Sudan University of Science and Technology

College of Post Graduate Studies

كلية الدراسات العليا

A Fully - Automated Center-Pivot Irrigation System Using a Microcontroller and a Solar Energy System

نظام ري محوري مركزي آلي بالكامل باستخدام المتحكم الدقيق ونظام الطاقة الشمسية

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of M.Sc. in Mechatronics Engineering

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DEDICATION

To my Dearest father and mother

To my sisters

Rawya

Amna

El safa

To all friends and relatives

hajir

ACKNOWLEDGEMENT

First and foremost, I have to thank my parents for their love and support throughout my life. Thank you both for giving me strength to reach for the stars and chase my dreams. My sisters, thanks as well. I would like to sincerely thank my supervisor, Dr. Fath Elrhaman, for his guidance and support throughout this study, and especially for his confidence in me.

To all my friends thank you for your understanding and encouragement in my many, many moments of crisis.

Thank you, Allah, for always being there for me. This thesis is only a beginning of my journey.

المستخلص

إن نظام الري المحوري اصبح أكثر أستخداما وشيوعا نسبة لكفائته العالية ولكنه يعاني من عيب إحتياج المضخات للصيانة المتكرّرة والمراقبة، التي كثيراً ما يحصل بها خلل أو أعطال. و بجعل النظام آلي بالكامل، فانه يصبح في حاجة أقل للمتابعة.جعل النظام آلياً بالكامل أيضاً، يقلّل التكلفة الكلية للنظام – المكلّف مسبقاً – بنسبة كبيرة بإقصاء تكاليف الصيانة والمراقبة التي يحتاجها النظام غير الآلي. هدف هذة الدراسة تصميم نظام ري محوري آلي كلياً يتكون من نظامين: نظام مجس مستوى الماء، ونظام ري متصل بنظام طاقة شمسية. ثم تمت تجربته بخلق محاكاة له على برنامج "بروتيوس" للتأكد من فعاليته ومدى عمليته قبل أن يُصمّم على أرض الواقع باستخدام المكونات المناسبة. تم الحصول على نتائج مرضية من ناحية سهولة إستخدام النظام ومراقبته عند تفعيل نظام الري الموفر للتكاليف والآلي بالكامل. تُضاف للنظام ميزة من الناحية الاقتصادية عندما يُستخدم نظام طاقة شمسية لتشغيله.

Abstract

The center-pivot irrigation system has become one of the most commonly used due to its efficiency worldwide but it suffers from the shortcoming of the pumps needing frequent maintenance and monitoring; which are prone to break down or malfunction. By fully-automating the system, considerably less attention will be required to maintain and monitor it. The full automation additionally reduces significantly the costs of the already expensive system by eliminating the expenses of the maintenance and monitoring with a non-automatic system. The aim of this thesis is to design a fully-automated center-pivot irrigation system consisting of two systems; a water level sensor system, and an irrigation system connected to a solar energy system. The proposed design simulated on the simulation software "Proteus" to test its functionality/practicality before it was materialized using the appropriate hardware. Satisfactory results in terms of ease of use and monitoring were obtained upon implementation of the fully-automated, cost-effective system, which is further more economical when connected to a solar energy system to operate.

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ABBREVIATIONS

A/D	Analog to Digital
CMOS	Complementary Metal Oxide Semiconductor
DC	Direct current
DFN	Dual Flat No-lead
EEPROM	Electrically Erasable Programmable Read Only
Memory	
I/O	Input / Output
LCD	Liquid Crystal Display
LED	Light Emitted Diode
LRDU	Last Regular Drive Unit
MSOP	Mini Small Outline Package
PDIP	Plastic Dual Inline Package
PIC	Programmable Intelligent Computer
PLCC	Plastic Leaded Chip Carrier
QIC	Quality Improvement Committee
RAM	Read Only Memory
RS	Rain Sensor
SMSs	Soil Moisture Sensors
SOT	Small-Outline Transistor
TQFP	Thin Quad Flat Pack
USART	Universal Synchronous and Asynchronous
Receiver Transmitter	
VAC	Volts of Alternating Current

List of Symbols

v	Mean velocity m/sec
d	Diameter of pipe
r	Radius of pipe in m
γ	Kinematics of fluid m^2/sec
ρ	Mass density of fluid kg/m^3
μ	Absolute viscosity pa-sec
Q	Discharge
C	Coefficient of pipe material
D	Internal diameter of pipe
L	Pipe length
m	Velocity exponent of used equation, ad
m	2 with Darcy-Weisbach equation
m	1.9 with Scobey equation
N	The number of outlets a long pipeline without outflow
Re	Reynolds's number with known (ρ, μ) of water at (20 ∘C).
$A1$	Area under first span (m^2)
$R1$	straight length off span one (all spans are equal).
At	(number of spans) ^{2} A1......(41)
$Q\,t$	(number of spans) ^{2} q1......(42)
Q_t	total water flow carried in span (x), (m^3/sec).
q_1	discharge of span one (m^3/sec).
n	total number of spans in Center Pivot lateral system.
X	span location number.

Chapter one

Introduction

1.1 preface

Irrigated agricultural schemes had played an important role in food production during the past century and are becoming even more important as the global population continues to increase. Farmers benefit from irrigation directly through increased and more stable incomes and the higher value of irrigated land. Communities benefit through better wages, lower food prices, a more varied diet and the health benefits of greater water availability. Studies have shown that every job created in irrigated agriculture yields another job in agricultural services and the processing industry. While large-scale irrigation schemes play an important role in improving food security, benefiting farmers who have more land, many low-cost small-scale techniques can be used by poorer farmers to increase yields. But the advanced technology such as the internet has hastened the dissemination of new irrigation technology and water management guidelines developed by specialists [1]. Personal computers have facilitated complex calculations and control of automated irrigation systems. However, there is still a need for irrigation system designers and system operators in this thesis; we take full control of the center pivot irrigation system, using solar energy to operate the system [2].

1.2 Problem Statement

The lack of control on a water pump in the center-pivot irrigation system is one main disadvantage in the system. Due to the fact that pumps are costly and need frequent maintenance and this lead breaking down or malfunctioning. The availability of power supply needed to operate the system also poses a challenge.

1.3 Proposed Solution

This thesis proposed a Fully automated control of pump could eliminate the control problem of the pump. Thereby, the costs associated with maintaining and monitoring these pumps are reduced. Adding the feature of utilizing solar power, instead of diesel, or other expensive power alternatives.

1.4 Objectives

1- To design a control system to be added to the center pivot irrigation using a microcontroller; ALN2003A, sensors and solar cells.

2- To simulate the system by proteus8 program.

3- To implement hardware using (sensors, ULN2003A, microcontroller, LCD, motor, pump and solar cells).

4- To test the system performance under different conditions.

1.5 Methodology

The design and development of the system involves the implementation of an electronic design of the center pivot irrigation system, hardware and software of the control system. These approaches must be well implemented so that it will produce a full, automated control on the center-pivot irrigation system that uses solar energy to run. The control system design lays out the construction of the system by using a microcontroller. A simulation has been creating using "Proteus". A module for the whole system has been implemented using the microcontroller and sensor.

1.6 Thesis Outlines

This thesis consists of five chapters their outlines are as follow: Chapter one is includes problem statement and proposed solution, in addition to the thesis objectives and its methodology. Chapter Two describes the literature review of this thesis. It includes the current and

previous works on design. Chapter Three illustrates some ideas on how the project is carried out. It lists out the steps involved in each stage of the project including the hardware design. Moreover, it explains the overall theory of the operation system. Chapter Four presents the results and data for the system evaluation. Chapter Five discusses the conclusion of the whole project. This chapter also contains suggestions for future improvements.

Chapter Two

Literature Review

2.1 Background

The availability of water as well as agricultural lands in Sudan is one factor that makes the center-pivot irrigation system optimal to be implemented to increase the efficiency of the irrigation process. Coupled with solar energy, the center-pivot irrigation system not only preserves water but also saves energy. Sudan is a predominantly agricultural country. More than 80% of the national wealth depends on agriculture which is either rained or irrigated. Irrigated agriculture relies on the water from the River Nile and its tributaries and is governed by the River Nile water agreement which was signed between Sudan and Egypt of which the 1925 – 1959 agreement is the most well-known. The 1959 Agreement gave the Sudan the right to use ($18.5 \text{ X } 10^9 \text{ m}^3$) per annum (As measured at Aswan). It should be noted that people usually use conventional ways to irrigate crops. These include different means, such as, surface irrigation, basin, border and furrow irrigation systems. Now, there are irrigation systems which can preserve water more efficiently. These include 'pressurized irrigation systems', drip 'trickle', sprinkler systems such as the center-pivot irrigation system, and each one of these ways of irrigation plays an important role and can be a great aid to the efficient usage of water. Recently some modern irrigation systems were introduced into Sudan with little expertise, in design and evaluation. Studies in various parts of the world have shown that the center-pivot irrigation system can be readily and economically adapted to all tillable soils, climates and crops. Hence, it can contribute substantially in the solution of food shortage [3].

Center-pivot irrigation (sometimes called central pivot irrigation), also called circle irrigation, is a method of crop irrigation in which equipment rotates around a pivot and crops are watered with sprinklers or

(nozzles). A circular area centered on the pivot is irrigated, often creating a circular pattern in crop when viewed from above. Most center-pivots were initially water-powered by electric or diesel motors and today, a new option of energy source such as solar energy is been looked into.

2.1.1 Objectives of Irrigation Methods

The methods of irrigation are shown in figure below and is objective to give the plant the amount of moisture it requires as well as provide the plant with a sufficient supply of water to endure short durations of droughts. Also, to cool the soil and the atmosphere and to provide a congenial atmosphere for plant growth by:

Washing or diluting harmful salts in soil, reducing hazards of soil piping. and making soil layers soft for tillage [3].

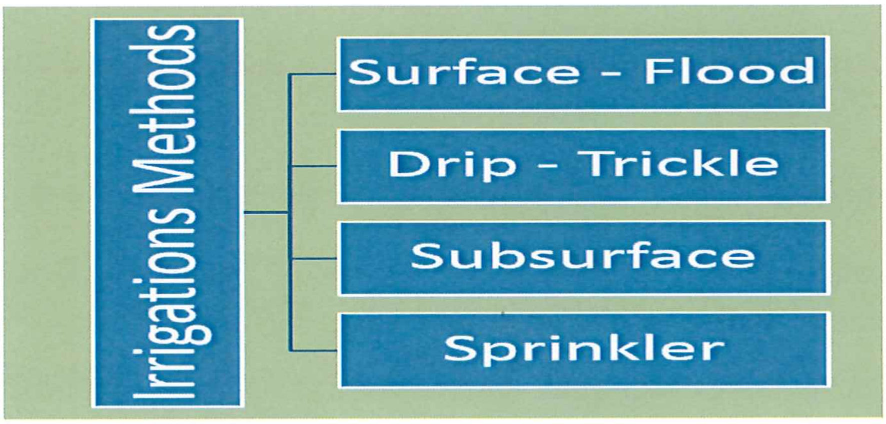


Figure (2.1): The method of irrigation [3]

2.1.2 The Center-Pivot Irrigation System

The center-pivot irrigation system is considered to be a highly efficient system which helps conserve water. Center-pivot irrigation typically uses less water compared to many surface irrigation and furrow irrigation techniques, which reduces expenditure of land-consumed water. It also helps reduce labor costs compared to some ground irrigation

techniques, which are often more labor-intensive. Some ground irrigation techniques involve the digging of channels on the land for the water flow, whereas the use of center-pivot irrigation can reduce the amount of soil tillage that occurs and helps to reduce water runoff and soil erosion that can occur with ground irrigation. Zybach , who lived in Strasburg, Colorado shown in figure (2.2) [3] :

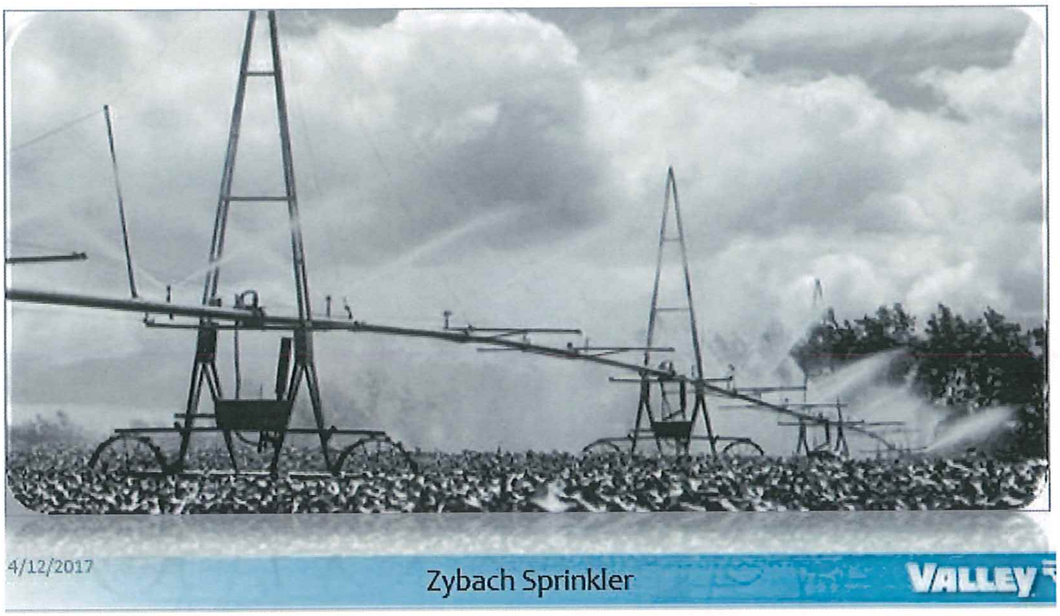


Figure. 2.2: zybach sprinkler irrigation system [3]

Center-pivot irrigation was invented in 1948 by farmer Frank. The propulsion system may be oil hydraulic, water hydraulic, or electric. The trend is toward the electric drive machines, 240 or 480 volt, three phases, with most being 480 volts. Electric motors of 0.5 to 1.5 horsepower are mounted on each tower with a drive shaft from the motor to a gear box on each wheel. The center pivot system sprinklers water from a continuously moving lateral pipeline. The self-propelled lateral is fixed at one end and rotates to irrigate a large circular area. The fixed end of the lateral, called the pivot point, is connected to the water supply. The lateral consists of a series of spans ranging in length from 27 to 76 m long, carried about 3m above the ground by drive units that consist of an "A-frame" supported on motor driven wheels [4].

Devices are installed at each drive unit to keep the lateral in line between the pivot and end drive unit. The end drive unit is set to control the speed of rotation. The most common center pivot lateral uses 168mm pipe, is 400m long, and covers a circle of 50 ha inscribed within a square "quarter section" of land with an area of 65 ha. An additional 1 to 4 ha of the quarter section may be irrigated by the pivots end gun. Laterals as short as 70m and as long as 800m are available with pipe sizes up to 255mm.The moving lateral pipeline is fitted with impact, spinner or spray nozzle sprinklers to spread the water uniformly over the circular field. The area irrigated by each sprinkler, if set at a uniform sprinkler spacing along the lateral, grows progressively larger toward the moving end. Therefore, to achieve uniform application, the sprinklers must be designed to have progressively greater discharges, closer spacing, or both, toward the moving end. Typically, when impact sprinklers are used, the application rate near the moving end is in the vicinity of 25 mm/h. With spray nozzles, it may be as high as 250mm/h. these application rates exceed the intake rate of many soils except for the first few minutes at the beginning of each irrigation. To minimize surface pending and runoff, the laterals are usually rotated every 10 to 72 hours depending on the soils infiltration characteristics, the system capacity and nuzzling configuration, and maximum desired soil moisture deficit. The different types of power units used to drive the wheels on center pivots are: electric, motors, water pistons or pump as shown in Appendix E, water spinners and turbines, hydraulic oil motors, and air pistons [3].

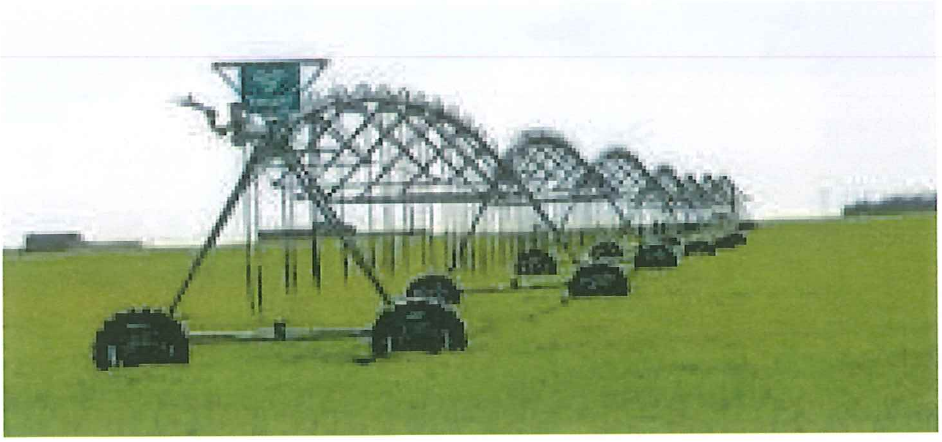


Fig. 2.3: center-pivot irrigation system [3]

The first pivots used water pistons; however, electric motors are the most common today because of their speed, reliability and ability to rotate the lateral clockwise or counterclockwise. Center pivot sprinkler systems are suitable for almost all field crops, including corn, but require fields free of any above ground obstructions. They are best adapted for use on soils having relatively high intake rates and uniform topography. When they are used with low intake rates and irregular topography, the resulting runoff causes erosion and puddles that may interfere with the uniform circular movement of the lateral around the pivot point. Where center pivot systems are used on square fields, some means of irrigating the four corners must be provided, or other uses must be made of the areas that are not irrigated. In a 64ha, squared field, from 9 to 12 ha are not irrigated by the center pivot system unless the pivot has a special corner irrigating apparatus. With some corner systems, only about 3ha are left unirrigated. Most pivot systems are permanently installed in a given field. However, for supplemental irrigation or for double cropping, it is practical to move a center pivot lateral back and forth between fields [5].

Pivot Point: The central point around which the pivot moves. This is where the water enters the pivot pipes and where the control panel is located.

Control Panel: A piece of hardware attached to the pivot point that gives commands to the center pivot machine. Control panels are considered the 'brain' of the machine. They control starting, stopping, changing directions, running wet versus dry, and much more. A variety of control panels are available, and you can choose panels with very basic capabilities, as previously mentioned, or digital panels that can be programmed to work with advanced irrigation technologies.

Drive Unit/Drive Tower: A drive unit or drive tower is the part of the machine that touches the ground, and contains the necessary components for the machine to move. It consists of a base beam, drive train, wheels, and various structural supports.

Span: The long pipes between drive units are called spans. Spans consist of the main water line, sprinklers, and a supporting structure of trusses to hold the weight between towers.

Tower Box: Located at each drive unit is a tower box. This compartment controls the drive unit components, telling it to move in the right direction and for how long.

Last Regular Drive Unit: The Last Regular Drive Unit, or LRDU, is the last tower on a regular pivot or the last tower before a corner arm or pivot add-on that extends your irrigated acres. You'll learn the importance of the LRDU below [3].

As the name suggests, center pivots irrigate in a circular pattern around a central pivot point. Pivots are capable of applying water, fertilizer, chemicals, and herbicides. This versatility can improve the efficiency of irrigation practices by using a single piece of machinery to perform several functions. Most center pivot machines are electrically powered, using either a generator or a public power source. Pivots use both 120 and 480 volts of alternating current (VAC) to operate. 120 VAC is used as the control circuit, powering the safety circuit, the forward and reverse

movement of the pivot, and, more precisely, the movement of the Last Regular Drive Unit (LRDU). The 480 VAC is the power circuit and supplies the needed energy for the drive units to move as in figure (2.5) [3].

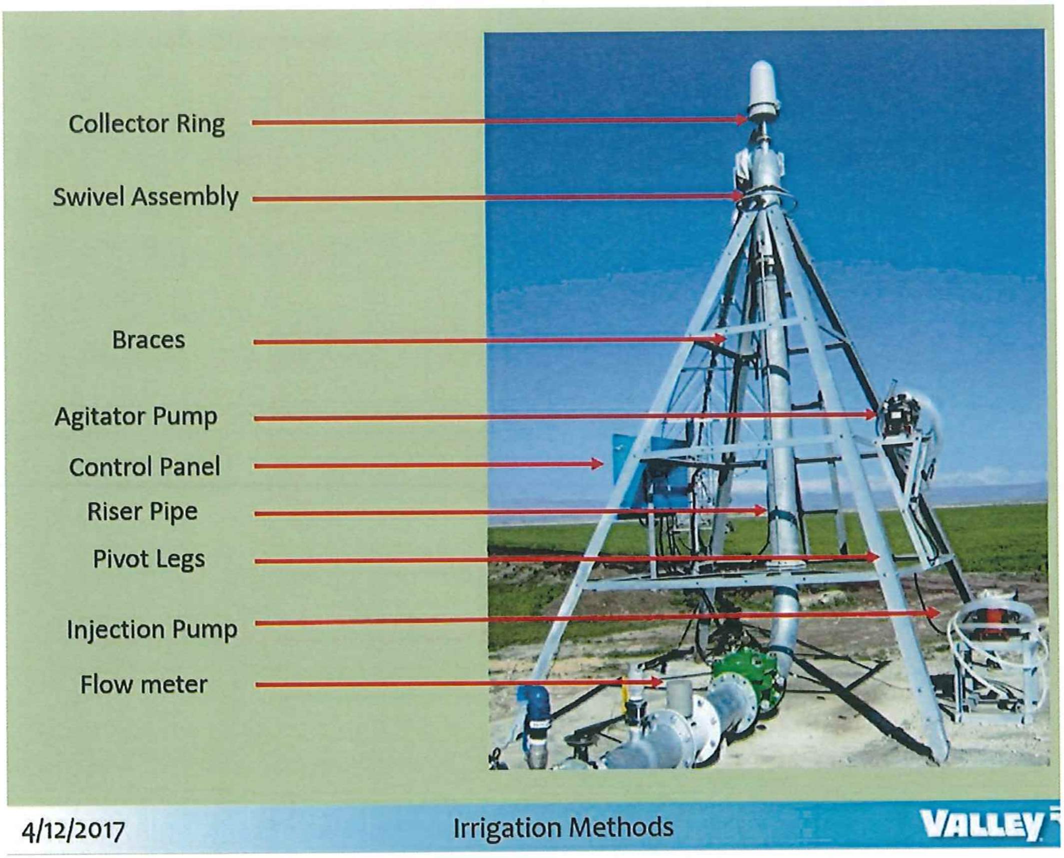


Fig. 2.4: components center-pivot irrigation system [3]

Center pivot irrigation systems have proven to be capable of giving high returns per unit area. The advantages of improving irrigation management (lower labor requirement) and reduced risk of crop failures compared with surface systems are paid for with higher energy and capital costs. Unfortunately, there are some who have invested large sums of money only to find that the system costs more to run than they had anticipated and the machine does not return the benefits they expected. Operational problems, usually due to lack of experience, add to the complication of the problem. An overhead irrigation system's maximum water delivery rate is effectively set and is only able to irrigate adequately

are necessary to justify additional costs over a "plain" center pivot as shown in figure (2.3) [10]

Fig. 2.5: Center pivot with corner attachment [10]

Thesis's in the area of the center pivot irrigation system are still ongoing. In order to get a historical background to improve mechanical control over the center pivot functionality, several studies have been conducted to quantify and better understand the nature of the center pivot irrigation system using solar energy.

2.2 Related Works

In [11] it is explained that: The performance of QIC (Quality Improvement Committee) has been evaluated, a newly designed real time irrigation controller based on soil moisture content, on tomato in the fall 2003 through the spring 2004The Tensiometer, QIC, and ET/weather-based methods were set to irrigate a maximum of four times each day (high- Frequency-Low-volume). The grower schedule was set to irrigate one time (Morning) per day (high volume / low frequency). The Tensiometer and QIC methods allowed irrigation only if soil tens ion exceeded set points for Tensiometer treatments or if soil moisture was below set points for QIC treatments, respectively.

Results of the sensor performance limitations:

Switching-Tensiometer, when subject to weekly maintenance, performed well and consistently across repetitions for each treatment. From a practical point of view, it is essential in South Florida field conditions to include routine

a specific area. A common reason for growers complaining about their machine's performance is that they have over-committed the machine to too large an area, that is, too many circles. When crop water use is at its peak the machine simply cannot keep up with the demand and the crop doses not reach their potential. Issues of concern include soils, infiltration, design, cropping options, friction and pressures, capital and running costs, power requirements and calculations, tree clearing and on-farm water storage. With rising fuel prices, it is increasingly important that irrigation systems apply water uniformly in order to achieve maximum benefit from the water applied. When irrigation systems are used to apply fertilizers and pesticides, application uniformity becomes even more critical. Consequently, it is important for center pivot owners and operators to periodically check the uniformity of their systems [6].

