V
Forward current		I_F	60	mA
Forward surge current	$t_p \le 10$ µs	I_{FSM}	3	A
Power dissipation	$T_{amb} \le 25$ °C	P_V	100	mW
Junction temperature		T_j	100	°C

Output (Detector)

Parameter	Test Conditions	Symbol	Value	Unit
Collector emitter voltage		V_{CEO}	70	V
Emitter collector voltage		V_{ECO}	5	V
Collector current		I_C	100	mA
Power dissipation	$T_{amb} \le 55$ °C	P_V	100	mW
Junction temperature		T_j	100	°C

Sensor

Parameter	Test Conditions	Symbol	Value	Unit
Total power dissipation	$T_{amb} \le 25$ °C	P_{tot}	200	mW
Operation temperature range		T_{amb}	−25 to +85	°C
Storage temperature range		T_{stg}	−25 to +100	°C
Soldering temperature	2 mm from case, $t \le 10$ s	T_{sd}	260	°C

Electrical Characteristics (T_{amb} = 25°C)

Input (Emitter)

Parameter	Test Conditions	Symbol	Min.	Typ.	Max	Unit
Forward voltage	I_F = 60 mA	V_F		1.25	1.5	V
Junction capacitance	V_R = 0 V, f = 1 MHz	C_j		50		pF

Output (Detector)

Parameter	Test Conditions	Symbol	Min.	Typ.	Max	Unit
Collector emitter voltage	I_C = 1 mA	V_{CEO}	70			V
Emitter collector voltage	I_E = 100 µA	V_{ECO}	7			V
Collector dark current	V_{CE} = 20 V, I_F = 0, E = 0	I_{CEO}		10	200	nA

Sensor

Parameter	Test Conditions	Symbol	Min.	Typ.	Max	Unit
Collector current	V_{CE} = 5 V, I_F = 10 mA, D = 12 mm	I_C [1,2]	0.5	1	2.1	mA
Collector emitter saturation voltage	I_F = 10 mA, I_C = 0.1 mA, D = 12 mm	V_{CEsat} [1,2]			0.4	V

[1] See test circuit

[2] Test surface: Mirror (Mfr. Spindler a. Hoyer, Part No 340005)

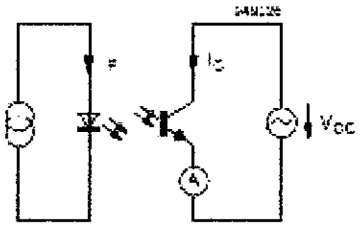


Figure 1. Test circuit

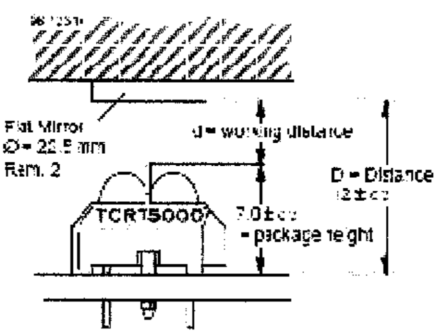


Figure 2. Test circuit

Typical Characteristics (T_{amb} = 25°C, unless otherwise specified)

