AUTOMATIC TEMPERATURE CONTROLLED LOW POWER WATER SUPPLY SYSTEM

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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June 2006

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.

Nondumiso Ngidi

ABSTRACT

Conventional water heaters store hot water in a cylinder or a tank. Hot water geysers are one of the largest consumers of electrical power in the average domestic household. The project aims to improve the current designs by using minimum power to heat water without jeopardizing the flow rate. The main objective of the project is to design a low power water heater system. The process variable to be controlled is temperature. Flow is another process variable to be monitored during the process. The project requires knowledge from different disciplines. The automatic low power domestic water heater requires the knowledge of thermo fluids, power electronics, and microprocessor programming. The simulation on LABVIEW is done to generate a trend of the system. A plot of the temperature changes will ensure that the operation of the sensor is monitored. The results show the open loop system of the project. The prototype had to be implemented to demonstrate the integration of different circuit that exist in this system, namely the microcontroller circuit and relay circuit. The project was a success.

ACKNOWLEDGEMENTS

My project has been completed successfully due to certain individuals who mentored throughout the duration of the process. Firstly, I would like to give honor to the Lord for giving me the strength and wisdom I needed to make the project a reality. To Dr Taj Baloch, my supervisor I am grateful for all the advice and assistance. He made this long stressful process bearable.

All my classmates and technicians contributed immensely towards making this project a success. Their inputs and experience have been incorporated in this system and I am truly grateful.

Lastly, I would like to acknowledge my family (my mother, Nomasonto and Sthembiso) for their support and encouragement throughout the year. Your kind words have made it easy for me to focus on my goal.

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CHAPTER 1
INTRODUCTION

Background of Study

Extensive work has been done on the improvement of power consumption by domestic water heaters. Hot water geysers are one of the largest consumers of electrical power in the average domestic household.

Conventional water heaters store hot water in a cylinder or a tank. Electrical elements controlled by thermostats heat the water and keep it hot. The element is wired to the mains /electrical supply via an isolating switch, and sometimes a timer which enables one to set the times one wishes to have the water heated.

The timers enable the heating process to be automatic. The main advantage of the automatic heating is that the water heater can be switched ON when there is less demand for power, thereby smoothing the peak demands on the power grid for the supplier. This method can only operate successfully if the demand hours of the user do not change. A change in the demand of hot water by the users will result in failure of the system.

Certain work has been done on the insulation of the tank. This reduces the losses due to material and the pipes. The effects of this method are minimal. Therefore it is not favored.

Tankless water heaters (also known as instantaneous heaters) are steadily dominating the industry. Tankless heaters heat water only as it is used, and do not store water for potential use. The size of a tankless unit will be determined by the peak demand for hot water, and the incoming temperature of the water supply.

They are activated by the flow of water when a hot water valve is opened. Once activated, they provide a constant supply of hot water at their rated capacity. Tankless units alter the flow rate to maintain constant preset temperature. The other benefits of tankless water heaters include:

- A Continuous and Endless Supply of Hot Water
- Space Savings
- Safety and Health Benefits
- Smart Technology
- No Maintenance
- Environmental Benefits

Their main disadvantage is the reduced flow rate. An example of this is during winter months, when incoming ground water is cooler; the flow is reduced because it takes longer for the system to raise the temperature of incoming cold water to a preset temperature. If the temperature is set to a higher level, flow is drastically reduced.
Existing water heaters have been included in Appendix A.

The project aims to improve the current designs by using minimum power to heat water without jeopardizing the flow rate. This will be financial viable for the consumers.

1.2 Problem Statement

Water heaters, also known as geysers, are the one of the largest consumers of electrical power in the average domestic household. Most domestic water heaters have a 3 kW heating element (sometimes as high as 15kW) which is controlled by a thermostat. The thermostat tries to maintain a water temperature of 55°-70°. The water heaters due their high power consumption usually need a separate circuitry during installation.

The current setup proves to be costly for the consumer. Maintenance of this circuitry is difficult. The consumer has no means of changing the maximum temperature of the water heater as the need arises. This will be useful when seasons change and the maximum temperature of water required by consumers for use varies. Therefore energy is wasted heating the water to a high value unnecessarily.

As mentioned, with tankless water heaters flow rate is reduced. Therefore the process is delayed. The drawback might limit the popularity of the system. Therefore, there is a need to improve the existing designs.

1.3 Objectives

The main objective of the project is to design a low power water heater system. The process variable to be controlled is temperature. Flow is another process variable to be monitored during the process.

The existing water heaters require a separate circuit during installations and the power consumption is high. The low power water system can be plugged to the wall plug/socket directly. This will reduce costs for the consumer and it also allows easy access for maintenance.

The project requires certain parameters to be chosen to enable simulation using LabView or Matlab.

The components are chosen based on an extensive study of the conditions of the systems.

1.4 Scope of Study

A study of control systems and instrumentation has to be conducted to successfully complete the project. The process control diagram has to be constructed, which clearly outlines the steps that exist in the process loop. The basic objective is to regulate the value of some quantity. To regulate means to maintain that quantity at some desired value regardless of external influences. The desired value is called a setpoint.

The project aims to reduce the consumption of power by the water heaters. It will achieve this by using a heating element that has lower power rating than the current heating elements in the market. The time it takes to heat the water to the set temperature should be reasonably fast.

Certain control techniques have to be implemented to make certain that there is communication between the consumer and the device, specifically the heating element which is responsible for heating water in the tank. The control techniques will also guarantee consumer that there will always be water heated to their set temperature ready for use.

1.5 Feasibility of the Project within the Scope and Time Frame

The project could be completed within the time specified. Appendix B is a Gantt chart for the project and following the proposed stages might lead to completion of the project within the time frame specified.

CHAPTER 2
LITERATURE REVIEW

2.1 Flow Rate

The project requires knowledge from different disciplines. The automatic low power domestic water heater requires the knowledge of thermo fluids, power electronics, and microprocessor programming.

The system will operate on the principle that cold water is denser than hot water. The warm water is displaced by cold water from one section of the tank to the second section. The heating element installed will be responsible for heating water. The amount of heat provided depends on the requirements of the system

Flow is one of the variables that has to be monitored/measured in this system. The rate at which cold water flows into and out of the tank will affect the temperature of water and switching times of the heating element. Therefore it is important to know the flow rate of the system. The measurement unit to express the rate of flow actually refers to the velocity of the flow, or how rapidly the substance moves. A flow rate is a measure of the distance a particle of a substance moves in a given period of time. The relationship is expressed by the equation below.

$$Q = VA$$

where;

Q = flow rate

V= velocity of the liquid

A= area

The method of measurement used to indicate the volume of fluid that passes a point over a period of time is volumetric flow rate. Volumetric flow rate is usually expressed in gallons per minute (GPM) or cubic feet per second.

A number of instruments are available today to measure flow rate namely flow rate meter. That is calibrated according to the requirements of the consumer. Prior to calibrating the flow rate of the water heater, the flow rates of the household should be noted. Table 1 below shows the estimated flow rates in an average household as formulated by some manufacturers of water heaters.

Table 1: Estimated Flow Rates For an Average Household

Application	Flow rate (GPM)
Bath tub	2.0-4.0
Shower	1.5 – 3.0
Kitchen sink	1.0 – 1.5
Pantry sink	1.0 – 2.5
Laundry sink	2.5 – 3.0
Dishwasher	1.0 – 3.0

In designing a water heater system, there are a few considerations to be taken into account. One must determine if the household is low or high demand (determined by the number of bathrooms and other warm water equipments). The size of the family will also determine the capacity of the water heater which will directly affect power consumption. Table 2 below shows different family sizes and their estimated water heater capacity as formulated by some manufacturers of water heaters.

Table 2: Family Size and Their Requirements

Family size (number of people)	Capacity (gallons)
2	45-55
3	55-65
4	65-75
5	75-85
6	85-100
7 or more	100 or more

In the design of an automatic temperature controlled low power water heater, only the shower will be considered. It has been mentioned earlier that with tankless water heaters the flow rate is reduced. Therefore, it is advisable to install separate water heaters for each device. This method is only practical for low demand household.

2.2 Heat Convection

Convection is the transfer of heat in a fluid by the circulation of flow due to temperature differences. In heat conduction, heat is transferred to solids and in heat convection heat is transferred to liquids. A typical heat convection formula is of the following form:

$$Q = hA\,(T_2 - T_1)$$

Where

Q = convection heat transfer rate (W)

h = coefficient of heat transfer

A = heat transfer area

$T_2 - T_1$ – temperature difference between the surface and the bulk of the fluid away from the surface (°C)

The above formula is also known as Newton's Law of Cooling

Basically, whenever heat is applied to a body, it receives thermal energy. The atoms of the body vibrate more intensely and the temperature increases. For a given amount of heat, the increase in temperature depends on upon the mass of the body and the material of which it is made. The relationship between these quantities is given by the equation

$$Q = mc\Delta T$$

where

Q = quantity of heat added to a body (J)

m = mass of the body (kg)

c = specific heat capacity of the material

ΔT = change in temperature (°C)

If heat is removed from a body, its temperature drops. However, the temperature cannot fall below a lower limit. This limit is called absolute zero. It corresponds to a temperature of 0 Kelvin. At absolute zero all atomic vibrations cease and only motion that subsists is that of the orbiting electrons.

Heat is therefore a form of energy and the SI unit is the Joule.

2.3 Relationship between Three Parameters

The power output of the heating element should be sufficient to implement real time heating. This report will illustrate a relationship between the power supplied to the heating element, flow rate of water into and out of the tank and the temperature of water.

The controller to be used is an ON/OFF controller. Therefore, the relationship that exists between the two parameters, power and temperature is linear. That is, if power is applied to the heating element, water temperature increases to the setpoint. The time it takes to reach setpoint should be minimal. The graph Figure 3 illustrates the relationship.

The flow of cold water into the tank will decrease the temperature of water. Therefore there exist an inversely proportional relationship between flow rate and temperature. That is, if flow rate of cold water is increased, the temperature decreases. The graphs below will attempt to illustrate the relationship. The graphs are not drawn to scale.

