بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering and Technology
Department of Mechanical Engineering
Mechatronics Engineering

Development Of An Optical Accelerometer

Project Team
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Supervisor
Eng. Jalal Al-salaiymeh

Hebron-Palestine
May, 2007

Palestine Polytechnic University
Hebron-Palestine

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According to the direction of the project supervisor and by agreement the committee member's entire. This project was submitted to Department of Mechanical Engineering-College of Engineering and Technology to partially fulfill of the B.Sc requirement.

Supervisor signature ……………………………

Department head signature ……………………………

Committee Member Signature

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Project Title
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A graduation project

Submitted to the Department of Mechanical Engineering-College of Engineering and Technology.

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Abstract

Development Of An Optical Accelerometer

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In this project an optical mount-on accelerometer is designed, that measures acceleration of many vibrating systems. A spring-mass-damper system with a seismic mass vibrating under base excitation is built, mass motion is sensed by an optical sensor, the output signal (pulses) is sent to a PIC-microcontroller to be treated. A liquid crystal display (LCD) views the measured acceleration, and a computer software (matlab) is used to plot the vibrating systems' displacement curve. This device will be used as a laboratory device to help students understanding accelerometers usage and vibration measurements.

Dedication

To our parents for their supports.

To our teachers for their advices.

To our supervisor for his help.

To our families for their supports.

To our homeland.

Acknowledgement

We would like to extend our gratitude to the administration of Palestine Polytechnic University in general, and the administration of the Mechanical Engineering Department in particular. At the same time express our special thanks to the teachers of the university with special reference to

Eng. Tariq Abu Hamdeah

Eng. Islam Al hoor

Eng. Iyad Al hashlamoon

for their help and suggestions that he used to give without grudges or complaints.

Special acknowledgment of appreciation and respect would be rendered to our project supervisor Eng. Jalal Al-salaiymeh. Little words remain short to express our regard and thank to our supervisor for his suggestions that he used to give without any complaint.

It's our pleasure to thank whoever will participate in backing up this project to be a real and successful one.

Nasim M. Al-Qadi
Iyas H. Shaheen

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m	Mass (kg)
c_v	Damping constant (N.s/m)
k	Spring constant (N/m)
x	Displacement of the seismic mass (m)
y	Displacement of the exciting base (m)
$\dot{x}$	Velocity of the seismic mass (m/s)
$\dot{y}$	Velocity of the exciting base (m/s)
$\ddot{x}$	Acceleration of the seismic mass (m/s^2)
z	Relative displacement (m)
$\dot{z}$	Relative velocity (m/s)
$\ddot{z}$	Relative acceleration (m/s^2)
ζ	Damping ratio
ω	Frequency (Hz)
ω_n	Natural frequency (Hz)
t	Time (sec)
Z	z(t) Amplitude (m)
r	Frequency ratio
F	Spring force (N)
g	Gravity acceleration (m/s^2)
δx	Spring deformation (m)
μ	Fluid viscosity (Pa.s)
h	Fluid thickness (m)
A	Seismic mass contact area (m^2)

Chapter One
Introduction

Chapter One
Introduction

1.1 Overview

Problems of vibration have engaged engineers; since man began to build machines for industrial use, and especially since motors have been used to power them. In practice it is very difficult to avoid vibration since it occurs due to dynamic effects of manufacturing tolerances, clearances, rolling and rubbing contact between machine parts and unbalanced forces in rotating and reciprocating members.

Often, small insignificant vibrations may excite the resonant frequencies of other structural parts and be amplified into major vibration and noise sources. Sometimes mechanical vibration performs a useful job, for example, vibration intentionally generated in component feeders, concrete compactors, ultrasonic surgery operations, rock drills and pile drivers.

Also, as vibration isolation and reduction techniques have become an integral part of machine design, the need for accurate measurement and analysis of mechanical vibration has grown. This need was largely satisfied, for slow machines, by the experienced ear and touch of the plant engineer, or by simple optical instruments measuring vibratory displacement.

Vibration of machines or any other structure is to be sensed by a transducer which transforms the changes in mechanical quantities (force, displacement, velocity, or acceleration) into electric quantities as an output signal to be treated.

Depending on the quantity measured, vibration measuring instrument is called vibrometer, phase meter, frequency meter, velocity meter, or accelerometer.

Acceleration is a measure of how quickly speed changes. As a speedometer is a meter that measures speed, an accelerometer is a meter that measures acceleration. Where an accelerometer's ability can be used for sensing acceleration to measure a variety of things that are very useful to electronic and robotic projects and machinery designs such as: acceleration, tilt and tilt angle, incline, rotation, collision, gravity, and vibration.

Accelerometers are already used in a wide variety of machines, specialized equipment and personal electronics, such as: Self balancing robots, tilt-mode game controllers, model airplane auto pilot, car alarm systems, crash detection/airbag deployment, leveling tools, and human motion monitoring.

A large variety of accelerometers are found, differs relative to special properties in one over the others. In this project an optical mount on accelerometer is designed, in the world of physics an optical accelerometer is a device that converts mechanical vibrations into an electrical signal (pulses) which will allow for further signal processing and analysis.

1.2 Importance of the Project

Since this project aims to design an optical accelerometer; it is a suitable example on Mechatronics engineering projects, since it contains some of the Mechatronics engineering skills. Also to increase acceleration measuring quality, since most of accelerometers and vibrometers suffer from using under critical conditions such as electromagnetic interferences and noise signals. In addition a laboratory device is to be added to our lab to help students understanding accelerometers usages and vibration measurements.

1.3 Literature Review

In order to find other research projects pertaining to this subject, very specific researches had to be conducted. The articles researched dealt with several working principles were applied for acceleration sensing and vibration measurements and analysis, most of them suffer from high cross-sensitivity to electromagnetic interferences (EMI) and they cannot be used under critical conditions. The goal of much of the research conducted is to limit such sufferers, also to reduce the effect of the measuring device itself.

Brothers Pierre and Jacques Curie, in there project [The Piezoelectric Effect in Crystals] demonstrated the relationship between a mechanical load on a crystal (they worked with tourmaline, quartz, and Rochelle salt) and the electric charge resulting from it. That is piezoelectricity is a linear electromechanical interaction between the mechanical and electrical states of crystals with no symmetric centers. They conclude that crystals can have one or more polar axes along which the effect occurs. **[1]**

Matt Brandt and Mike Gottshall, provides a study of Modal Analysis of a Simple Metal Pipe , the goal of this project was to analyze a metal pipe system and design methods to reduce the amount of noise that results from the vibration of the pipe. To accomplish this, a mount on piezo-resistive accelerometer held in place using wax adhesive as shown in figure (1.1) is used to measure the vertical acceleration of the piece. They conclude that using isolators would help eliminate the transfer of frequency waves from surrounding structures and would also help dampen excitations imposed on the pipes, or elastomeric joints and plastic material is to be used. **[2]**

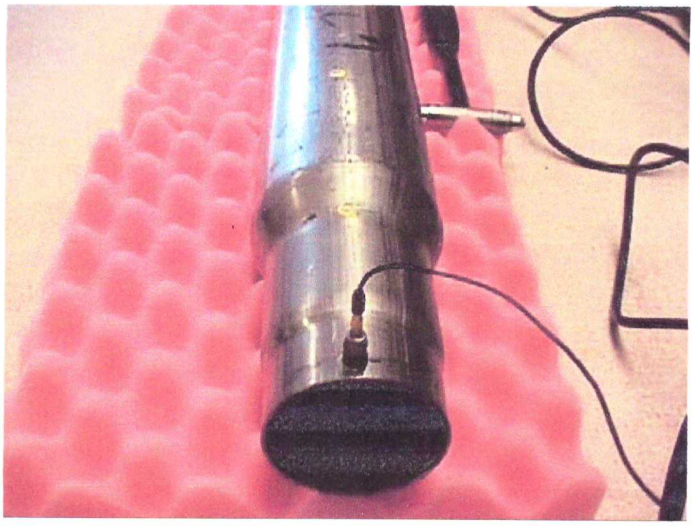

Figure (1.1) Modal Analysis of a Simple Metal Pipe

In the used piezoelectric or piezoresistive accelerometers, vibrating crystals have multi degree of freedom, from which measuring acceleration in one direction will be affected from crystals' vibrating in the other directions.

Jackson Lin, provides applying stator end-winding vibration monitoring technology. In which a piezoelectric accelerometers is used to monitor the end-winding vibration. That the movement of stator windings has been clearly linked to erosion of semi-conductive layer, abrasion of insulation and packing, increased partial discharges and ultimately generator failure. A strong electromagnetic forces causes end-windings significant vibration, which eventually lead to a weakened blocking and bracing system, insulation cracks, cooling leaks and potentially short-circuits. He conclude that fiber optic accelerometers should be used to monitor end-winding vibration since this is the only type of accelerometer that can be safely coupled to the end-windings themselves. **[3]**

Figure (1.2) Installation of the sensor head and
optical cable to brace end-windings

Due to the conductive nature and construction of accelerometers such as piezoelectric and piezoresistive, there are personnel and machine safety issues related to installing such equipment on high-voltage, 18-kV generators and particularly if such conductive devices were to be installed directly upon the end-winding themselves as shown in figure (1.2). Therefore, use of piezoelectric and piezoresistive accelerometers has generally been limited to indirect monitoring of the end-winding vibration by actually monitoring the motion of the brackets and support structures of the end-windings. This method, although shown to be useful in the past, is not as effective a measure of true end-winding vibration as having the accelerometer head firmly coupled to the end-winding itself. Additionally, certain installations of piezoelectric accelerometers have shown a high failure rate over the long-term possibly due to the harsh operating environment inside the turbo generator.

Figureliola, R. S. and Beasley, D. E., in studying the dynamic characteristics of a spring-mass-damper system, the aim of this study is to calibrate a position sensor. As shown in figure (1.3) the basic principles of linear potentiometer and accelerometer operation is used. They conclude that there is an uncertainty in the measurements. **[4]**

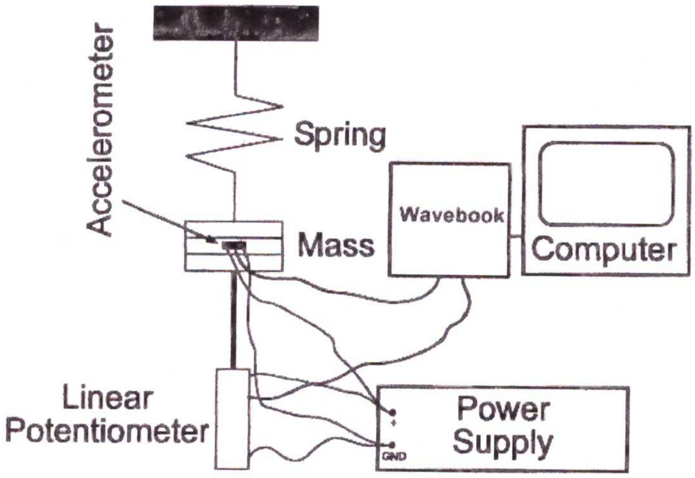

Figure (1.3) Vertical spring-mass-damper system

Accelerometers requires a sensor to sense the displacement of the vibrating body, if it is to be sensed using a contacting element such as a potentiometer as used in this experiment, high damping and loading effect will appear due to frictional force with the original system causing a very bad accuracy measurements.

1.4 Project Scope

Chapter one is an introduction to the field of vibration measurement, it introduces some background material, a literature review of accelerometers field is to be viewed, , and the time plan of the project, and it previews the materials in the later chapters.

In chapter two, theoretical subjects related to the main ideas of the project is to be viewed, a few fundamental ideas, also information about special components, and the system requirements.

Chapter three contains the project objectives, in addition to that a general block diagram of the project is described, also it contains applying Mechatronics design approach , and how the system works, and finally the system is modeled .

Chapter four deals with accelerometer's mechanical design, chapter five explains electrical and electronic design, and computer interface, chapter six ahows the software design, and finally chapter seven is the project conclusions and recommendations.

1.5 Budget

Component	**Quantity**	**Price/unit (NIS)**	**Cost(NIS)**
Linear optical encoder	2	Free from lab	-
LCD	1	25	25
PIC-microcontroller	1	65	65
Spring-mass-damper system	1	20	20
Computer (P –III)	1	Lab computer	-
Board	2	20	40
Electronic components	8	4	32
Others	-	-	100
Total	**282 NIS**		

Chapter Two

Theoretical Background of the Accelerometer

Chapter Two
Theoretical Background of the Accelerometer

2.1 Accelerometer Definition

An accelerometer is a device used to measure shock and vibration. An accelerometer transduces the acceleration of an object into a proportional analog signal. The analog signal indicates the real-time, instantaneous acceleration of that object.

2.2 Types of Accelerometers:

Accelerometers can be classified in a number of ways, such as deflection or null-balance types, mechanical or electrical types, dynamic or kinematic types. The majority of industrial accelerometers can be classified as either deflection type or null-balance type. Those used in vibration and shock measurements are usually the deflection types, whereas those used for measurements of motions of vehicles, aircraft, etc. for direction-finding purposes may be either type. In general, null-balance types are used when extreme accuracy is needed.

A large number of practical accelerometers are of the deflection type. There are many different deflection-type accelerometers, such examples are listed below. Although their principles of operation are similar, they only differ in minor details, such as the spring elements used, types of damping provided, and types of relative motion transducers employed.

2.2.1 Piezo-electric Accelerometer:

Piezo-electric crystals are man-made or naturally occurring crystals that produce a charge output when they are compressed, flexed or subjected to shear forces. The word piezo is a corruption of the Greek word for squeeze. In a piezo-electric accelerometer a mass is attached to a piezo-electric crystal which is in turn mounted to the case of the accelerometer. When the body of the accelerometer is subjected to vibration the mass mounted on the crystal wants to stay still in space due to inertia and so compresses and stretches the piezo electric crystal. This force causes a charge to be generated and due to Newton law $f = ma$ this force is in turn proportional to acceleration. The charge output is either converted to a low impedance voltage output by the use of integral electronics or made available as a charge output (Pico-coulombs /g) in a charge output piezo-electric accelerometer.

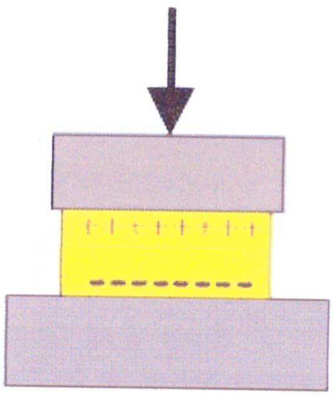

Figure (2.1) Piezoelectric accelerometer principle

2.2.2 Piezo-resistive Accelerometer

A piezo-resistive accelerometer is an accelerometer that uses a piezo-resistive substrate in place of the piezo electric crystal and the force exerted by the seismic mass changes the resistance of the etched bridge network and a whetstone bridge network detects this. Piezo-resistive accelerometers have the advantage over piezo-electric accelerometers in that they can measure accelerations down to zero Hertz.

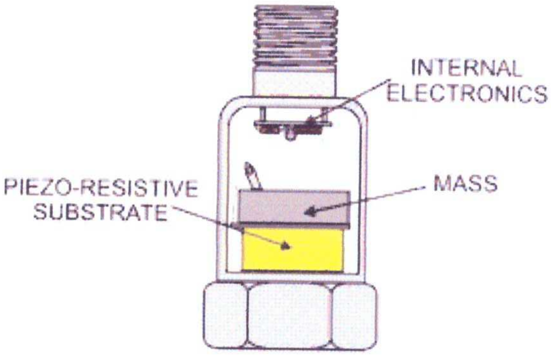

Figure (2.2) Piezo-resistive accelerometer

2.2.3 Strain gauge Based Accelerometer

A strain gauged based accelerometer is based on detecting the deflection of a seismic mass by using a silicon or foil strain gauged element. A whetstone bridge network detects the deflection. The deflection is directly proportional to the acceleration applied to the sensor. Like the piezo-resistive accelerometer it has a frequency response down to zero Hz.

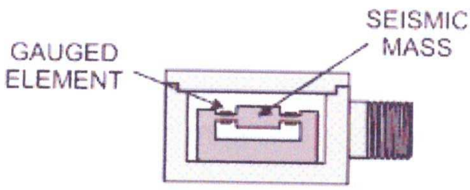

Figure (2.3) strain gage based accelerometer

2.3 Accelerometer Frequency Response Concepts

2.3.1 Useable Frequency Range

For an accelerometer to be useful the output needs to be directly proportional to the acceleration that it is measuring. This fixed ratio of output to input is only true for a range of frequencies as described by the frequency response curve

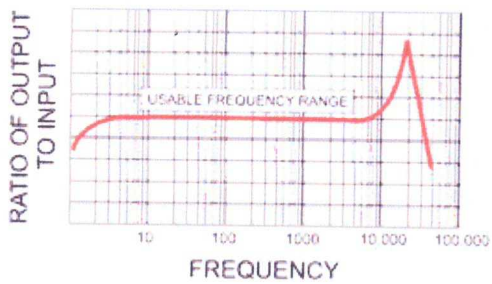

Figure (2.4) The Useable frequency range

The usable frequency response is the flat area of the frequency response curve and extends to approximately 1/3 to 1/2 of the natural frequency of the used accelerometer. The definition of flat also needs to be qualified and is done so by quoting the roll off of the curve in either percentage terms (typically 5% or 10%) or in dB terms (typically +/- 3db).

