Soil Moisture Content Detector

By

Alia Dawina binti Ab Karim

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

May 2011

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CERTIFICATION OF APPROVAL

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Electrical and Electronics Engineering Programme
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Approved by,

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TRONOH, PERAK

May 2011

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.

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ALIA DAWINA BINTI AB KARIM

ABSTRACT

A system to detect the soil moisture content has been developed. The detector uses probes as a sensing element to detect the moisture of the soil. The output of the device is represented as digital using microcontroller. The detector is designed based on concept of electrolysis and resistance method. The resistance of soil is increased inversely proportional with decreasing of the amount of water in soil. Furthermore, the device will be practical to use and affordable.

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere thanks to my supervisor, Assoc Prof Josefina Barnachea Janier for her patience, guidance and advice throughout the implementation of this project.

The appreciation also goes to my dearest family for the encouragement and financial support through all this year. This project would not be completed without their love and support.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Soil is an important natural resource, just as the air and water that surround us. The soil provides a major reservoir for water within a catchment. Soil moisture is a critical and potentially highly variable component of the soil environment. It is the water that held in the spaces between soil particles [1].

Rainfall and snowmelt are natural sources of soil water and are normally greatly reduced during drought. Slope shape, gradient, and soil surface roughness will affect soil water content since surface or subsurface run-on from adjacent upslope sites can add to the soil moisture, while surface runoff can remove water from a site. Evaporation, plant transpiration, and deep percolation beyond rooting depth are other factors that deplete soil moisture [2].

Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through evaporation and plant transpiration. Levels of soil moisture are important for plant and crop growth, soil erosion, and slope stability [2].

To determine the soil moisture content, it can be measured in two different methods: quantitatively, which means by amount, and quality, which is an indication of how tightly the water is held by the soil particles. Quantitative methods include gravimetric soil sampling, neutron scatter and di-electric constant. Qualitative in the other hand include tensiometer and electrical resistance (Gypsum-porous blocks) [3].

1.2 Problem Statement

1.2.1 Problem Identification

Soil moisture problems are usually related to soil drainage and having trouble with under watering or over watering the plants. Excessively drained soil fails to retain soil moisture and causing the plant transpiration drops. The water is becoming increasingly bound to the soil particles by suction [4].

In agriculture, the irrigation control systems waste tremendous amount of water as they water according to time and not according to the level of moisture in the soil. By keeping track of field's soil moisture status, the irrigation can be scheduled properly and evaluate the effectiveness of rain and irrigation water.

Soil moisture is also known to be an important factor in the landslide instability. For most types of slope failure, soil moisture plays a critical role because increased pore water pressure reduces the soil strength and increases the soil stress. If the moisture of soil is suitably determined, this brings benefit to construction industry to avoid land slide [5].

1.2.2 Significant of the Project

The soil moisture content detector is important in agricultural and construction industries. Therefore, this project will be focusing on the designing a sensor with a reliable sensitivity and applicable for moisture content detection application.

1.3 Objectives & Scope of Study

1.3.1 Objectives

The objectives of the project are:

- To design and construct prototype to detect soil moisture content.
- To come out with a cost effective and practical soil moisture detection system.

1.3.2 Scope of Study

The scope of the project is to design the device to detect the moisture of the soil. In this case, the moisture indicated by water content in the soil particles.

This project requires studying on the best suitable technique to detect the soil moisture content and after researching, the resistance method has been selected for this project. The understanding of circuit is needed to connect the sensors and display the output. This project is completed within two semesters.

1.4 Feasibility and Relevancy of the Project

It is fairly to say the project is feasible after taking into consideration all these aspect such as proper planning and utilization of the detector in many industries. This can be achieved by focusing on the sensitivity of the sensor and test the designed system to evaluate its practicability.

This project is relevant as it is useful in irrigated gardening, agricultural farming as well as construction industry. Besides, the cost of the project is estimated low and within the allocated budget.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic Concept of Measurement

The measurement method is important to select the best technique on developing the detector of soil moisture content. The techniques that will be discussed here consist of resistance method.

2.1.1 Resistance Method

This method depends upon the effect of moisture on the electrical properties of soil. Soil resistivity can serve as the basis for a sensor because it depends on moisture content. It is possible either to measure the resistivity between electrodes in a soil or to measure the resistivity of a material in equilibrium with the soil. The difficulty with resistive sensors is that the absolute value of soil resistivity depends on ion concentration as well as on moisture concentration. Therefore, careful calibration is required for these techniques.

Water is a very good conductor when minerals from the soil are added. More ionized atoms will be produced when the materials easily dissolved in water. Thus, the wet soil has higher moisture content because it has more ions. More water makes the soil conduct electricity more easily (less resistance), while dry soil conducts electricity more poorly (more resistance).

Theoretically, this method can provide absolute soil water content and can determine water content at any depth. Besides that, it has relatively high level of precision when ionic concentration of the soil does not change [8].

2.2 Electrolysis

Electrolysis is the passage of a direct electric current through an ionic substance that is either molten or dissolved in a suitable solvent, resulting in chemical reactions at the electrodes and separation of materials.

The main components required to achieve electrolysis are an electrolyte, a substance containing free ions which are the carriers of electric current in the electrolyte. A direct current (DC) supply provides the energy necessary to create or discharge the ions in the electrolyte. Electric current is carried by electrons in the external circuit. Two electrodes are an electrical conductor which provides the physical interface between the electrical circuit providing the energy and the electrolyte [15].

The key process of electrolysis is the interchange of atoms and ions by the removal or addition of electrons from the external circuit. The required products of electrolysis are in some different physical state from the electrolyte and can be removed by some physical processes. A soil moisture containing mobile ions (electrolyte) is produced by reaction of an ionic compound with a solvent (such as water) to produce mobile ions [15].

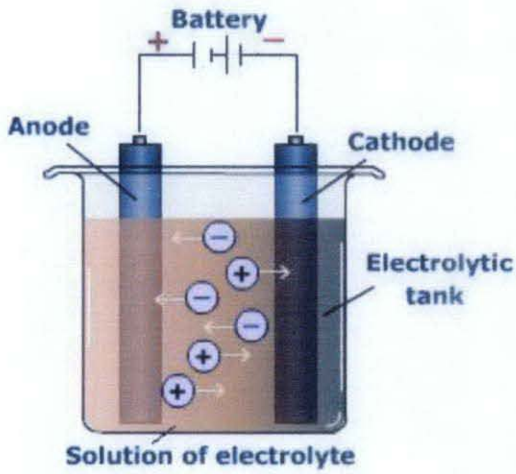


Figure 1: Experimental set up for electrolysis

An electrical potential is applied across a pair of electrodes immersed in the electrolyte. Each electrode attracts ions that are of the opposite charge. At the electrodes, electrons are absorbed or released by the atoms and ions. Therefore positively charged ions (called cations) move towards the electron emitting (negative) cathode, whereas negatively charged ions (called anions) move towards the positive anode.

Those atoms that gain or lose electrons to become charged ions pass into the electrolyte. Those ions that gain or lose electrons to become uncharged atoms separate from the electrolyte. The energy required causing the ions to migrate to the electrodes, and the energy to cause the change in ionic state, is provided by the external source of electrical potential [15].

2.3 Ohm's Law

Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference or voltage across the two points, and inversely proportional to the resistance between them. Thus, this law is a good fundamental in determining the relationship between the voltage drop and resistance [6].

$$V = IR \tag{1}$$

Based on Ohm's law, as the resistance increases, the voltage drop also increases. In this case, the lower percentage of soil moisture content has higher resistance and vice versa.

2.4 Soil Moisture Sensor

A probe containing two electrodes is used as moisture detector. In designing the probes, the distance between probes is one of the most important criteria because it might affect the measurement result. The probes will be inserted into the soil to measure resistance between probes. These are factors that influence the rate of evaporation from soil [3]:

i. Soil moisture content.
ii. Depth to water table.
iii. Soil texture.
iv. Soil colour.
v. Vegetation.

2.5 Soil Moisture Content

Determination on the percent of amount of water in the soil is based on the volume and weight. The containing of soil moisture can be determined by the amount of water following the weight and the amount of water following the volume.

The tree's root system explores the soil following its depth. Therefore, precipitation is declared as depth. Besides, the amount of water following the weight also can be said as depth ratio. The value of depth ratio and the amount of water following the volume is same [11].

2.6 Display Unit

The reading from sensor can be shown by using display unit [0–255] which in this case is by using a Liquid-Crystal Display (LCD). LCD needs to be programmed in order to display the reading output. The PIC16F877A is normally used for this purpose.

In this project the LCD 2x 16 characters is used. Number 2 means it has two lines and number sixteen means it can display up to 16 characters.

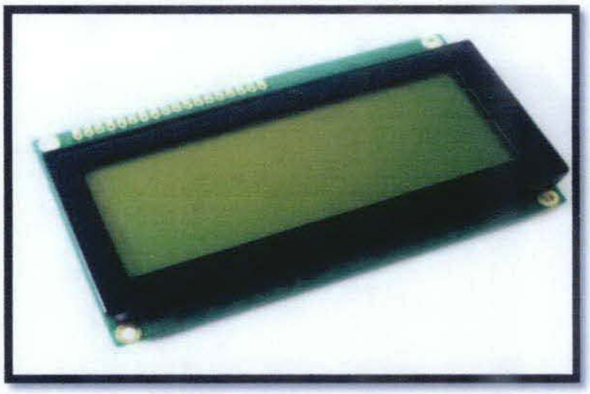


Figure 2: LCD Display

2.7 Microcontroller

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. A processor executes the programs digitally while program memory stores the program that has been compiled successfully by programmer [13].

