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Graduation Project

Controlling The Hand Movement At Elbow Joint Using EMG Signal

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Abstract

This project describes the control of the prosthetic limbs for human hand movement at elbow joint, it was built to help the patients who is suffer from permanent disability in upper limbs of the body Especially at elbow joint, because of the motion at elbow joint is one of the simplest and the most important motion of human beings everyday life, we will chose this project. the angular position of the robot system are controlled by the signal from biceps and triceps muscle movement ,This system will used multiple electrode at the skin surface to take EMG signal by Electromyogram circuit at biceps and triceps muscles as an input information of the controller , the activation level of the working muscle will be vary by human arm movement that will be vary the input of the information of the controller then control the position of the robotic hand .

ملخص

التحكم في حركة اليد عن طريق الإشارات الكهربائية الناتجة من حركة العضلات

هذا المشروع يصف عملية التحكم في حركة الأطراف الصناعية في المنطقة العليا من الجسم مثل اليد . ولقد تم بناء هذا المشروع لمساعدة المرضى من ذوي الاحتياجات الخاصة والاشخاص الذين يعانون إعاقات دائمة في الأطراف العلوية من الجسم تتمثل بفقدان جزء من اليد (عند مفصل المرفق) . ولأن حركة العضلات في الأطراف العليا من الأمور الضرورية والمهمة التي يقوم بها الإنسان في كل وقت تم اختيار هذا المشروع . يتم التحكم في هذا الجهاز عن طريق الإشارات الناتجة من انقباض وانبساط عضلات اليد في المنطقة العلوية من اليد ويتم تسجيل هذه الإشارات عن طريق جهاز مخصص لرصد الإشارات الكهربائية وبعد ذلك يتم معالجة الإشارات وعمل التحاليل اللازمة لها من أجل تزويدها لجهاز التحكم , حيث تعمل هذه الإشارات كبيانات للتحكم في اتجاه حركة اليد الصناعية .

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Chapter One

Introduction

1.1 Introduction

Electromyography is the technique used to measure and record the muscle response to electrical activity within muscle fibers, muscle stimulation caused by the nerve impulses at rest and during contraction. EMG signals are measured by the electrodes placed on certain body muscles.

EMG amplitude is affected by parameters such as electrode placement, electrode orientation, electrode type, inter-electrode distance, skin and electrode temperature.

Our project of (controlling the hand movement at elbow joint with EMG signal) that will be used for human motion support , in order to help the patients who have lost parts of body as a result of accidents ,diseases wars and many reasons ,This technique is very important for this persons to take care for help them to do the works .

1.2 Objectives

The main objectives of this project are

1- To study the physiological structure of the biceps and triceps muscle.
2- To study the electrical signal for those muscle at contraction and relaxation.

3- Find the Prosthetic hand is doing in place of natural hand and less side effects on the patient.

4- Work the Prosthetic hand at low cost.

1.3 Project Importance

Many people are missing parts of their bodies as a result of accidents ,diseases wars and many reasons .These persons will remain until death without the parts that help them in live as normal person that will be in past .

Sciences will become able to compensate those people who have lost their upper or lower limbs by providing them with artificial limbs is similar to the natural parties, the importance of this project is to provide artificial limbs for those people at low prices and give the best results .

1.4 Previous Studies

1-Scientists from Germany and Spain are benefited from the concept of movement of the hand, in the production of prosthetic hand works like a natural work of the hand and the lowest cost and less side effects on a patient.

2- Some scientists from Europe, America and Japan are found the hand operated by electrical signals resulting from the contraction muscle of the arm, where they worked on the design of prosthetic hand is made up of five fingers , each finger has an electrical circuit separate from the finger the other, so the patient can control each finger individually.

3- In national technical university of Athens, is made robot in two directions and robot consists of four electrode and record EMG signal of the elbow and wrist joint and it made of reinforced plastic.

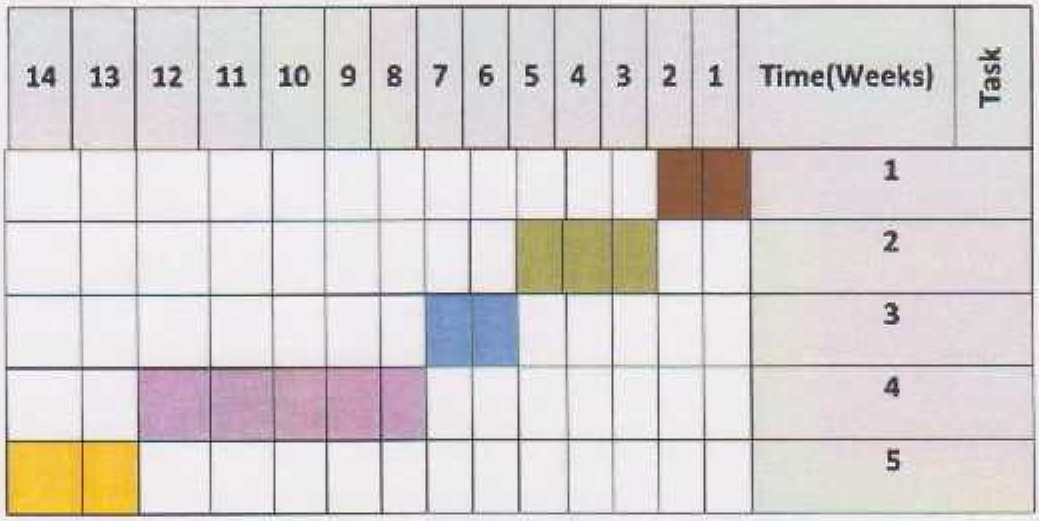
1.5 Task Time Schedule

Table (1.1): Task time schedule

Task Number	Task	Time (Weeks)
1	Collection information about the system	2
2	Planning for the system	3
3	Collecting the requirements	2
4	Design the system	5
5	Documentation of the system	2

1.6 Distribution of Task Schedule

Table (1.2): Distribution of Tasks Schedule



1.7 The cost of equipments

Table (1.3): The cost of equipments

Equipment	Cost(NIS)
The hand	100
PIC16f848	100
Motor controller	200
Ag-Agcl Electrodes	100
Batteries	180
Cover	50
AD620 Amplifier	200
Resistors	50
Capacitors	30
Rectifier	20
Stepper motor	200
Amplifiers	100
Total cost	**1330**

Chapter Two

Physiological Background

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2.1 Human muscle

2.1.1 Structure Of Human Muscle

Skeletal muscle is usually associated with the skeletal system. It is also called striated muscle because of the presence of alternating dark and light bands along the length of its fibers, Skeletal muscle is also called voluntary muscle because it is largely under voluntary control regarding contraction. To provide specific body movements, muscles work in what are called antagonistic pairs with one muscle contracting while the other is relaxing , When a muscle contracts it pulls on the tendon attached to a bone that lies across a particular joint, This moves the two bones closer or farther apart (e.g. flexion and extension of the arm) .The skeletal and muscular systems serve to give us our shape, and protect our internal organs. Examine the articulated skeleton and note the shapes of bones that articulate at specific joints, such as the hip , shoulder joint, skull joint, elbow joint, knee joint, wrist joint and fingers joint. Ligaments connect bones to each other and tendons connect muscles to bones.

2.1.2 Basic Structure Of Human Muscle

Skeletal muscle is just one type of muscle found in the body, smooth muscle and cardiac muscle are the other two type . When study the structure of skeletal muscle, we will examine an area that shows muscle fibers both in longitudinal sections and cross sections . Each muscle fiber is a single cell, which is quite long with easily recognizable striations and multiple nuclei located along the periphery of each fiber. The striations or striped appearance is due to the arrangement of actins and myosin filaments. In cross section that will show in fig(2.1) you can see the dark stained nuclei at the outer edge of each fiber. Tendons are types of dense connective tissue composed of parallel bundles of collage nous fibers. Bone is also a type of connective tissue composed of concentric layers of a mineralized matrix. For contraction to occur muscle fibers must receive nerve impulses and each muscle fiber is innervated by a single neuron.

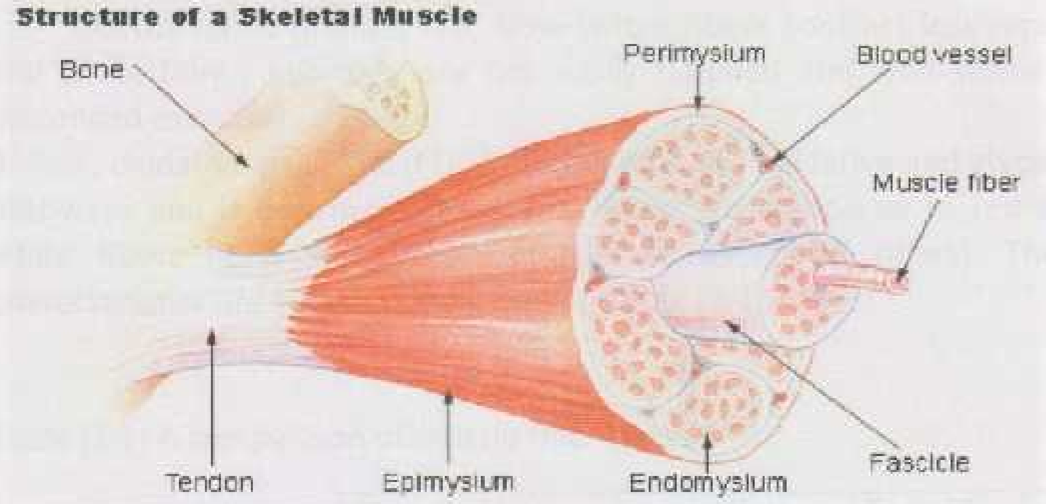


Fig (2.1) Structure of a skeletal muscle [1]

2.1.3 Muscle Fibers Types

The most important factors determining athletic performance are the cellular composition of the contracting muscles (Muscle cells) which are called fibers, can be broadly classified into categories based on their structural and metabolic characteristics. When we consider the biceps and triceps muscle in the upper arm .This muscles tissue is composed of distinct fiber types that play a critical role in determining the muscle's performance capacity.

Three main fiber types are commonly identified, although further sub-groupings are known. For our purposes, we will focus on the three major types described here:

1- White, fast-twitch and glycol tic fibers (FG) that generally quite large in diameter and can generate energy rapidly for quick powerful contractions.

2- White fibers rely on anaerobic metabolism to produce ATP and become fatigued with the accumulation of lactic acid, a noxious by-product that interferes with muscle contraction. Consequently white, fast-twitch fibers are generally activated in short-term sprint or power activities, as they fatigue rapidly. Red, slow-twitch, oxidative fibers (SO) are smaller in diameter, and generate a greater yield of ATP by aerobic metabolism and without the formation of lactic acid.

As the name implies, red, slow-twitch fibers contract less rapidly and powerfully , but they are not easily fatigued and well suited to prolonged exercise.

3- fast , oxidative-glycol tic (FOG), shares both the oxidative and glycoltic pathways and is intermediate in size. When we compared to red and white fibers (it is sometimes referred to as "pink" fibers). These characteristics are summarized below in Table (2.1).

Table (2.1) A comparison of muscle fiber types

	Slow, Oxidative	Intermediate	Fast, Glycolytic
Fiber color	Red	Pink - red	White
Predominant metabolic pathway	Aerobic	Aerobic	Glycolysis
Contraction speed	Slow	Fast	Fast
Rate of fatigue	Slow	Intermediate	Fast
Mitochondria	Many	Many	Few

It is widely known among sport physiologists that the "fiber-type" of elite, world-class athletes is a reliable predictor of performance in athletic events. Sprinters, weight-lifters, wrestlers and others that rely on short, powerful bursts of muscle activity generally have a predominance of twitch fibers, whereas marathon runners, cross-country skiers, cyclists, and other endurance athletes have a greater abundance of twitch fibers.

2.2 Muscle Action And Contraction

2.2.1 Muscle Action

Muscles of the human body vary in shape and size. While most are somewhat elongated in shape, others may be trapezoidal and a few circular. The thick fleshy part of the muscle is called the belly. You can easily relate to this by feeling the muscle of your upper arm and back of your lower leg. Many (but not all) muscles are directly connected to bones. The tapered ends of these muscles are connected to bone by tendons (a type of dense connective tissue). Most muscles of the body work in groups to perform a specific body movement. The area on a bone where a muscle is firmly attached is called the origin and the point of attachment to the bone it moves is called the insertion. The contraction of specific muscles results in an action and that action is often described in terms of "antagonistic pairs" of muscles. The main muscle that is responsible for a specific movement (or action) is called the agonist (or prime mover); the muscle that opposes it is called the antagonist. When one muscle contracts to produce a motion its opposing muscle is relaxed. This will become clearer as you perform some of the actions on your hand at elbow joint. Some basic types of body movements are flexion or extension(arm or leg), depression/elevation (jaw), and dorsiflexion / plantar flexion (foot).