2.1.3 Advantages of the Center Pivot System

Water delivery is simplified through the use of a stationary pivot point.

- Guidance and alignment are controlled as a fixed pivot point. Relatively high water application uniformities are easily achieved under- After completing one irrigation, the system is at the starting point for the next irrigation.
- Achieving good irrigation management is simplified because accurate and timely application of water is made easy. More accurate and timely applications of fertilized and other chemicals are possible by applying them through the irrigation water.
- Flexibility of operation makes it feasible to develop electric load management schemes.
- Fully automated and controlled from a panel near the pivot point or remotely from some office nearby. Time clocks are used to start

and stop the machine and many safety devices are used for protection.

- The above advantages eliminate the most difficult mechanical and operational problems associated with other sprinkler irrigation systems.
- As with all irrigation machines, to reduce the cost per unit of area irrigated, it is advantageous to irrigate as large an area as possible with a minimum amount of equipment.
- In the case of center pivots, this is accomplished by irrigating as large a circle as possible because the cost of equipment is proportional to the radius, but the area irrigated is proportional to the square of the radius [7].

2.1.4 Disadvantages of the Center Pivot System

From a water application standpoint, center pivots have the following disadvantages:

- Where the pivot point is in the center of a square field, the corners will not be irrigated (above 20%).The average application rate at the outer edge of the irrigated circle is usually quite high.
- In some systems, it may be over 100 mm/h with certain nozzle configurations. Relatively, light and frequent applications must be used on all but sandy soils to reduce or eliminate runoff problems associated with these high application rates.
- In extra cases to avoid runoff, it may even be necessary to set the travel speed so a center pivot lateral cycles faster than one revolution per day. This increases evaporation losses and center pivot maintenance costs and may decrease crop yield moreover Because each additional increment of radius irrigates a large

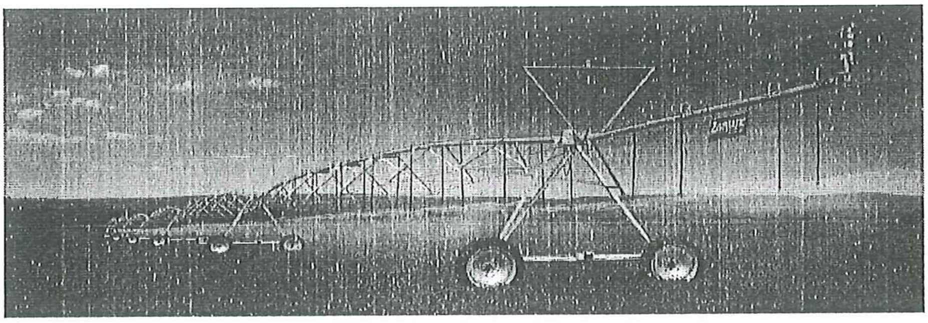
concentric band, most of the water must be carried toward the outer end of the lateral.

- This results in relatively high pipe friction losses. On slopping fields, the average lateral operating pressure will vary significantly depending on whether it is pointing up or downhill.
- This can result in large variations in discharge unless sprinklers with pressure or flow controlled nozzles are used. Using motors powered from water pressure in the lateral will make the system only move when irrigating [8].
- Despite the automaticity and completeness of the pivot machines, the field designer still has various interventions to carry out. To optimize the performance of these rather delicate irrigation machines, considerable expertise is needed in their selection, design and management. Working with a fast and continuously moving lateral that pivots around a fixed end and presents many unique design challenges.

2.1.5 Center Pivot with Corner Attachment

Corner attachments systems are available, which allow irrigation of most of the corner areas that a conventional center pivot system lacks. The most common method of corner irrigation has an additional span, complete with tower, attached to the end of the center pivot system mainline which swings out in the corners. Either a buried wire or mechanical switch controls the movement of the moving span. Another type of corner system uses several guns mounted on the end of the center pivot mainline. The system activates the guns in sequence from smallest to largest and back again as the machine moves past the corners. A corner span generally costs about half as much as the rest of the pivot. High value crops and/or high hand value as well as scarcity of irrigable land

are necessary to justify additional costs over a "plain" center pivot as shown in figure (2.3) [10]



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Results of the sensor performance limitations:

Switching-Tensiometer, when subject to weekly maintenance, performed well and consistently across repetitions for each treatment. From a practical point of view, it is essential in South Florida field conditions to include routine

maintenance of Tensiometer (a minimum of once a week is recommended). The QIC prototype performed consistently well without requiring any maintenance (2 boxes were substituted earlier on in the trial).

In [12] the presented study aims to: The present paper aims to discuss the scope and limitations of a photovoltaic solar water pumping system. Components and functioning of PV solar pumping system are described. However, typical irrigation systems consume a great amount of conventional energy through the use of electric motors and generators powered by fuel. Photovoltaic energy can find many applications in agriculture, providing electrical energy in various cases, particularly in areas without an electric grid. In this paper, the description of reviews on a photovoltaic irrigation system, is presented. Since various irrigation points of organization are located in areas without an electric grid, photovoltaic cells can provide the necessary power for the operation of this automatic irrigation system. To further enhance the daily pumping rates tracking arrays can be implemented. This system demonstrates the feasibility and application of using solar PV to provide energy for the pumping requirements for sprinkler irrigation.

In [13]: The main objectives of this experiment were to quantify differences in irrigation water use and turf quality between: a soil moisture sensor-based irrigation system compared to a time-based scheduling, different commercial irrigation soil moisture sensor (SMSs), and a time-based scheduling system with or without a rain sensor (RS). SMS - based treatments were able to follow and detect fairly well when sufficient rain occurred, overriding pre-set irrigation cycles, and allowing the rest of them to run when necessary. SMS-based treatments were, on average, significantly more efficient as a means to save water than the time-based treatments. However, the correct choice of a SMS should take into consideration features like its technology, response-time, irrigation scheduling strategy, and cost, among other aspects and the author suggests that they are often incorrectly installed. Therefore, the

limitation of appropriately installed and properly working rain sensors could signify not only substantial water savings to homeowners, but could also lead to sound environmental and economic benefits to the state.

Chapter Three

System Design

3.1 Hardware Design

The center pivot irrigation system is the most commonly used irrigation mechanism [18]. A model for an irrigation system has been created, whereby it employed full control of the system. In this chapter we are going to explain the design of the center pivot irrigation control electronics.

3.1.1 Control System Design

The irrigation control system is divided into three different blocks: Solar system contains irrigation system and water level system

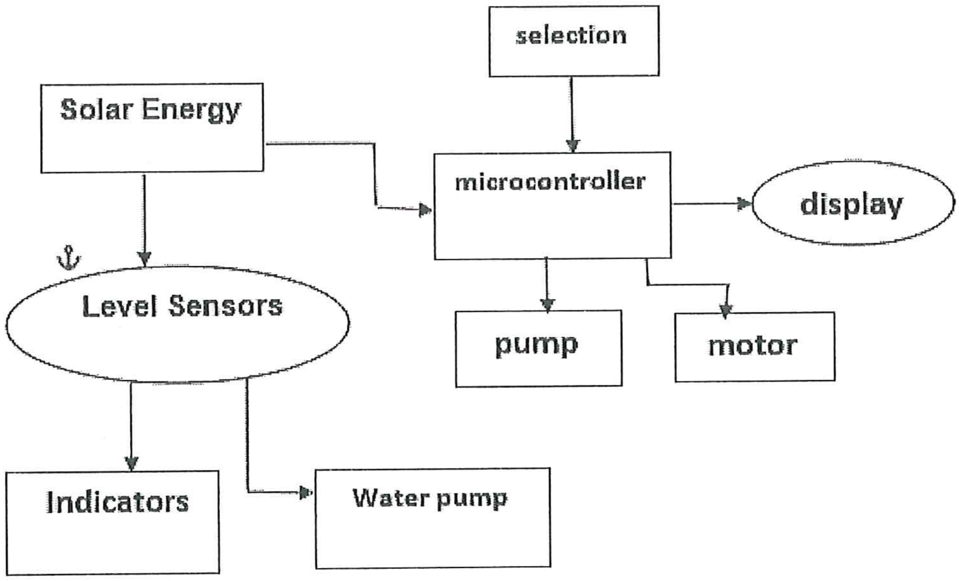

Figure 3.1: irrigation control system block diagram

3.1.2 Main Control System Block

As for the hardware development stages, the first step is to assemble the main control system block. This is where the PIC microcontroller circuit is built, assembled and tested. PIC microcontrollers are popular processors developed by Microchip Technology with built-in RAM, memory, internal bus, and peripherals that can be used for many applications. PIC originally stood for

"Programmable Intelligent Computer" but is now generally regarded as a "Peripheral Interface Controller".

PIC microcontrollers can be programmed in Assembly, C or a combination of the two. Other high level programming languages can be used but embedded systems software is primarily written in C. PIC microcontrollers are broken up into two major categories:8-bit microcontrollers and 16-bit Microcontrollers.

Each PIC has unique features and subtle differences. The correct choice for your project depends on many factors:

1) Whether the project requires analog input or output.

2) Whether the project requires digital input or output.

3) The number of I/O pins required.

4) Whether the project requires precise timing or not.

5) How much memory the project requires.

6) Whether serial I/O is required or not.

PICs also come in several types of packages:

1) Plastic Dual Inline Package (PDIP)

2) Small-Outline Transistor (SOT)

3) Dual Flat No-lead (DFN)

4) Mini Small Outline Package (MSOP)

5) Thin Quad Flat Pack (TQFP)

6) Plastic Leaded Chip Carrier (PLCC)

7) Ceramic QUAD pack (CERQUAD)

The PIC used in this system architecture is PIC16F877A. The PIC16F877A CMOS FLASH-based 8bit microcontroller is upward compatible with the PIC16C5x, PIC12Cxxx and PIC16C7x devices. It features 200 ns instruction execution, 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, a

synchronous serial port that can be configured as either 3-wire SPI or 2-wire I2C bus, a USART, and a Parallel Slave Port [18].

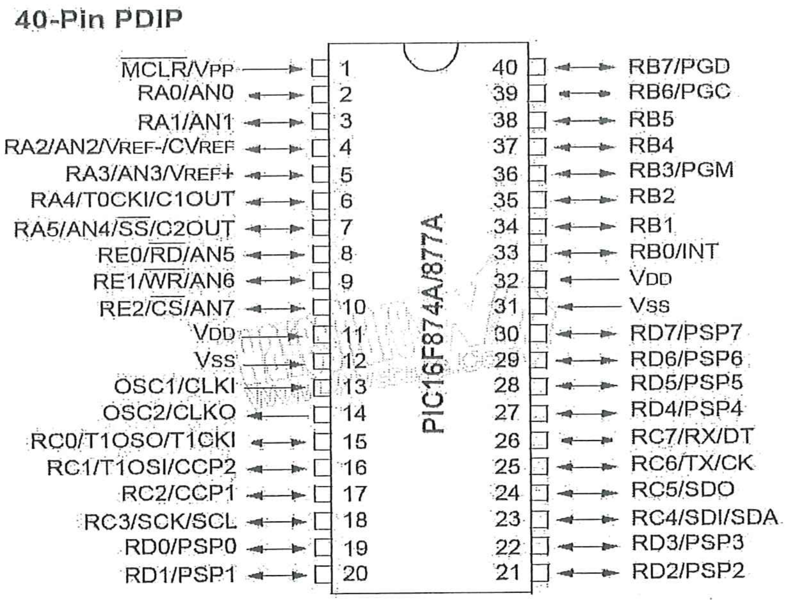

Figure 3.2: PIC16F877A pins layout [15]

Microchip PIC16F877A Microcontroller Features

□ High-Performance RISC

□ operating speed: 20 MHz, 200 ns instruction cycle

□ Operating voltage: 4.0-5.5V

□ Industrial temperature range (-40° to +85°C)

□ 15 Interrupt Sources

□ 35 single-word instructions

□ All single-cycle instructions except for program branches (two-cycle)

□ Flash Memory: 14.3 Kbytes (8192 words)

And other features (see data sheet, appendix A) [16]

The PIC circuit functional is checked and tested by using a simple program which receives input signals and turns the LEDs on and off. This checks the connection of the system input-output port. The system main program development initially starts once the PIC circuit has been

assembled and tested. It can be started in stages until the whole control system is integrated. Meanwhile, the software simulation can be done to check its functionality by using the Professional Proteus Software environment [17] as shown in Appendix D.

3.1.3 Solar Energy (Power Supply Module)

The climate in Sudan ranges from hyper-arid, in the north to tropical wet-and-dry in the far southeast. The sky is fully clear of clouds and the sunshine duration is near the theoretical maximum [19].

The factor which makes use of solar energy a practical alternative power source. Especially, since agricultural lands are usually located in remote areas and thus, getting electricity cables to these areas places a financial burden on the project. The currently used alternative, diesel, or fuel, used to power generators that are large enough to supply the system with the electricity needed, is also not cost-effective due to the high consumption of fuel by these generators, plus the cost of obtaining the generators themselves as well as the cost of the regular maintenance they require. Use of solar energy in Sudan is extremely limited. The capacity of the batteries currently in use are used with pumps not exceeding 5-10 acres. Solar power systems provide a continuous, reliable power solution that is easily deployed, cost-effective and requires little maintenance. Solar Power Systems are complete, fully integrated solar power supplies, designed for site loads requiring 12, 24 or 48 volts DC. Each solar power system provides safe and reliable power generation without the need and expense of installing utility power. The sealed, maintenance-free batteries are designed for deep cycle operation and extended life in solar applications. The aluminum array support structures and battery enclosures are strong yet lightweight and corrosion-resistant for harsh marine or severe weather locations. Solar power system is a system which can be conveniently installed and transported. It also has the perfect

characteristics of self-control, self-protection, needing little attention, compact structure, elegant outline and convenience of use etc. [21]

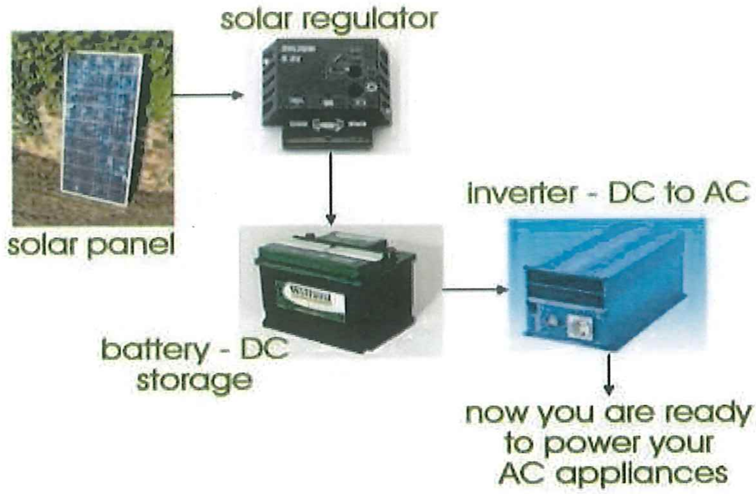

Figure 3.3: solar energy system [21]

3.1.3.1 Bank of Batteries

The batteries used in a solar system re deep cycle batteries, similar to those that power electric golf carts. The number of batteries used in a system varies depending on the type of battery and anticipated storage needs. [22]

3.1.3.2 Inverting Function

The off-grid inverter is mainly applied for isolated solar power systems. For example, a system can supply power for running a separate heating system, refrigerator, pumps, etc. [23]

3.1.3.3 Benefits of Installing an Alternative Solar Energy System

Using a solar system instead of having the utility company provide power to a remote site is significantly more cost-effective more over Cleaner power from a solar generating system that is free of surges,

spikes, brownouts and blackouts that can damage or shorten the life of appliances [20].

3.1.4 ULN 2003A Driver IC

TheULN2003A is a high-voltage, high-current Darlington transistor arrays. Each consists of seven NPN Darlington pairs that feature high-voltage outputs with common-cathode clamp diodes for switching inductive loads. The collector-current rating of a single Darlington pair is 500 mA. The Darlington pairs can be paralleled for higher current capability. Applications include relay drivers, hammer drivers, lamp drivers, display drivers (LED and gas discharge), line drivers, and logic buffers. For 100-V (otherwise interchangeable) versions of the ULN2003A and ULN2004A. The ULN2002A is designed specifically for use with 14-V to 25-V PMOS devices. Each input of this device has a Zener diode and resistor in series to control the input current to a safe limit. The ULN2003A and ULQ2003A have a 2.7-kΩ series base resistor for each Darlington pair for operation directly with TTL or 5-V CMOS devices. The ULN2004A and ULQ2004A have a 10.5-kΩ series base resistor to allow operation directly from CMOS devices that use supply voltages of 6 V to 15 V. The required input current of the ULN/ULQ2004A is below that of the ULN/ULQ2003A, and the required voltage is less than that required by the ULN2002A [17] as shown in Appendix B.

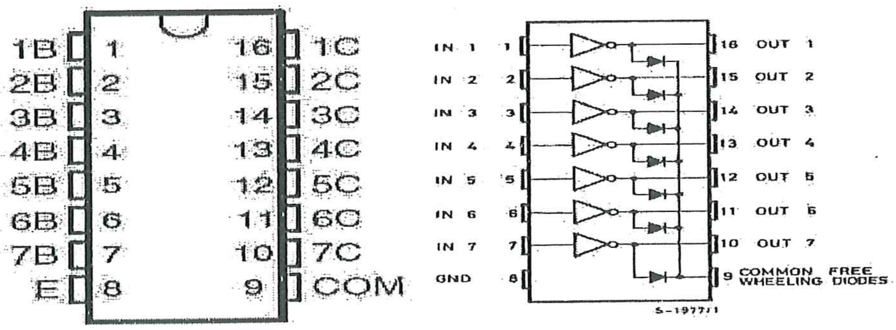

Figure 3.4: ULN2003A Driver IC [17]

3.1.5 Motor

An electric motor is an electrical machine that converts electrical energy into mechanical energy. The reverse of this is the conversion of mechanical energy into electrical energy and is done by an electric generator.[24] The hardware development processes or task of the system has to undergo several steps and stages as it is shown in Figure (3.2).

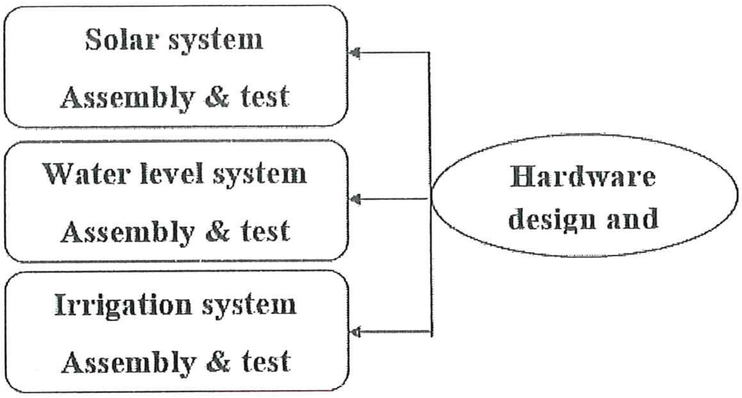

Figure 3.5: Hardware and task of the system

Finally, after all the modules have been tested, they are integrated and connected together to work and become a complete system. This is the part where the software plays an important role in operating the system.

3.2 Theory of System Operation

Figure 3.2 in previous paragraph shows the system block diagram showing the interconnections between each block and module. All the modules are mounted on board as to ease control of the center pivot irrigation system. For the power source, it uses a 12 V DC which comes from a power supply module then it will be regulated voltage to feed the all parts of circuit as shown in Appendix C. (The photoelectric panels convert solar energy to an electric current which charges a bank of batteries. The batteries supply the system with a 12 V.)

3.2.1The Irrigation System

The system consists of a Microcontroller, ULN2003A, a motor, a pump, a

relay, an LCD, and three push buttons. Components of the system are connected to a solar energy system. The microcontroller is programmed using Micro C programming language, so it can translate the orders to be inputted on the LCD screen. Upon turning the system on, a welcome message appears on the LCD screen. The system then enquires about the irrigation hours and the rest hours desired. A confirmation message then appears showing the information inputted into the system. The system turns the water pump and motor on for the period of the irrigation hours inputted and begins the rest cycle as indicated. The cycles of irrigation/rest hours are repeated indefinitely until reset.

3.2.2 Water-Level Sensor Irrigation System

The system consists of two relays and six transistors, a pump, a water tank, and an LED indicator. The components are connected electrically using solar energy and the tank is divided in the module to five safety levels for the pump.

- Level 1: 10%
- Level 2: 25% - 50%
- Level 3: 50% - 75%
- Level 4: 75% - 100%

When the water level in the tank is 0%, a sound feedback and an indicator (red) turns on. Consequently, the relay is connected to complete the circuit and the pump then begins to run.

When the water level in the tank is 25%, the alarm discontinues, an indicator (green) turns on and the pump continues to run. When the water level in the tank reaches 75%, the system continues to pump water and an indicator turns on pointing to the correspondent water level. When the water level reaches 100%, the tank is full, the circuit will automatically

be disconnected and the pump stops working. All the indicators turn on showing that the water level in the tank has reached 100%.

3.3 Software Design

The software development processes or task of the system have to undergo several steps and stages.

3.3.1 Irrigation System Module Initialization

When the irrigation system is turned on, a welcome message is displayed on the LCD screen, and the system is defined. The irrigation/rest hours' cycles are enquired by the system. The irrigation/rest cycles begin as inputted and repeated until the system is reset.

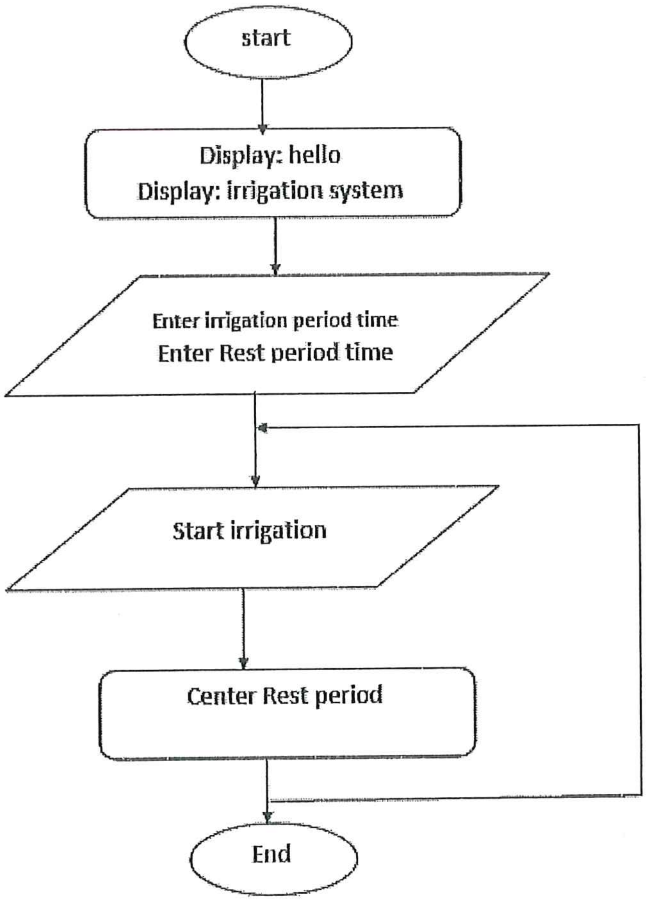

Figure 3.6: irrigation system Module initialization flow chart

3.3.2 Water Level System Module Initialization

Upon initializing the system, water level sensors are read, and the status is displayed on the indicators. If the water level is low, the water pump is run, and if it is not, the cycle is reset.

