SMART GUIDANCE ROBOT

By

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FINAL PROJECT REPORT

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

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MEI 2004

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.

Mohd. Sazri Bin Zainuddin

ABSTRACT

This project comprises the design and implementation of a fully autonomous Self Guidance Robot (SGR). The robot is an embedded system that integrates hardware and software in its design and operation. The hardware design includes a PIC microprocessor and other components that provide the circuitry for the robot operation. The software design will include programs written in assembly language. The main objective of the self guiding robot is to guide itself through a predetermined path and avoid any obstacle in its path.

The physical structure of the self guiding robot is mainly built using aluminum. And the tyre of the self guiding robot is built using fiberglass cylinder.

A transmitter receiver pair of ultrasonic sensors is used for the ultrasonic circuitry. The transmitter primarily consists of LM555 timer that is used to generate the 40 kHz signal to drive the ultrasonic sensors. The receiver circuit is primarily consists of two LM741 op amp. The op-amp is used to boost the signal received by the receiver transducer. The receiver circuit output is then fed to the PIC16f877 for processing.

A PIC16f877 and PIC16f84 microcontroller are used in this project. It functions as the brain of the self guiding robot. The microcontrollers coordinate the motions of the robot by controlling the servo and DC motor based on the signal it received from the ultrasonic receiver circuit.

An H-bridge circuit is used to control the motors' forward/reverse motion. The H-bridge primarily consists of 2 L298 chip. The L298 IC is a motor driver integrated circuit.

ACKNOWLEDGEMENTS

In The name of Allah the Beneficent, the Merciful

I would like to express my heartiest gratitude to Mr. Mohd .Haris Mohd Khir for willingly take me as his student under this project. The support and guidance that Mr Haris has showed was the motivating factor of this project. Without him the project would not be a successful one.

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My appreciation also goes to all who have directly and indirectly contributed to the project. Lastly I would like to thank my parents who have brought me to this world and raise me to be the man that I'm now.

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CHAPTER 1
INTRODUCTION

1.1 Background

It is becoming reality that robot act in our environment, not only in special environments like factories but also in the office buildings. Robots will be working without disturbing us or taking break. With improved computing capabilities and substantial progress in research, robots are becoming increasingly useful machine with great potential in the future. They provide ideal solutions to many different tasks in hazardous environment such as industry, minesweeping, etc.

In any work we do there will always be a human factor. The human factor will contribute the highest percentage of mistake in any process of work. For an example, car accident always happens due to human carelessness or mistake. The technical faulty of the car is always being the lowest percentage contributor. As we all know, machine do not make mistake, human do. Due to this fact, robots and machines are now taking place of man's work handling complicated or repetitive task. Robotics technology is still far behind in Malaysia. That is why a very simple robot cost a fortune compared to its application. However, due to machines and robots reliability in doing work, step have to be taken to popularize the research of the subject.

The subject of mobile robot has been around quite some time now. Though it is not so popular in Malaysia, mobile robot is very popular in other places in the world. Many Universities such as Massachusetts Institute of Technology (MIT) have taken up the research of building a more robust robot that can guide it self through path, avoid any obstacle, etc.

Application of the Self Guidance Robot varies from security surveillance; reach hard to reach places by man, etc. This project is merely the small step to be taken to advance the robotics research in University Technology Petronas (UTP). It is hoped that through this project, many others will be inspired to take up the challenges in robotics research in UTP.

1.2 Problem statement

Building a robot is not an easy task and requires more expertise than simple programming. The robot designer must own compendium skills from fields such as mechanical engineering, electrical engineering and computer science. Choosing the right component to meet the tasks will be challenging. The variety of components is very wide and expensive. The mechanical and sensor design should be finalized to develop the software (program) based upon a stable hardware platform. In this project a Self Guidance Robot will be built to compensate human inability to reach small places. The robot will be able to avoid any obstacle thus prevent crash.

1.3 Objectives and scope of study

The objective of this project is to research, design and built a working prototype of Self Guidance Robot which will have the feature of able to follow a predetermined path and avoid any obstacle while doing it. The scope of the study will cover all the subjects that concern the building of the SGR robot as follows:

1) Structure - This part is very important as the structure of the Self Guidance Robot needs to be stable, light and reliable.
2) Wheels - The wheels should be design carefully so that the robot has a small turning cycle which will help the robot navigate in small places.
3) Motors - Motors is another important part as it is the part that able the robot to move. There a wide selection of motor such as normal DC motor, stepper motor and servo motor. Research

have to be done to choose which type of motor is suitable for the SGR.

4) PIC - PIC is the heart and brain of the SGR. This is where the software will reside, making the SGR 'intelligent'. Much experiment will be done in the area of programming the PIC.

5) Sensors - The sensors are like eyes and ears of the SGR. It provides input of the environment data to the PIC. There are many types of sensors are available in the market and varies in price. The selection of the sensors are crucial as the reliability of the sensors will measure the project success

6) Circuits - The circuits will control the robot sensors, motors, servo motor and deliver the power needed to the robot

CHAPTER 2
THEORIES AND LITERATURE REVIEW

2.1 PIC microcontroller

The microchip PIC microcontroller is the controller of the robot. It acts as the ‘brain’ of the robot. Software (sets of instruction) will be burned into the PIC to able the PIC to control the robot. PIC microcontroller is suitable for this project because of the size is small, low power consumption and low in cost. This project uses the PIC16f877 model. PIC16f877 is a 40 pin PDIP type of microcontroller.

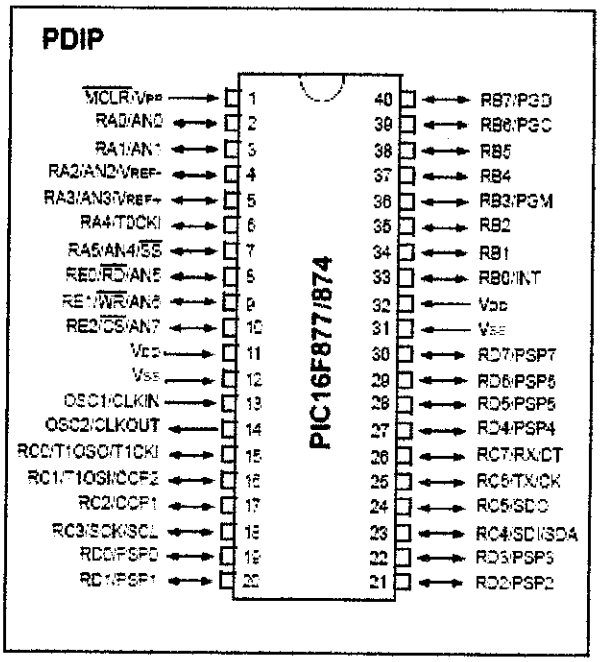

Figure 1 Pin layout of the PIC16f877 microcontoller

Key features	PIC16F877
Operating Freaquency	DC – 20 Mhz
RESETS (and delays)	POR, BOR (PWRT, OST)
FLASH Program memory (14-bit words)	8k
Data memory (bytes)	368
EEPROM Data Memory	256
Interupts	14
I/O ports	Ports A, B, C, D and E
Timers	3
Capture/Compare/PWM module	2
Serial Communications	MSSP, USART
Parallel Communications	PSP
10-bit Analog-to-Digital Module	8 input channels
Instruction Set	35 instructions

Table 1 PIC16F877 features table

The feature that is used in this project includes the PWM module, the interrupts and Analog-to-digital converter module. The PWM module is used to generate pulse width modulation signal to the motor to reduce effective voltage supplied to the motor. The A-to-D converter module is important to interpret the received signal from the ultrasonic circuit. The interrupts is used to interrupts the microcontroller routine if any obstacle is detected.

2.2 Sensors

Research on sensors has been done through browsing the web. There are many type of sensors have been discovered to be suitable for the project. However the most likely sensor that will be used is an ultrasonic sensor because it is reliable and considerably accurate.

2.2.1 *Ultrasonic sensors*

Ultrasonic waves are sound waves which are inaudible to human ears. The typical frequencies of ultrasonic sensors range above 20kHz. The speaker (transmitter) and the microphone (receiver) are called transducers. Normally, both transmitter and receiver are built into one transducer to transmit as well as receive the ultrasonic waves. Most ultrasonic sensors operate at frequencies between 40kHz and 250kHz.

Ultrasonic sensors are mainly used as presence, proximity, or distance measurement sensors. The basic principle in ultrasonic sensors is the transmission of short bursts of sound waves and the detection of its echo reflected by the presence of an obstacle. A proximity sensor will calculate the time for the echo to return to determine the distance of the obstacle.

As a sound wave, the ultrasonic requires a medium to traverse and will not work in vacuum. Ultrasonic proximity sensors are affected by various factors:

- Temperature
- Transmission medium
- Wavelength
- Attenuation due to the medium properties
- Background noises
- Transmission direction and reflection angle
- Size of obstacle
- Sound absorption property of the obstacle

Formula Related to Sound

An ultrasonic proximity sensor transmits short bursts of pulses and measures the time taken for the echo to the receiver. The calculation of the distance of an obstacle is then calculated using the time taken and the speed of sound in the specific medium. The accuracy of the computation is related to the accuracy of the speed of sound used. The speed of sound, in turn, is affected by both temperature and composition of the medium. A simplified formula to calculate the speed of sound in air as a function of temperature is given as follows:

$$c(T) = 326{,}100\sqrt{1 + \frac{T}{273.15}}$$

where,

$c(T)$ = speed of sound in millimeters per second

T = temperature of the air in °C

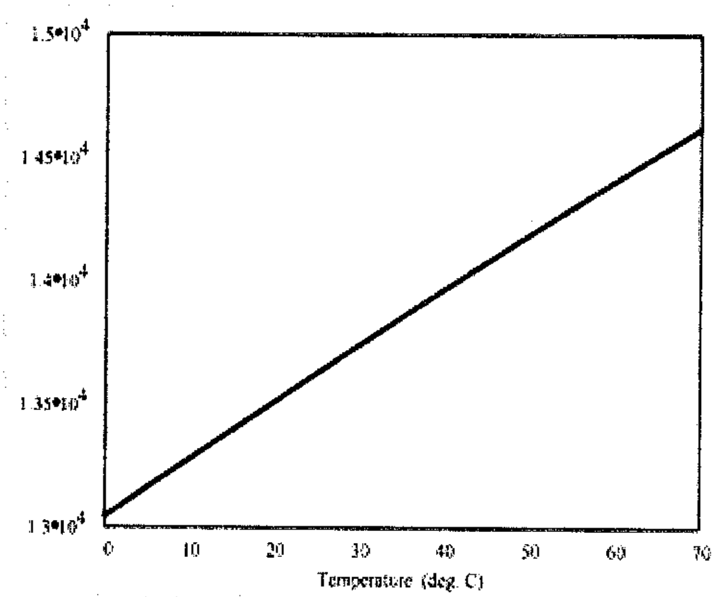

Figure 2 Speed of Sound vs Temperature

Friction losses in transmission medium reduce the amplitude of sound pressure as it travels. The attenuation affects how far the sound can be detected before it is overwhelmed by noise. In air, attenuation is mainly affected by two factors, namely the frequency of sound and the humidity of air.

An ultrasonic sensor needs to function within a wide range of attenuation, depending on the specific requirements. A good rule of thumb is to calculate the maximum attenuation to ensure usability of the sensor. A good approximation of the maximum attenuation level for normal room temperature and frequencies up to 50kHz can be attained using the following formula:

$$\alpha(f) = 0.01f$$

$\alpha(f)$ = maximum attenuation in dB/ft

f = frequency of sound in kHz

As noted, the maximum attenuation varies with frequency. As a rough guide, for frequencies above 125kHz, the maximum attenuation occurs at 100% RH, while at 40kHz, the maximum attenuation occurs at 50% RH.

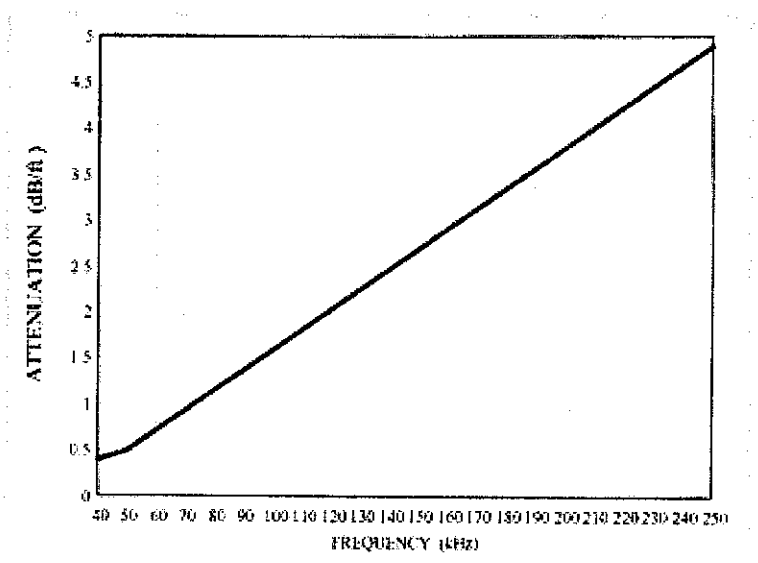

Figure 3 Maximum Attenuation of Sound at Room Temperature vs Frequency

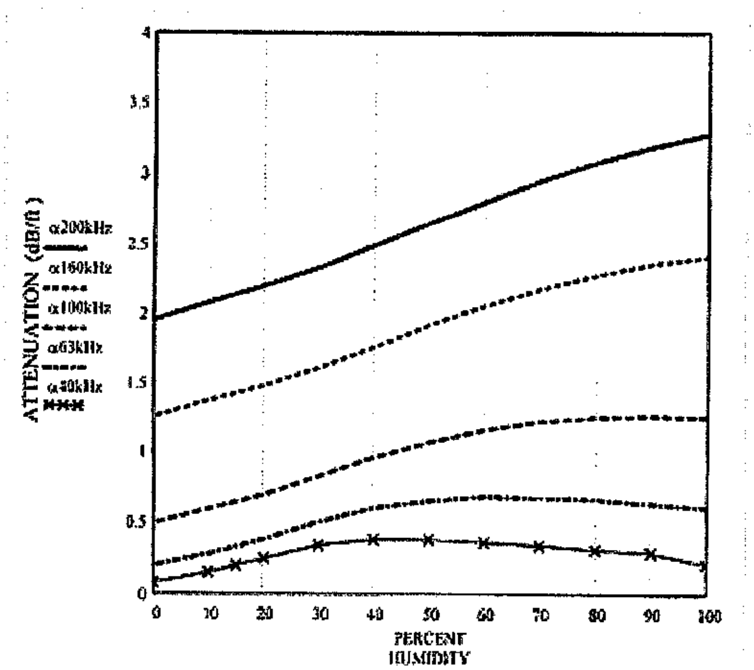

Figure 4 Attenuation of Sound at Room Temperature vs Humidity

A sound wave reflects similarly to a light (electromagnetic) wave. The echo level is determined by the distance of the reflector, its size, and its absorption property. To reduce the complexity of the calculation, we may assume that the size of obstacle is large enough to reflect the entire beam and exactly perpendicular to the source. Thus, the following formula stands:

Spreading Loss = 20 log (2R),

Absorption Loss = 2αR

Where R is the distance between the transducer and the obstacle and α is the absorption constant of the reflecting surface.

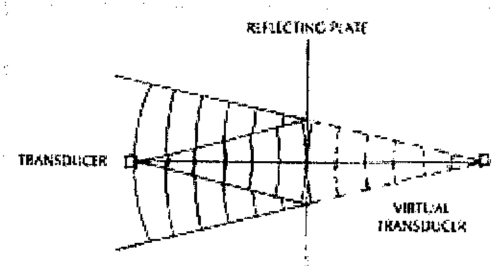

Figure 5 Echo from flat surface

2.3 Physical base structure

The student has made an extensive research on the physical structure possible for the mobile robot. It is no doubt is the most important part of the project. The physical structure need to be stable, though and sturdy to house in the electronics board, battery etc. The physical structure is built using aluminum. The aluminum is chosen as the physical base structure because it is strong and light. Though aluminum cannot be weld, it can be rivet or the joint together by using screws.

2.4 Motors

There are 2 type of motor used by the SGR which are the servo motor and the DC motor. The SGR uses 1 servo motor and 2 DC motor. The servo motor is mounted in the middle of the SGR at the bottom level of the SGR. The servo motor used is manufactured by Futaba and the model number of the servo motor is FP-S148. it is a small servo motor with an output torque of 42 oz/in or 3kg/cm. This torque is sufficient for its function which is turning the directional tires. The operating speed of the servo motor is 0.22 sec/60^{o}.

The DC motor used by the SGR is from the brand of Pittman with model number of 9232S001. The motor is direct coupled to the driving tires and are mounted on the bottom level of the SGR. It has a 3 channel encoder build in the motor. The no load speed of the motor is 7,015 rpm. There is no specific reason on why this DC motor is chosen as the driving motor of the SGR. The student just make use of what available to the student. A geared motor would be better because geared motor has higher torque and lower speed. This is crucial for the SGR, however 9232S001 is sufficient to drive the SGR, moreover the DC motor has extra feature of built in encoder. This encoder is not used in this project due to the time restriction. However it is good for future expansion as the encoder provide us good information of the distance and speed of the motor. This motor has a very high no load speed. The SGR when it starts moving can reach a very high speed if the voltage driving the DC motor is held constant. This is not wanted because if the SGR moves to quick, there is a high chance that the ultrasonic would not able to detect the obstacle fast enough to make the SGR stop before colliding with the obstacle. The solution to this is by giving decremental effective voltage to the motor. For example when the SGR wants to start moving we supplied it with the rated voltage. And when the SGR already start moving we reduce the voltage supplied stage by stage so that the SGR achieve a constant slow speed.

To reduce the voltage the student use Pulse Width Modulation (PWM). To illustrate this please refer to the figure 6 below.

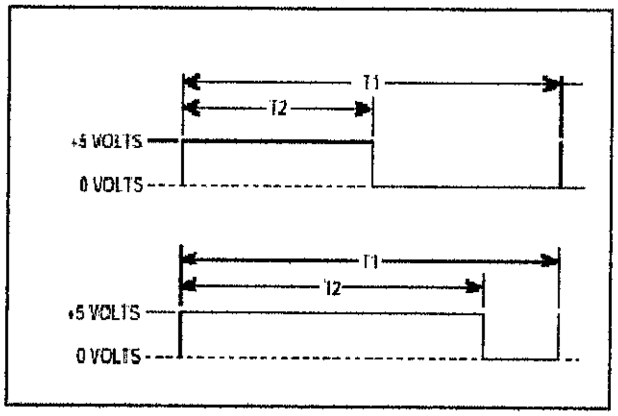

Figure 6 Pulse Width Modulation

The first PWM waveform shows a 50% duty cycle where the voltage is 5 V during the first half of the period and 0 V during the second half. By integrating the voltage of the PWM waveform over its period, an average DC voltage of 2.5 V is obtained.

Likewise, the second PWM waveform shows an 80% duty cycle and thus, and average DC voltage of 4.0 V. By changing the value of duty cycle which is the time on and off, we can control the effective voltage to the DC motor thus control the speed of the DC motor. The datasheet of the DC motor can be found in Appendix A of this report.

2.5 H-bridge theory

Several configurations of motor drive circuits are available. The H-bridge configuration allows control over the rotation torque and direction of the motor and can also be used for other resistive or inductive loads requiring control over the polarity of the drive voltage produced. This circuit consists of four switches connected in an H arrangement. By opening and closing the four switches in the correct sequence, the direction of current flow is reversed and hence, the direction of rotation.

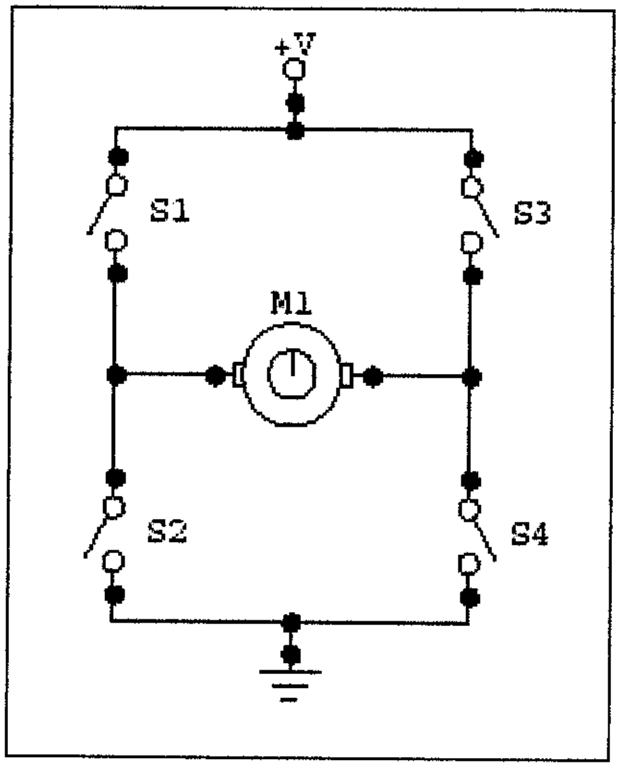

Figure 7 H-bridge concept

In figure 7, closing switch S1 and S4 and opening S2 and S3 will allow current to flow from left to right in the motor; while opening S1 and S4 and closing S2 and S3 will result in the opposite direction of current flow through the motor. Table 2 below summarizes the switch state for reverse and forward motion of the motor.

Motor Action	S1	S2	S3	S4
FORWARD	Close	Open	Open	Close
REVERSE	Open	Close	Close	Open

Table 2 H-bridge concept

2.6 Ultrasonic transmitter circuit

The preliminary transmitter circuit was extracted from Kam Leang Robotics web pages. The circuit contains a 555 timer chip that produces a 40Khz square wave signal. The signal is passed through to the ultrasonic transmitter using a 2N3904 transistor. The signal will then be transmitted the ultrasonic transducer.

The important part of the transmitter circuit is the 555 timer. In this circuit the 555 timer is configured to operate in the astable mode operation. The astable circuit configutraion can viewed in the figure below.

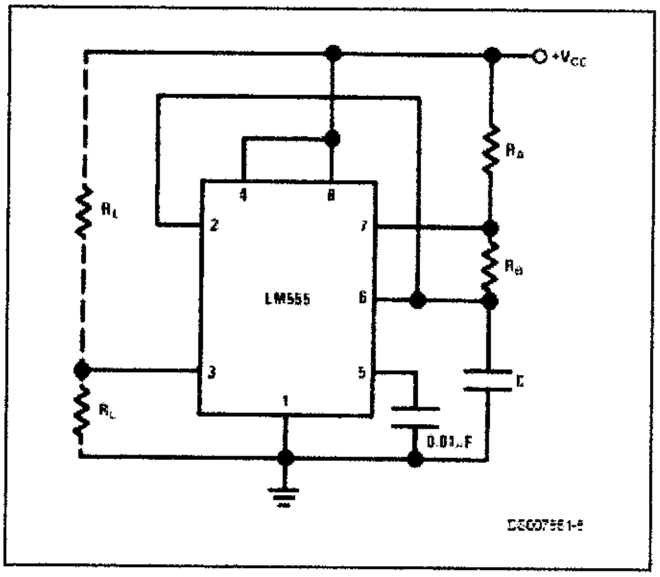

Figure 8 Astable circuit configuration

Pin 2 and pin 6 are connected making the 555 timer to trigger itself and free run as a multivibrator. The external capacitor of 0.001µf charges through the 10kΩ + (10kΩ+10kΩ variable resistor) and discharges through (10kΩ+10kΩ variable resistor). Thus the duty cycle may be precisely set by the ratio of this 2 resistor. The 10kΩ acts as 1 resistor and the (10kΩ + 10kΩ variable resistor) acts as 1 resistor. Thus by varying the 10kΩ variable resistor, we can change the duty cycle of the output thus varying the frequency of the output. In this project the 10kΩ variable resistor is varied so that the output is 40 kHz.