2.2.2 Muscle Contraction

2.2.2.1 The Motor Unit

A single nerve fiber innervates on average about (150 muscle fibers) .All of these fibers and the single nerve fiber innervating them are called a motor unit because muscle fibers of the unit are always excited simultaneously and contract in unison. It is important to note that terminal divisions of a motor neuron are distributed throughout the muscle belly. Stimulation of a single motor unit, therefore, causes weak action in a broad area of muscle rather than a strong contraction at one specific point.

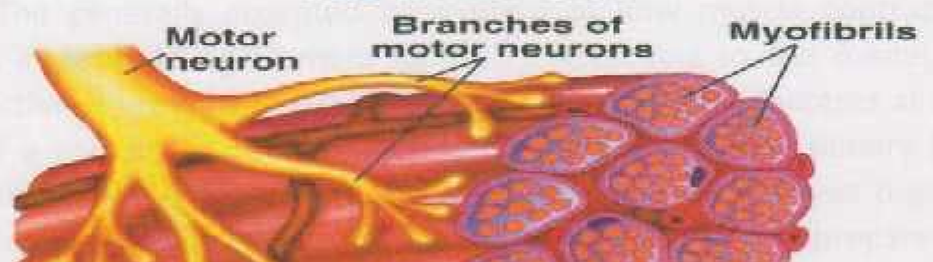


Fig (2.2) The motor unit [2]

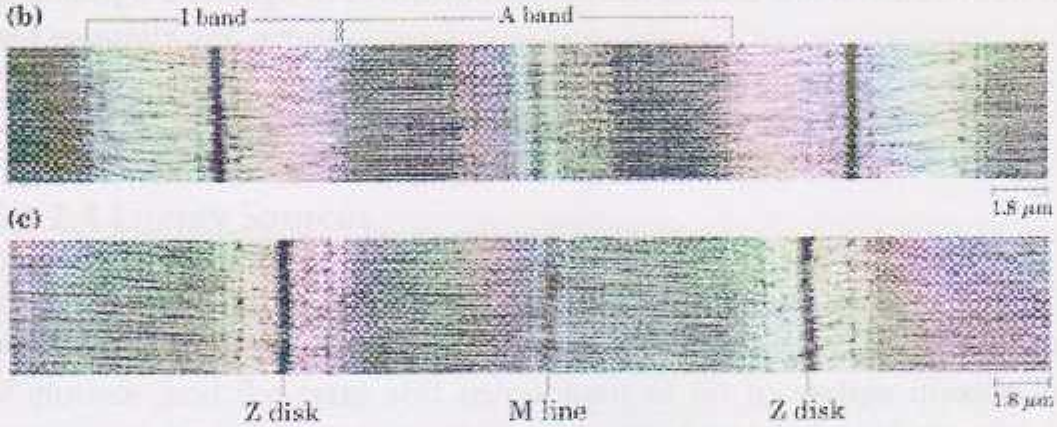
Muscles controlling many movements are characterized by the presence of a few muscle fibers in each motor unit, i.e. the ratio of nerve fibers to muscle fibers is high. For instance, each motor unit present in the ocular muscle contains less than (10 muscle fibers). On the other hand, gross movements, e.g. major limb muscles, may be governed by motor units containing (1000 or more muscle fibers).

2.2.2.2 Excitation Of Skeletal Muscle

Muscle fibers possess the property of being excitable. Any force affecting this excitability is called a stimulus, which in muscle tissue is usually conveyed by nerve fibers. The stimulus is an electrical impulse transmitted from a nerve fiber branch to a muscle fiber at a junction region called the neuromuscular junction. At the junction gap, the synaptic cleft, exists between a nerve branch terminal and a recess on the surface of the muscle fiber. A nerve impulse reaching the neuromuscular junction causes the release of acetylcholine, a neuro transmitter stored in synaptic vesicles within the nerve terminal. Acetylcholine crosses the gap and acts on the membrane of the muscle fiber, causing it to generate its own impulse, which travels along the muscle fiber in both directions at a rate of about (5 meters per second). at`s also conducted to the sarcoplasmic reticulum via the T system.

2.2.2.3 Mechanism Of Contraction

The generally accepted conception of how muscle contracts is known as the (sliding filament model) . According to this model, the contraction is brought about by the sliding of the thin filaments at each end of a sarcomere toward each other between the stationary thick filaments. As we show in fig (2.3) ,this draws the (Z) lines closer together and shortening the sarcomere. In sections of muscle prepared at sequential stages of contraction, it can be seen that as a sarcomere shortens, the (I) band of each myofibril (the region containing only thin filaments bisected by a Z line) narrows as the thin filaments move toward the centre of the sarcomere . whereas the (A) band (representing the length of the thick filaments) is unaltered. The (H) zone of the (A) band, the lighter, central region not penetrated by thin filaments in relaxed muscle, disappears as thin filaments come to completely overlap the thick filaments in the contracted state. When contraction is marked, a dense zone appears in the centre of the (A) band as a result of overlap of thin filaments from opposite ends of a sarcomere. In cross section this overlap is identified as a doubling (over the relaxed condition) of the ratio of thin to thick filaments.



Fig(2.3) Fiber filament model [3]

The movement of the thin filaments can be accounted for by cross-bridges extending from thick to thin filaments, which are utilized as mechanical pulling devices . Myosin molecules are constructed from the thick filaments and it's have a globular head and linear tail. They can be readily split enzymatically (with trypsin) into two sub units. One called heavy meromyosin, that's contains the globular head and a linear tail section, the other called light meromyosin , which is an all-linear tail segment. The head of heavy meromyosin, which can be enzymatically separated from the tail section, has the property of combining with actin and contains ATP-splitting enzymes. The linear light meromyosin subunits have a self-combining property. Thick filaments are assembled by tail-to-tail aggregation of myosin molecules so that in each half of the filaments the heads, which form the ends of the cross-bridges face opposite directions . This explains how thin filaments at opposite ends of a sarcomere can be pulled inward toward the centre of the thick filaments.

Action consists of two strands of spherical molecules coiled around one another. On the surface of each strand of actin is a filamentous tropomyosin. Troponin is a complex of three globular subunits positioned at regular intervals (400 angstroms) along the thin filament . The largest subunit of troponin_designated Tn-T_ binds to tropomyosin. Another Tn-I (the inhibitory subunit) reversibly binds to actin when bound the troponin complex, linked to tropomyosin and actin seems to act as a latch holding tropomyosin in a position that blocks the myosin binding site on actin. The latch is released when calcium binds the smallest subunit, (Tn-C) causing the troponin complex to undergo a change in conformation which breaks the link between the Tn-I subunits and actins.

2.2.2.4 Energy Sources

ATP is a direct source of energy for muscular contraction. ATP (Adenosine Triphosphate)is synthesised during the aerobic breakdown of glucose ,and the fatty acid component of fat to carbon dioxide and water and during glycolysis, the anaerobic breakdown of glucose (or glycogen) to lactic acid. ATP must be continuously resynthesised in muscle, since its reserves are very small. Muscle contains a small auxiliary source of high energy phosphate in the form of creatine phosphate. Creatine phosphate can be utilized during muscular contraction for the rapid re-synthesis of ATP by phosphate transfer to ADP(Adenosine Diphosphate) When muscle is at rest, the reverse reaction phosphate transfer from ATP to creatine rebuilds the reserves of creatine phosphate.

Muscle also has its own glycogen stores. Calculations based largely upon measurements of oxygen consumption .lactic acid production in human subjects suggests that during moderate exercise the energy is initially supplied by stored ATP and ATP resynthesized from creatine phosphate. Within a few seconds, the oxidation of fatty acids and glucose taken up from the blood stream provides an additional source of ATP. Oxygen consumption rises rapidly as increased amounts of fatty acids and glucose are oxidized. If any anaerobic breakdown of glycogen occurs under these conditions, it is too small to be detected. When the exercise is strenuous, a point is reached if the oxygen supply is insufficient to meet the energy needs an active muscle. When this occurs (estimated as an energy expenditure of approximately 220 calories per minute per kilogram of body weight), glycolysis provides a sizable portion of the energy needs . Far less ATP is produced by the anaerobic process than by the aerobic process. The lactic acid produced during glycolysis is released from the muscles into the blood stream to be subsequently taken up by the liver (where it is converted to glucose and glycogen). A reasonably accurate measure of the extent of glycolysis can be obtained by determining the concentration of lactic acid in blood sample drawn in two or three minutes after a strenuous exercise trial lasting up to a few minutes. Exercising to a state of exhaustion is associated with a steep and continuous rise in blood lactic acid. Reducing the effort or introducing rest intervals is reflected in a leveling off of blood lactic acid concentrations.

2.2.3 Comparison Between Isometric And Isotonic Contraction

The tension developed during contraction is utilized to perform work in moving a load some distance. This occurs normally when walking, climbing, lifting objects, or turning the head. If a muscle does not shorten as it contracts, the tension may be utilized for such actions as holding an object in a fixed position or maintaining posture against the force of gravity.

.When the muscle shorter against a constant load , it is called Isotonic .
.When the muscle doesn't shorter against a constant load ,it is called Isometric.

2.2.4 Contraction Times Of Muscles And Motor Units

Muscles differ considerably in the speed of their contractions. For example, the contraction times of the lateral rectus, gastrocnemius and soleus are different correlate with normal functions of rapid eye movements (lateral rectus). Moderately rapid movements in walking and running (gastrocnemius), and prolonged supportive action (soleus).Traditionally, certain muscles have been described on the basis of appearance and speed of contraction as either

Most muscles fall somewhere between the two extremes, and the proportions of the two basic fiber types vary considerably from one muscle to another. It has also been observed that the motor units of a muscle can be distinguished on the basis of contraction times and other characteristics. Fibers of fast-contracting units, which also fatigue rapidly, are of large diameter have few capillaries, mitochondria and contain an abundance of glycogen. Their apparent dependence upon anaerobic glycolysis could explain their rapid fatigue. Large-diameter fibers also have an extensive sarcoplasmic reticulum. Since this would allow rapid release and uptake of large amounts of calcium ions, it is consistent with their faster contraction. Fibers of slow-contracting and fatigue-resistant units have small diameters, a rich capillary supply, many mitochondria and little glycogen. This profile suggests a high capacity for aerobic energy pathways. Small-diameter fibers also contain large amounts of the oxygen-carrying heam protein myoglobin. This characteristic and the presence of cytochromes (also heam proteins) in the abundant mitochondria, as well as the vascularity of these fibers, account for the description of small fibers as red, as distinguished from the large, white fibers.

The fibers of a third group of motor units, described as fast-contracting and fatigue-resistant are of variable diameter and liberally supplied with capillaries. Their glycogen and mitochondrial content suggest utilization of both aerobic and anaerobic pathways.

2.3 Electromyography And Electrode

2.3.1 Electromyography

Electromyography (EMG) is referred to as myoelectric activity that will be measures the electrical impulses of muscles at rest and during contraction. As other electrophysiological signals, the EMG signal is small and needs to be amplified with an pre- amplifier that will be designed to measure physiological signals. This signal can be recorded or measured with an electrode, and then displayed on an oscilloscope, or LCD. This LCD would provide the information that will describe the ability of the muscle to response to nerve stimuli based upon the presence size and shape of the signal that resulting on action potential.

In this project a skin surface electrode is often the preferred instrument, because it is placed directly on the skin surface above the muscle. When EMG is measured from electrodes, the electrical signal is composed of all the action potentials occurring in the muscles underlying the electrode. This signal could either be of positive or negative voltage since it is generated before muscle force is produced and occurs at random intervals.

The EMG signal is first picked up by electrode and amplified. By more than one amplification stages are needed, since before the signal could be displayed or recorded, it must be processed to eliminate low or high frequency noise, or any other factors that may affect the outcome of the data. The point of interest of the signal is the amplitude which can range between 20 to 5000 microvolt's (peak-to-peak). The frequency of an EMG signal is between 6 to 30 Hz and interval of 3 to 10 millisecond .

In order to obtain a signal that yields the maximum information, the method employed and the implementation device has to be considered. There are many dependent factors that could affect a surface EMG since the signal is susceptible to noise interference such as hum, signal acquisition such as clipping and baseline drift, skin artifacts, processing errors, and interpretation problems. For example, the contact of electrode to the skin could distort a recording signal. The inadequate amplification of the signal could cause a recorder detection problem. A wrong filter could efface some of desirable information of a signal. Moreover, there are other factors such as the distance between electrodes as well as the recording times used in the experiment. The device utilized in the measuring of the signal must also be considered since low-level input into a recording device could also affect data and yield inaccurate results.