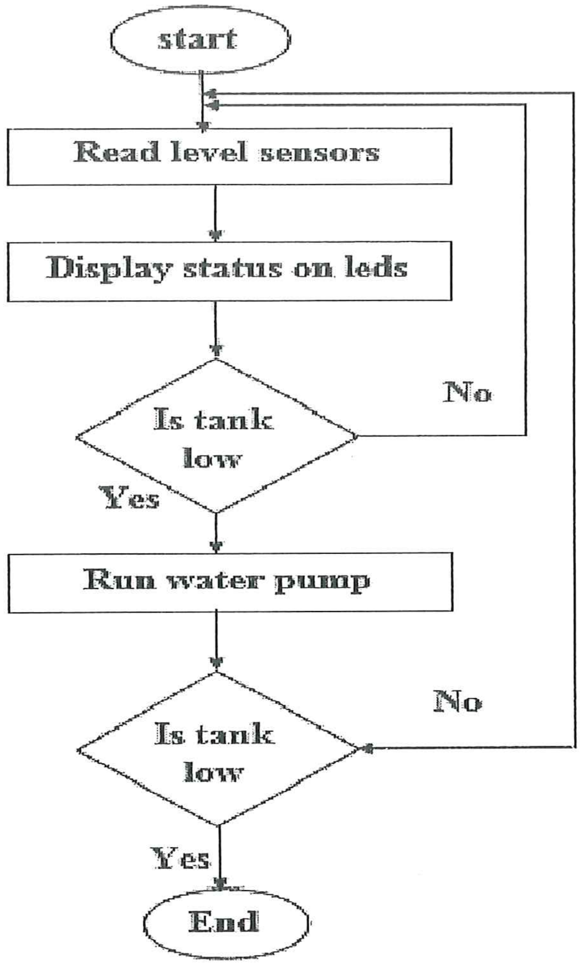

Figure 3.7: Water Level System Module initialization flowchart

3.4 Control System Software

In order to ensure that the written software works efficiently with the hardware, a system simulation is carried out in the Windows based environment called 'Proteus'. And The Software Development Process Involves: Writing and debugging a Mikro C language program as a main control language program according to the PIC word instructions, Simulation in the Proteus environment is carried out, Embedding the code

into the PIC microcontroller and Testing the whole system. The software is written and developed in a Window-based environment called Mikro C Pro for PIC where it is converted to machine code for the embedding process in the embedding process, a device called a 'programmer' is used to program or transfer the software into the PIC microcontroller. (Figure 3.8) as shown in Appendix A.

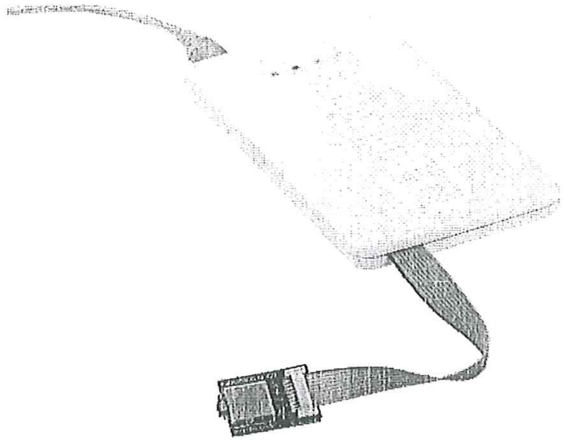

Figure 3.8: Mikro programmer

After the above process is completed, the center pivot irrigation control system is then tested and evaluated. Evaluations made are of the accuracy of the irrigation -output result, the functionality of the programmed cycles and operability of the hardware. A total of 4 sets of data are taken for the evaluation.

Chapter Four

Results and Discussions

4.1 Result and Discussions

This chapter presents the discussion and results obtained from running the system.

4.2 Irrigation System Design:

The irrigation system controls the irrigation/rest hours cycle according the pre-inputted information by the user.

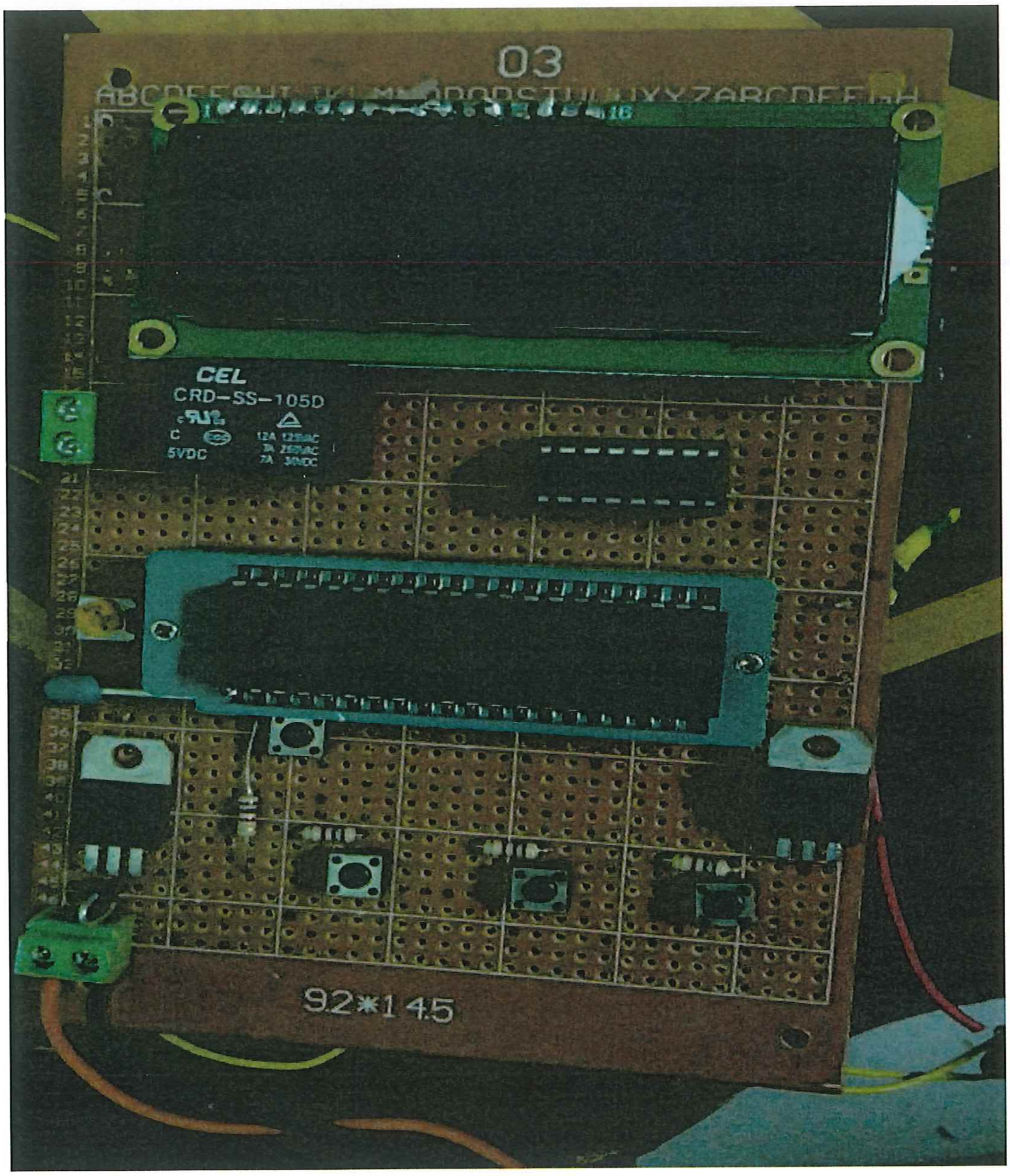

Figure 4.1: Printed Board of the System

4.2.1 Irrigation System Simulation

The system stating by screen definition testing is carried out by sending a welcome message from the microcontroller to the LCD screen. Testing of the inputs; the irrigation/ rest hours' cycles. Testing of the input confirmation and Testing of the functioning of the pump and the motor which are connected to the relay, ULN2003A, and the microcontroller. The programming is designed using mickoC Pro compiler and Proteus simulation environment as shown in figure (4.2).

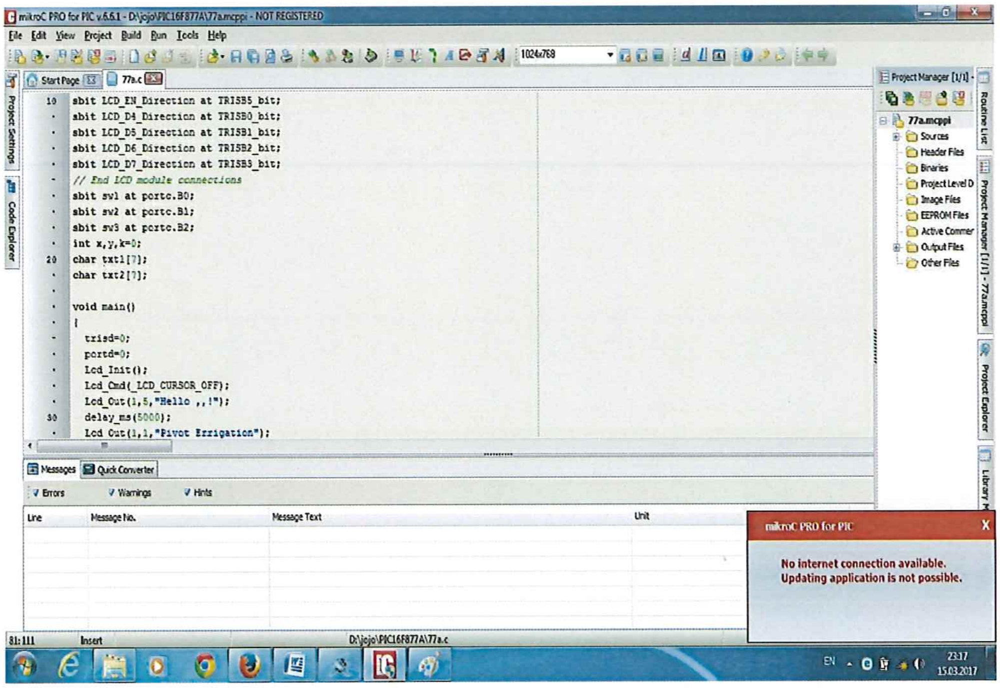

Figure 4.2: Running of MikroC Code

4.2.2 Testing the Irrigation Module and Simulation

The input hours are tested on the LCD screen in the simulation and hardware to see whether or not the program runs as defined in the microcontroller, When the irrigation system is turned on, a welcome message is displayed on the LCD screen as shown in figures (4.3) and (4.4):

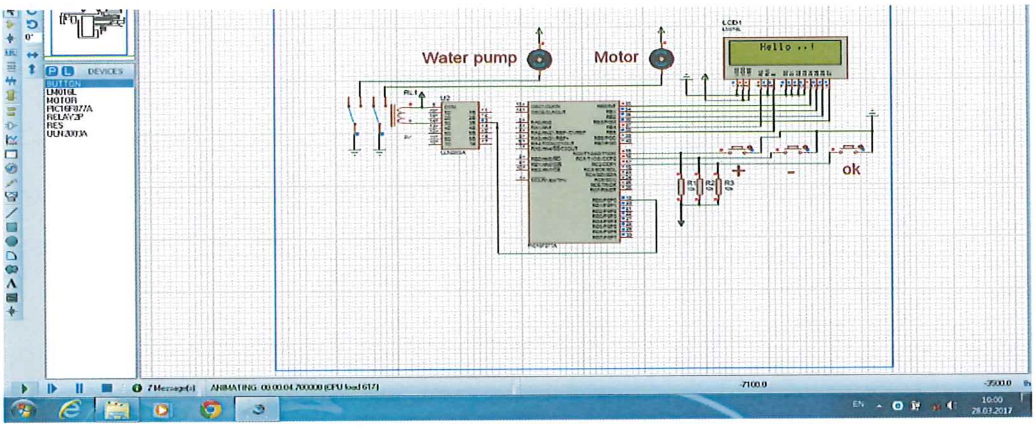

Figure 4.3: Testing the Welcome Message of the Irrigation System in Proteus Program

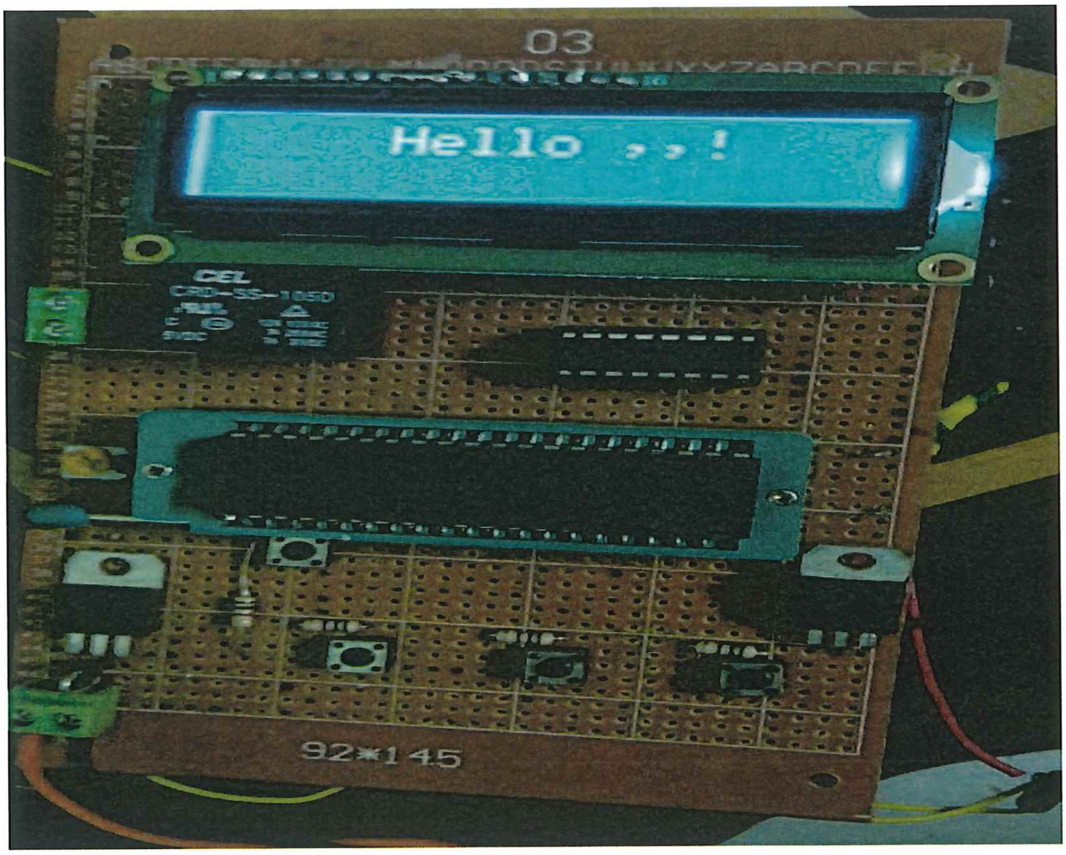

Figure 4.4: Testing the Welcome Message of Irrigation System

Upon a welcome message appears on the LCD screen. The system then Define (pivot irrigation system) as inputted code of microcontroller as in figures (4.5) and (4.6):

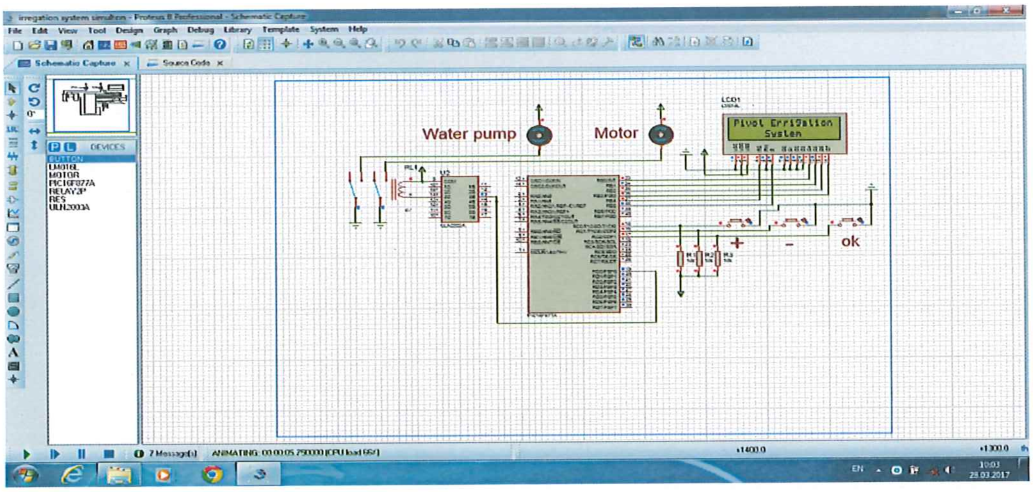

Figure 4.5: Testing the Pivot Irrigation System in Proteus Program

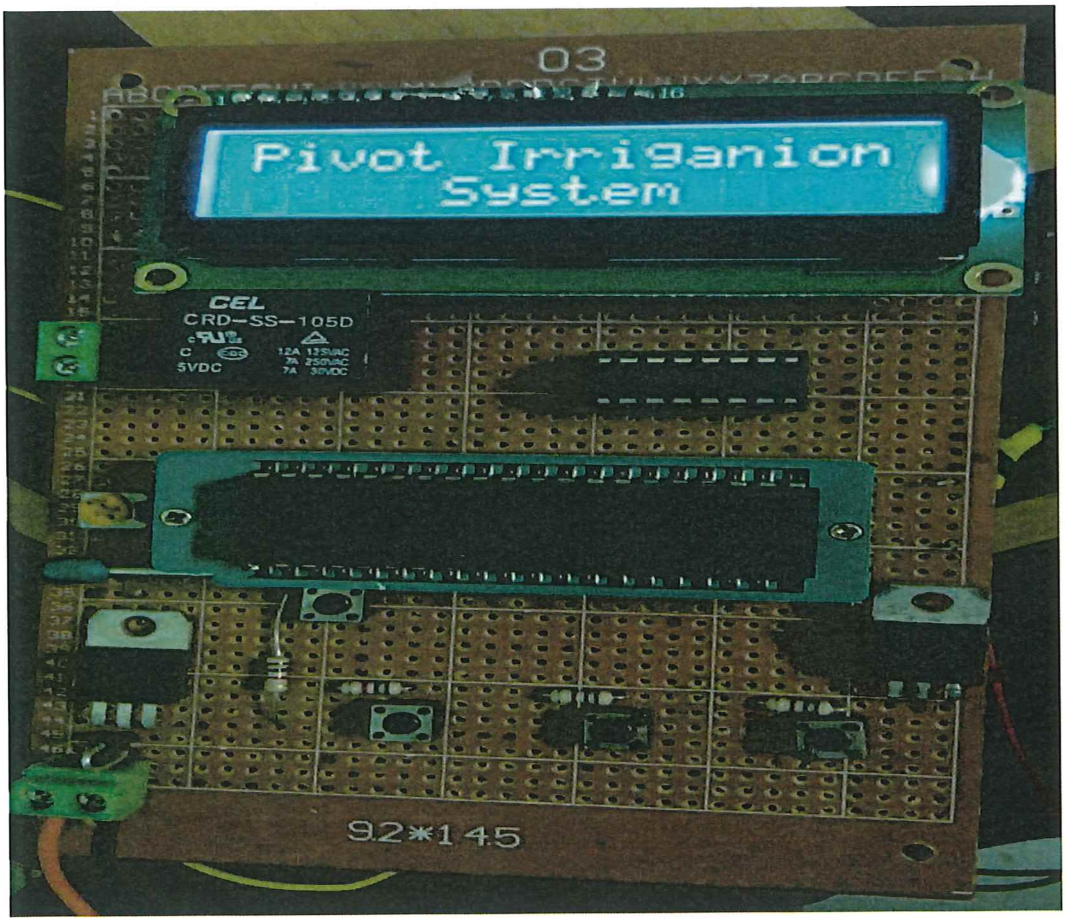

Figure 4.6: Testing the Pivot Irrigation System

The system then enquires about the irrigation hours and the rest hours desired as show in figures (4.7), (4.8):