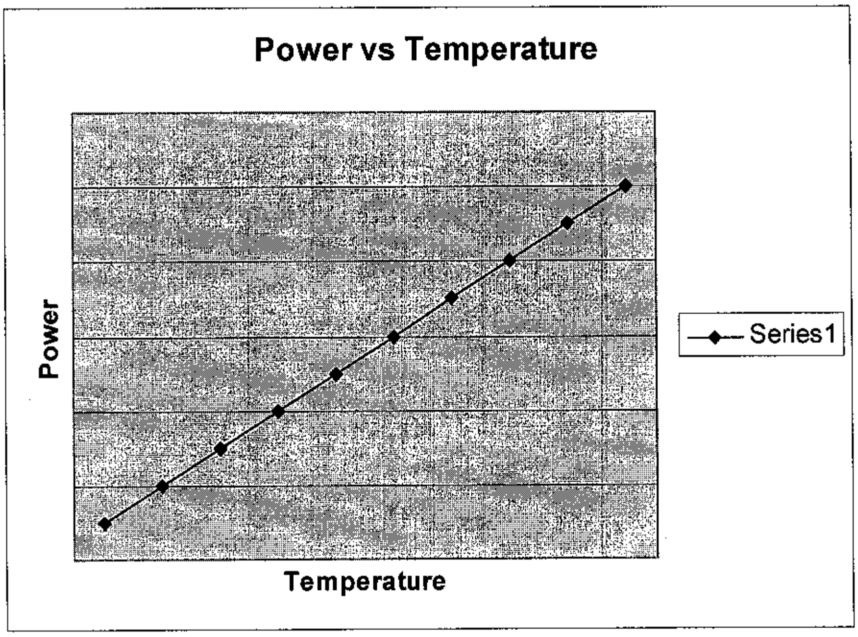


Figure 1: Power versus Temperature

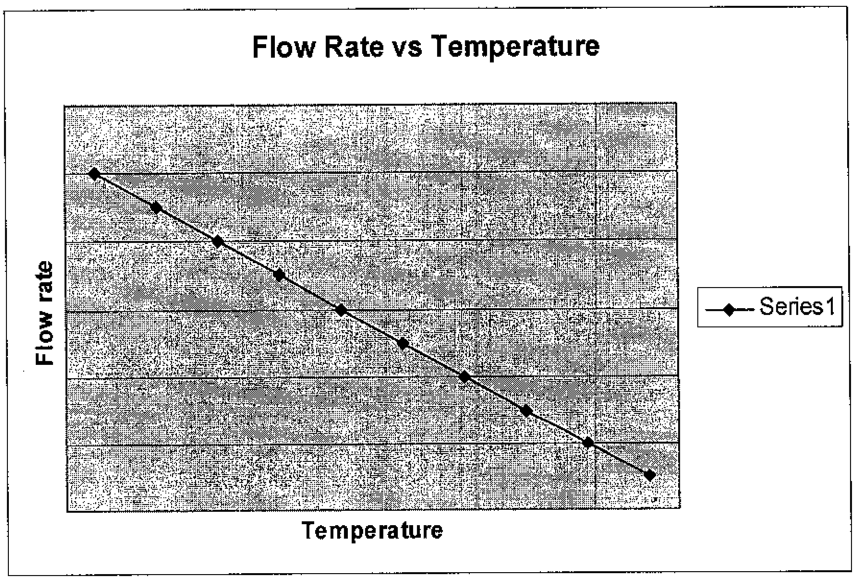


Figure 2: Flow Rate versus Temperature

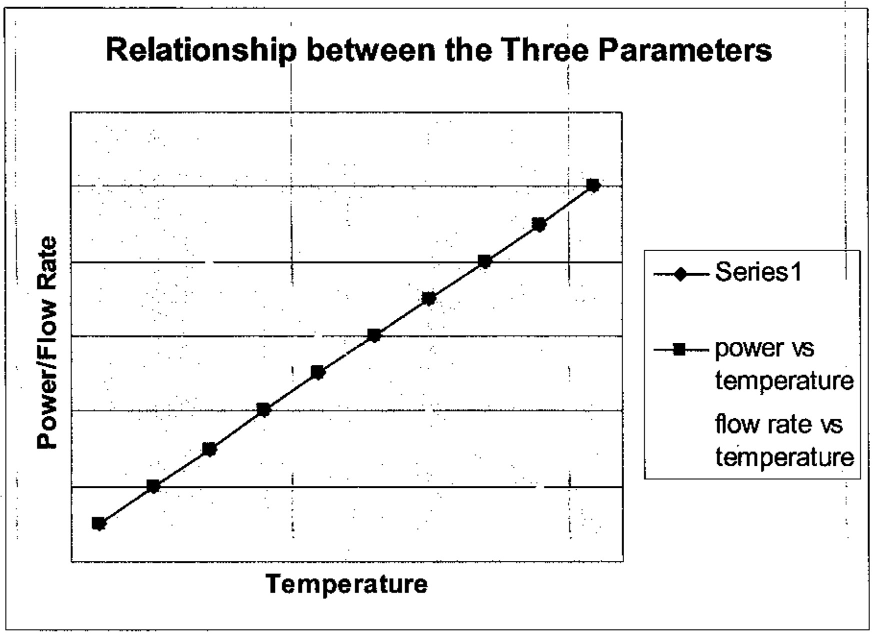


Figure 3: Relationship between Three Parameters

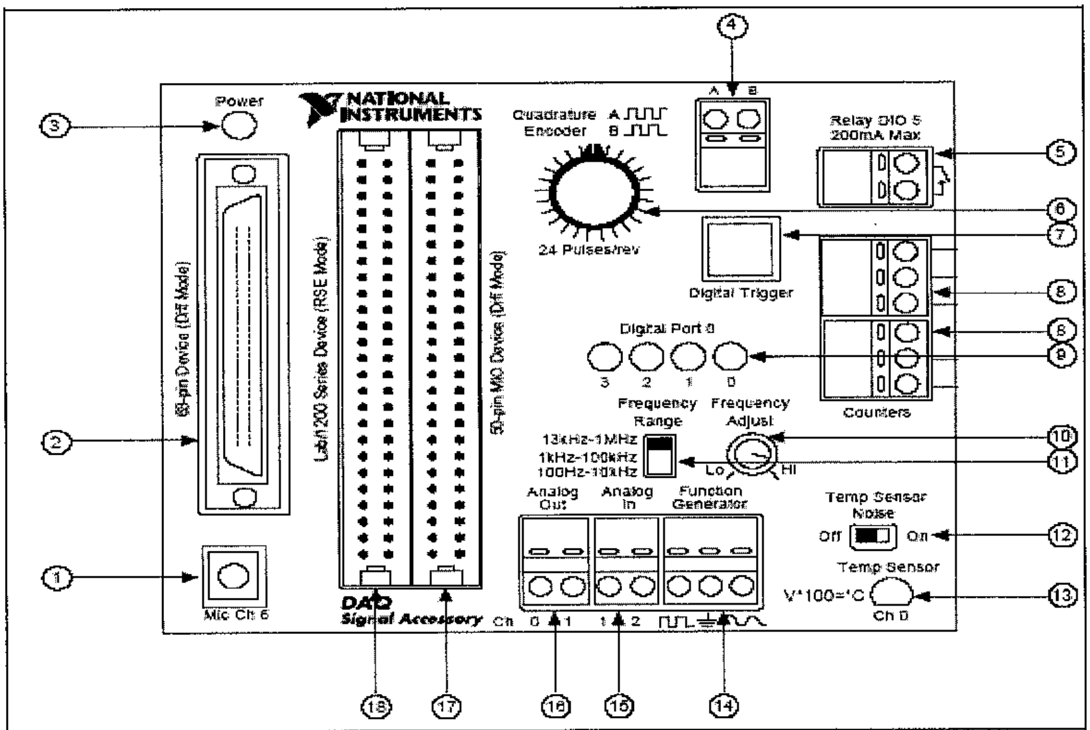
The point of intersection represents an ideal temperature to implement the real time heating and storage. It can be concluded that there is a linear relationship between power and flow rate since power is proportional to temperature.

2.4 LABVIEW

LABVIEW is simply the most elegant programming language for data acquisition analysis, simulation or computer control of instruments, techniques or processes. LABVIEW is an acronym for Laboratory Virtual Instrument Engineering Workbench. LABVIEW is an object oriented language and its style, syntax and data flow is different from conventional linear programming languages. LABVIEW programming requires a change in the designer's mind. [1]

2.4.1. Data Acquisition and Signal Accessory (DAQ)

The DAQ Signal Accessory is ideal for demonstrating or teaching PC-based data acquisition and control. Because the DAQ Signal Accessory can be used to demonstrate and test the use of analog, digital, and counter/timer functions of DAQ devices, it is flexible enough to be used not only in classrooms and laboratories but also in industry to test and prototype DAQ applications. Note: An appropriate cable is required to connect the DAQ Signal Accessory to the DAQ device. A DAQ is shown in Figure 4



1	3.5 mm Mono Microphone Jack	10	Function Generator Frequency Adjust Knob
2	68-Pin Device Connector	11	Function Generator Frequency Range Selector
3	Power LED Indicator	12	Noise Generator Switch
4	Quadrature Encoder Output	13	IC Temperature Sensor
5	Quick Connect Terminal for Relay DIO 5	14	Quick Connect Terminals for Function Generator
6	Quadrature Encoder Knob	15	Quick Connect Terminal for AI Channels 1 and 2
7	Digital Trigger Push-Button Switch	16	Quick Connect Terminal for AO Channels 0 and 1
8	Quick Connect Terminals for Counters	17	50-Pin MIO Device Connector
9	Digital Port LEDs	18	Lab/1200 Series Device Connector

Figure 4: DAQ Pin Layout

The device is connected to a temperature sensor which monitors changes when power is constant. Other parameters are also varied to determine the relationship. Simulation using an external sensor is not possible since they are not available presently.
The results of the simulation evaluate the open loop system of the project. It mainly shows the trend of the process as regulated by the temperature. The simulation can also be used to monitor the status of the temperature sensor-which is the primary component of the system. Failure of the temperature sensor will cause the entire system to fail.

2.5 Microcontrollers

A 16F877 will be used to control the system. Therefore it is worth noting the background concepts on microcontrollers.

Microcontrollers are embedded devices having a central processing unit, interrupts, counters, timers, I/O ports, RAM, ROM/EPROM which are used to control other systems. As their structures are based on CMOS technology, PICs consume very less energy. The integrated circuit used in this study operates at 20 MHz clock frequency and runs each instruction as fast as 200ns. It has 8Kx14 words of flash as a program memory and 256 byte EEPROM as a data memory. As their structures are based on CMOS technology, PICs consume very less energy. Nowadays, PICs have been the most preferable devices due to their properties. The PIC 16F877 has 33 I/O pins, divided into 5 ports, which can be configured in various ways to communicate with many different peripheral devices.[14]

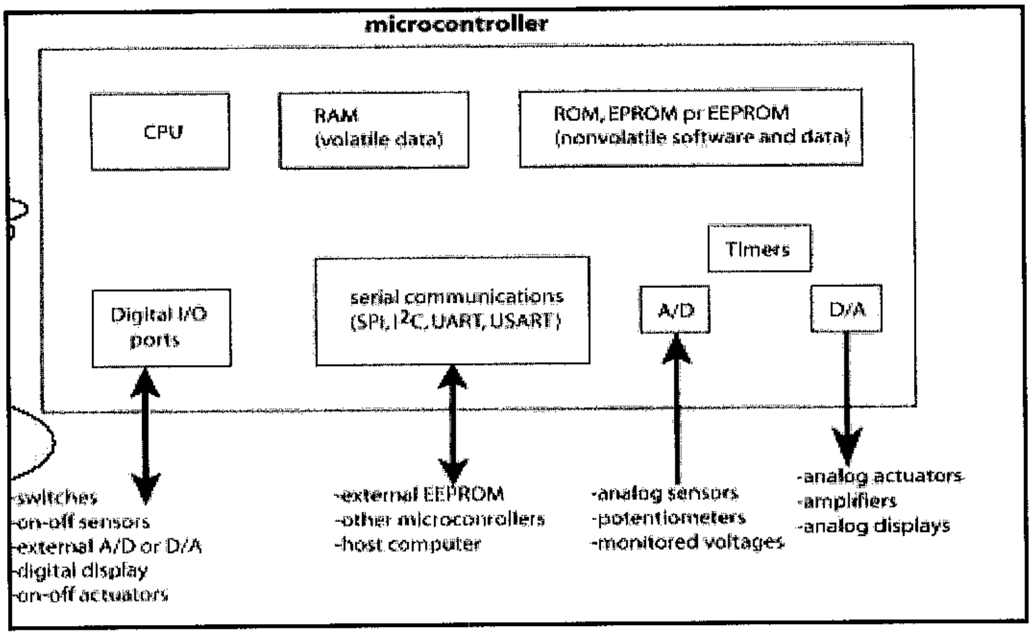


Figure 5: Microcontroller Structure

2.5.1 Functions

A) Program memory (FLASH)

Program memory is used for storing a written program. Since memory made in FLASH technology can be programmed and cleared more than once, it makes this microcontroller suitable for device development.

B) EEPROM

EEPROM is data memory that needs to be saved when there is no supply. It is usually used for storing important data that must not be lost if power supply suddenly stops. For instance, one such data is an assigned temperature in temperature regulators. If during a loss of power supply this data was lost, we would have to make the adjustment once again upon return of supply. Thus our device looses on self-reliance.

C) RAM

RAM is data memory used by a program during its execution. In RAM are stored all inter-results or temporary data during run-time.

D) CENTRAL PROCESSING UNIT

CPU has a role of connective element between other blocks in the microcontroller. It coordinates the work of other blocks and executes the user program.

CHAPTER 3
METHODOLOGY

3.1 Project Work

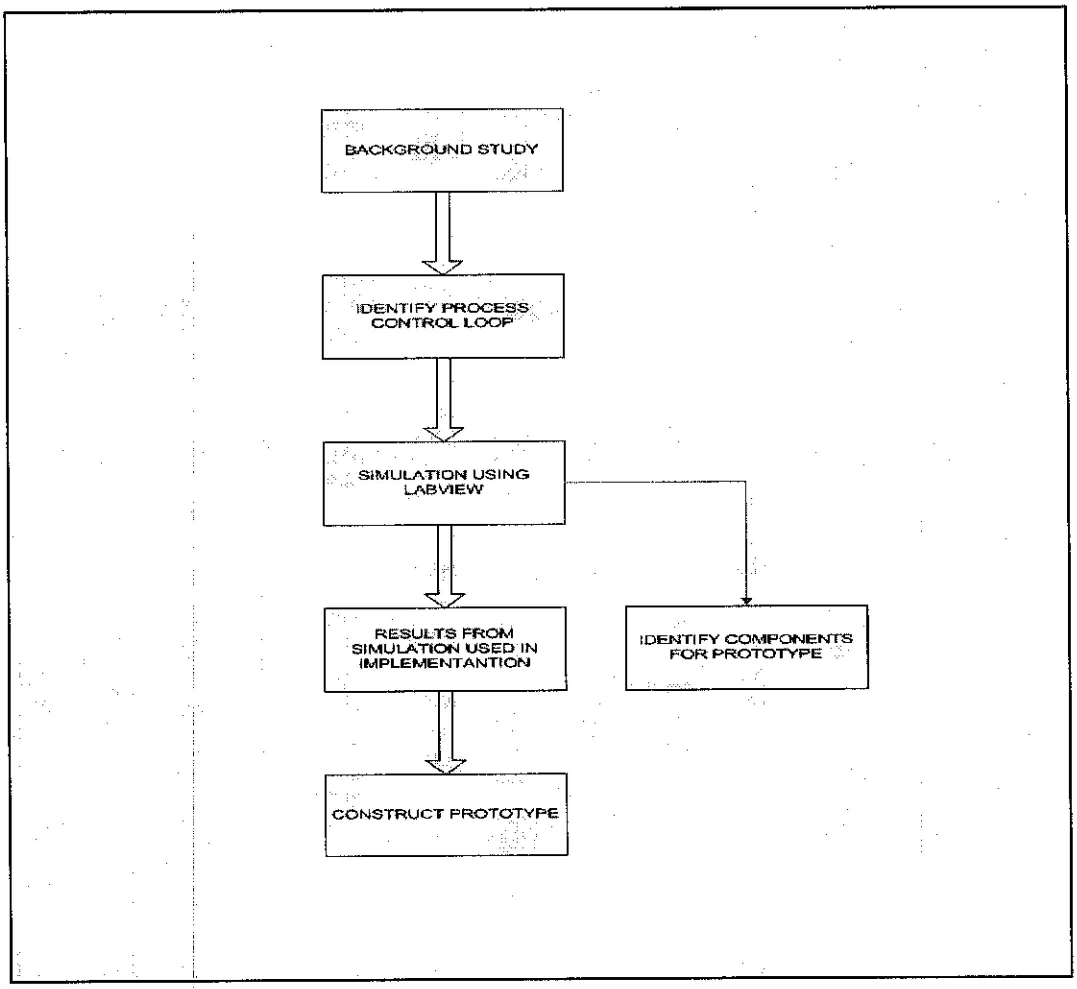


Figure 6: Project Flow Chart

3.2 Process Control Loop

The system is to function as illustrated by Figure 7.