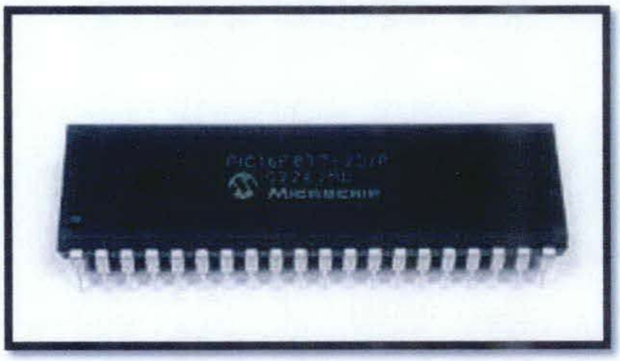


Figure 3: PIC16F877A

The PIC16F877A features 256 bytes of EEPROM data memory, self programming, an ICD, 2 Comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I^2C™) bus and a Universal Asynchronous Receiver

Transmitter (USART). All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications [14].

As a summary, the sensors for this project are two parallel resistive probes to detect soil moisture content. The sensor circuit is connected to the sensor probes as an external power for the operation of active sensors. The circuit is connected to microcontroller and programmed to display digital output in the LCD.

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

The expectation of the project is to achieve the objectives of the project. Thus, a well structured work flow was made. First, the research work is to understand and gain information of the project. Then, planning is needed to schedule the tasks and ensure all activities will be done on time as well as the development of the model.

This is then continued with the designing and analysis where many factors need to be considered before implementing the project. These include the output of the project, sizing of the equipment, and the engineering calculation. All the components required for this project have to be specified.

After all the factors have been considered, the next phase is selection and purchasing of the equipments. The surveys of the components are based on the components availability, the compatibility, and the optimum efficiency with low cost and low power.

Next, the model is then constructed according to the design. The prototype is tested to ensure the performance of the model is functional. The result from the test will be analyzed and compared. The modification is made to increase the quality of the model.

3.2 Flow chart

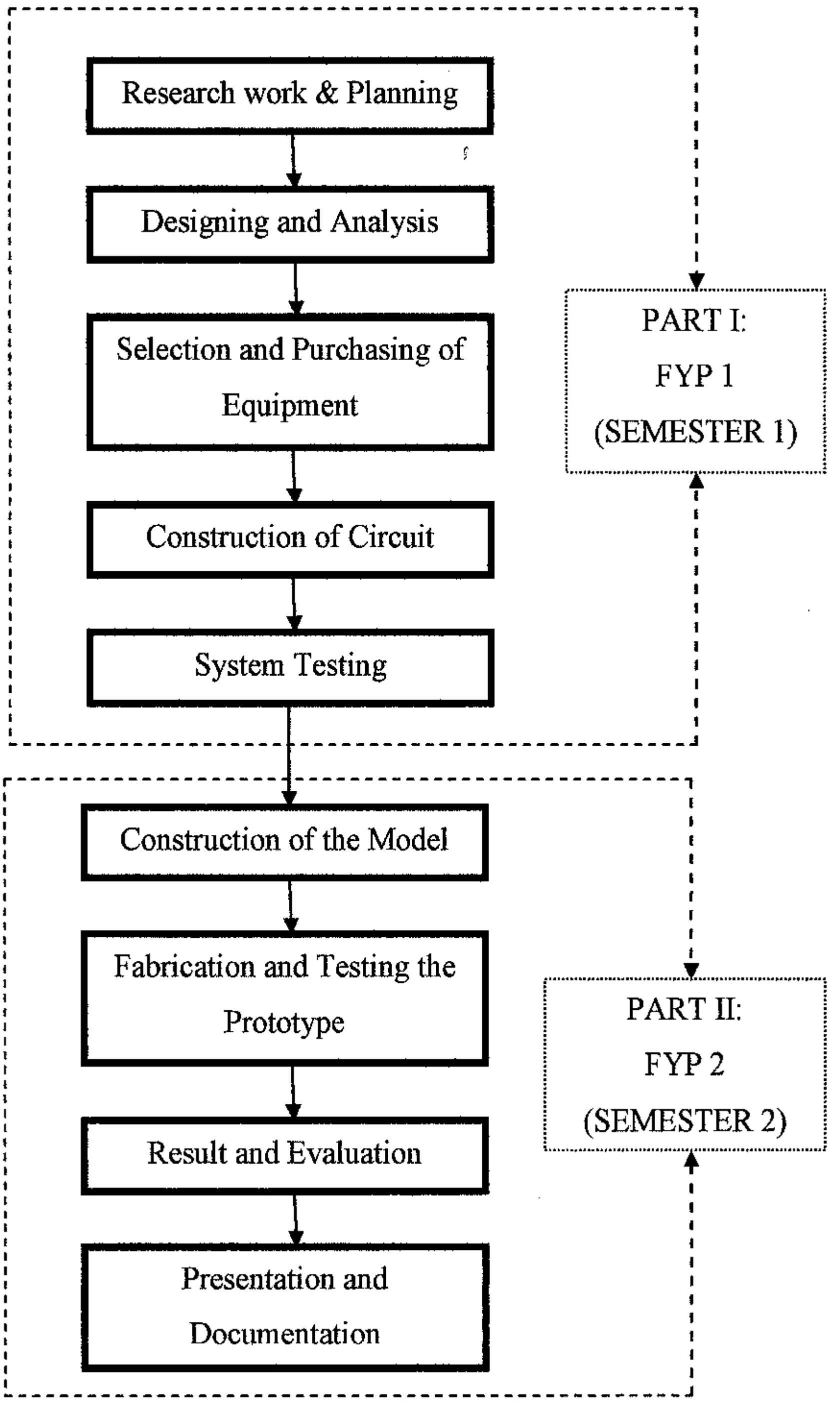


Figure 4: Work Flow of FYP

3.3 Operational Flow Diagram

An electrical potential is applied between a pair of electrodes absorbed in the soil as the switch button is turn on. Each electrode attracts ions from the soil. The sensing circuit calculates the voltage drop based on the soil moisture content.

Then, the voltage of the sensor is amplified to the highest value equal to maximum voltage reference. The microcontroller converts the voltage drop into percentage of the moisture content. The percentage value is displayed at the LCD as a digital output.

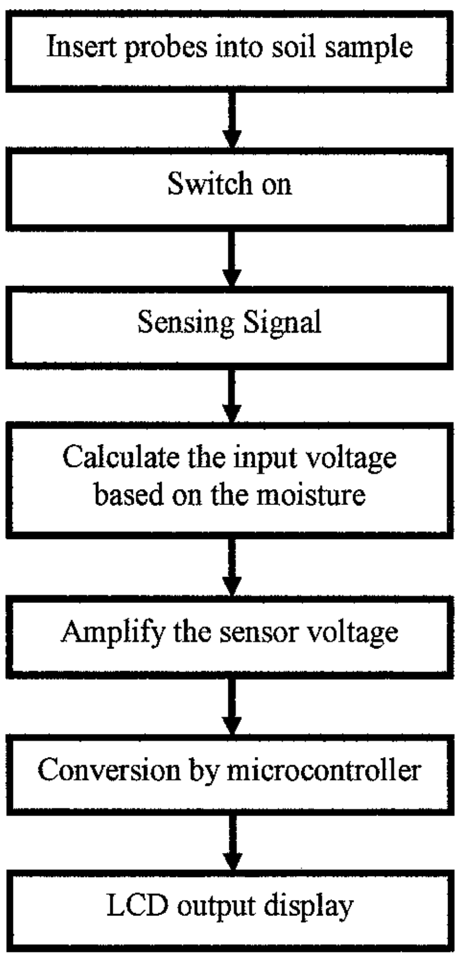


Figure 5: Operational Flow Diagram of Detector

3.4 Functional Block Diagram

The soil moisture content detector consists of four main parts which are soil moisture sensor, detection circuit, PIC circuit and LCD display. The resistance method is chosen due to a good response with presence of soil moisture. Therefore, two resistive sensor probes will be placed in parallel with each.

The circuit provides a voltage output directly proportional to relative moisture. The PIC circuit results the conversion of input from analog to digital. The circuit is connected to LCD to display the output value.

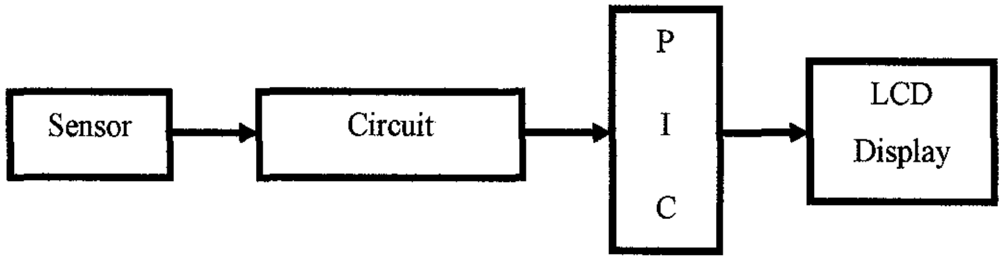


Figure 6: Block Diagram of Prototype

3.5 Tools and Equipment

The tools of equipment, hardware, and software are needed in this project.

3.5.1 Hardware Equipment

The hardware components used in this project are listed below:

- PIC 16F877A
- LCD Display
- Breadboard/Veraboard
- Wire Cable PIC
- Crystal Oscillator
- Switch button
- Power Supply

Table 1: List of Components for Sensor Circuit

COMPONENT	TYPE	QUANTITY
Resistor	100	4
	1k	2
	330	2
	1M	2
Capacitor	220u	2
	10n	2
	100u	2
Voltage Regulator	5V	2
Diode	1N4001	2
Transistor	2N2222	2
Amplifier	UA741	2
LED	Red	2

3.5.2 Testing Equipment

The testing equipments used in this project are listed in the Table 1 below:

Table 2: List of Testing Equipment

NAME	FUNCTION
Digital Multimeter	• An electronic measuring instrument that combines several measurement functions in one unit.
Oscilloscope	• Type of electronic test instrument that allows observation of constantly varying signal voltages.