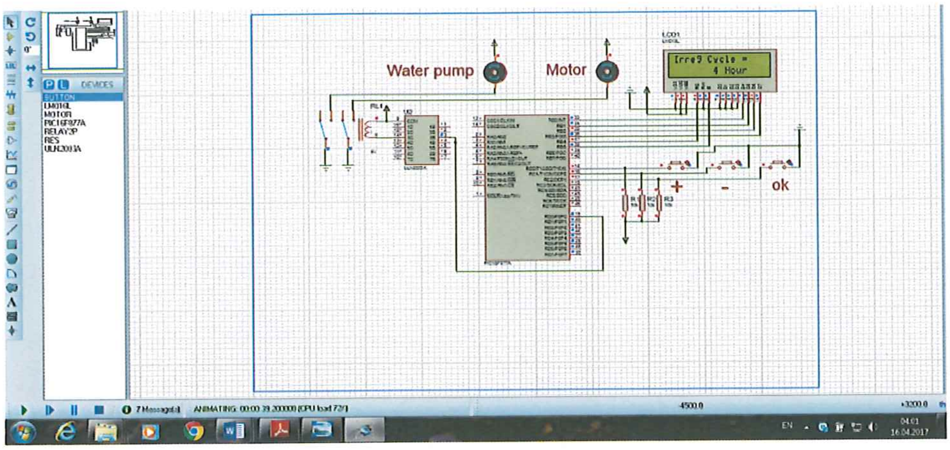

Figure 4. 7: Testing the Irrigation System Cycle in Proteus Program

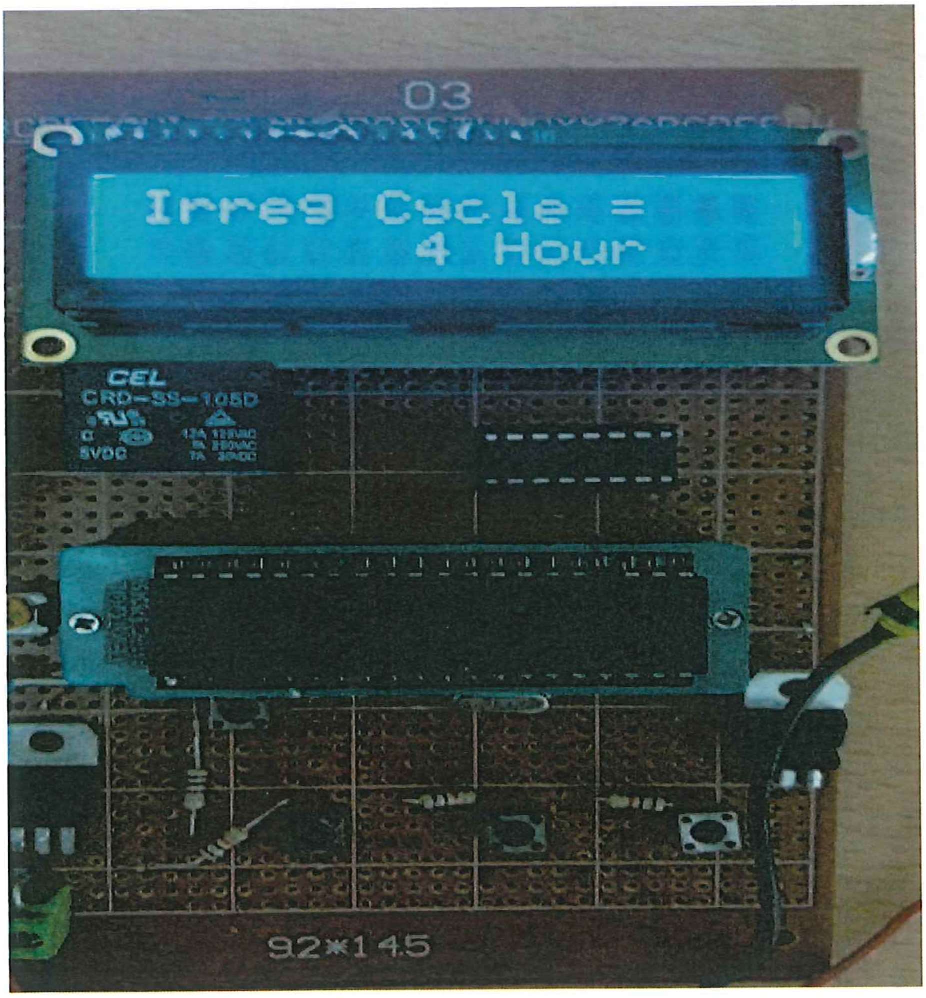

Figure 4.8: Testing the Irrigation Cycle System

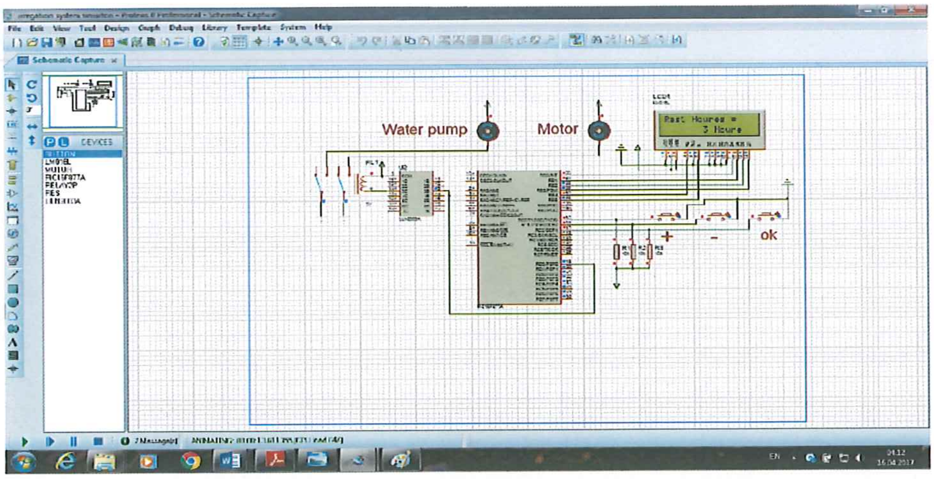

Figure 4.9: Testing the Rest Period of Irrigation System in Proteus Program

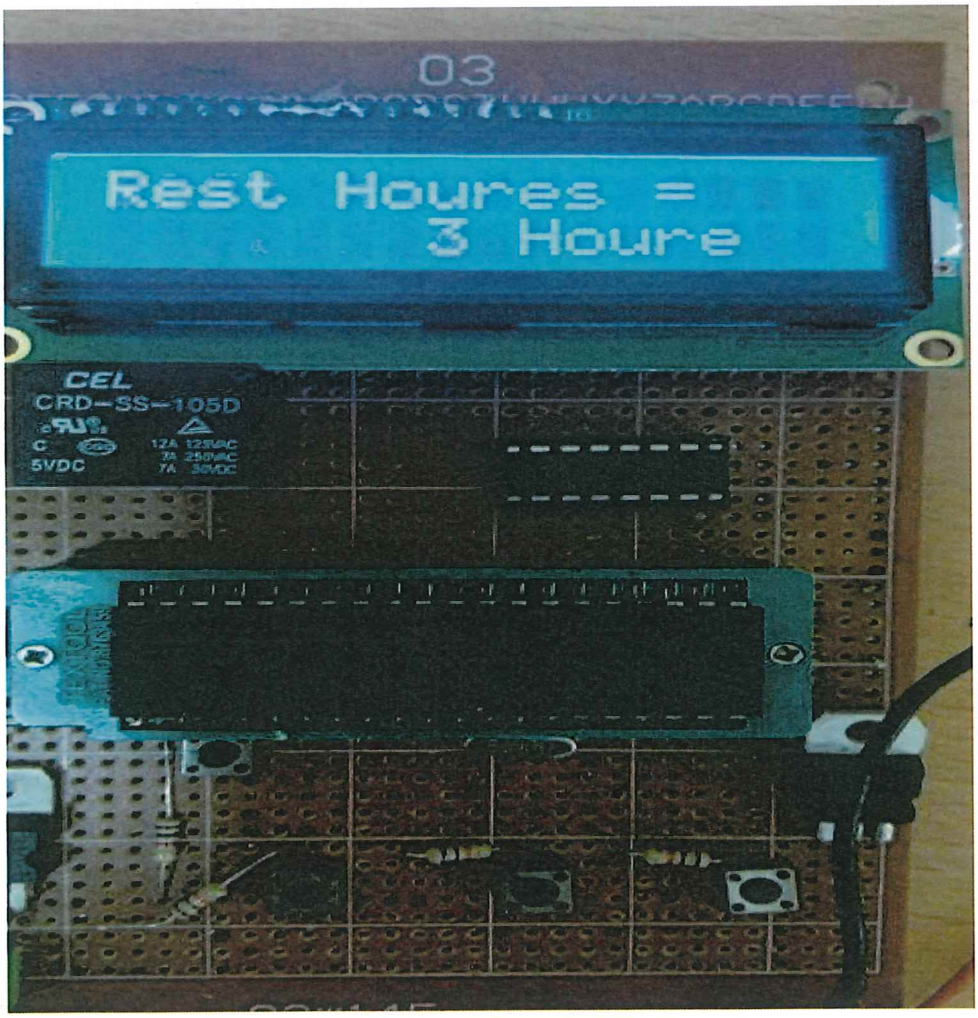

Figure 4.10: Testing the Rest period of Irrigation System

A confirmation message then appears showing the information inputted into the system. The system turns the water pump and motor on for the period of the irrigation hours inputted and begins the rest cycle as indicated. The cycles of irrigation/rest hours are repeated indefinitely until reset as shown in figures (4.11) and (4.12):

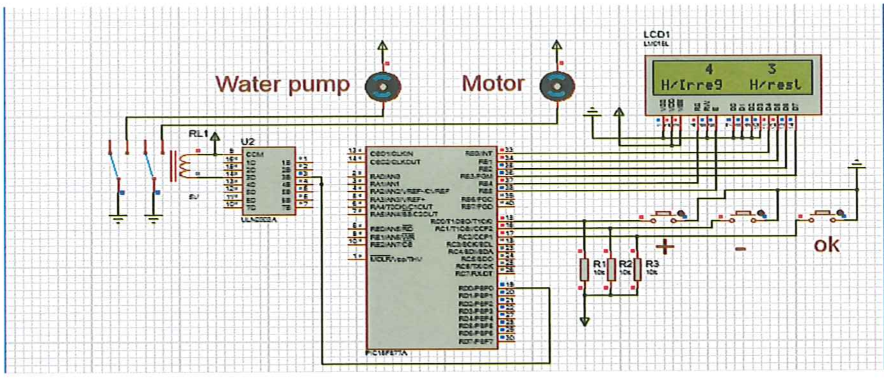

Figure 4.11: Testing Conformation Command of the Irrigation System in Proteus Program

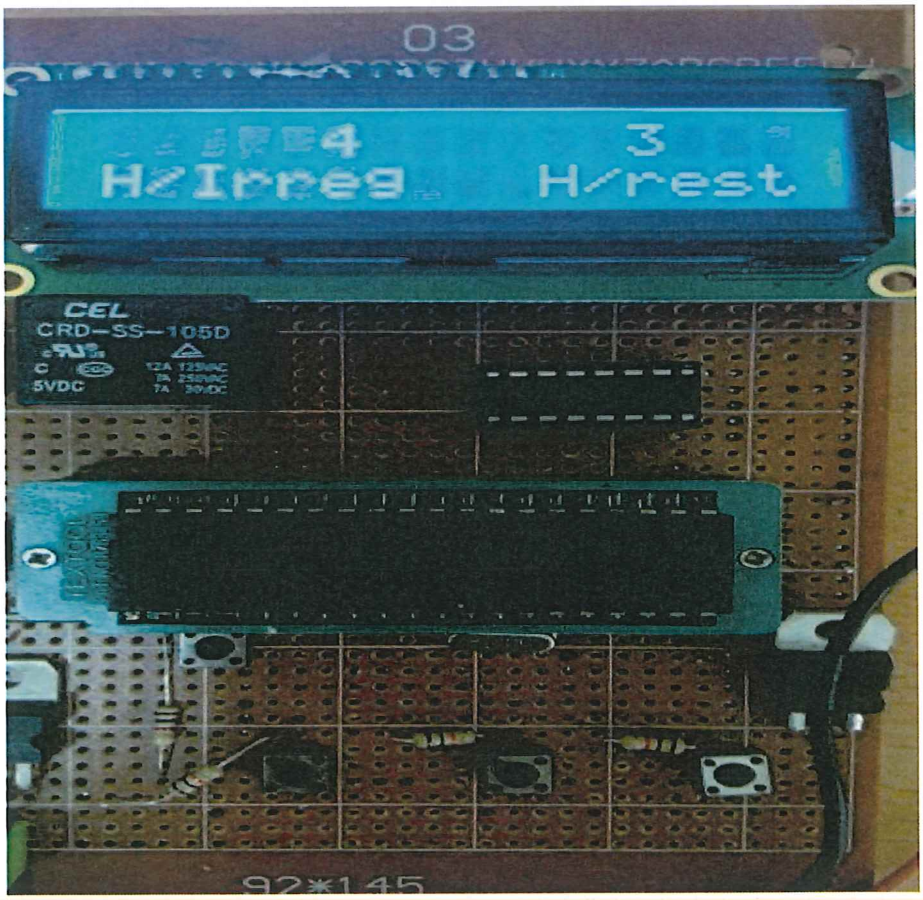

Figure 4.12: Testing Conformation of the Irrigation System

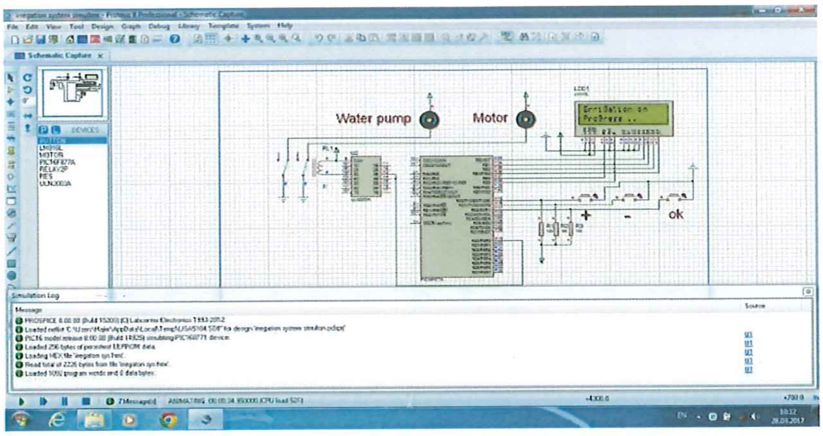

Figure 4.13: Testing the Irrigation cycle of the Irrigation System Progress on the Proteus Program

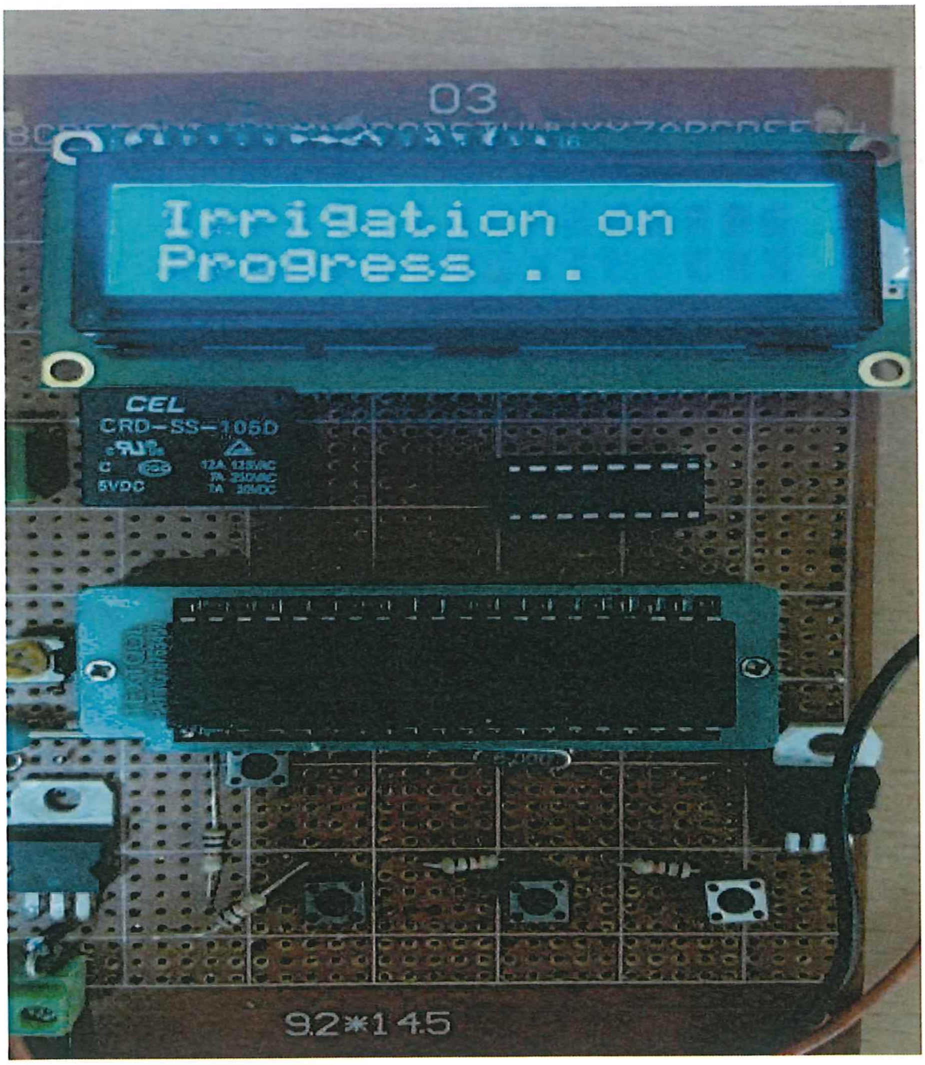

Figure 4.14: Testing the Irrigation cycle on Progress of the Irrigation System

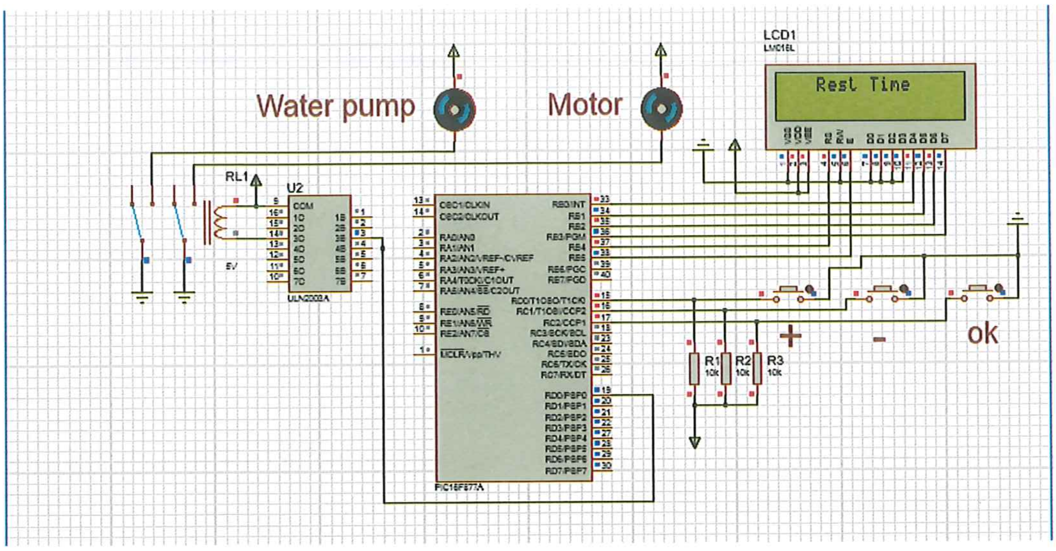

Figure 4.15: Testing the Irrigation Rest Cycle of the Irrigation System on Proteus Program

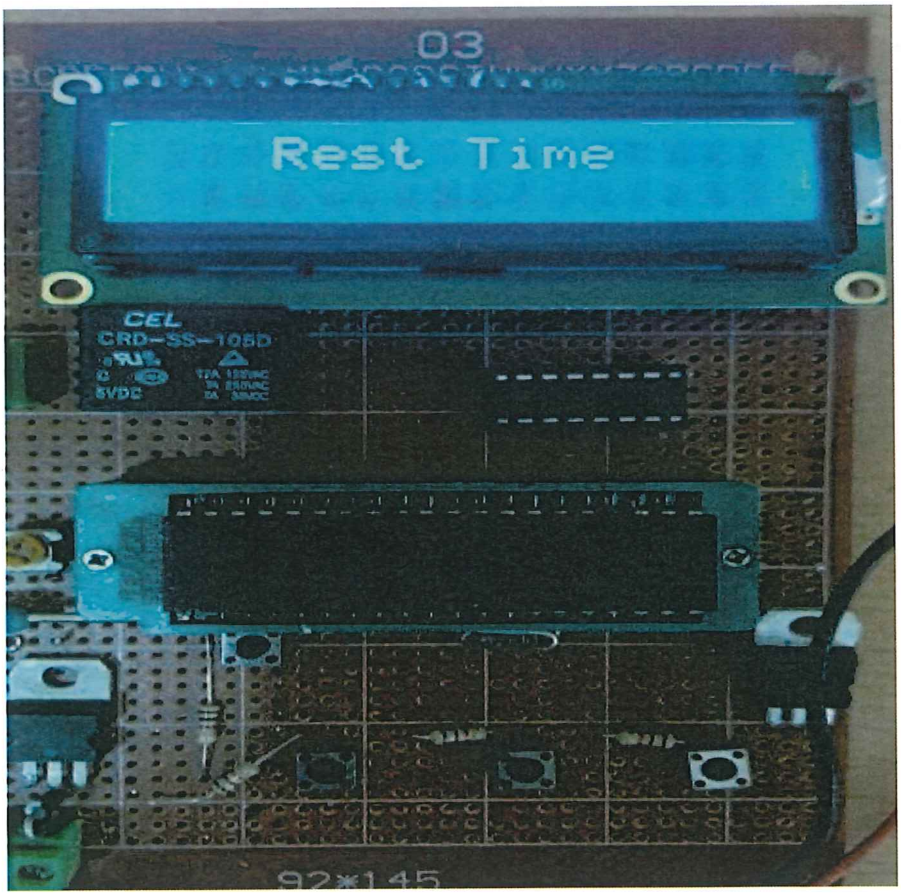

Figure 4.16: Testing the Rest Cycle of the Irrigation System

4.3 Water Level System Design

Depending on the gradients of the sensors in the system, any indicator corresponds to a certain level of water. For example, when the water starts to recede from the tank, there are two initial results indicating the lack of water appearing in the indicators, followed by running of the pump to supply the water to the tank to the required limit.

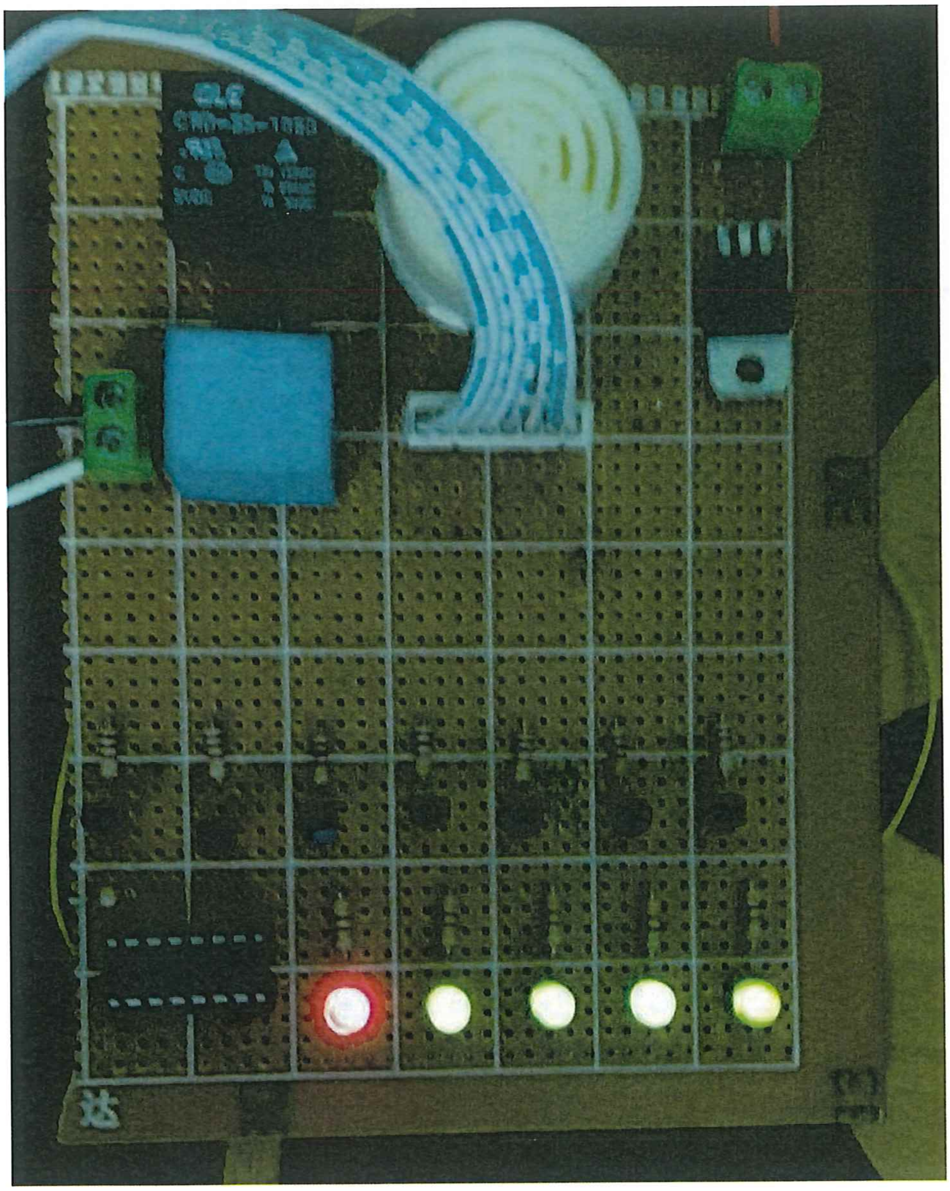

Figure 4.17: Forming the Level of Water System

4.3.1 Testing the Water Level Module and Simulation

After completing the design and configuration of the water level sensor as mentioned in Chapter 3, the water level will be tested incrementally along the tank to determine the system's efficiency. Testing the water level sensor in an empty tank; in which case an indicator will turn on showing a low water level as shown in figure (4.18) and (4.19).