In this mode of operation, the capacitor charges and discharges between 1/3 VCC and 2/3 VCC. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

If we let the variable resistor to be RB2 and the 10kΩ as RB1 and 10kΩ as RA we can calculate he actual value of the RB2.

The charge time (output high) is given by:

$$t1 = 0.693\ (R_A + R_B)\ C$$

$$t1 = 0.693\ (R_A + (R_{B1}+R_{B2}))\ C$$

And the discharge time (output low) by:

$$t2 = 0.693\ (R_B)\ C$$

$$t2 = 0.693\ (R_{B1}+R_{B2})\ C$$

Thus the total period is:

$$T = t1 + t2 = 0.693\ (R_A + 2R_B)\ C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2(R_{B1} + R_{B2}))C}$$

If we want the f to be 40 kHz and R_A=10kΩ, R_{B1}=10kΩ and C=0.001µf we can find R_{B1},

$$R_{B1} = (\frac{1.44}{C(40k)} - R_A - 2R_{B1})(\frac{1}{2})$$

And R_{B1} = 3kΩ

So the variable resistor will be roughly 3kΩ. However this value may not be accurate because here we assume all other parameters are accurate but unfortunately the physical implementation of it the parameters may change a little bit. This is where the variable resistor comes into play. The student will be able to vary the variable resistor and make sure the transmitter output is 40 kHz.

The output of the timer and the can be viewed in the figure below.

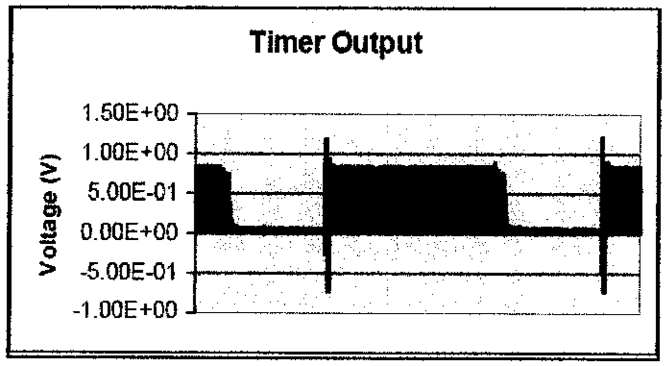

Figure 9 Oscillator output of the transmitter circuit

CHAPTER 3
METHODOLOGY

In doing the research and literature review for this project, student obtains the relevant and important information via surfing the internet, browsing books and journals and also with the assistance from supervisor in charge.

Several methods have to be implemented for the project success. Experiment is one of the methods. By experimenting, the student theories is supported and make sure the project work physically and not just in theories. Other than that, research is a good method as it can open the student mind to available robots presently. Through these researches, the student will know more about robot and can know which method will work and which will not.

During the first semester of the project the student has completed the ultrasonic sensor circuitry. The circuitry was done by experimenting the ultrasonic sensors on various surface and angle. The student main objective is to improve the signal received by the microcontroller. The stand alone circuit is tested and was found reliable. The second stage of the project is to integrate the ultrasonic circuit with a PIC microcontroller and try to manipulate the signal it received from the ultrasonic receiver circuit. The PIC must be able to distinguish the various distances by using the signal it receives from the ultrasonic circuit. The integration was successful.

Concurrently with the ultrasonic circuit integration, the student also built an H-bridge circuit to drive the DC motor. The H-bridge is built using mosfet transistors. The H-bridge was successful in driving the motor on no load. However on load the motor was observed to pull high current from the power source, and consequently burning the H-bridge circuit. The H-bridge circuit building is put on hold and will be continued the next semester. The first prototype of the physical structure of the self guiding robot was also built during the first semester.

The second semester of the project, the student has improved the physical structure of the robot. The improvement made are reducing the weight of the robot and reducing the drag of the robot.

The H-bridge circuit also has been change to a new circuit which utilize L298n which is a integrated circuit motor driver. The new circuit was able to withstand current up to 3A.

The power supply circuit also has been developed to provide the various circuitry of the robot with voltages they needed. The power supply circuit is powered using two 6V lead acid battery.

The last step of the project is to integrate the various together to form the self guiding robot. This step is the most important step as the stand alone circuit may behave differently when integrated with other circuits. After the integration process is finished. The student starts to program the robot to avoid obstacles and follow certain predetermined path which is the main objective of the project.

3.1.1 Tools

Some tools which were used for the initial part of the design are:

- Software – Multisim 2001, Ultiboard 2001, MPLab 6, PIC C Compiler, WARP13 PIC Programmer
- Microcontroller – PIC16F84A
- Circuit board – Breadboards, veroboards, electronic components, ultrasonic transducers,
- Motors - 2 units 12V DC motors and 1 unit of servo motor.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Physical structure

The physical structure is built to satisfy requirement of the SGR. The final product of the physical structure with the motors, battery and circuits mounted on it are as showed in the figure below.

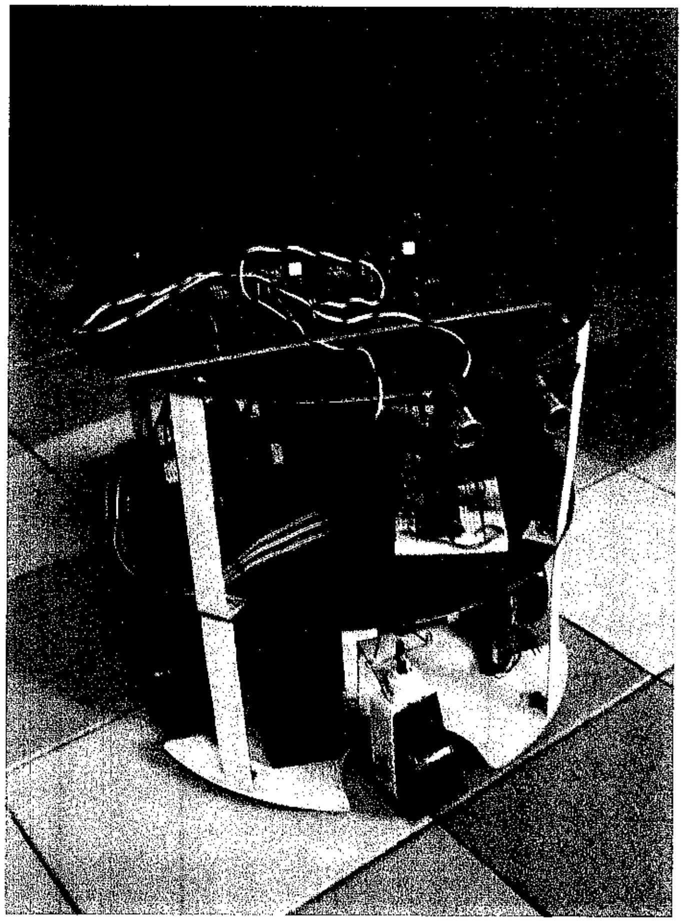

Figure 10 The final physical structure of the self guiding robot

4.1.1 Requirements of the physical structure

1) The physical structure need to be build so that the robot is stable, sturdy, reliable and light
2) It has to provide placement of components such as motors, circuits and batteries
3) Able to move in small places
4) Zero turning cycle
5) Able to carry payload not exceeding 1 kg

4.1.2 Implementation of the physical structure

After doing so much research on the internet on the topic of mobile robot physical structure, the student has come out with his own design of the physical structure. The design of the physical structure can be viewed in figure 11, 12 and 13 on the following pages. Figure 11 shows the top view while figure 12 shows the front view and figure 13 shows the side view of the physical structure.

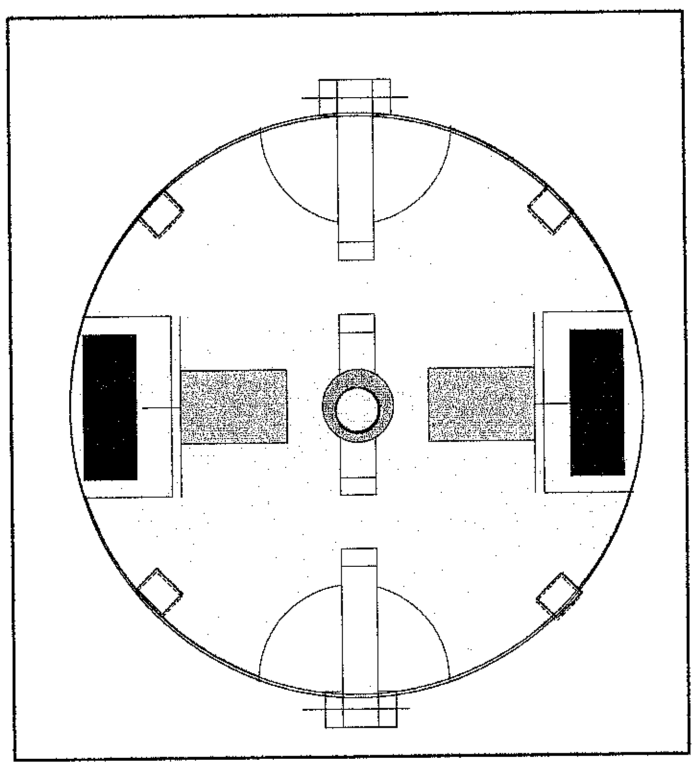

Figure 11 Top view of the SGR design

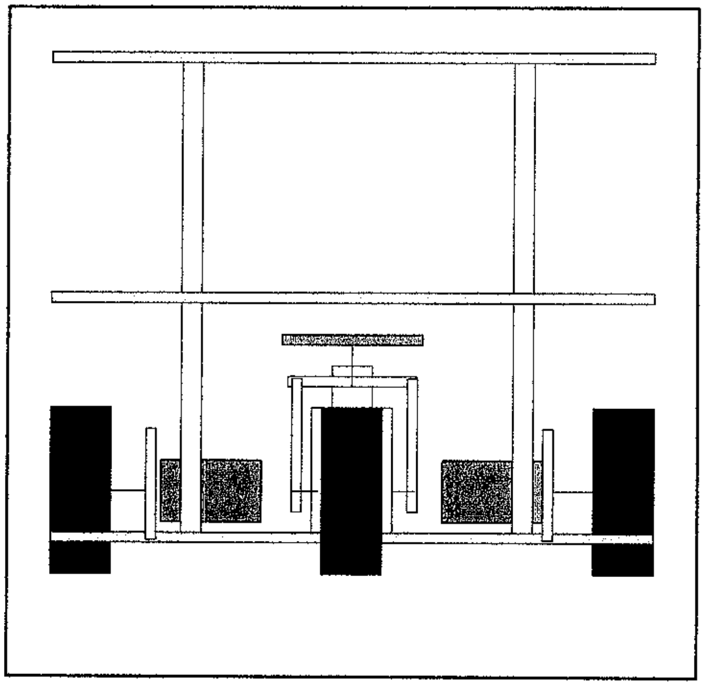

Figure 12 Front view of the SGR design

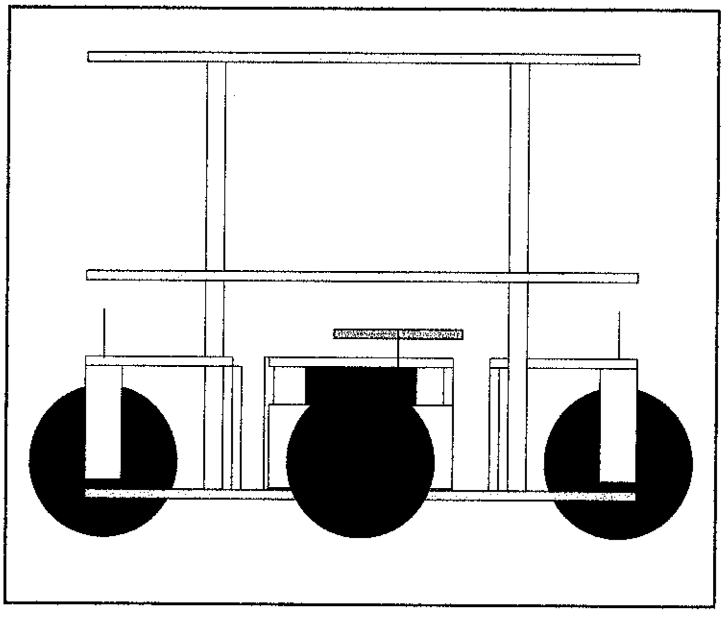

Figure 13 Side view of the SGR

The design of the physical structure is made in cylindrical form specifically to conform to the third requirement of the physical structure that is to able the SGR to move in small places smoothly. Together with the zero turning cycle of the SGR, the SGR will able to move in places that other design of robot cannot go through. To illustrate this advantage please refer figure 14 below.

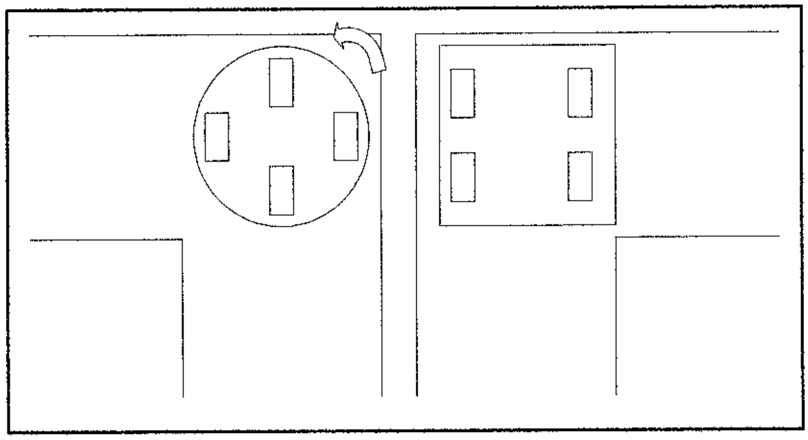

Figure 14   Structure comparison in small places

The Figure 14 above shows us to possible structure that can be built. On the left side is the cylindrical base structure and on the right side is a square base structure which has the same diameter or lenght. Both the left and right structure is negotiating a corner with their tires facing north. Now lets assume that both structures can change their tires position so that they can turn with zero turning cycle. The cylindrical structure on the left will have no problem as they can still turn in that small place. The square structure on the right will not able to turn because the corners of the structure will prevent them from turning in the same place. Refer figure 15 below.

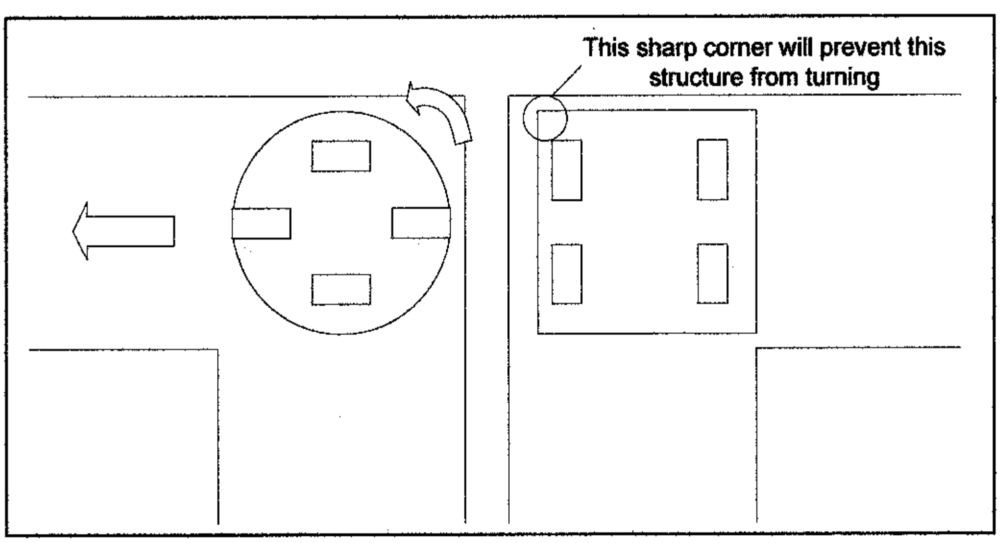

Figure 15   The cylindrical structure versus the square structure

The zero turning cycle is achieved by rotating both the front and back directional tires to 90°. Please refer the figure 16 illustrating how the zero turning cycle is achieved by the design.

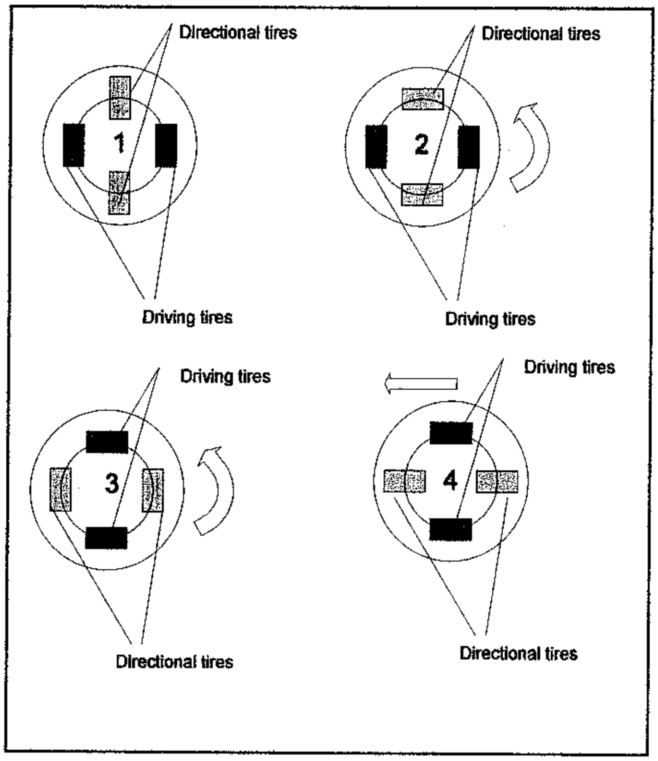

Figure 16 Zero turning circle implementation

The figure 16 above shows how the cylindrical structure from state 1 to 4 turn to left with zero turning circle. First let's identify the tires. The green tires are the directional tires which can turn 90° left or right and the blue tires are the driving tires. The driving tires which are coupled to the DC motor are the tires that drive the structure back and forth. In state 1 all the tires are facing north and the next state the directional tires are turned 90° to either left or right so that the directional tires now facing north. In state 3 the structure need to turn anti-clockwise 90°. This is done by driving the right driving tyre forward and driving the left tyre reversed. In state 4 the directional tires are turned so that they are facing west same with the driving tires. Now the structure can move freely to the right. As we can see here the structure can do a zero turning cycle with the design and placement of the tires.

The physical structure is built using aluminum and iron. Aluminum is chosen because it is a strong and light material. This will make the structure light but strong.

4.1.2.1 Tires

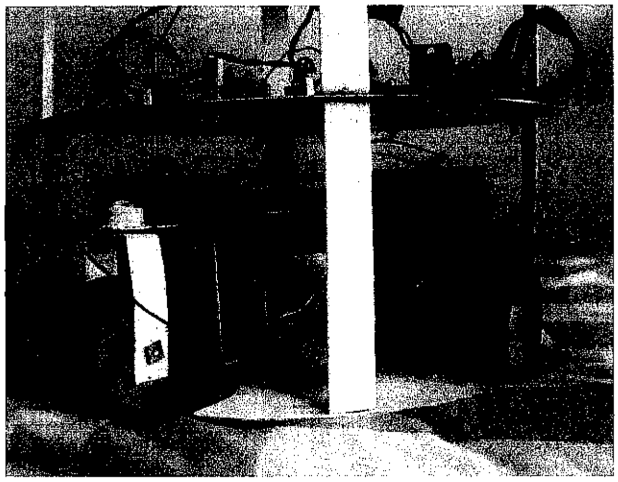

Figure 17 The directional and drive tyres

The tires of the SGR are made using cylindrical fiberglass. The cylindrical fiber glass is very strong and easy to shape and drilled. The tires are drilled so that it can be direct coupled to the DC motor. The first version of the tires has rubber around it with the intention to give the tire more traction. However consequently the rubber were thrown away because without the rubber the SGR has less drag and thus need less starting current to overcome the stall position. The tires without the rubber give the SGR a considerably good traction because of the weight of the SGR.

4.2 H-bridge circuit

The h-bridge circuit is to drive both the dc motor of the structure to make the SGV moves.

4.2.1 H-bridge implementation

The H-bridge circuit implementation is rather different than the initial approach to the H-bridge implementation. In the initial phase of the project, the student tried to build the H-bridge circuit by himself. The circuit was build using MOSFET transistors. The H-bridge circuit was operational; however it could not withstand high current flowing through it. The SGR tends to pull out very large current of more than 2 amps when overcoming the starting torque. The complication is that the H-bridge can not be operated using battery because battery have no current limiters. If the student uses the external power supply which has current control, the circuit can control the motor perfectly. Due to time constraint and the availability of motor driver integrated circuit (IC), the student has opt to use L298n.

The L298n 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. This IC can drive a motor of up to 50 V and can handle up to 2 amp of current.

4.2.1.1 Paralleling Outputs

A single l289n IC consists of 2 drivers which each have 2 signal inputs and 1 enable input. The current rating of the driver can be increased further to 3.5amp by paralleling the 2 drivers. The paralleled configuration is shown in figure 10 below.

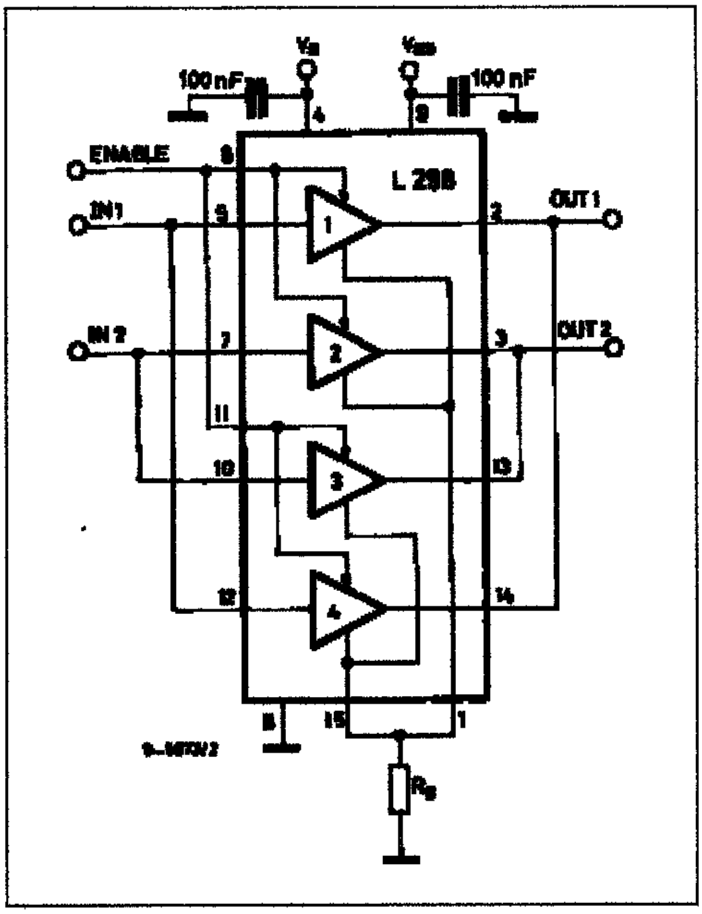

Figure 18 Parallel configuration of the l298n IC

To ensure that the current is fairly divided between the bridges they must be connected as shown in figure 2. In other words, channel one should be paralleled with channel four and channel two paralleled with channel three. Apart from this rule the connection is very straightforward - the inputs, enables, outputs and emitters are simply connected together.