3.5.3 Software Equipment

The software equipments used in this project are listed in the below:

Table 3: List of Software Equipment

NAME	FUNCTION
AutoCAD	• Software application for 2D and 3D design and drafting, for designing a prototype.
Microsoft Office 2007	• For making writing documents (proposals, reports, etc.) • For Project Presentations
Pspice Schematics and Capture	• To design and simulate the circuit.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Circuit Analysis

The system consists of soil, two electrodes, circuit of the sensor and the power supply. The connection setting is shown as Figure 7:

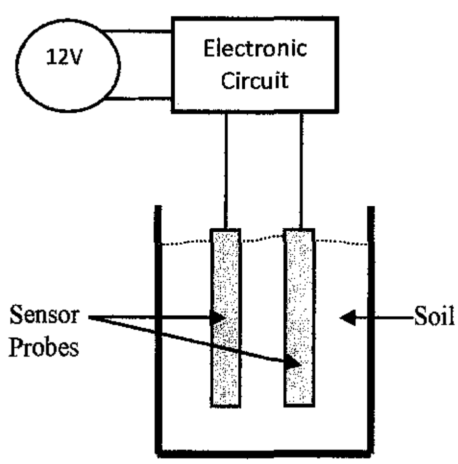


Figure 7: Connection Setting of the System

The voltage coming from power supply is 12V but the voltage to connect the circuit is 5V. Thus, the power supply needs to be connected to the voltage regulator. Voltage regulator as shown in Figure 8 is an electrical regulator designed to automatically maintain a constant voltage level from 12V to 5V.

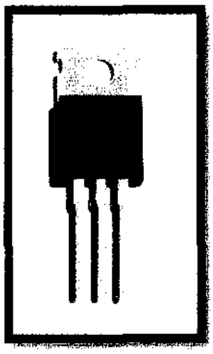


Figure 8: Voltage Regulator

The diode (IN4001 rectifier) is connected at the input pin of voltage regulator to allow electricity to flow in only one direction. Capacitor can store voltage and does not allow voltage across it to be changed instantaneously. The LED (D4) is lighted whenever there is power supply.

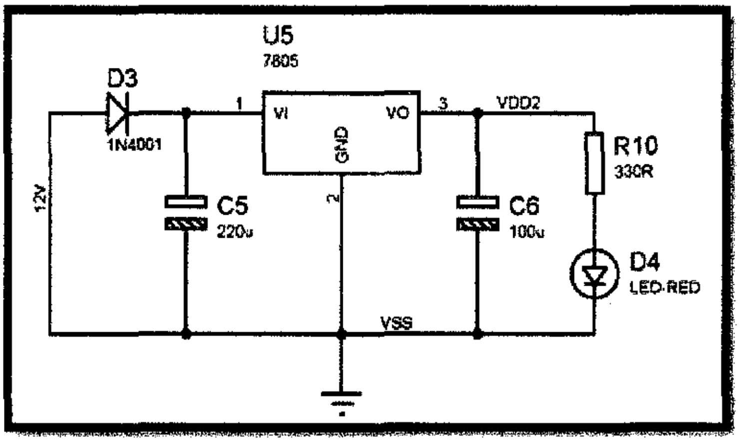


Figure 9: Voltage Regulator Circuit

The output voltage (VDD2) is connected to the 100 Ω resistor as shown in Figure 10. Then, collector of the transistor is directly connected to the resistor. At the same time, the probe is connected at resistor node and base transistor.

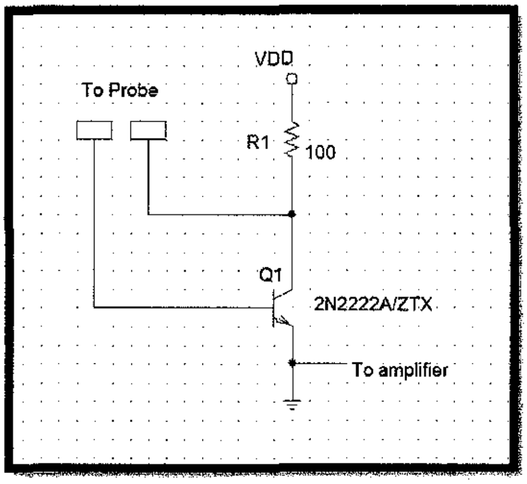


Figure 10: Sensor Circuit Schematic

The node on the transistor's emitter is connected to non inverting input on the operational amplifier.

4.2 Operational Amplifier Circuit

The soil moisture produce by the electrodes are less than 5 volts. However, the maximum voltage reference applied to PIC microcontroller is 5 Volt. In order to get accuracy conversion of the voltage analog value to digital, the voltage of the sensor must be amplified to the highest value equal to maximum voltage reference (5 Volt).

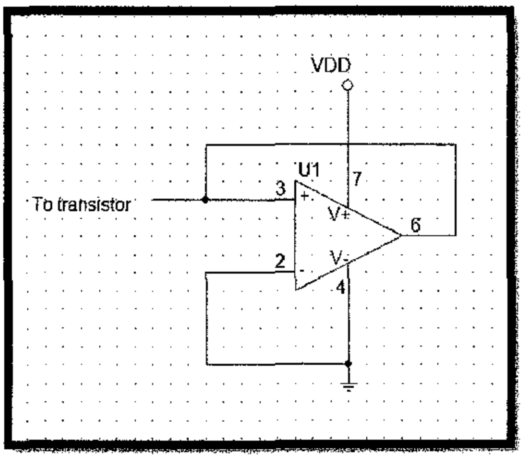


Figure 11: Amplifier Circuit Schematic

4.3 PIC Component Selection

A few basic components must be installed within the PIC microcontroller to ensure the operation of PIC as control unit is running properly. The first to consider is the external oscillator combination which includes one Crystal oscillator and two capacitors.

Table 4: Capacitor Selection for Crystal Operation

MODE	FREQUENCY	C1, C2
LP	32kHz	68-100pF
LP	200kHz	15-33pF
XT	100kHz	100-150pF
XT	**2MHz**	**15-33pF**
XT	4MHz	15-33pF
HS	4MHz	15-33pF
HS	10MHz	15-33pF

Crystal oscillator was chosen in this project because the mode is designed to give compromise between high frequency operation and modest consumption, and also more stable resonators and RC networks. For XT mode, two capacitors are needed. The chosen components for the external oscillator are XT = 2 MHz and C1 = C2 = 15pF. These components are connected at the 13 and 14 pin of PIC16F877A.

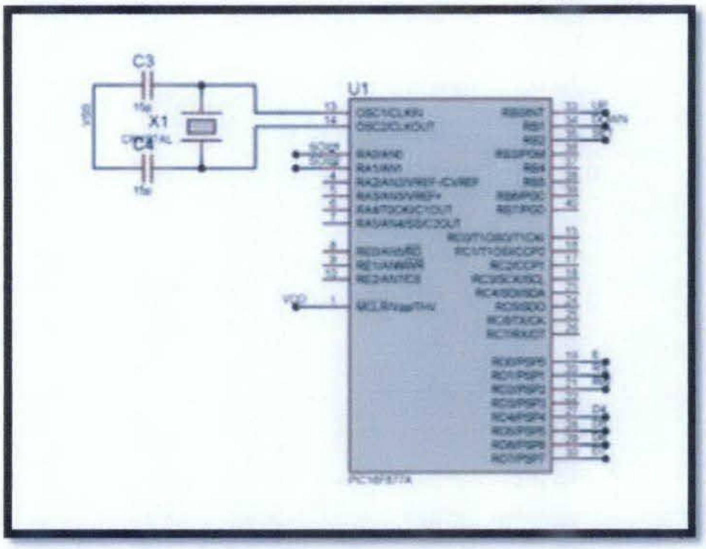


Figure 12: PIC configuration

4.4 Experimentation Results

4.4.1 Soil Moisture Sensor

For this project, the probes consist of two electrodes are used as a soil moisture sensor. The combination of two probes in parallel is to give better averaged results. This is due to inconsistencies which occur in soils. The readings of the moisture is been averaged.

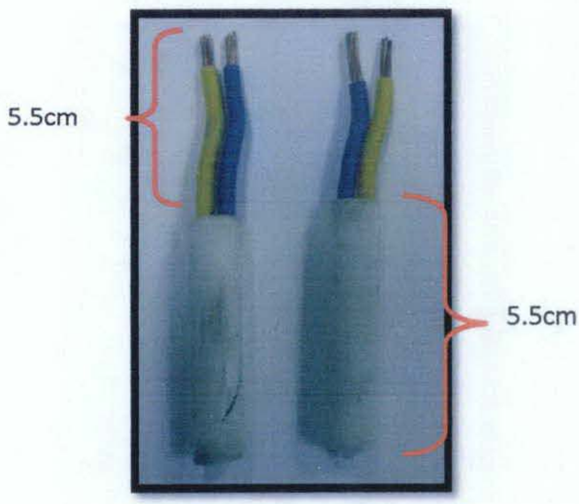


Figure 13: Soil Moisture Sensors

The probes are made of gypsum block give a reliable relative reading of moisture content for a given soil type. The two copper wires are connected to each probe. A block of gypsum placed in the soil will wet up and dry out at close to the rate of soil.

When the gypsum is wet it conducts electricity easily (it is low resistance), and when dry is a poor conductor (high resistance). Water is a very good conductor when minerals from the soil are added. Each probe attracts ion in the soil, thus more ionized atoms will be produced when the materials easily dissolved in water.

4.4.2 Observation of Moisture Content

The hardware is tested with the soil with three conditions of the soil to observe moisture content. The value displayed on LCD represents as the moisture content of soil. These experiments are conducted several times to ensure the value is the same for each experiment.