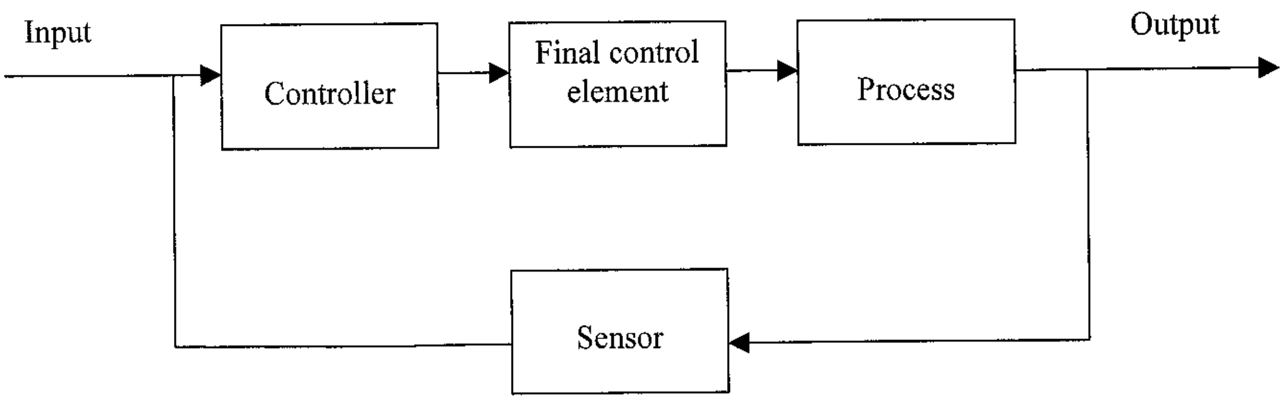


Figure 7: Process Control Loop

3.2.1 Sensor

The sensor will detect the temperature of the water and send a modified temperature value (voltage signal) to the controller. The temperature sensor chosen for the system is a thermistor. The name derived from the words "thermally sensitive resistors". It is a semiconductor device. It is assumed that the relationship between resistance and temperature is linear (i.e. we make a first-order approximation), then we can say that:

$$\Delta R = k\Delta T$$

Where

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance

Thermistors can be classified into two types depending on the sign of k. If k is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (PTC) thermistor. If k is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (NTC) thermistor. Resistors that are not thermistors are designed to have the smallest possible k, so that their resistance remains almost constant over a wide temperature range.

The sensor is connected to the microcontroller as illustrated in Figure 8.

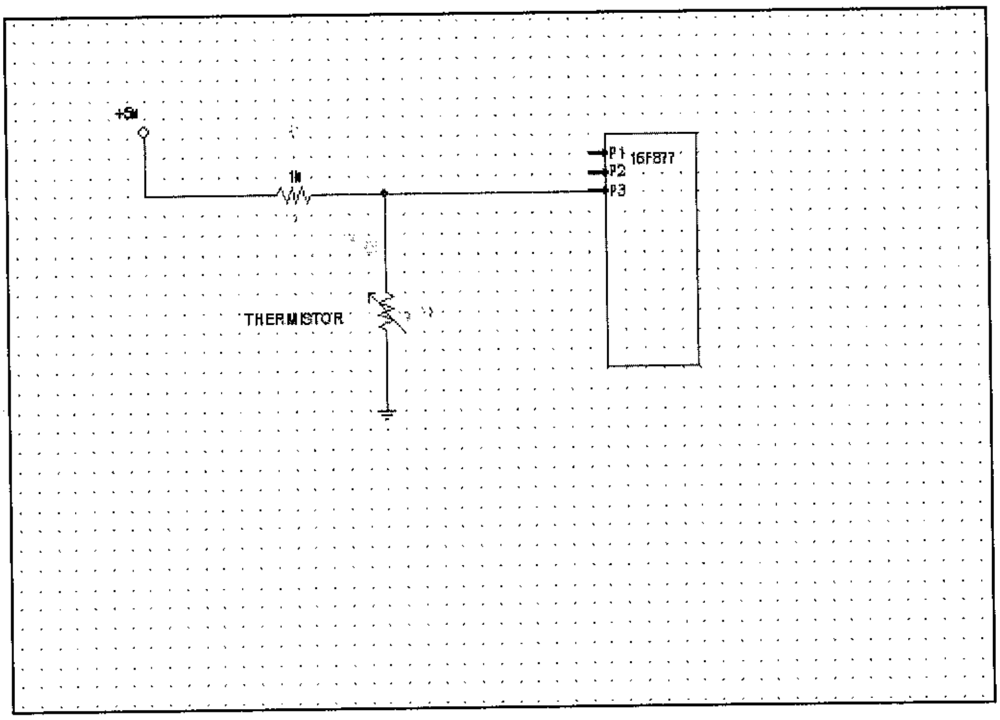


Figure 8: Thermistor Connections

3.2.2 Controller

Using a microcontroller can reduce the number of components, the amount of design work and wiring required for a project. The interfaces between the microcontroller and the outside world vary with the application and may include equipments such as display, sensors, relays, motors, and so on.[3] The microcontroller to be used for the project is 40 pin CMOS FLASH **Microchip**16F877. The data sheet for the microcontroller is shown in Appendix C.

The microcontroller will have 2 inputs namely temperature sensor and flow meter/ sensor. The outputs will be 1 LED, display screen, and control circuits for the heater.
The algorithm for the program is shown in Figure 5. The variable that activates the system is flow. Flow will signal the system to start monitoring the temperature of water and increase heat to achieve the setpoint of the system.

In programming the microcontroller 16F877, there is choice between Assembly language and C language. C language was chosen because of it accessibility and easy with which to troubleshoot/modify.
The program for the system is shown in Appendix D. The program is in C language. The logic of the program is similar to the flow chart (program algorithm) shown Figure 9.

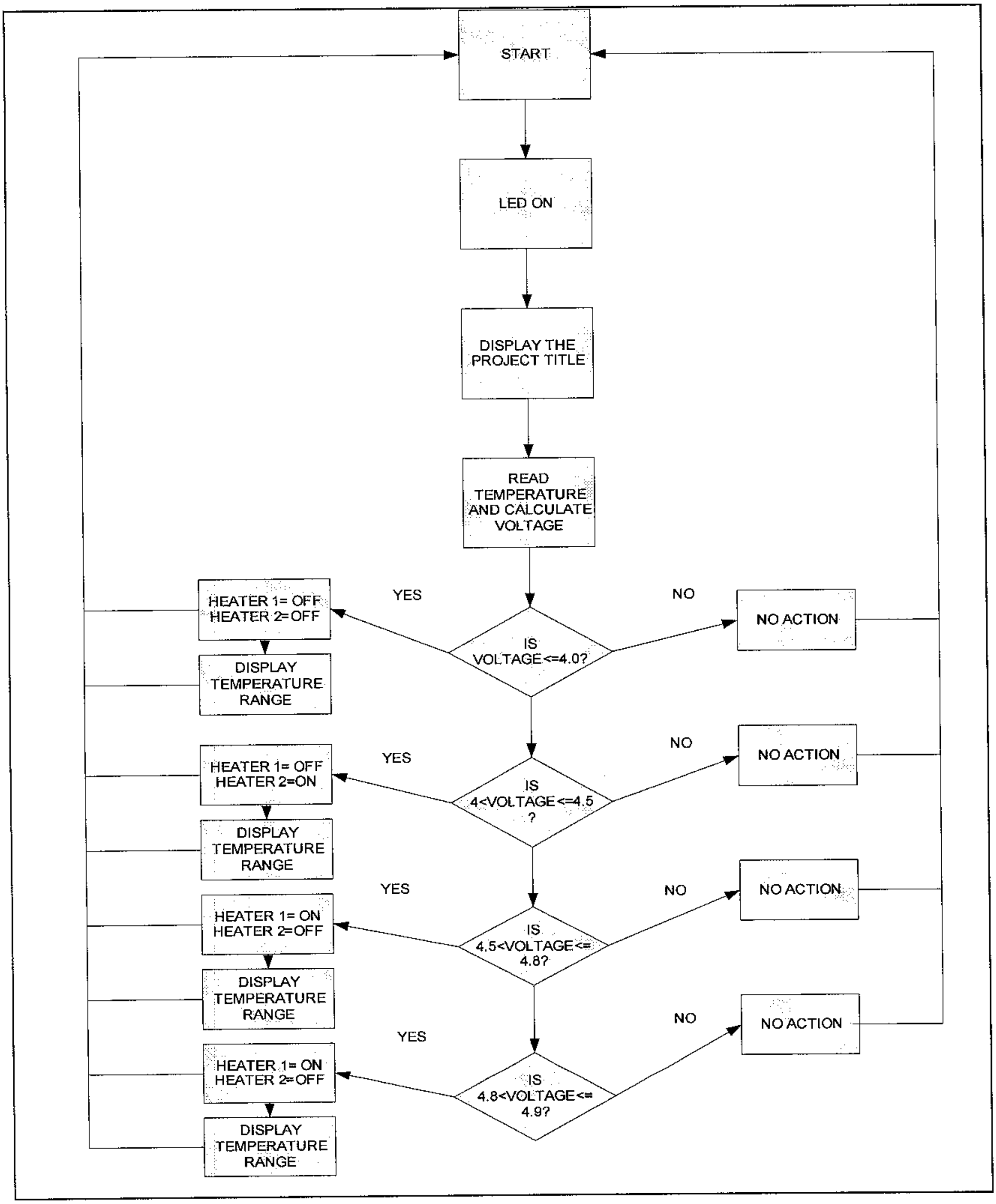


Figure 9: Program Algorithm

The controller should retain the water temperature at a range of 50 degrees Celsius using power of 1.5 kW or less for the heating element. The heating elements used for the model should sum up to the specified limit. The heating element 1= 800W and heating element 2= 500W. Therefore the design satisfies requirements.

3.2.3 Final Control Element

The final control element of the project is a heating element. It is essential that the element be able to transfer heat in the least time possible. In physics, thermal conductivity, λ or k, is the intensive property of a material which relates its ability to conduct heat. Thermal conductivity is the quantity of heat, Q, transmitted through a thickness L, in a direction normal to a surface of area A; due to a temperature difference ΔT, under steady state conditions and when the heat transfer is dependent only on the temperature gradient.

Thermal conductivity = heat flow rate × distance / (area × temperature difference)

$$\frac{dq}{dt} = -\lambda A \frac{dT}{dx}$$

It is difficult to control the flow of heat, but for accurate thermal conductivity measurements, the power coming from the hot plate must flow only along the axis of the specimen and not start wandering off into the surroundings. Good insulation could be used but as it was mentioned earlier, the effects of insulation are negligible.
The values of thermal conductivity of materials need to be known to determine which material can be used for certain functions.

The heating elements are activated via a relay depending on the current temperature of water in the heating chamber. The connection of the relay to the microcontroller and the heating element is shown in Figure 10. The highlighted section represents the relay.

The transistor connected provides a form of switching in the circuit. The data sheet for the transistor is included in Appendix E

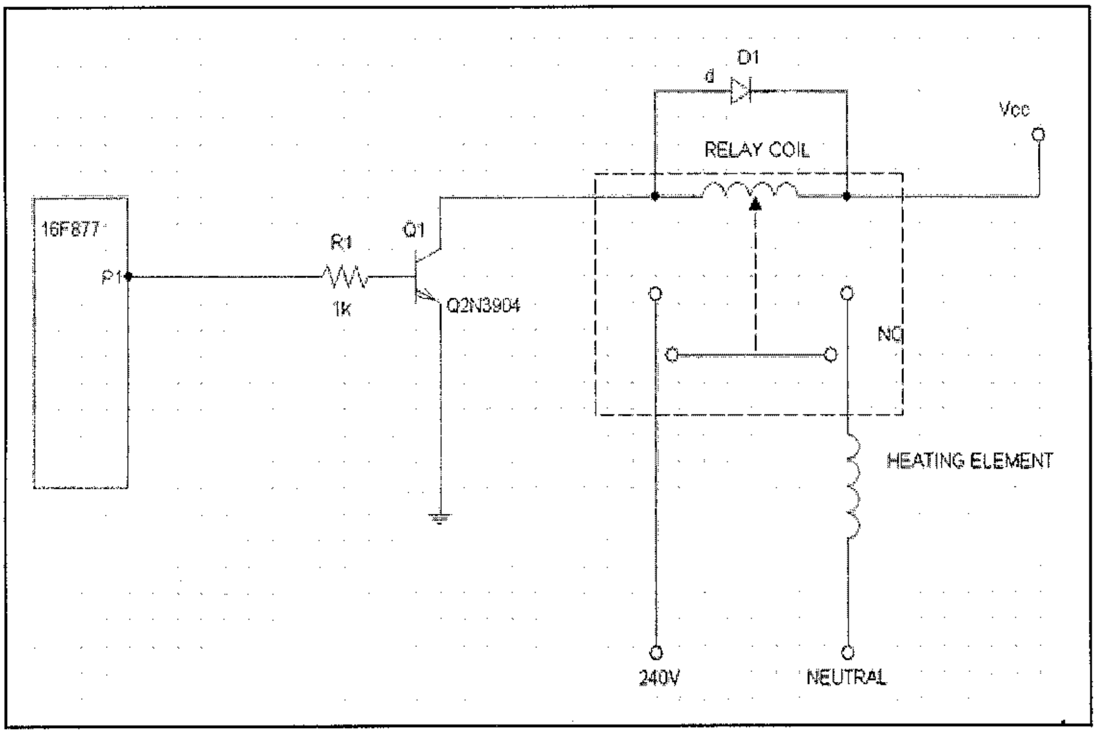


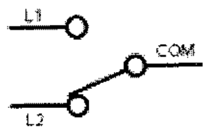
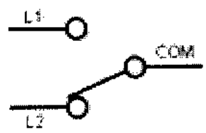
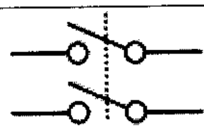
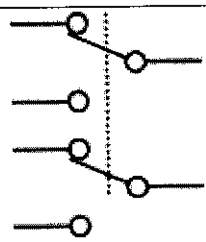
Figure 10: Relay Circuit

3.2.3.1 Relays

A relay is simply a switch- device for changing the course (or flow) of a circuit. In the simplest case, a switch has two pieces of metal called contacts that touch to make a circuit, and separate to break the circuit[6]. The different switches available are shown in Table 4. The relay that is used in the system is DPDT due to availability. SPDT can be used as well with the same effect shown in Appendix F.