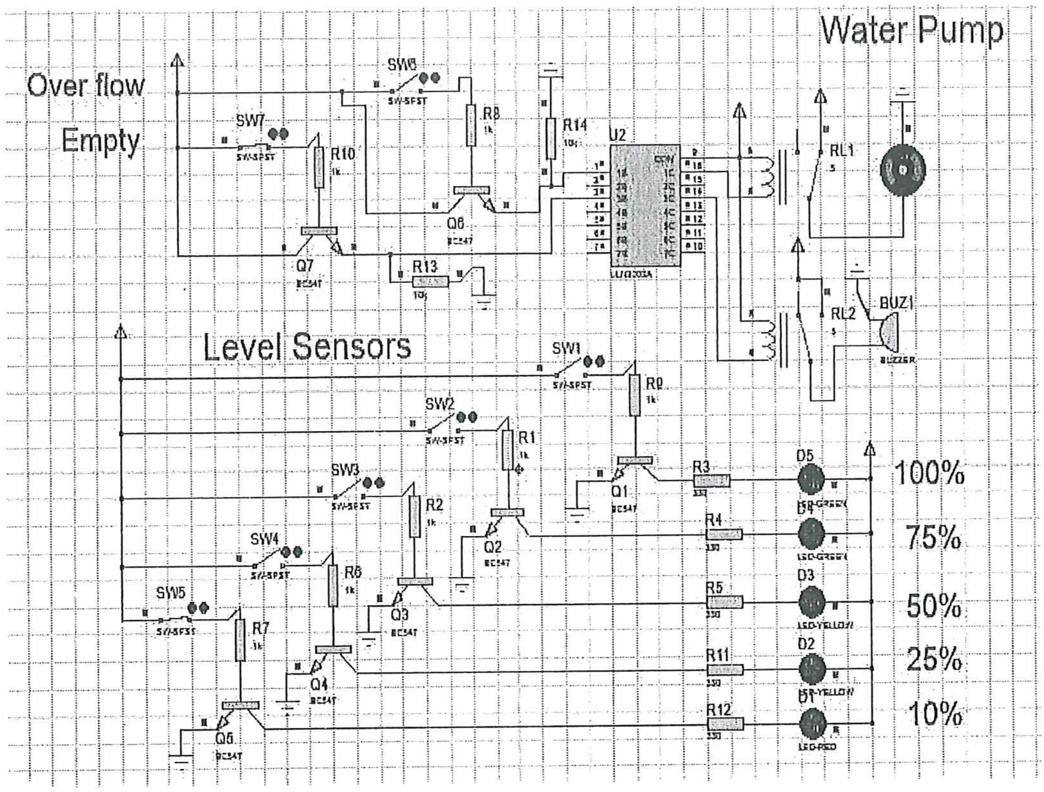

Figure 4.18: Testing "10%, of Water in Tank" command on Proteus Program

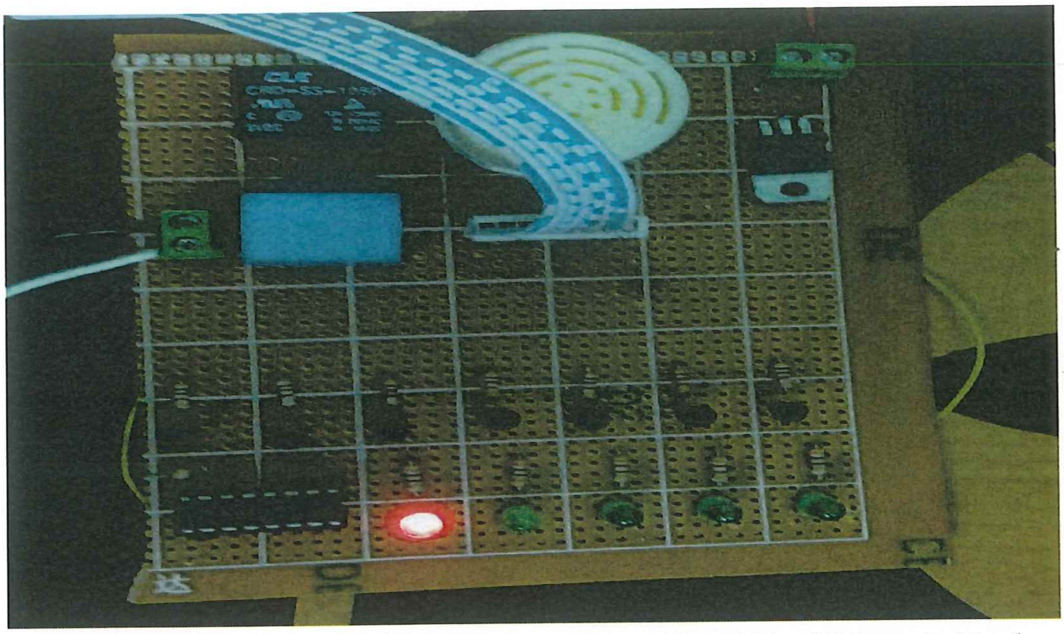

Figure 4.19: Testing the Water Level Sensor in 10% of Water in Tank Proteus

When the water level reaches 50% of the tank, the indicators corresponding to the level will turn on with the pump continuing to run as shown in figures below:

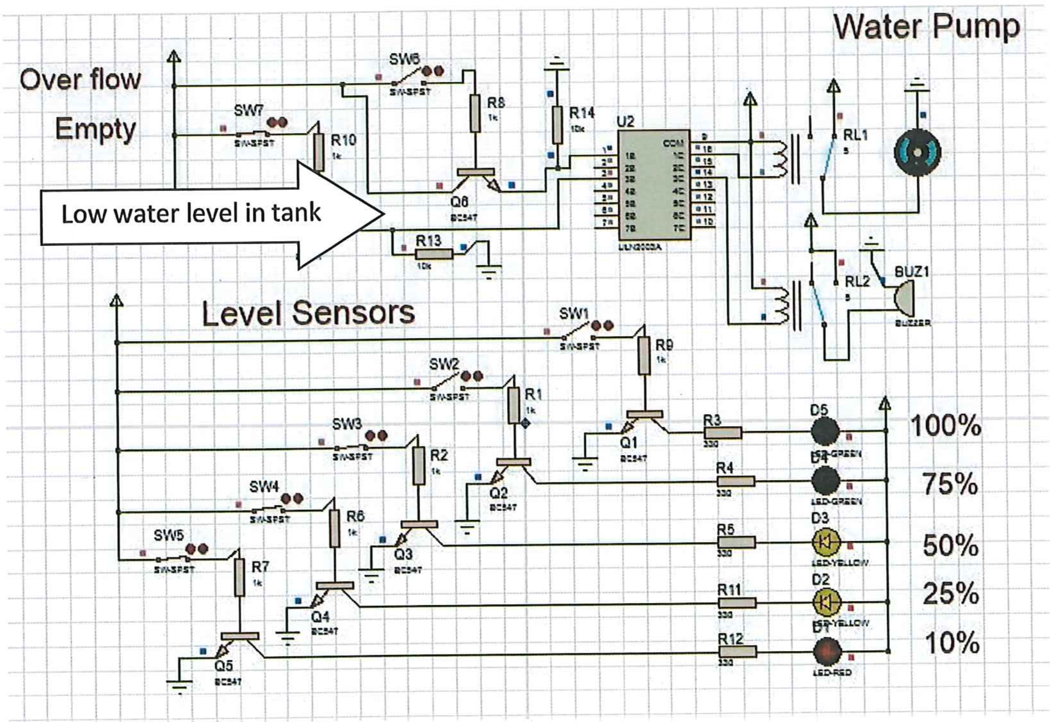

Figure 4.20: Testing "50% Water of Tank" Command on Proteus

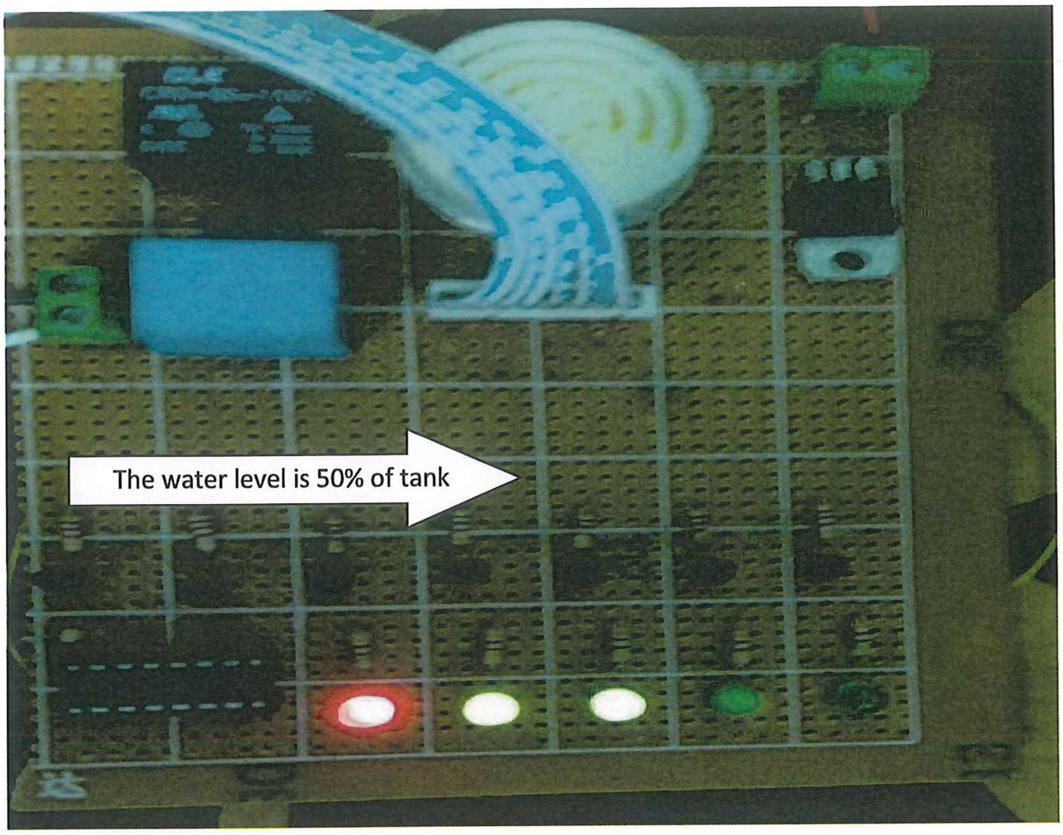

Figure 4.21: Testing the Water Level (50%) of the Tank"

When the water level reaches 100%, the pump ceases to operate with all of the indicators remaining turned on.

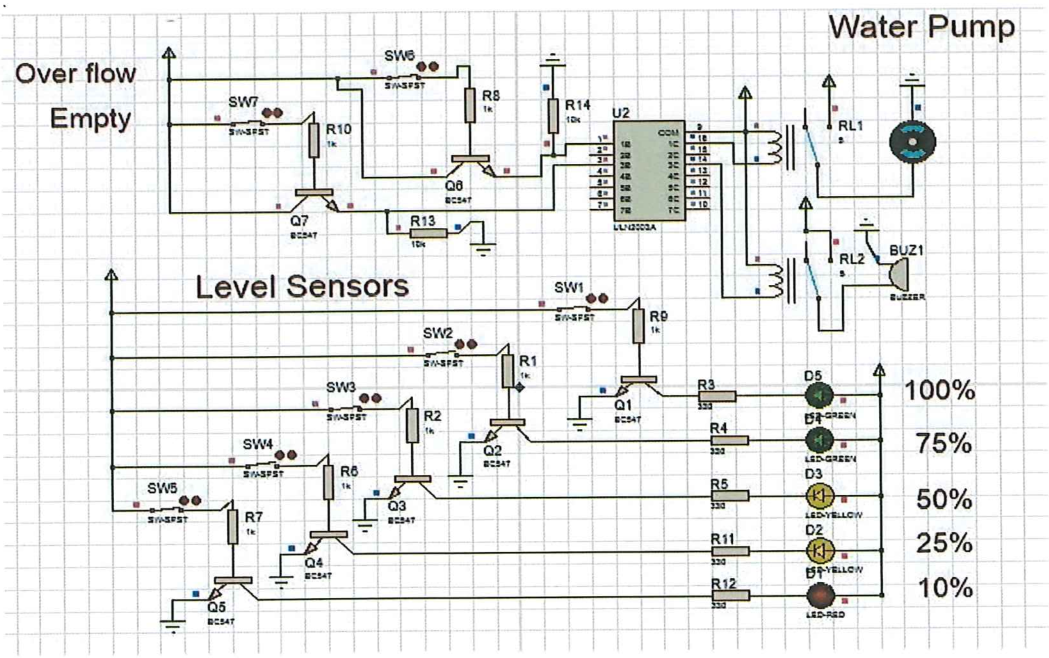

Figure 4.22: Testing "100% water of tank" command on proteus

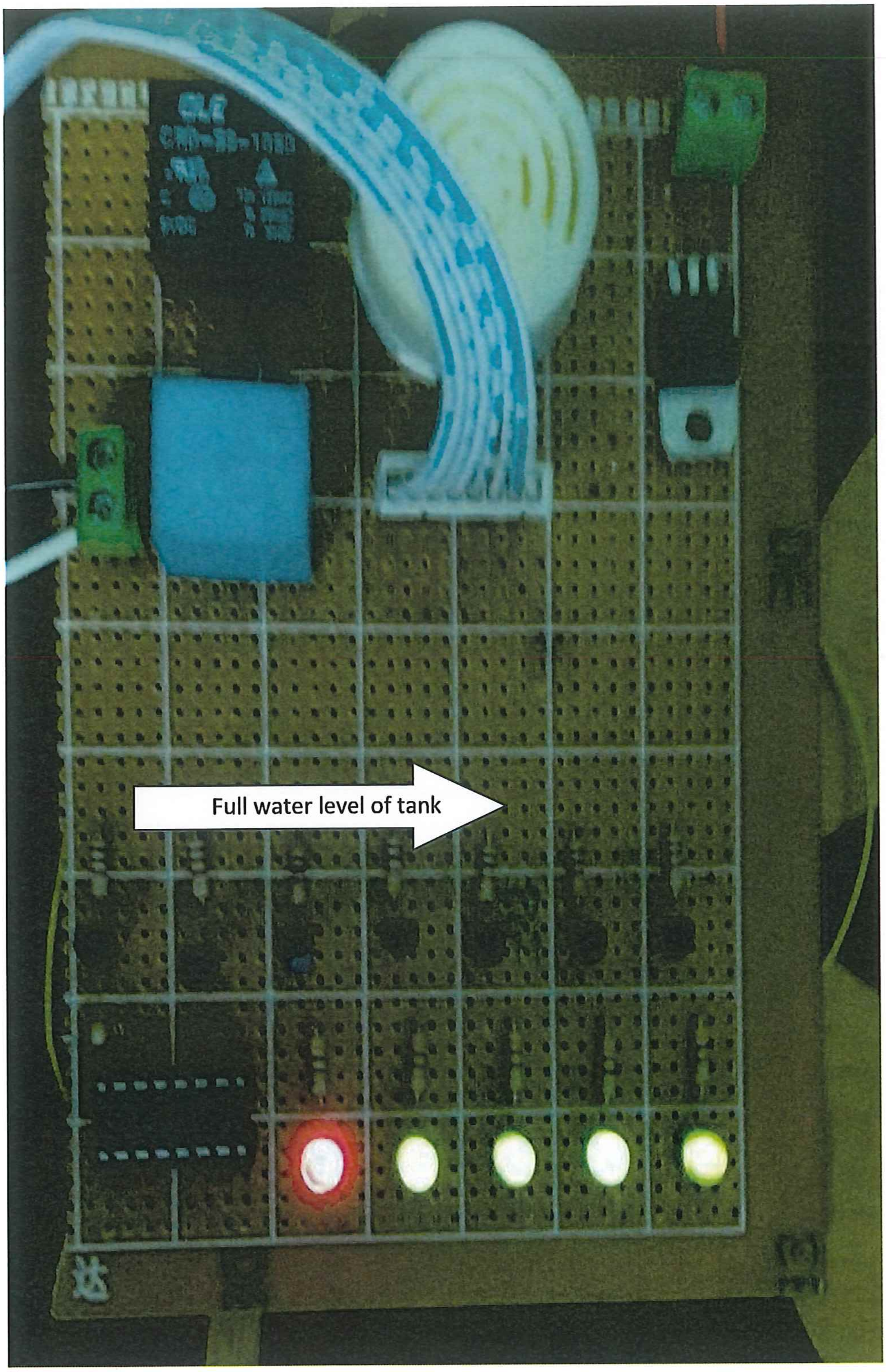

Figure 4.23: System feedback with a full tank.

Water carried by span 2= $(n^2 - 1)\, q_1$

Water carried by span 3= $(n^2 - 4)\, q_1$

Water carried by span 4= $(n^2 - 9)\, q_1$

Water carried by span 5= $(n^2 - 16)\, q_1$

That means:

Water carried by span (x) = $(n^2 - (x-1)^2)\, q_1$

Where:

q_t =total water flow carried in span (x), (m^3/sec).

q_1=discharge of span one (m^3/sec).

n= total number of spans in Center Pivot lateral system.

X= span location number.

Figure shown: the way of movement center pivot irrigation system

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

In this thesis, a fully-automated center-pivot irrigation system was designed and implemented consisting of: Water-level system: consists of a transistor, pump, relay, LED, sensor, and a water tank. Each water level has a specific sensor that detects it and gives a reading at the indicators thereby, the pump is either turned on or off. Irrigation module is used to determine the irrigation/rest hours' cycles using a microcontroller and LCD screens, with solar cells that supplies the system with power.

The Proteus simulation was used to develop the simulation design of the circuit. Hardware was implemented according to the simulation module – A microcontroller from PIC family, which is the practical choice for this kind of system, giving a satisfactory result as the coordination component for the system. It has been concluded that synchronization or real-time operation of irrigation pump control and DC motor control are possible.

It has been successfully demonstrated that the system can aptly be used to control the pump according to the water level in the tank in the irrigation/ rest hours cycles as inputted into the system.

5.2 Recommendations

The following issues are to be addressed for possible potential improvements in the design; Currently, the design is limited to a level sensor and the water irrigation system.

For further future development of this system, the following recommendations could be considered:

- Adding monitoring cameras to the system and connecting them wirelessly to a smartphone or computer.
- Using the alarm signal from the water sensor level system and connecting it with a smart phone as a system output feedback mechanism when the water level system is low.
- Utilizing a simplified control system to dust the solar cell panels used to generate electricity for the system.
- Adding a gearbox to the pump to control its speed (RPM) according to the level of water to be pumped.

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[23] Clean Power Estimator:
http://www.energy.ca.gov/cleanpower/index.html
List of Certified PV Modules:

http://www.energy.ca.gov/greengrid/certified_pv_modules.html
List of Certified Inverters:
http://www.energy.ca.gov/greengrid/certified_inverters.html
California Energy Commission, 1516 9th Street, Sacramento, CA 95814-5512, 800-555-7794 (Renewable Energy Call Center),
[24] http://en.wikipedia.org/wiki/Electric_motor

Appendix A

MikroC Code

```
// LCD module connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;
sbit LCD_RS_Direco  n at TRISB4_bit;
sbit LCD_EN_Direco  n at TRISB5_bit;
sbit LCD_D4_Direco  n at TRISB0_bit;
sbit LCD_D5_Direco  n at TRISB1_bit;
sbit LCD_D6_Direco  n at TRISB2_bit;
sbit LCD_D7_Direco  n at TRISB3_bit;
// End LCD module connections
sbit sw1 at portc.B0;
sbit sw2 at portc.B1;
sbit sw3 at portc.B2;
int x,y,k=0;
char txt1[7];
char txt2[7];
void main()
{
  trisd=0;
  portd=0;
  Lcd_Init();
```

```
Lcd_Cmd(_LCD_CURSOR_OFF);
Lcd_Out(1,5,"Hello ,,!");
delay_ms(500);
Lcd_Out(1,1,"Pivot Errigao   n");
Lcd_Out(2,6,"System");
delay_ms(1500);
Lcd_Cmd(_LCD_CLEAR);
 while(1){
IntToStr(x, txt1);
IntToStr(y, txt2);
   l2:
  Delay_ms(50);   //Switch Debounce
  if(x <= 0)
   {x=0;}
  if(y <= 0)
   {y=0;}
  Lcd_Out(1,1,"Irreg Cycle =");
  Lcd_Out(2,10,"Hour");
  Lcd_Out(2,3,txt1);

   if(sw1 == 0)
   {x++;Delay_ms(200);}

   if(sw2 == 0)
   {x--;delay_ms(200);}
```

```
if(sw3 == 0) {delay_ms(50);goto h1}
}
h1:
while(1)
{Lcd_Cmd(_LCD_CLEAR);Lcd_Out(1,1,"Rest Houres
=");Lcd_Out(2,10,"Houre"); IntToStr(y,
txt2);Lcd_Out(2,3,txt2);delay_ms(200);
if(sw1 == 0)
{y++;Delay_ms(200);}
if(sw2 == 0)
{y--;delay_ms(200);}
if(sw3 == 0){delay_ms(200);goto h2}
}
h2:
while(1){
Lcd_Cmd(_LCD_CLEAR);Lcd_Out(2,1,"H/Irreg   H/rest");
Lcd_Out(1,1,txt1);Lcd_Out(1,8,txt2);delay_ms(500);
if(sw3 == 0){delay_ms(200);goto h3}
}
h3:
while(1){
for (k=0;k<=x;k++){Lcd_Cmd(_LCD_CLEAR);Lcd_Out(1,1,"Errigao  n
on");Lcd_Out(2,1,"Progress ..");portd.b0=1;delay_ms(1000);}
for (k=0;k<=y;k++){Lcd_Cmd(_LCD_CLEAR);Lcd_Out(1,4,"Rest
Time");portd.b0=0;delay_ms(1000);}
}
}
```

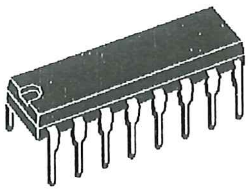
Appendix B

ULN2003A Datasheet

ULN2001A-ULN2002A
ULN2003A-ULN2004A

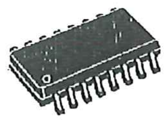
SEVEN DARLINGTON ARRAYS

- SEVEN DARLINGTONS PER PACKAGE
- OUTPUT CURRENT 500mA PER DRIVER (600mA PEAK)
- OUTPUT VOLTAGE 50V
- INTEGRATED SUPPRESSION DIODES FOR INDUCTIVE LOADS
- OUTPUTS CAN BE PARALLELED FOR HIGHER CURRENT
- TTL/CMOS/PMOS/DTL COMPATIBLE INPUTS
- INPUTS PINNED OPPOSITE OUTPUTS TO SIMPLIFY LAYOUT



DIP16

ORDERING NUMBERS: ULN2001A/2A/3A/4A



SO16

ORDERING NUMBERS: ULN2001D/2D/3D/4D

DESCRIPTION

The ULN2001A, ULN2002A, ULN2003 and ULN2004A are high voltage, high current darlington arrays each containing seven open collector darlington pairs with common emitters. Each channel rated at 500mA and can withstand peak currents of 600mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout.

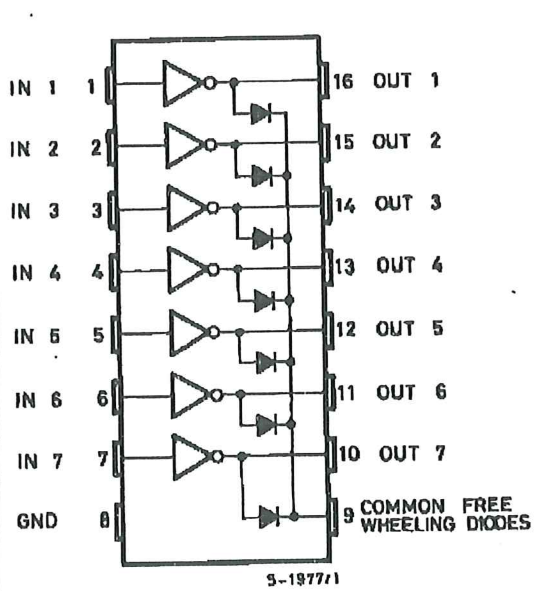
The four versions interface to all common logic families :

ULN2001A	General Purpose, DTL, TTL, PMOS, CMOS
ULN2002A	14-25V PMOS
ULN2003A	5V TTL, CMOS
ULN2004A	6–15V CMOS, PMOS

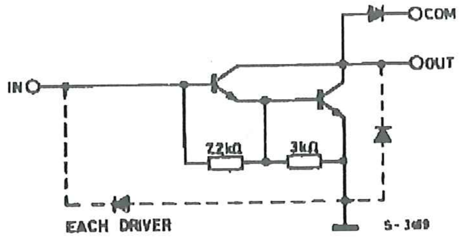
These versatile devices are useful for driving a wide range of loads including solenoids, relays DC motors, LED displays filament lamps, thermal printheads and high power buffers.

The ULN2001A/2002A/2003Aand 2004A are supplied in 16 pin plastic DIP packages with a copper leadframe to reduce thermal resistance. They are available also in small outline package (SO-16) as ULN2001D/2002D/2003D/2004D.

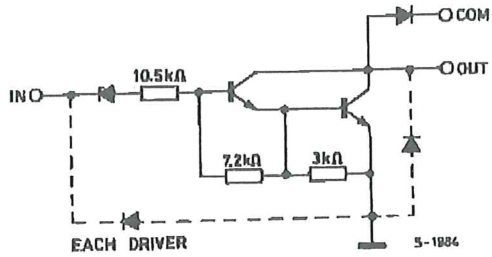
PIN CONNECTION



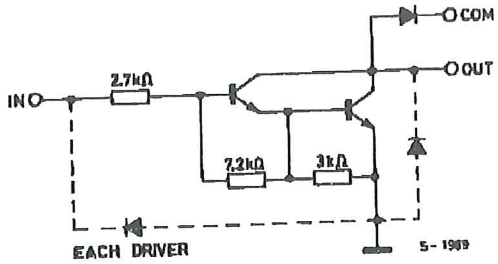
SCHEMATIC DIAGRAM



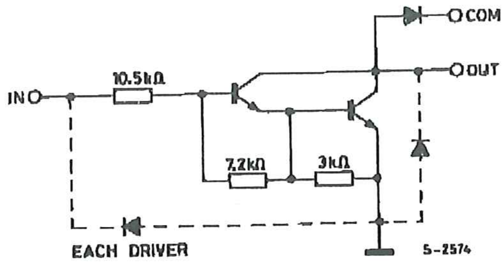
Series ULN-2001A
(each driver)



Series ULN-2002A
(each driver)



Series ULN-2003A
(each driver)



Series ULN-2004A
(each driver)

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_o	Output Voltage	50	V
V_{in}	Input Voltage (for ULN2002A/D - 2003A/D - 2004A/D)	30	V
I_c	Continuous Collector Current	500	mA
I_b	Continuous Base Current	25	mA
T_{amb}	Operating Ambient Temperature Range	– 20 to 85	°C
T_{stg}	Storage Temperature Range	– 55 to 150	°C
T_j	Junction Temperature	150	°C

THERMAL DATA

Symbol	Parameter		DIP16	SO16	Unit
$R_{th\ j\text{-}amb}$	Thermal Resistance Junction-ambient	Max.	70	100	°C/W

ELECTRICAL CHARACTERISTICS (T_{amb} = 25°C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit	Fig.
I_{CEX}	Output Leakage Current	V_{CE} = 50V T_{amb} = 70°C, V_{CE} = 50V T_{amb} = 70°C for ULN2002A V_{CE} = 50V, V_I = 6V for ULN2004A V_{CE} = 50V, V_I = 1V			50 100 500 500	µA µA µA µA	1a 1a 1b 1b
$V_{CE(sat)}$	Collector-emitter Saturation Voltage	I_C = 100mA, I_B = 250µA I_C = 200 mA, I_B = 350µA I_C = 350mA, I_B = 500µA		0.9 1.1 1.3	1.1 1.3 1.6	V V V	2 2 2
$I_{I(on)}$	Input Current	for ULN2002A, V_i = 17V for ULN2003A, V_i = 3.85V for ULN2004A, V_i = 5V V_I = 12V		0.82 0.93 0.35 1	1.25 1.35 0.5 1.45	mA mA mA mA	3 3 3 3
$I_{I(off)}$	Input Current	T_{amb} = 70°C, I_C = 500µA	50	65		µA	4
$V_{I(on)}$	Input Voltage	V_{CE} = 2V for ULN2002A I_C = 300mA for ULN2003A I_C = 200mA I_C = 250mA I_C = 300mA for ULN2004A I_C = 125mA I_C = 200mA I_C = 275mA I_C = 350mA			 13 2.4 2.7 3 5 6 7 8	V	5
h_{FE}	DC Forward Current Gain	for ULN2001A V_{CE} = 2V, I_C = 350mA	1000				2
C_i	Input Capacitance			15	25	pF	
t_{PLH}	Turn-on Delay Time	0.5 V_i to 0.5 V_o		0.25	1	µs	
t_{PHL}	Turn-off Delay Time	0.5 V_i to 0.5 V_o		0.25	1	µs	
I_R	Clamp Diode Leakage Current	V_R = 50V T_{amb} = 70°C, V_R = 50V			50 100	µA µA	6 6
V_F	Clamp Diode Forward Voltage	I_F = 350mA		1.7	2	V	7

TEST CIRCUITS

Figure 1a.