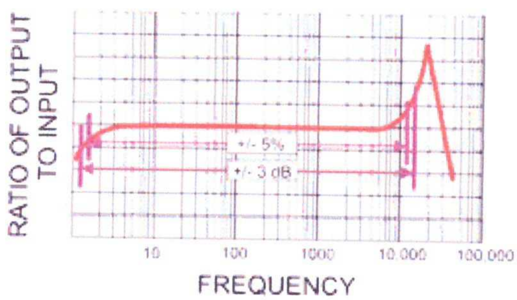

Figure (2.5) The qualified useable frequency response range

2.3.2 Dynamic Range

The dynamic range of an accelerometer is the range between the smallest acceleration detectable by the accelerometer to the largest. A piezo-electric accelerometer produces a charge proportional to the force applied to the crystal, which due to the seismic mass on the crystal is proportional to acceleration applied. The piezo electric effect can be detected for very small forces or accelerations all the way through to very large accelerations. The design of the accelerometer will also play a part in what shock g levels an accelerometer can withstand before the crystal is irreparably damaged or the structure holding the crystal is distorted. Compression accelerometers are the most shock resistant design of accelerometer.

The dynamic range describes the minimum to maximum accelerations that can be detected. The output of an IEPE (IEPE stands for Integrated Electronics Piezo Electric) accelerometer can typically go from 100 micro g to 500g. This dynamic range is dependent on the electronics used with the accelerometer either internal or external, as is the output linearity over the dynamic range.

Accelerometers with integral electronics have a maximum output voltage determined by the circuit design and the input voltage. The maximum output for an IEPE accelerometer is typically 4-8 volts. An accelerometer with a sensitivity of 100mV/g with electronics that has a maximum output of 5V will obviously have a dynamic range of +/- 50g while an accelerometer of sensitivity of 10mV/g will have a dynamic range of +/- 500g.

2.3.3 Natural Frequency of an Accelerometer

The natural frequency of an accelerometer is the frequency where the ratio of output is at it highest. The natural frequency of an accelerometer is defined by the equation:

$$f_N = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad 2.1$$

where :

f_N :Natural frequency (Hz).

k :Stiffness (N/m).

m :Mass (kg).

From a frequency roughly 1/3 to 1/2 of the natural frequency the ratio of output to input becomes non-linear and therefore makes measurements from this region difficult to interpret. Therefore the higher the natural frequency of an accelerometer the higher frequencies where the output to input is linear and the higher the frequencies that can be measured.

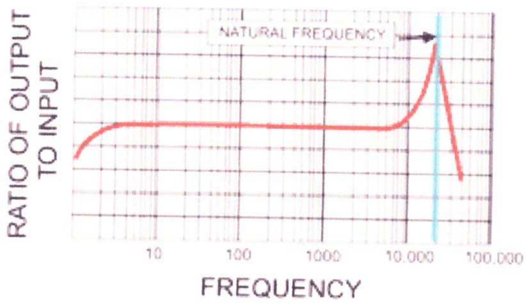

Figure (2.6) Natural frequency

It can be seen from the formula for natural frequency that to increase the natural frequency the mass needs to be as small as possible and the stiffness needs to be as high as possible. A small mass usually means a lower sensitivity and this is true of most high frequency accelerometers.

2.3.4 Desired Frequency Response from an Accelerometer

The frequency response of the accelerometer needed for testing depends on what frequencies of vibration are required to be measured. An accelerometer should have a high enough natural frequency as to capture all the frequencies required to be measured.

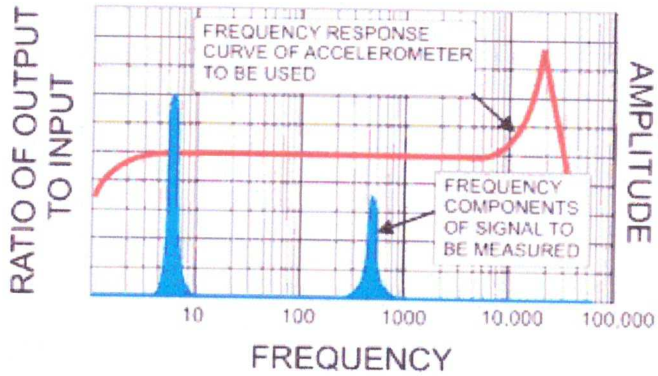

Figure (2.7) Natural frequency sufficiently high to capture all frequency signals

Problems start to arise however when the vibration content of the acceleration to be measured gets close to the natural frequency of the accelerometer

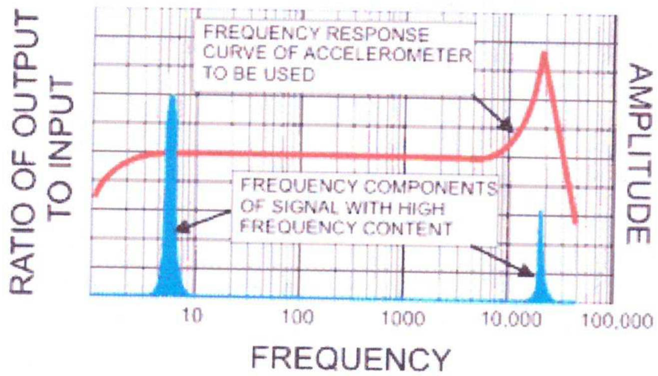

Figure (2.8) Frequencies to be measured approaches the natural frequency of the accelerometer

In these instances distortion of the acceleration by the high gains seen near the natural frequency can give a false picture of the reported acceleration amplitudes at high frequencies.

To overcome this problem one of the two following solutions is used:

1. Higher frequency accelerometer needs to be used

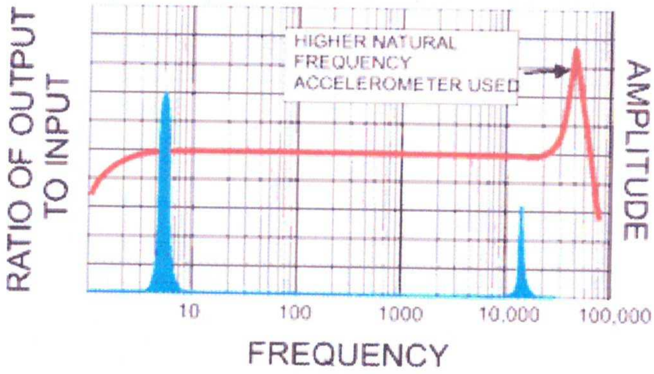

Figure (2.9) Higher natural frequency

2. If the higher frequencies are not required to be measured then using a low pass filter should filter them out.

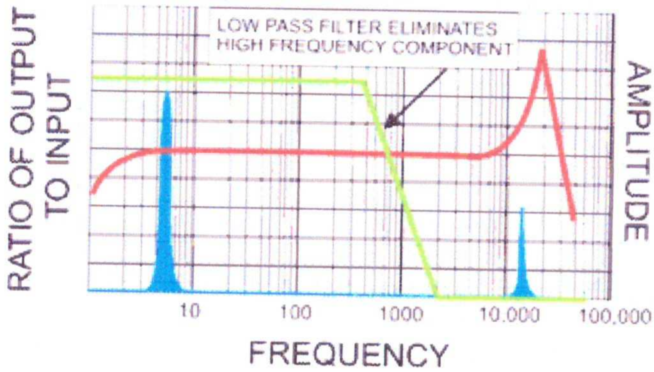

Figure (2.10) Low pass filter

2.3.5 Base Strain Sensitivity

Base strain sensitivity is the erroneous signal that is generated by an accelerometer when the base is subjected to bending, torque or distortion either by mechanical movement or thermal stressing as shown in figure (2.11).

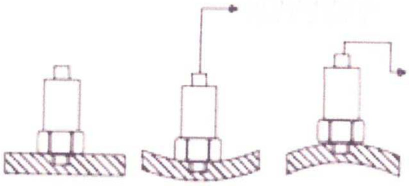

Figure (2.11) The base sensitivity

The relative movement of the base of the accelerometer squeezes the crystal in an accelerometer and the seismic mass mounted on the crystal. Base strain is where the base distorts the mass while acceleration causes the seismic mass to distort the crystal. These two forces on the crystal are indistinguishable and so reduction of the base strain is vital for good signals only to be generated. The more indirectly that a crystal is mounted to the base under strain the less sensitive the accelerometer is to base strain. Single ended compression sensors are the most prone to base strain sensitivity and shear type accelerometers the least. Isolated compression accelerometers are a good compromise between have good base strain immunity and the disadvantages that shear type accelerometers bring in terms of sensitivity an robustness.

2.4 Calibration of an Accelerometer

Calibration is the process of comparing a measuring instrument with a measurement standard to establish the relationship between the values indicated by the instrument and those of the standard.

Any measurement is subject to degradation due to use, abuse, drift or ageing. To understand this degradation calibration at regular intervals needs to be carried out to characterize the instrument after degradation, to restore the instrument to an 'as new' condition as regards its measurement performance and to reference the measurement to National Standards.

Chapter Three

Architectural Design

3.1 Project objectives

3.2 Theory of Operation

3.3 Mechatronics Design Approach

3.4 System Modeling

Chapter Three
Architectural Design

3.1 Project Objectives

- To design an optical accelerometer for measuring acceleration, other vibration parameters for a vibrating body.
- To prove optical accelerometers' advantages in measuring quality over other accelerometers.

3.2 Theory of Operation

Accelerometers are inertial measurement devices that convert mechanical motion to an electrical signal. This signal is proportional to the vibrating systems' acceleration. Inertial measurement devices measure motion relative to a mass, this follows Newton's Third Law of Motion: A body acting on another will result in an equal action on the first.

In the optical accelerometer, vibration of the body will be dedicated by an optical encoder which used to convert the vibration of the body into a series of square waves (pulses). This process will be accomplished by attaching the binary code strip vertically to the vibrating body and encoded the pulses which initiated when the body starts to vibrate between the two optical elements, transmitter which is the source of light, and the receiver.

The Receiver will handle pulses to a PIC-microcontroller, which is programmed to count the received pulses, calculate the systems' displacement and acceleration, and views acceleration on a LCD (Liquid Crystal Display). While acceleration changes continuously; a computer is used to receive the treated data from the PIC-microcontroller through the serial port to plot it with respect to time using a software such as Matlab software to enable the user justifying which type of response the body have. The general block diagram in figure 3.1 below describes the operation.

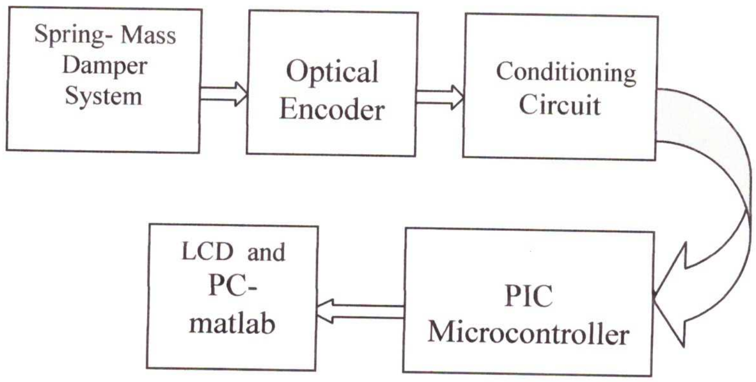

Figure (3.1) general block diagram

Additional conditioning circuits will be constructed according to the type of noise that the system have. an opto-coupler will be used to protect the computer against the differences in the voltages levels.

3.3 Mechatronics Design Approach

A Mechatronics system is multi-disciplinary, embodying four fundamental disciplines: electrical and electronics, mechanical, computer science, and information technology.**[5]**

3.3.1 Mechatronics System Key Elements

The key elements of the Mechatronics approach are to be presented for each discipline

3.3.1.1 Information Systems

Information systems application is most concerned with modeling, simulation, automatic control, and numerical methods for optimization.

3.3.1.2 Mechanical Systems

Most mechanical application involves rigid-body systems, and the study of such systems relies on some fundamental laws such as Newton's laws, principle of transmissibility, parallelogram law for the addition of forces.

Seismic accelerometers make use of a seismic mass that is suspended by a spring or a lever inside a rigid frame. The schematic diagram of a typical instrument is shown in Figure (4.4).

3.3.1.3 Electrical systems

Electrical systems are concerned with the behavior of three fundamental quantities: charge, current, and voltage. They are an integral part of a Mechatronics application, containing many components such as motors and generators, sensors and actuators (transducers), circuits such as signal conditioning, impedance matching, and amplifiers.

In this project sensors and electronic components are the only used since it works on a low level voltage; the used components are listed bellow:

- Optical encoder.
- Sensor's signal conditioning circuit (schmitt trigger, inverter, D-flip flop, regulators, capacitors, resistors).
- PIC-microcontroller.

3.3.1.4 Real-Time Interface

An embedded computer (PIC) is used for signal processing, and an other desktop computer is used for plotting the graph.

3.4 System Modeling

The simplest vibratory system can be described by a single spring-mass-damper system; the mass is allowed to travel only along the spring elongation direction. Such systems are called Single Degree-of-Freedom (SDOF) systems and are modeled as shown in figure (3.2) if it is to be base excited.

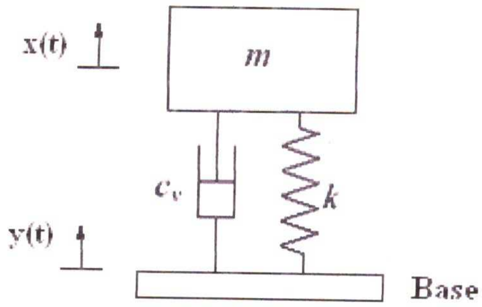

Figure (3.2): SDOF-system under base excitation

From the free body diagram shown in figure (3.2), the following equation may be written by using Newton's second law of motion to describe the response of the seismic arrangement

$$m\ddot{x} + c_v(\dot{x} - \dot{y}) + k(x - y) = 0 \qquad 3.1$$

where

m : Mass (kg)

c_v = Damping constant (N.s/m)

k = Spring constant (N/m)

x = Displacement of the seismic mass (m)

y = Displacement of the exciting base (m)

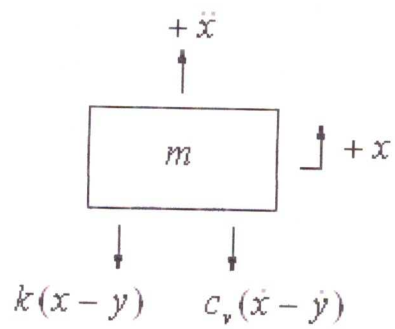

Figure (3.3): SDOF-system's free body diagram

If the relative displacement between the mass and the system's base is denoted by $z = x - y$

Then relative velocity will be

$\dot{z} = \dot{x} - \dot{y}$

By substituting z , $\dot{z}$ in the equation of motion it will become

$$m\ddot{z} + c_v\dot{z} + kz = -m\ddot{y} \quad 3.2$$

Dividing both sides of the equation over m, this yields

$$\ddot{z} + 2\zeta\omega_n\dot{z} + \omega_n^2 z = -\ddot{y} \quad 3.3$$

From this equation, natural frequency and damping ratio are introduced respectively as

$$\omega_n = \sqrt{k/m}$$

$$\zeta = \frac{c}{c_c} = \frac{c}{2m\omega_n} = \frac{c}{2\sqrt{km}} \quad 3.4$$

Excitation input has two types: step input, and sinusoidal input. Step input happens when the seismic mass is to be suddenly displaced from its balanced position. The response to a sinusoidal input is essential for many periodic signals analysis, where spectral analysis is used to break down a periodic signal into a combination of sinusoidal inputs.

If a harmonic vibratory motion is impressed on the system such that:

$$y(t) = Y\sin(\omega t) \qquad 3.5$$

Where ω is the frequency of the base motion. This yield

$$\dot{y}(t) = \omega Y\cos(\omega t)$$

$$\ddot{y}(t) = -\omega^2 Y\sin(\omega t)$$

Substitute in the equation of motion yield

$$m\ddot{z} + c\dot{z} + kz = m\omega^2 Y\sin(\omega t) \qquad 3.6$$

Equation will have transient and steady-state solutions. The steady-state solution of the differential Equation can be determined as:

$$z(t) = Z\sin(\omega t - \phi_1) = \frac{m\omega^2 Y\sin(\omega t - \phi_1)}{[(k - m\omega^2)^2 + (c\omega^2)^2]^{1/2}} \qquad 3.7$$

Where Z is the amplitude of z (t), which can be expressed as

$$Z = \frac{m\omega^2 Y}{[(k - m\omega^2)^2 + (c\omega^2)^2]^{1/2}} = Y\frac{r^2}{\sqrt{(1-r^2)^2 + (2\zeta r)^2}} \qquad 3.8$$

And ϕ is the phase angle which can be expressed as

$$\phi = \tan^{-1}\left(\frac{c\omega}{k - m\omega^2}\right) = \tan^{-1}\left(\frac{2\zeta r}{1-r^2}\right) \qquad 3.9$$

Where $r = \frac{\omega}{\omega_n}$ is the frequency ratio.