The relay is used in this system to implement control of the heating element. Depending on the output of the microcontroller, the relay will be energized or deactivated, thus connecting or isolating live wire (240 VAC). The schematic circuit of the system is included in Appendix G. The relay has a diode connected to prevent the flow of current is reverse direction. Flow of current in reverse direction might damage the system

Table 3: Types of Switches That Can Be Used

Electronics abbreviation	Name	Description	Symbol
SPST	Single pole, single throw	A simple on-off switch: The two terminals are either connected together or not connected to anything.	
SPDT	Single pole, double throw	A simple changeover switch: C (Common) is connected to L1 or to L2.	
SPCO	Single pole changeover *or* Single pole, centre off	Equivalent to *SPDT*. Some suppliers use *SPCO* for switches with a stable off position in the centre and *SPDT* for those without.	
DPST	Double pole, single throw	Equivalent to two *SPST* switches controlled by a single mechanism	
DPDT	Double pole, double throw	Equivalent to two *SPDT* switches controlled by a single mechanism: A is connected to B and D to E, or B is connected to	
DPCO	Double pole changeover *or* Double pole, centre off		

3.2.4 Process

The heating chambers will need a material which ensures that heat is not transferred easily. This is necessary to provide security for the components in the system. The heating element material must be able to transfer heat instantly to ascertain that the tankless water heater is implemented according to the design/ requirements.

The heating process will occur in the heating chamber as shown in Figure 11.

Cold water flows from the top of the chamber to the second section of the chamber where it exits. The chamber is partitioned to induce a delay in the process. The delay will ensure the water reaches the desired setpoint. The delay induced is short; therefore the risk of reduced flow rates for the system is completely eliminated. The material used for the partition was carefully chosen to ensure that heat is transferred with ease between the two sections.

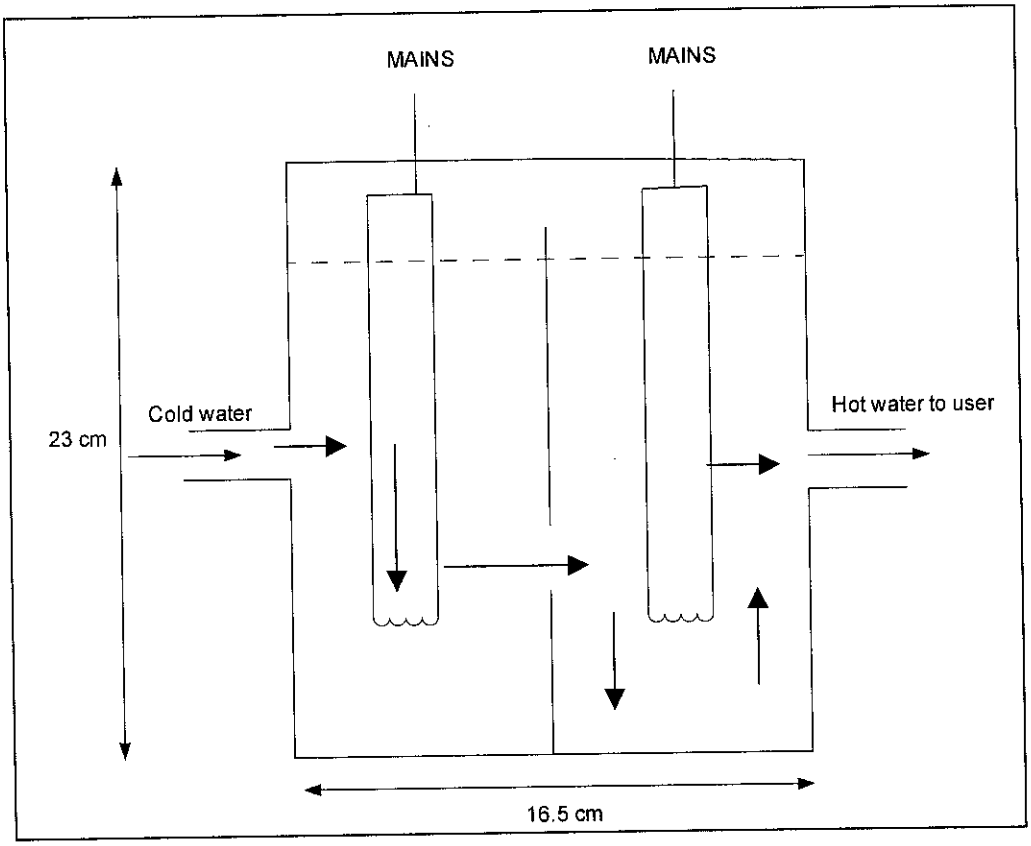


Figure 11: Heating Chamber

3.2.5 Output

The output of the system will be a change in temperature of cold water that enters the chamber. The related temperature values will be displayed on a Liquid Crystal Display (LCD). The LCD is interfaced with the microcontroller and the pin connections are shown in Appendix H. The LCD directive has to be included in the main program for the LCD to function. The directive program is shown in Appendix I There are only 4 pins used for data in the system. Therefore this is termed a 4 bit interface.

The type of LCD can display characters, numbers and special characters. The most common type of alphanumeric LCD uses a Hitachi HD44780 as display controller as is the case in this system.

The LCD screen is included in the system to allow the user to monitor the process. The user can compare the displayed temperature with the actual temperature of the water. The difference between the two should approach zero. The test will further prove that the system is functioning as per design.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 LabView Simulation

The simulation on LABVIEW is done to generate a trend of the system. A plot of the temperature changes will ensure that the operation of the sensor is monitored. As mentioned previously, the temperature sensor is the integral part of the system and might cause the system to collapse if it fails.

The appropriate sensor for the DAQ (Data Acquisition and Signal Accessory) was not available. Therefore the results of the experiment may not be accurate because the internal sensor is not accurate. Therefore the results show the open loop system of the project. The correct sensor for the DAQ will yield desirable results.

The figures below show the results of the simulation. Figure 12 shows the front panel of LabView workspace. The front panel is used to create a user interface display thus it displays the actual temperature of the system.

Figure 13 shows the block diagram of the system where temperature is measured and manipulated (voltage to temperature in degrees in Celsius) so as to be understood by the user. The user has an option of displaying the temperature in degrees Celsius in Fahrenheit.