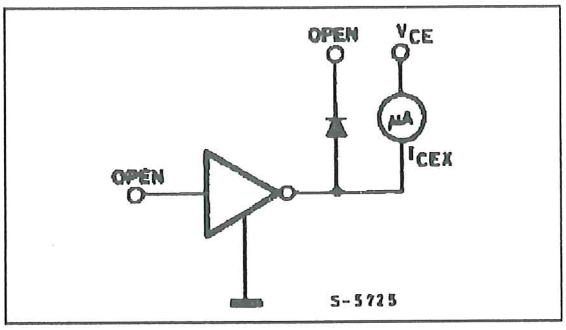


Figure 1b.

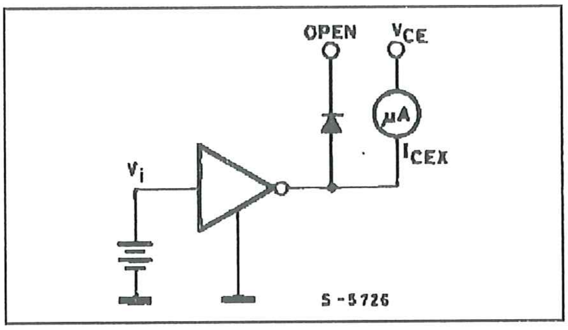


Figure 2.

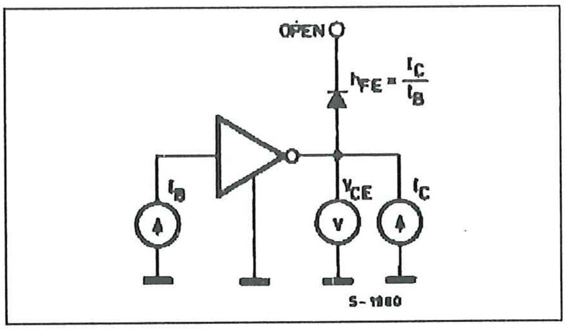


Figure 3.

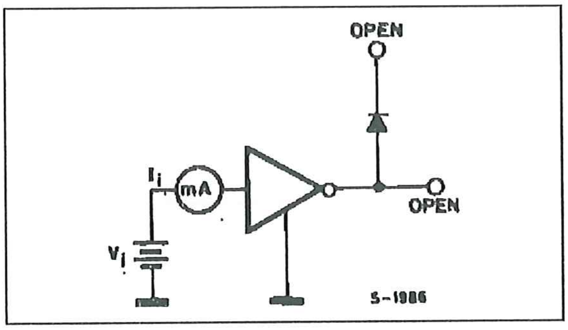


Figure 4.

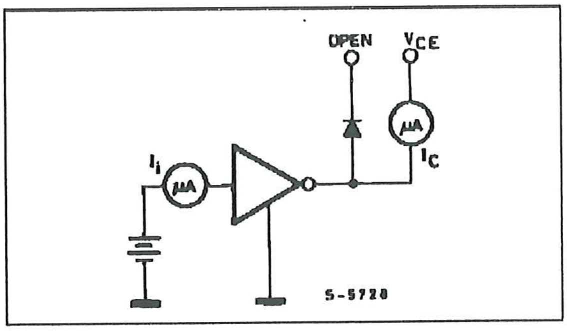


Figure 5.

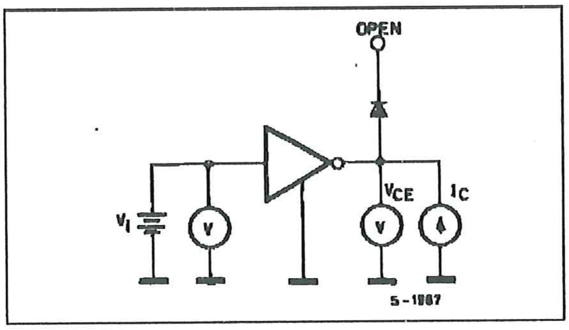


Figure 6.

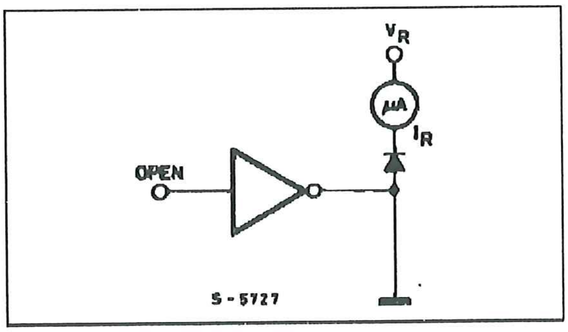


Figure 7.

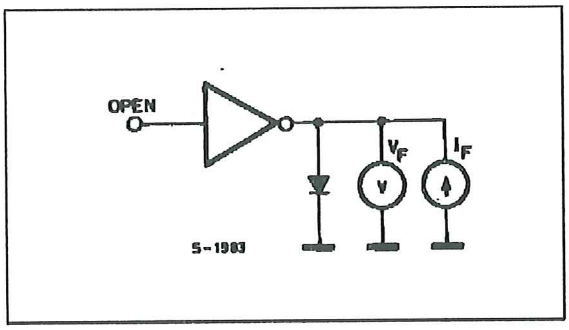


Figure 8: Collector Current versus Input Current

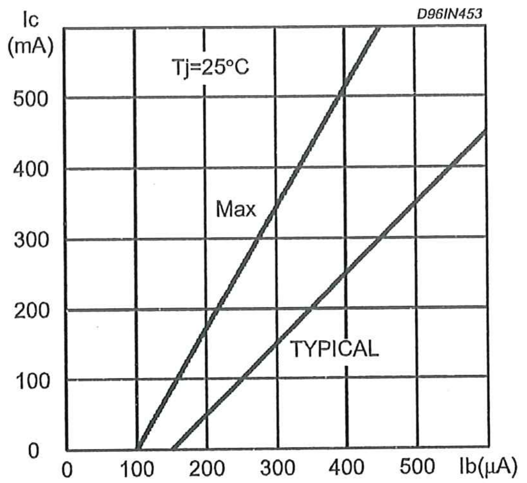


Figure 9: Collector Current versus Saturation Voltage

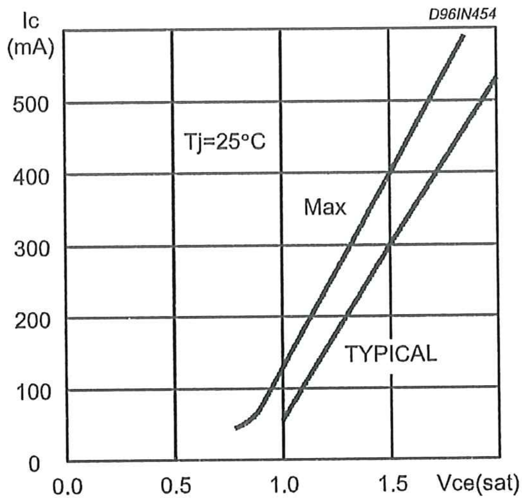


Figure 10: Peak Collector Current versus Duty Cycle

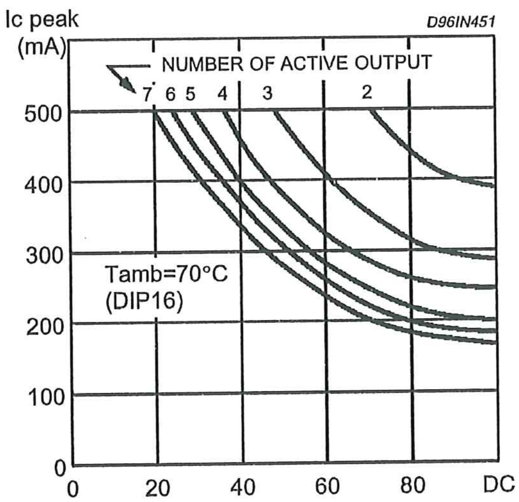
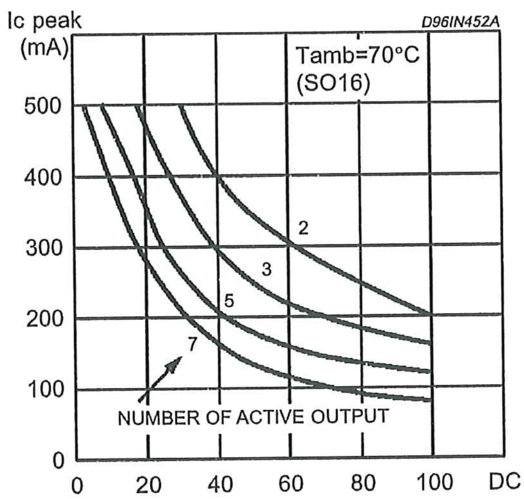
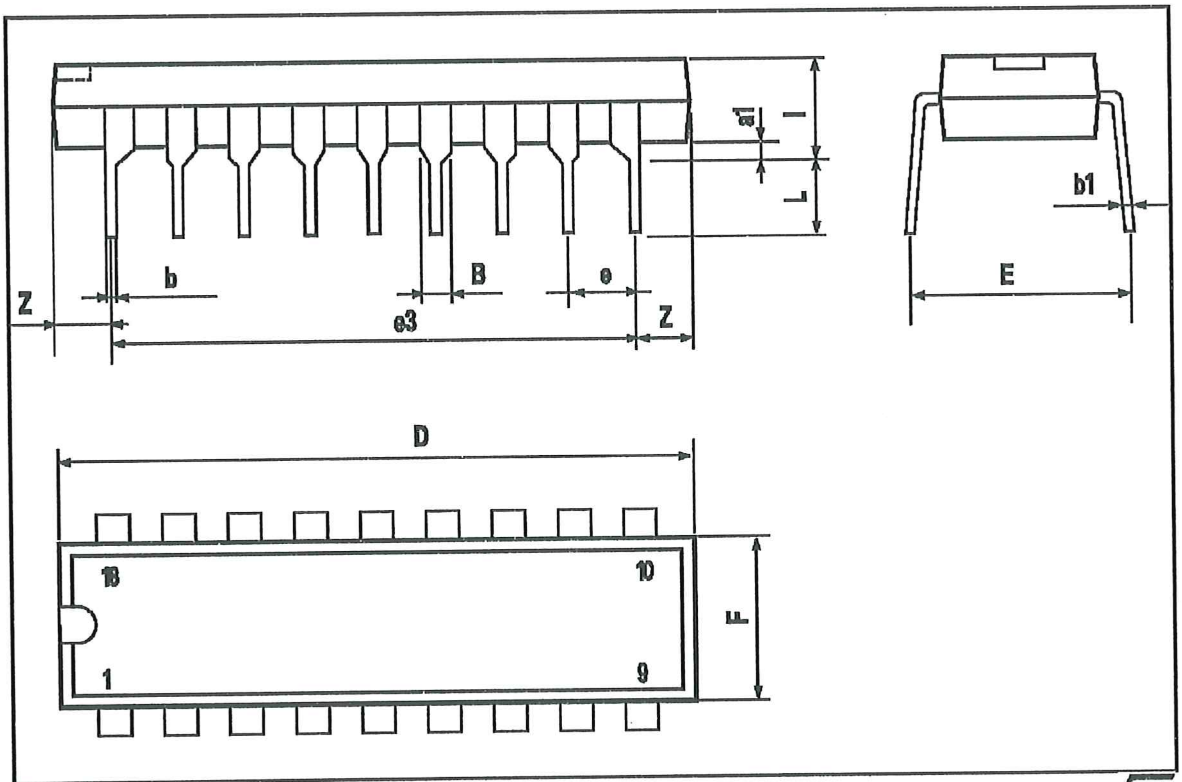


Figure 11: Peak Collector Current versus Duty Cycle



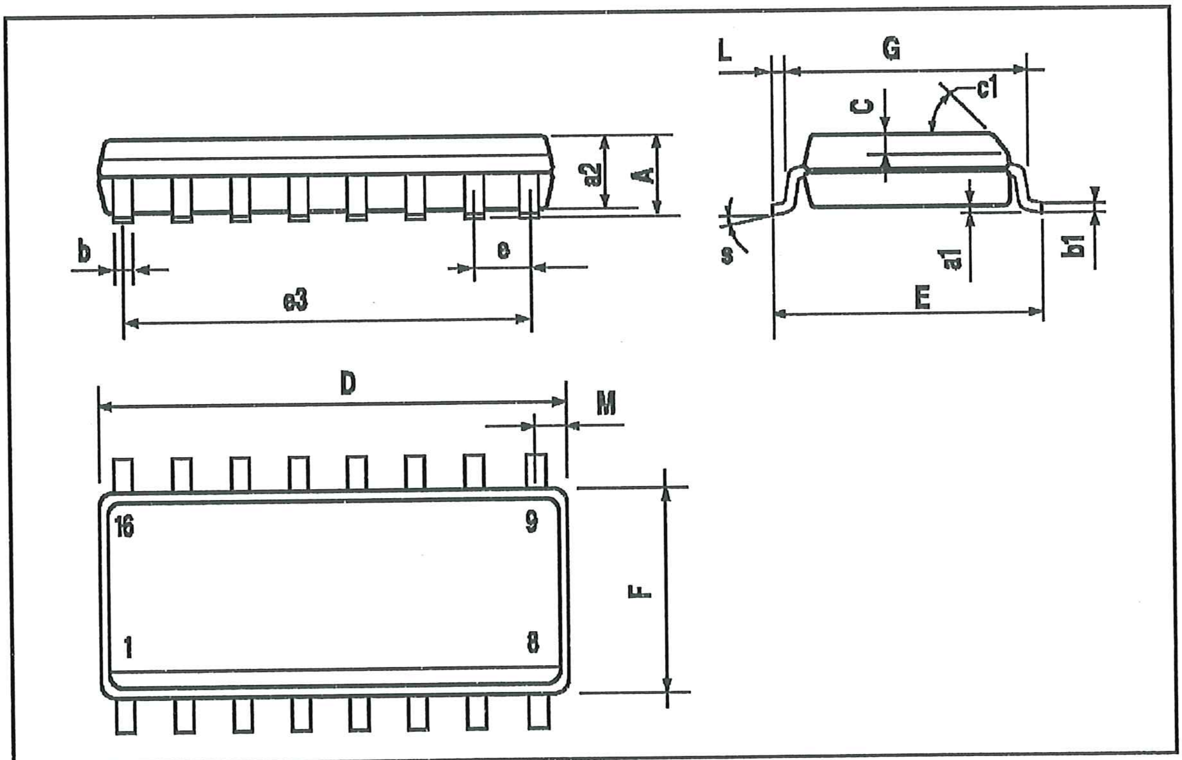
DIP16 PACKAGE MECHANICAL DATA

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
a1	0.51			0.020		
B	0.77		1.65	0.030		0.065
b		0.5			0.020	
b1		0.25			0.010	
D			20			0.787
E		8.5			0.335	
e		2.54			0.100	
e3		17.78			0.700	
F			7.1			0.280
I			5.1			0.201
L		3.3			0.130	
Z			1.27			0.050



SO16 PACKAGE MECHANICAL DATA

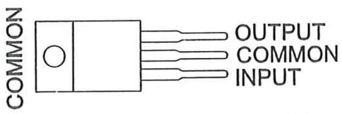
DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A			1.75			0.069
a1	0.1		0.25	0.004		0.009
a2			1.6			0.063
b	0.35		0.46	0.014		0.018
b1	0.19		0.25	0.007		0.010
C		0.5			0.020	
c1	45 (typ.)					
D	9.8		10	0.386		0.394
E	5.8		6.2	0.228		0.244
e		1.27			0.050	
e3		8.89			0.350	
F	3.8		4.0	0.150		0.157
L	0.4		1.27	0.016		0.050
M			0.62			0.024
S	8 (max.)					



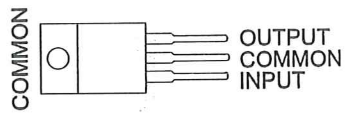
Appendix C
LM7805 Datasheet

- 3-Terminal Regulators
- Output Current up to 1.5 A
- Internal Thermal-Overload Protection
- High Power-Dissipation Capability
- Internal Short-Circuit Current Limiting
- Output Transistor Safe-Area Compensation

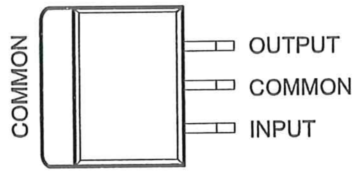
KC (TO-220) PACKAGE
(TOP VIEW)



KCS (TO-220) PACKAGE
(TOP VIEW)



KTE PACKAGE
(TOP VIEW)



description/ordering information

This series of fixed-voltage integrated-circuit voltage regulators is designed for a wide range of applications. These applications include on-card regulation for elimination of noise and distribution problems associated with single-point regulation. Each of these regulators can deliver up to 1.5 A of output current. The internal current-limiting and thermal-shutdown features of these regulators essentially make them immune to overload. In addition to use as fixed-voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents, and also can be used as the power-pass element in precision regulators.

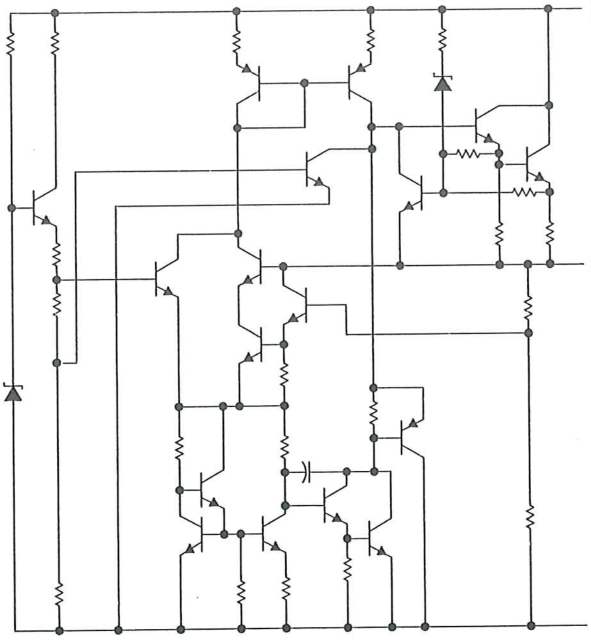
ORDERING INFORMATION

T_J	$V_{O(NOM)}$ (V)	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 125°C	5	POWER-FLEX (KTE)	Reel of 2000	μA7805CKTER	μA7805C
		TO-220 (KC)	Tube of 50	μA7805CKC	μA7805C
		TO-220, short shoulder (KCS)	Tube of 20	μA7805CKCS	
	8	POWER-FLEX (KTE)	Reel of 2000	μA7808CKTER	μA7808C
		TO-220 (KC)	Tube of 50	μA7808CKC	μA7808C
		TO-220, short shoulder (KCS)	Tube of 20	μA7808CKCS	
	10	POWER-FLEX (KTE)	Reel of 2000	μA7810CKTER	μA7810C
		TO-220 (KC)	Tube of 50	μA7810CKC	μA7810C
	12	POWER-FLEX (KTE)	Reel of 2000	μA7812CKTER	μA7812C
		TO-220 (KC)	Tube of 50	μA7812CKC	μA7812C
		TO-220, short shoulder (KCS)	Tube of 20	μA7812CKCS	
	15	POWER-FLEX (KTE)	Reel of 2000	μA7815CKTER	μA7815C
		TO-220 (KC)	Tube of 50	μA7815CKC	μA7815C
		TO-220, short shoulder (KCS)	Tube of 20	μA7815CKCS	
	24	POWER-FLEX (KTE)	Reel of 2000	μA7824CKTER	μA7824C
		TO-220 (KC)	Tube of 50	μA7824CKC	μA7824C

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

schematic



absolute maximum ratings over virtual junction temperature range (unless otherwise noted)†

Input voltage, V_I: μA7824C	40 V
All others	35 V
Operating virtual junction temperature, T_J	150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	260°C
Storage temperature range, T_{stg}	–65°C to 150°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

package thermal data (see Note 1)

PACKAGE	BOARD	θ_{JC}	θ_{JA}
POWER-FLEX (KTE)	High K, JESD 51-5	3°C/W	23°C/W
TO-220 (KC/KCS)	High K, JESD 51-5	3°C/W	19°C/W

NOTE 1: Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) – T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can affect reliability.