4.2.1.2 Final schematic design of the H-bridge

In this project the student use this parallel configuration to drive the motors. As a result 2 l298n IC are needed to build the H-bridge circuit. The schematic design of the circuit can be viewed in the figure below. The schematic design is produced using Multisim 2001 software. The student could not simulate the circuit as there are virtual components in the schematic diagram as the student did not able to get the library for the l298. The only purpose of the schematic design is produce is to build the Printed Circuit Board of the circuit. The student has tested the circuit on a breadboard and it works.

Inputs		
V_{inh} = H	C = H ; D = L	Turn Right
	C = L ; D = H	Turn Left
	C = D	Fast Motor Stop
V_{inh} = L	C = X ; D = X	Free Running Motor Stop

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

Table 3 Inputs and the action to the SGR

Table 3 summarize the inputs condition and the motor action corresponding to the inputs. V_{inh} is the enable input. H is equal to high voltage and L is equal to low voltage. As we can see from the table, the enable pin must be held high to control the motor. If the motor inputs is complement each other the motor will turn either to the right or to the right. The L298n IC has a special feature that no other ordinary can perform which is fast motor stop. Whenever the motor inputs is equal to each other, either both high voltage or both low voltage, the motor will stop.

The final schematic design of the H-bridge circuit can be seen in the figure on the next page. In the figure J1 and J3 connector is the motor connector. The diode act as the external bridge to protect the motor from back EMF when the motor change direction. The PCB files can be found in the Appendix part of this report.

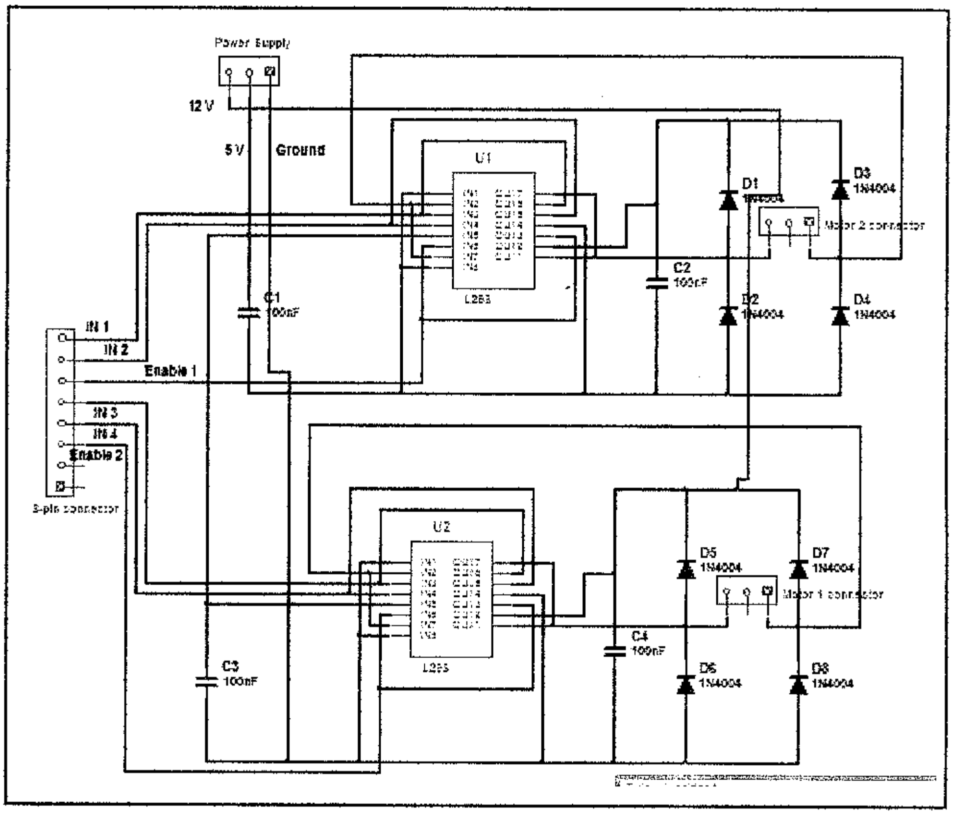

Figure 19 Multisim circuit of the H-bridge

4.3 Power Supply circuit

This project needs to have a power supply circuit to provide the H-bridge circuit and the ultrasonic circuit with appropriate voltage supply. The power supply to this circuit are 2 6V lead acid rechargeable batteries with a maximum current of 4.5Ah and 1 standard 9v battery. The desired voltage outputs of the power supply circuit are -9V, 12V, 9V, 5V and ground. The ultrasonic circuit uses the 9V, -9V, 5V and ground voltages, while the H-bridge circuit uses the 12V, 5V and ground voltage. The schematic design of the circuit is drawn using the Multisim 2001 software. The schematic drawing can be viewed in the figure on the next page. As we can see from the figure, the student uses voltage regulators to produce the 9V and 5V voltage output and the 9V battery is used to provide the -9V voltage. The 1μf capacitor put between the output and ground is to make sure the voltage output is smooth.

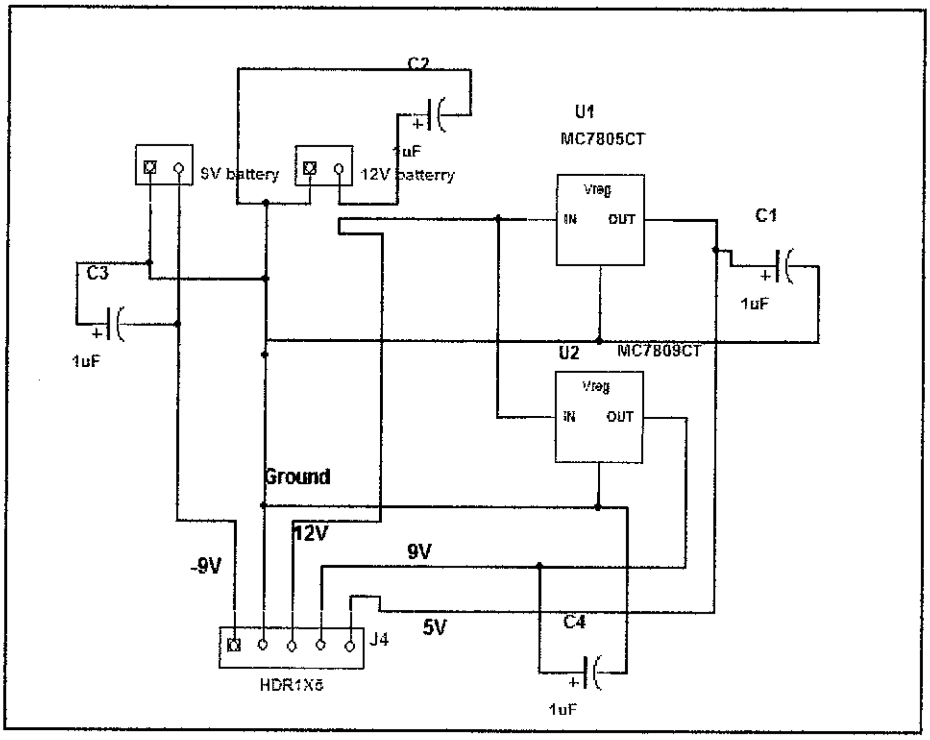

Figure 20 Power supply schematic drawing

4.4 Ultrasonic circuit

The ultrasonic circuit is no doubt the important par of the SGR system because the ultrasonic circuit is the eye for the SGR. The ultrasonic circuit senses the environment and provides information for the PIC microcontroller. The PIC microcontroller then process this input and takes action by controlling the motors of the SGR. The ultrasonic circuit can be divided into two parts; the receiver and the transmitter circuit.

4.4.1 *The transmitter circuit*

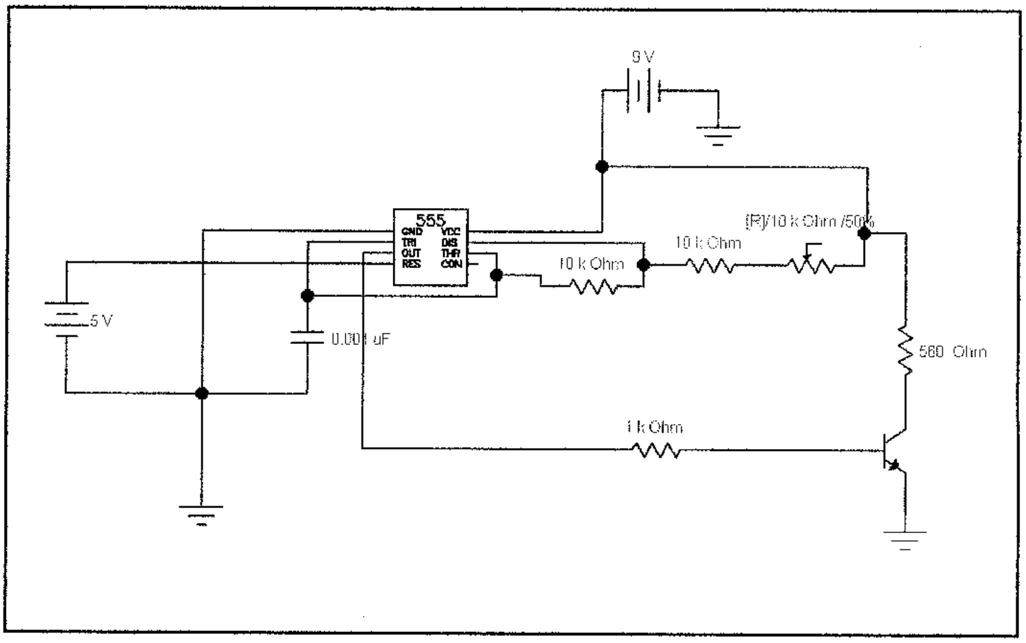

Figure 21 Transmitter circuit

The final transmitter circuit is as shown in the figure above. The output of the transmitter circuit is as shown in the figure below.

The output of the timer and the can be viewed in the figure below.

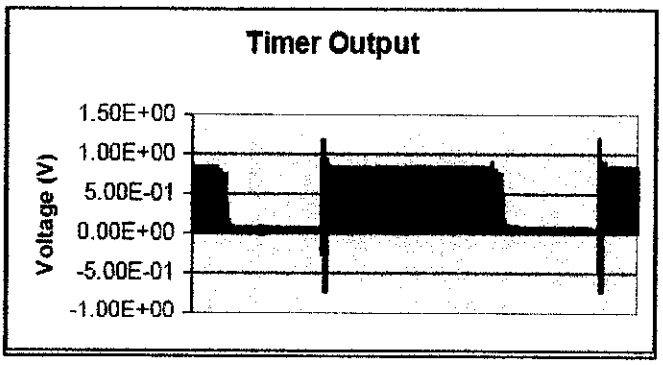

Figure 22 Oscillator output of the transmitter circuit

4.4.2 The receiver circuit

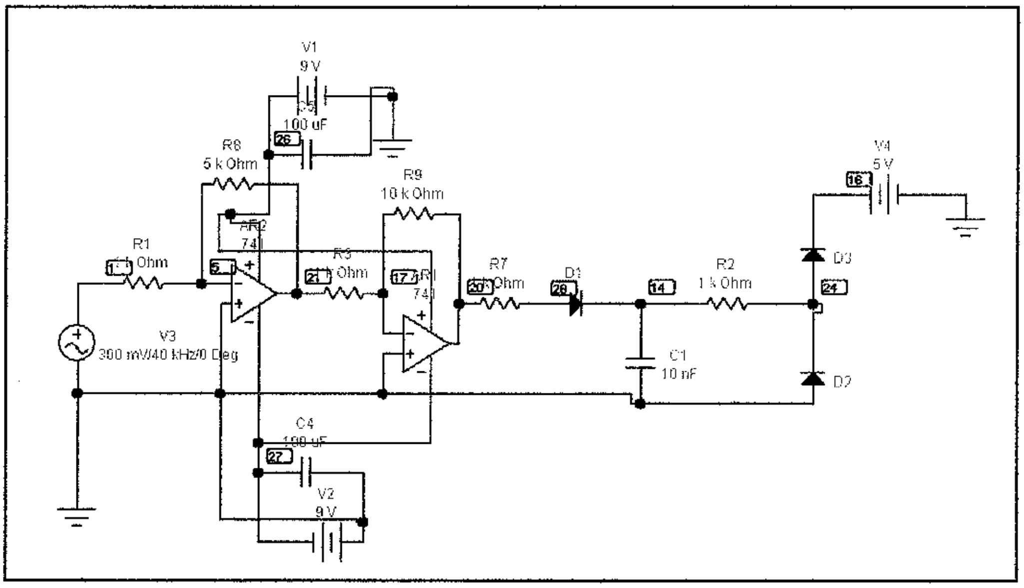

Figure 23 Receiver circuit

The receiver circuit schematic diagram can be viewed in the figure above. The receiver circuit can be into 3 parts; the amplification stage, the rectifying stage and the diode protection circuit.

4.4.2.1 Amplification stage

The received signal of the ultrasonic transducer is as shown in figure below.

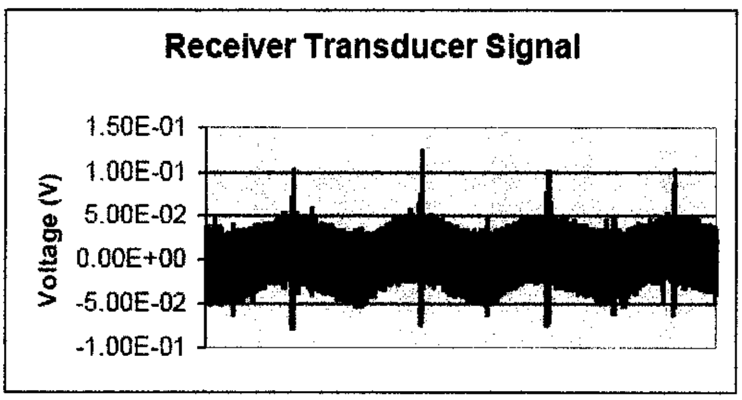

Figure 24 Receiver transducer signal

The received signal is taken when the student put a book about 6 inches in front of both the transducers. After the amplification stage the signal looks like the figure 25 on next page.

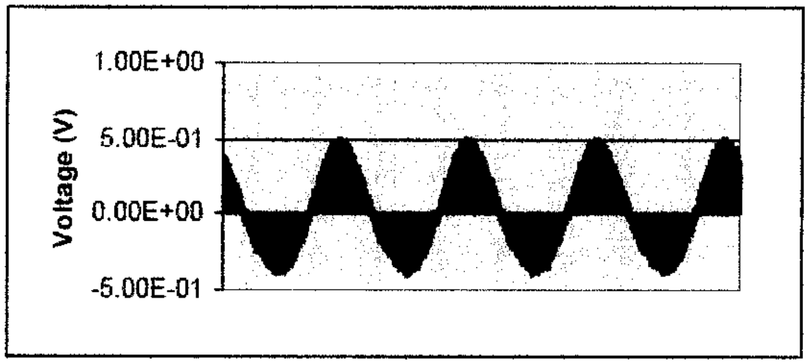

Figure 25 Signal after the amplification stage

The amplification stage of the circuit uses 2 741 op-amp. The ratio between the resistor connected to the output and the resistor connected between the output and the inverting input determine the amplification value. The resistors value have to be selected carefully so that the amplification of the signal is near to 5V.

4.4.2.2 Rectifying stage

The inputs for the ADC in the PIC microcontroller accepts only DC signals. After the two amplification stages, a half-wave rectifier circuit was added in series to change the amplified AC signal to DC. The half wave rectifier circuit was comprised of a 1N4005 diode and a 10nF capacitor connected to ground (refer to figure 15). The rectifier circuit smoothed the sinusoidal signal to a reasonable DC signal as desired.

4.4.2.3 Diode protection circuit

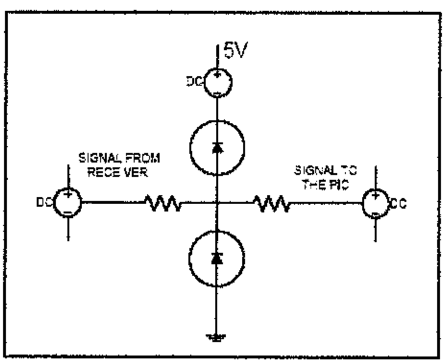

Figure 26 Diode protection circuit

Figure 26 above show the diode protection circuit. Following this rectification the student added a voltage clamping circuit so that the circuit could limit the voltage going into the PIC to be less 5.0V. This way the receiver circuit would not supply voltages of over 5V to the PIC because the PIC itself has a very limited amount of diode protection. If the voltage of over 5V were to get inputted in the PIC we could easy fry the PIC and render it useless. The student was unable to limit the output to exactly 5V, however the student were able to limit the output voltage to 5.2V which was acceptable.

4.4.3 Results

Distance from Transducer	DC voltage (V)
5 cm	5.088
10 cm	4.897
15 cm	3.373
20 cm	3.160
25 cm	2.854
30 cm	1.508
35 cm	1.146
40 cm	0.708

Table 4 Distance and DC voltage table

The data acquired after measuring the voltage of specified distance from transducer are tabulated in the table above.

From what the student experience from the project the ultrasonic transducer is very sensitive to the angle of reflection from the object. And the signal tends to fluctuate if the object is not stagnant giving the student false result.

4.5 The PIC microcontroller circuit

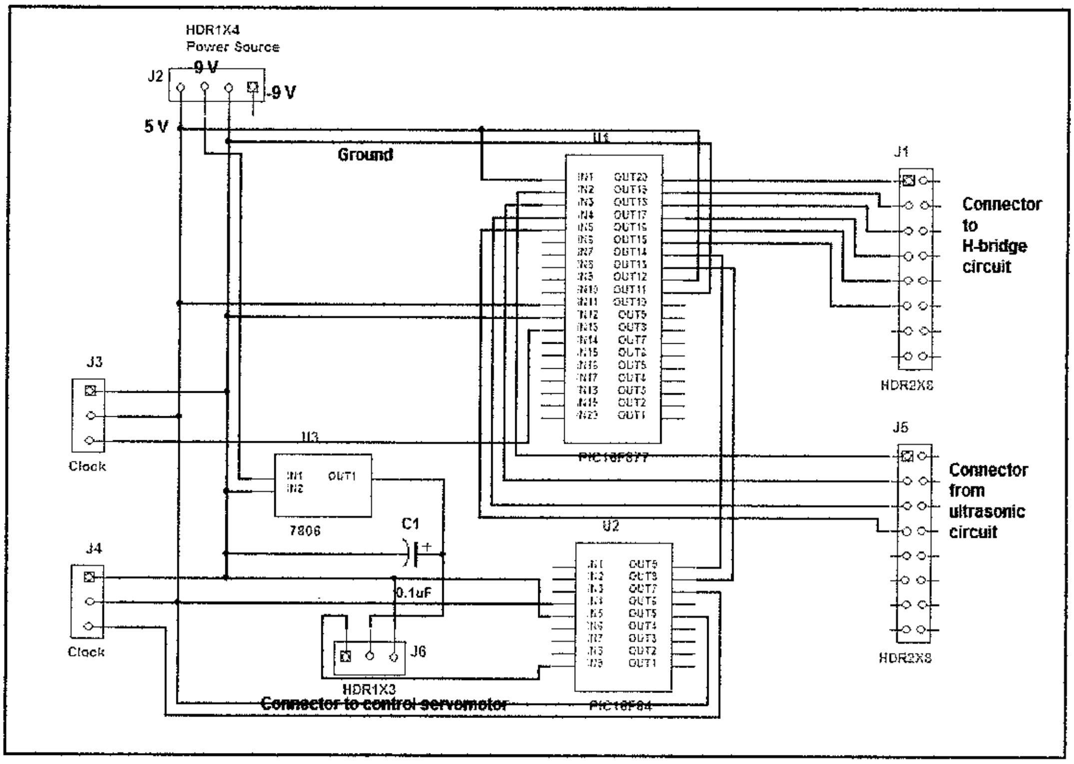

Figure 27 PIC microcontroller schematic diagram

The figure 27 above shows the PIC microcontroller schematic diagram. The circuit consists of 2 PIC microcontroller namely the PIC16f84A and the PIC16f877. The PIC16f877 is used to control the DC motor based on inputs from the ultrasonic circuits. There are 4 inputs from the ultrasonic circuit. The PIC16F84 is used to control the servomotor. The servomotor needed 6V power supply to operate and thus the voltage regulator to provide the 6V is introduced in the circuit. Others unused pins of the PIC microcontroller are tied to ground using resistors, and leave them tri-stated (if they are programmable i/o). Anything from about 1K to about 10K will work fine. This way, if the pins get set to an unintended state (due to software bugs or electrical noise or whatever), the chip will not be damaged because the current will be limited by the resistor.

4.6 Software

The software part of the project is no doubt important as it will determine how intelligent the robot will be. Since the student use 2 PIC microcontroller there are 2 programs for the 2 PIC microcontrollers. The student will discuss both the programs in the section

4.6.1 Program for PIC16F877 microcontroller

The PIC16F877 is used to process input from the ultrasonic circuit and control the DC motor. The input from ultrasonic circuit is fed to the analog-to-digital converter of PIC16F877. The ultrasonic circuit would operate most efficiently running under autonomous mode. The software was designed using assembly language and parts of DEBUG.HEX that used the ADC.

This part of the report will give a thorough explanation of the A/D converter module. The A/D conversion of the analog input signal results in a corresponding 10-bit digital number. The 10-bit A/D result is loaded onto the register pair ADRESH:ADRESHL which is a 16-bit wide register pair. The A/D module gives the programmer a choice whether to left or right justify the 10-bit result into the 16-bit register (refer to PIC16F87X manual).

Since the student are using Debug.Hex and for simplicity purposes, the subroutine in Debug.Hex for initializing the ADC, the subroutine *initADC* right justifies the result.

Therefore, the student let the A/D result to be right justified. The A/D module has a high reference voltage of 5V and a low reference voltage of 0V; therefore, we must assure that the analog input voltage is within the 0-5V range.

An example to convert the corresponding voltage level to a hexidecimal number is as follows:

Since the maximum voltage allowed is 5V the corresponding 10-bit binary number would be "11 1111 1111" which equals 1024_{10} .For, a 3.75V input the following equation:

$$3.75V * 1024 / 5V = 7681_{10} = 11\ 0000\ 0000_2$$

The following table displays the range of values set in the program and the corresponding output that is to be displayed.