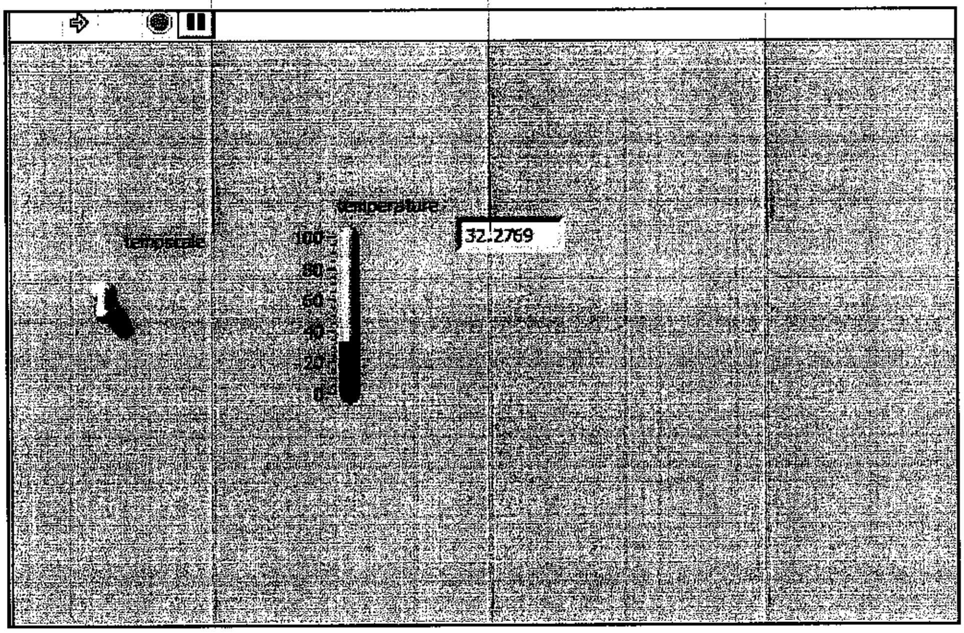


Figure 12: Front Panel

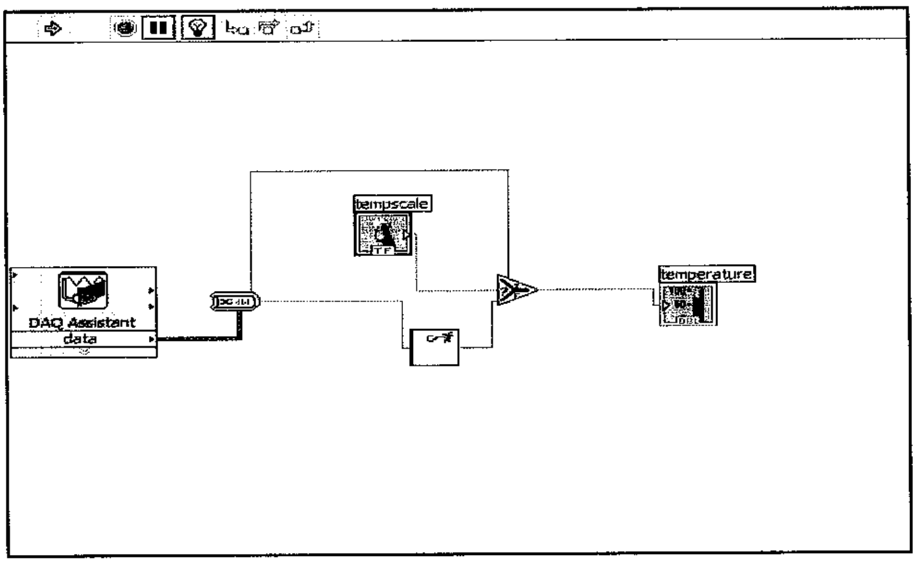


Figure 13: Block Diagram

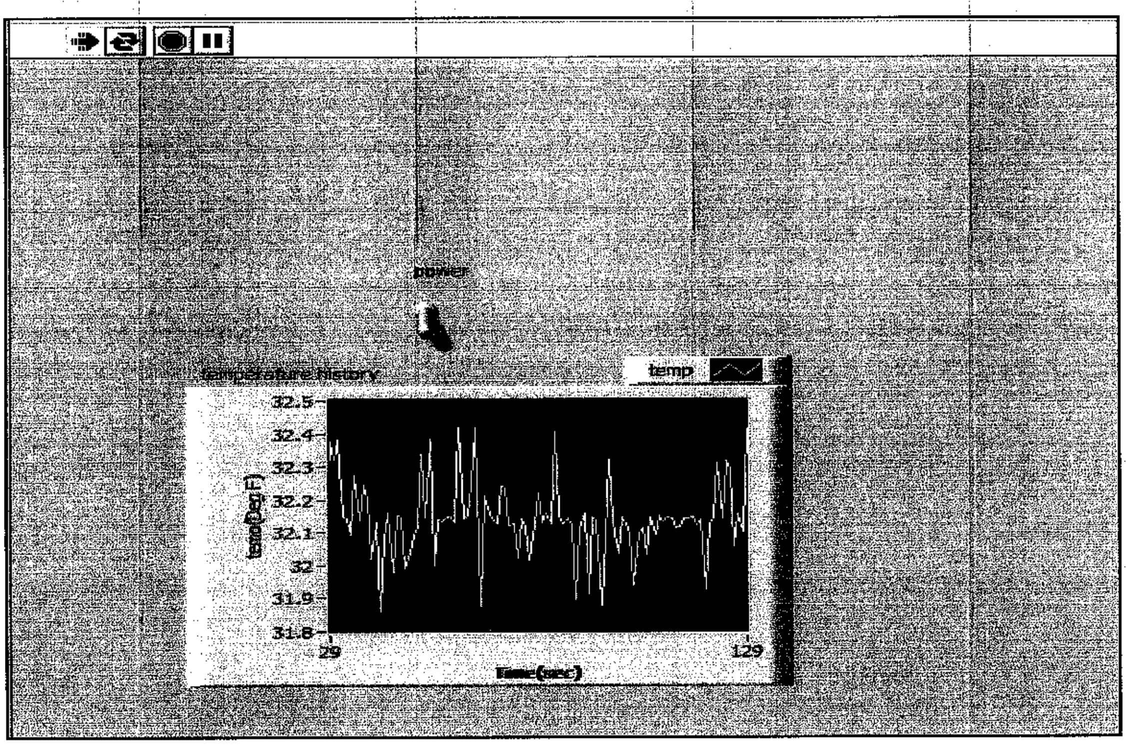


Figure 14: Plot of Changes in Temperature-Front Panel

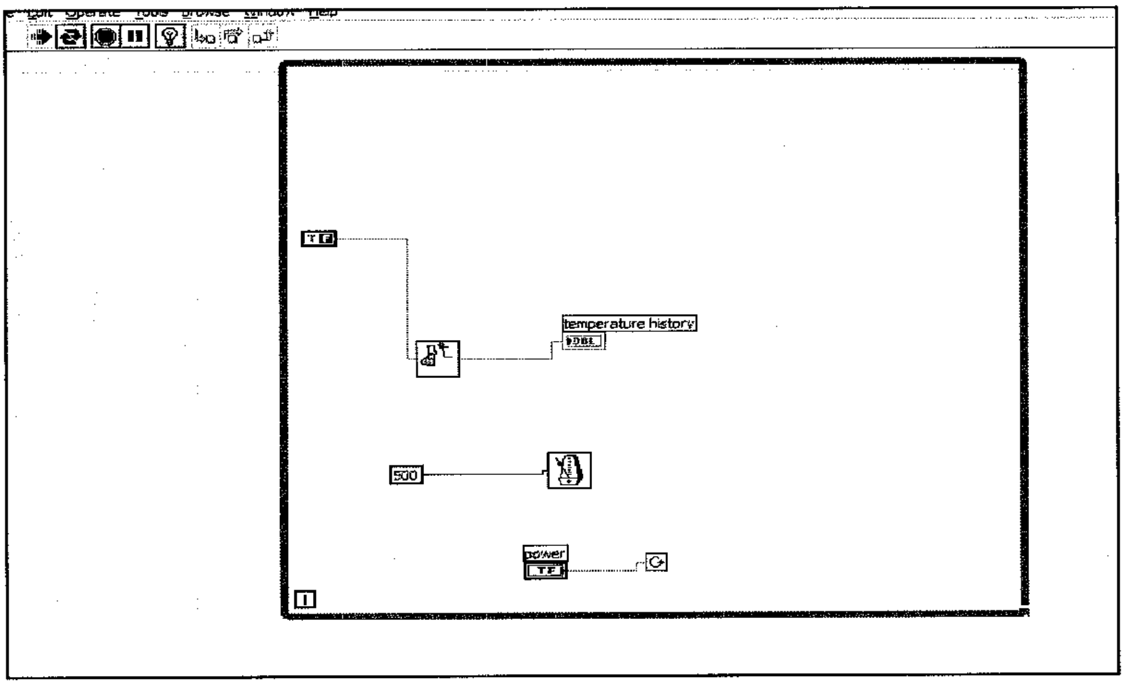


Figure 15: Plot of Changes in Temperature- Block Diagram

Figure 13 and Figure 14 show the front panel and block diagram for the plot of changes in temperature respectively. As mentioned previously, the temperature is the main component in this system therefore it must be monitored constantly. The program can be utilized not only for domestic purposes but also for industrial purposes to monitor certain devices.

4.2 Programming

The C language program that is used to control the system is included in Appendix F. The program is the same as the program algorithm shown earlier. An experiment had to be conducted to calibrate the sensor used in the system. The thermistor varies its resistance in proportion to changes in temperature. When the thermistor was subjected to temperature variation, the resistance hence the voltage varied and the results are tabulated below. The calibration results were used to formulate an equation in the program.

Table 4: Experimental Results

TEMPERATURE(°C)	RESISTANCE (kΩ)	VOLTAGE (V)
23	3.83	4.84
30	3.82	4.80
35	3.8	4.79
40	3.71	4.78
45	3.78	4.74
50	3.78	4.71
55	3.79	4.59
60	3.76	4.54
65	3.76	4.43
70	3.73	4.34
75	3.72	4.45
80	3.70	4.18
85	3.68	3.94
90	3.67	3.71
100	3.65	3.22

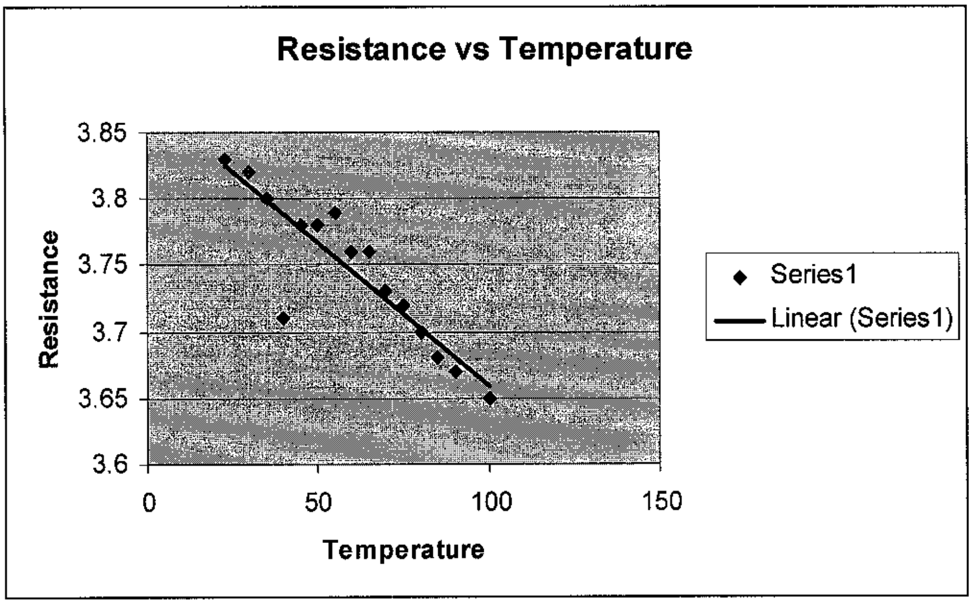


Figure 16: Resistance versus Temperature

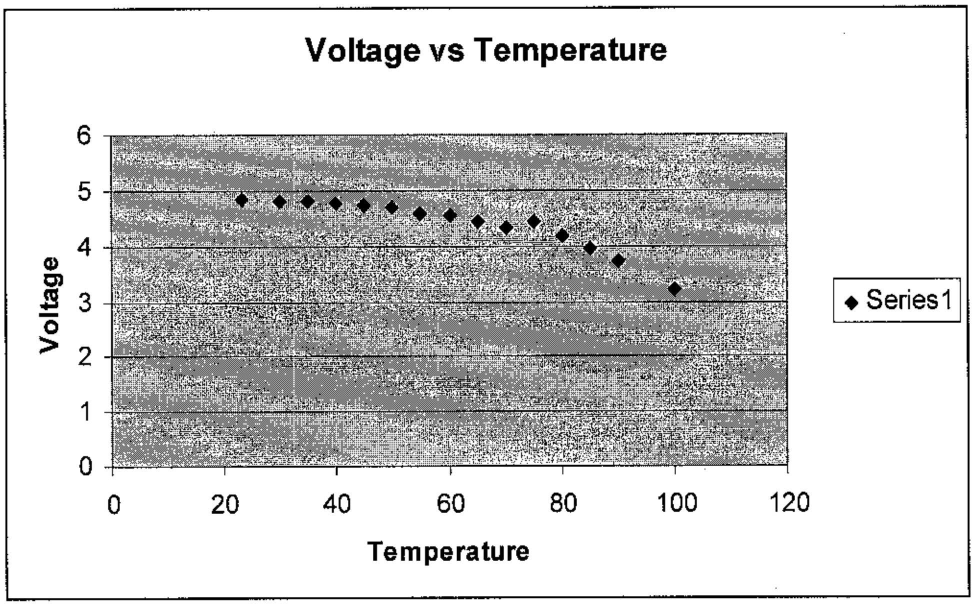


Figure 17: Voltage versus Temperature

The results above are consistent with the predicted results shown in **section 2.3.** Therefore the equation formulated for the microcontroller is accurate.

4.3 Prototype

The control circuit has been separated to two namely microcontroller circuit and the relay circuit. The circuits were separated for safety reason because the relay circuit uses 240V.

The relay circuit has relays that cannot be mounted to the Vero board as shown in Figure 18. The circuit functions according to the design.

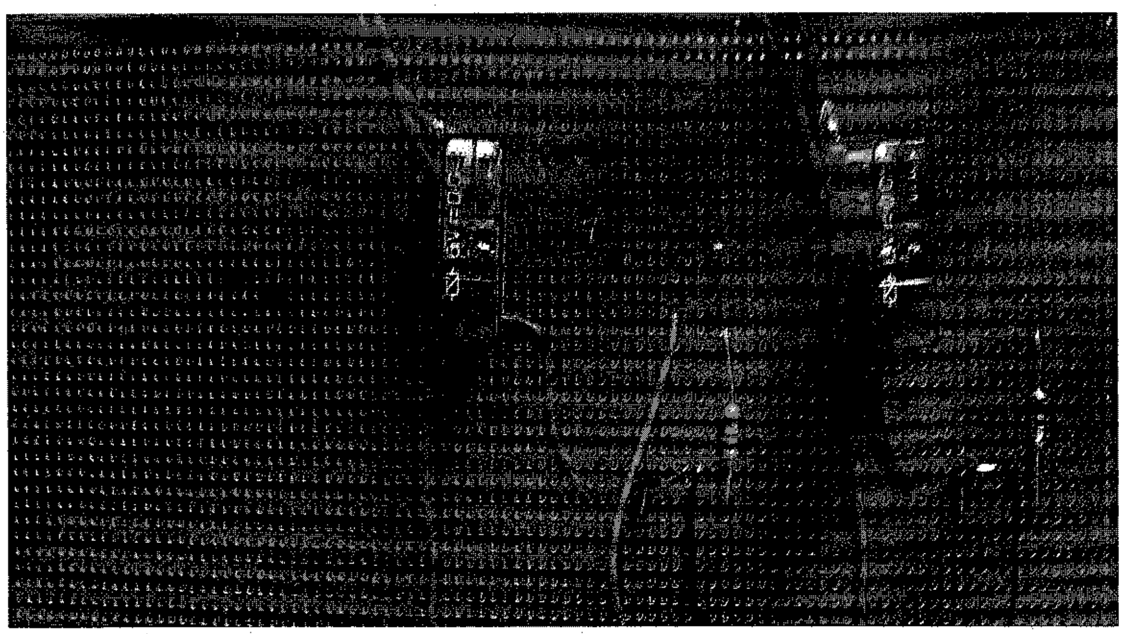


Figure 18: Prototype-Relay Circuit

The microcontroller circuit has the 16F877 microcontroller where all the instructions are executed. The thermistor sensor is connected to the microcontroller is PORT A as in Figure 19.

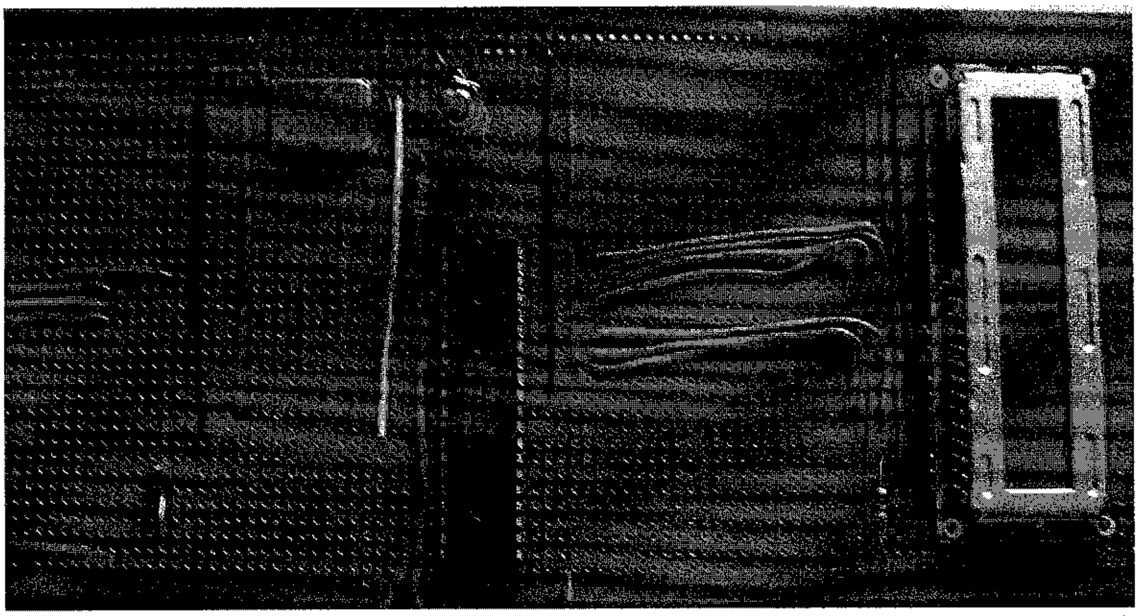


Figure 19: Prototype –Microcontroller Circuit

4.3.1 Circuit Operation

Circuit operation for the system is simple. When power is supplied to the system, a status LED will turn ON. The LED will indicate the system is ready for use. When there is flow (as required by the user) the flow sensor will detect it and initialize the system. In this project, flow has been assumed to be at maximum. When the flow is nonzero, the temperature sensor will be activated to start detecting the actual temperature of the water. The output of the sensor is voltage. Using the equation formulated during the experiment, voltage is calculated as the equation:

$$\text{Voltage} = 5.000 * \text{adcValue} / 255.000$$

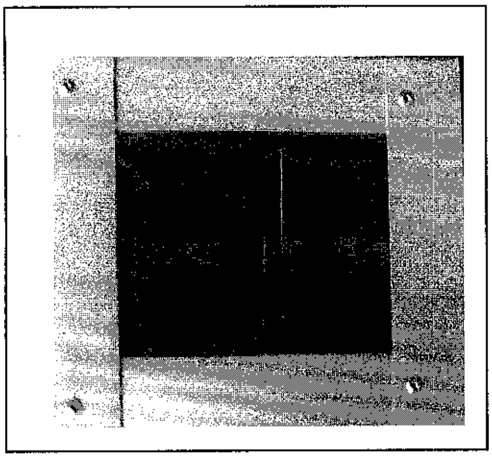
The microcontroller has an internal A/D; therefore there is no need for external A/D. The feature further indicates the advantages of this particular microcontroller (16F877).

The algorithm will run the loop to determine the action to be taken. The result of the loop will be turning ON/OFF the heating elements.