The resultant acceleration amplitude is

$$a = \frac{k}{m}z \qquad 3.10$$

Chapter Four

Mechanical design

Chapter Four

Mechanical design

4.1 Introduction

The spring-mass-damper principle applies to many common accelerometer designs. The mass that converts the acceleration to spring displacement is referred to as the seismic mass. This reduces acceleration measurement to a linear displacement measurement that is to be made using a linear optical encoder.

4.2 Accelerometer mechanical design

By proper selection of mass, spring, and damper combinations, device may be used for either acceleration or displacement measurements. In general, a large mass and soft spring are suitable for vibration and displacement measurements, while a relatively small mass and stiff spring are used in accelerometers.**[6]**

4.2.1 Useable frequency range

The usable frequency range as defined in section 2.3.1 is the flat area of the frequency response curve in which amplitude ratio is directly proportional to the frequency ratio. It is approximately when $\zeta = 0.707$. For this value of damping ratio, the effective frequency range can be up to 0.4 ω_n with less than 1% error. In fact, the results are often acceptable up to 0.6 ω_n without adjustment. **[7]**

4.2.2 Spring-mass-selection

Most accelerometers are constructed with a small mass and a short stiff spring, such that the natural frequency ω_n is much higher than the working frequency ω.

4.2.2.1 Spring constant

Spring is the potential energy storing element in a vibratory system, or it is the elasticity element along side inertia and the damper. A linear spring is a type of mechanical link that generally assumed to have negligible mass and damping. A force is developed in the spring when a relative motion between its two ends is applied.

The spring force is proportional to the deformation amount that is given by

$$F = kx \qquad 4.1$$

Where:

F: spring force (N)

x: spring deformation (m)

k: spring constant (N/m)

A simple experiment is done to calculate the spring constant and natural frequency, it involves hanging the spring in the vertical mode as shown in figure (4.1) and Appling several loads on it. And while

$$w_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{g}{\delta x}}$$

$$k = \frac{mg}{\delta x} \qquad 4.2$$

Then spring constant is calculated as in table (4.1):

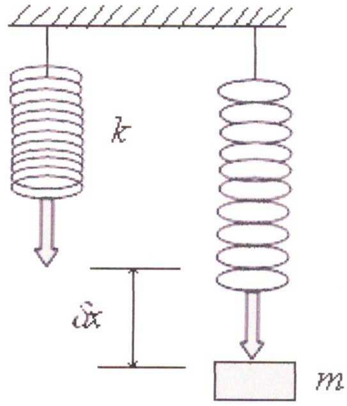

Figure (4.1) Spring Deflection Due to Load

#	Weight (N)	mass (kg)	δx (m)	k (N/m)
1	1	0.102	0.021	47.6
2	1.2	0.122	0.025	47.9
3	1.4	0.143	0.029	48.4
4	1.5	0.153	0.031	48.4
5	1.6	0.163	0.033	48.45
6	1.8	0.184	0.037	48.6

Table (4.1) Spring Constant Calculation

The mean value of spring constant is k = 48.25 N/m.

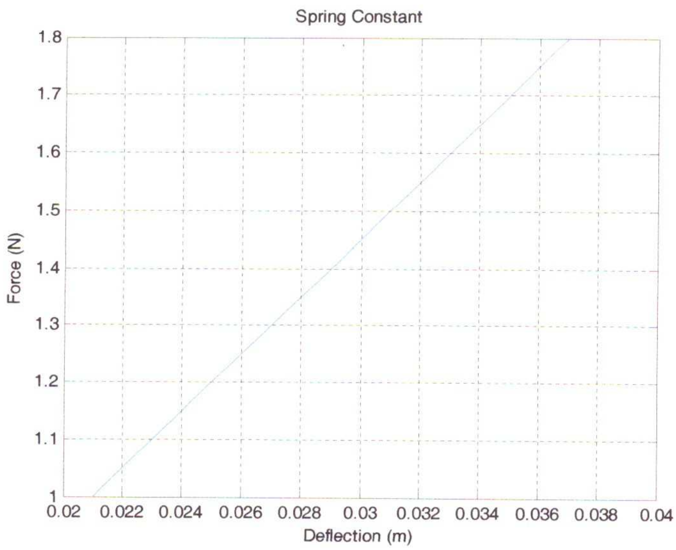

Figure (4.2) Spring constant

4.2.2.2 Natural frequency

In particular, a system consisting of a spring and attached mass always exhibits oscillations at some characteristic natural frequency. Experience tells that if a mass is pulled back and then release it in the absence of acceleration, it will be pulled back by the spring, overshoot the equilibrium, and oscillate back and forth. Only damping associated with the viscous damping eventually brings the mass to rest. Any displacement measuring system will respond to this oscillation as if an actual acceleration occurs. This natural frequency is given by

$$F_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad 4.3$$

Where Fn = natural frequency in Hz

k = spring constant in N/m

m = seismic mass in kg

While the spring mass is not negligible relative to the seismic mass (1.8 gram), the equivalent mass is 4.6 grams according to

$$m_{eq} = m + \frac{m_s}{3} \qquad 4.4$$

By substituting spring constant of k = 48.25 N/m and equivalent mass of 4.6 grams, the resultant natural frequency is 16.3 Hz .

4.2.3 Viscous damper construction

A viscous damper can be constructed using two parallel plates separated by a distance h, with a fluid of viscosity μ between the plates, and surface area of moving plate A as shown in figure (4.2)

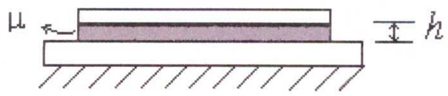

Figure (4.3) viscous damper construction

Damping constant is

$$c_v = \frac{\mu A}{h} \qquad 4.5$$

Recalling

$$\varsigma = \frac{c}{2m\omega_n} \qquad 4.6$$

By substituting 4.6 gram mass, 102.4 Hz natural frequency, and 0.707 damping ratio the resultant viscous damping is 0.67 N.s/m. The used viscous fluid viscosity is 0.081 Pa.s , and the contact area between the two plates is 4 cm^2, that yields 48 μm fluid height.

4.2.4 Frame design

The seismic-mass vibration is only up to about 0.25fn, Figure (4.4) shows two effects. The first is that the actual seismic-mass motion is limited by the physical size of the accelerometer. It will hit "stops" built into the assembly that limits its motion during resonance. The figure also shows that for frequencies well above the natural frequency, the motion of the mass is proportional to the table peak motion, xo, but not to the frequency. Thus, it has become a displacement sensor.

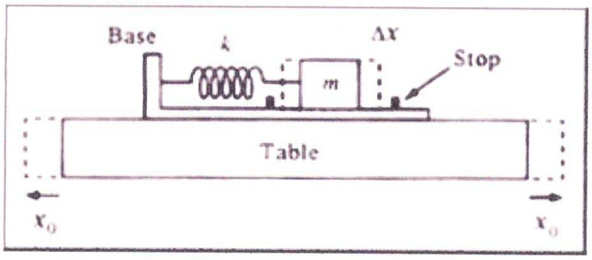

Figure (4.4) a spring-mass accelerometer has been attached to a table which is exhibiting vibration.

Chapter Five

Electronic Hardware Design

Chapter Five
Electronic Hardware Design

5.1 Linear incremental optical encoder

The linear incremental encoder, sometimes called a relative encoder, is simpler in design than the absolute encoder. It consists of two tracks and two sensors whose outputs are called channels A and B. As the system reciprocates, pulse trains occur on these channels at a frequency proportional to the reciprocating speed, and the phase relationship between the signals yields the direction of reciprocating. The coded track pattern and output signals A and B are illustrated in Figure (5.1) below. By counting the number of pulses and knowing the resolution of the track, the linear motion can be measured.

The A and B channels are used to determine the direction of reciprocation by assessing which channels "leads" the other by means of a D-flip-flop. The signals from the two channels are a 1/4 cycle out of phase with each other and are known as quadrature signals. Often a third output channel, called INDEX, yields one pulse per reciprocation, which is useful in counting full reciprocations. It is also useful as a reference to define a home base or zero position.

Figure (5.1) illustrates two separate tracks for the A and B channels and encoder circuit but a more common configuration uses a single track with the A and B sensors offset a 1/4 cycle on the track to yield the same signal pattern.

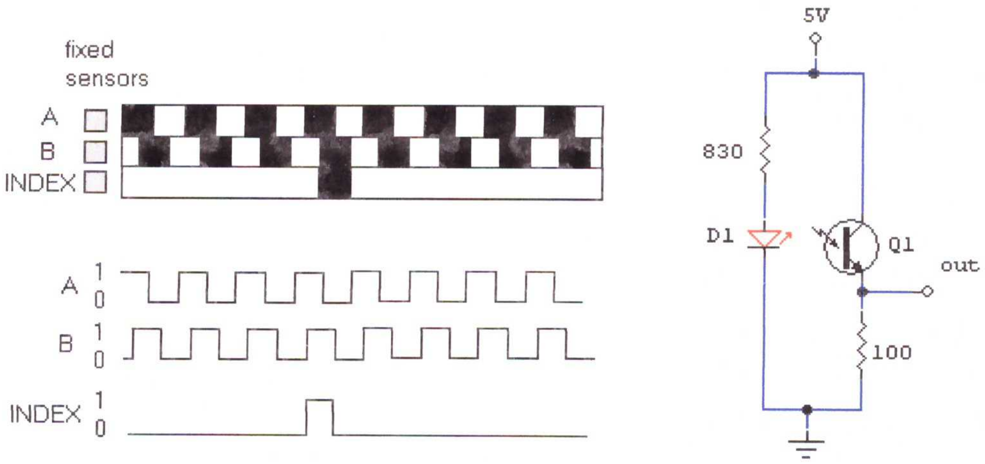

Figure (5.1) The coded track pattern and encoder circuit

A single-coded track with 2mm is used to achieve construction simplicity; the two mouse encoders are positioned on the track in a manner to have 1/4 cycle phase shift between the two output signals.

5.1.1 Optical Encoder conditioning circuits

Optical encoder output pulses on channels A and B are not exactly zero-one signals (digital), they may be noisy -more than zero and less than five volts- this yields a need for conditioning circuits to obtain the desired signal.

5.1.1.1 Schmitt Trigger

The Schmitt Trigger is useful to “square up” slow input rise and fall times, due to hysteretic voltage of the environment; the Schmitt Trigger finds its application in noisy environments. Figure (5.2-a) shows the used Schmitt trigger and its logic diagram, and figure (5.2-b) shows its interfacing circuit. Since this Schmitt is inverted an inverter is used to obtain the original signal shape.

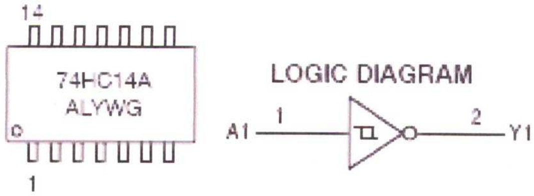

Figure (5.2-a) Schmitt trigger and its logic diagram

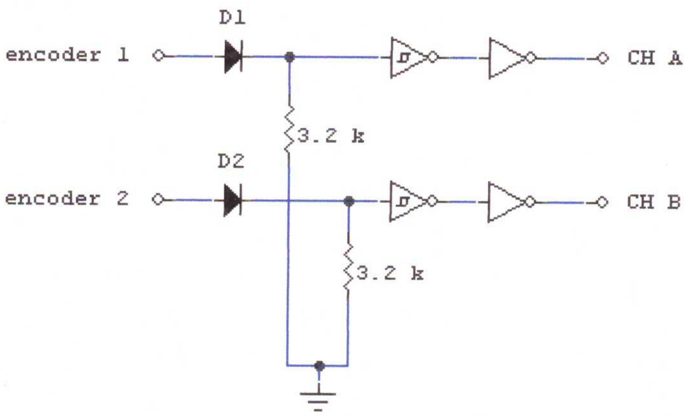

Figure (5.2-b) Schmitt trigger conditioning circuit

5.1.1.2 Encoder Direction Detection Circuit

The A and B channels are used to determine the direction of reciprocation by assessing which channels "leads" the other by means of an edge-trigger D flip-flop. The output Q is equal to the input D when the CK (clock) signal transit from low-to-high, so by connecting the two channels to the D flip-flop as shown in figure (5.3), the direction of reciprocation can be determined. An opto-coupler may be used to protect the microprocessor from overvoltage damage, but since there is no voltage difference there is no need for it.

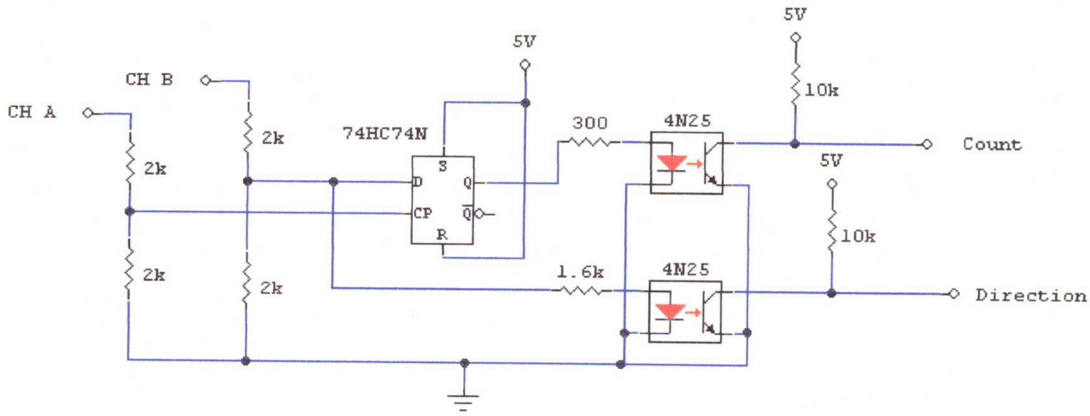

Figure (5.3) Detection of reciprocating direction

5.2 PIC Microcontroller

Microcontroller is a computer-on-a-chip used to control electronic devices. that contains the processor (the CPU), non-volatile memory for the program (ROM or flash), volatile memory for input and output (RAM), a clock and an I/O control unit. Also called a "computer on a chip".

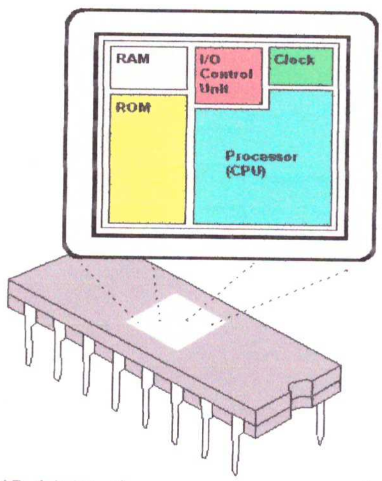

Figure. (5.4) Entire computer on a single chip

5.2.1 16F877 PIC Microcontroller

According to our application requirements, 16f877 PIC had been been choosed to drive our project.

PIC 16F877 Features :

- High-performance CPU.
- Interrupt capability.
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Selectable oscillator options technology.
- Low-power, high-speed CMOS FLASH/EEPROM pins.
- Processor read/write access to program memory.
- Wide operating voltage range: 2.0V to 5.5V.
- High Sink/Source Current: 25 mA.
- Commercial and Industrial temperature ranges.
- Low-power consumption.
- Multiple programming choices.
- Debugger availability.

5.2.2 Clocking Scheme

The clocking scheme and instruction cycle of the PIC microcontroller are described. A microcontroller needs a clock input to synchronize and execute the Instructions in its program memory. The external clock input to the microcontroller is through pins OSC1 and OSC2. The PIC16F877 microcontroller communicates with the external world using the pins. The pin description of the PIC16F877 is given later. The four valid clock modes are described below:

1. RC mode. In this mode, an external resistor and a capacitor circuit provides a clock input to the microcontroller on the OSC1 pin. The frequency of the clock input is a function of the supply voltage, and the values of the resistor and capacitor. In this mode, the microcontroller outputs a clock pulse on the OSC2 pin, which can be used for clocking other devices. The frequency of this clock pulse is one-fourth of the frequency of the RC clock signal on the OSC1 pin.

2. LP mode. In this mode, the microcontroller uses an external crystal of low speed (usually less than 2 MHz). Of all the 4 modes, this mode consumes the least power.

3. XT mode. In this mode, the microcontroller uses an external crystal. Typical clock speeds include 2-4 MHz

4. HS mode. In this mode, the microcontroller uses an external crystal. The clock speeds are usually greater than 4MHz.

During an instruction cycle, an instruction is executed and the next instruction is fetched simultaneously. Hence, each instruction of the microcontroller takes a time of 4/Fosc seconds, where Fosc is the frequency of the clock input to the microcontroller.

5.2.3 Memory Organization

The memory of a PIC microcontroller is divided into two main components. They are the program memory and the data memory. The PIC16F877 is an Electrically Erasable Programmable Read Only Memory (EEPROM) device (also known as a flash microcontroller).