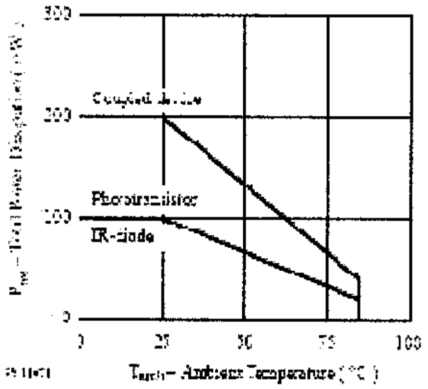


Figure 3. Total Power Dissipation vs. Ambient Temperature

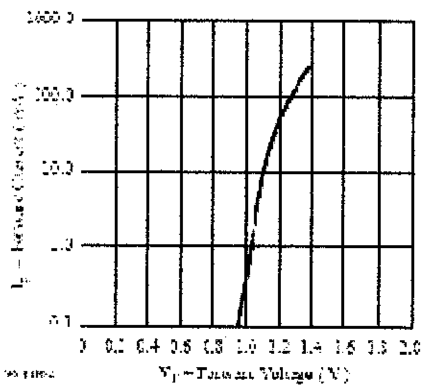


Figure 4. Forward Current vs. Forward Voltage

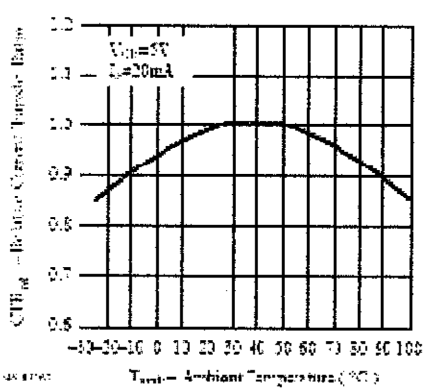


Figure 5. Rel. Current Transfer Ratio vs. Ambient Temp.