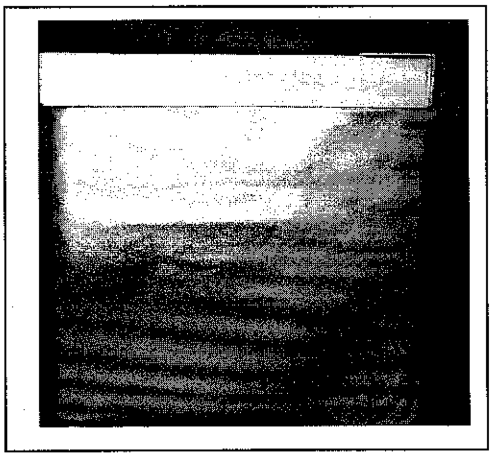
The loop will run as long as flow is nonzero. When the output of the flow sensor is zero, the system will cease to function.

4.3.2 Model

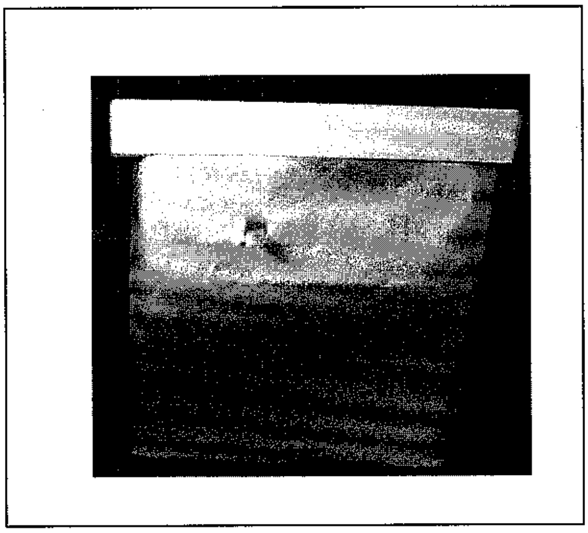
The model for the project is shown in Figure 19. The material used for the model is suitable for heating purposes. In addition to material, the heating chamber is insulated using a mineral blanket. The mineral blanket ensures that heat is not lost. When heat is dissipated to the environment, the heating process will be longer; therefore more power will be utilized unnecessarily.



a) Top View



b) Front View



c) Cross-Sectional view

Figure 20: Model

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The studies done and experiments conducted on heater systems in various conditions have been carried out to produce preliminary results. The preliminary results were used to design and select proper equipment for the prototype of a water heater. The water heater runs at low power and hence it will be portable, economical, low cost and easily fitted to a power socket.

LABVIEW has many applications. LABVIEW has clearly showed that there exists a relationship between the three parameters. Further experiments will show graphs of such a relationship. Simulating the project on LABVIEW provides a much needed monitoring system for the vital component of the system. The principles of operation of a normal water heater were used in designing the low power water heater. Flow rate and heat being transferred are some of the factors to be considered in this project. The project was able to function properly because the two factors were properly manipulated to implement the system.

The prototype had to be implemented to demonstrate the integration of different circuit that exist in this system, namely the microcontroller circuit and relay circuit. The prototype has a heating chamber which is the location for the process. Experiments conducted ensure that flow rate is not reduced; therefore the system improves the flaws of existing water heaters.

Although the system functions as required, there still exists a room for improvement. The system is designed and implemented on the assumption that flow rates are at maximum. In reality, flow rates will vary according to the needs of the user. Therefore, integrating flow rate to the system will improve efficiency.

The design of the system has a fixed setpoint that cannot be changed or programmed by the user. Different users have different needs and therefore each user should be able to program the water heater to suit their needs. The current design lacks that flexibility which can be rectified by using switches. Switches can be used to select a setpoint set by the user and the system can manipulate the data available to reach setpoint. Alternatively, the user can use a keypad to input the setpoint. A keypad will provide a simpler and more precise tool for the user. The reliability of the output from the system will be increased.

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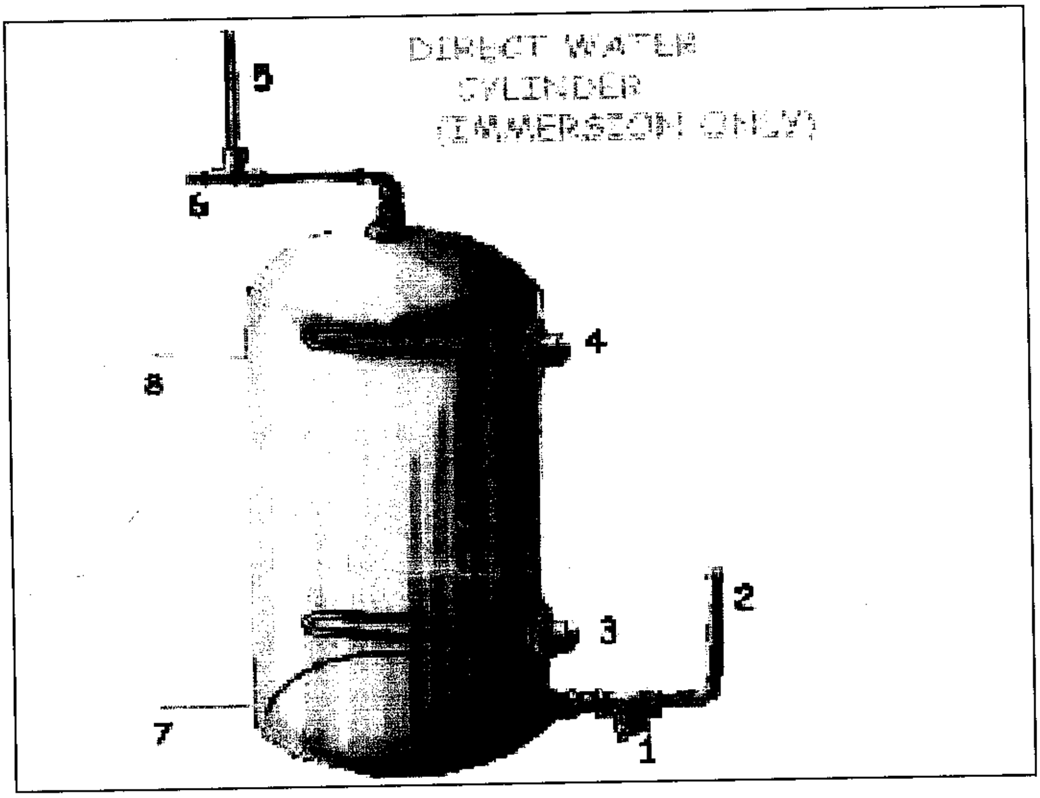
APPENDICES

Appendix A

Existing Water Heaters



1. Drain cock
2. Incoming cold feed
3. Main tank immersion (night use mostly)
4. Top up immersion
5. Vent pipe leading back to cold water tank
6. Hot pipe to feed taps.
7. Cold feed out. (see below)
8. Hot from boiler (see below)

APPENDIX B

Gantt Chart

Semester I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	█													
	-Propose Topic														
	-Topic assigned to students														
2	Preliminary Research Work		█	█											
	-Introduction														
	-Objective														
	-List of references/literature														
	-Project planning														
3	Submission of Preliminary Report			●											
4	Project Work				█	█	█	█							
	-Reference/Literature														
	-Practical/Laboratory Work														
5	Submission of Progress Report								●						
6	Project work continue								█	█	█	█			
	-Practical/Laboratory Work														
7	Submission of Interim Report Final Draft												●		
8	Oral Presentation													●	
9	Submission of Interim Report														●

1	Literature Review														
	-Choose programming language														
	-Analyze test programs														
2	Construct test programs														
3	Submission of Progress Report 1			●											
4	Construct the final program														
	-Integrate LCD to the program														
	-Integrate the sensor														
5	Submission of Progress Report 2							●							
6	Troubleshooting														
7	Pre-Edx Presentation										●				
8	Construction of the final circuit and model														
9	Submission of Draft Report												●		●

Suggested milestone
Process

Appendix C

Microcontroller Data Sheet

MICROCHIP

PIC16F87X

28/40-pin 8-Bit CMOS FLASH Microcontrollers

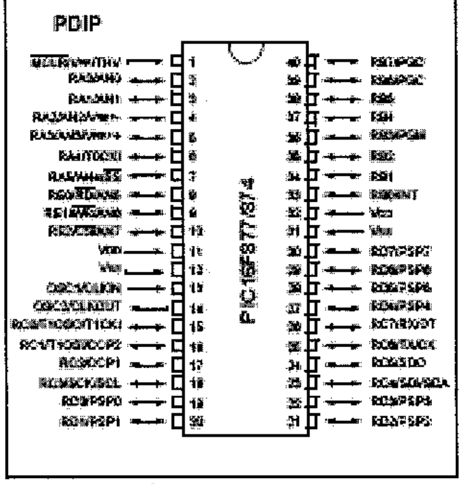
Devices Included in this Data Sheet:

- PIC16F873
- PIC16F874
- PIC16F876
- PIC16F877

Microcontroller Core Features:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM data memory
- Pinout compatible to the PIC16C73B/74B/76/77
- Interrupt capability (up to 14 sources)
- Eight level deep hardware stack
- Direct, indirect and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS FLASH/EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ (ICSP) via two pins
- Single 5V In-Circuit Serial Programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.0V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 20 μA typical @ 3V, 32 kHz
  - < 1 μA typical standby current

Pin Diagram



Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI™ (Master Mode) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

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

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.
MCLR/VPP/THV	1	1	I/P	ST	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
					PORTA is a bi-directional I/O port.
RA0/AN0	2	2	I/O	TTL	RA0 can also be analog input0
RA1/AN1	3	3	I/O	TTL	RA1 can also be analog input1
RA2/AN2/VREF-	4	4	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/VREF+	5	5	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	6	I/O	ST	RA4 can also be the clock input to the Timer0 module. Output is open drain type.
RA5/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^2C modes.
RC4/SDI/SDA	15	15	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I^2C 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/THV	1	2	18	I/P	ST	Master clear (reset) input or programming voltage input or high voltage test mode control. This pin is an active low reset to the device.
						PORTA is a bi-directional I/O port.
RA0/AN0	2	3	19	I/O	TTL	RA0 can also be analog input0
RA1/AN1	3	4	20	I/O	TTL	RA1 can also be analog input1
RA2/AN2/VREF-	4	5	21	I/O	TTL	RA2 can also be analog input2 or negative analog reference voltage
RA3/AN3/VREF+	5	6	22	I/O	TTL	RA3 can also be analog input3 or positive analog reference voltage
RA4/T0CKI	6	7	23	I/O	ST	RA4 can also be the clock input to the Timer0 timer/counter. Output is open drain type.
RA5/$\overline{SS}$/AN4	7	8	24	I/O	TTL	RA5 can also be analog input4 or the slave select for the synchronous serial port.
						PORTB is a bi-directional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	I/O	TTL/ST(1)	RB0 can also be the external interrupt pin.
RB1	34	37	9	I/O	TTL	
RB2	35	38	10	I/O	TTL	
RB3/PGM	36	39	11	I/O	TTL	RB3 can also be the low voltage programming input
RB4	37	41	14	I/O	TTL	Interrupt on change pin.
RB5	38	42	15	I/O	TTL	Interrupt on change pin.
RB6/PGC	39	43	16	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming clock.
RB7/PGD	40	44	17	I/O	TTL/ST(2)	Interrupt on change pin or In-Circuit Debugger pin. Serial programming data.
						PORTC is a bi-directional I/O port.
RC0/T1OSO/T1CKI	15	16	32	I/O	ST	RC0 can also be the Timer1 oscillator output or a Timer1 clock input.
RC1/T1OSI/CCP2	16	18	35	I/O	ST	RC1 can also be the Timer1 oscillator input or Capture2 input/Compare2 output/PWM2 output.
RC2/CCP1	17	19	36	I/O	ST	RC2 can also be the Capture1 input/Compare1 output/PWM1 output.
RC3/SCK/SCL	18	20	37	I/O	ST	RC3 can also be the synchronous serial clock input/output for both SPI and I²C modes.
RC4/SDI/SDA	23	25	42	I/O	ST	RC4 can also be the SPI Data In (SPI mode) or data I/O (I²C mode).
RC5/SDO	24	26	43	I/O	ST	RC5 can also be the SPI Data Out (SPI mode).
RC6/TX/CK	25	27	44	I/O	ST	RC6 can also be the USART Asynchronous Transmit or Synchronous Clock.
RC7/RX/DT	26	29	1	I/O	ST	RC7 can also be the USART Asynchronous Receive or Synchronous Data.

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

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

3.0 I/O PORTS

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

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

3.1 PORTA and the TRISA Register

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

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

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

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

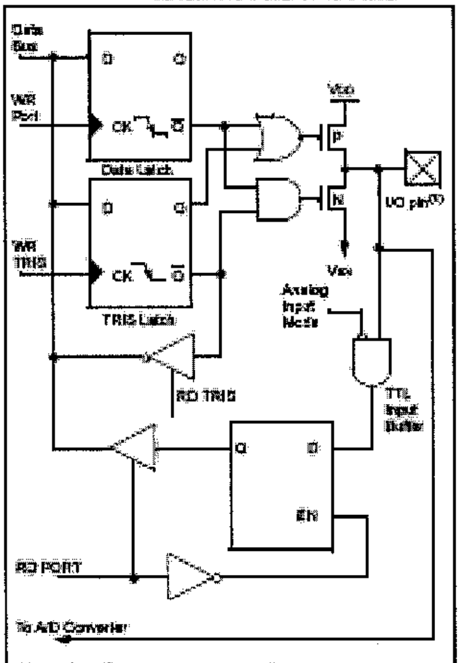
Note:	On a Power-on Reset, these pins are configured as analog inputs and read as '0'.