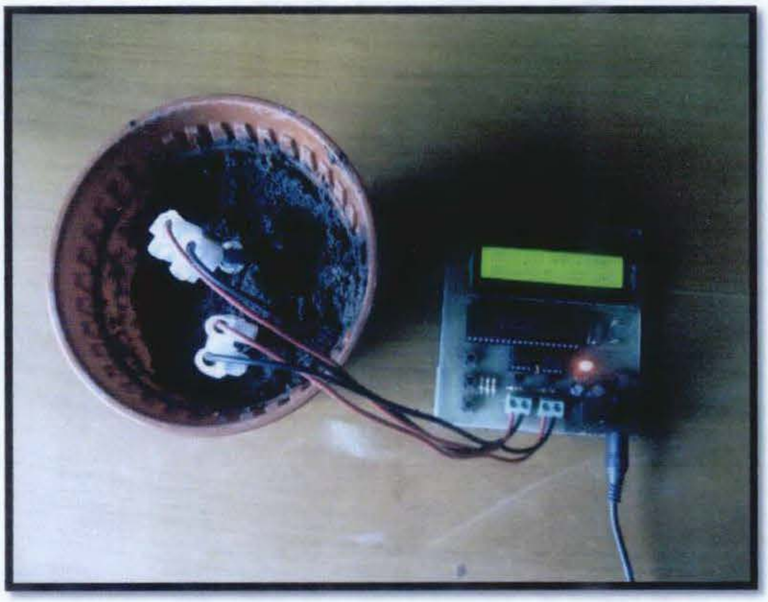


Figure 14: Testing the Hardware

Three vases are used for each experiment and each vase is labelled as dry normal and wet condition respectively. The initial soil condition is regarded as dry condition where no water is added (0ml). Then, 25 ml water is added into the soil for normal condition and 50ml water for wet condition.

Table 5: Experiment Results for Three Soil Conditions

Soil Condition	**Probe**	**Value Displayed on LCD**			
		Experiment 1	Experiment 2	Experiment 3	**Average**
Dry (0ml of water)	Probe 1	234	234	235	**233.5**
	Probe 2	230	234	234	
	Average	**232**	**234**	**234.5**	
Normal (25ml of water)	Probe 1	237	239	240	**236.6**
	Probe 2	235	235	234	
	Average	**236**	**237**	**237**	
Wet (50ml of water)	Probe 1	245	243	241	**242**
	Probe 2	243	239	241	
	Average	**244**	**241**	**241**	

The reading of probe 1 and probe 2 is observed and the average reading for the probes is taken. After the three experiments are conducted, the average value for each condition is calculated. As shown in the table, the average is 233.5, 236.6 and 240 for dry, normal and wet condition respectively.

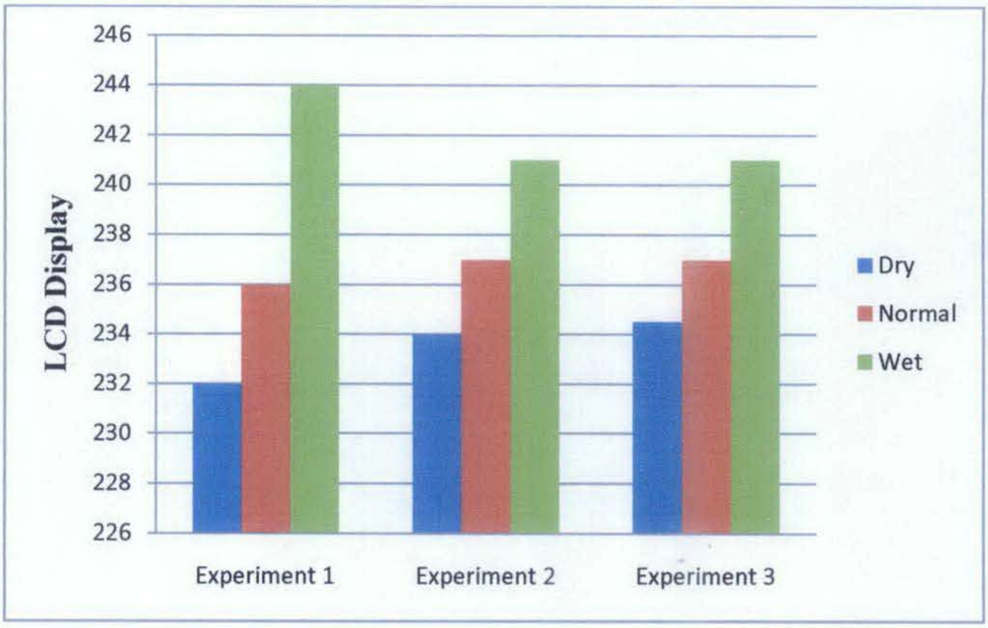


Figure 15: Graphical Representation for Each Experiment

Based on the experiment, the value displayed on the LCD is increased when the water is added to the soil. For dry condition, the range of LCD display is 230-235. For normal condition the range is 235-240 while for wet condition the range is 240 - 245.

This will be the threshold where the value is less than 235 and more than 240 for dry and wet condition respectively. These values will be set during the LCD display.

Table 6: Range for Each Condition

SOIL CONDITION	RANGE
Dry	<235
Normal	235-240
Wet	>240

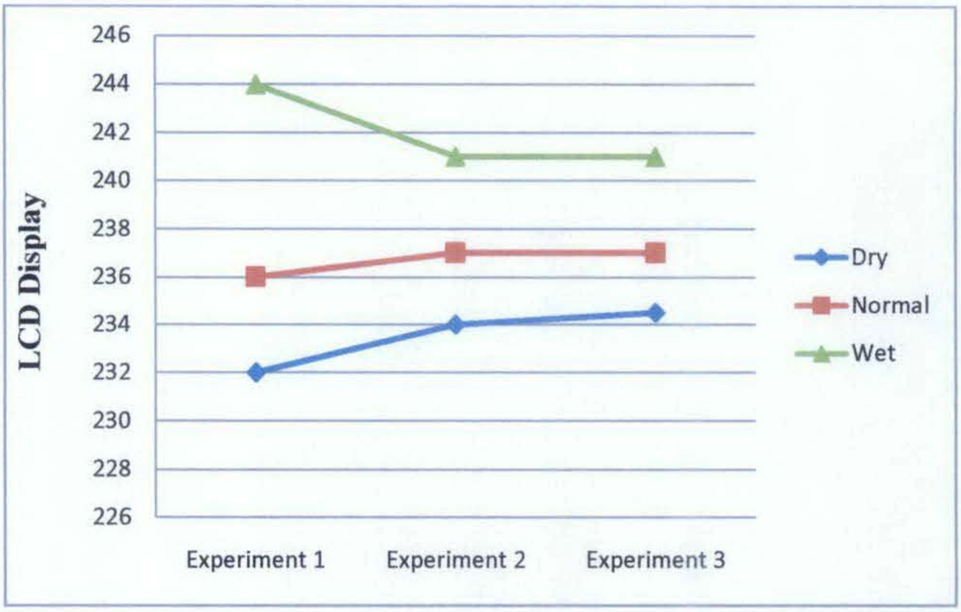


Figure 16: Graphical Representation of Range in Three Conditions

Finally, we can conclude the moisture content changes with respect to soil condition. When the soil is in damp condition, more current will flow between two probes because of the presence of ion OH^- and H_2 from water molecule (H_2O) and vice versa. Based on the ohm's law, the resistance of soil is decreasing inversely proportional with increasing current.

Figure 17: Wet Soil Condition

Figure 18: Dry Soil Condition

4.5 LCD Output Display

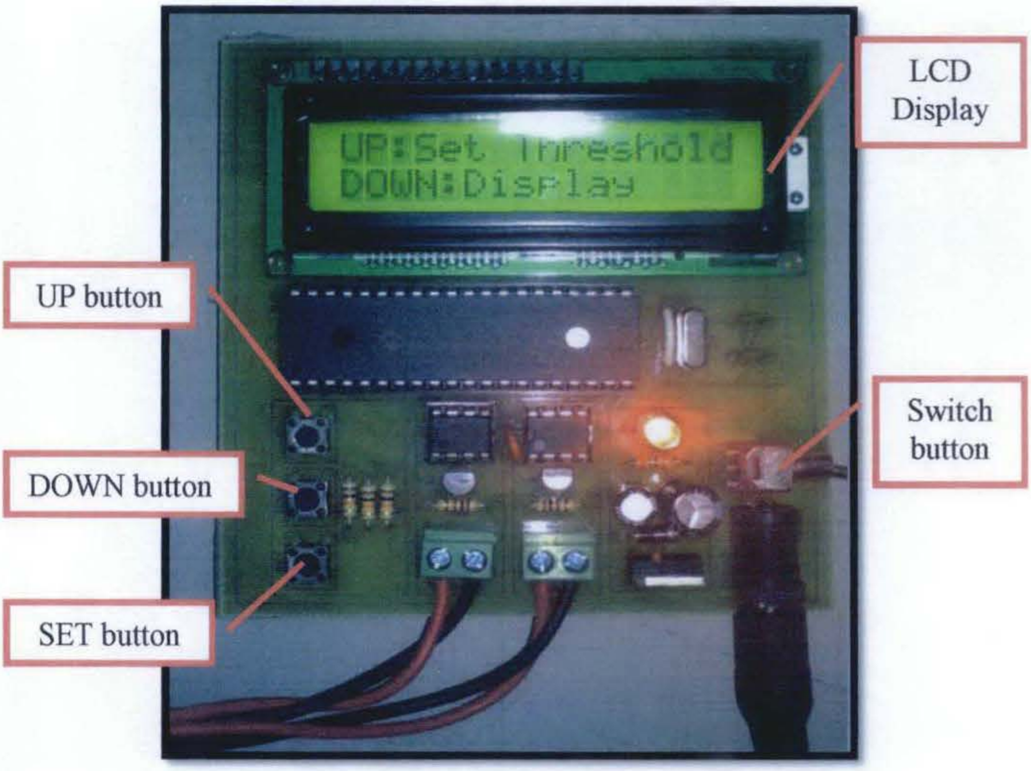


Figure 19: System Hardware

The coding has been programmed in the PIC and connected to the LCD display. The output is displayed in the LCD as soil moisture content from 230 to 255.