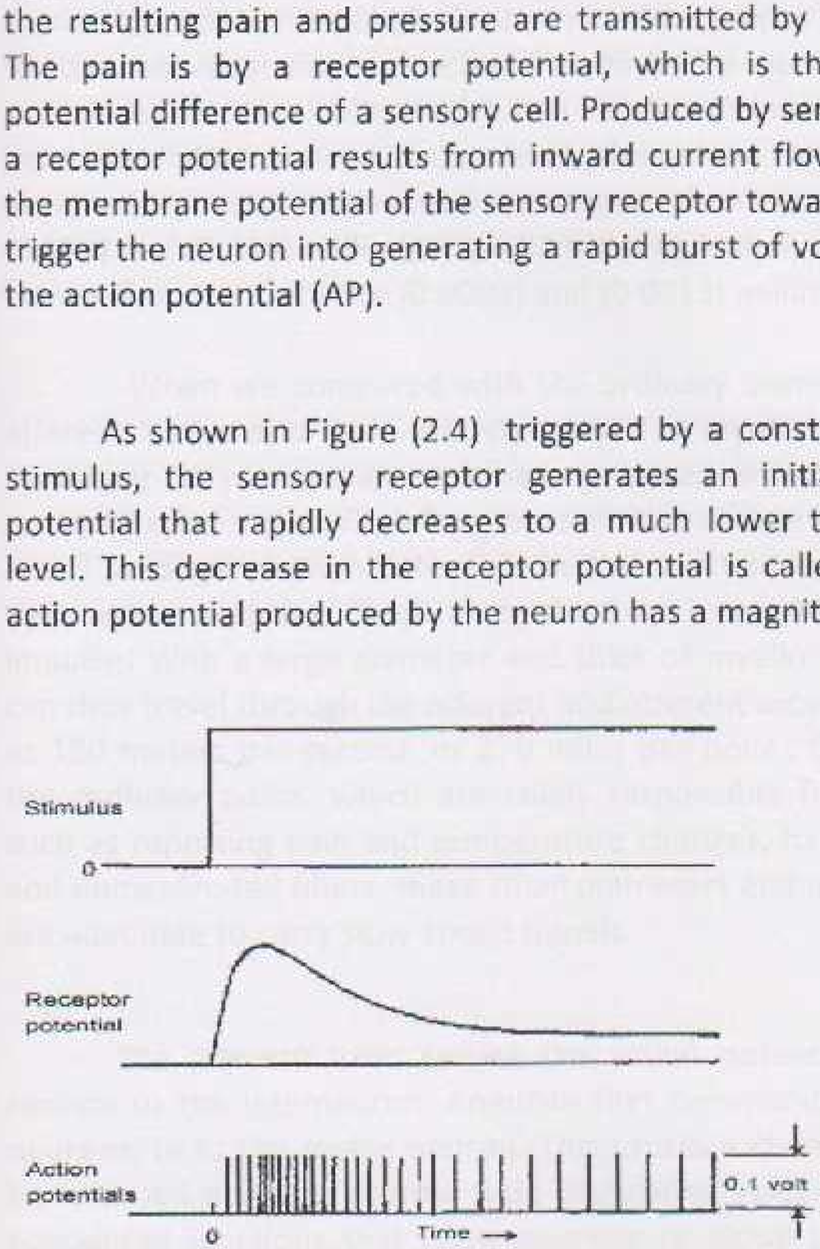
2.3.2 Excitable Tissue And Action Potential

There are two main types of tissue in the nervous system: excitable tissue and non-excitable tissue.

1-The excitable tissue : which is composed of neurons, responds to and transmits nerve stimuli.

2-The non-excitable tissue: composed of glial cells, does not response to voltage or any other conventional stimulus, since glial cells are non-conducting, and function only as support cells in the nervous system.
Excitable tissue can be divided into four components: sensory receptors, neuron cell bodies, axons, and muscle fibers. In a situation involving a harmful stimulus such as contact with a sharp pebble or a hot surface, the resulting pain and pressure are transmitted by sensory receptors. The pain is by a receptor potential, which is the transmembrane potential difference of a sensory cell. Produced by sensory transduction, a receptor potential results from inward current flow, which will bring the membrane potential of the sensory receptor toward the threshold to trigger the neuron into generating a rapid burst of voltage pulses called the action potential (AP).

As shown in Figure (2.4) triggered by a constant high-pressured stimulus, the sensory receptor generates an initially high receptor potential that rapidly decreases to a much lower that will be steady level. This decrease in the receptor potential is called adaptation. The action potential produced by the neuron has a magnitude of 0.1 volts .



Fig(2.4) Typical time variations associated with a sudden, steady stimulus. [4]

To step off that pebble, the neuron sends a message along a nerve axon to the base of the spinal cord. The axon, or nerve fiber is the slender projection of a neuron that conducts electrical impulses away from the nerve cell body. There are two types of axons: the afferent axon and efferent axon.

1-The afferent axon or sensory axon, leads to the central nervous system, and carries messages from sensory receptors at the peripheral endings to the spinal cord or brain.

2-The efferent axon, or motor axon, originates at the spinal cord and carries information through the body parts, synapse with muscle fibers to stimulate muscular contraction as well as the muscle spindles to alter proprioceptive sensitivity, which is a key factor in muscle memory and hand-eye coordination. Because of these two types of axons are designed to relay high-speed messages, their diameter is between (0.001) and (0.022) millimeters, which is longer than ordinary axons that have a diameter between (0.0003) and (0.0013) millimeters .

When we compared with the ordinary axons, the efferent and afferent axons also have a thicker layer of myelin and an electrically insulating fatty layer that increases the speed of impulses by means of saltatory conduction. Therefore, by inhibiting charge leakage myelinated axons propagate action potentials that recur at successive nodes rather than waves; and thus "hop" along the axon increasing the speed of the impulse. With a large diameter and thick of myelin sheaths, all signals can thus travel through the afferent and efferent axons at speeds as high as 120 meters per second, or 270 miles per hour . On the other hand, the ordinary axons, which are solely responsible for simple activities such as reporting pain and temperature changes, have small diameters and unmyelinated fibers. these small diameters and unmyelinated fibers are adequate to carry slow-speed signals.

The afferent axon carries the action potential burst from the neuron to the interneuron, Aneuron that communicates only to other neurons, or to the motor neuron. This causes a chemical transmitter to be released across a narrow fluid gap called synapses. The latter are specialized junctions that allow neurons to signal to their target cell, which could be another neuron or a non-neuronal cell such as a muscle or gland. The action potential crosses this junction to either another interneuron or a motor neuron, triggering another action potential burst as the process repeats until the message reaches the efferent axon. Then it carries the action signal back down to the leg muscle. Once the signal reaches the muscle tissue, the message instructs the muscle to contract, resulting in lifting the foot off the pebble.

2.3.3 GENERATION OF ACTION POTENTIAL

After a sensory receptor generates information, the electric signal is transmitted to its intended target by traveling through an axon. However, the axon is a relatively poor conductor because it rapidly attenuates the electrical signal . The potential can decrease to 37 % of its original value after traveling a distance of only 0.15 millimeters along an axon , resulting in an unusable potential value . This distance in which the potential becomes unusable is called the length constant. The length constant is dependent upon the size of the axon as it is proportional to the square root of an axon diameter. To overcome this tendency of signal attenuation, the nervous system uses a method to increase the strength of the electric signal. When the potential decreases to a threshold level that equal eight millivolts , the neuron will fire another 100 millivolts action potential .However, the action potential will keep decreasing after travel through the axon, which in effect will stimulate the neuron to fire one burst of action potential after action potential. process this is referred to as frequency modulation.

To get more information about action potential , we must understand the structure of the axon . There are ions arranged in constant random thermal motion inside an axon, with protein molecules being one of the main components of the axon membrane. Under normal conditions, sodium (Na^+) and calcium (Ca^{2+}) are more concentrated in the extracellular fluid, while potassium (K^+) is more concentrated within the cell. In effect of (K^+) that will be the key determinant of the resting membrane potential, since the resting cell membrane is more permeable to(K^+) than to the (Ca^{2+}) and (Na^+) molecules . However, while it plays a small part in the resting membrane potential,(Na^+) is a key player in the generation of electric signals. When a cell goes from a resting to an excited state or firing level, the cell increases its (Na^+) permeability. This causes (Na^+) molecules to enter the cell through voltage-gated channels, thus moving down its chemical gradient. This addition of the positive charge of (Na^+) to the intracellular fluid causes the cell to become depolarized and initiates an action potential. The extinguishing level that marks the falling phase of the action potential is the result of an increase in(K^+) permeability in the cell. However, the closing and opening of the voltage-gated channels is regulated by the jostling of the atoms within the cell, which results in randomness in the train of the generated action potentials.

Consequently, any undesired departure from a perfectly ordered system may give rise to so called noise.

Higher receptor potential will initiate less noisy action potentials. However, a noisy system is not always bad, as it enables living things to be able to adjust themselves to changing environment .The action potential is not only in the shape of narrow spike, it also suggests another model of action potential. They applied a (+20) mille volts trigger at zero time to the giant axon of the squid, and found that during an action potential, an ion moves to the axon membrane by using its protein molecules to create bridge to the membrane.

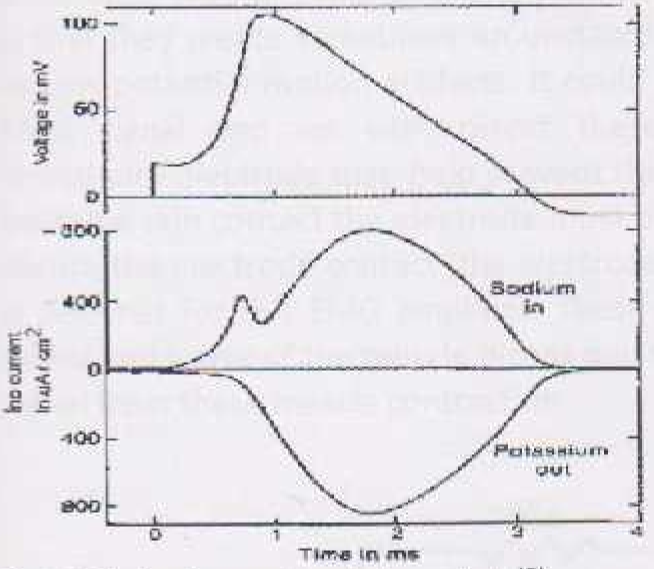


Fig (2.5) Action potential model [5]

The protein molecules are unique for each ion species. The (Na+) ions are trying to diffuse into the axon while the(K+) ions are trying to diffuse out of the axon membrane. From Figure (2.3), the 'sodium in' curve is negative because the current that flows into the axonplasm is defined as negative. On the other hand, the current that flows out of the axonplasm is defined as positive. The sodium carrier proteins convey (Na+) ions into the axon in accordance with the 'sodium in' curve. When crossing the membrane, there is only low voltage left to drive the sodium ions into the bridges of the transport proteins. Consequently, the dip of the sodium curve exists at the peak of action potential curve. On the opposite side of the sodium curve, the potassium carrier proteins convey (K+) ions out of the axon in accordance with the "potassium out" curve. To the left of the sodium dip, the (Na+) current in is much greater than the(K+) current. As a result, the voltage rapidly rises to 100 mille volts above the resting potential. To the right of the dip, the potassium ions are small excess to the sodium ions, which marks the slow drop in voltage.

2.3.4 Electrode

There are many types of electrode that will be used to detect the biopotintial signal .In this project we will use the skin surface electrode. This type of electrode is defined as a bipolar electrode. The surface electrodes are not expensive. The problem with skin surface electrodes is that they create sometimes an unstable contact. An unstable contact causes potential motion artifacts. It could also add thermal noise to an EMG signal and we will correct these problems by using ahigh impedance electrode that help prevent thermal noise problem. To avoid unstable skin contact the electrode must be placed firmly to the skin. To secure the electrode contact ,the electrode that has an adhesive surface is selected for this EMG amplifier. These electrode will be put on the upper and lower of the muscle biceps and triceps to detect the electrical signal from these muscle contraction .