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

EXAMPLE 3-1: INITIALIZING PORTA

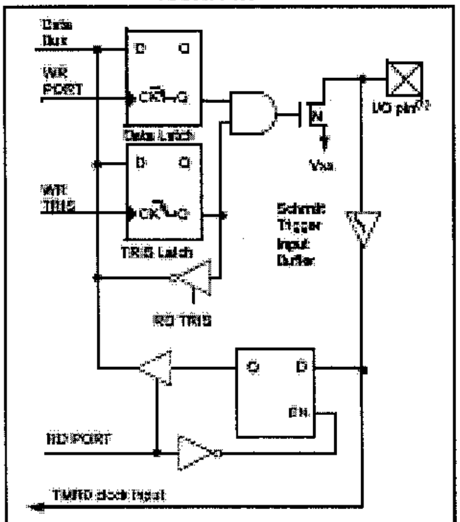
```
BCF     STATUS, RP0    ;
BCF     STATUS, RP1    ; Bank0
CLRF    PORTA          ; Initialize PORTA by
                       ; clearing output
                       ; data latches
BSF     STATUS, RP0    ; Select Bank 1
MOVLW   0x06           ; Configure all pins
MOVWF   ADCON1         ; as digital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

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



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

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



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

TABLE 3-3: PORTB FUNCTIONS

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

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

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.

2: This buffer is a Schmitt Trigger input when used in serial programming mode.

TABLE 3-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTB

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

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

Appendix D

Main Program

```
#include <16F877.h>
#device ADC=8
#fuses XT,NOWDT,NOPROTECT,NOLVP,NOPUT,NOBROWNOUT
#use delay(clock = 4000000)
#include <LCD.C>
#include <string.h>
#include <stdio.h>

unsigned int8 adcValue;
float voltage;



void main()
{

    setup_adc_ports( ALL_ANALOG );
    setup_adc(ADC_CLOCK_INTERNAL);      // Use internal ADC clock.
    set_adc_channel(1);
    lcd_init();

while(1)
    {
        delay_us(50); // Delay for sampling cap to charge
        adcValue = read_adc(); // Get ADC reading


        delay_us(50); // Preset delay, repeat every 10ms

        voltage = 5.000 * adcValue / 255.000;
        output_high(PIN_D0);
        lcd_gotoxy(1,1);
        lcd_putc('\f');
        lcd_putc("Tankless/ Unit Nd/u");

            if (voltage <=4 )
              {
              lcd_gotoxy(1,1);
              lcd_putc('\f');
              lcd_putc("Range:80/+");

              output_low(PIN_D1);
              output_low(PIN_D2);
```

```
    }
else if ((voltage>4)&& (voltage<=4.5))
    {
     lcd_gotoxy(1,1);
     lcd_putc('\f');
     lcd_putc("Range:60/-80 degr/ees");
     output_low(PIN_D1);
     output_high(PIN_D2);
    }

else if ((voltage >4.6) && (voltage<=4.8))
    {

     lcd_gotoxy(1,1);
     lcd_putc('\f');
     lcd_putc("Range:30/-50 degr/ees");
     output_high(PIN_D1);
     output_low(PIN_D2);
    }
else if ((voltage >4.8) && (voltage<=4.9))
    {
     lcd_gotoxy(1,1);
     lcd_putc('\f');
     lcd_putc("Room tem/perature");
     output_high(PIN_D1);
     output_high(PIN_D2);

    }
  }
}
```

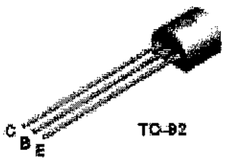
Appendix E

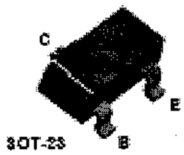
Transistor 3904 Data Sheet

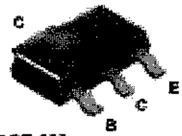
FAIRCHILD
SEMICONDUCTOR ™

2N3904 / MMBT3904 / PZT3904

2N3904	MMBT3904	PZT3904







NPN General Purpose Amplifier

This device is designed as a general purpose amplifier and switch. The useful dynamic range extends to 100 mA as a switch and to 100 MHz as an amplifier.

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*[illegible]

NOTES:
1) [illegible]
2) [illegible]

Thermal Characteristics T_A = 25°C unless otherwise noted

Symbol	Characteristic	Max			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

**[illegible]

NPN General Purpose Amplifier
(continued)

Electrical Characteristics
T_A = 25°C unless otherwise noted

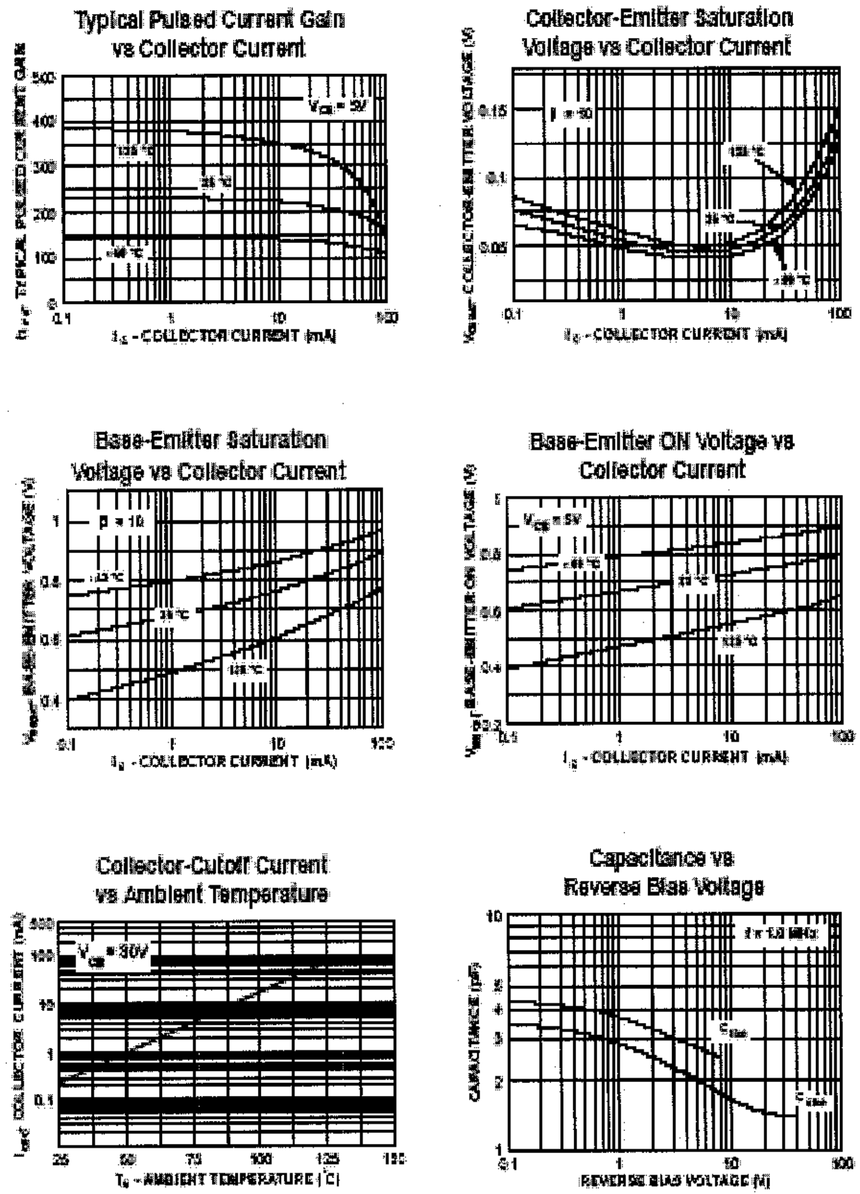
Symbol	Parameter	Test Conditions	Min	Max	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0 mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10 μA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10 μA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30 V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1 mA, V_{CE} = 1.0 V I_C = 1.0 mA, V_{CE} = 1.0 V I_C = 10 mA, V_{CE} = 1.0 V I_C = 50 mA, V_{CE} = 1.0 V I_C = 100 mA, V_{CE} = 1.0 V	40 70 100 60 30	 300	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10 mA, I_B = 1.0 mA I_C = 50 mA, I_B = 5.0 mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10 mA, V_{CE} = 20 V, f = 100 MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0 V, I_E = 0, f = 1.0 MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5 V, I_C = 0, f = 1.0 MHz		8.0	pF
NF	Noise Figure	I_C = 100 μA, V_{CE} = 5.0 V, R_S = 1.0kΩ, f=10 Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0 V, V_{BE} = 0.5 V,		35	ns
t_r	Rise Time	I_C = 10 mA, I_{B1} = 1.0 mA		35	ns
t_s	Storage Time	V_{CC} = 3.0 V, I_C = 10mA		200	ns
t_f	Fall Time	I_{B1} = I_{B2} = 1.0 mA		50	ns

*Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle ≤ 2.0%

Spice Model

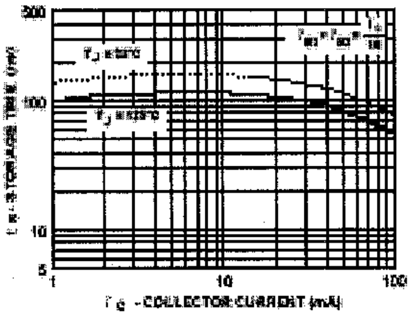
NPN (Is=6.734f Xti=3 Eg=1.11 Vaf=74.03 Bf=416.4 Ne=1.259 Ise=6.734 Ikf=66.78m Xtb=1.5 Br=.7371 Nc=2 Isc=0 Ikr=0 Rc=1 Cjc=3.638p Mjc=.3085 Vjc=.75 Fc=.5 Cje=4.493p Mje=.2593 Vje=.75 Tr=239.5n Tf=301.2p Itf=.4 Vtf=4 Xtf=2 Rb=10)

Typical Characteristics

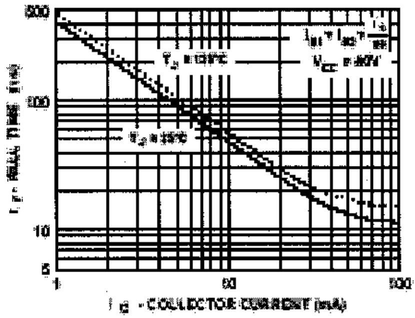


Typical Characteristics (continued)

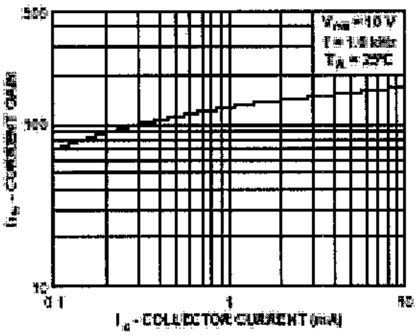
Storage Time vs Collector Current



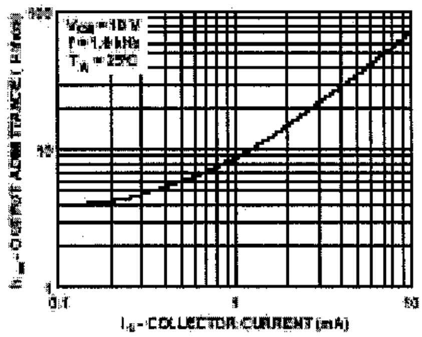
Fall Time vs Collector Current



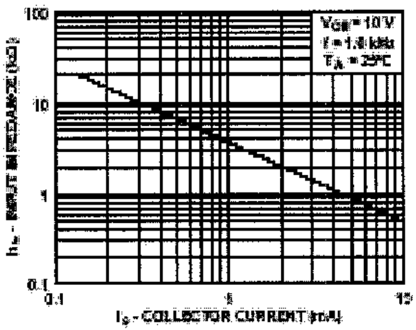
Current Gain



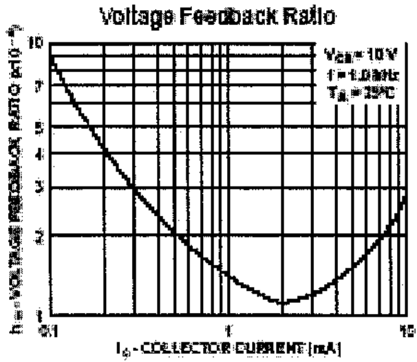
Output Admittance



Input Impedance



Voltage Feedback Ratio



Appendix F

Relay Datasheet

finder

40 Series - Miniature PCB relays 8 - 10 - 16 A

Features

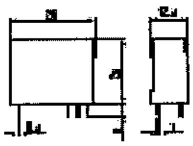
1 & 2 Pole relay range
- 40.31 - 1 Pole 10 A (3.5 mm pin pitch)
- 40.51 - 1 Pole 10 A (5 mm pin pitch)
- 40.52 - 2 Pole 8 A (5 mm pin pitch)

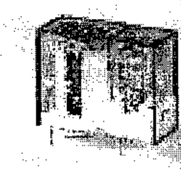
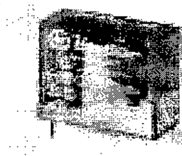
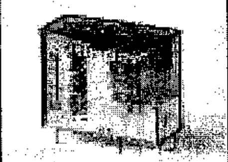
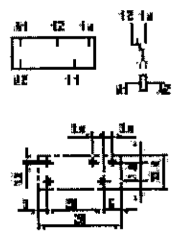
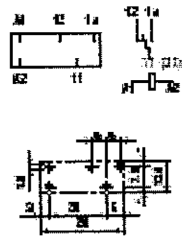
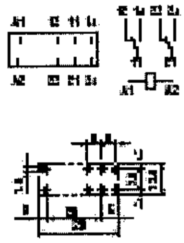
PCB mount
- direct or via PCB socket

35 mm rail mount
- via screw and screwless sockets

- DC coils (standard or sensitive) & AC coils
- Cadmium Free contact material
- 8 mm, 6 kV (1.2/50 μs) isolation, coil-contacts
- UL Listed (certain relay/socket combinations)
- Flux proof: RT II standard, (RT III option)
- 95 series sockets, coil EMC suppression and timer accessories

40



	40.31	40.51	40.52
			
	• 3.5 mm contact pin pitch • 1 Pole 10 A • PCB or 95 series sockets	• 5 mm contact pin pitch • 1 Pole 10 A • PCB or 95 series sockets	• 5 mm contact pin pitch • 2 Pole 8 A • PCB or 95 series sockets
	 Copper side view	 Copper side view	 Copper side view
Contact specification			
Contact configuration	1 CO (SPDT)	1 CO (SPDT)	2 CO (DPDT)
Rated current/Maximum peak current A	10/20	10/20	8/15
Rated voltage/Maximum switching voltage V AC	250/400	250/400	250/250
Rated load AC1 VA	2,500	2,500	2,000
Rated load AC15 (230 V AC) VA	500	500	400
Single phase motor rating (230 V AC) kW	0.37	0.37	0.3
Breaking capacity DC1: 30/110/220 V A	10/0.3/0.12	10/0.3/0.12	8/0.3/0.12
Minimum switching load mW (V/mA)	300 (5/5)	300 (5/5)	300 (5/5)
Standard contact material	AgNi	AgNi	AgNi
Coil specification			
Nominal voltage (U_N) V AC (50/60 Hz)	6 - 12 - 24 - 48 - 60 - 110 - 120 - 230 - 240		
V DC	5 - 6 - 7 - 9 - 12 - 14 - 18 - 21 - 24 - 28 - 36 - 48 - 60 - 90 - 110 - 125		
Rated power AC/DC/sens. DC VA (50 Hz)/W/W	1.2/0.65/0.5	1.2/0.65/0.5	1.2/0.65/0.5
Operating range AC	(0.8...1.1)U_N	(0.8...1.1)U_N	(0.8...1.1)U_N
DC/sens. DC	(0.73...1.5)U_N/(0.73...1.75)U_N	(0.73...1.5)U_N/(0.73...1.75)U_N	(0.73...1.5)U_N/(0.73...1.75)U_N
Holding voltage AC/DC	0.8 U_N/0.4 U_N	0.8 U_N/0.4 U_N	0.8 U_N/0.4 U_N
Must drop-out voltage AC/DC	0.2 U_N/0.1 U_N	0.2 U_N/0.1 U_N	0.2 U_N/0.1 U_N
Technical data			
Mechanical life AC/DC cycles	$10 \cdot 10^6/20 \cdot 10^6$	$10 \cdot 10^6/20 \cdot 10^6$	$10 \cdot 10^6/20 \cdot 10^6$
Electrical life at rated load AC1 cycles	$200 \cdot 10^3$	$200 \cdot 10^3$	$100 \cdot 10^3$
Operate/release time ms	7/3 - (12/4 sensitive)	7/3 - (12/4 sensitive)	7/3 - (12/4 sensitive)
Insulation between coil and contacts (1.2/50 μs) kV	6 (8 mm)	6 (8 mm)	6 (8 mm)
Dielectric strength between open contacts V AC	1,000	1,000	1,000
Ambient temperature range °C	–40...+85	–40...+85	–40...+85
Environmental protection	RT II**	RT II**	RT II**
Approvals (according to type)	CE ABS RINA		

** See page 239 "Guidelines for automatic flow solder processes".

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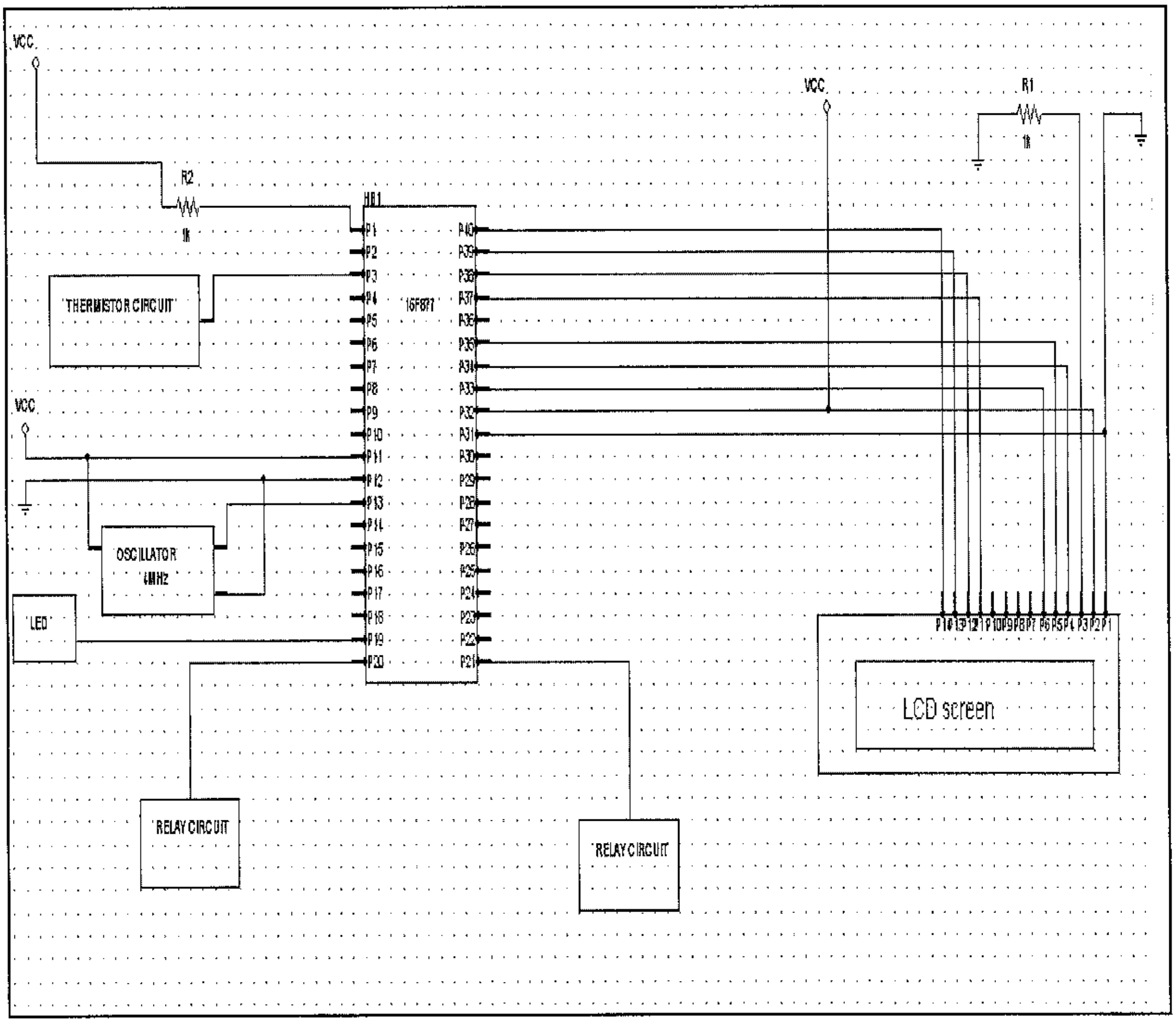
Appendix G

PSpice Schematic



Appendix H
LCD Pin Connection

Pin number	Symbol	Level	I/O	Function
1	Vss	-	-	Power supply (GND)
2	Vcc	-	-	Power supply (+5V)
3	Vee	-	-	Contrast adjust
4	RS	0/1	I	0 = Instruction input 1 = Data input
5	R/W	0/1	I	0 = Write to LCD module 1 = Read from LCD module
6	E	1, 1->0	I	Enable signal
7	DB0	0/1	I/O	Data bus line 0 (LSB)
8	DB1	0/1	I/O	Data bus line 1
9	DB2	0/1	I/O	Data bus line 2
10	DB3	0/1	I/O	Data bus line 3
11	DB4	0/1	I/O	Data bus line 4
12	DB5	0/1	I/O	Data bus line 5
13	DB6	0/1	I/O	Data bus line 6
14	DB7	0/1	I/O	Data bus line 7 (MSB)

Appendix I
LCD Directive