Program Memory

The program memory of the PIC16F877 microcontroller is an EEPROM. The size of this memory is 8K X14 bits (as each instruction is 14 bits long). This program memory is divided into four equally sized blocks called pages. The two important locations in the program memory are:

• Reset vector. This is the address at which the microcontroller looks for instructions whenever there is a device reset or whenever the microcontroller starts. The address of the reset vector is 0h.

• Interrupt vector. This is the address to which the program branches whenever there is an enabled interrupt. Interrupts are special events which might have to be serviced depending upon the application. Common examples are timer interrupts, serial port interrupts, etc. In order to service an interrupt, the interrupt enable flag for that particular interrupt and the global interrupt flag should be set. If the aforementioned flags are set, whenever the interrupt occurs, the microcontroller services the interrupt by making the program jump to the interrupt vector. Enabling and disabling of the interrupts is done in the program.

Data Memory

Data Memory can be divided into three categories. They are:

1. General Purpose Registers (GPR) and the Special Function registers (SFR) form the RAM (Random Access Memory) of the microcontroller. The size of this RAM is 368 bytes for PIC16F877. GPR are used for storing the variables and other temporary values that are used in the program.

2. Special Function Registers. The SFR controls the various core and peripheral features of the microcontroller. The core features are the features necessary for the microcontroller to operate. These include the STATUS, PCL, etc. The peripheral features include features like the Analog to Digital Converter (ADC), USART (Universal Synchronous Asynchronous Receiver Transmitter), etc.

3. Data EEPROM. The Data EEPROM is an EEPROM. This can be used for storing permanent data or some other valuable information. The microcontroller uses a protocol for writing and reading data from the data EEPROM so that the existing

data is not written over accidentally. PIC16F877's data EEPROM has 256 locations and the size of each location is 1 byte.

5.2.4 Pin Description

The microcontroller communicates with the external world using its pins. In this section, the pin layout of PIC16F877 is described in the following figure which shows the pin diagram of PIC16F877. These can broadly be classified as Input/Output (I/O) pins and power pins. Each class is now described.

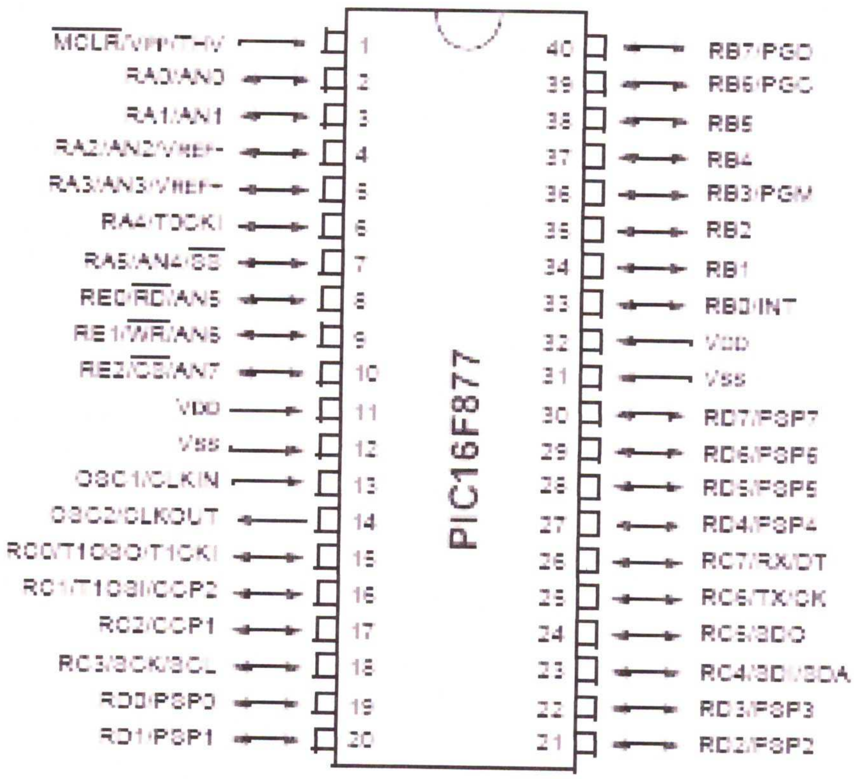

Figure (5.5) 16f877 Pin diagram

I/O pins

I/O ports are the ports by which the microcontroller communicates with external devices for I/O operations. The PIC16F877 has 40 pins, of which 33 are I/O pins. Most of the I/O pins are multiplexed to perform other functions. The 33 I/O pins are divided into 5 ports named A, B, C, D and E. The registers corresponding to these ports are PORTA, PORTB, PORTC, PORTD and PORTE respectively. An I/O pin can be either configured as input or output by setting or clearing the corresponding bit in a corresponding register. These registers are referred by the prefix TRIS. (TRISA corresponding to PORTA and so on). TRIS stands for tri-state. As the name suggests, tri-state devices have three states. These are logical 1, logical 0 (when the device is in its output mode) and off state (when the device is in its input mode).

Power pins and other pins

These pins correspond to the pins which are either connected to the power or ground lines. The other pins apart from the power pins are the pins for the clock input, which are OSC1 and OSC2.

5.2.5 Instruction Set

The microcontroller needs to be programmed for it to perform any task. The instructions to the microcontroller are written in hexadecimal format which is not convenient way (for humans) to code the microcontroller. So one has to use either an assembly language or a high-level language like C or BASIC to write the program. This program is then compiled by a special compiler which compiles it into the hexadecimal format, which the microcontroller understands. A programmer then burns (Electrically) this program onto the microcontroller's program memory.

5.3 Liquid Crystal Display (LCD)

A type of display used in digital circuits applications. LCD displays utilize two sheets of polarizing material with a liquid crystal solution between them. An electric current passed through the liquid causes the crystals to align so that light cannot pass through them. Each crystal, therefore, is like a shutter, either allowing light to pass through or blocking the light.

Figure (5.6) LCD

The possibility of use LCD with the determined PIC enables user to read the results easily.

According to our application (agena 16244) display will be used which have the following pin table.

Pin No	Name	I/O	Description
1	Vss	Power	GND
2	Vdd	Power	+5v
3	Vo	Analog	Contrast Control
4	RS	Input	Register Select
5	R/W	Input	Read/Write
6	E	Input	Enable(Strobe)
7	D0	I/O	Data LSB
8	D1	I/O	Data
9	D2	I/O	Data
10	D3	I/O	Data
11	D4	I/O	Data
12	D5	I/O	Data
13	D6	I/O	Data
14	D7	I/O	Data MSB

Table (5.1). LCD pins

5. 4 Regulation Circuit

Regulation circuit will be used to provide constant voltage to whole circuit. Such circuit will be like the circuit shown in figure (5.7).

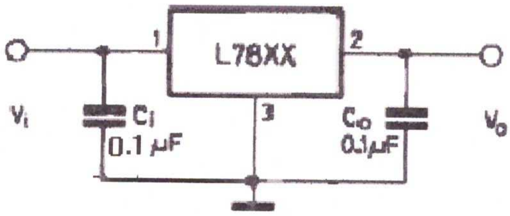

Figure (5.7). Regulator application circuit

Circuit specification

- Output current up to 1.5 A
- Output voltage of 5 V
- Thermal overload protection.
- Short-circuit protection.

5.5 Serial Port Interface

To connect the pic to pc we will use the serial port interface .A level converter should be used to convert the TTL (0-5V_ levels that the PIC operates with to the RS-232 voltages (+/- 3-12V) used by the PIC. The following is a popular configureuration using the MAX232 chip as a level converter.

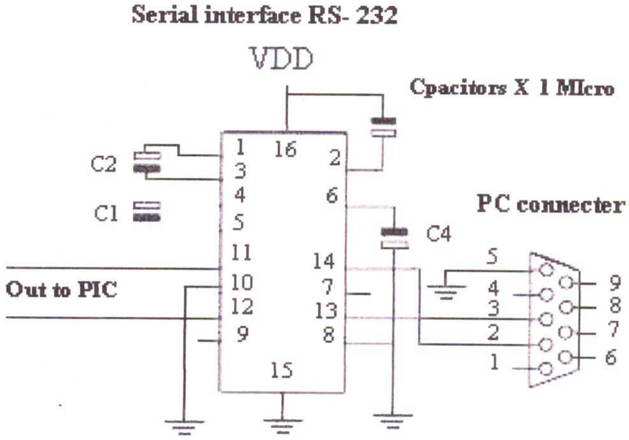

Figure (5.8) serial port interface

5.6 PIC Microcontroller Schematic

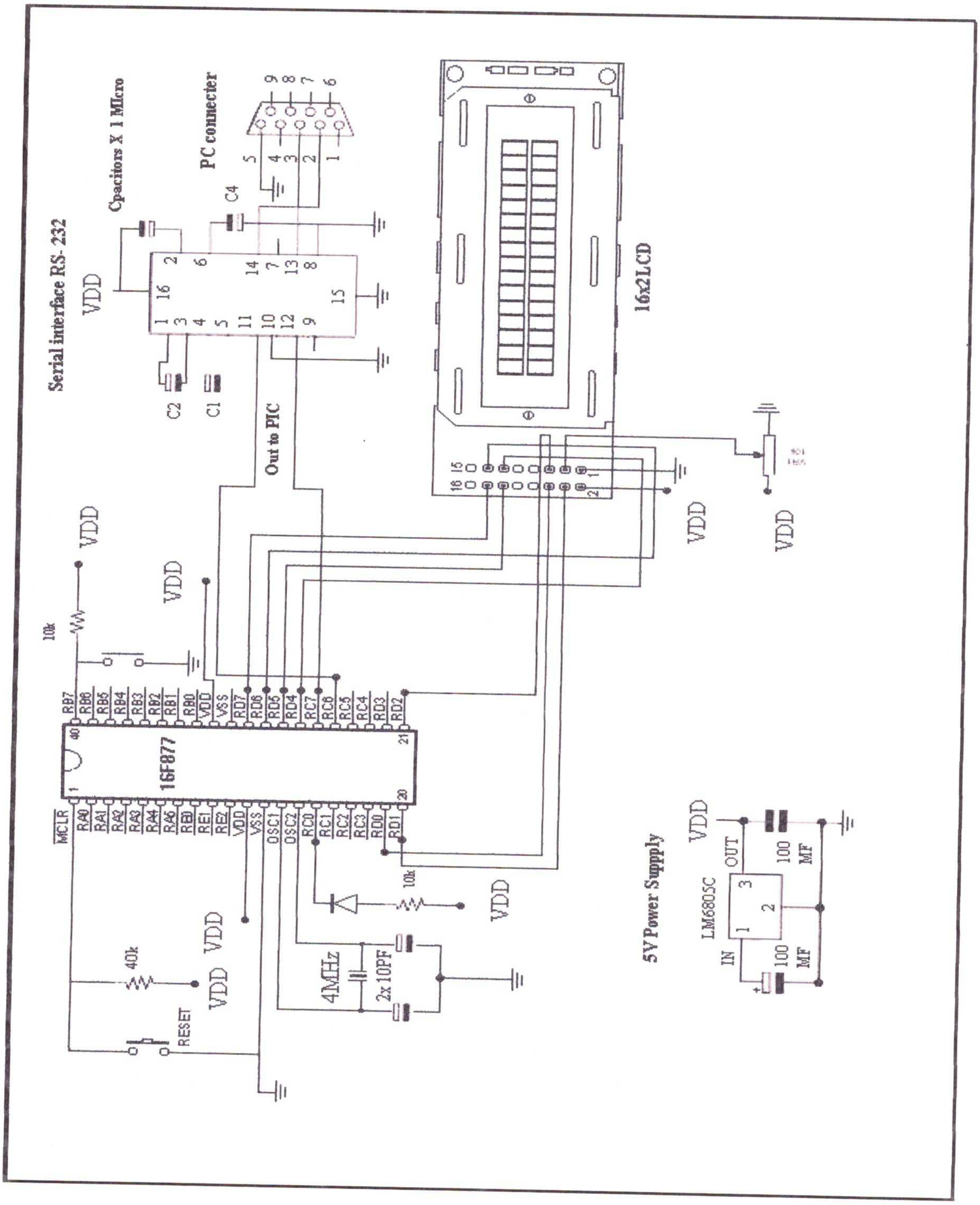

Figure (5.9) PIC schematic

Chapter Six

Software

Chapter Six
Software

6.1 PIC-C Compiler

This kind of PIC-C Compilers gives a firmware developer the capability to quickly produce very efficient code from the easily maintainable, high level, C Language. The compilers are based on the standard Kernighan-Ritchie C Language but also include powerful language extensions and are fully optimized for use with Microchip PIC Microcontrollers.

Language extensions include, but are not limited to, built-in functions to access the PICmicro hardware such as, read_adc() to read a value from the A/D converter, #use RS232 to generate a hardware or software UART, and write_eeprom() for data storage to PIC-resident nonvolatile memory. Additionally, functions such as input() and output_high() will read and write the I/O ports while automatically and dynamically maintaining the port direction registers.

Variables, including structures, may be directly mapped to control registers and I/O ports for source code readability and easy management of those hardware resources. When the contents of these "variables" are changed, the data is actually written directly to the hardware. In this manner hardware peripherals with unique data structures are efficiently managed by name.

Functions may be implemented inline or separate allowing optimization for either code size or speed of execution. In order to relieve the developer of stack depth issues, function parameters are passed in reusable registers. Inline functions with reference parameters are implemented efficiently with no memory overhead.

Interrupts (on supporting devices) are easily established and serviced. The user essentially enables a list of interrupts by name and provides an interrupt function for each. The compiler will call the appropriate interrupt function when that interrupt is detected. Code to save and restore the machine state and clear the interrupt request is automatically generated as well.

During the linking process the program structure, including the call tree, is analyzed. Functions contained in #included libraries but never called are automatically excluded from the final code output. Functions that call one another frequently are grouped together in the same code page. Calls across pages are handled automatically by the compiler making code page selection transparent to the user. RAM banks are also switched automatically. RAM is allocated optimally by using the call tree to determine how memory locations can be reused. Constant strings and tables are saved in the device's program memory in order to conserve RAM.

The output Hex and debug file formats are selectable and compatible with popular programmers and emulators, including MPLAB IDE, for source-level debugging.

6.1.1 PIC-C Compiler Features

- Predefined header file for each supported device
- Standard C and language extensions optimized to produce very efficient code
- C Aware Editor
- 1, 8, 16, and 32-bit integer types and 32-bit Floating Point
- Selectable automatic/manual port direction handling
- Interrupt functions supported on all devices

- Supports embedded Assembly code
- Built-in Libraries for RS232 serial I/O
- Built-in Functions for Timers
- Standard compiler outputs are C/Assembly listing, errors, and statistics
- Source code drivers included for LCD modules
- Context Sensitive Help
- Source Code Bookmaking
- PIC Microcontroller Selection Assistant
- Provide New Project Wizard

6.1.2 PIC-C Setup

For the purpose of developing a C language program on PIC-C Compiler software we will follow the following format:

1. Open PIC-C program
2. Select new project as shown in figure(6.1)

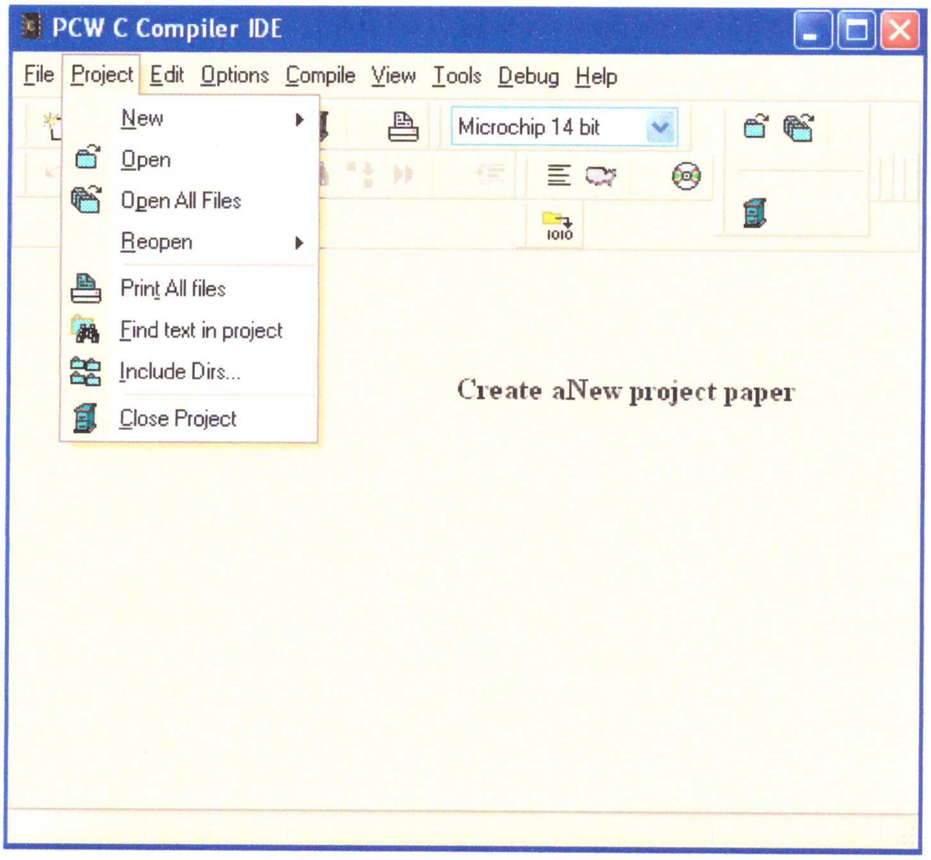

Figure (6.1) New PIC-C project paper

3. Program setup :

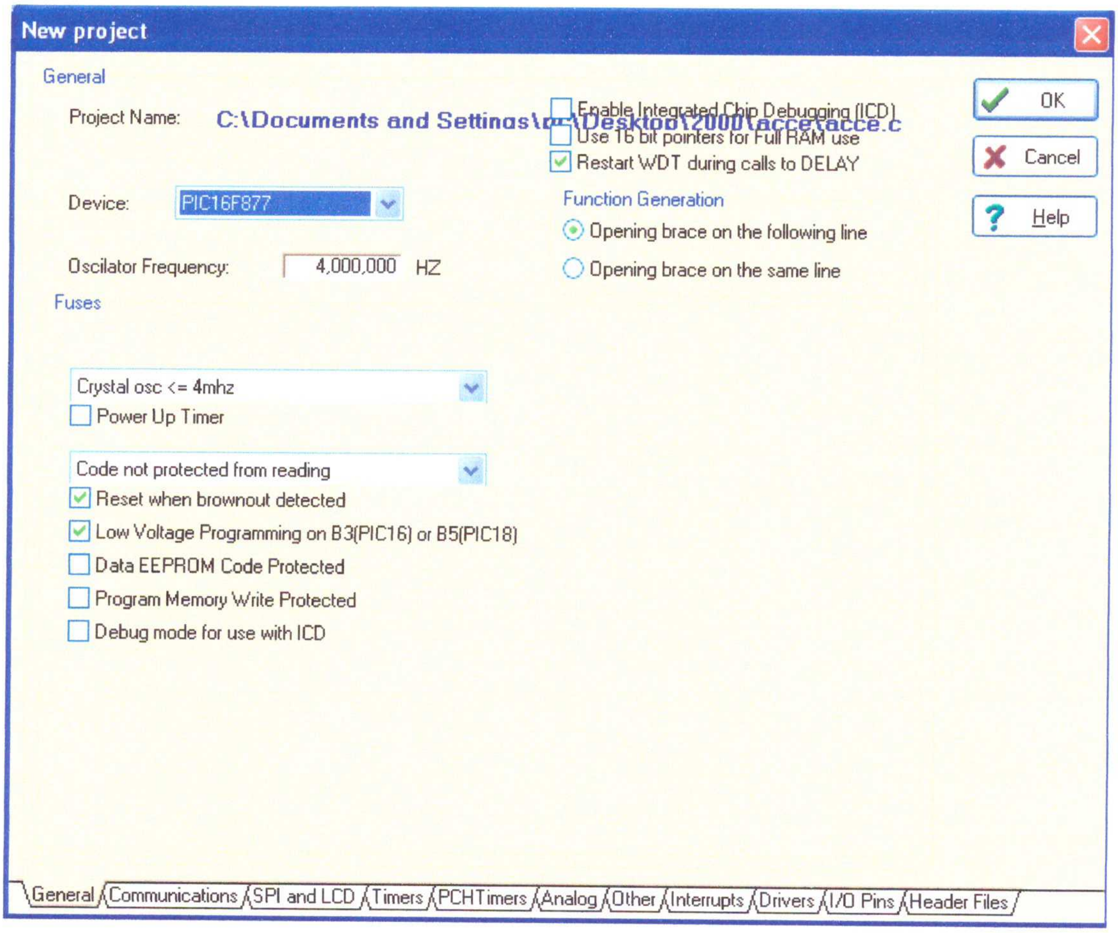

Figure (6.2) PIC-C project setup

A. General parameters

In this window we will choose the device as **16f877** , enabling restart WDT

(Watchdog timer) and determine the oscillator frequency as 4MHz which we used in our circuit.

B. Communications

We will use RS-232 with baud rate 9600 bit per second.

C. Timers Selection

According to our system two timers must be used ,so timer 1 and timer 2 will enabled.

D. Interrupts

We need two interrupts function to select timer 1 and timer 2 overflow periods.

E. Drivers

Since we have LCD we will enable LCD driver from this window.

F. I/O Pins

Port D pins will used for LCD communication and pin C2,C3 as two input pins.

G. Header file

In this window we select the libraries we need in the program which is (stdio.h)

After the above parameters determined, the target program will be written as in the following section.

6.2. C Program

According to our application, this program will enable the PIC microcontroller to view acceleration amplitude on LCD ,also will enable the PIC to send data to MATLAB software through serial port interface for the purpose of plotting the acceleration versus time.

Program flow:

```
//#include "C:\Documents and Settings\pc\Desktop\New\pro.h"
#include "pro.h"
#include <LCD.C>
#define Time2 400
#define Time1 17

float K=48.25;
float M=.0046;
float X;
float A;
float g;
float t=0.0;
float t1=0.0;
float T11=0.0;
float t2=0.0;
float T22=0;
int8 timer1=0;
int8 timer2=0;
int1 sensor;                    // to move  between the tow timers//
float copuls=0.0;
float copuls2=0.0;
float Dpulse=0.0;
#int_TIMER1                          // to calculate the off pulse period time//
TIMER1_isr()
{
            restart_wdt();
            ++timer1;
  if ( timer1 >= Time1 || sensor==0 )
```

```
  {
            restart_wdt();
            timer1 = 0;
            restart_wdt();
  }
            restart_wdt();
}
#int_TIMER2                          //to calculate the on pulse period time//
TIMER2_isr()
{
        restart_wdt();
        ++timer2;
if ( timer2 >= Time2 || sensor==1 )
  {
       restart_wdt();
       timer2 = 0;
       restart_wdt();
  }
       restart_wdt();
}
void main()
{
        setup_adc_ports(NO_ANALOGS);
        setup_adc(ADC_OFF);
        setup_psp(PSP_DISABLED);
        setup_spi(FALSE);
        setup_counters(RTCC_INTERNAL,RTCC_DIV_1);
        setup_timer_1(T1_INTERNAL|T1_DIV_BY_1);
        setup_timer_2(T2_DIV_BY_1,160,16);
```

```
        lcd_init();                                  // to initialize LCD with PIC//
        enable_interrupts(INT_TIMER1);
        enable_interrupts(INT_TIMER2);
        enable_interrupts(global);

        printf(LCD_PUTC,"\r\n\fWellcome...\n");
         delay_ms(2500);
         restart_wdt();
do{
while(input(pin_c3)){        // to calculate the acceleration in the positive direction//
while(input(PIN_C2) && (timer2<400)){
        restart_wdt();
        sensor=0;
        restart_wdt();
        TIMER2_isr();
        restart_wdt();
        t2=timer2*0.0025;                 // to represent the time in seconds//
        restart_wdt();
        T22+=t2;
        restart_wdt();

if(timer2 == 400)
       {
        T22-=t2;
        copuls-=1.0;
       }
       }
       copuls+=1.0;
       while(!input(PIN_C2)&& (timer1<17)){
              restart_wdt();
```

```
            sensor=1;
            restart_wdt();
            TIMER1_isr();
            restart_wdt();
            t1=timer1*0.0655;                    // to represent the time in seconds//
            restart_wdt();
            T11+=t1;
            restart_wdt();
                                             // counte of pulses in this direction //
   if(timer1 == 17)
  {
          T11-=t1;
           copuls-=1.0;
  }


  }
          copuls+=1.0;
          Dpulse=copuls-copuls2;
          restart_wdt();
          restart_wdt();
          restart_wdt();
          fn();

}copuls2=0;
copuls=Dpulse;
while(!input(pin_c3)){
                              // to calculate acceleration in the reverse direction//
while(input(PIN_C2) && (timer2<400)){
          restart_wdt();
          sensor=0;
```

```
            restart_wdt();
           TIMER2_isr();
           restart_wdt();
            t2=timer2*0.0025;
            restart_wdt();
            restart_wdt();
            T22+=t2;
            restart_wdt();
                                        // count of pulses in this direction //
            restart_wdt();
      if(timer2 == 400)
      {
            T22-=t2;
            Dpulse-=1.0;
      }

            restart_wdt();


      }
           copuls2+=1.0;


      while(!input(PIN_C2)&&  (timer1<17)){
            restart_wdt();
            sensor=1;
            restart_wdt();
            TIMER1_isr();
            restart_wdt();
            t1=timer1*0.0655;
```

```
                restart_wdt();
               T11+=t1;
                restart_wdt();

                                        // count of pulses in this direction //
       if(timer1 == 17)
     {
                T11-=t1;
               Dpulse-=1.0;
     }

     }
             copuls2+=1.0;
             restart_wdt();
             Dpulse=copuls-copuls2;
             restart_wdt();
             fn();
             restart_wdt();
   }
             copuls=0;
             copuls2=Dpulse;
    }while(timer1 != 17);
 }
    void fn(){
             X=0.002*Dpulse;
             restart_wdt();
             A=k*X/M;
             restart_wdt();
             printf(LCD_PUTC,"\r\n\fA=%fm/s2\n",A);
                                        //acceleration amplitude to b sent to LCD //
```

```
            delay_ms(50);
            g=A/9.81;
            printf(LCD_PUTC,"\r\nA=%f g\n",g);
            delay_ms(15);
            restart_wdt();
        }
\///////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////\
```

LCD Program:

The following program will be enabled through lcd_init() instruction which written in main program in order to interface LCD with PIC Microcontroller and so results can be sent to LCD .

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


#if defined(__PCH__)
#if defined use_portb_lcd
 #byte lcd = 0xF81                   // This puts the entire
structure
#else
 #byte lcd = 0xF83                   // This puts the entire
structure
#endif
#else
#if defined use_portb_lcd
 #byte lcd = 6                       // on to port B (at address 6)
#else
 #byte lcd = 8                       // on to port D (at address 8)
#endif
#endif
```

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


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


BYTE const LCD_INIT_STRING[4] = {0x20 | (lcd_type << 2), 0xc, 1, 6};
                                        // These bytes need to be sent to the
LCD
                                        // to start it up.
                                        // The following are used for setting
                                        // the I/O port direction register.

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


BYTE lcd_read_byte() {
        BYTE low,high;
```

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


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


void lcd_send_byte( BYTE address, BYTE n ) {

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

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

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

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

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

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

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

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

6.3 PIC 16F877 Boot Loader Download

The PIC Boot Loader (PICBL) is a bootstrap loader that, once programmed into the PIC16F877 processor, allows reprogramming of PIC microcontrollers without need for a chip programmer. The PICBL makes use of the self-programming features of the PIC microcontrollers to allow in-circuit reprogramming. Once the PICBL is programmed into the microcontroller, it remains resident until the chip is erased. Application programs require only a very minimum software interface to use the PICBL.

6.4 Program Downloading

For this purpose we used TR software designed especially for 16F877 PIC microcontroller, which enables us to download programs through RS-232 serial interface.

To download program with TR software we followed:

- Open TR software
- Choose baud rate 9600 bit/s
- Choose COM1 as COM port
- Open the Hex copy of the designed program developed by C-compiler.
- Send Hex file

These process shown in figure (6.3)

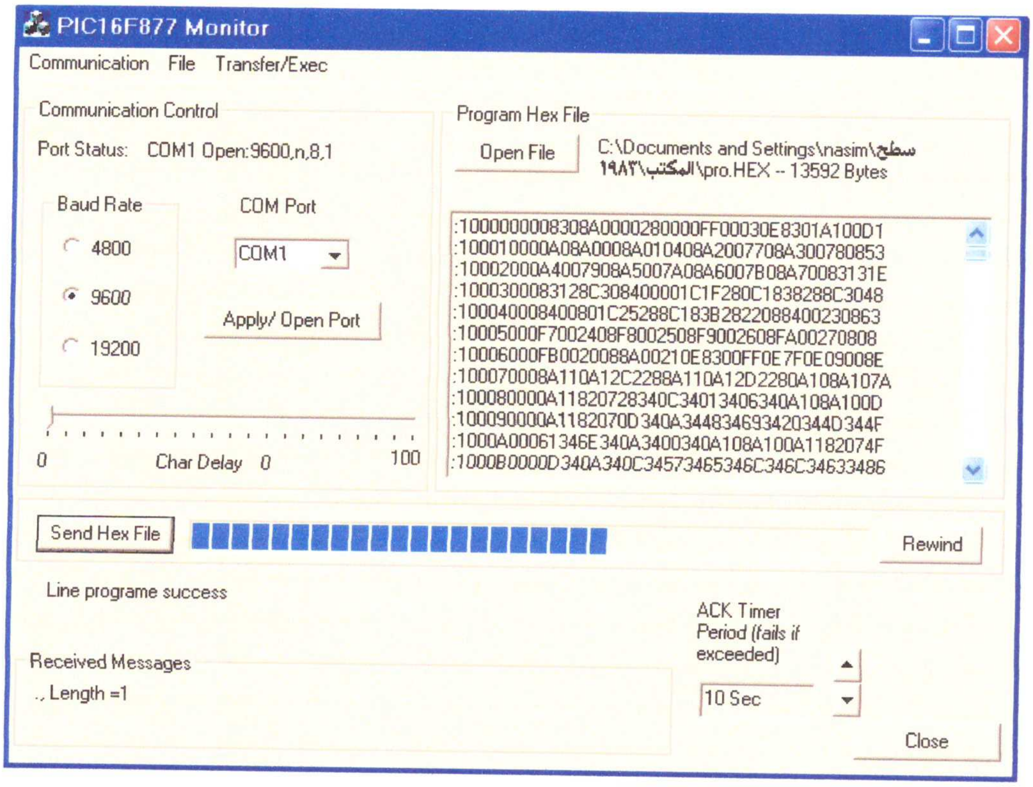

Figure (6.3) TR software window

Chapter Seven
Conclusion and Recommendations

Chapter Seven

Conclusion and Recommendations

7.1 Conclusion

An optical accelerometer is designed with the following specifications:

- Digital output .
- Single degree of freedom seismic accelerometer.
- Output range: maximum +50.5g, minimum -16g
- Resolution 2.1g
- Bandwidth 9 Hz.
- 5V power supply
- Base mounting: adhesive
- Weight 0.12 kg

7.2 Recommendations

- The optical sensors that are used in the project are not enough accurate, so an accurate optical sensor must be used in order to get more accurate data.
- The mechanical system's design is constructed upon the available spring, which is not enough elastic to have accurate measurements, so a low spring constant must be used.

7.3 Expandability

A large mass and soft spring are suitable for vibration and displacement measurements, while a relatively small mass and stiff spring are used in accelerometers. Regarding to this, and to have a wide range of usage capability, this design can be used at any frequency value less than 4 MHz.

The designed spring-mass-damper system with 16.3 Hz natural frequency can be replaced by any other one with less than 4 MHz natural frequency, thus this system can be used either an accelerometer or vibrometer.

References:

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[2] Matt Brandt,Mike Gottshall," Modal Analysis of a Simple Metal Pipe Water Pipe Simulation",Miami University,2003.

[3] Jackson Lin," Applying Stator End-wending Vibration monitoring Technology",J.H. Campbell Generation Plant,2002

[4] Figliola, R. S. and Beasley, D. E., "Theory and Design for Mechanical Measurements", Third Ed., Wiley, 2000.

[5] Devdas Shetty,Richard A. Kolk,"Mechatronics System Design",2000.

[6] Halit Eren, "Acceleration, Vibration, and Shock Measurement", CRC Press LLC, 2000.

[7] http://www.efunda.com/formulae/vibrations/sdof_eg_accelerometer.cfm.

[8] Singiresu S. Rao, "Mechanical Vibrations", Purdue University,1995.