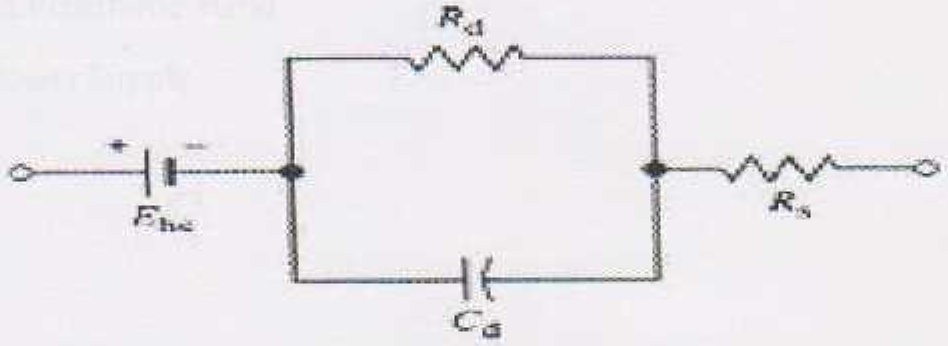
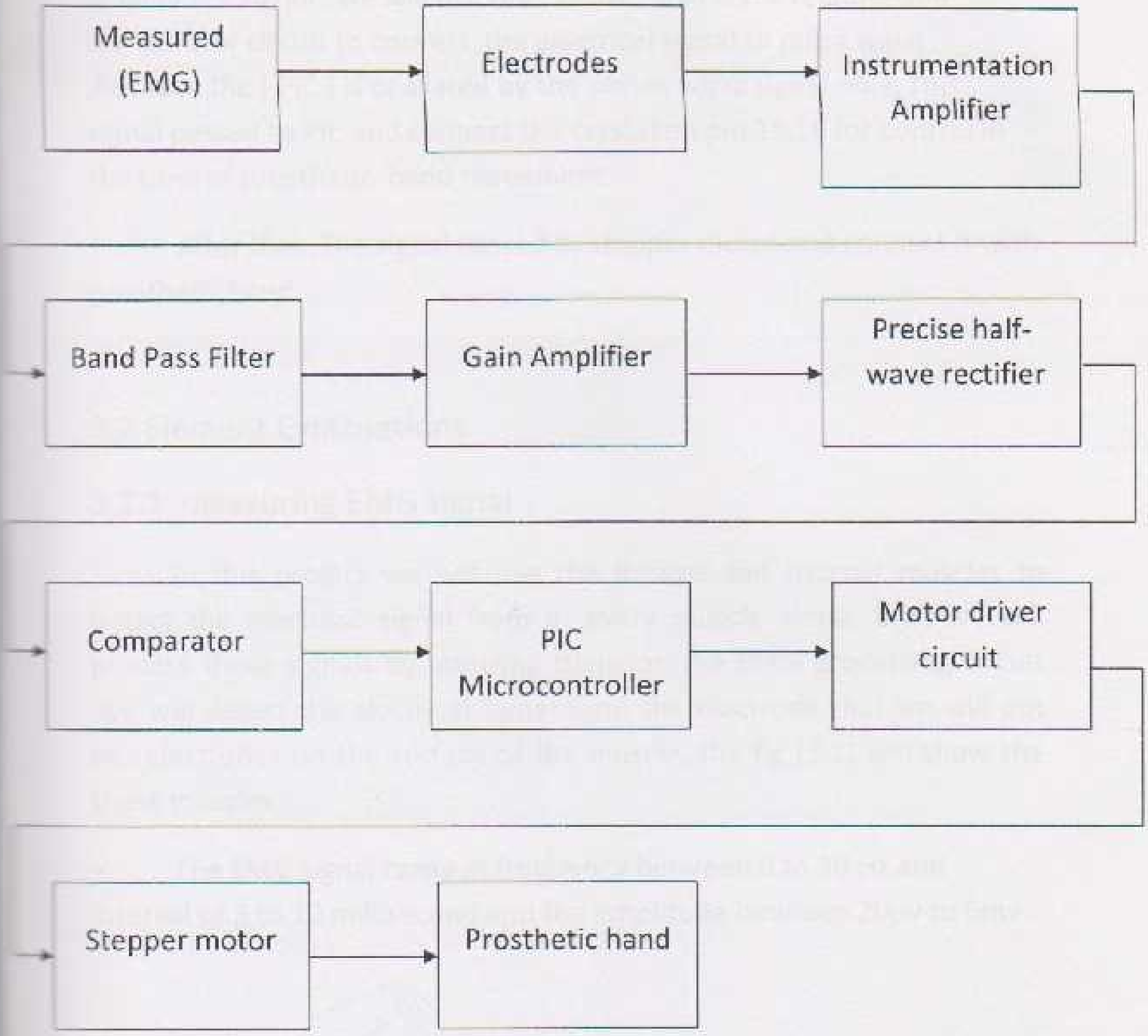


Fig (2.6) The equivalent circuit of the electrodes

Chapter Three

EMG system

3.1 Block Diagram



As a result of contraction and relaxation the muscle the ion signal is generated, where this signal is detect by electrodes and converted to an electrical signal , The instrumentation amplifier will connect directly to the electrodes, this instrumentation amplifier take the difference between two electrodes and take this difference and amplify it .

We use the Band Pass Filter circuit that will passes only the frequency with limited range , and reject frequency outside of the range .

We need to amplify this signal ,so we use gain amplifier , After amplify the signal , we will use the Precise –half wave rectifier and comparator circuit to convert the electrical signal to pulse wave ,Because the (PIC) is operated by the pulses wave signal only, This signal passed to PIC and connect the crystal on pin 15,16 for control in the time of prosthetic hand movement .

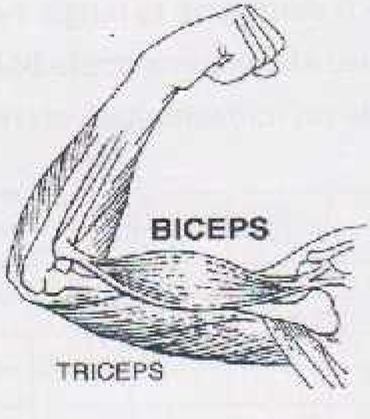
After that ,The signal passed to stepper motor and connect it with prosthetic hand .

3.2 Element Explanations

3.2.1 measuring EMG signal

In this project we will use the (biceps and triceps) muscles to detect the electrical signal from it, every muscle alone, then we will process these signals by interring them on the EMG processing circuit .we will detect the electrical signal from the electrode that we will put the electrodes on the surface of the muscle, the fig (3.1) will show the these muscles.

The EMG signal range in frequency between 6 to 30 Hz and interval of 3 to 10 millisecond and the amplitude between 20μv to 5mv



Fig(3.1) Biceps and triceps muscles [6]

3.2.2 Electrodes

In our design of the EMG circuit , we will use one type of many types of electrode, we will use the (Ag-Agcl) electrode, the reason for using this type that their performance such as high sensitivity and high accuracy of detecting signal .In this project the electrodes will be put in five different places to detect the electrical signal from the muscle .Tow of these electrodes are put above the biceps muscle ,one on the upper part and the other on the lower part of muscle. And tow electrodes will put above the triceps muscle as same as biceps , the fifth electrode will be used as reference electrode and will put on any place on the body such as the other hand .

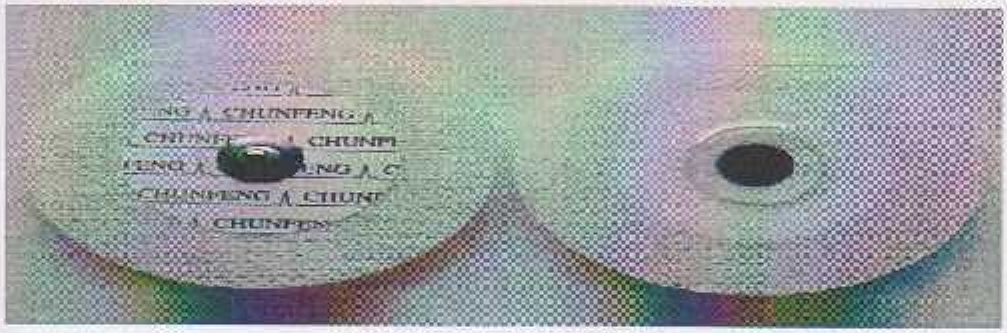


Fig (3.2) Ag-AgCl electrodes [7]

Let the signal is appear after using Ag-AgCl electrodes is same for FM wave signal at amplitude 0.4mV and the frequency is 15 Hz , Until it is clarified electronic circuits used in the project after making the appropriate magnification on electronic circuit at every step .

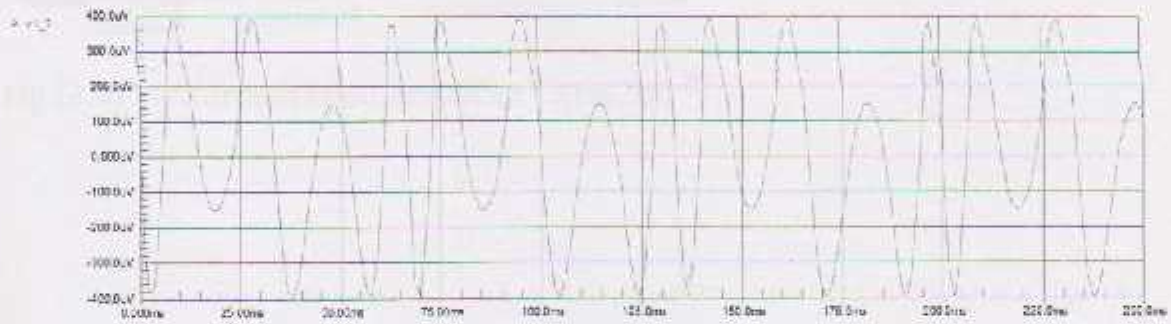


Fig (3.3) FM wave signal

3.2.3 Instrumentation Amplifier

EMG signal it is very small in amplitude and needs to amplify to be suitable to use ,this amplification is done on multi stages , in our design we will use an instrumentation amplifier that will connect directly to the electrodes, this instrumentation amplifier take the difference between two electrodes and take this difference and amplify it to be an electrical signal that will be developed and generated from contraction muscle.

The Instrumentation amplifier circuit contains two stages , it is found on IC (AD620) that used in this design ,this IC have many properties noticed when we use it as an instrumentation amplifier such as:

1. High input impedance and low output impedance

2. High common mode rejection ratio (CMMR), at remove the small voltage noise, it is passed by electrodes

3. High accuracy that requires only external resistor to set the gain of circuit

4. Low cost

Fig (3.4) Instrumentation amplifier (AD620) [8]

The signal is appear after using AD620 at gain equal 10

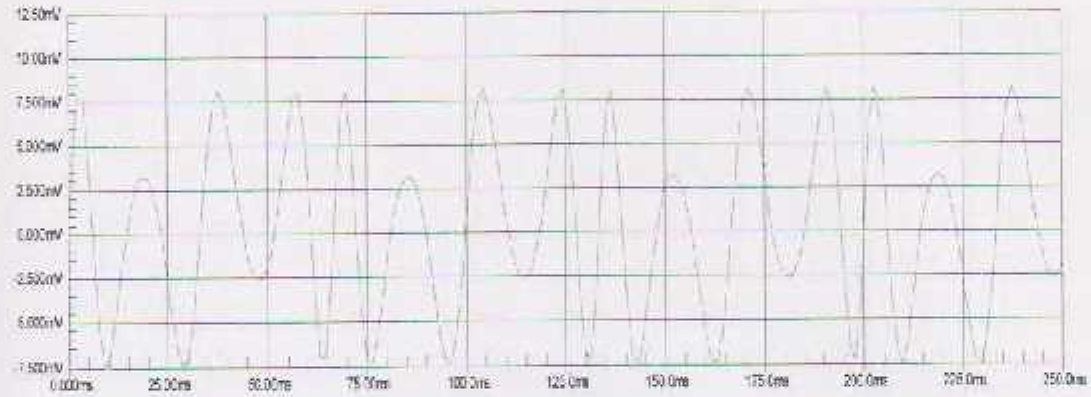


Fig (3.5) AD 620 signal

3.2.4 Band Pass Filter

Band Pass Filter is a circuit that will passes only the frequency with limited range , and reject frequency out side of the range , in our design we will use second order band pass filter (active filter) with one operational amplifier type (IC 741) to limit the band width of frequency between (6 Hz - 30 Hz) , and the operational amplifier must have gain equal (10).