```
////////////////////////////////////////////////////////////////////////////
////                            LCDD.C                                  ////
////                Driver for common LCD modules                       ////
////                                                                    ////
//// lcd_init()   Must be called before any other function.             ////
////                                                                    ////
//// lcd_putc(c)  Will display c on the next position of the LCD.       ////
////                  The following have special meaning:               ////
////                  \f  Clear display                                 ////
////                  \n  Go to start of second line                    ////
////                  \b  Move back one position                        ////
////                                                                    ////
//// lcd_gotoxy(x,y) Set write position on LCD (upper left is 1,1)      ////
////                                                                    ////
//// lcd_getc(x,y)   Returns character at position x,y on LCD           ////
////                                                                    ////
////////////////////////////////////////////////////////////////////////////
////        (C) Copyright 1996,2003 Custom Computer Services            ////
//// This source code may only be used by licensed users of the CCS C  ////
//// compiler.  This source code may only be distributed to other      ////
//// licensed users of the CCS C compiler.  No other use, reproduction ////
//// or distribution is permitted without written permission.          ////
//// Derivative programs created using this software in object code    ////
//// form are not restricted in any way.                               ////
////////////////////////////////////////////////////////////////////////////

// As defined in the following structure the pin connection is as follows:
```

```
//    RB0    Chip Enable (CE)
//    RB1    Register Select (RS)
//    RB2    Read/Write* (R/W*)
//    RB4    Data Bit 4 (DB4)
//    RB5    Data Bit 5 (DB5)
//    RB6    Data Bit 6 (DB6)
//    RB7    Data Bit 7 (DB7)
//
//  LCD pins DB0-DB3 are not used and PIC's RB3 is not used.

// Un-comment the following define to use port B
#define use_portb_lcd TRUE


struct lcd_pin_map {              // This structure is overlayed
        BOOLEAN enable;           // on to an I/O port to gain
        BOOLEAN rs;               // access to the LCD pins.
        BOOLEAN rw;               // The bits are allocated from
        BOOLEAN unused;           // low order up.  ENABLE will
        int     data : 4;         // be pin B0.
      } lcd;


#if defined(__PCH__)
#if defined use_portb_lcd
  #byte lcd = 0xF81               // This puts the entire structure
#else
  #byte lcd = 0xF83               // This puts the entire structure
#endif
#else
#if defined use_portb_lcd
```

```
  #byte lcd = 6              // on to port B (at address 6)
#else
  #byte lcd = 8              // on to port D (at address 8)
#endif
#endif

#if defined use_portb_lcd
  #define set_tris_lcd(x) set_tris_b(x)
#else
  #define set_tris_lcd(x) set_tris_d(x)
#endif


#define lcd_type 2         // 0=5x7, 1=5x10, 2=2 lines
#define lcd_line_two 0x40   // LCD RAM address for the second line


BYTE const LCD_INIT_STRING[4] = {0x20 | (lcd_type << 2), 0xc, 1, 6};
                   // These bytes need to be sent to the LCD
                   // to start it up.



                   // The following are used for setting
                   // the I/O port direction register.

struct lcd_pin_map const LCD_WRITE = {0,0,0,0,0}; // For write mode all pins are out
struct lcd_pin_map const LCD_READ = {0,0,0,0,15}; // For read mode data pins are in



BYTE lcd_read_byte() {
```

```
   BYTE low,high;
   set_tris_lcd(LCD_READ);
   lcd.rw = 1;
   delay_cycles(1);
   lcd.enable = 1;
   delay_cycles(1);
   high = lcd.data;
   lcd.enable = 0;
   delay_cycles(1);
   lcd.enable = 1;
   delay_us(1);
   low = lcd.data;
   lcd.enable = 0;
   set_tris_lcd(LCD_WRITE);
   return( (high<<4) | low);
}


void lcd_send_nibble( BYTE n ) {
    lcd.data = n;
    delay_cycles(1);
    lcd.enable = 1;
    delay_us(2);
    lcd.enable = 0;
}


void lcd_send_byte( BYTE address, BYTE n ) {

    lcd.rs = 0;
    while ( bit_test(lcd_read_byte(),7) ) ;
```

```
    lcd.rs = address;
    delay_cycles(1);
    lcd.rw = 0;
    delay_cycles(1);
    lcd.enable = 0;
    lcd_send_nibble(n >> 4);
    lcd_send_nibble(n & 0xf);
}


void lcd_init() {
   BYTE i;
   set_tris_lcd(LCD_WRITE);
   lcd.rs = 0;
   lcd.rw = 0;
   lcd.enable = 0;
   delay_ms(15);
   for(i=1;i<=3;++i) {
     lcd_send_nibble(3);
     delay_ms(5);
   }
   lcd_send_nibble(2);
   for(i=0;i<=3;++i)
     lcd_send_byte(0,LCD_INIT_STRING[i]);
}


void lcd_gotoxy( BYTE x, BYTE y) {
   BYTE address;

   if(y!=1)
```

```
    address=lcd_line_two;
  else
    address=0;
  address+=x-1;
  lcd_send_byte(0,0x80|address);
}

void lcd_putc( char c) {
  switch (c) {
    case '\f'  : lcd_send_byte(0,1);
                 delay_ms(2);
                              break;
    case '\n'  : lcd_gotoxy(1,2);        break;
    case '\b'  : lcd_send_byte(0,0x10);  break;
    default    : lcd_send_byte(1,c);     break;
  }
}

char lcd_getc( BYTE x, BYTE y) {
  char value;

   lcd_gotoxy(x,y);
   while ( bit_test(lcd_read_byte(),7) ); // wait until busy flag is low
   lcd.rs=1;
   value = lcd_read_byte();
   lcd.rs=0;
   return(value);
}
```