Voltage (V)	Binary	Hexl	Output
5 3.75	11 1111 1111 11 0000 0000	03FF 0300	Very near
3.74	10 1111 1111 00 1111 1111	02FF	Near
1.25 0	01 1111 1111 00 0000 0000	0080 0000	Far

Table 5 Binary voltage output table

With the corresponding output the student can program the PIC16F877 to correspond to the output and control the DC motor as well as send signal to the PIC16F84 microcontroller to control the servomotor. The first version of the PIC microcontroller program uses the processed input to tell the SGR to stop forwarding when the obstacle is near and turn to the right for several seconds and then turn left for several second and after that once again turn left to bring the robot to the original path. The first version of the program can avoid an obstacle in front of it and continue its path. The flowchart and the program of the PIC16F877 can be found in the next page.

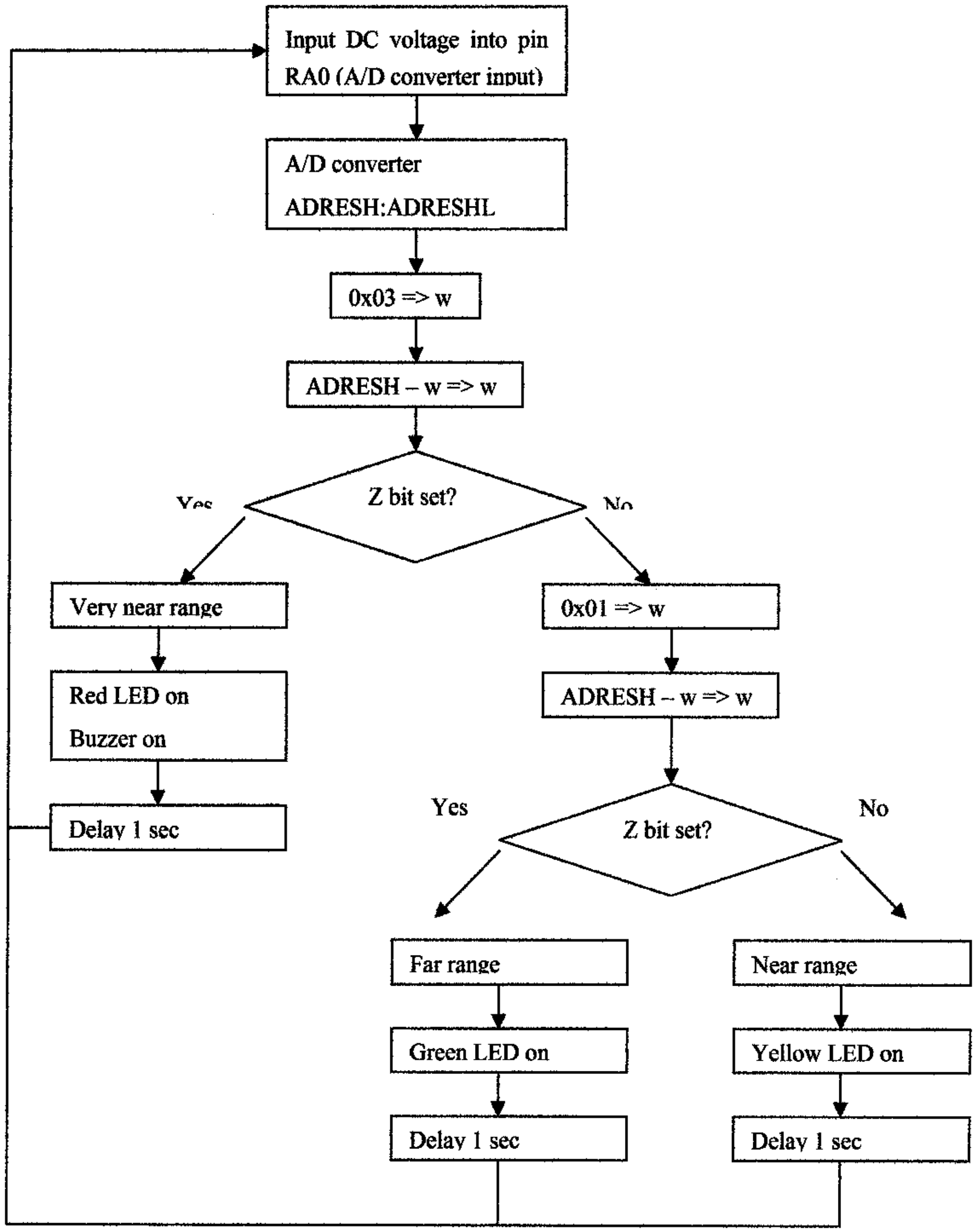

Figure 28 Flow chart of the program

4.6.2 Program for PIC16F84 microcontroller

The program for the PIC16F84 is in C code. The student wanted to try programming the PIC microcontroller using C. This microcontroller has to control the servo motor based on the input it receives from PIC16F877. The servo motor is simple to operate. The servomotor needs to be supply 6V of voltage supply and to turn the servomotor we will have to give the servomotor pulses. The length of the on pulses determines the degree the servo turns. For this project the servomotor has a centre reference point when a pulse of 1500ms delay is pulsed to the servomotor. To turn left 45 degree on pulses of 1000ms have to be provided to the servo and if we want to turn left 90 degrees, we gives the servo motor on pulse of 500ms. To turn right 45 degrees, pulses of 2000ms have to be provided to the servomotor.

Input 1	Input 2	Action to servomotor
1	1	The servomotor reference point. This action is used for the SGR to move straight forward or reverse
0	1	Turn clockwise 45 degrees. The SGR use this function to turn right
1	0	Turn anticlockwise 45 degrees. The SGR use this function to turn left
0	0	Turn 90 degrees. The SGR use this function to do the zero turning cycle

Table 6 Input and servomotor action table.

The programme and flowchart can be viewed in the appendix part of the report.

CHAPTER 5
RECOMMENDATION

The transmitter circuit that the writer use is commonly used to generate a 40 kHz signal using a 555 timer and the writer had very little trouble getting the transmitter to function properly. However the writer would like to recommend the used of PIC to generate the 40 kHz signal as the PIC is capable of generating the signal b itself using some programming.

The receiver circuit is based on a couple of amplifications and a rectification. In regards to the code, we simply took the voltage being inputted into the PIC and depending on what that voltage was the PIC will trigger an output response. This idea initially seemed like a very good idea but when the writer implemented this idea into the project the writer were getting a very unstable input to the PIC, the voltage tended to oscillate in the range +/- 0.4V range. This caused a problem because the output signal of the PIC at one moment was saying that the object was near while at the next moment the output signal would tell us that the object was either very near or far.

To combat this problem the writer suggest that the program be designed to take a sample of 20 values, average these values and then output the appropriate signal based on this average because this way we could have had a more stable output even though the signal coming into the PIC was somewhat unstable. Another suggestion to combat the difficulties of an unstable voltage being inputted into the PIC would be to use the PIC programming to rectify the situation. Through programming we can control the transmitter circuit and the receiving circuit timing. This would help in avoiding crosstalk which another possibility why the voltage input to PIC is not stable. The writer believes that one of the main reasons for the voltage coming out of receiver circuit being so varied at certain points was due to constructive and destructive interference.

The whole method of calculating the range can be modified by calculating the time it takes the echo to come back. This is yet another suggestion to improve the ultrasonic system accuracy.

Beside that the physical structure can be further improved by building it more carefully. The design of the SGR to the writer opinion is perfect. The fabrication of it needs some improvement.

The writer also wants to recommend the use of gear motor system as oppose to what has been implemented in this project. The geared motor can gives more torque and less speed which is appropriate in building robots. The higher torque in geared motor will allow a higher payload robot to be built.

The programming of the SGR could also be improved further. The SGR should be program to avoid any obstacle whether from front, back or side. Mapping is also possible if the SGR can be program to remember the obstacle it encounter and can draw the map of a room.

CHAPTER 6
CONCLUSION

The student is satisfy with the design of the physical structure of the robot as the robot is able to satisfy the requirements set by student earlier stage of the project. The fabrication of the physical structure of the robot is however can be improve further as the student did not have to complete tool and funding to built the perfect robot. However the prototype built for the project is good enough for the student to attain its main objective, which is to avoid any obstacle while following its predetermined path.

The ultrasonic circuit is reliable enough for implementation of this project. However the performance of the circuit can be improved further by experimenting more with the circuits. The ultrasonic circuit built by the student can detect obstacle in front of it from 2cm to 40cm the furthest.

The H-bridge circuit is very good as it can drive the motor with certain load without burning. The H-bridge circuit is important as it is required to handle huge amount of current flow because the DC motor will pull a lot of current when it is starting to move.

The PIC16F877 microcontroller circuit and the program used to control the robot is quite simple. As the robot can only move a predetermined path and avoid any obstacle while doing it. A more complex program can further improve the intelligence of the robot.

Overall the robot is able to perform the task it required with minimal error.

The Self Guidance Robot is a very interesting project. Learning on how to build a robot will be a pleasant experience. The application of the Self Guiding Robot will include collision avoidance, security surveillance etc. It is hoped that this project will inspire others to delve into the robotics research.

The experience of building a ultrasonic ranging system was a very enjoyable. Though the student's project was successful, there many improvement that can be made to the project. The student also learns many things in the process of doing the project. To name a few are programming the PIC microcontroller, using the A/D converter module of the PIC, converting AC signal to DC signal, soldering board and project time management.

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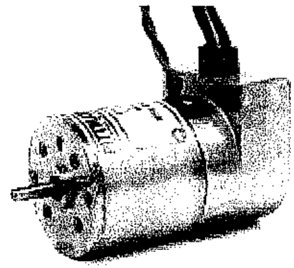
APPENDIX A
PITTMAN DC MOTOR DATA SHEET

9232S001

Lo-Cog® DC Servo Motor



Assembly Data	Symbol	Units	Value	
Reference Voltage	E	V	12	
No-Load Speed	S_{NL}	rpm (rad/s)	7,015	(735)
Continuous Torque (Max.)[1]	T_C	oz-in (N-m)	2.4	(1.7E-02)
Peak Torque (Stall)[2]	T_{PK}	oz-in (N-m)	14	(9.7E-02)
Weight	W_M	oz (g)	10	(283)
Motor Data				
Torque Constant	K_T	oz-in/A (N-m/A)	2.20	(1.55E-02)
Back-EMF Constant	K_E	V/krpm (V/rad/s)	1.63	(1.55E-02)
Resistance	R_T	Ω	1.93	
Inductance	L	mH	1.16	
No-Load Current	I_{NL}	A	0.32	
Peak Current (Stall)[2]	I_P	A	6.22	
Motor Constant	K_M	oz-in/√W (N-m/√W)	1.62	(1.14E-02)
Friction Torque	T_F	oz-in (N-m)	0.50	(3.5E-03)
Rotor Inertia	J_M	oz-in-s^2 (kg-m^2)	2.7E-04	(1.9E-06)
Electrical Time Constant	τ_E	ms	0.63	
Mechanical Time Constant	τ_M	ms	14.4	
Viscous Damping	D	oz-in/krpm (N-m-s)	0.027	(1.8E-06)
Damping Constant	K_D	oz-in/krpm (N-m-s)	1.9	(1.3E-04)
Maximum Winding Temperature	θ_{MAX}	°F (°C)	311	(155)
Thermal Impedance	R_{TH}	°F/watt (°C/watt)	72.9	(22.7)
Thermal Time Constant	τ_{TH}	min	7.2	
Gearbox Data				
Encoder Data				
Channels			3	
Resolution		CPR	500	

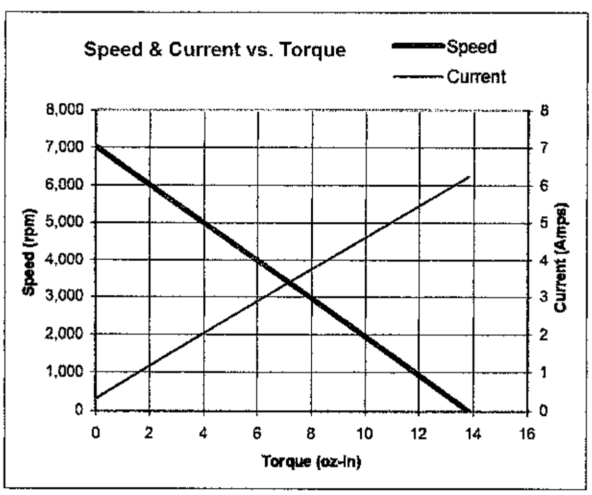
1 - Specified at max. winding temperature at 25°C ambient without heat sink. 2 - Theoretical values supplied for reference only.

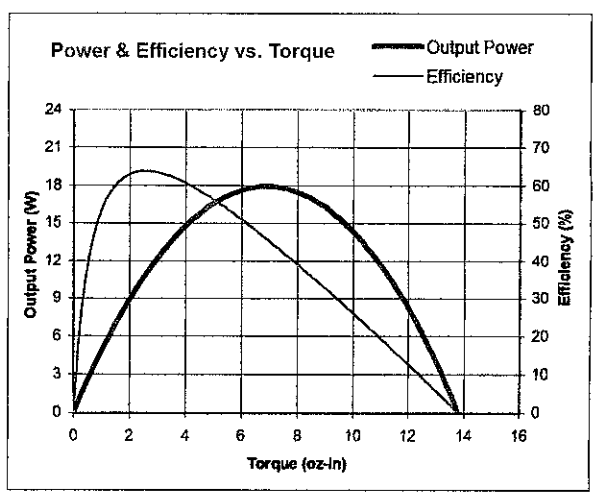
Included Features

2-Pole Stator
Ceramic Magnets
Heavy-Guage Steel Housing
7-Slot Armature
Silicon Steel Laminations
Stainless Steel Shaft
Copper-Graphite Brushes
Diamond Turned Commutator
Motor Ball Bearings

Customization Options

Alternate Winding
Sleeve or Ball Bearings
Modified Output Shaft
Custom Cable Assembly
Special Brushes
EMI/RFI Suppression
Spur or Planetary Gearbox
Special Lubricant
Optional Encoder
Fail-Safe Brake



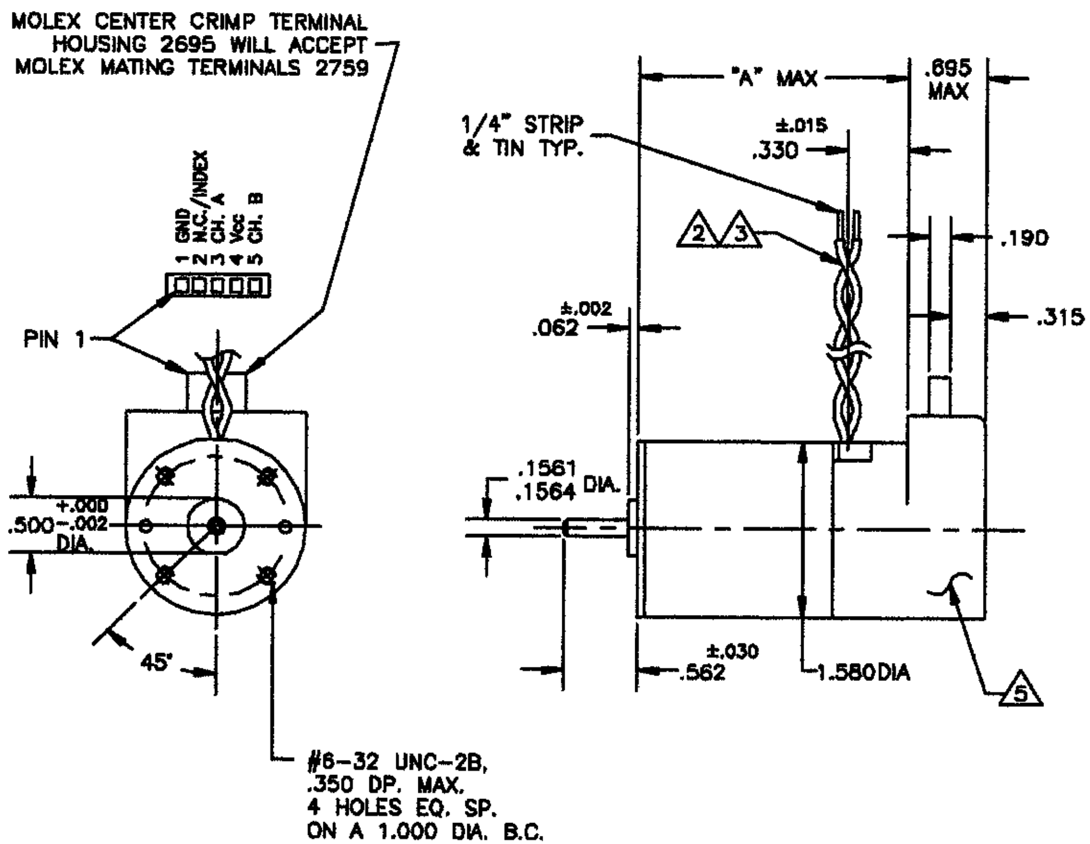


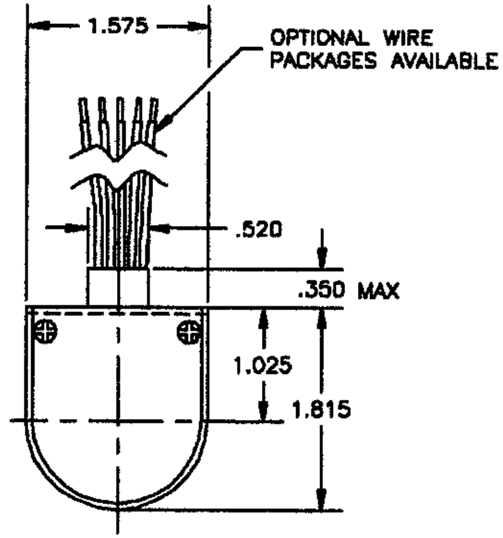
All values are nominal. Specifications subject to change without notice. Graphs are shown for reference only.

PITTMAN, 343 Godshall Drive, Harleysville, PA 19438, Phone: 877-PITTMAN, Fax: 215-256-1338, E-mail: info@pittmannet.com, Web Site: www.pittmannet.com

REVISIONS

LTR	DESCRIPTION	DRFT/ENGR	DATE	APPR
D	REDRAWN, UPDATED TO CURRENT STDS	KUH/KUH	5/12/98	JRM
E	.330 WAS .315	TMG/DLF	4/3/01	JRM
F	SPECIFIED TOLERANCE FOR DIM. .562	TMG/TMG		





MODEL NO.	"A" MAX
92X6	3.021
92X5	2.671
92X4	2.371
92X3	2.171
92X2	1.796

NOTES:

1. SHAFT ROTATION IS CW WHILE VIEWING MOUNTING END WITH POSITIVE (+) VOLTAGE APPLIED TO THE RED LEAD.
2. LEADS ARE 22 AWG (7X30), PVC INSULATED, UL STYLE 1569/1007. ONE LEAD IS RED, THE OTHER IS BLACK.
3. STANDARD LEAD LENGTH IS 18 ±1/2 INCHES.
4. BALL BEARINGS ARE PRELOADED PER P-107.
5. ENCLOSED IS A HP HEDS-91X0 OPTICAL ENCODER MODULE.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTION ±1/64 DECIMAL ANGLES BREAK ALL SHARP EDGES

MATERIAL:

FINISH:

FILE: 150\402

DRAFTED BY	KUH	5/11/98
ENGINEERED BY	KUH	5/11/98
APPROVED BY	JR MELA	5/12/98

NEXT ASSY:

USED ON:

PITTMAN

TITLE: OUTLINE & MOUNTING DIMENSIONS 9200 SERIES MOTOR WITH 9100 H.P. ENCODER MODULE

DWG. NO. B- 150-402 REV. F

SCALE: DNS SHEET 1 OF 1

APPENDIX B
PHYSICAL STRUCTURE

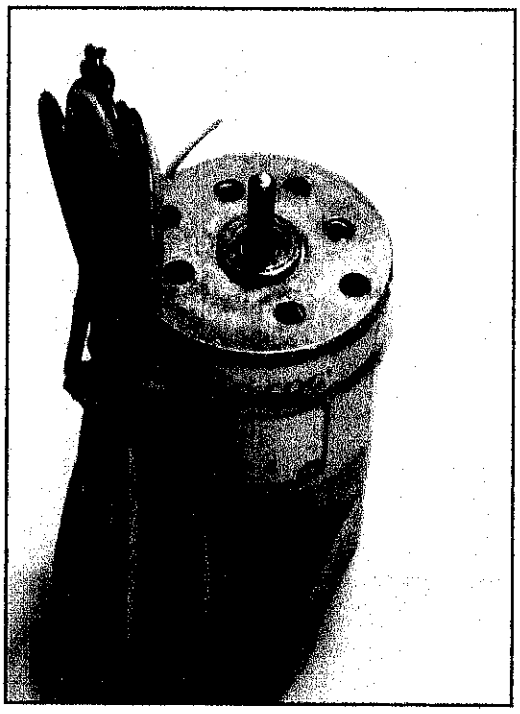


Figure 29 PITTMANDc motor

Figure 30 Futaba servomotor

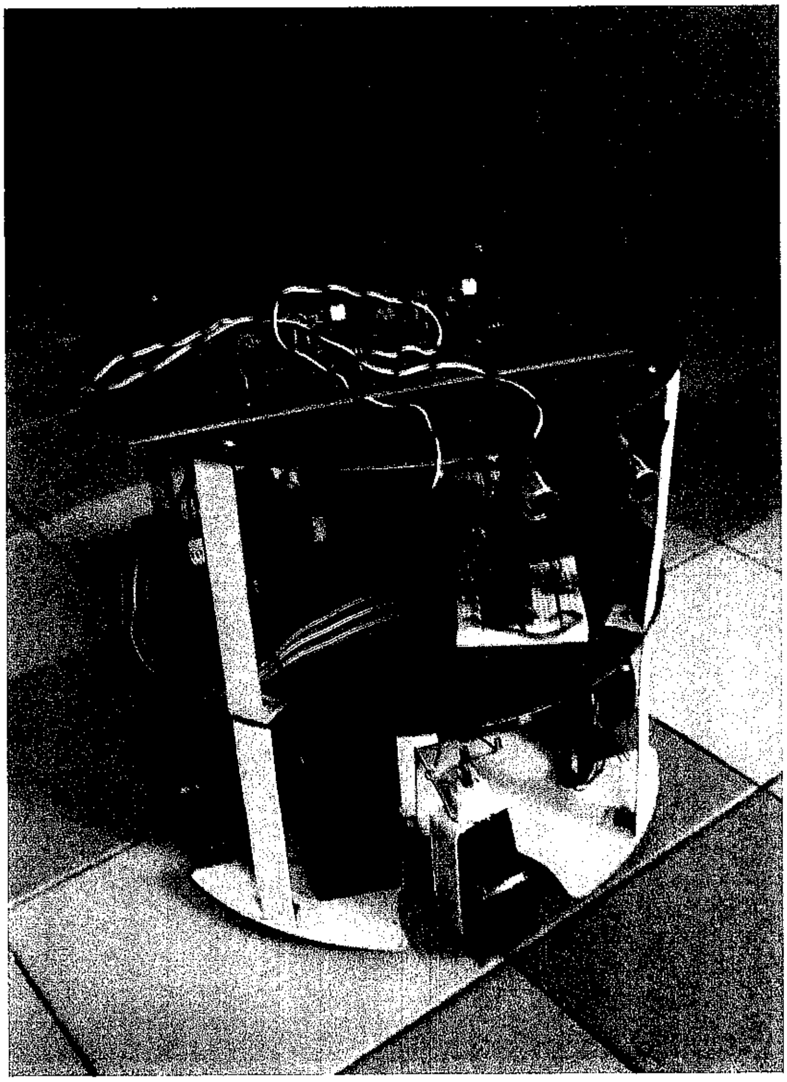


Figure 31 SGR complete structure

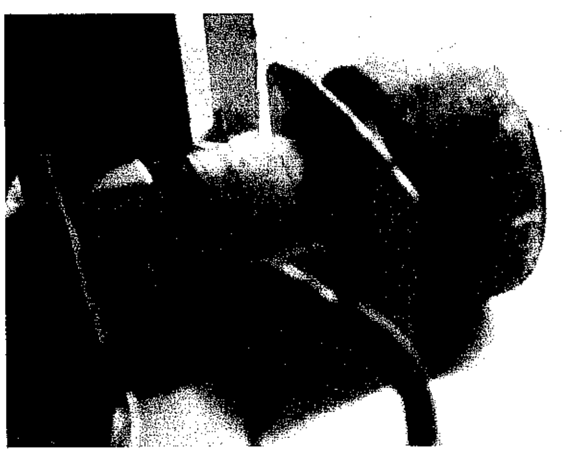


Figure 32 DC motor and tyre coupling

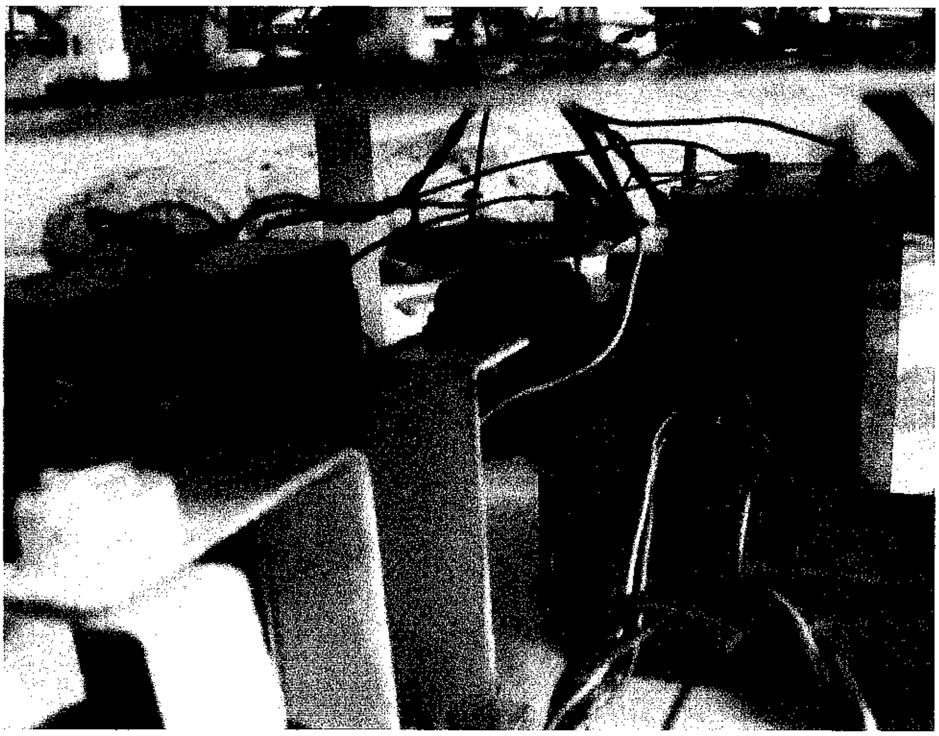


Figure 33 Bottom level of the SGR(DC mototor servo motor and Battery)