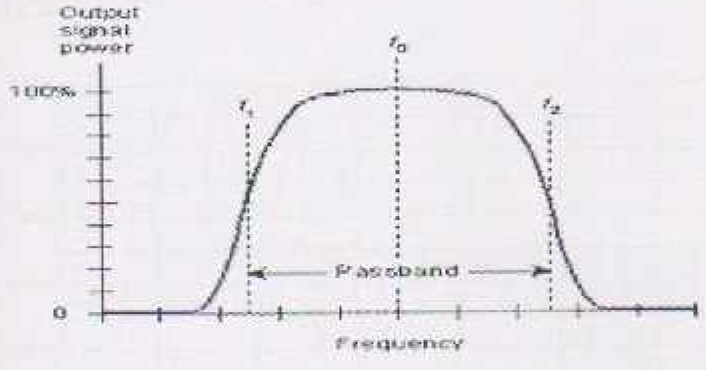
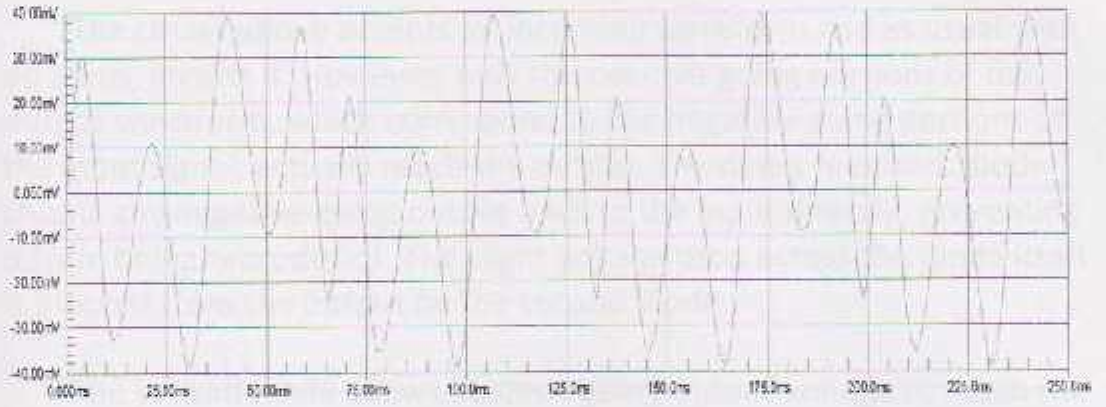


Fig (3.6) Band pass filter [9]

The signal is appear after using Band pass filter at gain 10



Fig(3.7) band pass filter signal

3.2.5 Gain Amplifier

In our design we will use non-inverting amplifier, this amplifier is used to amplify the EMG signal on final view to make the amplitude in voltage , this amplified stage will have gain equal (120) , we will use in this circuit IC (741) to amplify the signal.

The signal is appear after using Operational amplifier at gain equal 120

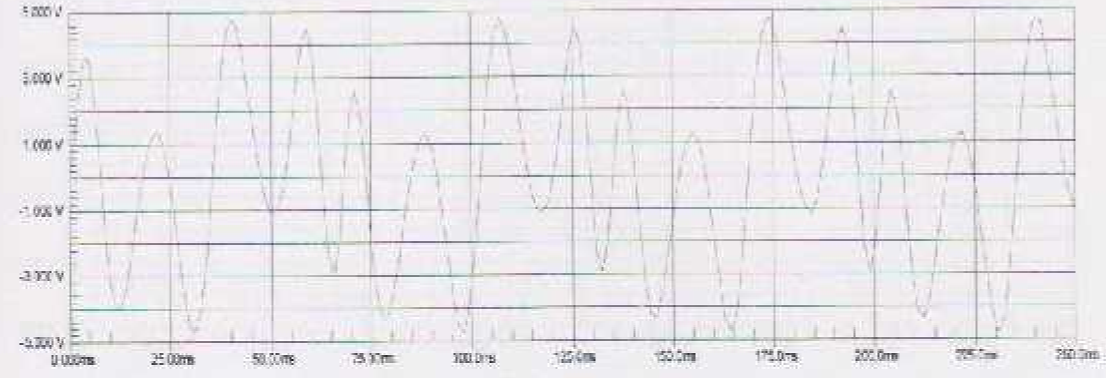


Fig (3.8) Operational amplifier signal

3.2.6 Precise half-wave rectifier circuit

The circuit above accepts an incoming waveform and as usual with op amps, inverts it. However, only the positive-going portions of the output waveform, which correspond to the negative-going portions of the input signal, actually reach the output. The direct feedback diode shunts any negative-going output back to the input directly, preventing it from being reproduced. The slight voltage drop across the diode itself is blocked from the output by the second diode.

The second diode allows positive-going output voltage to reach the output. Furthermore, since the output voltage is taken from beyond the output diode itself, the op amp will necessarily compensate for any non-linear characteristics of the diode itself. As a result, the output voltage is a true and accurate (but inverted) reproduction of the negative portions of the input signal. Thus, this circuit operates as a precision half-wave rectifier.

If you want to keep the positive-going of the input signal instead of the negative-going , simply reverse the two diodes. The result will be a negative-going copy of the positive part of the input signal.

The signal is appear after using Precise half-wave rectifier circuit at Cut off the negative part and keep to the positive part from the operation amplifier signal .

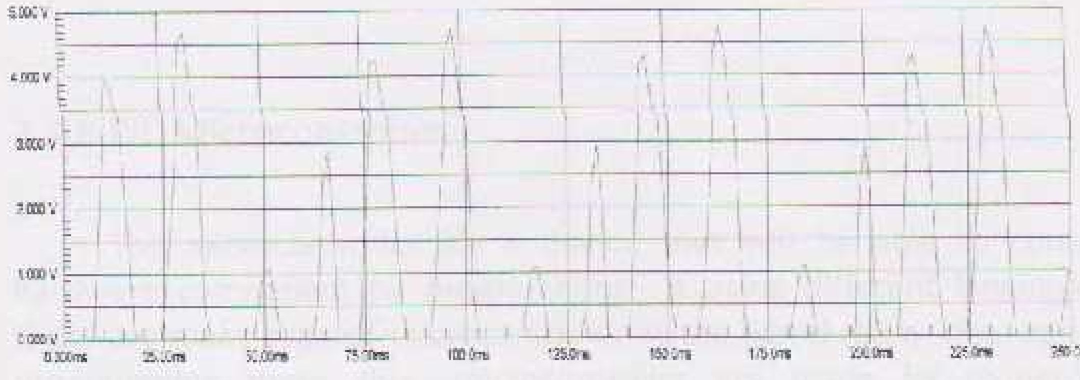


Fig (3.9) Precise half-wave rectifier signal

3.2.7 Comparator circuit

Below are some examples of 741 IC. based circuits. However, this case the 741 is used as a comparator and not an amplifier. The difference between the two is small but significant. Even if used as a comparator the 741 still detects weak signals so that they can be recognised more easily.

A 'comparator' is an circuit that compares two input voltages. One voltage is called the reference voltage (Vref) is used to determined the amplitude and duration for the pulses, and the other is called the input voltage (Vin) .

The signal is appear after using comparator circuit

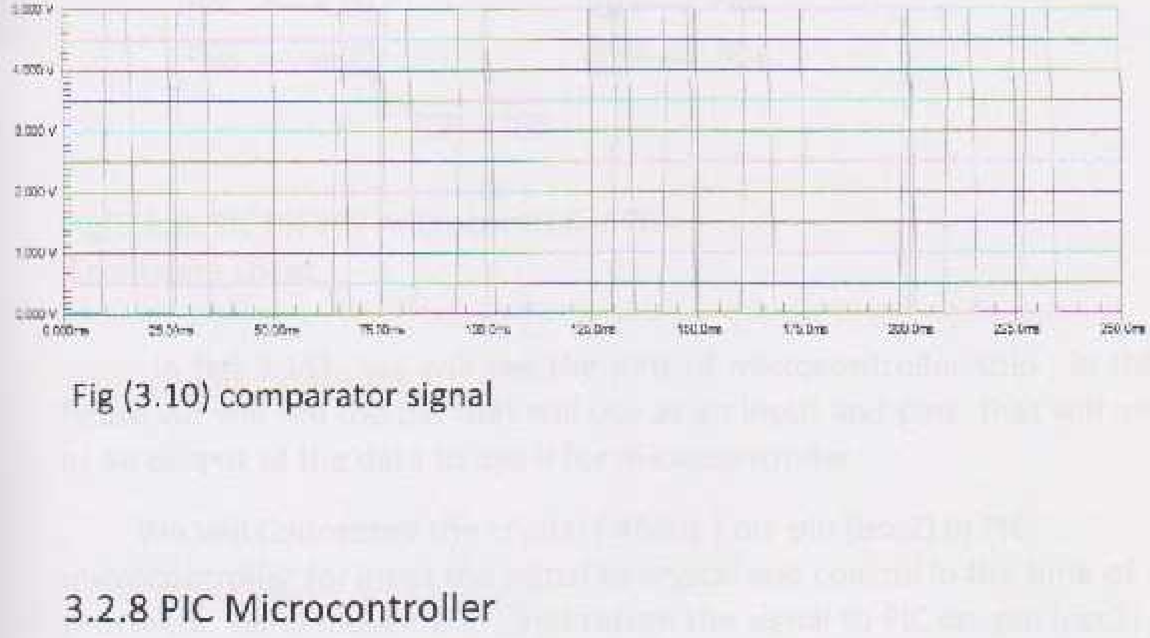
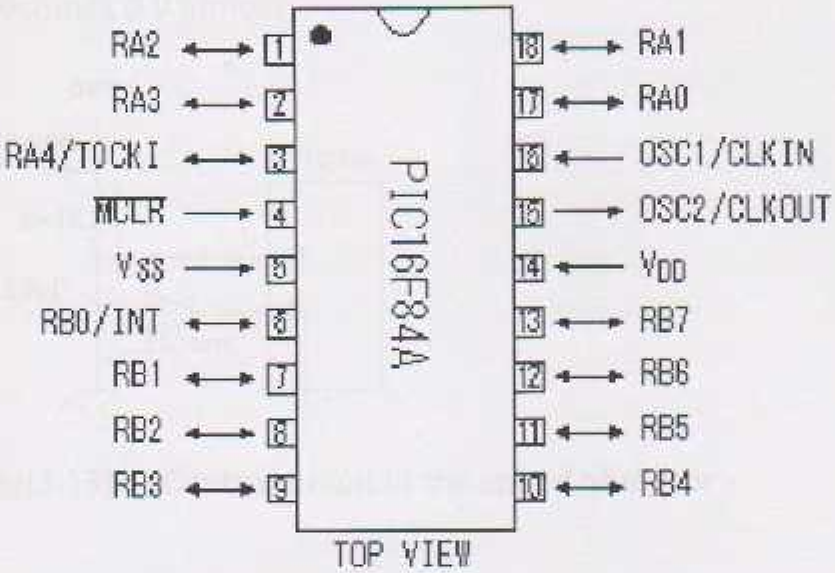


Fig (3.10) comparator signal

3.2.8 PIC Microcontroller

The microcontroller it's a device that will be able to control hardware component by programming it using different language , there are many type of microcontroller in the world many language of programming these ship, microcontroller are made by numerous different manufactures. Different microcontroller are used in many applications on our life and the most common used family are (PIC16F) and (PIC18F) . In our design we will use PIC16F84A microcontroller which can be easily interfaced with the chopper from it's output by using specific software writing in HEX language , the software will be written using HEX language because this language is assembly to understand from the chip and programmer.

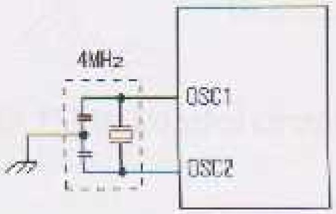
PIC16F84A microcontroller



Fig(3.11): PIC16F877 microcontroller Pins
From data sheet

In fig(3.11) , we will see the pins of microcontroller ship , in this figure we will see the pin that will use as an input and pins that will use as an output of the data to use it for microcontroller .

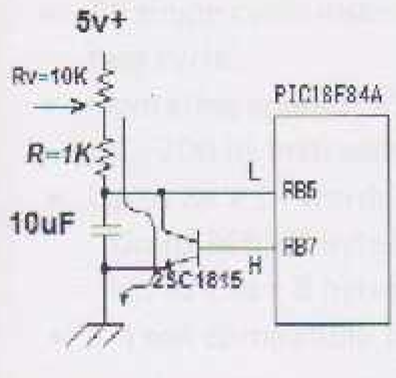
We will Connected the crystal (4MHz) on pin (osc2) in PIC microcontroller for input the signal to crystal and control in the time of prosthetic hand movement , and return the signal to PIC on pin (osc1) .