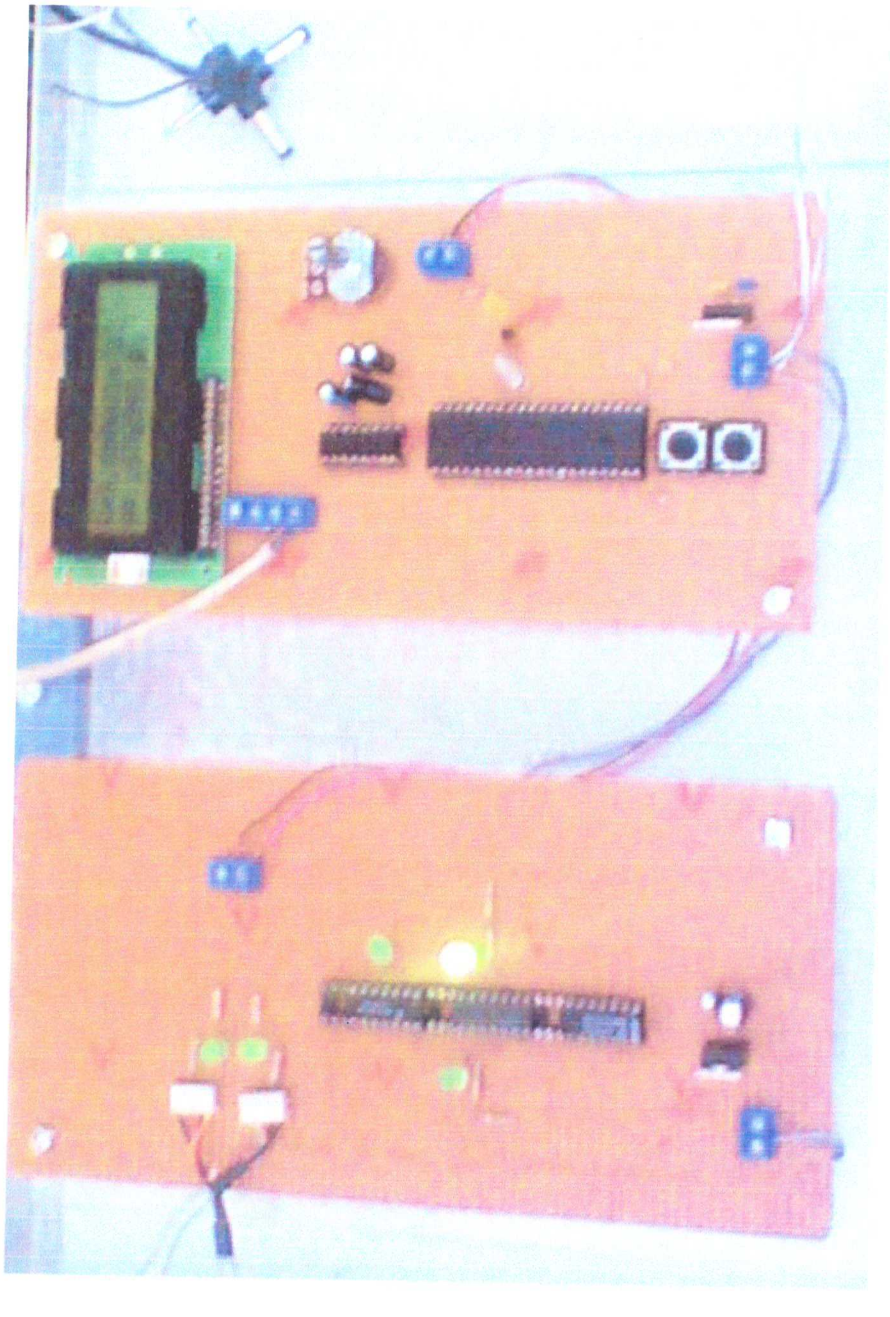
[9] Robert H. Bishop,"The Mechatronics Handbook", University of Texas, Austin,Texas,2002.

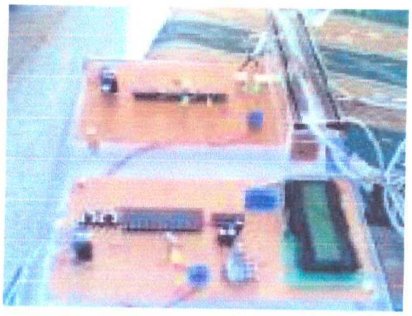
[10] http://zone.ni.com/devzone/cda/ph/p/id/12#toc1#toc1

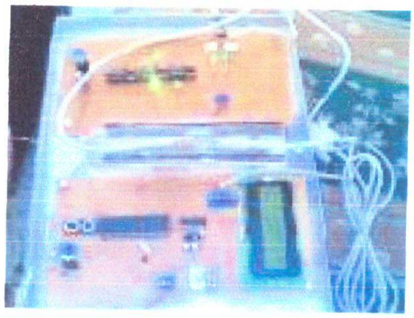
[11] PIC-C Compiler software help and documentation

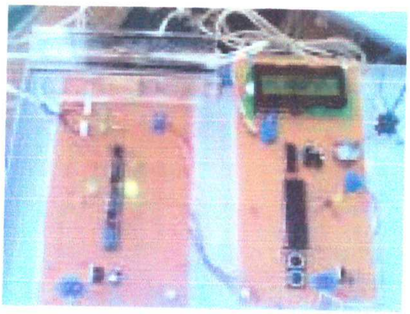
Appendix A

System in Real-world









PACIFIC DISPLAY DEVICES

LCD Component Data Sheet

Model Number: 16244

16 Character by 2 Line
Alphanumeric LCD Assembly
With Embedded Controller

CONTENTS

139 Avenida Victoria – Suite 100 – San Clemente, CA – 92672
Tel: 949-361-8957 – Fax: 949-361-9158 – Web: www.pacificdisplay.com

1. GENERAL INFORMATION

1.1 Product Overview

- 16 Character x 2 line Alphanumeric Dot Matrix LCD Module
- LCD Controller: Embedded S6A0069 or equivalent alpha-numeric controller
- Multiplexing driving: 1/16 duty, 1/5 bias
- Operating Mode: Super Twisted Nematic (STN) technology
- LCD Module Service Life: 100,000 hours minimum

1.2 Part Numbering System

16244		-SL	-F	-ST	-LED	-GY	-6

➢ **Custom Option Designator**
- (Blank)

➢ **Operating Mode**
- (-GR) Green
- (-SL) Silver
- (-BN) Blue Negative

➢ **Rear Polarizer Options:**
- (-R) Reflective
- (-F) Transflective
- (-M) Transmissive

➢ **Operating Temperature**
- (-ST) Standard (0 to +50 °C)
- (-ET) Extended (-20 to +70 °C)

➢ **Backlight Options:**
- (-LED) LED Array Backlight
- (-ELP) EL Panel Backlight
-

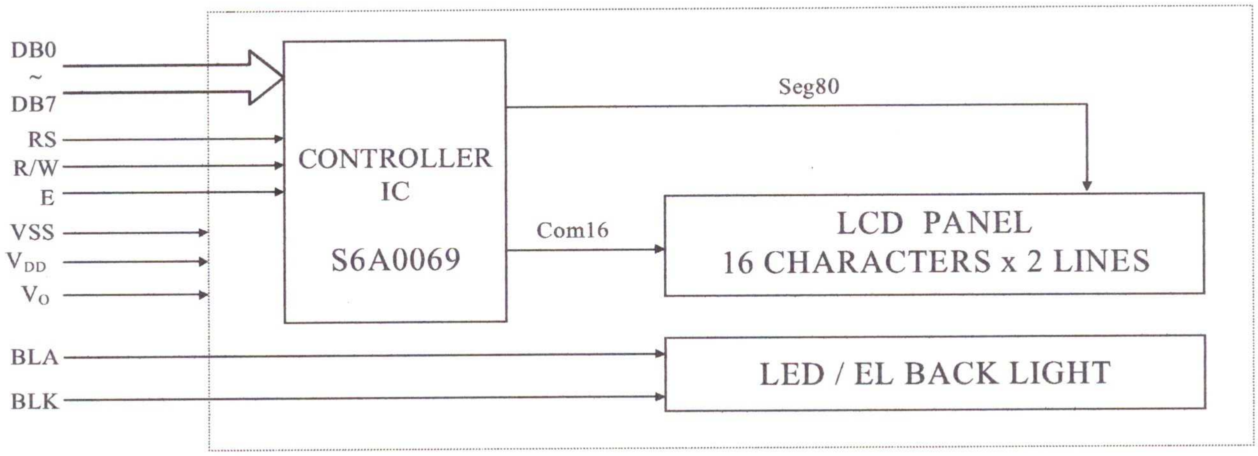
➢ **Backlight Coloration Options:**
- (-GY) LED - Green/Yellow
- (-AM) LED - Amber
- (-RD) LED - Red
- (-BG) ELP – Blue Green

➢ **Viewing Angle**
- (-6) 6 o'clock
- (-12) 12 0'clock

1.3 Absolute Maximum Ratings

Parameter	Symbol	Min	Max	Unit
Supply voltage for logic	V_{DD}	-0.3	7.0	V
Supply voltage for LCD	$V_{DD} - V0$	--	V_{DD} +0.3	V
Input voltage	VI	-0.3	V_{DD} +0.3	V
Standard Operating temperature	TOP (-ST)	0	50	ºC
Standard Storage temperature	TST (-ST)	-10	60	ºC
Extended Operating temperature	TOP (-ET)	-20	70	ºC
Extended Storage temperature	TST (-ET)	-30	80	ºC
Soldering Temp	Tsolder	260		ºC

1.4 Circuit Block Diagram



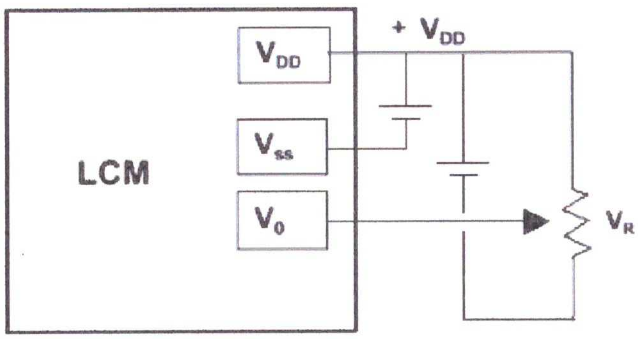
1.5 Mechanical Characteristics

Item	Contents	Unit
Module size (W×H×T)	84.0 x 44.0 x 14.2 Max (w/ LED Backlight) 84.0 x 44.0 x 10.0 Max (w/ ELP, Reflective)	mm
Viewing area (W×H)	62.2 x 17.9	mm
Character matrix (W×H)	5 × 8	dots
Character size (W×H)	2.95 x 5.55	mm
Dot size (W×H)	0.55 x 0.65	mm
Dot pitch (W×H)	0.60 x 0.70	mm

1.6 Input Signal Function

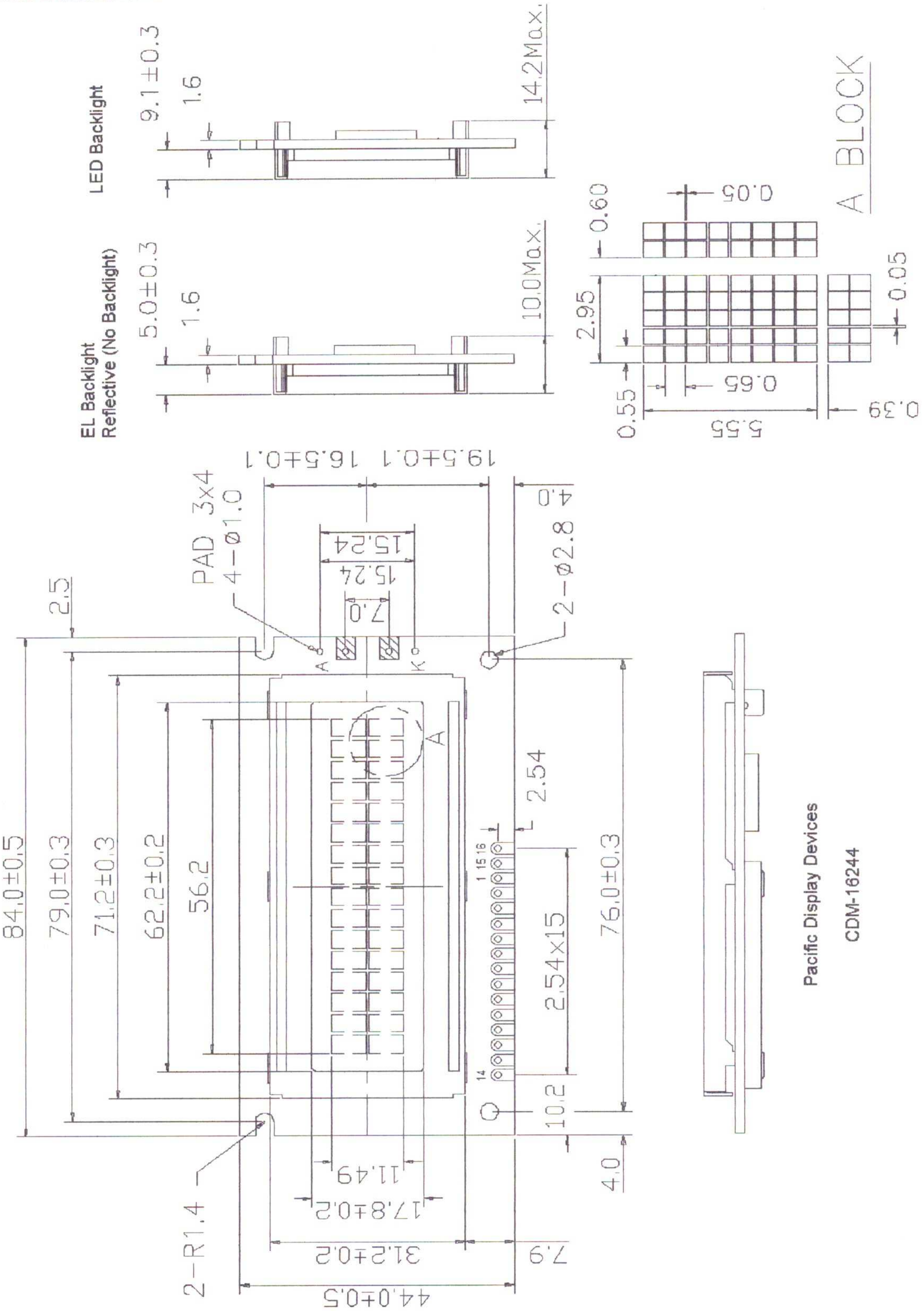
Pin NO.	Symbol	Level	Description
1	VSS	0V	Ground
2	VDD	5.0V	Supply voltage for logic
3	VO	---	Input voltage for LCD
4	RS	H/L	H : Data signal, L : Instruction signal
5	R/W	H/L	H : Read mode, L : Write mode
6	E	H, H → L	Chip enable signal
7	DB0	H/L	Data bit 0
8	DB1	H/L	Data bit 1
9	DB2	H/L	Data bit 2
10	DB3	H/L	Data bit 3
11	DB4	H/L	Data bit 4
12	DB5	H/L	Data bit 5
13	DB6	H/L	Data bit 6
14	DB7	H/L	Data bit 7
15	LED A(+)	4.2V	Back light anode
16	LED K (-)	0V	Back light cathode

1.7 LCM Contrast Control and Bias



V_{DD}-V_0 : LCD Driving Voltage
V_R : 10K- 20K

1.8 LCM Dimensions



TEXAS INSTRUMENTS

Data sheet acquired from Harris Semiconductor
SCHS117

August 1997

CD54HC04, CD54HCT04, CD74HC04, CD74HCT04

High Speed CMOS Logic Hex Inverter

Features

- Buffered Inputs
- Typical Propagation Delay: 6ns at V_{CC} = 5V, C_L = 15pF, T_A = 25°C
- Fanout (Over Temperature Range)
  - Standard Outputs . . . . 10 LSTTL Loads
  - Bus Driver Outputs . . . . 15 LSTTL Loads
- Wide Operating Temperature Range . . . -55°C to 125°C
- Balanced Propagation Delay and Transition Times
- Significant Power Reduction Compared to LSTTL Logic ICs
- HC Types
  - 2V to 6V Operation
  - High Noise Immunity: N_{IL} = 30%, N_{IH} = 30% of V_{CC} at V_{CC} = 5V
- HCT Types
  - 4.5V to 5.5V Operation
  - Direct LSTTL Input Logic Compatibility, V_{IL}= 0.8V (Max), V_{IH} = 2V (Min)
  - CMOS Input Compatibility, $I_I \leq 1\mu A$ at V_{OL}, V_{OH}

Description

The Harris CD54HC04, CD54HCT04, CD74HC04 and CD74HCT04 logic gates utilize silicon gate CMOS technology to achieve operating speeds similar to LSTTL gates with the low power consumption of standard CMOS integrated circuits. All devices have the ability to drive 10 LSTTL loads. The 74HCT logic family is functionally pin compatible with the standard 74LS logic family.

Ordering Information

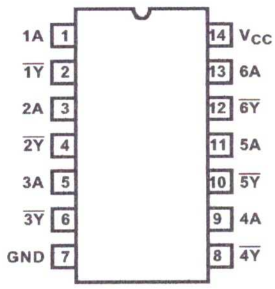
PART NUMBER	TEMP. RANGE (°C)	PACKAGE	PKG. NO.
CD74HC04E	-55 to 125	14 Ld PDIP	E14.3
CD74HCT04E	-55 to 125	14 Ld PDIP	E14.3
CD74HC04M	-55 to 125	14 Ld SOIC	M14.15
CD74HCT04M	-55 to 125	14 Ld SOIC	M14.15
CD54HC04F	-55 to 125	14 Ld CERDIP	F14.3
CD54HCT04F	-55 to 125	14 Ld CERDIP	F14.3
CD54HC04W	-55 to 125	Wafer	
CD54HCT04W	-55 to 125	Wafer	
CD54HC04H	-55 to 125	Die	
CD54HCT04H	-55 to 125	Die	

NOTE:

1. When ordering, use the entire part number. Add the suffix 96 to obtain the variant in the tape and reel.

Pinout

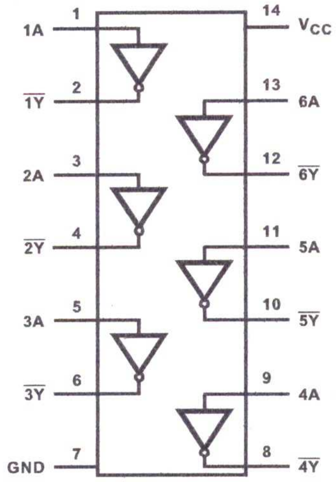
CD54HC04, CD54HCT04, CD74HC04, CD74HCT04
(PDIP, CERDIP, SOIC)
TOP VIEW



CAUTION: These devices are sensitive to electrostatic discharge. Users should follow proper IC Handling Procedures.