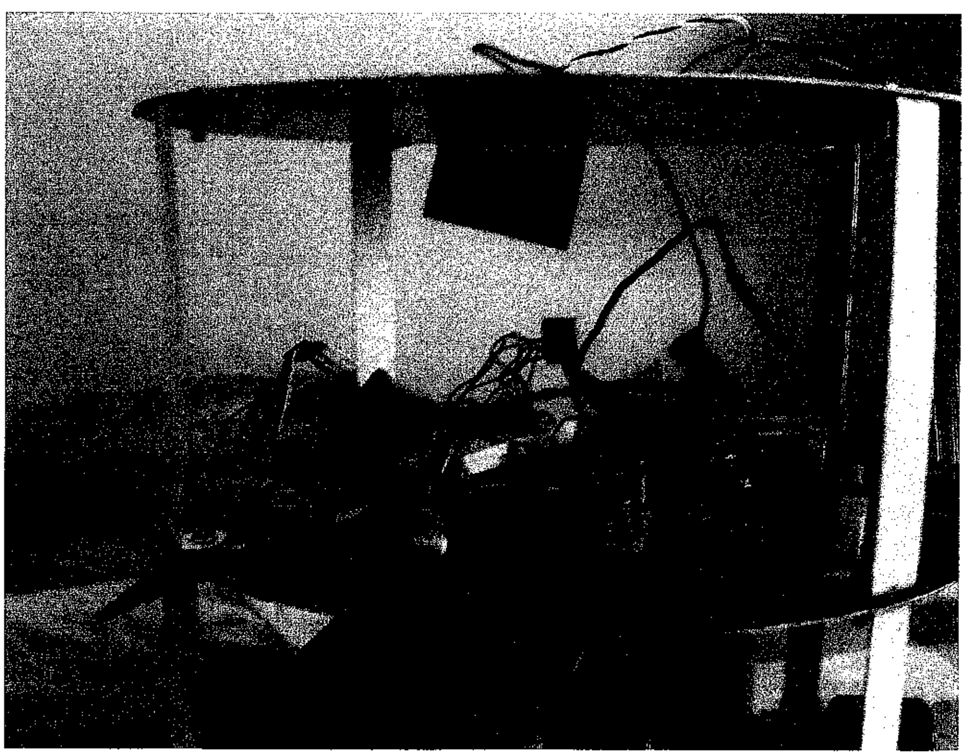


Figure 34 Second level of the SGR

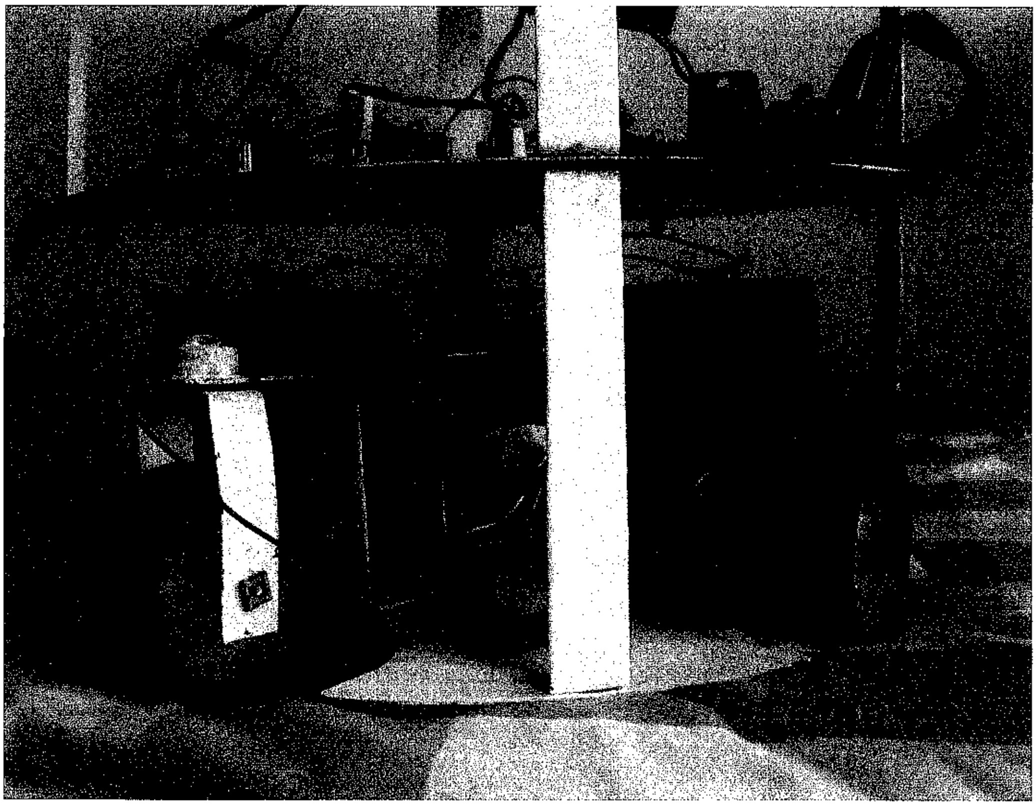
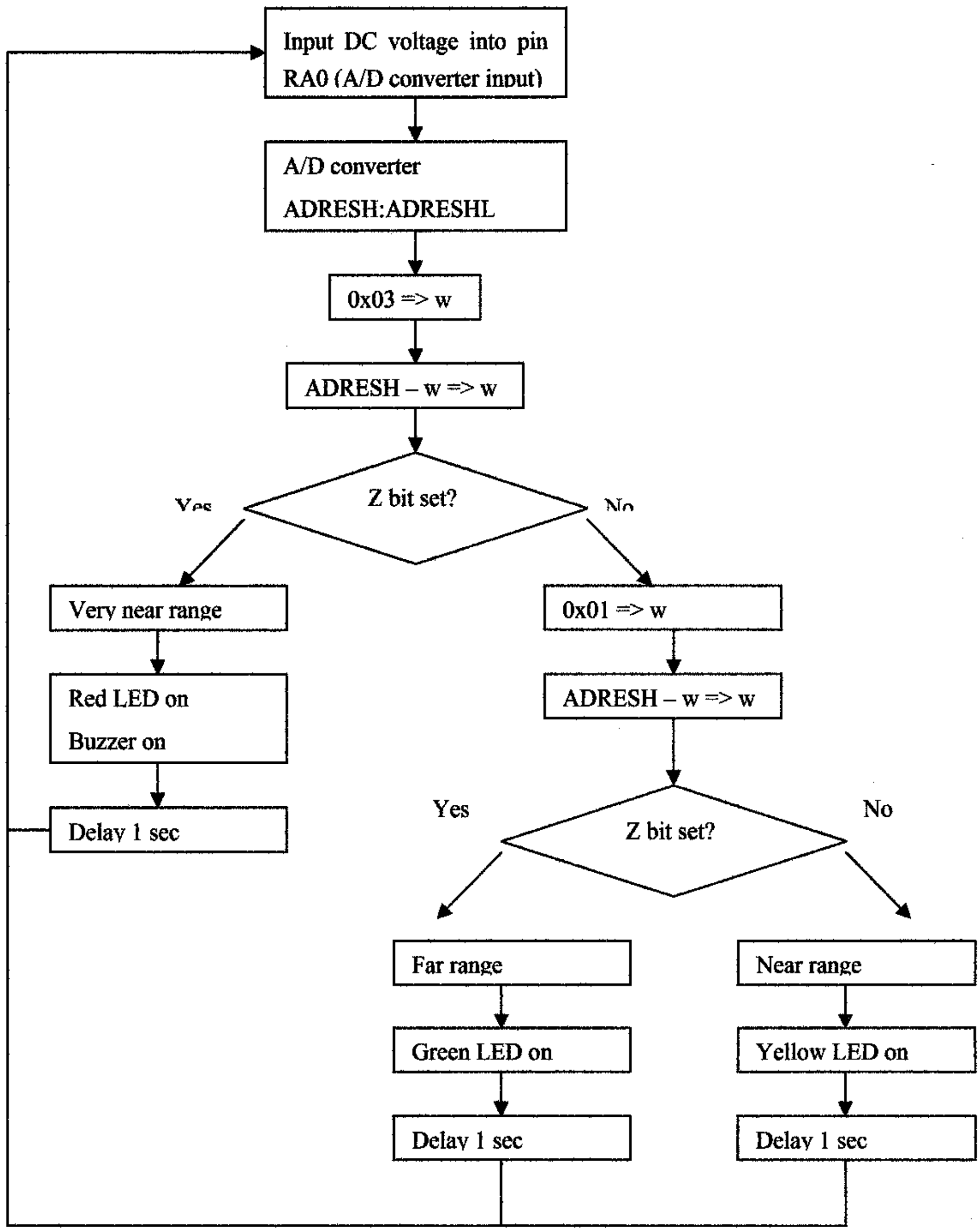


Figure 35 Directional tyre and servo motor

APPENDIX C
PROGRAM FLOWCHART



APPENDIX D
PIC16F877 PROGRAM

```
;*************************************************************************
;          The file was originally started with use of the 16F877 code
;          template supplied by Microchip.
;;*************************************************************************
;          Filename: RangeUltra.asm
;          Last Revision Date:   October 16, 2003
;          File Version:         1.0
;
;          Author:               Mohd.Sazri Bin Zainuddin
;          Company: University Technology Petronas
;*************************************************************************
;          Files required:       P16F877.inc
;                                16F877.lkr
;*************************************************************************
          list     p=16f877                  ; List directive to define processor
          #include <p16f877.inc>             ; Processor specific variable definitions

          errorlevel -302                    ; These remove unwanted warnings
          errorlevel -305                    ;  from the compile information listing
          errorlevel -306

          __CONFIG _CP_OFF & _WDT_OFF & _BODEN_OFF & _PWRTE_OFF & _XT_OSC & _WRT_ENABLE_ON
& _LVP_OFF & _CPD_OFF

; '__CONFIG' directive is used to embed configuration data within .asm file.
; The labels following the directive are located in the respective .inc file.
; See respective data sheet for additional information on configuration word.


;***** VARIABLE DEFINITIONS
;**** Variables
input            EQU    0x60                 ; Buffer used up to 0x2C+D'21'= 0x41
offsetLow EQU    0x22
offsetHigh EQU   0x23
length           EQU    0x24
char             EQU    0x25
tableOffsetEQU   0x26
expectedLength   EQU    0x27
hexByteLow       EQU    0x28
hexByteHigh      EQU    0x29
temp             EQU    0x2A
```

```
;**** Delay
DCOUNT1                 EQU     0x2F            ; Used in Delay subroutines
DCOUNT2                 EQU     0x30
DCOUNT3                 EQU     0x31
DCOUNT4                 EQU     0x32
;** General

BANK0           EQU     0x0000  ; Data Memory start positions
BANK1           EQU     0x0080
BANK2           EQU     0x0100
BANK3           EQU     0x0180

PAGE0           EQU     0x0000  ; Program Memory start positions
PAGE1           EQU     0x0800

;*******************************************************************
;*** On reset these are the first commands performed
;*******************************************************************
        ORG   0x000             ; processor reset vector
        clrf  PCLATH            ; ensure page bits are cleared
        goto  main              ; go to beginning of program
;**********************************************************************
;*** This is the start of the main code for receiving input
;**********************************************************************
main
start
        call    initializeChip  ; Initialize the entire Chip to known state

        call    initADC         ; initialize the ADC
mainLoop

        banksel BANK0
        movlw   0x64
        call    delayWx10ms
        call    readADC
        banksel BANK0
        movlw   0x03            ;binary'0000 0011'
        subwf   ADRESH,w
        btfsc   STATUS,Z        ;check if high byte equal to h'03' (very near range)
        goto    redlighton
        movlw   0x00            ;check if high byte equal to h'00' (far range)
        subwf   ADRESH,w
        btfsc   STATUS,Z
        goto    greenlighton
        goto    yellowlighton
```

```
redlighton                              ; very near range
        call    redlight
        goto    resume
greenlighton                                    ; far range
        call    greenlight
        goto    resume
yellowlighton                                   ; near range
        call    yellowlight
        goto    resume
resume
        banksel BANK0
        movlw   0x64
        call    delayWx10ms
        goto    mainLoop
;*******************************************************************
;       Function subroutine to turn on an LED at PORTC bit0
; receives: nothing
; uses: nothing
; returns: nothing
;*******************************************************************
redlight
        banksel BANK0
        movlw   0xF6
        movwf   PORTC
        return
;*******************************************************************
;       Function subroutine to turn on an LED at PORTC bit1
; receives: nothing
; uses: nothing
; returns: nothing
;*******************************************************************
greenlight
        banksel BANK0
        movlw   0xFB
        movwf   PORTC
        return
;*******************************************************************
;       Function subroutine to turn on RED LED at PORTC bit2
;                       and on buzzer PortC bit4
; receives: nothing
; uses: nothing
; returns: nothing
;*******************************************************************
yellowlight
        banksel BANK0                   ;turn on yellow led and buzzer
        movlw   0xFD
```

```
        movwf   PORTC
        return
;*******************************************************************
;       Function subroutine to set specific registers on
;         initialization of software.
; receives: nothing
; uses: W
; returns: nothing
;*******************************************************************
initializeChip                  ; Set all Pins to output (low) (high impedence)
        banksel BANK0           ; Move to Bank 0
        clrf    PORTA           ; Clear Port A
        clrf    PORTB           ; Clear Port B
        clrf    PORTC           ; Clear Port C
        banksel BANK1           ; Move to Bank 1
        movlw   0x86            ;
        movwf   ADCON1          ; Set all Port A to Digital I/O
        clrf    TRISA           ; Set Port A to digital out
        clrf    TRISB           ; Set Port B to digital out
        clrf    TRISC           ; Set Port C to digital out
        banksel BANK0           ; Move to Bank 0
        clrf    ADCON0          ; Shutoff all ADC function and set available
                                ;  channel to AN0
        clrf    PORTA           ; Clear Port A
        clrf    PORTB           ; Clear Port B
        movlw   0xff
        movwf   PORTC           ; set Port C

        return
;*******************************************************************
;       ADC Module Subroutines
;*******************************************************************
;       Function subroutine to initialize RA0 as an ADC input.
;         Sets the (right justified) data flag.
; receives: nothing
; uses: W
; returns: nothing
;*******************************************************************
initADC
        banksel BANK1           ; Move to Bank 1
        movlw   0x82            ; Set all AN pins on Port A as analog
        movwf   ADCON1          ;   and right justify data in ADRESH and ADRESL
        banksel BANK0           ; Move to Bank 0
        movlw   0x01            ; Shutoff all ADC function and set available
        movwf   ADCON0          ;  channel to A0
                                ;  Also selects: A/D clock = Fosc/2
```

```
        movf    PORTA,W         ; Initialize Port A values to 0
        andlw   0x10
        movwf   PORTA
        banksel BANK1           ; Set to bank1
        bcf     PIE1,ADIE       ; Disable A/D interupt
        movf    TRISA,W         ; Initialize Port A Analog ANs to inputs
        iorlw   0x2f
        movwf   TRISA
        banksel BANK0           ; Move to Bank 0
        bcf     PIR1,ADIF       ; Clear A/D interupt flag
        return
;*******************************************************************
;       Function subroutine to initiate a read of ADC port pins
;         which stores its value in ADRESH, and ADRESL (right justified)
; receives: W - <0 to 4> pin to read
; uses: W, char
; returns: nothing
;*******************************************************************
readADC
        movwf   char
        swapf   char            ; Move input value into the ADC
        bcf     STATUS,C        ;   pin selection bits
        rrf     char
        bsf     char,0          ; Set the enable bit 0
        movf    char,W
        movwf   ADCON0
        bsf     ADCON0,GO       ; Start A/D conversion (sets bit 2)
        btfsc   ADCON0,GO       ; Repeat until the GO bit is automatically
        goto    $ - 1           ;   set low by hardware
        bcf     PIR1,ADIF       ; Clear A/D interupt flag
                                ; Values are now stored in ADRESH and ADRESL
        return
;*******************************************************************
;       Function subroutine to perform multiple 10ms delays
; receives: W - a multiplier of the 1ms time
; uses: W,DCOUNT1,DCOUNT2, DCOUNT3
; returns: nothing
;*******************************************************************
delayWx10ms
        movwf   DCOUNT1                 ; DCOUNT1 = W
        movlw   0x64
        movwf   DCOUNT2
        movlw   0x20
        movwf   DCOUNT3
        decfsz  DCOUNT3                 ; delay of > (((3 * DCOUNT3)+3)*DCOUNT2)+3*W)
        goto    $ - 1           ;   * instruction cycle time (1us for 4MHz)
```

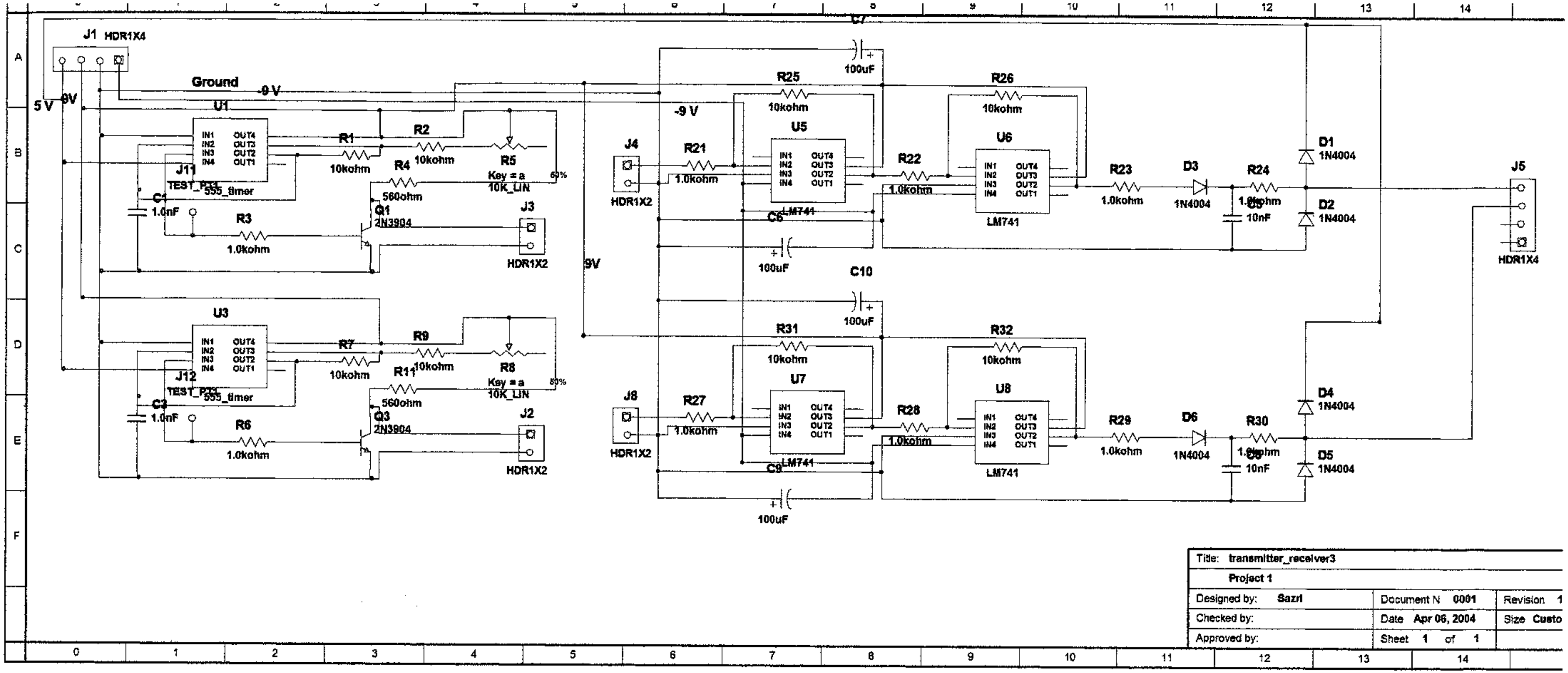
```
decfsz   DCOUNT2
goto     $ - 5              ; so currently W x 10ms
decfsz   DCOUNT1
goto     $ - 9
return
END      ; Directive 'end of program'
         ; Code reaching this point may perform irratically.
```