Fig(3.12): connect the crystal on PIC 16F84A

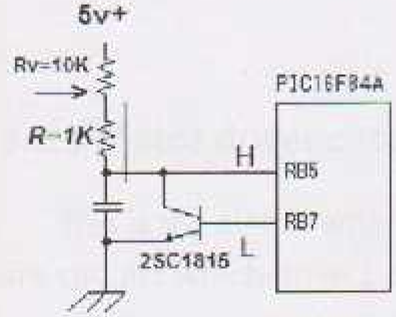
We will connect the control circuit in the speed on pin RB7 and pin RB5 .

This is the circuit which controls the rotational speed of the motor. TR1 becomes ON condition when RB7 becomes H level (the capacitor is discharge) . In this condition, the electric charge of capacitor C1 flows through the transistor and the voltage of the both edges of the capacitor becomes 0 V almost.



Fig(3.13):a- Control circuit in the speed of motor

When RB7 becomes an L level (the capacitor is charge) , the transistor becomes OFF condition. In this condition, the electric current flows through Rv and resister into capacitor and the charging to the capacitor begins. The voltage of the both edges of the capacitor becomes high gradually as charging is done.



Fig(3.13):b- Control circuit in the speed of motor

The voltage of the capacitor is detected by RB5. The software of PIC interrupts the control of the motor until it checks RB5 after making RB7 an L level and RB5 becomes H level. When making the value of VR1 small, the charging time of the capacitor is short and the control of the motor becomes quick. The control of the motor becomes slow when making VR1 big.

Features of (PIC16F84A)

- High performance RISC CPU.
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle.
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of FLASH Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM) .
  Up to 256 x 8 bytes of EEPROM Data Memory .
- Pin out compatible to the PIC16C73B/74B/76/77.

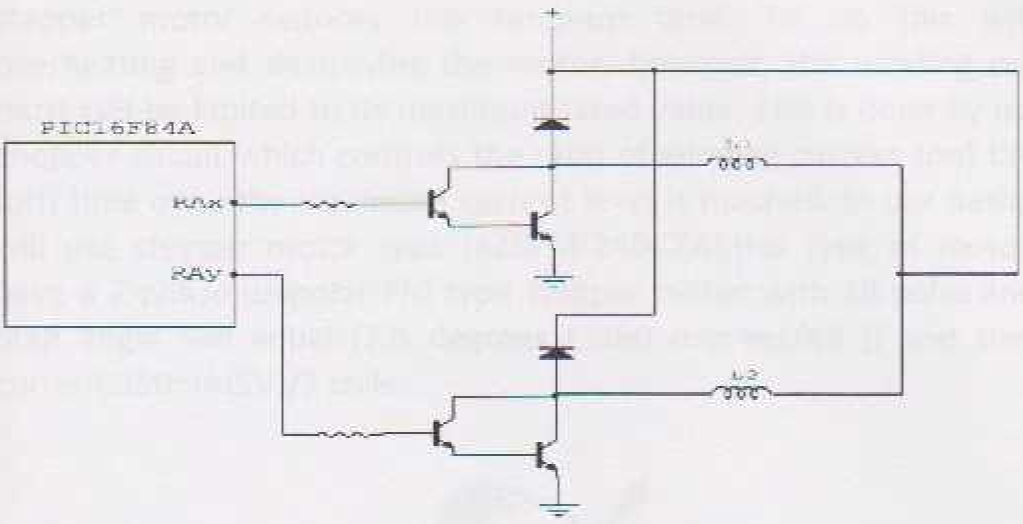
Fig(3.14): PIC16F84A microcontroller [10]

3.2.9 Motor driver circuit

This is the circuit which drives the coil of stepper motor. There are circuits which drive 1 coil, 2 coil , 3 coil and 4 coil respectively.

Darlington connection-type transistor is used for the drive of the coil. As for the Darlington connection , 2 stages of transistors are connected inside in series .

The diode to be putting between the collector and the power is for the protection of the transistor. When the transistor becomes OFF from ON, the coil of the motor tries to continue to pass an electric current and generates high voltage. An electric current by this voltage is applied to the diode and the high voltage which applies over the transistor is prevented.



Fig(3.15): control circuit in two coil in the stepper motor

3.2.10 Stepper Motor

Stepper motors operate by sequentially energizing coils located in the stator. Depending upon the stepper motor's type: variable reluctance, permanent magnet, or hybrid, the rotor contains a toothed soft-iron core, permanent magnets, or both. What sets a stepper motor apart from other motor types is the ability to step (or turn) its rotor in small, precise increments and lock it in place. Three configurations are typically found for wiring a stepper motor's windings; variable reluctance, unipolar, and bipolar.

Each configuration requires different drive circuitry and its associated method of control. This application report focuses on controlling stepper motors with bipolar windings. Bipolar stepper motors are driven using an H-bridge circuit since current flow is bi-directional through the windings. Based on its internal winding resistance, stepper motors are rated for maximum current at a particular voltage. Maximum torque is developed when maximum current is flowing through the windings.

Operating at this voltage, however, is inefficient due to the ramp-up time it takes for current flow to overcome the winding's inherent inductance. Applying a voltage much higher than it's rated for to a stepper motor reduces this ramp-up time. To do this without overheating and destroying the motor, however, the winding current must still be limited to its maximum rated value. This is done by using a chopper circuit which controls the ratio of winding current (on) time to (off) time once the maximum current level is reached. In our design we will use stepper motor type (42SPM-24DCZA),this type of motor will have a 2-phase unipolar PM type stepper motor with 48-poles.and the Step angle will equal (7.5 degrees (360 degrees/48)) and the Coil current:250mA(5V)/2 coils .

Fig(3.16) Stepper Motor[11]

3.2.10 The Prosthetic Hand

we will use Prosthetic hand ,it is made of Reinforced plastic material and it should be similar to the neutral hand to be acceptable from the patient and it will have many properties that make its able to be used.

3.3 Power Supply

We will use the battery 5volt and battery 12volt .
The battery 5volt is used in PIC microcontroller and the battery 12volt is used in other circuit in this project ,and the current is 250mA (because the current in the battery is equal 250mA).

Chapter Four

Design And Implementation

Circuit Diagram And Calculation

4.1 Electromyogram Circuit

4.1.1 Electrodes

4.1.2 Instrumentation Amplifier

4.1.3 Band Pass Filter

4.1.4 Gain Amplifier

4.1.5 Precise half-wave rectifier circuit

4.1.6 Comparator circuit

4.2 PIC Microcontroller

4.3 Motor driver circuit

4.4 Stepper Motor

4.5 The Prosthetic hand

4.1 Electromyogram Circuit

4.1.1 Electrode

The fig (4.1) shows the places that we will put the electrode on it, the place will be on the surface of the biceps and triceps muscle, and it will be on the upper part of the muscle and the lower part of the muscle .

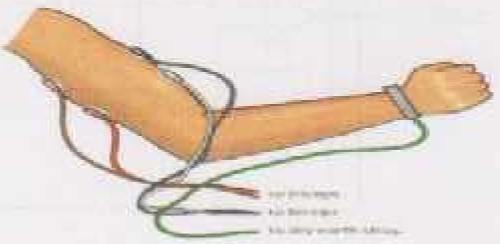


Fig (4.1) The place of electrode on the biceps and triceps muscle[12]

4.1.2 Instrumentation Amplifier

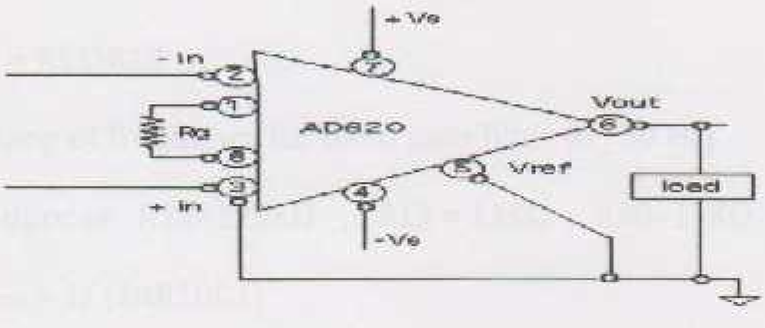


Fig (4.2) (AD620) Instrumentation amplifier

AV = (49.4 KΩ /Rg)+1

We used gain equal 10

RG= 5.48K Ω , is used to control in the gain

4.1.3 Band Pass Filter

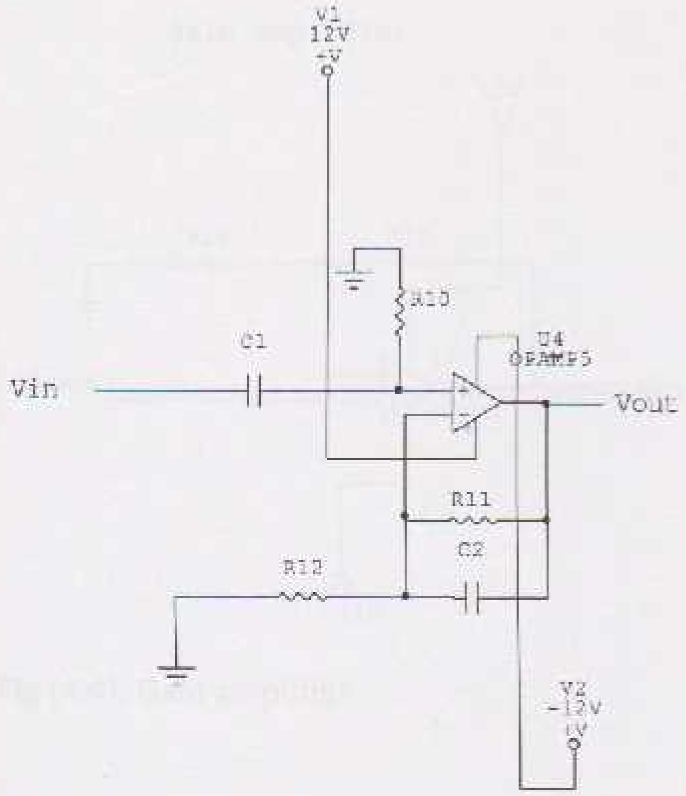


Fig (4.3): Second order band pass filter (active filter)

Av = (R11/R12) +1

9 = R11\R12

Rang of frequency for band pass filter (6_ 30 Hz)

Suppose R11=120KΩ , R12 = 13KΩ , R10=13KΩ

F_{CH} = 1/ (2πR10C1)

6=1/ (2*3.14*13KΩ*C1) .... C1= 2.04μF

F_{CL} = 1/ (2πR11C2)

30 = 1/ (2*3.14*120KΩ*C2) .... C2= 45nF

4.1.4 Gain Amplifier

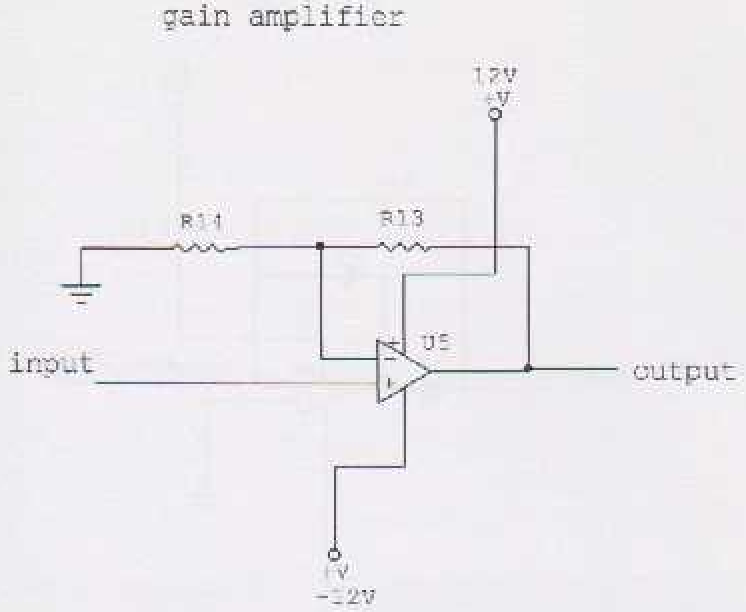


Fig (4.4): Gain amplifier

Suppose R14 = 1KΩ , R13 = 119KΩ

Av =(R13/R14) +1

Av =(119/1)+1 .... Av = 120

4.1.5 Precise half-wave rectifier circuit

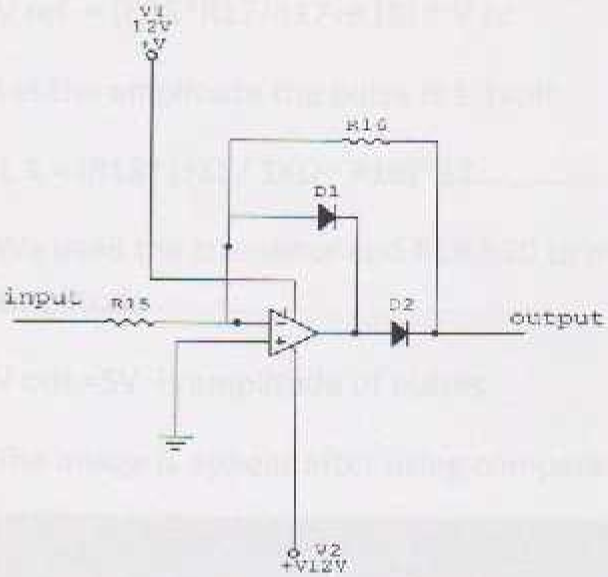


Fig (4.5): Precise half-wave rectifier circuit

R15,R16 = 1KΩ

We used R15 equal R16 until the output voltage is have the same of amplitude for input voltage