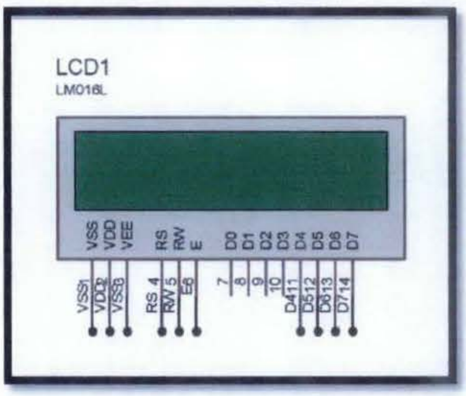


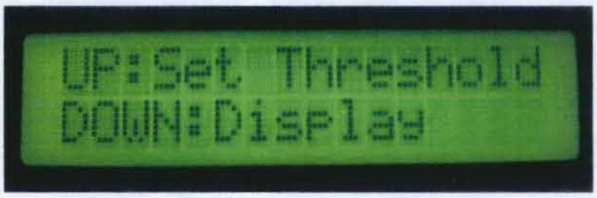
Figure 20: LCD Pin Diagram

To get started, the threshold of average readings for both probes must be set. The 'UP' button is chosen for threshold setting. Next, the minimum value is set based on the soil in dry condition. The "UP" or "DOWN" button are pressed for adjusting the value. After done, "SET" button is pressed to set the maximum value (soil in wet condition). The procedure is repeated to set the minimum value.

The system monitors the moisture content of the soil and display at the LCD. PB1 display is reading of moisture for probe 1 while PB2 display is reading of moisture for probe 2. Then, the AV display is for the average value for probe 1 and probe 2. Lastly, the R display is the range (threshold) value that has been set before.

If the average value is below the minimum value, the LCD will display "Soil is too dry" as. However, if the average value is above the maximum value the LCD will display "Soil is too wet".

Table 6: LCD Display

LCD Display	Description
	The LCD display when the Switch button is turned on • Up – Press "UP" button to set the threshold • Down – Press "DOWN" button to display the reading
	Setting the minimum value

<table>
<tr><td></td><td>Setting the maximum value</td></tr>
<tr><td></td><td>Soil Moisture Percentage Display

• PB1 – Probe 1
• PB2 – Probe 2
• AV – Average reading
• R- Range</td></tr>
<tr><td></td><td>Soil Condition below the Minimum Value</td></tr>
<tr><td></td><td>Soil Condition above the Maximum Value</td></tr>
</table>

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The soil moisture content detector will help on detecting the presence of moisture content in soil. The resistance is chosen due to a good response with presence of soil moisture. The soil humidity sensor used the concept of resistance method and electrolysis by two electrode probes.

An excitation signal is needed for the sensor to detect the variations due to soil moisture. Thus, the sensor circuit is designed to obtain a useful signal from variation of resistance.

The circuit is connected to the PIC to execute the program digitally. The digital value output is displayed by using LCD from 230 to 255 in order to display the level amount of moisture content.

The experiments are conducted to determine the soil moisture content. 0ml of water is used for soil in dry condition, 25ml of water for normal condition and 50ml of water for wet condition. The average results based on the LCD display are 233.5, 236.6 and 242 for soil in dry, normal and wet condition respectively.

In conclusion, the experiment is able to detect the presence of soil moisture contents as expected. The objective of this project which is to design and construct a prototype to detect soil moisture content had been achieved.

5.2 Recommendations

For further recommendation, the moisture sensor can be replaced by using capacitance method. The capacitive sensor is high sensitivity and detect more accurate.

Besides that, the circuit can be improved to sense the signal more precise. The programming can be improved to display the output more reliably by calculating the value of voltage from the sensing signal and converting to the moisture content percentage.

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APPENDICES

APPENDIX A

GANTT CHART FOR FYP I JULY 2010

NO	ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	FYP Briefing															
2	Selection of Project Title															
3	Preliminary Research Work															
4	Submission of Preliminary Report				19/8											
5	Research Work Continues															
6	Design															
7	Submission of Progress Report								22/9							
8	Seminar															
9	Material & Software Selection															
10	Circuit Construction & testing															
11	Submission of Draft Report													18/10		
12	Submission of Interim Report														2/11	
13	Oral Presentation															TBA

APPENDIX B

GANTT CHART FOR FYP II JANUARY 2011

No.	ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continue							Mid-Sem Break								
2	Submission of Progress Report 1								14/3							
3	Project Work Continue															
4	Poster Exhibition													6/4		
5	Project Work Continue															
6	Submission of Draft Report													18/4		
7	Submission of Dissertation (soft bound)														28/4	
8	Submission of Technical Paper														28/4	
9	Oral Presentation															
10	Submission of Project Dissertation (Hard Bound)															20/5

APPENDIX C

PIC16F877A DATASHEET

40-Pin PDIP

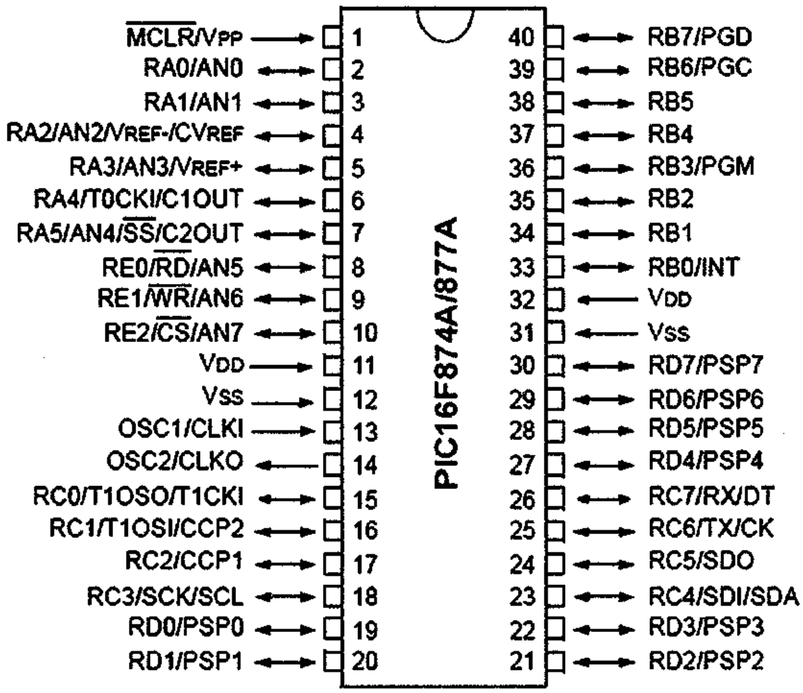


TABLE 1-1: PIC16F87XA DEVICE FEATURES

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

TABLE 1-3: PIC16F874A/877A PINOUT DESCRIPTION

Pin Name	PDIP Pin#	PLCC Pin#	TQFP Pin#	QFN Pin#	I/O/P Type	Buffer Type	Description
OSC1/CLKI	13	14	30	32		ST/CMOS(4)	Oscillator crystal or external clock input.
OSC1					I		Oscillator crystal input or external clock source input. ST buffer when configured in RC mode; otherwise CMOS.
CLKI					I		External clock source input. Always associated with pin function OSC1 (see OSC1/CLKI, OSC2/CLKO pins).
OSC2/CLKO	14	15	31	33		—	Oscillator crystal or clock output.
OSC2					O		Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO					O		In RC mode, OSC2 pin outputs CLKO, which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
$\overline{\text{MCLR}}$/VPP	1	2	18	18		ST	Master Clear (input) or programming voltage (output).
$\overline{\text{MCLR}}$					I		Master Clear (Reset) input. This pin is an active low Reset to the device.
VPP					P		Programming voltage input.
							PORTA is a bidirectional I/O port.
RA0/AN0	2	3	19	19		TTL	
RA0					I/O		Digital I/O.
AN0					I		Analog input 0.
RA1/AN1	3	4	20	20		TTL	
RA1					I/O		Digital I/O.
AN1					I		Analog input 1.
RA2/AN2/VREF-/CVREF	4	5	21	21		TTL	
RA2					I/O		Digital I/O.
AN2					I		Analog input 2.
VREF-					I		A/D reference voltage (Low) input.
CVREF					O		Comparator VREF output.
RA3/AN3/VREF+	5	6	22	22		TTL	
RA3					I/O		Digital I/O.
AN3					I		Analog input 3.
VREF+					I		A/D reference voltage (High) input.
RA4/T0CKI/C1OUT	6	7	23	23		ST	
RA4					I/O		Digital I/O – Open-drain when configured as output.
T0CKI					I		Timer0 external clock input.
C1OUT					O		Comparator 1 output.
RA5/AN4/$\overline{\text{SS}}$/C2OUT	7	8	24	24		TTL	
RA5					I/O		Digital I/O.
AN4					I		Analog input 4.
$\overline{\text{SS}}$					I		SPI slave select input.
C2OUT					O		Comparator 2 output.