APPENDIX E
PIC16F84 PROGRAM

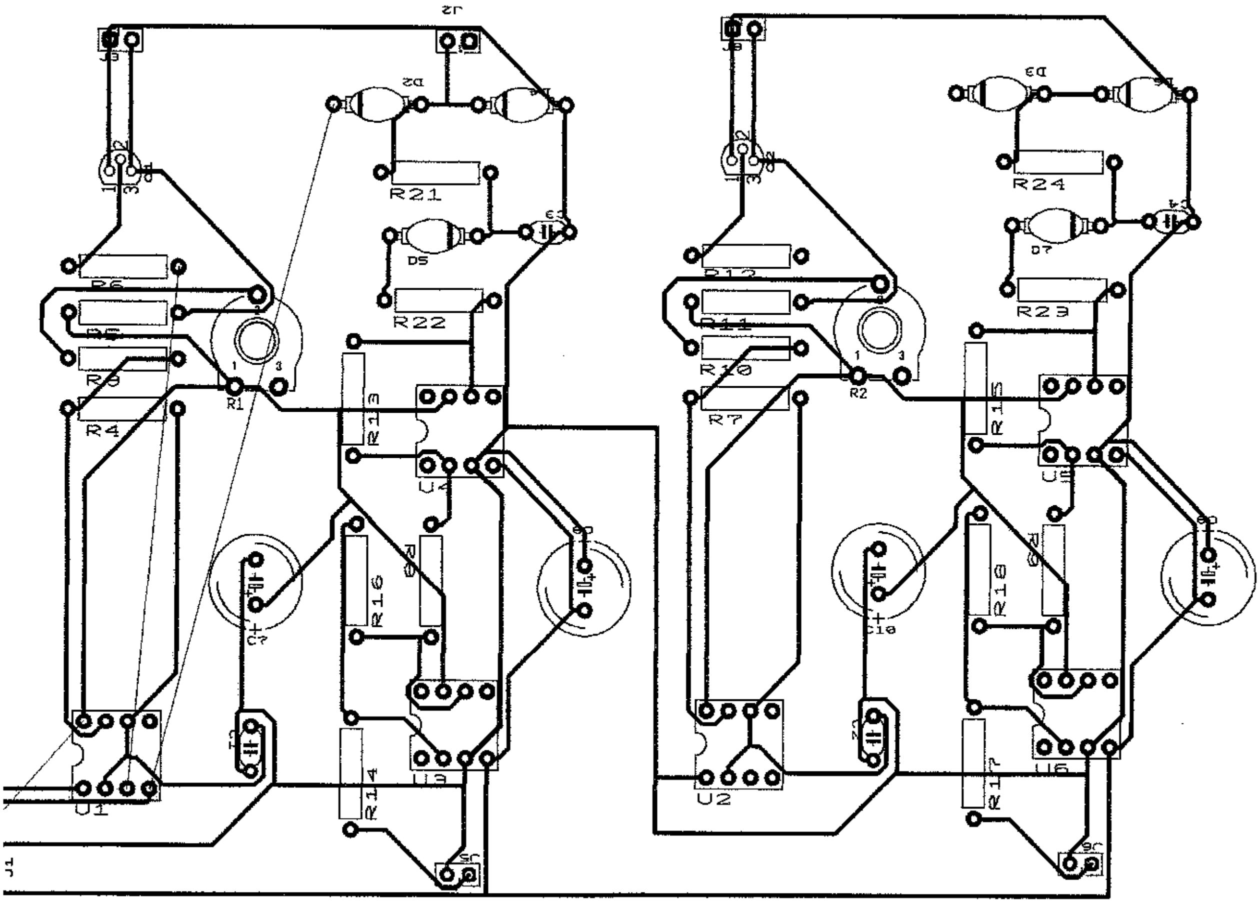
```
#include <16f84.h>
#fuses XT,NOPROTECT,NOWDT
#use delay(clock=4000000)

void main()
{
            while(true)
  {
    if (PIN_A0==1 & PIN_A1==1)
    {
    output_high(PIN_B3);
    delay_us(1500);
    output_low(PIN_B3);
    }

    else if (PIN_A0==0 & PIN_A1==0)

    {
    output_high(PIN_B3);
    delay_us(500);
    output_low(PIN_B3);
    }

    else if (PIN_A0==1 & PIN_A1==0)

    {
    output_high(PIN_B3);
    delay_us(1000);
    output_low(PIN_B3);
    }

    else

    {
    output_high(PIN_B3);
    delay_us(2000);
    output_low(PIN_B3);
    }
```

```
        output_high(PIN_B5);
    delay_us(500);

    output_high(PIN_B4);
    delay_us(500);

    output_high(PIN_B3);
    delay_us(500);

    output_high(PIN_B2);
    delay_us(500);

    output_high(PIN_B1);
    delay_us(500);


    output_low(PIN_B5);
    output_low(PIN_B1);
    output_low(PIN_B2);
  output_low(PIN_B3);
    output_low(PIN_B4);

    delay_ms(20);
  }
}
```

APPENDIX F
ULTRASONIC CIRCUIT

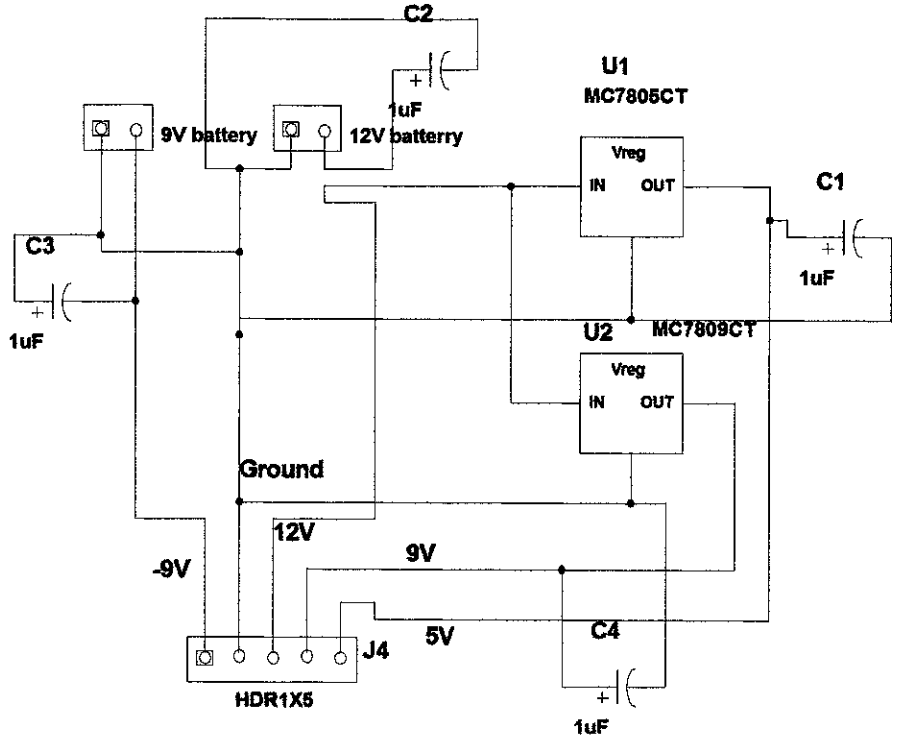


J1 HDR1X4
5 V
9V
Ground
-9 V
U1
IN1 IN2 IN3 IN4 OUT4 OUT3 OUT2 OUT1
J11
TEST_PT1
555_timer
C1
1.0nF
R1
10kohm
R2
10kohm
R5
Key = a
10K_LIN
60%
R4
560ohm
R3
1.0kohm
Q1
2N3904
J3
HDR1X2
U3
J12
TEST_PT2
555_timer
C3
1.0nF
R7
10kohm
R9
10kohm
R8
Key = a
10K_LIN
60%
R11
560ohm
R6
1.0kohm
Q3
2N3904
J2
HDR1X2
9V
C7
100uF
R25
10kohm
R26
10kohm
-9 V
J4
HDR1X2
R21
1.0kohm
U5
LM741
R22
1.0kohm
U6
LM741
C6
100uF
R23
1.0kohm
D3
1N4004
R24
C5
10nF
D1
1N4004
D2
1N4004
J5
HDR1X4
C10
100uF
R31
10kohm
R32
10kohm
J8
HDR1X2
R27
1.0kohm
U7
LM741
R28
1.0kohm
U8
LM741
C9
100uF
R29
1.0kohm
D6
1N4004
R30
C8
10nF
D4
1N4004
D5
1N4004
A B C D E F
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Title: transmitter_receiver3
Project 1
Designed by: Sazri
Document N 0001
Revision 1
Checked by:
Date Apr 06, 2004
Size Custo
Approved by:
Sheet 1 of 1



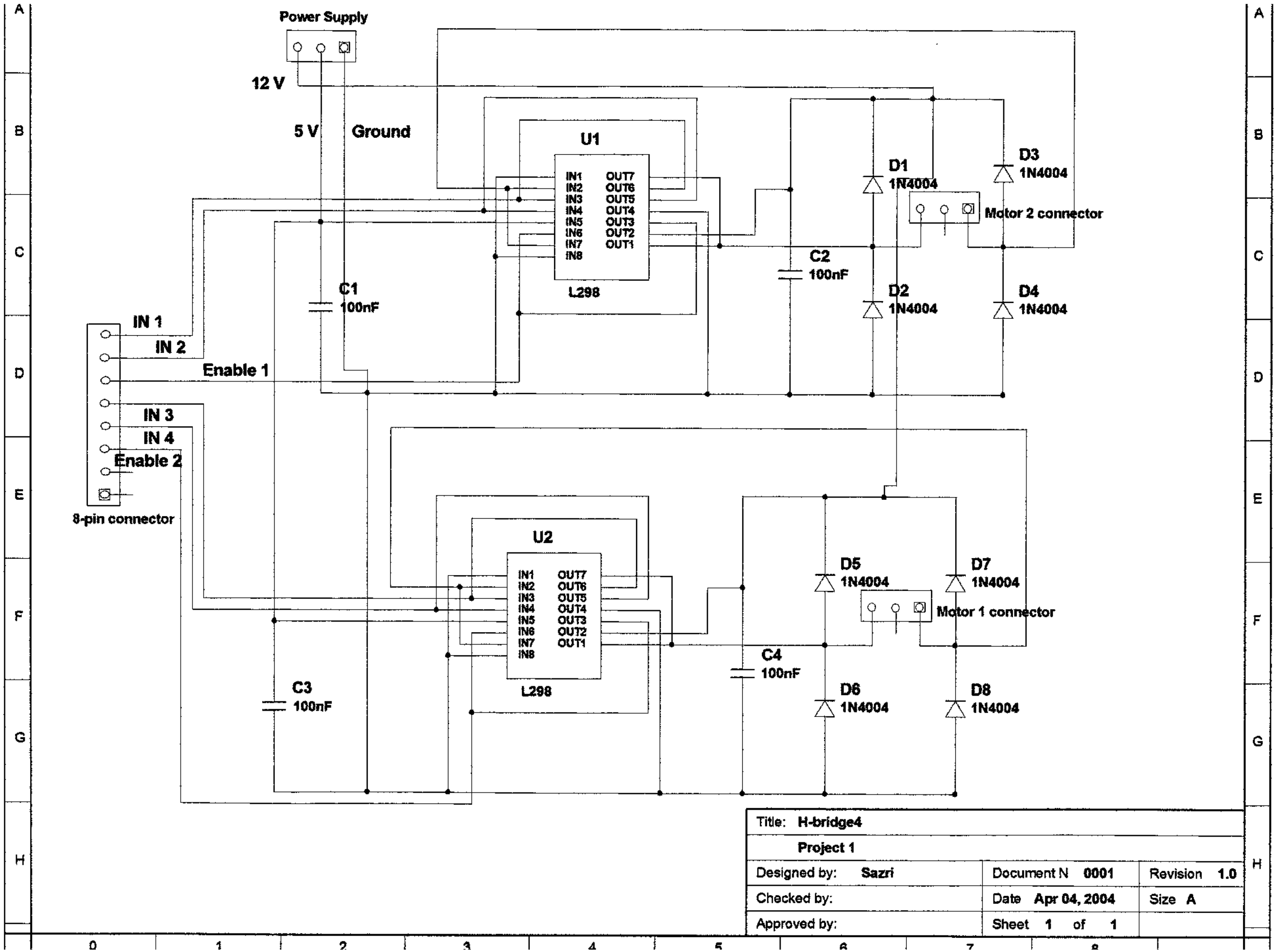
J2
R21
D5
R22
R6
R4
R1
R13
U4
R16
C7
U1
R14
U3
J5
R24
D7
R23
R12
R11
R10
R7
R2
R15
R18
C10
U2
R17
U6

APPENDIX G
POWER SUPPLY CIRCUITS

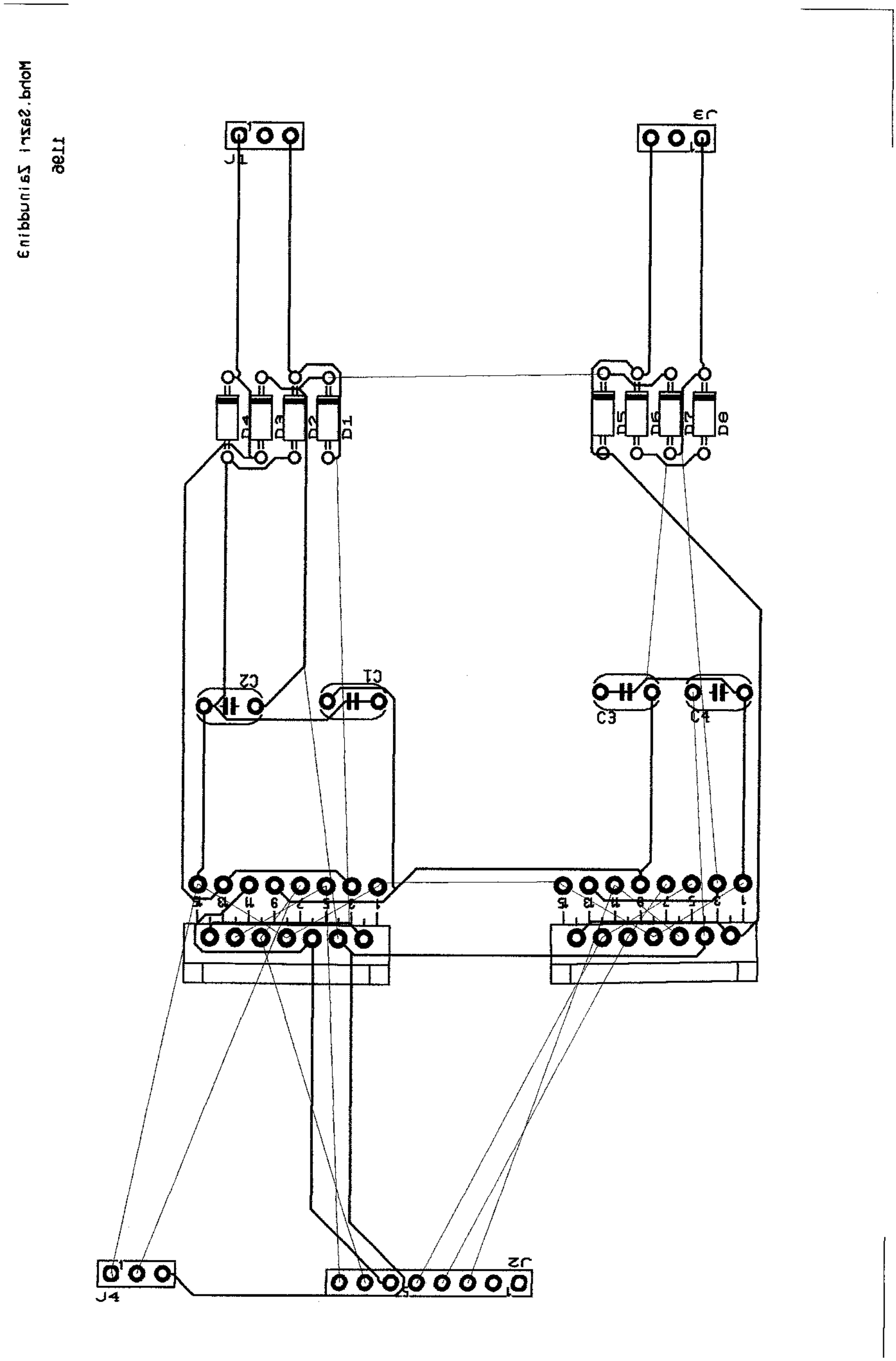


Title: power_supply		
Project 1		
Designed by: Sazri	Document N 0001	Revision 1.0
Checked by:	Date May 07, 2004	Size A
Approved by:	Sheet 1 of 1	

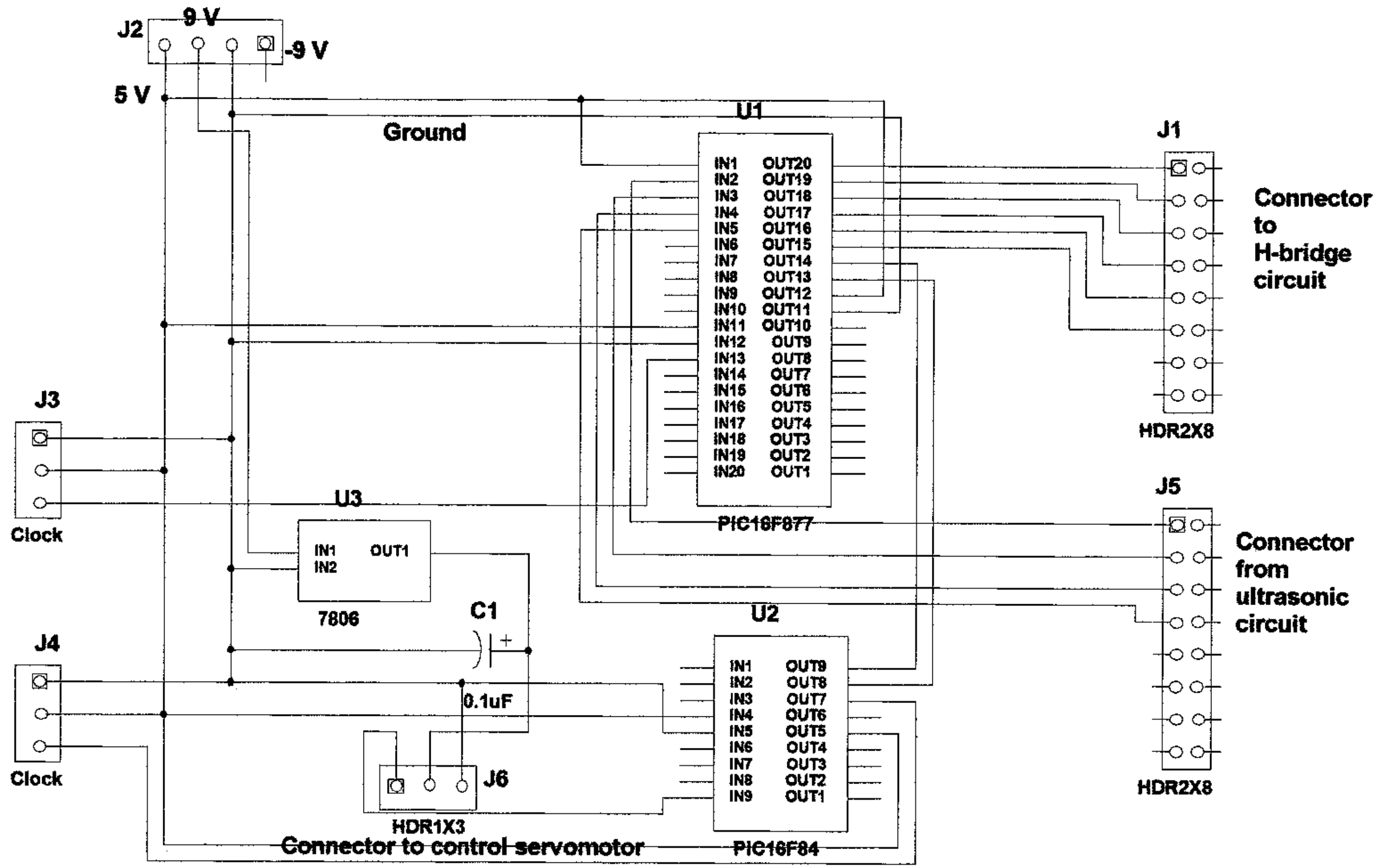
APPENDIX H
H-BRIDGE CIRCUITS



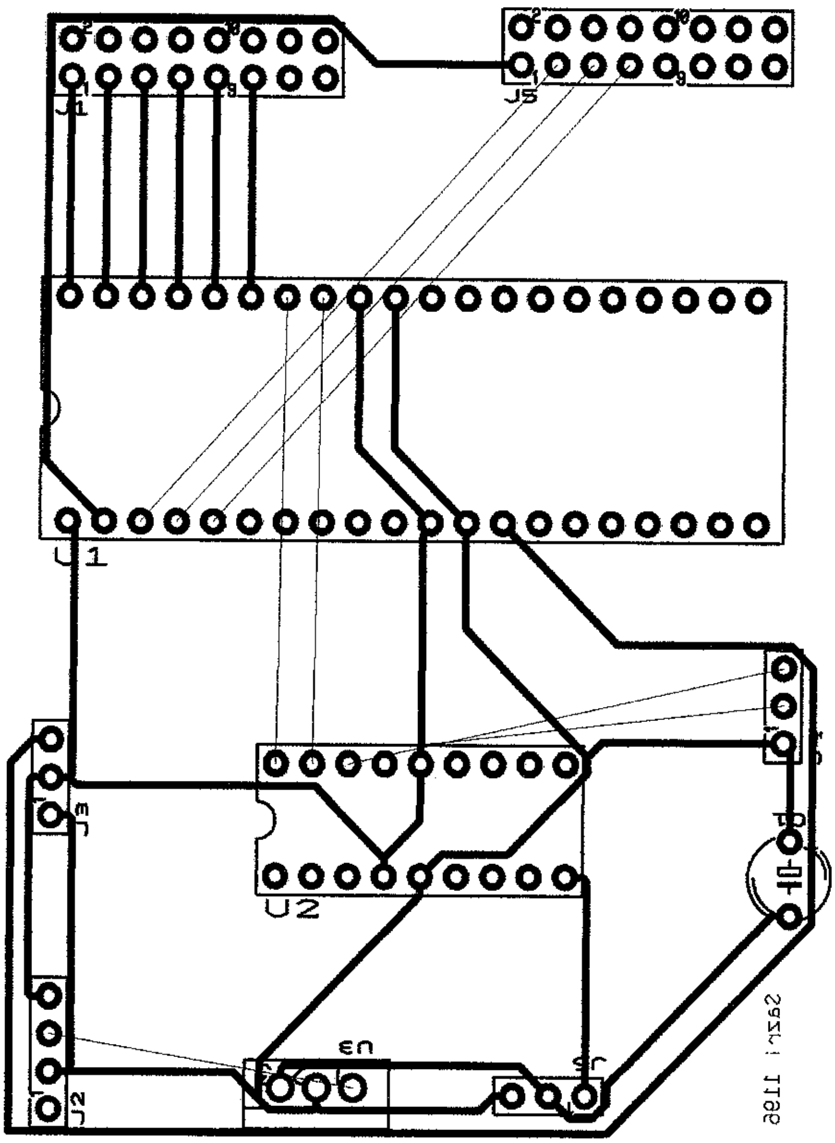
Title: H-bridge4		
Project 1		
Designed by: Sazri	Document N 0001	Revision 1.0
Checked by:	Date Apr 04, 2004	Size A
Approved by:	Sheet 1 of 1	


Mohd.Sazri Zainuddin3
1196
J1
J2
J3
J4
D1
D2
D3
D4
D5
D6
D7
D8
C1
C2
C3
C4

APPENDIX I
PIC MICROCONTROLLER CIRCUIT



Title: pic16f877_3		
Project 1		
Designed by: Sazri	Document N 0001	Revision 1.0
Checked by:	Date Apr 05, 2004	Size A
Approved by:	Sheet 1 of 1	



J1
J5
U1
U2
J3
J2
U3

APPENDIX J
L298 DATASHEET

L298

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)

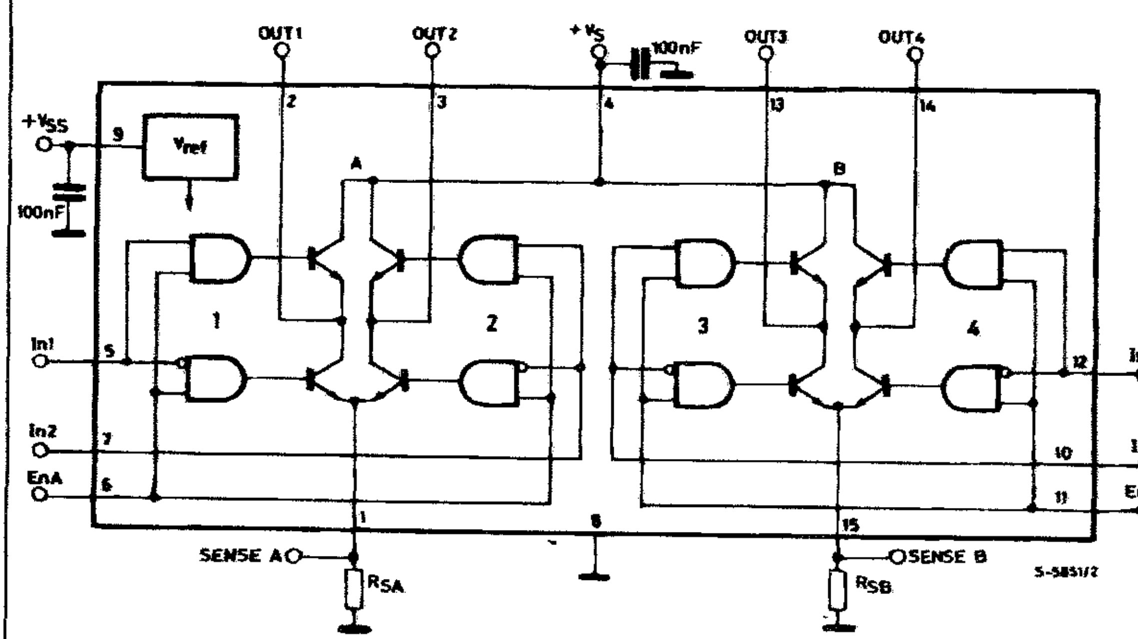
Multiwatt15 **PowerSO20**

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.