4.1.6 Comparator circuit

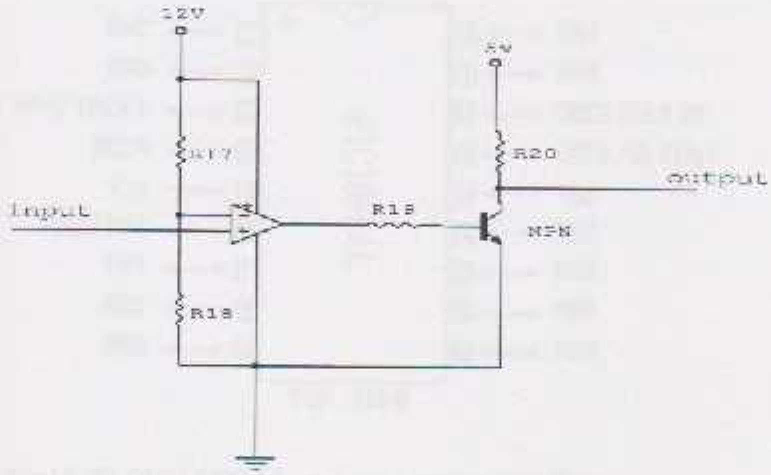


Fig (4.6): comparator circuit

R19=R20=10KΩ

R17=1KΩ

V ref = (R18*R17/R17+R18) * V cc

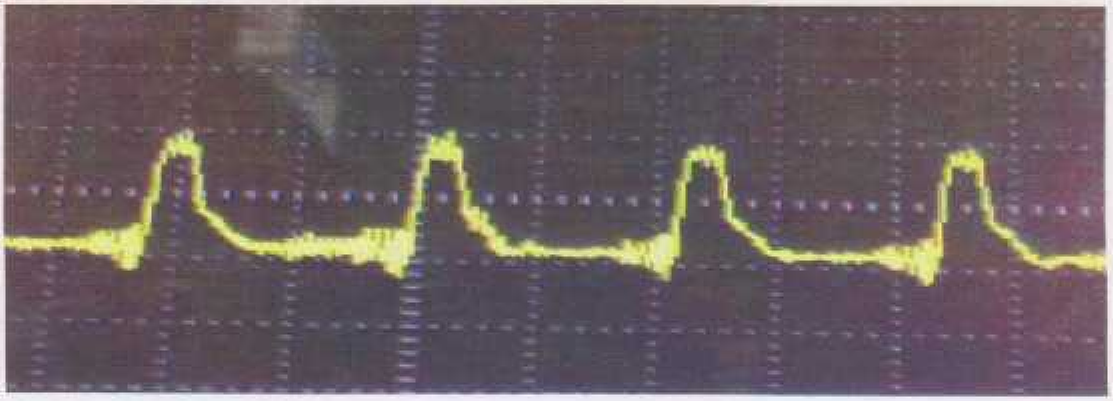
Let the amplitude the pulse is 1.1volt

1.1 = (R18*1KΩ / 1KΩ+ R18)*12........................R18=100Ω

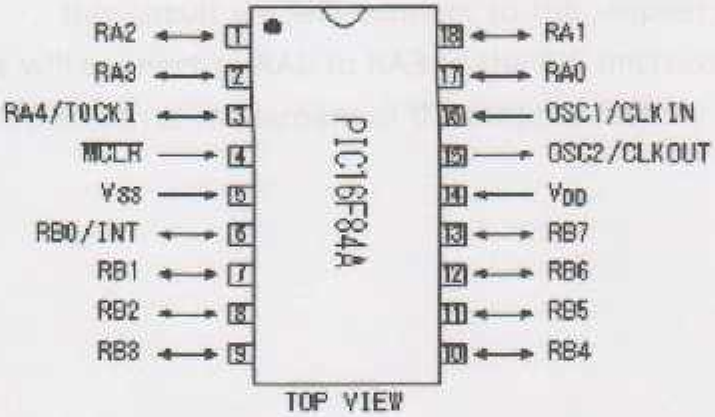
We used the transistor and R19,R20 to make the pulses at same amplitude .

V out =5V is amplitude of pulses

The image is appear after using comparator circuit in the project .

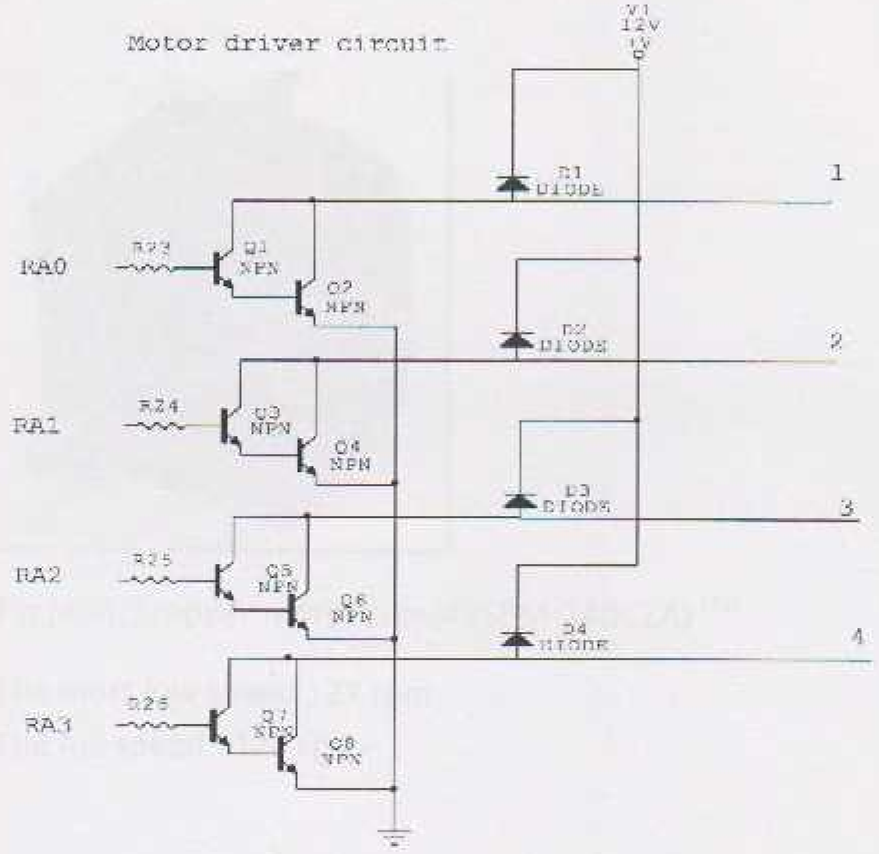


4.2 PIC Microcontroller



Fig(4.7) PIC16F84A microcontroller Pins

4.3 Motor driver circuit



Fig(4.8) Motor driver circuit

D1=D2=D3=D4 =1N914

R23=R24=R25=R26=3.3KΩ

Q1=Q2=Q3=Q4=Q5=Q6=Q7=Q8= 2SD1209K

this circuit we will connect to the stepper motor ,the R23 to R26 we will connect to RA0 to RA3 of the PIC microcontroller, will be control the position of movement of the stepper motor.

4.4 Stepper Motor

Fig (4.9): Stepper motor type(42SPM-24DCZA) [19]

The most low speed : 27 rpm
The full speed : 128 rpm

Feature of this type stepper motor

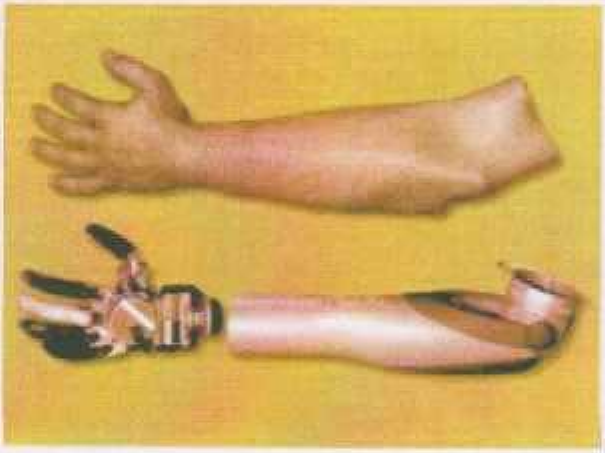
- it's a 2-phase unipolar PM type stepper motor with 48-poles.
- Step angle is 7.5 degrees (360 degrees/48)
- Drive voltage equal (5v-6v)
- Coil current is 250mA(5V)/2 coils

4.5 The Prosthetic Hand

It`s a device that we will use in our project that will be same as the neutral hand , this device movement depends by the stepper motor movement . the stepper motor will connect directly to this device and move it on different position as the position of the motor .

This device have many properties to be able to use in this design this properties will be :

1-low cost .
2-heavy ,low weight to be move easy .
3-biocompatible form .



Fig(4.10)Prosthetic hand [14]

Chapter Five

Testing and Implementation

5.1 Results

5.2 Conclusion

5.3 Suggestions

5.4 final project circuit

5.1 Results

1 - Implemented the muscle zoom signal circuit, and the resulting after the zoom signal is the same signal required.
2 - We faced some problems in dealing with PIC in terms of connectivity and programming.
3-Using the electronic circuit instead of switch to stop the work of the prosthetic hand .
4 - Used transistor 2SD1853 instead of 2SD1209K transistors, leading to not move stepper motor .
5 -Use a variable resistance R18 to be controlled in the value of the duration pulse .
6 - High temperature regulator because increasing the loads .

5.2 Conclusion

1 - Prosthetic hand the hand that can help patients who suffer from loss of part of the hand.
2- Design a simple can help the patient to do his work.
3- Prosthetic hand can be moved up or down .

5.3 Suggestions

1 - The possibility of moving the fingers by taking the signal from the muscle of the hand .
2 - The possibility of taking the signal from the brain
3 - the possibility of using another PIC in the project to facilitate the delivery process and programming .
4 - The possibility of using motor is moving at an angle different from the angle used in the project