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 1-3: PIC16F874A/877A PINOUT DESCRIPTION (CONTINUED)

Pin Name	PDIP Pin#	PLCC Pin#	TQFP Pin#	QFN Pin#	I/O/P Type	Buffer Type	Description
							PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-up on all inputs.
RB0/INT	33	36	8	9		TTL/ST(1)	
RB0					I/O		Digital I/O.
INT					I		External interrupt.
RB1	34	37	9	10	I/O	TTL	Digital I/O.
RB2	35	38	10	11	I/O	TTL	Digital I/O.
RB3/PGM	36	39	11	12		TTL	
RB3					I/O		Digital I/O.
PGM					I		Low-voltage ICSP programming enable pin.
RB4	37	41	14	14	I/O	TTL	Digital I/O.
RB5	38	42	15	15	I/O	TTL	Digital I/O.
RB6/PGC	39	43	16	16		TTL/ST(2)	
RB6					I/O		Digital I/O.
PGC					I		In-circuit debugger and ICSP programming clock.
RB7/PGD	40	44	17	17		TTL/ST(2)	
RB7					I/O		Digital I/O.
PGD					I/O		In-circuit debugger and ICSP 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 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 1-3: PIC16F874A/877A PINOUT DESCRIPTION (CONTINUED)

Pin Name	PDIP Pin#	PLCC Pin#	TQFP Pin#	QFN Pin#	I/O/P Type	Buffer Type	Description
							PORTC is a bidirectional I/O port.
RC0/T1OSO/T1CKI	15	16	32	34		ST	
RC0					I/O		Digital I/O.
T1OSO					O		Timer1 oscillator output.
T1CKI					I		Timer1 external clock input.
RC1/T1OSI/CCP2	16	18	35	35		ST	
RC1					I/O		Digital I/O.
T1OSI					I		Timer1 oscillator input.
CCP2					I/O		Capture2 input, Compare2 output, PWM2 output.
RC2/CCP1	17	19	36	36		ST	
RC2					I/O		Digital I/O.
CCP1					I/O		Capture1 input, Compare1 output, PWM1 output.
RC3/SCK/SCL	18	20	37	37		ST	
RC3					I/O		Digital I/O.
SCK					I/O		Synchronous serial clock input/output for SPI mode.
SCL					I/O		Synchronous serial clock input/output for I²C mode.
RC4/SDI/SDA	23	25	42	42		ST	
RC4					I/O		Digital I/O.
SDI					I		SPI data in.
SDA					I/O		I²C data I/O.
RC5/SDO	24	26	43	43		ST	
RC5					I/O		Digital I/O.
SDO					O		SPI data out.
RC6/TX/CK	25	27	44	44		ST	
RC6					I/O		Digital I/O.
TX					O		USART asynchronous transmit.
CK					I/O		USART1 synchronous clock.
RC7/RX/DT	26	29	1	1		ST	
RC7					I/O		Digital I/O.
RX					I		USART asynchronous receive.
DT					I/O		USART 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 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 1-3: PIC16F874A/877A PINOUT DESCRIPTION (CONTINUED)

Pin Name	PDIP Pin#	PLCC Pin#	TQFP Pin#	QFN Pin#	I/O/P Type	Buffer Type	Description
							PORTD is a bidirectional I/O port or Parallel Slave Port when interfacing to a microprocessor bus.
RD0/PSP0	19	21	38	38		ST/TTL(3)	
RD0					I/O		Digital I/O.
PSP0					I/O		Parallel Slave Port data.
RD1/PSP1	20	22	39	39		ST/TTL(3)	
RD1					I/O		Digital I/O.
PSP1					I/O		Parallel Slave Port data.
RD2/PSP2	21	23	40	40		ST/TTL(3)	
RD2					I/O		Digital I/O.
PSP2					I/O		Parallel Slave Port data.
RD3/PSP3	22	24	41	41		ST/TTL(3)	
RD3					I/O		Digital I/O.
PSP3					I/O		Parallel Slave Port data.
RD4/PSP4	27	30	2	2		ST/TTL(3)	
RD4					I/O		Digital I/O.
PSP4					I/O		Parallel Slave Port data.
RD5/PSP5	28	31	3	3		ST/TTL(3)	
RD5					I/O		Digital I/O.
PSP5					I/O		Parallel Slave Port data.
RD6/PSP6	29	32	4	4		ST/TTL(3)	
RD6					I/O		Digital I/O.
PSP6					I/O		Parallel Slave Port data.
RD7/PSP7	30	33	5	5		ST/TTL(3)	
RD7					I/O		Digital I/O.
PSP7					I/O		Parallel Slave Port data.
							PORTE is a bidirectional I/O port.
RE0/$\overline{RD}$/AN5	8	9	25	25		ST/TTL(3)	
RE0					I/O		Digital I/O.
$\overline{RD}$					I		Read control for Parallel Slave Port.
AN5					I		Analog input 5.
RE1/$\overline{WR}$/AN6	9	10	26	26		ST/TTL(3)	
RE1					I/O		Digital I/O.
$\overline{WR}$					I		Write control for Parallel Slave Port.
AN6					I		Analog input 6.
RE2/$\overline{CS}$/AN7	10	11	27	27		ST/TTL(3)	
RE2					I/O		Digital I/O.
$\overline{CS}$					I		Chip select control for Parallel Slave Port.
AN7					I		Analog input 7.
VSS	12, 31	13, 34	6, 29	6, 30, 31	P	—	Ground reference for logic and I/O pins.
VDD	11, 32	12, 35	7, 28	7, 8, 28, 29	P	—	Positive supply for logic and I/O pins.
NC	—	1, 17, 28, 40	12,13, 33, 34	13	—	—	These pins are not internally connected. These pins should be left unconnected.

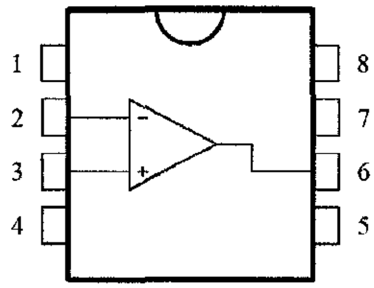
Legend: I = input O = output I/O = input/output P = power
— = Not used TTL = TTL input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as 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 D

UA741 DATASHEET

PIN CONNECTIONS (top view)



1 - Offset null 1
2 - Inverting input
3 - Non-inverting input
4 - V_{CC}^-
5 - Offset null 2
6 - Output
7 - V_{CC}^+
8 - N.C.

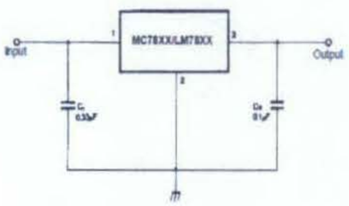
ELECTRICAL CHARACTERISTICS
$V_{CC} = \pm 15V$, $T_{amb} = +25°C$ (unless otherwise specified)

Symbol	Parameter	Min.	Typ.	Max.	Unit
V_{io}	Input Offset Voltage ($R_S \leq 10k\Omega$) $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$		1	5 6	mV
I_{io}	Input Offset Current $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$		2	30 70	nA
I_{ib}	Input Bias Current $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$		10	100 200	nA
A_{vd}	Large Signal Voltage Gain * (V_O ±10V, R_L = 2kΩ) $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$	50 25	200		V/mV
SVR	Supply Voltage Rejection Ratio ($R_S \leq 10k\Omega$) $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$	77 77	90		dB
I_{CC}	Supply Current, no load $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$		1.7	2.8 3.3	mA
V_{icm}	Input Common Mode Voltage Range $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$	±12 ±12			V
CMR	Common-mode Rejection Ratio ($R_S \leq 10k\Omega$) $T_{amb} = +25°C$ $T_{min.} \leq T_{amb} \leq T_{max.}$	70 70	90		dB
I_{OS}	Output Short-circuit Current	10	25	40	mA
$\pm V_{OPP}$	Output Voltage Swing $T_{amb} = +25°C$ R_L = 10kΩ R_L = 2kΩ $T_{min.} \leq T_{amb} \leq T_{max.}$ R_L = 10kΩ R_L = 2kΩ	12 10 12 10	14 13		V
SR	Slew Rate (V_i = ±10V, R_L =2kΩ, C_L= 100pF, T_{amb} = 25°C, unity gain)	0.25	0.5		V/μs
t_r	Rise Time (V_i = ±20mV, R_L = 2kΩ, C_L = 100pF, T_{amb} = 25°C, unity gain)		0.3		μs
K_{OV}	Overshoot (V_i = 20mV, R_L = 2kΩ, C_L = 100pF, T_{amb} = 25°C, unity gain)		5		%
R_i	Input Resistance	0.3	2		MΩ
GBP	Gain Bandwidth Product (V_i = 10mV, R_L = 2kΩ, C_L= 100pF, f = 100kHz)	0.7	1		MHz
THD	Total Harmonic Distortion (f = 1kHz, Av = 20dB, R_L =2kΩ, V_O = 2V_{PP}, C_L = 100pF, T_{amb} = 25°C)		0.06		%
e_n	Equivalent Input Noise Voltage (f = 1kHz, R_s = 100Ω)		23		$\frac{nV}{\sqrt{Hz}}$
Øm	Phase Margin		50		Degrees

APPENDIX E

LM7805 DATASHEET

Typical Applications



TO-220

1

D-PAK

1

1. Input 2. GND 3. Output

Absolute Maximum Ratings

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

Electrical Characteristics (MC7805/LM7805)