File Number 1471.1

Functional Diagram

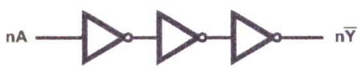


TRUTH TABLE

INPUTS	
nA	nY
L	H
H	L

NOTE: H = High Voltage Level, L = Low Voltage Level

Logic Symbol



Absolute Maximum Ratings

DC Supply Voltage, V_{CC} . . . . . -0.5V to 7V
DC Input Diode Current, I_{IK}
For $V_I < -0.5V$ or $V_I > V_{CC} + 0.5V$ . . . . . ±20mA
DC Output Diode Current, I_{OK}
For $V_O < -0.5V$ or $V_O > V_{CC} + 0.5V$ . . . . . ±20mA
DC Output Source or Sink Current per Output Pin, I_O
For $V_O > -0.5V$ or $V_O < V_{CC} + 0.5V$ . . . . . ±25mA
DC V_{CC} or Ground Current, I_{CC} or I_{GND} . . . . . ±50mA

Operating Conditions

Temperature Range (T_A) . . . . . -55°C to 125°C
Supply Voltage Range, V_{CC}
HC Types . . . . . 2V to 6V
HCT Types . . . . . 4.5V to 5.5V
DC Input or Output Voltage, V_I, V_O . . . . . 0V to V_{CC}
Input Rise and Fall Time
2V . . . . . 1000ns (Max)
4.5V. . . . . 500ns (Max)
6V . . . . . 400ns (Max)

Thermal Information

Thermal Resistance (Typical, Note 2)	θ_{JA} (°C/W)	θ_{JC} (°C/W)
PDIP Package	100	N/A
CERDIP Package	130	55
SOIC Package	180	N/A

Maximum Junction Temperature (Hermetic Package or Die) . . . 175°C
Maximum Junction Temperature (Plastic Package) . . . . . 150°C
Maximum Storage Temperature Range . . . . . -65°C to 150°C
Maximum Lead Temperature (Soldering 10s) . . . . . 300°C
(SOIC - Lead Tips Only)

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

NOTE:

2. θ_{JA} is measured with the component mounted on an evaluation PC board in free air.

DC Electrical Specifications

PARAMETER	SYMBOL	TEST CONDITIONS V_I (V)	TEST CONDITIONS I_O (mA)	V_{CC} (V)	25°C MIN	25°C TYP	25°C MAX	-40°C TO +85°C MIN	-40°C TO +85°C MAX	-55°C TO 125°C MIN	-55°C TO 125°C MAX	UNITS
HC TYPES												
High Level Input Voltage	V_{IH}	-	-	2	1.5	-	-	1.5	-	1.5	-	V
				4.5	3.15	-	-	3.15	-	3.15	-	V
				6	4.2	-	-	4.2	-	4.2	-	V
Low Level Input Voltage	V_{IL}	-	-	2	-	-	0.5	-	0.5	-	0.5	V
				4.5	-	-	1.35	-	1.35	-	1.35	V
				6	-	-	1.8	-	1.8	-	1.8	V
High Level Output Voltage CMOS Loads	V_{OH}	V_{IH} or V_{IL}	-0.02	2	1.9	-	-	1.9	-	1.9	-	V
			-0.02	4.5	4.4	-	-	4.4	-	4.4	-	V
			-0.02	6	5.9	-	-	5.9	-	5.9	-	V
High Level Output Voltage TTL Loads			-	-	-	-	-	-	-	-	-	V
			-4	4.5	3.98	-	-	3.84	-	3.7	-	V
			-5.2	6	5.48	-	-	5.34	-	5.2	-	V
Low Level Output Voltage CMOS Loads	V_{OL}	V_{IH} or V_{IL}	0.02	2	-	-	0.1	-	0.1	-	0.1	V
			0.02	4.5	-	-	0.1	-	0.1	-	0.1	V
			0.02	6	-	-	0.1	-	0.1	-	0.1	V
Low Level Output Voltage TTL Loads			-	-	-	-	-	-	-	-	-	V
			4	4.5	-	-	0.26	-	0.33	-	0.4	V
			5.2	6	-	-	0.26	-	0.33	-	0.4	V
Input Leakage Current	I_I	V_{CC} or GND	-	6	-	-	±0.1	-	±1	-	±1	µA

DC Electrical Specifications (Continued)

PARAMETER	SYMBOL	TEST CONDITIONS V_I (V)	TEST CONDITIONS I_O (mA)	V_{CC} (V)	25°C MIN	25°C TYP	25°C MAX	-40°C TO +85°C MIN	-40°C TO +85°C MAX	-55°C TO 125°C MIN	-55°C TO 125°C MAX	UNITS
Quiescent Device Current	I_{CC}	V_{CC} or GND	0	6	-	-	2	-	20	-	40	µA
HCT TYPES												
High Level Input Voltage	V_{IH}	-	-	4.5 to 5.5	2	-	-	2	-	2	-	V
Low Level Input Voltage	V_{IL}	-	-	4.5 to 5.5	-	-	0.8	-	0.8	-	0.8	V
High Level Output Voltage CMOS Loads	V_{OH}	V_{IH} or V_{IL}	-0.02	4.5	4.4	-	-	4.4	-	4.4	-	V
High Level Output Voltage TTL Loads			-4	4.5	3.98	-	-	3.84	-	3.7	-	V
Low Level Output Voltage CMOS Loads	V_{OL}	V_{IH} or V_{IL}	0.02	4.5	-	-	0.1	-	0.1	-	0.1	V
Low Level Output Voltage TTL Loads			4	4.5	-	-	0.26	-	0.33	-	0.4	V
Input Leakage Current	I_I	V_{CC} and GND	0	5.5	-		±0.1	-	±1	-	±1	µA
Quiescent Device Current	I_{CC}	V_{CC} or GND	0	5.5	-	-	2	-	20	-	40	µA
Additional Quiescent Device Current Per Input Pin: 1 Unit Load (Note)	ΔI_{CC}	V_{CC} - 2.1	-	4.5 to 5.5	-	100	360	-	450	-	490	µA

NOTE: For dual-supply systems theorectical worst case (V_I = 2.4V, V_{CC} = 5.5V) specification is 1.8mA.

HCT Input Loading Table

INPUT	UNIT LOADS
nB	1.2

NOTE: Unit Load is ΔI_{CC} limit specified in DC Electrical Specifications table, e.g. 360µA max at 25°C.

Switching Specifications Input t_r, t_f = 6ns

PARAMETER	SYMBOL	TEST CONDITIONS	V_{CC} (V)	25°C MIN	25°C TYP	25°C MAX	-40°C TO 85°C MIN	-40°C TO 85°C MAX	-55°C TO 125°C MIN	-55°C TO 125°C MAX	UNITS
HC TYPES											
Propagation Delay, Input to Output (Figure 1)	t_{PLH}, t_{PHL}	C_L = 50pF	2	-	-	85	-	105	-	130	ns
			4.5	-	-	7	-	21	-	67	ns
			6	-	-	14	-	18	-	22	ns
Propagation Delay, Data Input to Output Y	t_{PLH}, t_{PHL}	C_L = 15pF	5	-	6	-	-	-	-	-	ns

Switching Specifications Input t_r, t_f = 6ns **(Continued)**

PARAMETER	SYMBOL	TEST CONDITIONS	V_{CC} (V)	25°C			-40°C TO 85°C		-55°C TO 125°C		UNITS
				MIN	TYP	MAX	MIN	MAX	MIN	MAX	
Transition Times (Figure 1)	t_{TLH}, t_{THL}	C_L = 50pF	2	-	-	75	-	95	18	110	ns
			4.5	-	-	15	-	19	-	22	ns
			6	-	-	13	-	16	-	19	ns
Input Capacitance	C_I	-	-	-	-	10	-	10	-	10	pF
Power Dissipation Capacitance (Notes 3, 4)	C_{PD}	-	5	-	21	-	-	-	-	-	pF
HCT TYPES											
Propagation Delay, Input to Output (Figure 2)	t_{PLH}, t_{PHL}	C_L = 50pF	4.5	-	-	19	-	24	-	29	ns
Propagation Delay, Data Input to Output Y	t_{PLH}, t_{PHL}	C_L = 15pF	5	-	7	-	-	-	-	-	ns
Transition Times (Figure 2)	t_{TLH}, t_{THL}	C_L = 50pF	4.5	-	-	15	-	19	-	22	ns
Input Capacitance	C_I	-	-	-	-	10	-	10	-	10	pF
Power Dissipation Capacitance (Notes 3, 4)	C_{PD}	-	5	-	24	-	-	-	-	-	pF

NOTES:

3. C_{PD} is used to determine the dynamic power consumption, per gate.
4. $P_D = V_{CC}^2 f_i (C_{PD} + C_L)$ where f_i = input frequency, C_L = output load capacitance, V_{CC} = supply voltage.

Test Circuits and Waveforms

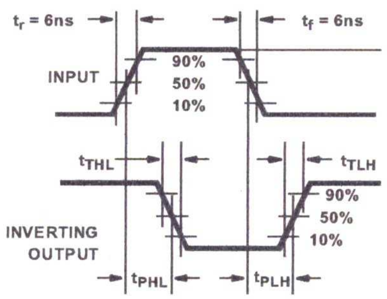


FIGURE 1. HC TRANSITION TIMES AND PROPAGATION DELAY TIMES, COMBINATION LOGIC

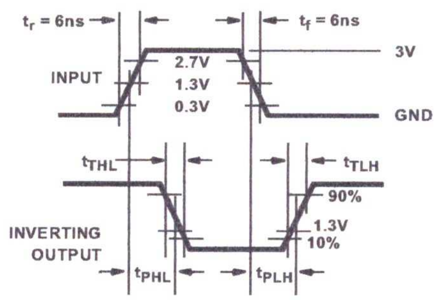
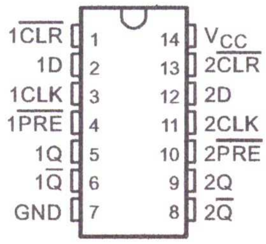


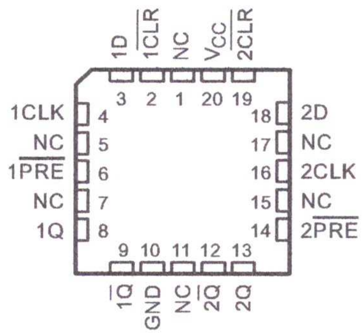
FIGURE 2. HCT TRANSITION TIMES AND PROPAGATION DELAY TIMES, COMBINATION LOGIC

- **Package Options Include Plastic Small-Outline (D), Shrink Small-Outline (DB), Thin Shrink Small-Outline (PW), and Ceramic Flat (W) Packages, Ceramic Chip Carriers (FK), and Standard Plastic (N) and Ceramic (J) 300-mil DIPs**

SN54HC74 . . . J OR W PACKAGE
SN74HC74 . . . D, DB, N, OR PW PACKAGE
(TOP VIEW)



SN54HC74 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

description

The ’HC74 contain two independent D-type positive-edge-triggered flip-flops. A low level at the preset ($\overline{PRE}$) or clear ($\overline{CLR}$) inputs sets or resets the outputs regardless of the levels of the other inputs. When $\overline{PRE}$ and $\overline{CLR}$ are inactive (high), data at the data (D) input meeting the setup time requirements are transferred to the outputs on the positive-going edge of the clock (CLK) pulse. Clock triggering occurs at a voltage level and is not directly related to the rise time of CLK. Following the hold-time interval, data at the D input can be changed without affecting the levels at the outputs.

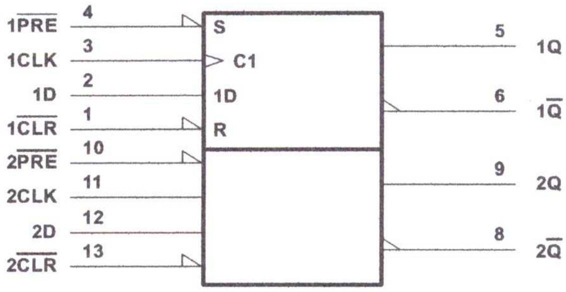
The SN54HC74 is characterized for operation over the full military temperature range –55°C to 125°C. The SN74HC74 is characterized for operation from –40°C to 85°C.

FUNCTION TABLE

INPUTS				OUTPUTS	
$\overline{PRE}$	$\overline{CLR}$	CLK	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H†	H†
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q_0	$\overline{Q}_0$

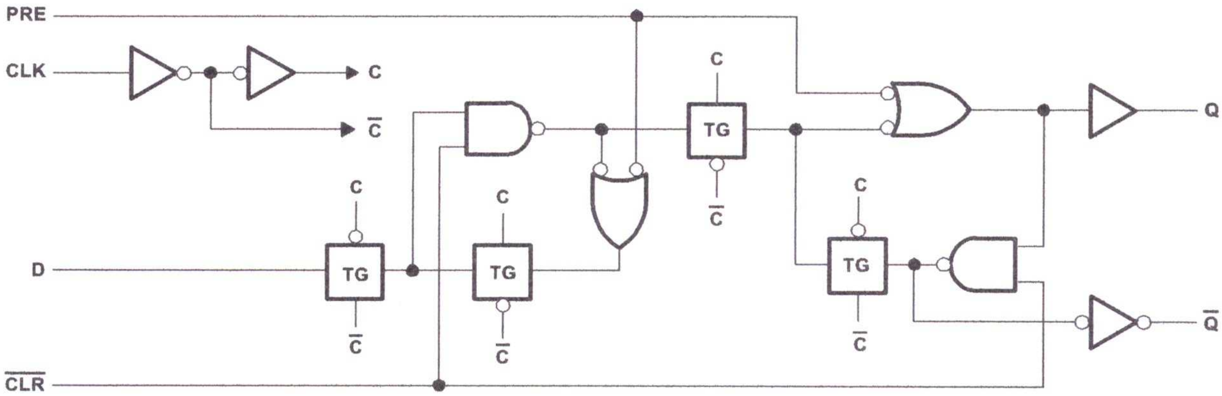
† This configuration is unstable; that is, it does not persist when $\overline{PRE}$ or $\overline{CLR}$ returns to its inactive (high) level.

logic symbol†



† This symbol is in accordance with ANSI/IEEE Std 91-1984 and IEC Publication 617-12.
Pin numbers shown are for the D, DB, J, N, PW, and W packages.

logic diagram (positive logic)



absolute maximum ratings over operating free-air temperature range‡

Supply voltage range, V_{CC}	–0.5 V to 7 V
Input clamp current, I_{IK} ($V_I < 0$ or $V_I > V_{CC}$) (see Note 1)	±20 mA
Output clamp current, I_{OK} ($V_O < 0$ or $V_O > V_{CC}$) (see Note 1)	±20 mA
Continuous output current, I_O ($V_O = 0$ to V_{CC})	±25 mA
Continuous current through V_{CC} or GND	±50 mA
Package thermal impedance, θ_{JA} (see Note 2): D package	127°C/W
DB package	158°C/W
N package	78°C/W
PW package	170°C/W
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.