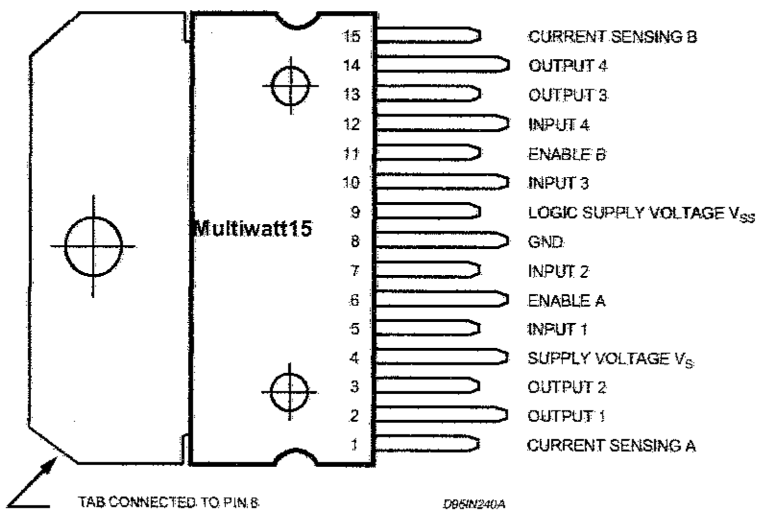
BLOCK DIAGRAM

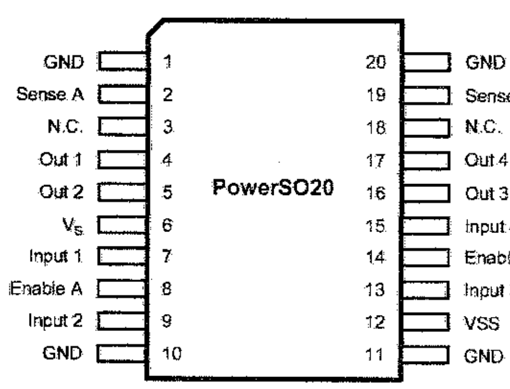


ABSOLUTE MAXIMUM RATINGS

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
fc (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.

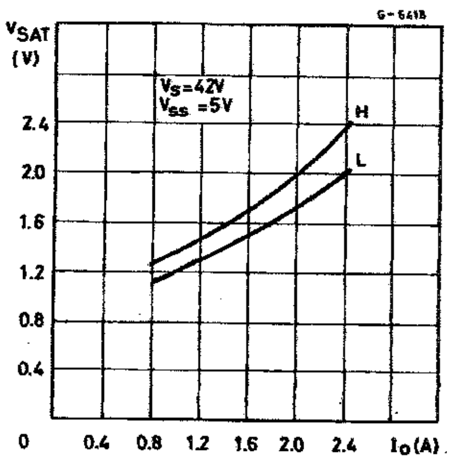
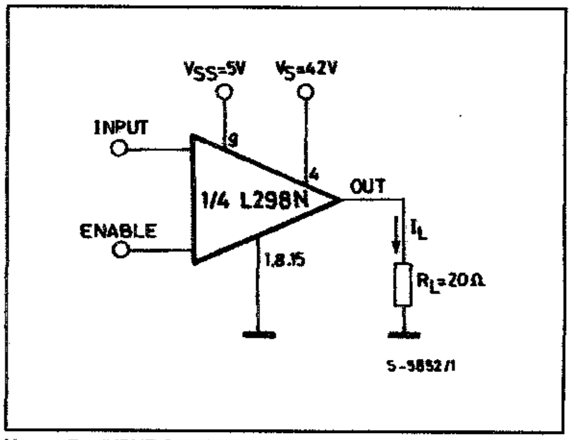


Figure 2 : Switching Times Test Circuits.



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

APPENDIX K
LM 741 OP-AMP DATASHEET

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

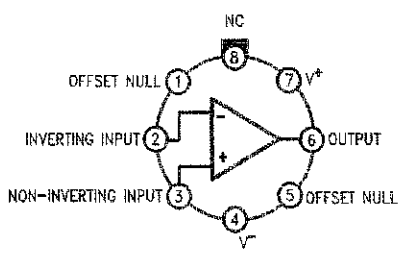
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Connection Diagrams

Metal Can Package

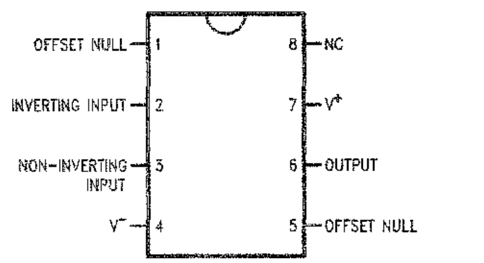


DS009341-2

Note 1: LM741H is available per JM38510/10101

Order Number LM741H, LM741H/883 (Note 1), **LM741AH/883 or LM741CH**
See NS Package Number H08C

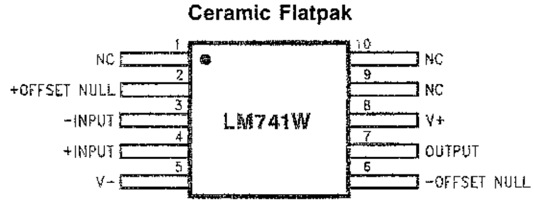
Dual-In-Line or S.O. Package



DS009341-3

Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

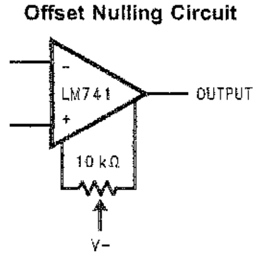


DS009341-6

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



DS009341-7

Absolute Maximum Ratings (Note 2)

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

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
N-Package (10 seconds)	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	T_A = 25°C										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	T_A = 25°C, V_S = ±20V	±10				±15			±15		mV
Input Offset Current	T_A = 25°C		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	T_A = 25°C		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	T_A = 25°C, V_S = ±20V	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, V_S = ±20V	0.5									MΩ
Input Voltage Range	T_A = 25°C							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V

:lectrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
je Signal Voltage Gain	T_A = 25°C, R_L ≥ 2 kΩ										
	V_S = ±20V, V_O = ±15V	50									V/mV
	V_S = ±15V, V_O = ±10V				50	200		20	200		V/mV
	T_{AMIN} ≤ T_A ≤ T_{AMAX},										
	R_L ≥ 2 kΩ,										
	V_S = ±20V, V_O = ±15V	32									V/mV
	V_S = ±15V, V_O = ±10V				25			15			V/mV
	V_S = ±5V, V_O = ±2V	10									V/mV
put Voltage Swing	V_S = ±20V										
	R_L ≥ 10 kΩ	±16									V
	R_L ≥ 2 kΩ	±15									V
	V_S = ±15V										
	R_L ≥ 10 kΩ				±12	±14		±12	±14		V
	R_L ≥ 2 kΩ				±10	±13		±10	±13		V
put Short Circuit	T_A = 25°C	10	25	35		25			25		mA
rent	T_{AMIN} ≤ T_A ≤ T_{AMAX}	10		40							mA
nmon-Mode	T_{AMIN} ≤ T_A ≤ T_{AMAX}										
ection Ratio	R_S ≤ 10 kΩ, V_{CM} = ±12V				70	90		70	90		dB
	R_S ≤ 50Ω, V_{CM} = ±12V	80	95								dB
ply Voltage Rejection	T_{AMIN} ≤ T_A ≤ T_{AMAX},										
o	V_S = ±20V to V_S = ±5V										
	R_S ≤ 50Ω	86	96								dB
	R_S ≤ 10 kΩ				77	96		77	96		dB
nsient Response	T_A = 25°C, Unity Gain										
ise Time			0.25	0.8		0.3			0.3		μs
vershoot			6.0	20		5			5		%
dwidth (Note 6)	T_A = 25°C	0.437	1.5								MHz
v Rate	T_A = 25°C, Unity Gain	0.3	0.7			0.5			0.5		V/μs
ply Current	T_A = 25°C					1.7	2.8		1.7	2.8	mA
er Consumption	T_A = 25°C										
	V_S = ±20V		80	150							mW
	V_S = ±15V					50	85		50	85	mW
M741A	V_S = ±20V										
	T_A = T_{AMIN}			165							mW
	T_A = T_{AMAX}			135							mW
M741	V_S = ±15V										
	T_A = T_{AMIN}					60	100				mW
	T_A = T_{AMAX}					45	75				mW

te 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is ıctional, but do not guarantee specific performance limits.

Electrical Characteristics (Note 5) (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

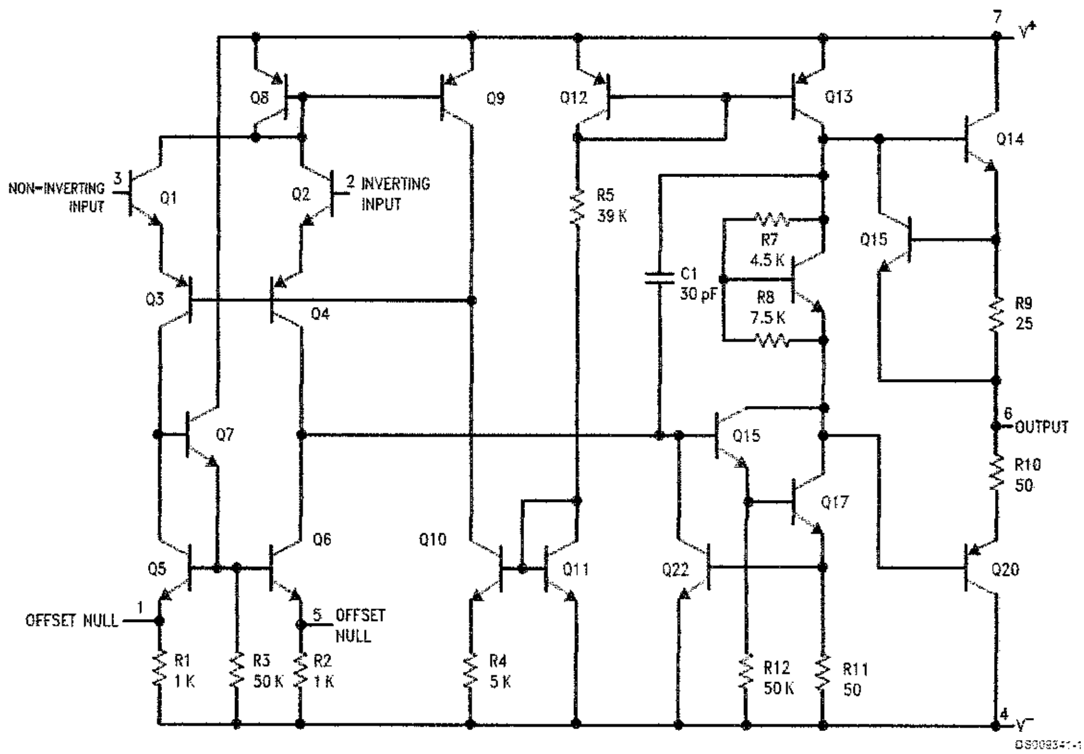
Note 5: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram



APPENDIX L
LM555 TIMER DATASHEET

National Semiconductor

February 2000

LM555
Timer

General Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200mA or drive TTL circuits.

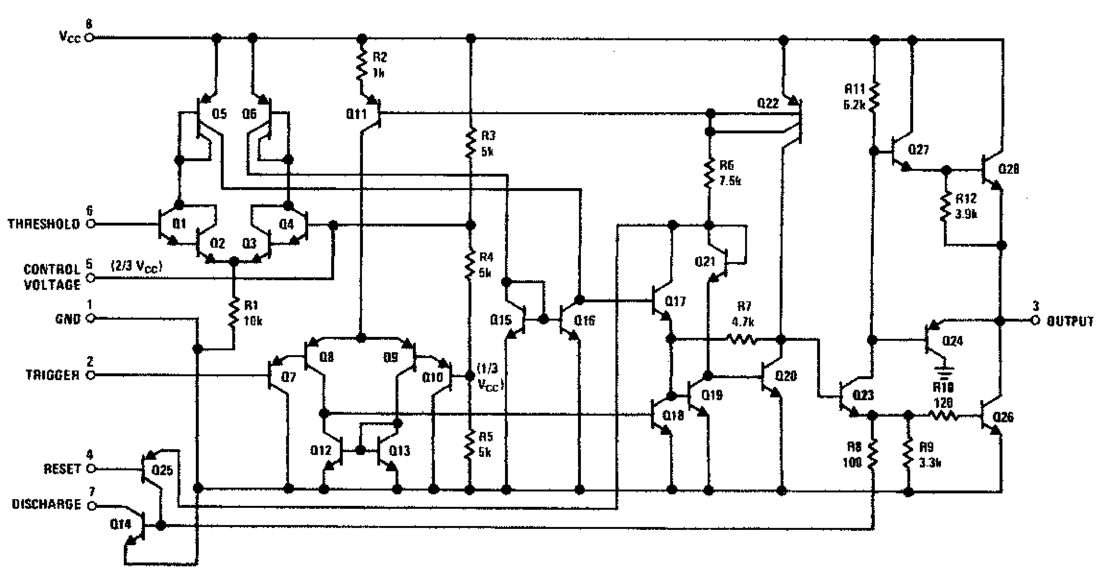
Features

- Direct replacement for SE555/NE555
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- Output can source or sink 200 mA
- Output and supply TTL compatible
- Temperature stability better than 0.005% per °C
- Normally on and normally off output
- Available in 8-pin MSOP package

Applications

- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Linear ramp generator

Schematic Diagram

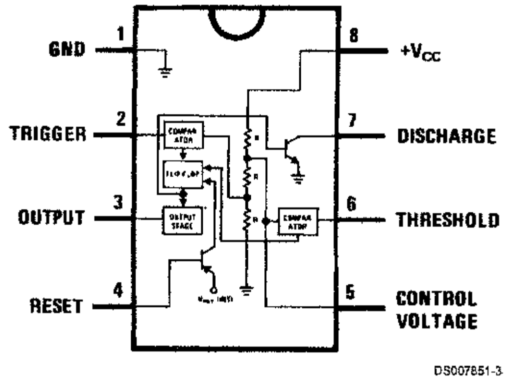


DS007851-1

 DS007851

Connection Diagram

Dual-In-Line, Small Outline and Molded Mini Small Outline Packages



Top View

Ordering Information

Package	Part Number	Package Marking	Media Transport	NSC Drawing
8-Pin SOIC	LM555CM	LM555CM	Rails	M08A
	LM555CMX	LM555CM	2.5k Units Tape and Reel	
8-Pin MSOP	LM555CMM	Z55	1k Units Tape and Reel	MUA08A
	LM555CMMX	Z55	3.5k Units Tape and Reel	
8-Pin MDIP	LM555CN	LM555CN	Rails	N08E

Absolute Maximum Ratings (Note 2)

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

Supply Voltage	+18V
Power Dissipation (Note 3)	
LM555CM, LM555CN	1180 mW
LM555CMM	613 mW
Operating Temperature Ranges	
LM555C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

Soldering Information	
Dual-In-Line Package	
Soldering (10 Seconds)	260°C
Small Outline Packages (SOIC and MSOP)	
Vapor Phase (60 Seconds)	215°C
Infrared (15 Seconds)	220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Electrical Characteristics (Notes 1, 2)

(T_A = 25°C, V_{CC} = +5V to +15V, unless othewise specified)

Parameter	Conditions	Limits LM555C Min	Limits LM555C Typ	Limits LM555C Max	Units
Supply Voltage		4.5		16	V
Supply Current	V_{CC} = 5V, R_L = ∞ V_{CC} = 15V, R_L = ∞ (Low State) (Note 4)		3 10	6 15	mA
Timing Error, Monostable					
Initial Accuracy			1		%
Drift with Temperature	R_A = 1k to 100kΩ, C = 0.1µF, (Note 5)		50		ppm/°C
Accuracy over Temperature			1.5		%
Drift with Supply			0.1		%/V
Timing Error, Astable					
Initial Accuracy			2.25		%
Drift with Temperature	R_A, R_B = 1k to 100kΩ, C = 0.1µF, (Note 5)		150		ppm/°C
Accuracy over Temperature			3.0		%
Drift with Supply			0.30		%/V
Threshold Voltage			0.667		x V_{CC}
Trigger Voltage	V_{CC} = 15V		5		V
	V_{CC} = 5V		1.67		V
Trigger Current			0.5	0.9	µA
Reset Voltage		0.4	0.5	1	V
Reset Current			0.1	0.4	mA
Threshold Current	(Note 6)		0.1	0.25	µA
Control Voltage Level	V_{CC} = 15V V_{CC} = 5V	9 2.6	10 3.33	11 4	V
Pin 7 Leakage Output High			1	100	nA
Pin 7 Sat (Note 7)					
Output Low	V_{CC} = 15V, I_7 = 15mA		180		mV
Output Low	V_{CC} = 4.5V, I_7 = 4.5mA		80	200	mV

Electrical Characteristics (Notes 1, 2) (Continued)

(T_A = 25°C, V_{CC} = +5V to +15V, unless othewise specified)

Parameter	Conditions	Limits LM555C			Units
		Min	Typ	Max	
Output Voltage Drop (Low)	V_{CC} = 15V				
	I_{SINK} = 10mA		0.1	0.25	V
	I_{SINK} = 50mA		0.4	0.75	V
	I_{SINK} = 100mA		2	2.5	V
	I_{SINK} = 200mA		2.5		V
	V_{CC} = 5V				
	I_{SINK} = 8mA				V
	I_{SINK} = 5mA		0.25	0.35	V
Output Voltage Drop (High)	I_{SOURCE} = 200mA, V_{CC} = 15V		12.5		V
	I_{SOURCE} = 100mA, V_{CC} = 15V	12.75	13.3		V
	V_{CC} = 5V	2.75	3.3		V
Rise Time of Output			100		ns
Fall Time of Output			100		ns

Note 1: All voltages are measured with respect to the ground pin, unless otherwise specified.

Note 2: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. Electrical Characteristics state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: For operating at elevated temperatures the device must be derated above 25°C based on a +150°C maximum junction temperature and a thermal resistance of 106°C/W (DIP), 170°C/W (S0-8), and 204°C/W (MSOP) junction to ambient.

Note 4: Supply current when output high typically 1 mA less at V_{CC} = 5V.

Note 5: Tested at V_{CC} = 5V and V_{CC} = 15V.

Note 6: This will determine the maximum value of $R_A + R_B$ for 15V operation. The maximum total ($R_A + R_B$) is 20MΩ.

Note 7: No protection against excessive pin 7 current is necessary providing the package dissipation rating will not be exceeded.

Note 8: Refer to RETS555X drawing of military LM555H and LM555J versions for specifications.