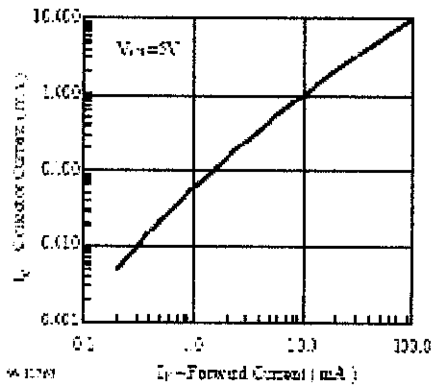


Figure 6. Collector Current vs. Forward Current

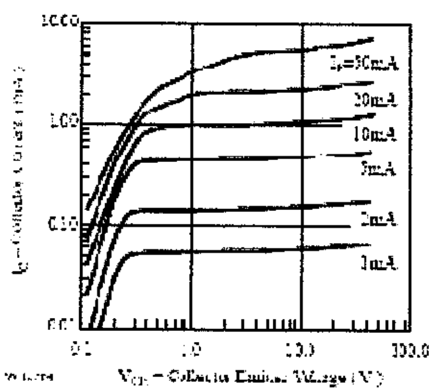


Figure 7. Collector Emitter Saturation Voltage vs. Collector Current

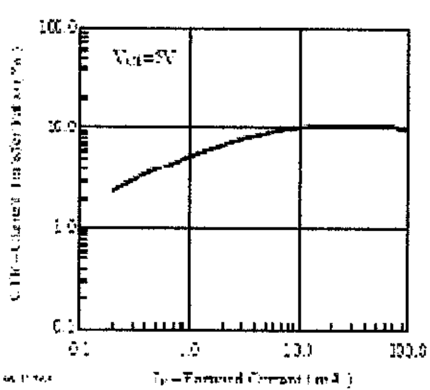


Figure 8. Current Transfer Ratio vs. Forward Current

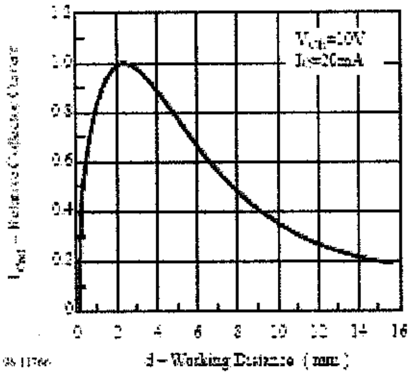


Figure 9. Relative Collector vs. Distance

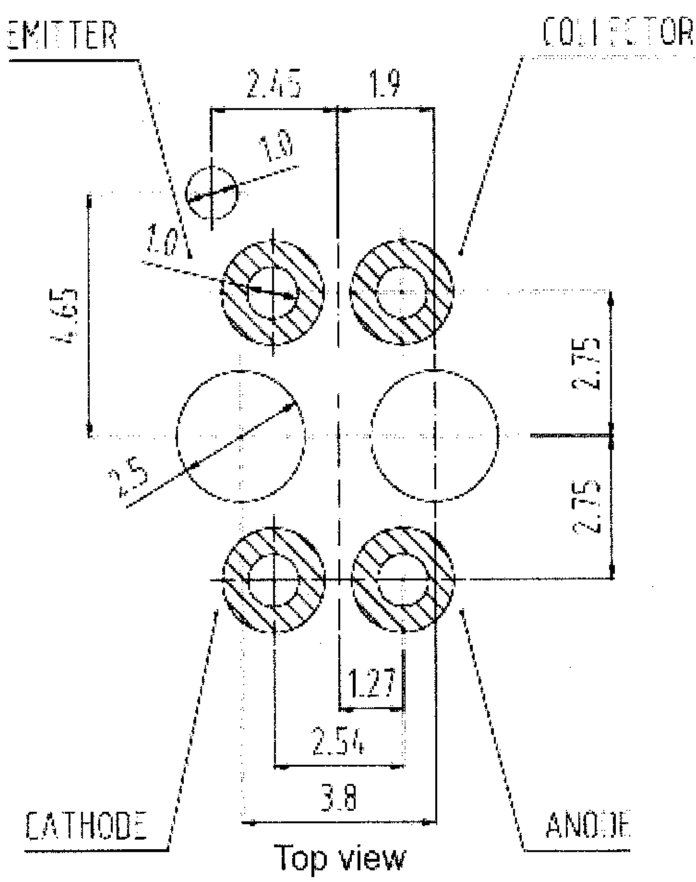
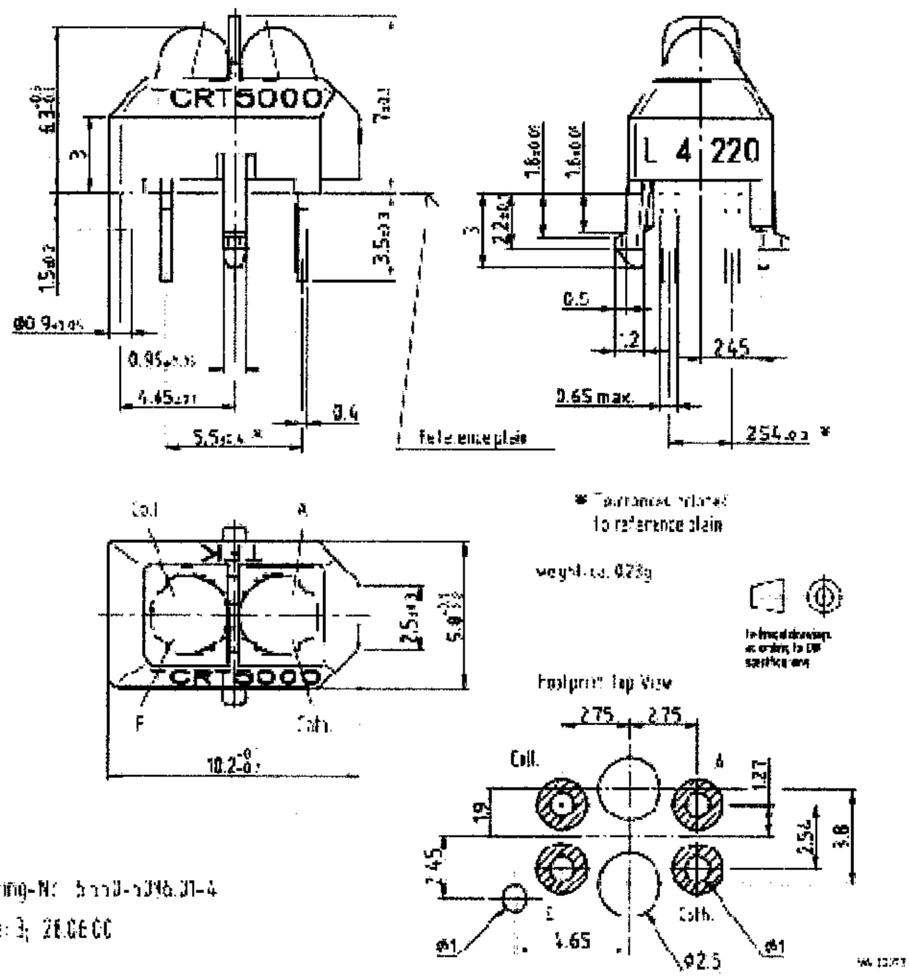


Figure 10. Footprint

Dimensions of TCRT5000 in mm



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Dimensions of TCRT5000L in mm