NOTES: 1. The input and output voltage ratings may be exceeded if the input and output current ratings are observed.
2. The package thermal impedance is calculated in accordance with JESD 51, except for through-hole packages, which use a trace length of zero.

timing requirements over recommended operating free-air temperature range (unless otherwise noted)

			V_{CC}	T_A = 25°C MIN	T_A = 25°C MAX	SN54HC74 MIN	SN54HC74 MAX	SN74HC74 MIN	SN74HC74 MAX	UNIT
f_{clock}	Clock frequency		2 V	0	6	0	4.2	0	5	MHz
			4.5 V	0	31	0	21	0	25	
			6 V	0	36	0	25	0	29	
t_w	Pulse duration	$\overline{PRE}$ or $\overline{CLR}$ low	2 V	100		150		125		ns
			4.5 V	20		30		25		
			6 V	17		25		21		
		CLK high or low	2 V	80		120		100		
			4.5 V	16		24		20		
			6 V	14		20		17		
t_{su}	Setup time before CLK↑	Data	2 V	100		150		125		ns
			4.5 V	20		30		25		
			6 V	17		25		21		
		$\overline{PRE}$ or $\overline{CLR}$ inactive	2 V	25		40		30		
			4.5 V	5		8		6		
			6 V	4		7		5		
t_h	Hold time, data after CLK↑		2 V	0		0		0		ns
			4.5 V	0		0		0		
			6 V	0		0		0		

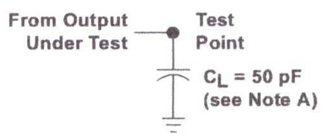
switching characteristics over recommended operating free-air temperature range, C_L = 50 pF (unless otherwise noted) (see Figure 1)

PARAMETER	FROM (INPUT)	TO (OUTPUT)	V_{CC}	T_A = 25°C MIN	T_A = 25°C TYP	T_A = 25°C MAX	SN54HC74 MIN	SN54HC74 MAX	SN74HC74 MIN	SN74HC74 MAX	UNIT
f_{max}			2 V	6	10		4.2		5		MHz
			4.5 V	31	50		21		25		
			6 V	36	60		25		29		
t_{pd}	$\overline{PRE}$ or $\overline{CLR}$	Q or $\overline{Q}$	2 V		70	230		345		290	ns
			4.5 V		20	46		69		58	
			6 V		15	39		59		49	
	CLK	Q or $\overline{Q}$	2 V		70	175		250		220	
			4.5 V		20	35		50		44	
			6 V		15	30		42		37	
t_t		Q or $\overline{Q}$	2 V		28	75		110		95	ns
			4.5 V		8	15		22		19	
			6 V		6	13		19		16	

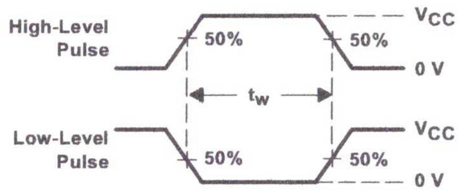
operating characteristics, T_A = 25°C

PARAMETER		TEST CONDITIONS	TYP	UNIT
C_{pd}	Power dissipation capacitance per flip-flop	No load	35	pF

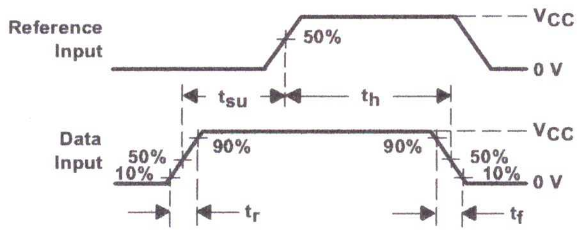
PARAMETER MEASUREMENT INFORMATION



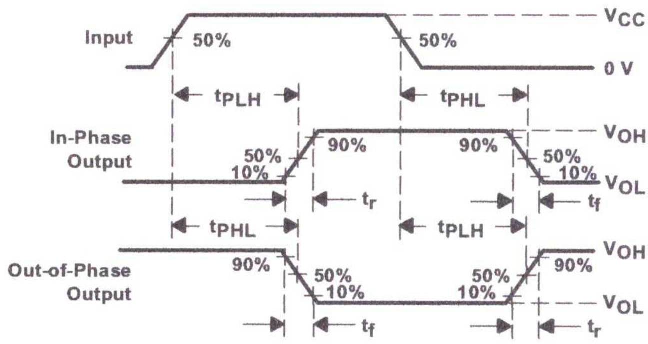
LOAD CIRCUIT



VOLTAGE WAVEFORMS
PULSE DURATIONS



VOLTAGE WAVEFORMS
SETUP AND HOLD AND INPUT RISE AND FALL TIMES



VOLTAGE WAVEFORMS
PROPAGATION DELAY AND OUTPUT TRANSITION TIMES

NOTES: A. C_L includes probe and test-fixture capacitance.
B. Phase relationships between waveforms were chosen arbitrarily. All input pulses are supplied by generators having the following characteristics: PRR ≤ 1 MHz, Z_O = 50 Ω, t_r = 6 ns, t_f = 6 ns.
C. For clock inputs, f_{max} is measured when the input duty cycle is 50%.
D. The outputs are measured one at a time with one input transition per measurement.
E. t_{PLH} and t_{PHL} are the same as t_{pd}.

Figure 1. Load Circuit and Voltage Waveforms

MC74HC14A

Hex Schmitt-Trigger Inverter

High–Performance Silicon–Gate CMOS

The MC74HC14A is identical in pinout to the LS14, LS04 and the HC04. The device inputs are compatible with Standard CMOS outputs; with pullup resistors, they are compatible with LSTTL outputs.

The HC14A is useful to "square up" slow input rise and fall times. Due to hysteresis voltage of the Schmitt trigger, the HC14A finds applications in noisy environments.

Features

- Output Drive Capability: 10 LSTTL Loads
- Outputs Directly Interface to CMOS, NMOS and TTL
- Operating Voltage Range: 2.0 to 6.0 V
- Low Input Current: 1.0 μA
- High Noise Immunity Characteristic of CMOS Devices
- In Compliance With the JEDEC Standard No. 7.0 A Requirements
- Chip Complexity: 60 FETs or 15 Equivalent Gates
- Pb–Free Packages are Available

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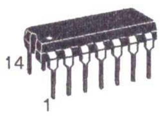
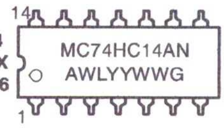
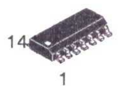
MARKING DIAGRAMS

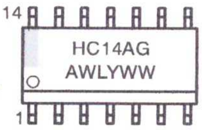


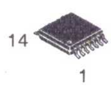
PDIP–14
N SUFFIX
CASE 646



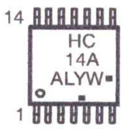


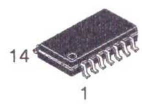
SOIC–14
D SUFFIX
CASE 751A



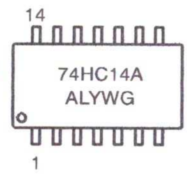


TSSOP–14
DT SUFFIX
CASE 948G





SOEIAJ–14
F SUFFIX
CASE 965



A	=	Assembly Location
L, WL	=	Wafer Lot
Y, YY	=	Year
W, WW	=	Work Week
G or ▪	=	Pb–Free Package

(Note: Microdot may be in either location)

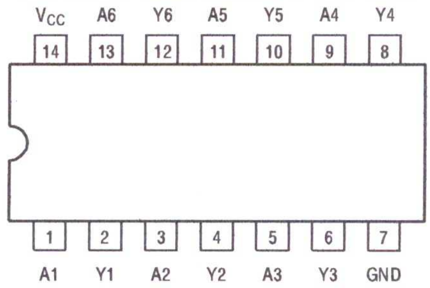
ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 2 of this data sheet.

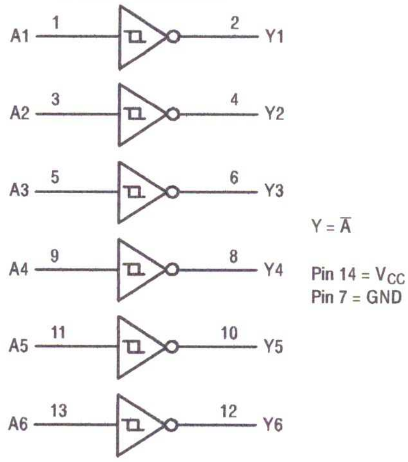
October, 2006 – Rev. 11

Publication Order Number:
MC74HC14A/D

Pinout: 14–Lead Packages (Top View)



LOGIC DIAGRAM



FUNCTION TABLE

Inputs	Outputs
A	Y
L	H
H	L

ORDERING INFORMATION

Device	Package	Shipping†
MC74HC14AN	PDIP–14	25 Units / Rail
MC74HC14ANG	PDIP–14 (Pb–Free)	
MC74HC14AD	SOIC–14	55 Units / Rail
MC74HC14ADG	SOIC–14 (Pb–Free)	
MC74HC14ADR2	SOIC–14	2500 / Tape & Reel
MC74HC14ADR2G	SOIC–14 (Pb–Free)	
MC74HC14ADT	TSSOP–14*	96 Units / Rail
MC74HC14ADTG	TSSOP–14*	
MC74HC14ADTR2	TSSOP–14*	2500 / Tape & Reel
MC74HC14ADTR2G	TSSOP–14*	
MC74HC14AF	SOEIAJ–14	50 Units / Rail
MC74HC14AFG	SOEIAJ–14 (Pb–Free)	
MC74HC14AFEL	SOEIAJ–14*	2000 / Tape & Reel
MC74HC14AFELG	SOEIAJ–14*	

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.
*This package is inherently Pb–Free.

MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_{CC}	DC Supply Voltage (Referenced to GND)	– 0.5 to + 7.0	V
V_{in}	DC Input Voltage (Referenced to GND)	– 0.5 to V_{CC} + 0.5	V
V_{out}	DC Output Voltage (Referenced to GND)	– 0.5 to V_{CC} + 0.5	V
I_{in}	DC Input Current, per Pin	±20	mA
I_{out}	DC Output Current, per Pin	±25	mA
I_{CC}	DC Supply Current, V_{CC} and GND Pins	±50	mA
P_D	Power Dissipation in Still Air, Plastic DIP† SOIC Package† TSSOP Package†	750 500 450	mW
T_{stg}	Storage Temperature Range	– 65 to + 150	°C
T_L	Lead Temperature, 1 mm from Case for 10 Seconds Plastic DIP, SOIC or TSSOP Package	260	°C

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

†Derating — Plastic DIP: – 10 mW/°C from 65° to 125°C
SOIC Package: – 7 mW/°C from 65° to 125°C
TSSOP Package: – 6.1 mW/°C from 65° to 125°C

For high frequency or heavy load considerations, see Chapter 2 of the ON Semiconductor High–Speed CMOS Data Book (DL129/D).

This device contains protection circuitry to guard against damage due to high static voltages or electric fields. However, precautions must be taken to avoid applications of any voltage higher than maximum rated voltages to this high–impedance circuit. For proper operation, V_{in} and V_{out} should be constrained to the range GND ≤ (V_{in} or V_{out}) ≤ V_{CC}.

Unused inputs must always be tied to an appropriate logic voltage level (e.g., either GND or V_{CC}). Unused outputs must be left open.

RECOMMENDED OPERATING CONDITIONS

Symbol	Parameter	Min	Max	Unit
V_{CC}	DC Supply Voltage (Referenced to GND)	2.0	6.0	V
V_{in}, V_{out}	DC Input Voltage, Output Voltage (Referenced to GND)	0	V_{CC}	V
T_A	Operating Temperature Range, All Package Types	– 55	+ 125	°C
t_r, t_f	Input Rise/Fall Time (Figure 1) V_{CC} = 2.0 V V_{CC} = 4.5 V V_{CC} = 6.0 V	0 0 0	No Limit* No Limit* No Limit*	ns

*When V_{in} = 50% V_{CC}, I_{CC} > 1mA

DC CHARACTERISTICS (Voltages Referenced to GND)

Symbol	Parameter	Condition	V_{CC} V	Guaranteed Limit -55 to 25°C	≤85°C	≤125°C	Unit
V_{T+} max	Maximum Positive-Going Input Threshold Voltage (Figure 3)	V_{out} = 0.1V $\lvert I_{out} \rvert \leq 20\mu A$	2.0 3.0 4.5 6.0	1.50 2.15 3.15 4.20	1.50 2.15 3.15 4.20	1.50 2.15 3.15 4.20	V
V_{T+} min	Minimum Positive-Going Input Threshold Voltage (Figure 3)	V_{out} = 0.1V $\lvert I_{out} \rvert \leq 20\mu A$	2.0 3.0 4.5 6.0	1.0 1.5 2.3 3.0	0.95 1.45 2.25 2.95	0.95 1.45 2.25 2.95	V
V_{T-} max	Maximum Negative-Going Input Threshold Voltage (Figure 3)	$V_{out} = V_{CC} - 0.1V$ $\lvert I_{out} \rvert \leq 20\mu A$	2.0 3.0 4.5 6.0	0.9 1.4 2.0 2.6	0.95 1.45 2.05 2.65	0.95 1.45 2.05 2.65	V
V_{T-} min	Minimum Negative-Going Input Threshold Voltage (Figure 3)	$V_{out} = V_{CC} - 0.1V$ $\lvert I_{out} \rvert \leq 20\mu A$	2.0 3.0 4.5 6.0	0.3 0.5 0.9 1.2	0.3 0.5 0.9 1.2	0.3 0.5 0.9 1.2	V
$V_H$max Note 2	Maximum Hysteresis Voltage (Figure 3)	V_{out} = 0.1V or $V_{CC} - 0.1V$ $\lvert I_{out} \rvert \leq 20\mu A$	2.0 3.0 4.5 6.0	1.20 1.65 2.25 3.00	1.20 1.65 2.25 3.00	1.20 1.65 2.25 3.00	V
$V_H$min Note 2	Minimum Hysteresis Voltage (Figure 3)	V_{out} = 0.1V or $V_{CC} - 0.1V$ $\lvert I_{out} \rvert \leq 20\mu A$	2.0 3.0 4.5 6.0	0.20 0.25 0.40 0.50	0.20 0.25 0.40 0.50	0.20 0.25 0.40 0.50	V
V_{OH}	Minimum High-Level Output Voltage	$V_{in} \leq V_{T-}$ min $\lvert I_{out} \rvert \leq 20\mu A$	2.0 4.5 6.0	1.9 4.4 5.9	1.9 4.4 5.9	1.9 4.4 5.9	V
		$V_{in} \leq V_{T-}$ min $\lvert I_{out} \rvert \leq 2.4mA$ $\lvert I_{out} \rvert \leq 4.0mA$ $\lvert I_{out} \rvert \leq 5.2mA$	3.0 4.5 6.0	2.48 3.98 5.48	2.34 3.84 5.34	2.20 3.70 5.20	
V_{OL}	Maximum Low-Level Output Voltage	$V_{in} \geq V_{T+}$ max $\lvert I_{out} \rvert \leq 20\mu A$	2.0 4.5 6.0	0.1 0.1 0.1	0.1 0.1 0.1	0.1 0.1 0.1	V
		$V_{in} \geq V_{T+}$ max $\lvert I_{out} \rvert \leq 2.4mA$ $\lvert I_{out} \rvert \leq 4.0mA$ $\lvert I_{out} \rvert \leq 5.2mA$	3.0 4.5 6.0	0.26 0.26 0.26	0.33 0.33 0.33	0.40 0.40 0.40	
I_{in}	Maximum Input Leakage Current	$V_{in} = V_{CC}$ or GND	6.0	±0.1	±1.0	±1.0	μA
I_{CC}	Maximum Quiescent Supply Current (per Package)	$V_{in} = V_{CC}$ or GND $I_{out} = 0\mu A$	6.0	1.0	10	40	μA

1. Information on typical parametric values along with frequency or heavy load considerations can be found in Chapter 2 of the ON Semiconductor High-Speed CMOS Data Book (DL129/D).
2. $V_H$min > (V_{T+} min) – (V_{T-} max); $V_H$max = (V_{T+} max) – (V_{T-} min).

AC CHARACTERISTICS (C_L = 50pF, Input t_r = t_f = 6ns)

Symbol	Parameter	V_{CC} V	Guaranteed Limit -55 to 25°C	≤85°C	≤125°C	Unit
t_{PLH}, t_{PHL}	Maximum Propagation Delay, Input A or B to Output Y (Figures 1 and 2)	2.0 3.0 4.5 6.0	75 30 15 13	95 40 19 16	110 55 22 19	ns
t_{TLH}, t_{THL}	Maximum Output Transition Time, Any Output (Figures 1 and 2)	2.0 3.0 4.5 6.0	75 27 15 13	95 32 19 16	110 36 22 19	ns
C_{in}	Maximum Input Capacitance		10	10	10	pF

NOTE: For propagation delays with loads other than 50 pF, and information on typical parametric values, see Chapter 2 of the ON Semiconductor High–Speed CMOS Data Book (DL129/D).

		Typical @ 25°C, V_{CC} = 5.0 V	
C_{PD}	Power Dissipation Capacitance (Per Inverter)*	22	pF

* Used to determine the no–load dynamic power consumption: $P_D = C_{PD} V_{CC}^2 f + I_{CC} V_{CC}$. For load considerations, see Chapter 2 of the ON Semiconductor High–Speed CMOS Data Book (DL129/D).

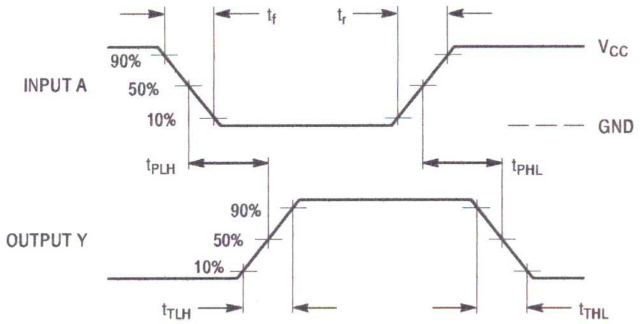
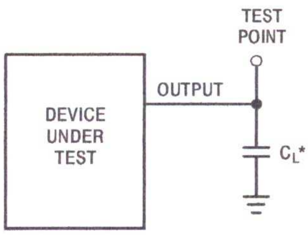


Figure 1. Switching Waveforms



*Includes all probe and jig capacitance

Figure 2. Test Circuit