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

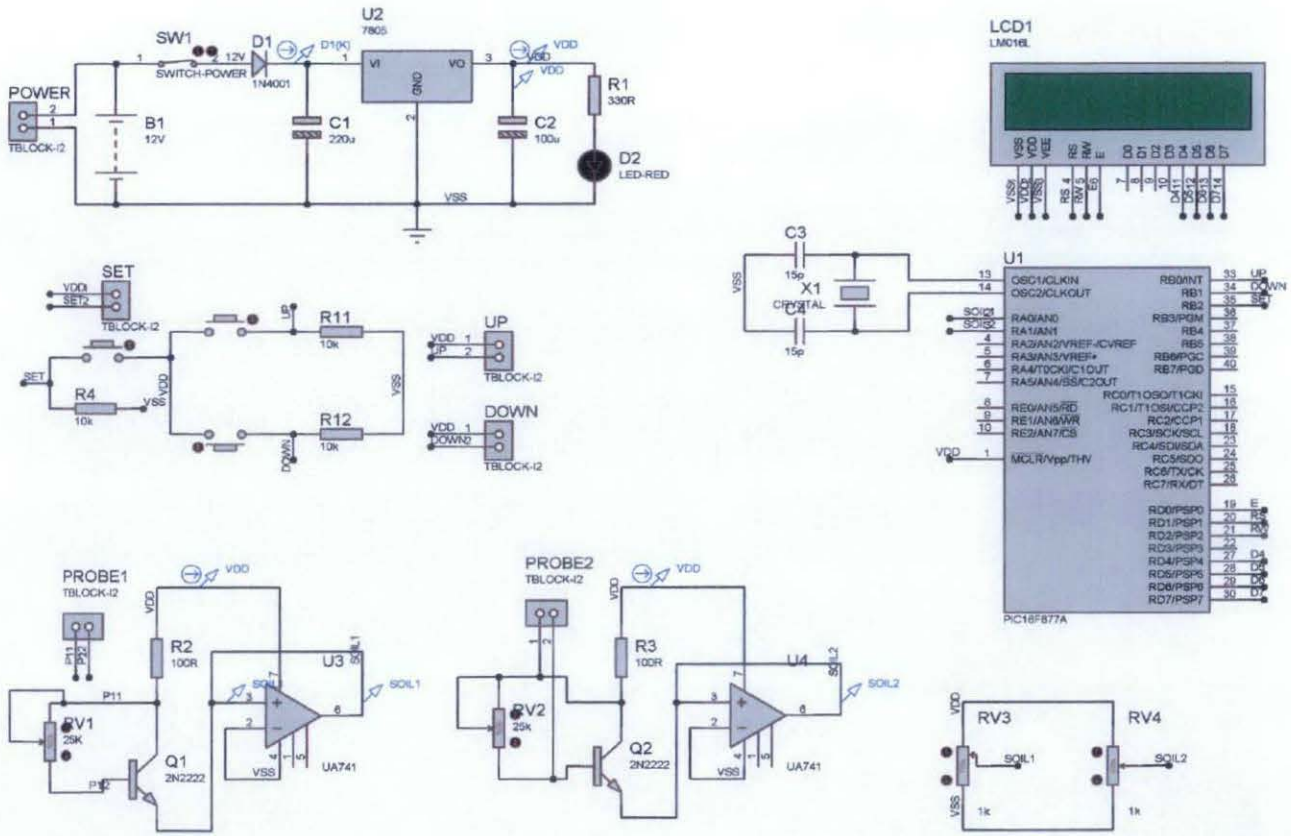
Parameter	Symbol	Conditions		MC7805/LM7805			Unit
				Min.	Typ.	Max.	
Output Voltage	V_O	T_J =+25 °C		4.8	5.0	5.2	V
		5.0mA ≤ Io ≤ 1.0A, P_O ≤ 15W V_I = 7V to 20V		4.75	5.0	5.25	
Line Regulation (Note1)	Regline	T_J=+25 °C	V_O = 7V to 25V	-	4.0	100	mV
			V_I = 8V to 12V	-	1.6	50	
Load Regulation (Note1)	Regload	T_J=+25 °C	I_O = 5.0mA to1.5A	-	9	100	mV
			I_O =250mA to 750mA	-	4	50	
Quiescent Current	I_Q	T_J =+25 °C		-	5.0	8.0	mA
Quiescent Current Change	ΔI_Q	I_O = 5mA to 1.0A		-	0.03	0.5	mA
		V_I= 7V to 25V		-	0.3	1.3	
Output Voltage Drift	$\Delta V_O/\Delta T$	I_O= 5mA		-	-0.8	-	mV/ °C
Output Noise Voltage	V_N	f = 10Hz to 100KHz, T_A=+25 °C		-	42	-	µV/Vo
Ripple Rejection	RR	f = 120Hz V_O = 8V to 18V		62	73	-	dB
Dropout Voltage	V_{Drop}	I_O = 1A, T_J =+25 °C		-	2	-	V
Output Resistance	rO	f = 1KHz		-	15	-	mΩ
Short Circuit Current	I_{SC}	V_I = 35V, T_A =+25 °C		-	230	-	mA
Peak Current	I_{PK}	T_J =+25 °C		-	2.2	-	A

Note:

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

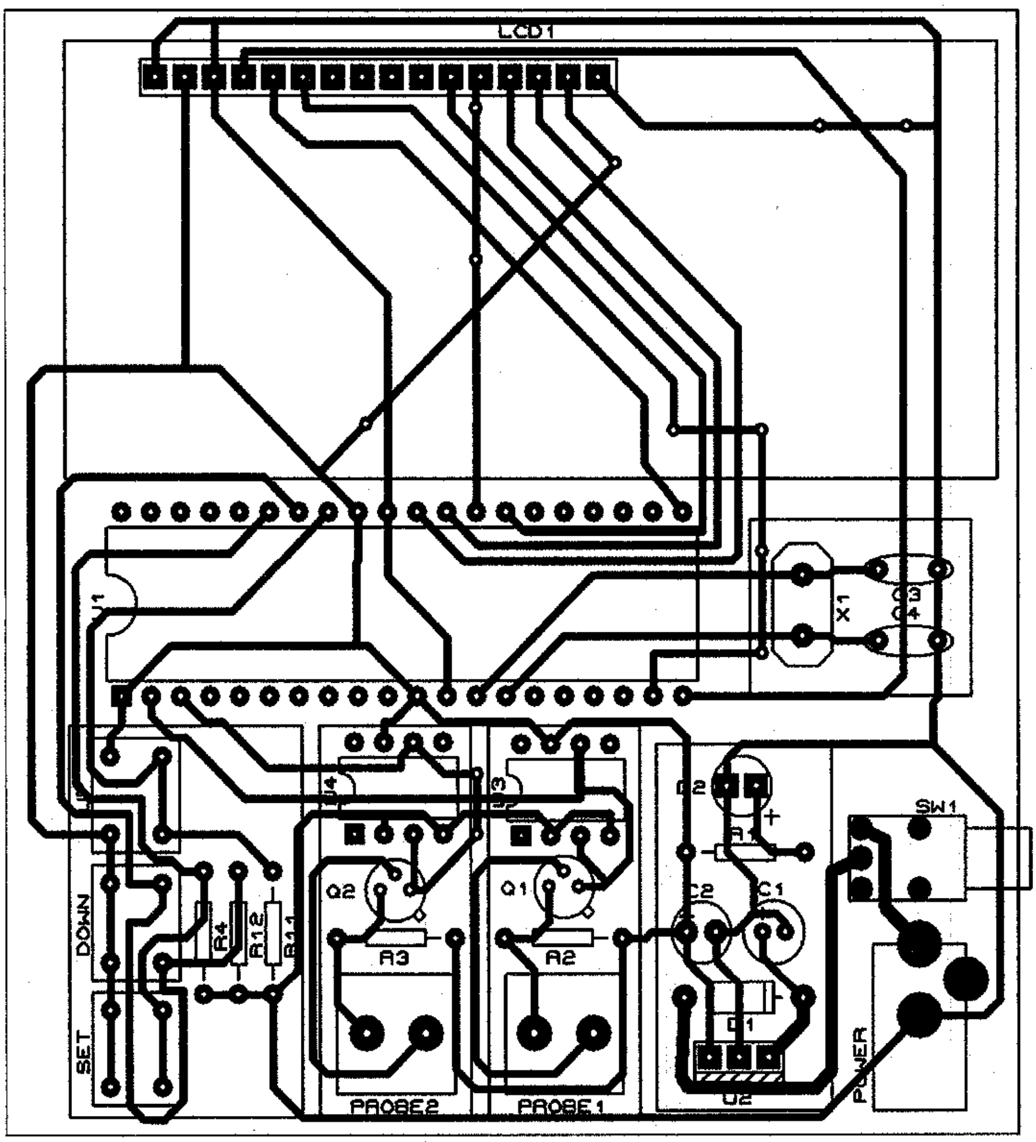
APPENDIX F

CIRCUIT SCHEMATIC DIAGRAM



APPENDIX G

PCB LAYOUT



APPENDIX H

PROGRAMMING CODE

```
#include <16F877a.h>
#device adc=8
#include <stdio.h>
#fuses hs,noprotect,nowdt,nolvp,NOBROWNOUT,PUT
#use delay(clock=20000000)

#include <lcd.c>

#byte porta=5
#byte portb=6
#byte portc=7
#byte portd=8

int value=50;

int number()
{
   //int value;

   if (input(pin_b0))
   {
      if (value<255)
      {
      value=value+5;
      delay_ms(200);
      }
      else
      {
      value=5;
      delay_ms(200);
      }
   }
   else if (input(pin_b1))
   {
      if (value>5)
      {
      value=value-5;
      delay_ms(200);
      }
      else
      {
      value=255;
      delay_ms(200);
      }
   }
   else
   {
      value=value;
   }
```

```
   return (value);
}

void maximum()
{
   int max;
   int status=0;

   while (status==0)
   {
      if (input(pin_b2))
      {
         write_eeprom(1,max);
         printf(lcd_putc,"\fMaximum: %u",max);
         delay_ms(500);
         status=1;
      }
      else
      {
         max=number();
         lcd_gotoxy(1,2);
         printf(lcd_putc,"%3u",max);
         delay_ms(100);
         status=0;
      }
   }
}

void minimum()
{
   int min;
   int status=0;

   while (status==0)
   {
      if (input(pin_b2))
      {
         write_eeprom(0,min);
         printf(lcd_putc,"\fMinimum: %u",min);
         delay_ms(500);
         status=1;
      }
      else
      {
         min=number();
         lcd_gotoxy(1,2);
         printf(lcd_putc,"%3u",min);
         delay_ms(100);
         status=0;
      }
   }
}

void both_probe()
{
   int status=0;
   unsigned int average,probe1,probe2;
```

```
   while (status==0)
   {
      if (input(pin_b2))
      {
         delay_ms(100);
         status=1;
      }
      else
      {
         set_adc_channel(0);
         probe1=read_adc();
         delay_us(10);
         set_adc_channel(1);
         probe2=read_adc();
         average=((long)probe1+probe2)/2;
         printf(lcd_putc,"\fPB1:%3u PB2:%3u
\nAVERAGE:%3u",probe1,probe2,average);
         delay_ms(10);
         status=0;
      }
   }
}

void mode()
{
   int status=0;

   lcd_putc("\fUP:Set Threshold \nDOWN:Display");

   while (status==0)
   {
      if (input(pin_b0))
      {
         printf(lcd_putc,"\fMode 1 selected");
         delay_ms(500);
         printf(lcd_putc,"\fMin value: ");
         minimum();
         printf(lcd_putc,"\fMax value: ");
         maximum();
         status=1;
      }

      else if (input(pin_b1))
      {
         printf(lcd_putc,"\fMode 2 selected");
         delay_ms(500);
         both_probe();
         status=1;
      }

      else
      {
         status=0;
      }
   }
}

void controller()
{
```

```
   unsigned int average,probe1,probe2;

   set_adc_channel(0);
   probe1=read_adc();
   delay_us(10);
   set_adc_channel(1);
   probe2=read_adc();
   average=((long)probe1+probe2)/2;

   if (average<=read_eeprom(0))
   {
      lcd_putc("\fSoil too dry");
      delay_ms(10);
   }
   else if (average>=read_eeprom(1))
   {
      lcd_putc("\fSoil too wet");
      delay_ms(10);
   }
   else
   {
      printf(lcd_putc,"\fPB1:%3u PB2:%3u \nAV:%u R:%u-
%u",probe1,probe2,average,read_eeprom(0),read_eeprom(1));
      delay_ms(10);
   }
}

void main() {

   setup_adc_ports(ALL_ANALOG);                        //set port a as
analog input
   setup_adc(ADC_CLOCK_INTERNAL);                      //use internal
clock

   lcd_init();

   mode();

   while (true)
   {
      if (input(pin_b2))
      {
         mode();
      }
      else
      {
         controller();
      }
   }
}
```