recommended operating conditions

			MIN	MAX	UNIT
V_I	Input voltage	µA7805C	7	25	V
		µA7808C	10.5	25	
		µA7810C	12.5	28	
		µA7812C	14.5	30	
		µA7815C	17.5	30	
		µA7824C	27	38	
I_O	Output current			1.5	A
T_J	Operating virtual junction temperature	µA7800C series	0	125	°C

electrical characteristics at specified virtual junction temperature, V_I = 10 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_J†	µA7805C MIN	µA7805C TYP	µA7805C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, V_I = 7 V to 20 V, $P_D \le$ 15 W	25°C	4.8	5	5.2	V
		0°C to 125°C	4.75		5.25	
Input voltage regulation	V_I = 7 V to 25 V	25°C		3	100	mV
	V_I = 8 V to 12 V			1	50	
Ripple rejection	V_I = 8 V to 18 V, f = 120 Hz	0°C to 125°C	62	78		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		15	100	mV
	I_O = 250 mA to 750 mA			5	50	
Output resistance	f = 1 kHz	0°C to 125°C		0.017		Ω
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–1.1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		40		µV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.2	8	mA
Bias current change	V_I = 7 V to 25 V	0°C to 125°C			1.3	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		750		mA
Peak output current		25°C		2.2		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-µF capacitor across the input and a 0.1-µF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 14 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_J†	μA7808C MIN	μA7808C TYP	μA7808C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, V_I = 10.5 V to 23 V, P_D ≤ 15 W	25°C	7.7	8	8.3	V
		0°C to 125°C	7.6		8.4	
Input voltage regulation	V_I = 10.5 V to 25 V	25°C		6	160	mV
	V_I = 11 V to 17 V			2	80	
Ripple rejection	V_I = 11.5 V to 21.5 V, f = 120 Hz	0°C to 125°C	55	72		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	160	mV
	I_O = 250 mA to 750 mA			4	80	
Output resistance	f = 1 kHz	0°C to 125°C		0.016		Ω
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–0.8		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		52		μV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.3	8	mA
Bias current change	V_I = 10.5 V to 25 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		450		mA
Peak output current		25°C		2.2		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 17 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_J†	μA7810C MIN	μA7810C TYP	μA7810C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, V_I = 12.5 V to 25 V, P_D ≤ 15 W	25°C	9.6	10	10.4	V
		0°C to 125°C	9.5	10	10.5	
Input voltage regulation	V_I = 12.5 V to 28 V	25°C		7	200	mV
	V_I = 14 V to 20 V			2	100	
Ripple rejection	V_I = 13 V to 23 V, f = 120 Hz	0°C to 125°C	55	71		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	200	mV
	I_O = 250 mA to 750 mA			4	100	
Output resistance	f = 1 kHz	0°C to 125°C		0.018		Ω
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		–1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		70		μV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.3	8	mA
Bias current change	V_I = 12.5 V to 28 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		400		mA
Peak output current		25°C		2.2		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 19 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS		T_J†	μA7812C MIN	μA7812C TYP	μA7812C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, $P_D \le$ 15 W	V_I = 14.5 V to 27 V,	25°C	11.5	12	12.5	V
			0°C to 125°C	11.4		12.6	
Input voltage regulation	V_I = 14.5 V to 30 V		25°C		10	240	mV
	V_I = 16 V to 22 V				3	120	
Ripple rejection	V_I = 15 V to 25 V,	f = 120 Hz	0°C to 125°C	55	71		dB
Output voltage regulation	I_O = 5 mA to 1.5 A		25°C		12	240	mV
	I_O = 250 mA to 750 mA				4	120	
Output resistance	f = 1 kHz		0°C to 125°C		0.018		Ω
Temperature coefficient of output voltage	I_O = 5 mA		0°C to 125°C		−1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz		25°C		75		μV
Dropout voltage	I_O = 1 A		25°C		2		V
Bias current			25°C		4.3	8	mA
Bias current change	V_I = 14.5 V to 30 V		0°C to 125°C			1	mA
	I_O = 5 mA to 1 A					0.5	
Short-circuit output current			25°C		350		mA
Peak output current			25°C		2.2		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 23 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS		T_J†	μA7815C MIN	μA7815C TYP	μA7815C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, $P_D \le$ 15 W	V_I = 17.5 V to 30 V,	25°C	14.4	15	15.6	V
			0°C to 125°C	14.25		15.75	
Input voltage regulation	V_I = 17.5 V to 30 V		25°C		11	300	mV
	V_I = 20 V to 26 V				3	150	
Ripple rejection	V_I = 18.5 V to 28.5 V,	f = 120 Hz	0°C to 125°C	54	70		dB
Output voltage regulation	I_O = 5 mA to 1.5 A		25°C		12	300	mV
	I_O = 250 mA to 750 mA				4	150	
Output resistance	f = 1 kHz		0°C to 125°C		0.019		Ω
Temperature coefficient of output voltage	I_O = 5 mA		0°C to 125°C		−1		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz		25°C		90		μV
Dropout voltage	I_O = 1 A		25°C		2		V
Bias current			25°C		4.4	8	mA
Bias current change	V_I = 17.5 V to 30 V		0°C to 125°C			1	mA
	I_O = 5 mA to 1 A					0.5	
Short-circuit output current			25°C		230		mA
Peak output current			25°C		2.1		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

electrical characteristics at specified virtual junction temperature, V_I = 33 V, I_O = 500 mA (unless otherwise noted)

PARAMETER	TEST CONDITIONS	T_J†	μA7824C MIN	μA7824C TYP	μA7824C MAX	UNIT
Output voltage	I_O = 5 mA to 1 A, V_I = 27 V to 38 V, P_D ≤ 15 W	25°C	23	24	25	V
		0°C to 125°C	22.8		25.2	
Input voltage regulation	V_I = 27 V to 38 V	25°C		18	480	mV
	V_I = 30 V to 36 V			6	240	
Ripple rejection	V_I = 28 V to 38 V, f = 120 Hz	0°C to 125°C	50	66		dB
Output voltage regulation	I_O = 5 mA to 1.5 A	25°C		12	480	mV
	I_O = 250 mA to 750 mA			4	240	
Output resistance	f = 1 kHz	0°C to 125°C		0.028		Ω
Temperature coefficient of output voltage	I_O = 5 mA	0°C to 125°C		−1.5		mV/°C
Output noise voltage	f = 10 Hz to 100 kHz	25°C		170		μV
Dropout voltage	I_O = 1 A	25°C		2		V
Bias current		25°C		4.6	8	mA
Bias current change	V_I = 27 V to 38 V	0°C to 125°C			1	mA
	I_O = 5 mA to 1 A				0.5	
Short-circuit output current		25°C		150		mA
Peak output current		25°C		2.1		A

† Pulse-testing techniques maintain the junction temperature as close to the ambient temperature as possible. Thermal effects must be taken into account separately. All characteristics are measured with a 0.33-μF capacitor across the input and a 0.1-μF capacitor across the output.

APPLICATION INFORMATION

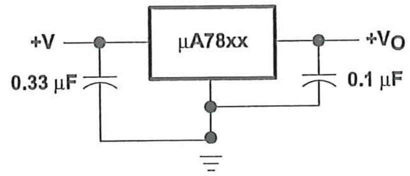


Figure 1. Fixed-Output Regulator

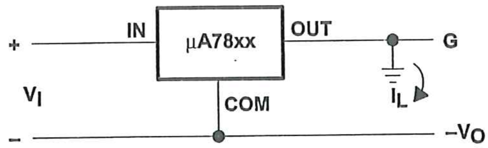
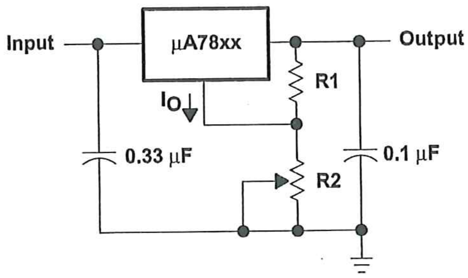


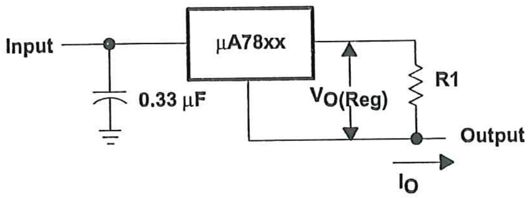
Figure 2. Positive Regulator in Negative Configuration (V_I Must Float)



NOTE A: The following formula is used when V_{xx} is the nominal output voltage (output to common) of the fixed regulator:

$$V_O = V_{xx} + \left(\frac{V_{xx}}{R1} + I_Q\right)R2$$

Figure 3. Adjustable-Output Regulator



$I_O = (V_O/R1) + I_O$ Bias Current

Figure 4. Current Regulator

APPLICATION INFORMATION

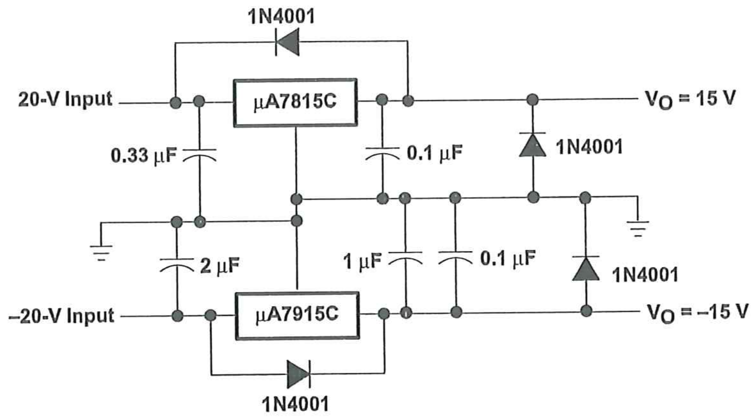


Figure 5. Regulated Dual Supply

operation with a load common to a voltage of opposite polarity

In many cases, a regulator powers a load that is not connected to ground but, instead, is connected to a voltage source of opposite polarity (e.g., operational amplifiers, level-shifting circuits, etc.). In these cases, a clamp diode should be connected to the regulator output as shown in Figure 6. This protects the regulator from output polarity reversals during startup and short-circuit operation.

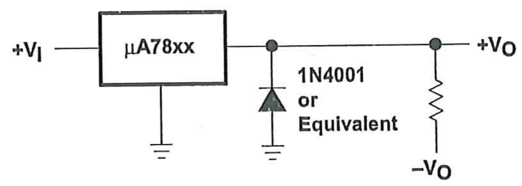


Figure 6. Output Polarity-Reversal-Protection Circuit

reverse-bias protection

Occasionally, the input voltage to the regulator can collapse faster than the output voltage. This can occur, for example, when the input supply is crowbarred during an output overvoltage condition. If the output voltage is greater than approximately 7 V, the emitter-base junction of the series-pass element (internal or external) could break down and be damaged. To prevent this, a diode shunt can be used as shown in Figure 7.

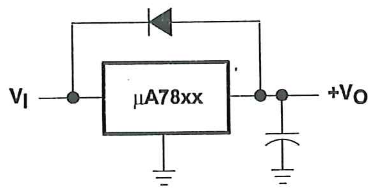
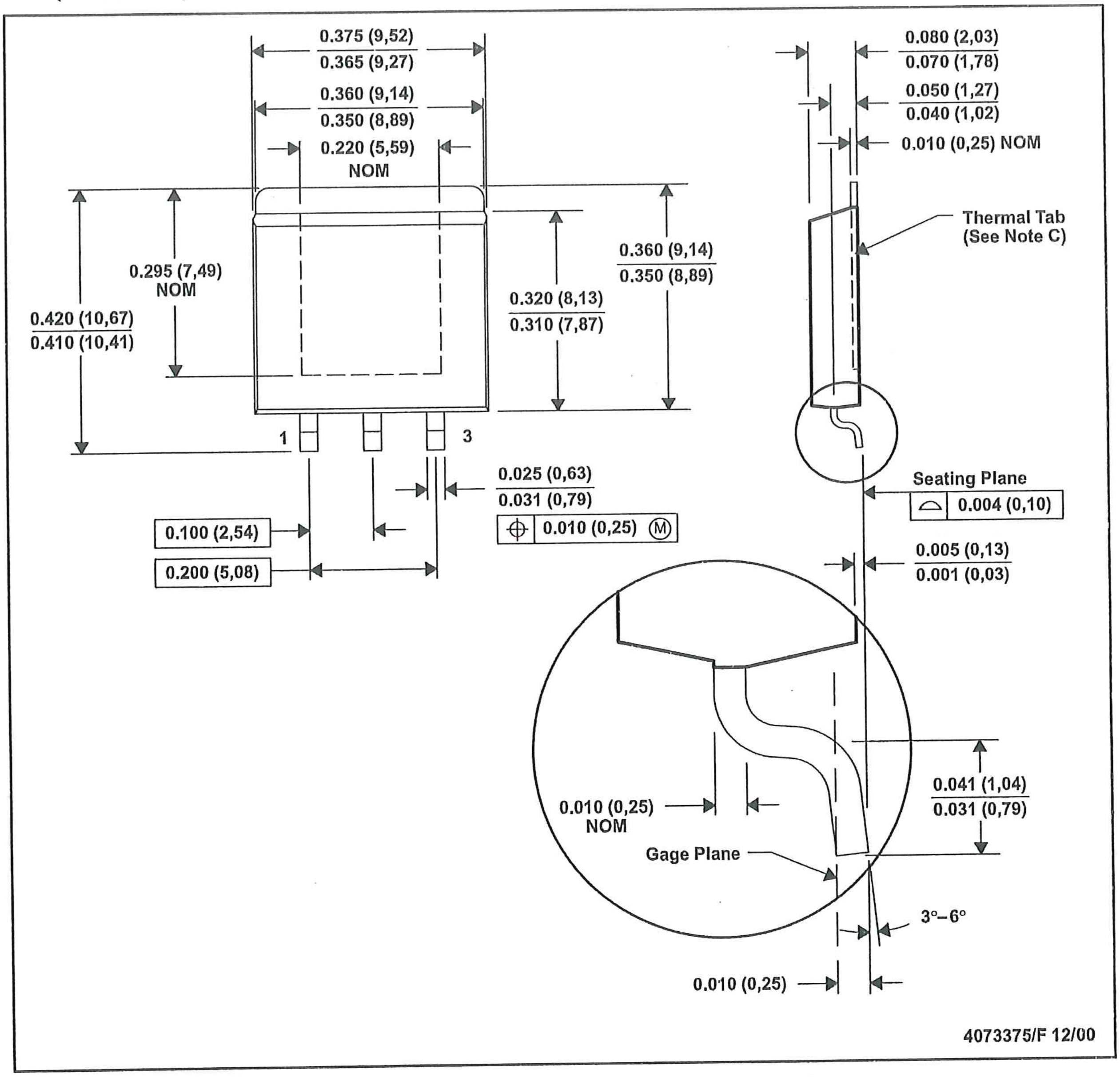


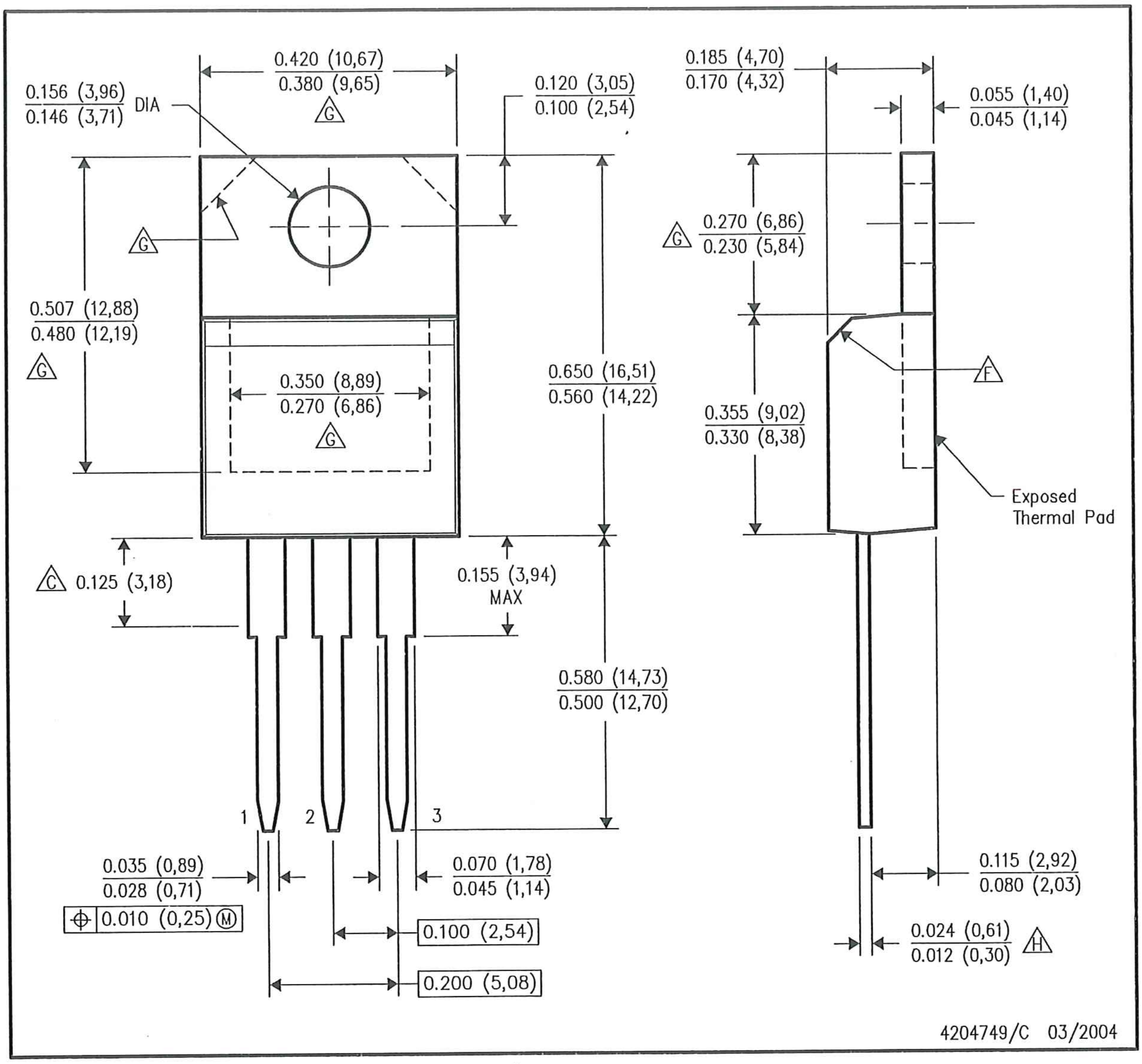
Figure 7. Reverse-Bias-Protection Circuit

KTE (R-PSFM-G3) **PowerFLEX™ PLASTIC FLANGE-MOUNT**



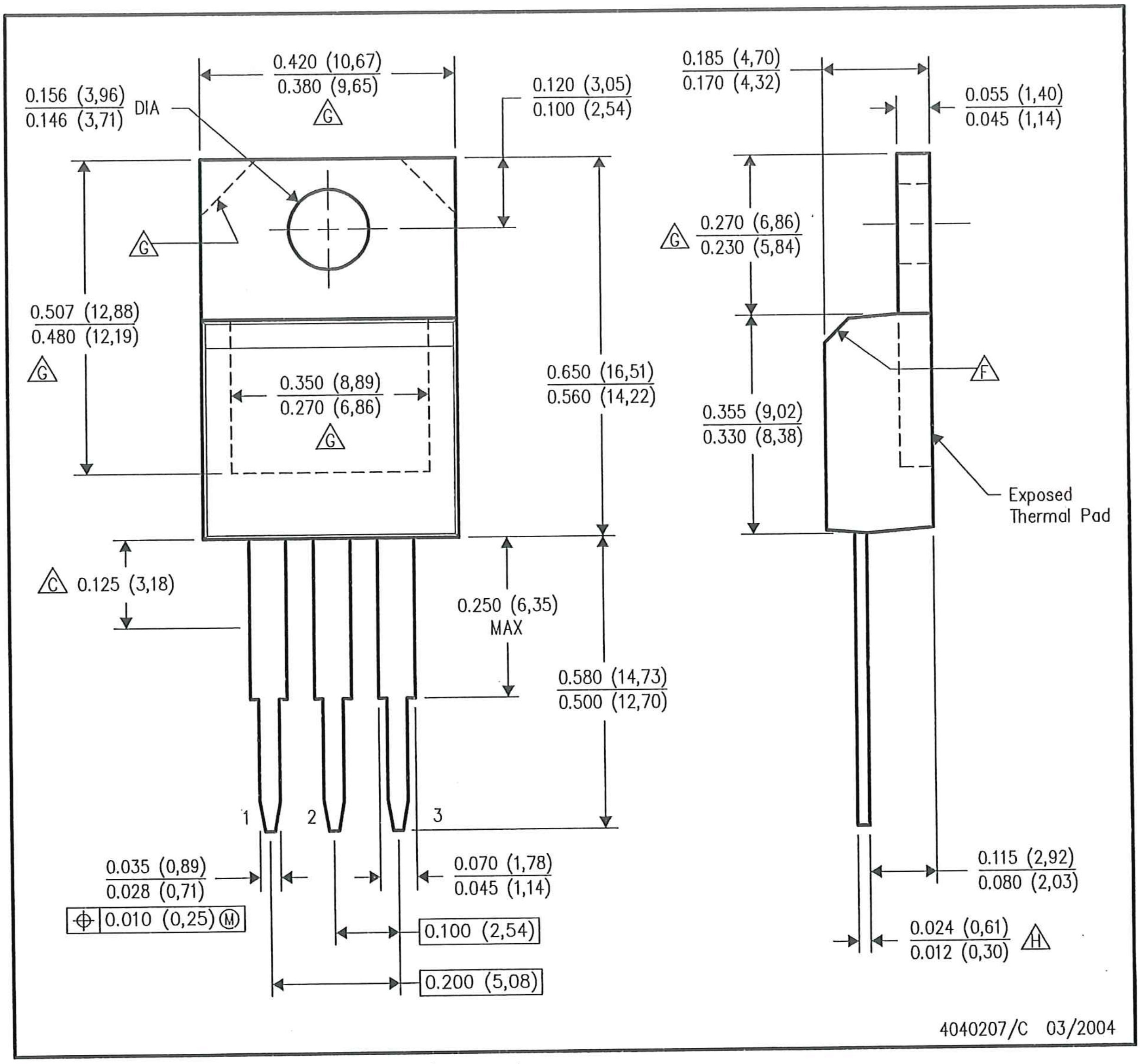
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. The center lead is in electrical contact with the thermal tab.
D. Dimensions do not include mold protrusions, not to exceed 0.006 (0,15).
E. Falls within JEDEC MO-169

KCS (R-PSFM-T3) PLASTIC FLANGE-MOUNT PACKAGE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C (triangle). Lead dimensions are not controlled within this area.
- D. All lead dimensions apply before solder dip.
- E. The center lead is in electrical contact with the mounting tab.
- F (triangle). The chamfer is optional.
- G (triangle). Thermal pad contour optional within these dimensions.
- H (triangle). Falls within JEDEC TO-220 variation AB, except minimum lead thickness.

KC (R-PSFM-T3) PLASTIC FLANGE-MOUNT PACKAGE



NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Lead dimensions are not controlled within this area.
- D. All lead dimensions apply before solder dip.
- E. The center lead is in electrical contact with the mounting tab.
- F. The chamfer is optional.
- G. Thermal pad contour optional within these dimensions.
- H. Falls within JEDEC TO-220 variation AB, except minimum lead thickness.