APPENDIX M
PIC16F84 DATASHEET

MICROCHIP

PIC16F84A Data Sheet

18-pin Enhanced FLASH/EEPROM 8-bit Microcontroller

PIC16F84A

18-pin *Enhanced* FLASH/EEPROM 8-Bit Microcontroller

High Performance RISC CPU Features:

- Only 35 single word instructions to learn
- All instructions single-cycle except for program branches which are two-cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- 1024 words of program memory
- 68 bytes of Data RAM
- 64 bytes of Data EEPROM
- 14-bit wide instruction words
- 8-bit wide data bytes
- 15 Special Function Hardware registers
- Eight-level deep hardware stack
- Direct, indirect and relative addressing modes
- Four interrupt sources:
  - External RB0/INT pin
  - TMR0 timer overflow
  - PORTB<7:4> interrupt-on-change
  - Data EEPROM write complete

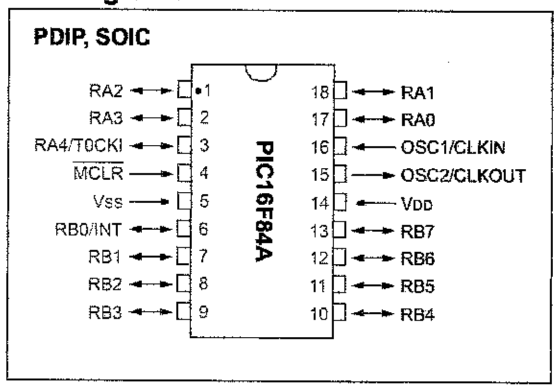
Peripheral Features:

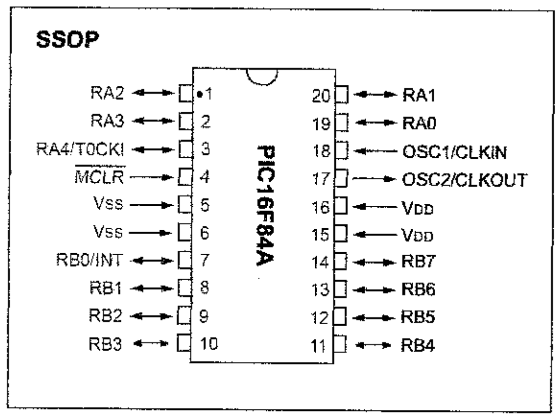
- 13 I/O pins with individual direction control
- High current sink/source for direct LED drive
  - 25 mA sink max. per pin
  - 25 mA source max. per pin
- TMR0: 8-bit timer/counter with 8-bit programmable prescaler

Special Microcontroller Features:

- 10,000 erase/write cycles *Enhanced* FLASH Program memory typical
- 10,000,000 typical erase/write cycles EEPROM Data memory typical
- EEPROM Data Retention > 40 years
- In-Circuit Serial Programming™ (ICSP™) - via two pins
- Power-on Reset (POR), Power-up Timer (PWRT), Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own On-Chip RC Oscillator for reliable operation
- Code protection
- Power saving SLEEP mode
- Selectable oscillator options

Pin Diagrams





CMOS Enhanced FLASH/EEPROM Technology:

- Low power, high speed technology
- Fully static design
- Wide operating voltage range:
  - Commercial: 2.0V to 5.5V
  - Industrial: 2.0V to 5.5V
- Low power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 15 µA typical @ 2V, 32 kHz
  - < 0.5 µA typical standby current @ 2V

1.0 DEVICE OVERVIEW

This document contains device specific information for the operation of the PIC16F84A device. Additional information may be found in the PICmicro™ Mid-Range Reference Manual, (DS33023), which may be 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.

The PIC16F84A belongs to the mid-range family of the PICmicro® microcontroller devices. A block diagram of the device is shown in Figure 1-1.

The program memory contains 1K words, which translates to 1024 instructions, since each 14-bit program memory word is the same width as each device instruction. The data memory (RAM) contains 68 bytes. Data EEPROM is 64 bytes.

There are also 13 I/O pins that are user-configured on a pin-to-pin basis. Some pins are multiplexed with other device functions. These functions include:

- External interrupt
- Change on PORTB interrupt
- Timer0 clock input

Table 1-1 details the pinout of the device with descriptions and details for each pin.

FIGURE 1-1: PIC16F84A BLOCK DIAGRAM

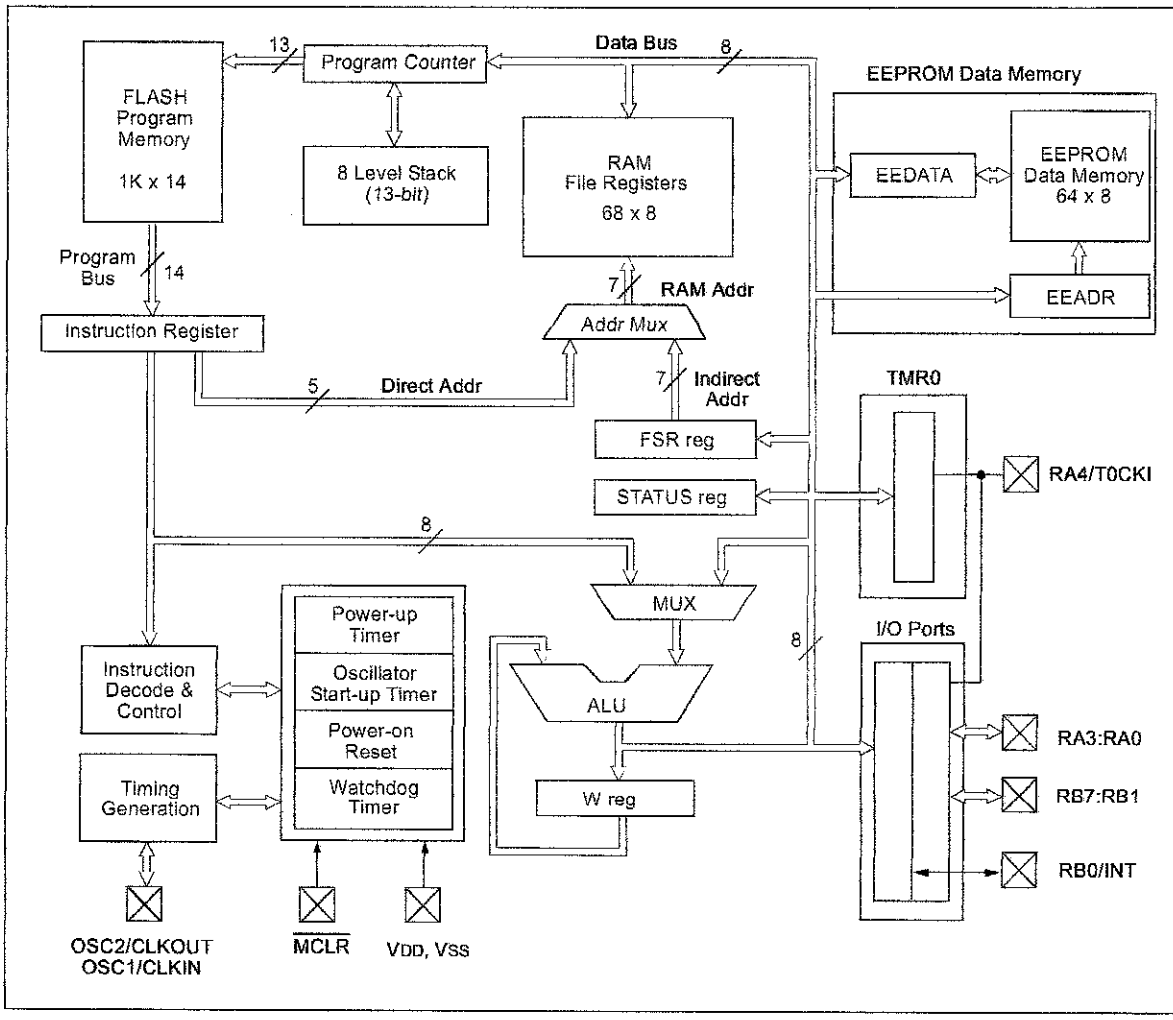


TABLE 1-1: PIC16F84A PINOUT DESCRIPTION

Pin Name	PDIP No.	SOIC No.	SSOP No.	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	16	16	18	I	ST/CMOS(3)	Oscillator crystal input/external clock source input.
OSC2/CLKOUT	15	15	19	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.
$\overline{MCLR}$	4	4	4	I/P	ST	Master Clear (Reset) input/programming voltage input. This pin is an active low RESET to the device.
						PORTA is a bi-directional I/O port.
RA0	17	17	19	I/O	TTL	
RA1	18	18	20	I/O	TTL	
RA2	1	1	1	I/O	TTL	
RA3	2	2	2	I/O	TTL	
RA4/T0CKI	3	3	3	I/O	ST	Can also be selected to be the clock input to the TMR0 timer/counter. Output is open drain type.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	6	6	7	I/O	TTL/ST(1)	RB0/INT can also be selected as an external interrupt pin.
RB1	7	7	8	I/O	TTL	
RB2	8	8	9	I/O	TTL	
RB3	9	9	10	I/O	TTL	
RB4	10	10	11	I/O	TTL	Interrupt-on-change pin.
RB5	11	11	12	I/O	TTL	Interrupt-on-change pin.
RB6	12	12	13	I/O	TTL/ST(2)	Interrupt-on-change pin. Serial programming clock.
RB7	13	13	14	I/O	TTL/ST(2)	Interrupt-on-change pin. Serial programming data.
Vss	5	5	5,6	P	—	Ground reference for logic and I/O pins.
VDD	14	14	15,16	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.

APPENDIX N
PIC16F877 DATASHEET

PIC16F87X
Data Sheet

28/40-Pin 8-Bit CMOS FLASH

Microcontrollers

PIC16F87X

28/40-Pin 8-Bit CMOS FLASH Microcontrollers

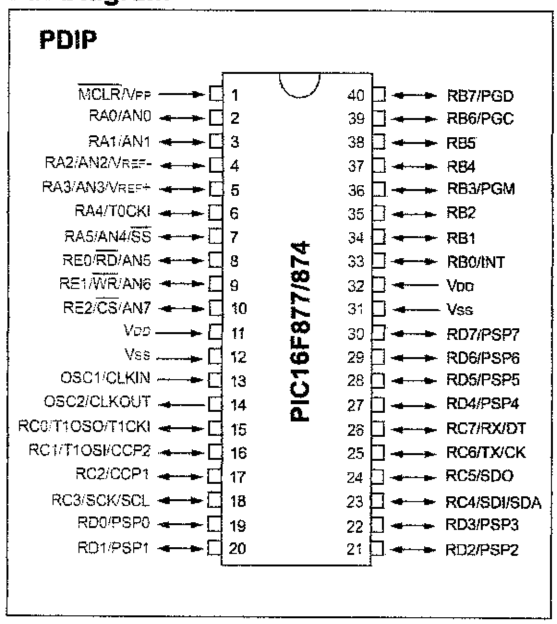
Devices Included in this Data Sheet:

- 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, Industrial and Extended temperature ranges
- Low-power consumption:
  - < 0.6 mA typical @ 3V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

Pin Diagram

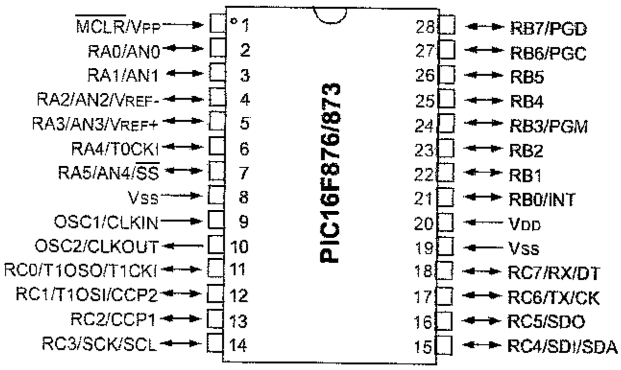


Peripheral Features:

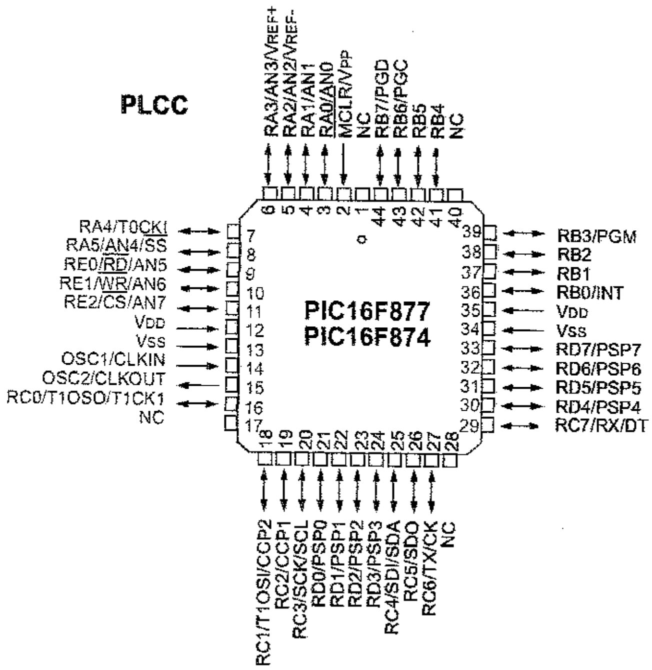
- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during SLEEP via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max.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

Pin Diagrams

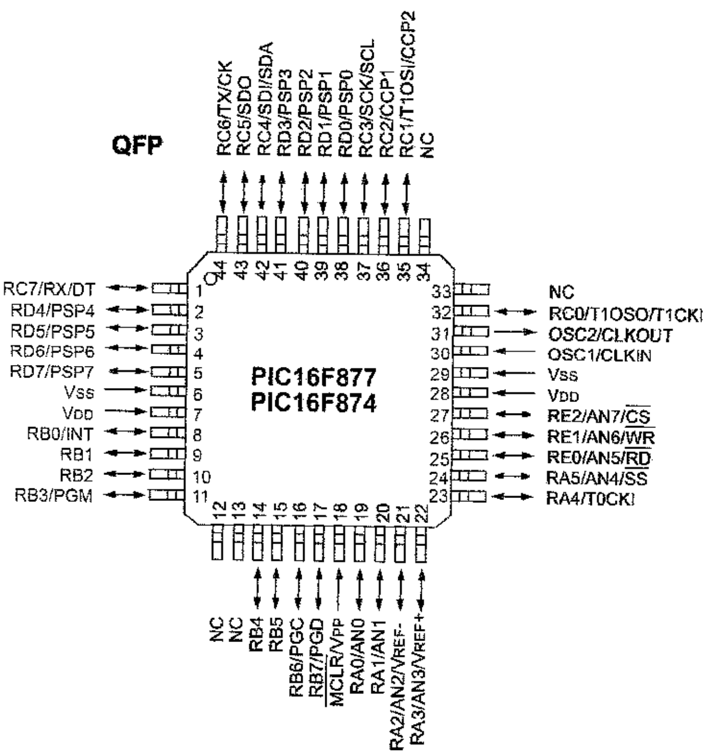
PDIP, SOIC



PLCC



QFP



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

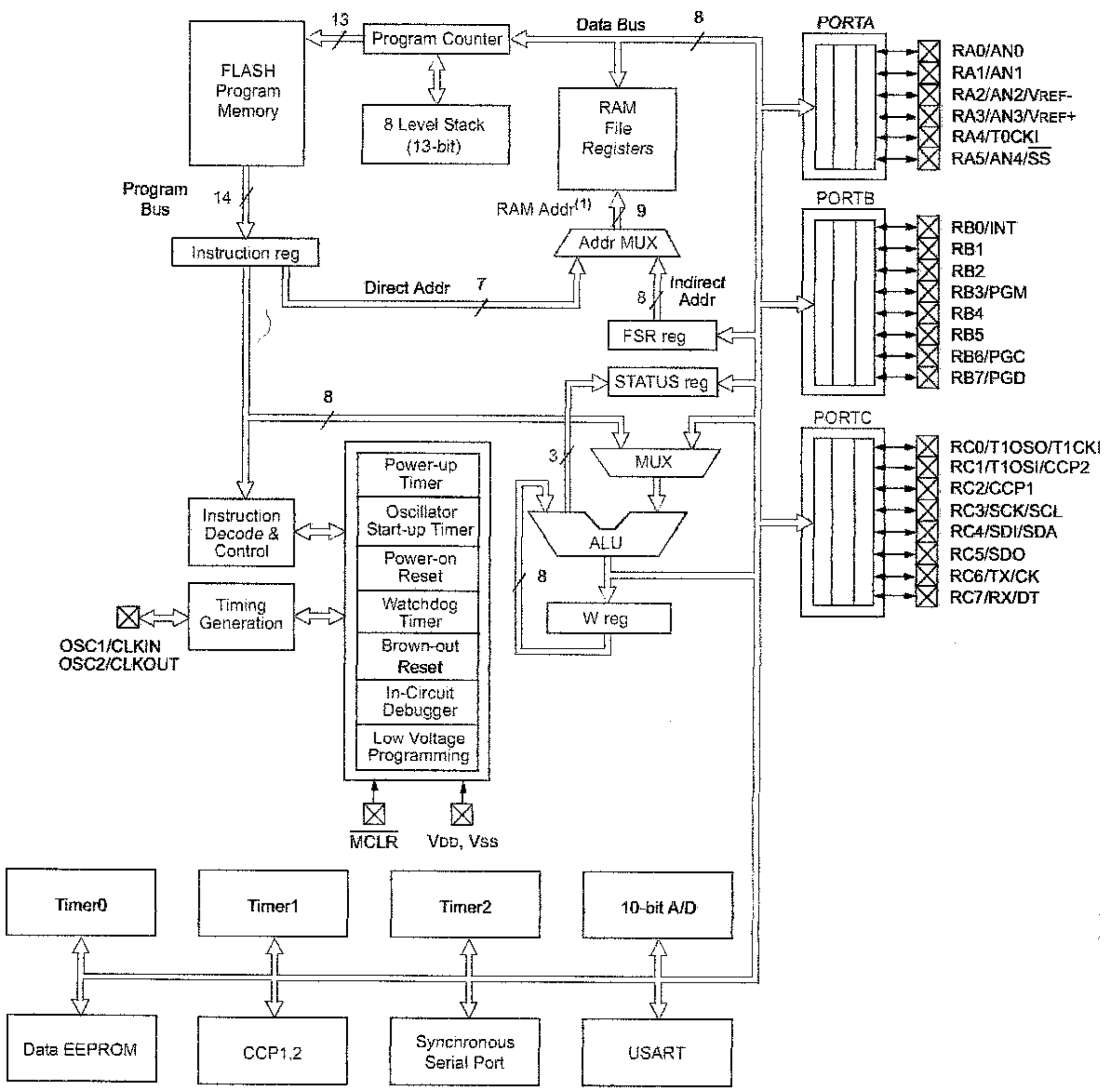
This document contains device specific information. Additional information may be found in the PICmicro™ Mid-Range Reference Manual (DS33023), which may be obtained from your local Microchip Sales Representative or downloaded from the Microchip website. The Reference Manual should be considered a complementary 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 Parallel Slave Port is not implemented on the 28-pin devices.

The following device block diagrams are 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

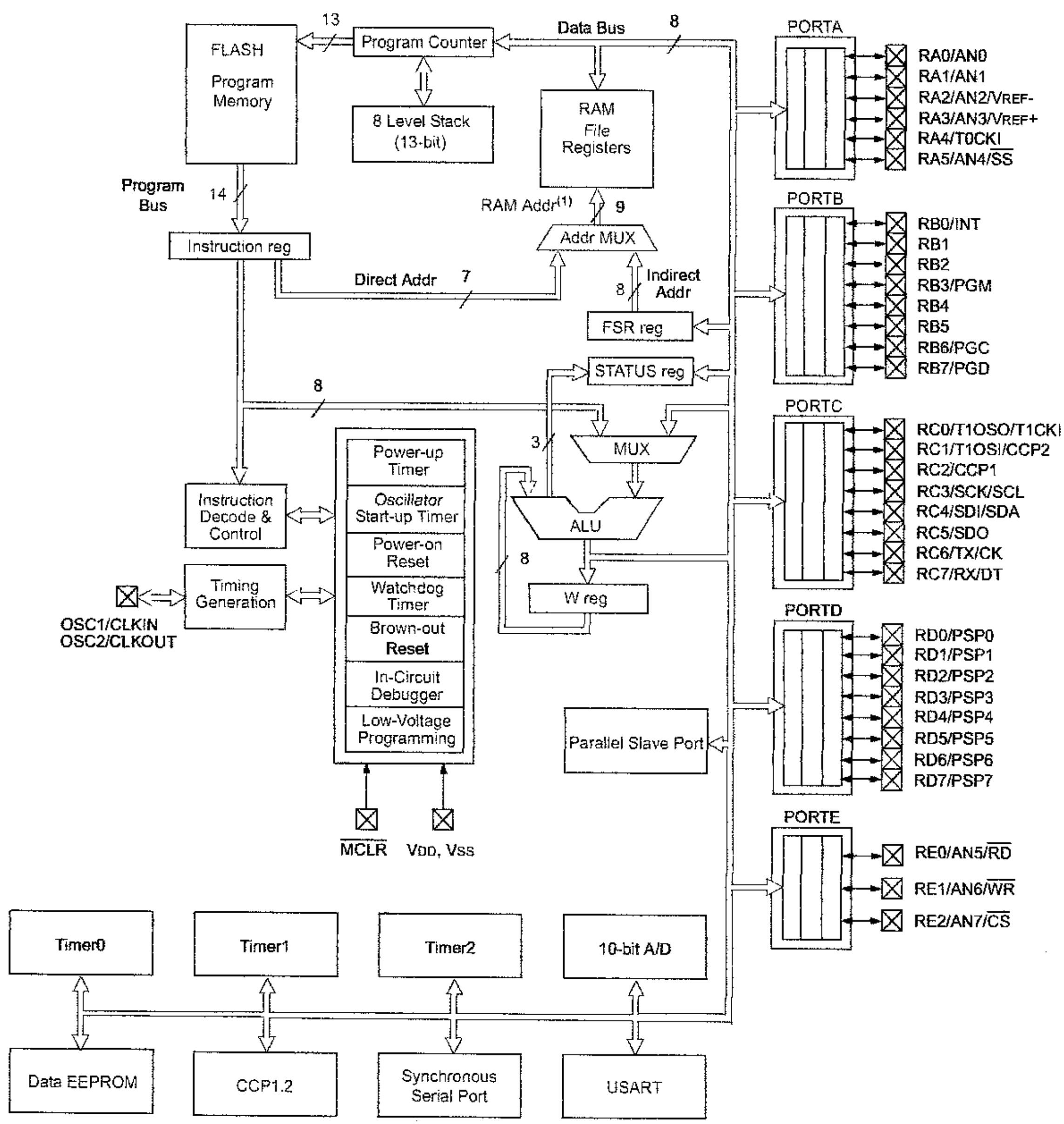
Device	Program FLASH	Data Memory	Data EEPROM
PIC16F873	4K	192 Bytes	128 Bytes
PIC16F876	8K	368 Bytes	256 Bytes



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	1	1	I/P	ST	Master Clear (Reset) input or programming voltage input. 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 I^{2}C modes.
RC4/SDI/SDA	15	15	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^{2}C 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	I	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	1	2	18	I/P	ST	Master Clear (Reset) input or programming voltage input. 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.

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
						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.
						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.

APPENDIX O
L298 PIN DESCRIPTION

Pin no.	Description
1	Current sensing A. Control current to load. If not used have to be grounded
2	Output 1. Connect to one of the terminal of motor A.
3	Output 2. Connect to the other terminal of motor B.
4	Supply Voltage (VS). Voltage with which the motor to be driven.
5	Input 1. TTL compatible to drive motor A. Should be logic voltage (0V or 5V). With input 2 will determine whether the motor reverse or forward.
6	Enable A. TTL compatible enable input for motor A. 5V to run the motor and 0V to disable/stop the motor.
7	Input 2. TTL compatible to drive motor A. Should be logic voltage (0V or 5V). With input 1 will determine whether the motor reverse or forward.
8	Ground (GND)
9	Logic supply voltage (VSS). 5-7 V
10	Input 3. TTL compatible to drive motor B. Should be logic voltage (0V or 5V). With input 4 will determine whether the motor reverse or forward.
11	Enable B. TTL compatible enable input for motor B. 5V to run the motor and 0V to disable/stop the motor.
12	Input 4. TTL compatible to drive motor B. Should be logic voltage (0V or 5V). With input 3 will determine whether the motor reverse or forward.
13	Output 3. Connect to one of the terminal of motor B.
14	Output 4. Connect to other terminal of motor B.
15	Current sensing A. Control current to load. If not used have to be grounded.