APPENDIX I

RESISTOR AND CAPACITOR DATASHEET

Electus Distribution Reference Data Sheet: RESCODE.PDF (1)

RESISTOR & CAPACITOR DATA

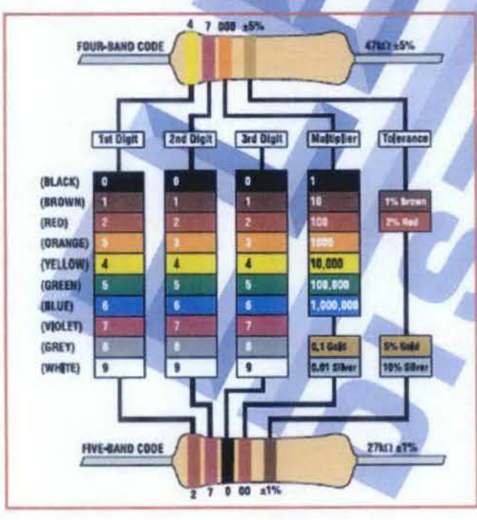
Resistors

Many resistors are so small that it would be difficult to print their value and % tolerance on their body in digits. To overcome this, a coding system based on bands of distinctive colours was developed to assist in identification. Learning this 'colour code' is not as necessary as it used to be (thanks to accurate, low cost digital multimeters!), but it's not hard to learn and it's quite useful knowledge anyway.

The first thing to know is that in each decade of resistance — i.e., from 10 - 100Ω, 100 - 1kΩ, 1k - 10kΩ, etc — there are only a finite number of different nominal values allowed. Most common resistors have values in the 'E12' series, which only has 12 allowed values per decade. Normalised these are 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8 and 8.2. Multiples of these values are simply repeated in each decade — e.g., 10, 12, 15, 18 and so on. Note that the 'steps' between these values are always very close to 20%, because the E12 series dates from the days of resistors with ±10% tolerance.

To allow greater accuracy in circuit design, modern 1% tolerance resistors are made in a larger range of values: the 'E24' series, which has 12 *additional* allowed values per decade as shown in the table. As before, these nominal values are simply repeated in each decade. The table at right shows both the E12 and E24 allowed values for comparison.

The next thing to know is that there are two different resistor colour coding systems in use: one using a total of 4 colour bands, and the other 5. The 5-band system is generally used for 2% and closer tolerance resistors, even though the 4-band system is quite capable of handling any resistors with E12 or E24 values. Both systems use the same band colours to represent the various digits; the main difference is that 5-band resistors have an additional 'third band', which is almost always BLACK to represent a third digit of '0'. Here's how both systems work in practice:



4-band resistors will almost always have values in the E12 series, while 5-band resistors can have any value in the E24 series. This is worth remembering, because depending on the resistor's body colour, some of the band colours may not be easy to distinguish. Blue (6) and grey (8) sometimes look very similar, as do red (2), brown (1) and orange (3). So if you're in doubt, check the apparent coded value against the allowed E12 or E24 values to see if it's 'legal' — or check with a digital multimeter, just to make sure.

Preferred Resistor Values (within each decade)

E12 Series	E24 Series
10	10
	11
12	12
	13
15	15
	16
18	18
	20
22	22
	24
27	27
	30
33	33
	36
39	39
	43
47	47
	51
56	56
	62
68	68
	75
82	82
	91

Capacitors

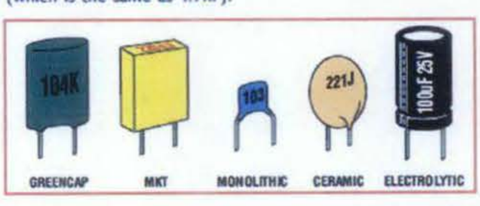
Virtually all of the capacitors stocked by Jaycar have their electrical values printed directly on their body, in digits and letters. However there's often still a coding system, which can make it a bit tricky to work out the capacitance, voltage rating, tolerance and so on until you know how it works. This is explained below.

Incidentally, so-called 'greencaps' (which can actually be brown, dark red or even blue!) are one type of metallised polyester film capacitor, like the 'MKT' type — which tends to be smaller, and in a more tightly controlled rectangular package. Similarly the 'monolithic' type is a type of multilayer ceramic capacitor, designed to combine high capacitance with very low self-inductance.

Plastic film, Ceramic & Monolithic Capacitors

Most of these types have their nominal value either printed directly on them or use the 'EIA' coding system, which is a bit like resistor colour coding, but in digits: the first two digits followed by a 'multiplier' showing the number of zeroes. With this code the value is generally given in picofarads (pF), which you'll need to divide by either one million or one thousand (respectively) if you want the value in microfarads (μF) or nanofarads (nF).

Hence a capacitor marked '104' has a value of 10 with 4 zeroes after it, or 100,000pF (which is the same as 100nF, or 0.1μF). Similarly '681' means 68 with a single zero, or 680pF, while '472' means 47 with two zeroes, or 4700pF (which is the same as 4.7nF).



Alternatively the value may be given directly in nanofarads, with three significant digits but the third generally '0'. In this case there's generally also a small 'n', which can be used in place of a decimal point. So '220n' means a 220nF capacitor, which is the same as 0.22µF, while '3n3' means 3.3nF (= 3300pF).

Many of these capacitors also have a capital letter to indicate their tolerance rating, according to the following coding system:

Capacitor Tolerance Marking Codes					
F	G	J	K	M	Z
±1%	±2%	±5%	±10%	±20%	-20%, +80%
Examples: 104K = 0.1µF ± 10%; 4n7J = 4.7nF ± 5%					

Material Codes for Plastic Film Capacitors

Capacitors which use a plastic film dielectric are identified using the following codes:

MKT	Metallised Polyester (PETP)
KS	Polystyrene film/foil
MKC	Metallised Polycarbonate
KP	Polypropylene film/foil
KT	Polyester film/foil
MKP	Metallised polypropylene

Ceramic Capacitor Colour coding for Temperature Coefficient

Capacitors which use a plastic dielectric have a very low *temperature coefficient* (tempco) — i.e., their capacitance scarcely varies with temperature, and can generally be regarded as 'stable'. However, this isn't true with many ceramic-dielectric types. Many of the ceramic materials produce a negative tempco, where capacitance *decreases* with temperature, while a few give a positive tempco where capacitance increases with temperature.

By careful mixing of materials, manufacturers can produce a ceramic which gives a tempco very close to zero, but the resulting dielectric constant is also quite low. That is why such 'NP0' capacitors are normally only available in relatively low values — less than about 200pF, typically.

The following colour bands are used on ceramic capacitors to indicate their tempco. Note that 'P' indicates a positive tempco and 'N' a negative one, with the number indicating parts per million per degree C.

P100	Red/Violet	NP0	Black
N033	Brown	N075	Red
N150	Orange	N220	Yellow
N330	Green	N470	Blue
N750	Violet	N1500	Orange/Orange

Electrolytic Capacitors

Electrolytic capacitors take advantage of the ability of some metal oxides to act as an excellent insulator (at low voltages) and also form a dielectric material with a very high dielectric constant 'K'. Most common electrolytic capacitors use aluminium oxide as the dielectric, but special-purpose and low leakage types generally use tantalum oxide.

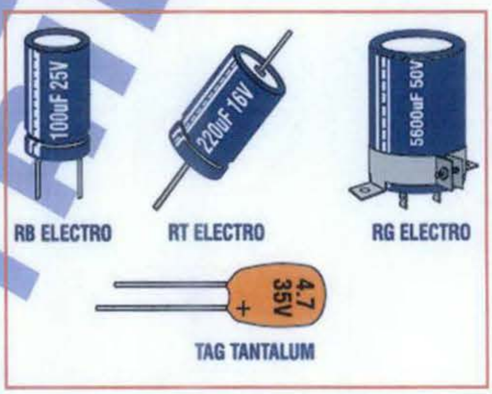
The main shortcoming of electrolytic capacitors is that the insulating and dielectric properties of the metallic oxides are polarity sensitive — so most electrolytic capacitors must be connected into circuit so that voltage is always applied to them with the correct polarity (which is marked on their body). The only exception is 'non polarised' or *bipolar* (BP) electrolytics, which are effectively two electrolytics in series back-to-back.

Because the oxide dielectric layer in electrolytic capacitors is extremely thin, these capacitors are more prone to breakdown at higher voltages. So all electrolytics are clearly marked in terms of their safe maximum operating voltage.

In most cases electrolytics also have their capacitance value shown directly on the case as well.

The three most common types of aluminium electrolytic in current use are the axial-lead or RT type, the radial-lead or RB type (for vertical mounting on PC boards) and the chassis-mounting or RG type. There's also a variation on the RB type called the RP, with a third lead for orientation and added support.

The most common type of tantalum electrolytic in current use is the solid or TAG tantalum type, where the tantalum oxide dielectric is formed on the surface of a solid block of sintered tantalum granules. These capacitors provide low leakage and very high capacitance in a very small volume, but are limited to quite low voltages — typically less than 33V.



APPENDIX J

MOISTURE CONTENT DETECTOR PROTOTYPE