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Appendix D

PIC16F877A Datasheet

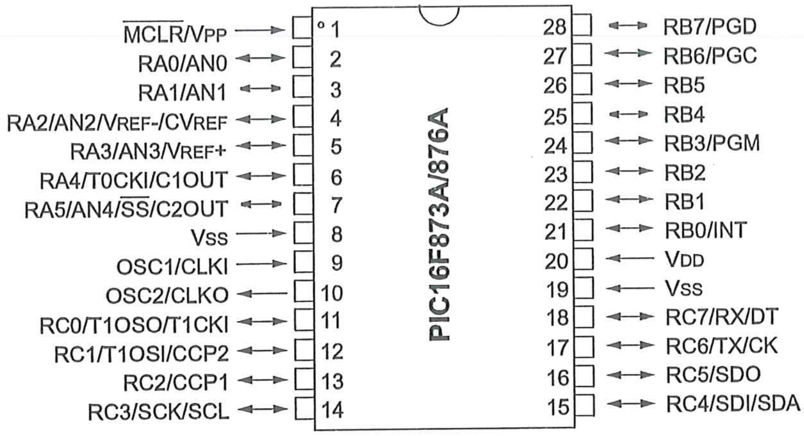
MICROCHIP

PIC16F87XA Data Sheet

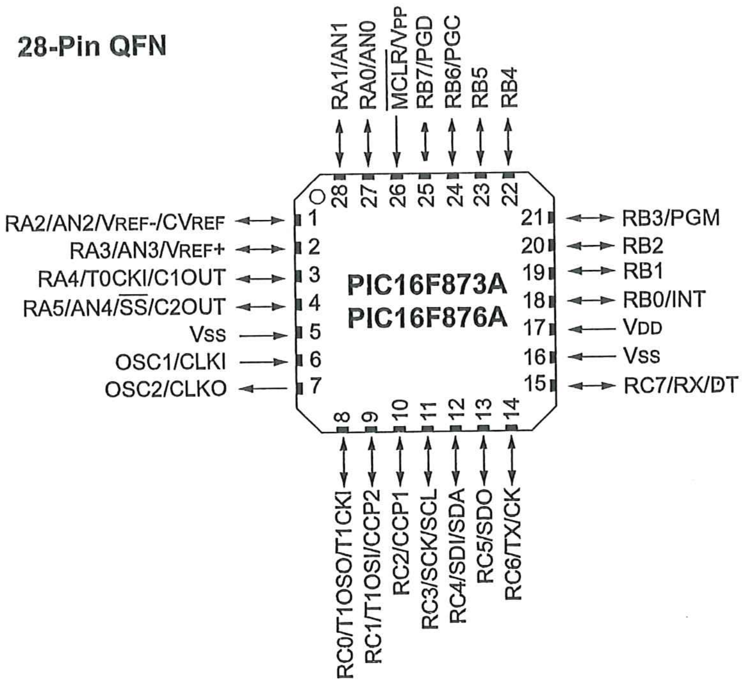
28/40/44-Pin Enhanced Flash Microcontrollers

Pin Diagrams

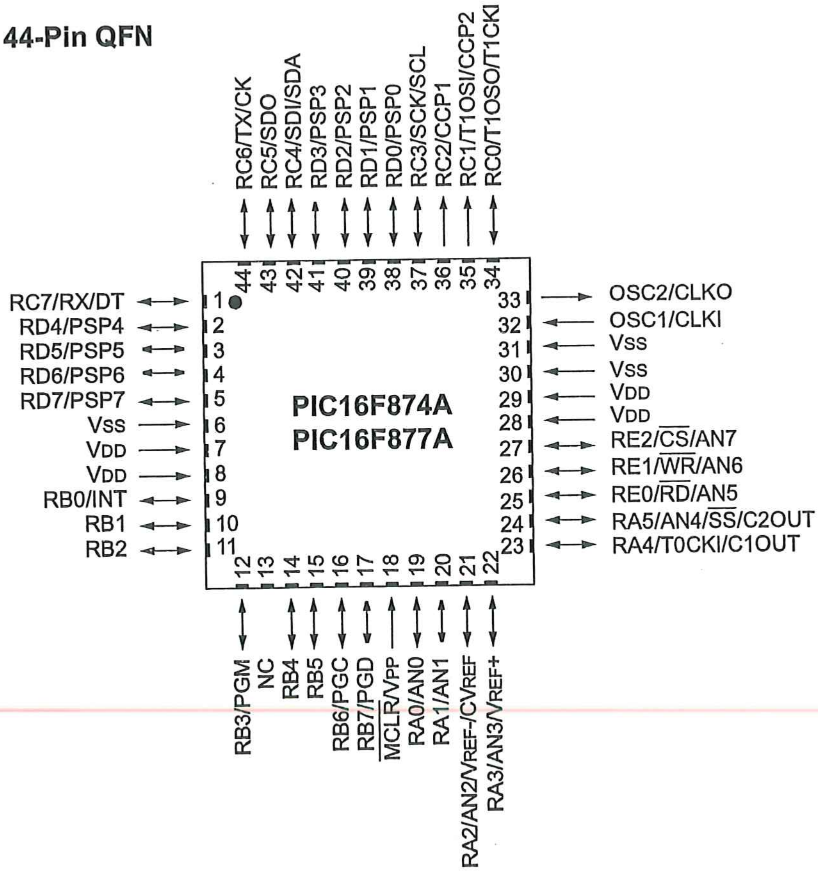
28-Pin PDIP, SOIC, SSOP



28-Pin QFN

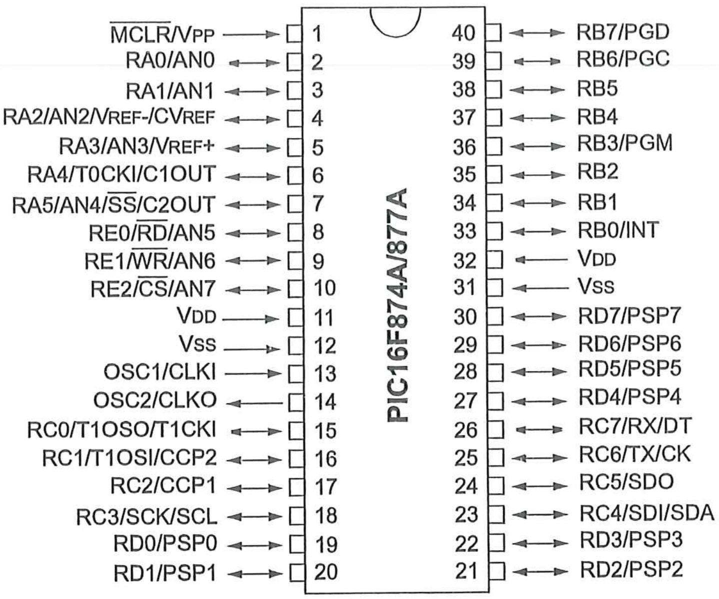


44-Pin QFN

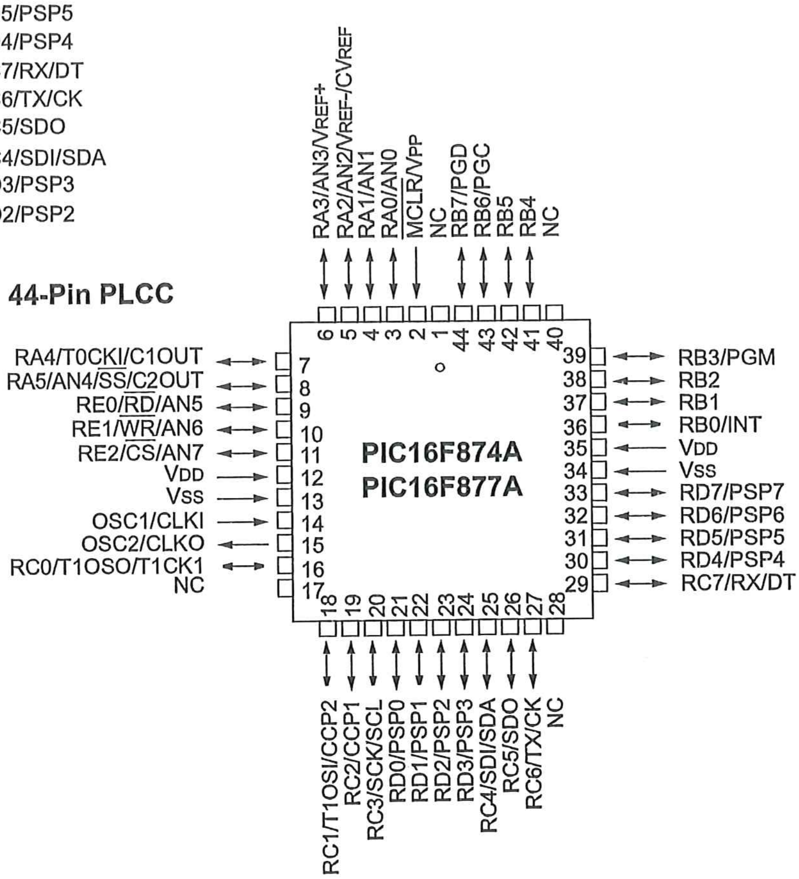


Pin Diagrams (Continued)

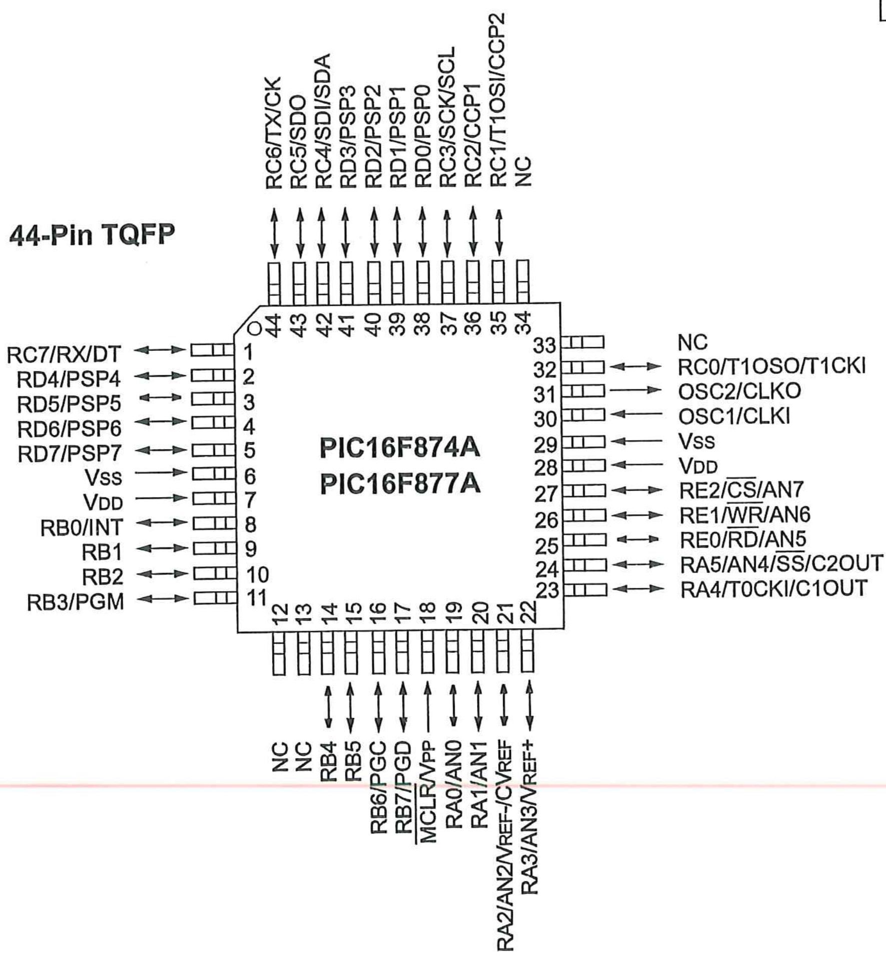
40-Pin PDIP



44-Pin PLCC



44-Pin TQFP



Appendix E

The Center Pivot Irrigation System Hydraulics

The mechanical design:

The main considerations taken during the design process were to design the center pivot irrigation system whereby the overall cost for the mechanical design should be low.

The Center Pivot Irrigation System Hydraulics:

The equation of continuity results from the principle of conservation of mass. For a steady flow, the mass of fluid passing all sections in a stream of fluid per unit of time is the same. This can be evaluated as [10]:

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2 = \text{constant kg/sec} \ldots\ldots\ldots (1)$$

$$\gamma_1 A_1 V_1 = \gamma_2 A_2 V_2 = \text{constant kg/sec} \ldots\ldots\ldots (2)$$

Or for incompressible fluids and where for all practical purposes, the equation becomes:

$$Q = A_1 V_1 = A_2 V_2 = \text{constant} \ldots\ldots\ldots\ldots (3)$$

Where A and V are respectively the cross-sectional areas and average velocity, of the stream at section1, with similar terms for sector 2. The commonly used units of flow in water supply work are cubic meters per second or liters per minute.

Energy and head:

Energy is defined as the ability to do work. Work is the result of the application of a force through a distance and is generally defined, . therefore [11],

$$k_e = \tfrac{1}{2} (Mv^2) \ldots\ldots\ldots (4)$$

The mass term may be replaced (w/g), (where w is the weight and g is the acceleration of gravity), giving:

$$k_e = \tfrac{1}{2} (Wv^2/g) \ldots\ldots\ldots (5)$$

Pressure energy, sometimes called flow energy, is the amount of work required to force the element of fluid across a certain distance against the

pressure. The pressure energy f_e can be evaluated by determining the work done in moving the fluid element a distance equal to the segments length d. the fore causing work is the product of pressure (P) and cross sectional area (A) of the element. Hence:

$$F_e = P\ A\ d \ldots\ldots (6)$$

Term A d is, in fact, the volume of the element, which can itself be replaced by (W/γ), where (γ) is the specific weight of the fluid. Hence,

$$F_e = P\ W / \gamma \ldots\ldots (7)$$

Total energy (E) is the sum of p_e, k_e, and F_e or

$$E = W\ Z + \tfrac{1}{2}(W\ v^2/g) + P\ W / \gamma \ldots\ldots (8)$$

Careful examination of the total energy equation reveals that each term and hence the total energy can be expressed in N.m. in fluid mechanisms and hydraulics.

Equation (3.8) can be modified to express total energy as a head (H) by dividing each term on the right-hand side of the equation by (W), the weight of the fluid. This gives.

$$H = Z + v^2/2g + P/\gamma \ldots\ldots (9)$$

The term (Z) is known as the elevation head; ($v^2 2g$) is known as the velocity head; and (P/ γ) is known as the pressure head.

Energy equation:

The energy equation results from application of the principle of conservation of energy to fluid flow. The energy possessed by a flowing fluid consists of internal energy and energies due to pressure, velocity and position. In the direction of flow, the energy principle is summarized by the general equation.

(Energy at section 1 + energy added – energy lost – energy extracted = energy at section 2).

This equation, for a steady flow of incompressible fluids in which the change in internal energy is negligible, is simplified to:

$$(Z_1 + V^2{}_1/2g + P_1/\gamma) + H_A - H_L - H_E = (Z_2 + V^2{}_2/2g + P_2/\gamma) \ldots (10)$$

This equation is known as the Bernoulli theorem. The units used are meters of the fluid. Many problems dealing with flow of liquids use this equation as the basis of solution.

Power:

Power is calculated by multiplying the number of (Newton's) of fluid flowing per second (γ Q) by energy (H) in (m.n/n). Thereby, the following equation results:

$$\text{Power } P = \gamma\, Q\, H \text{ NM/sec (Watts)} \ldots\ldots (11)$$

$$P = \gamma\, Q\, H/1000 \text{ Kw} \ldots\ldots (12)$$

Different laws govern the two types of flow:

- **Laminar flow:**

In laminar flow, fluid particles move a long straight, parallel path in layers or lamina. Magnitudes of the velocities of adjacent lamina are not the same. Laminar flow is governed by the law relating shear stress to the rate of angular deformation. i.e. the product of viscosity of the fluid and viscosity of the fluid are dominant and thus suppress any tendency to turbulent conditions [12].

- **Turbulent flow:**

In turbulent flow, fluid particles move in a haphazard fashion in all directions. It is virtually impossible to trace the motion of an individual particle.

- **Reynolds's number:**

The Reynolds number (Re), which is dimensionless, and represents the ratio of inertia forces to viscous force for circular pipes.

Reynold's number $Re = \rho \underline{v\ d}$ .... (13)

μ

or

$v\,d/\gamma \quad = V\,(2\,r)/\gamma$...... (14)

Where:

v = Mean velocity m/sec

d = Diameter of pipe

r = Radius of pipe in m

γ = Kinematics of fluid m^2/sec

ρ = Mass density of fluid kg/m^3

μ = Absolute viscosity pa-sec

- **Critical velocity:**

The critical velocity of practical interest is the velocity below which all turbulence is damped out by the viscosity of the fluid. It is found that the upper limit of laminar flow of partial interest is represented by Reynold's number of about 2000.

The flow of water in closed conduits is always accompanied by loss of pressure head due to friction. There are several common equations for computing head loss in pipelines. The most employed equations in irrigation engineering calculations are probably Haze-William, Daracy-Weisbach, Scobey formulas. Hazen-William equation substantially underestimates friction losses especially when Reynolds number approaches the laminar range of values and the more correct model is the Darcy-Weisbach formula. Those equations compute the **head** loss (hl) directly along with straight uniform pipe without outlets and no outflow and no change of pipe diameter [13].

I. Hazard-William equation

$$H\,L_{1\text{-}2} = \frac{J\,L}{100}$$

$$J = K\,(Q/C)^{1.85} \times D^{-4.87} \text{ .... (15)}$$

Where:

K= 1.212×10^{12}

Q= Discharge (1/sec)

C= Coefficient of pipe material

D= Internal diameter of pipe (mm)

L= Pipe length (m)

II. Darcy-Weisbach equation:

$$H L_{1\text{-}2} = \frac{FL}{D} \frac{V^2}{2g} \quad \text{.......... (16)}$$

Where:

f= Friction factor

L= Pipe length of distance (1-2) m

D= Pipe diameter m.

V= Flow velocity m/sec

G= Acceleration due to gravity m/sec_2

III. Scobey equation:

$$H L_{1\text{-}2} = \frac{kL\, V^{1.9}}{D^{1.1}}$$

.... (17)

Where:

K= Scobey coefficient

L= Pipe length of distance (1-2) m

D= Pipe diameter m.

V= Flow velocity m/sec

Vi. Christiansen factor "C":

$$C = \frac{1}{m+1} + \frac{1}{2N} + \frac{\sqrt{m} - 1}{6N^2}$$

.... (18)

Where:

m= Velocity exponent of used equation, ad

m= 2 with Darcy-Weisbach equation

m= 1.9 with Scobey equation

N= The number of outlets a long pipeline without outflow at the downstream and no change of pipeline diameter.

As confirmed by experimental results and previous analysis in fluid mechanics, the friction factor "F" in Darcy-Weisbach may depend on Reynolds number "Re" of the flow and/or on the relative roughness (e/d) of the pipe. Hence,

$F \alpha (Re, e/d)$.

This relationship makes it possible to determine the friction factor (f) of Darcy-Weisbach friction formula on basis of (Re) as follows:

- **Laminar flow**

$F = 64/Re$ for $Re \leq 2000$.........(19)

$F = 0.04$ for $2000 < Re \leq 300$.........(20)

- **Turbulent flow**

$F = 0.32/Re^{0.25}$ for $3000 < Re \leq 10^5$........... (21)

$F = 0.13/Re^{0.172}$ for $10_5 < Re \leq 10^7$........... (22)

Discharge in pipes (Q) (m^3/sec) with critical velocity (V)(m/sec) usually ranges from 06 to 2.2 m/sec and not exceeding (1.5 m/sec) is simply dependent on the cross-sectional area of the flow (A) and can be derived from the continuity equation as flow:

$V = Q/A$ .... (23)

Taking pipe critical velocity V= 1.5 m/se

Pipe cross-sectional area $A = \pi d^2/4$

And discharge $Q = 1.5 \times 3.14 d^2/4$

$D = 0.92 \sqrt{Q}$ .... (24)

This relation is helpful in determining the suitable diameter to a certain discharge to avoid high head loss (h_l).

Darcy-Weisbach equation is reported to be exact and amenable to dimensional analysis, and hence considered accurate to determine the friction loss in the flow of pipes. The friction coefficient that depends on Reynolds's number (Re) which is generally used to distinguish between laminar and turbulent flow and can be described as:

$Re = \rho \, v \, d/\mu$ .... (25)

For specific conditions of irrigation water flowing in pipe (Q m^3/sec) where water density and viscosity at 20°C are known should be:

$Re = 1.26 \times 10^6 \, (Q/d)$ .... (26)

Consequently, it is reasonable to adopt a solution that describes the turbulent flow in the lateral sprinkler and as such friction loss (hl) may be estimated in pipe section or reach with ($Re \leq 10^5$) at which (F) coefficient $= 0.32/Re^{0.25}$, and can be estimated in suction or each with $Re > 10^5$.

These enable the direct computation of head losses in each pipe section carrying different flow and then different valves of (Re) without using the correction factor Christiansen (C).

Parameters for Designing the Pipe of Center Pivot Irrigation System:

The following parameters should be defined:

- Area in square meters or acre (one acre = 4047m^2)
- Crop water required per day (m/day).
- Compute the total water required per day (m^3/day).
- Determine suitable operating hours per day (from pump discharge and overall efficiency).
- Determine the radius length (Center Pivot lateral).

- Define the towers(spans) number with the suitable and technical length.
- Calculate the suitable starting pipe diameter (inlet pipe), according to a critical velocity (1.5m/sec).
- By reference to Reynold's number, the suitable inlet pipe length and the other reducer one as diameter and length are determining to avoid a sudden contraction.

Assumptions:

(1) Critical velocity (1.5m/sec) relation

$$D = 0.92\sqrt{Q} \quad \text{.........(27)}$$

Where:

D = pipe diameter (m).

Q = discharge through the pipe (m^3/sec).

(2) Reynolds number

$$Re = \frac{\rho\, v\, d}{\mu} \quad \text{........... (28)}$$

for irrigation water properties of (20 ◦C) (ρ, μ) are known values, in this case Re should be as:

$$Re = 1.26\times10^{6}\,(Q/D) \quad \text{...... (29)}$$

Re =Reynolds's number with known (ρ, μ) of water at (20 ◦C).

Q= Discharge flow in (20 ◦C) for water (m^3/sec).

D= pipe diameter (m).

(1) Using Darcy –Weisbach equation to calculate head loss (hl), and then define the friction factor (f) of Darcy –Weisbach equation with (Re).

F factor relation:

Laminar flow:

$$F = 64/Re \quad \text{for} \quad Re \leq 2000 \text{......(30)}$$

$$F = 0.04 \quad \text{for} \quad 2000 < Re \leq 3000 \text{......(31)}$$

Turbulent flow

$F = 0.32/Re^{0.25}$ for $3000 < Re \leq 10^5$.........(32)

$F = 0.13 / Re^{0.172}$ for $10\ 5 < Re \leq 10^7$ ....(33)

(2) Darcy –Weisbach equation is defined as:
Where:

$$H\,L_{1\text{-}2} = \frac{FL}{D} \quad \frac{V^2}{2\,g} \quad ....(3.34)$$

Hl=head loss (1-2)

f = friction factor

L = pipe length of distance (1 – 2) m, (segment length).

D = pipe diameter m.

V = flow velocity m / sec.

g= acceleration due to gravity m / sec^2.

- Any span carries total flow of the system minus water required for the area under the same span and the other before it, and mention as (q m /sec^2).

(3) The head loss runs from the first segment (span) near the pivot with Darcy –Weisbach equation and (Re) that no way to use Christiansen correction factor.

(4) Relation between spans areas and discharge as the following:

(i) Area of span one equal $A1 = \pi \times r\ 1$......(36)

Where:

A1= Area under first span (m^2)

r1= straight length off span one (all spans are equal).

(ii) Total water needed to irrigate (A1) computed as:

Total water of (A1/day) = A1×depth of required water per day.

(iii) The total water needed to irrigate area one can be mentioned as discharge (m^3/sec). If the operating hours per day are defined.

(iv) as the following:

$$A1 = \pi \times r\ 1 \text{.......} (35)$$

$$A\ 2 = 3(\pi \times r\ 1) \text{......} (36)$$

A3= $5(\pi \times r\ 1)$ Relation of spans area defined

$$A4 = 7\ (\pi \times r\ 1) \text{......} (37)$$

$$Ax = (2x-1)\ A1 \text{......} (38)$$

(v) Most irrigation water flows in turbulent flow with (Re) relations:
Turbulent flow

$$F = 0.32/Re^{0.25} \quad \text{for} \quad 3000 < Re \leq 10^5 \text{.......}(39)$$

$$F = 0.13 / Re^{0.172} \ \text{for} \quad 10^5 < Re \leq 10^7 \text{.......}(40)$$

(vi) Total area under all spans can be computed as:

AT = (number of spans)^2 A1......(41)

Q t= (number of spans)^2 q1......(42)

Where:

q_{1}= span one discharge (m^3/sec).

A1 = area under span one (m^2)

W_r= water required per day as water depth(m/day).

(5) Head loss through lateral of Center Pivot (spans) as the following steps:

(i) Define number of spans (n).

(ii) Obtain relation of water carried through each span in the unit of (q) (m^3/sec).

(iii) Water carried in span one equal total water inter the system (q t), in span (2) equal (qt-q1) in span (3) (qt-q1-q2) and so on up to the last segment (span). This relation can be illustrated as:

Total water in span 1= (number of spans)^2 q1

w t of span 1 = $n^2 q_1$.........(43)

Or

Water carried by span 1= $n^2 q_1$

Water carried by span 2= $(n^2 - 1) q_1$

Water carried by span 3= $(n^2 - 4) q_1$

Water carried by span 4= $(n^2 - 9) q_1$

Water carried by span 5= $(n^2 - 16) q_1$

That means:

Water carried by span (x) = $(n^2 - (x-1)^2) q_1$

Where:

q_t =total water flow carried in span (x), (m^3/sec).

q_1=discharge of span one (m^3/sec).

n= total number of spans in Center Pivot lateral system.

X= span location number.

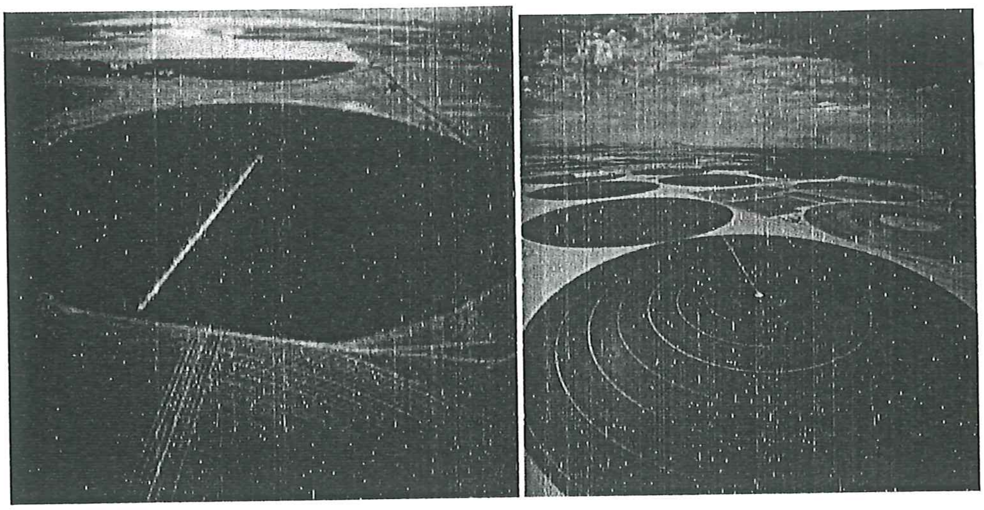


Figure shown: the way of movement center pivot irrigation system