5.4 final project circuit

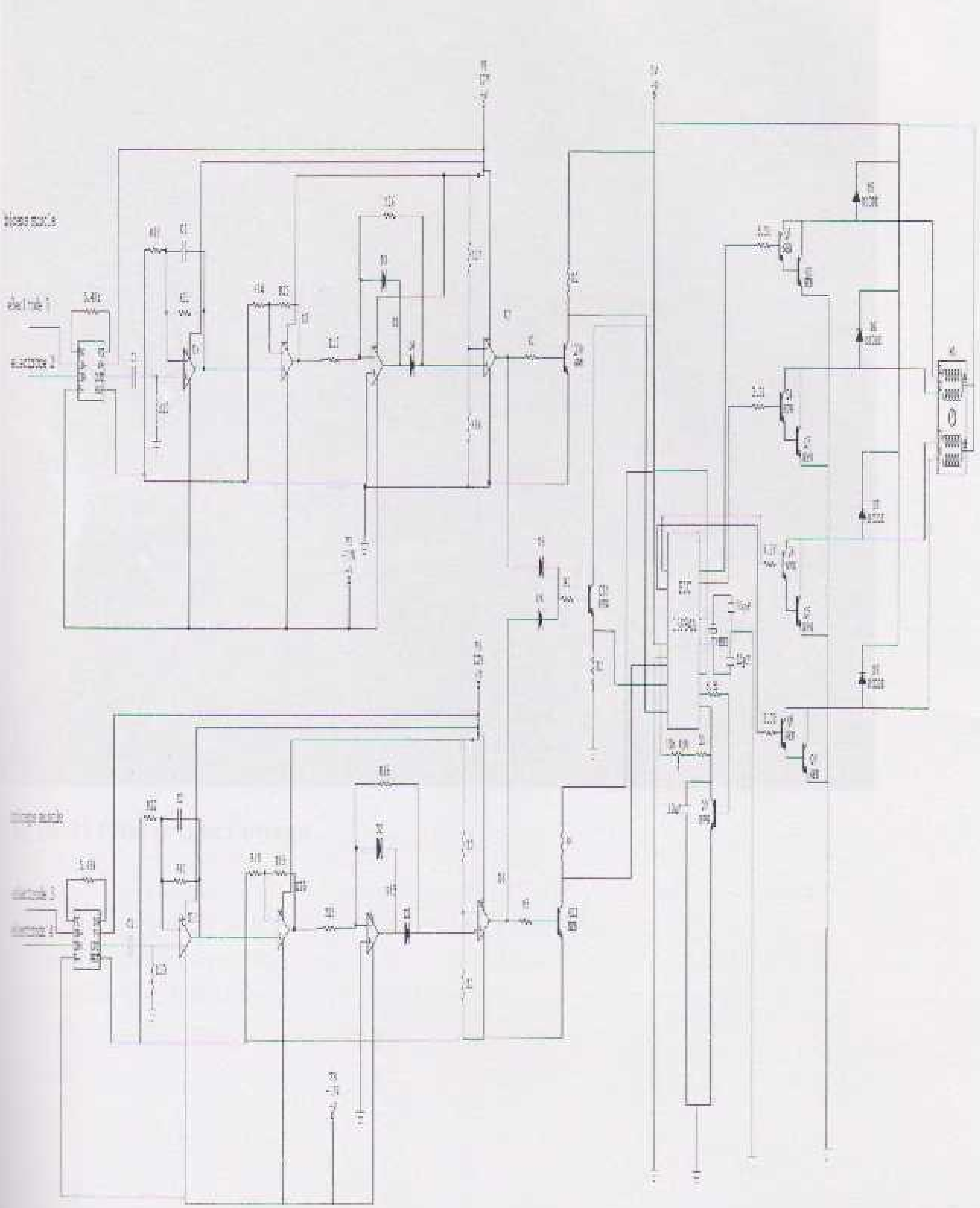


Fig (5.1) final project circuit

Final project image

Fig (5.2) final project image

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Figures:

[1]Imagesource:http://training.seer.cancer.gov/module_anatomy/unit4_2_muscle_structure.html (23-3-2011)

[2] http://natchem.wordpress.com/2009/11/23/motor-unit-recruitment-strategies-during-deep-muscle-pain/ (23-3-2011)

[3]http://zlrbryxr.co.cc/?s=sF02w5fGyTHpsN0cW%2BxluDF9CxG7AX34a5FMQ%2BNjhPt33zgsSvC1oJYnNDI0Bg8F1g%3D%3D (24-3-2011)

[4] http://jn.physiology.org/content/95/2/1134.full (25-3-2011)

[5]http://physiome.org/model/doku.php?id=Cell_Physiology:Action_potential:ten_Tusscher_Noble_Noble_Panfilov_2004:model_detail (25-3-2011)

[6]http://www.clipartmonsterclub.com/clipart/medical-clip-art/biceps-and-triceps-16041.html (14-4-2011)

[7]http://www.chinagauze.com/instrument/ECG%20electrode/monitoring.htm(14-4-2011)

[8]http://www.antury.net/publicaciones/publicacion%20ad620/publicacion%20ad620.html (14-4-2011)

[9]http://hossainhere.wordpress.com/2010/07/19/bandpass-filter/ (27-4-2011)

[10] http://www.piclist.com/images/www/hobby_elec/e_pic6_13.htm (30-4-2011)

[11] http://www.piclist.com/images/www/hobby_elec/e_step4.htm (27-4-2011)

[12]https://www.adinstruments.com/solutions/experiments/labchart_experiments/full.php?exp_id=235&section_id=25&group_id=5&name_id=304&template=teaching (27-4-2011)

[13] http://www.almohandesen.org/vb/showthread-t_1013.html

[14]http://www.alardha.com/forums/showthread.php?t=12879 (27-4-2011)

Appendix

A

Definition

Biceps and Triceps Muscle

The triceps is an extensor muscle of the elbow joint, and is an antagonist of the biceps and brachial is muscles. It can also fixate the elbow joint when the forearm and hand are used for fine movements, e.g., when writing. It has been suggested that the long head fascicle is employed when sustained force generation is demanded, or when there is a need for a synergistic control of the shoulder and elbow or both. The lateral head is used for movements requiring occasional high-intensity force, while the medial fascicle enables more precise, low-force movements.

Electromyography

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated. The signals can be analyzed to detect medical abnormalities, activation level, recruitment order or to analyze the biomechanics of human or animal movement.

Electrode

An electrode is an electrical conductor used to make contact with a nonmetallic part of a circuit (e.g. a semiconductor, an electrolyte or a vacuum). The word was coined by the scientist Michael Faraday from the Greek words elektron (meaning amber, from which the word electricity is derived) and hodos, a way.

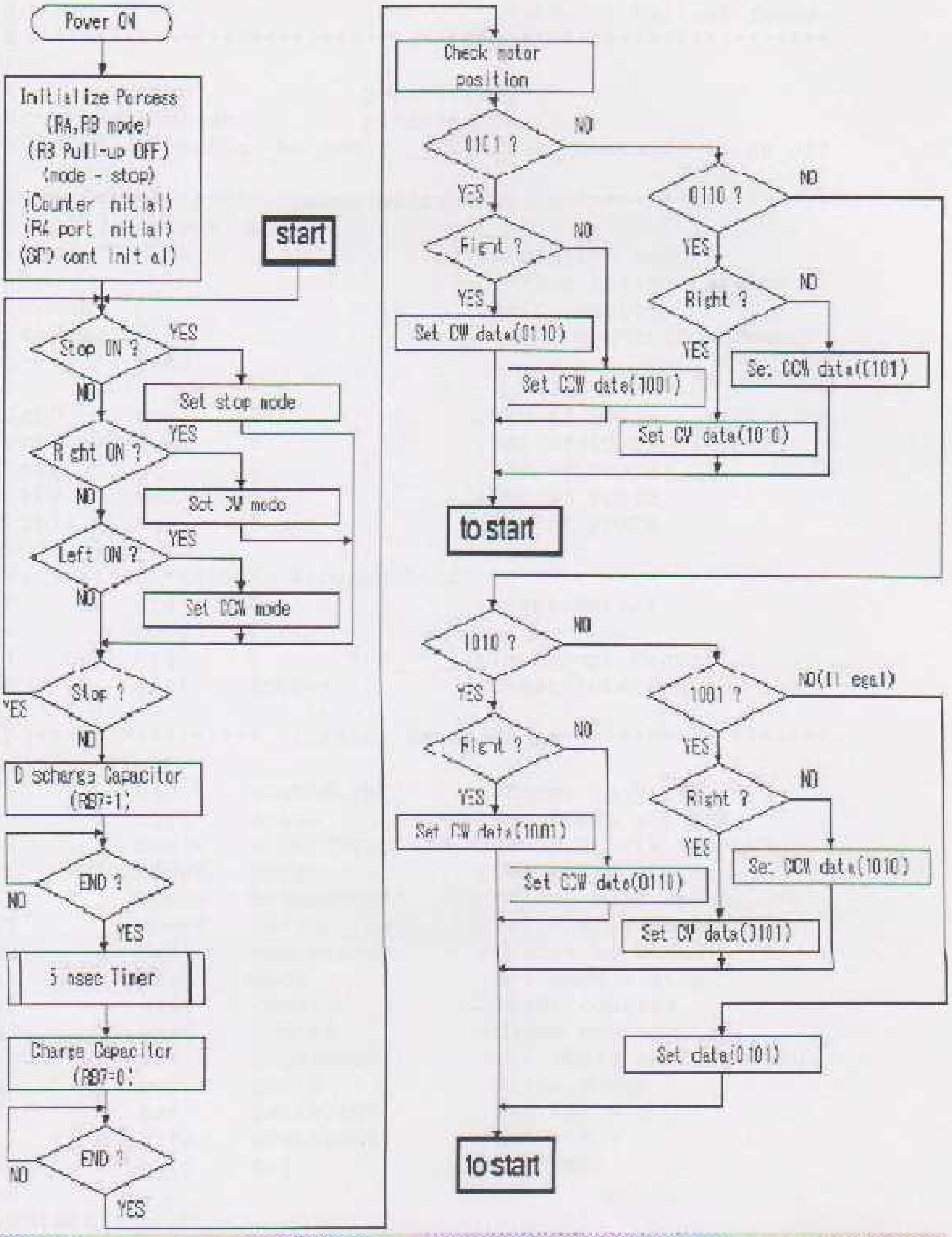
PIC Microcontroller

PIC is a family of Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1640 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to "Peripheral Interface Controller". PICs are popular with both industrial developers and hobbyists alike due to their low cost, wide availability, large user base, extensive collection of application notes, availability of low cost or free development tools, and serial programming (and re-programming with flash memory) capability. Microchip announced on February 2008 the shipment of its six billionth PIC processor.

Stepper Motor

A stepper motor (or step motor) is a brushless, synchronous electric motor that can divide a full rotation into a large number of steps. The motor's position can be controlled precisely without any feedback mechanism (see Open-loop controller), as long as the motor is carefully sized to the application. Stepper motors are similar to switched reluctance motors (which are very large stepping motors with a reduced pole count, and generally are closed-loop commutated).

The software for PIC 16F84A



```
;***********************************************************
;
;                Stepper Motor controller
;
;                                      Author : Seiichi Inoue
;***********************************************************

        list        p=pic16f84a
        include     p16f84a.inc
        __config _hs_osc & _wdt_off & _pwrte_on & _cp_off

;****************  Label Definition  ********************
        cblock  h'0c'
mode                                ;Operation mode
                                    ;0=stop 1=right 2=left
count1                              ;Wait counter
count2                              ;Wait counter(for 1msec)
        endc

rb0     equ     0                   ;RB0 of PORTB
rb1     equ     1                   ;RB1 of PORTB
rb2     equ     2                   ;RB2 of PORTB
rb5     equ     5                   ;RB5 of PORTB
rb7     equ     7                   ;RB7 of PORTB

;****************  Program Start  ***********************
        org     0                   ;Reset Vector
        goto    init
        org     4                   ;Interrupt Vector
        clrf    intcon              ;Clear Interruption reg

;****************  Initial Process  *********************
init
        bsf     status,rp0          ;Change to Bank1
        clrf    trisa               ;Set PORTA all OUT
        movlw   b'00100111'         ;RB0,1,2.5=IN RB7=OUT
        movwf   trisb               ;Set PORTB
        movlw   b'10000000'         ;RBPU=1 Pull up not use
        movwf   option_reg          ;Set OPTION_REG
        bcf     status,rp0          ;Change to Bank0
        clrf    mode                ;Set mode = stop
        clrf    count1              ;Clear counter
        clrf    count2              ;Clear counter
        movlw   b'00000101'         ;Set PORTA initial value
        movwf   porta               ;Write PORTA
        bsf     portb,rb7           ;Set RB7 = 1
        btfsc   portb,rb5           ;RB5 = 0 ?
        goto    $-1                 ;No. Wait

start
;**************  Check switch condition  *****************
        btfsc   portb,rb1           ;RB1(stop key) = ON ?
```

```
          goto    check1           ;No. Next
          clrf    mode             ;Yes. Set stop mode
          goto    drive            ;No. Jump to motor drive
check1
          btfsc   portb,rb2        ;RB2(right key) = ON ?
          goto    check2           ;No. Next
          movlw   d'1'             ;Yes. Set right mode
          movwf   mode             ;Save mode
          goto    drive            ;No. Jump to motor drive
check2
          btfsc   portb,rb0        ;RB0(left key) = ON ?
          goto    drive            ;No. Jump to motor drive
          movlw   d'2'             ;Yes. Set left mode
          movwf   mode             ;Save mode

;********************  Motor drive  ********************
drive
          movf    mode,w           ;Read mode
          bz      start            ;mode = stop
          bsf     portb,rb7        ;Set RB7 = 1
          btfsc   portb,rb5        ;RB5 = 0 ?
          goto    $-1              ;No. Wait
          movlw   d'5'             ;Set loop count(5msec)
          movwf   count1           ;Save loop count
loop      call    timer            ;Wait 1msec
          decfsz  count1,f         ;count - 1 = 0 ?
          goto    loop             ;No. Continue
          bcf     portb,rb7        ;Set RB7 = 0
          btfss   portb,rb5        ;RB5 = 1 ?
          goto    $-1              ;No. Wait
          movf    porta,w          ;Read PORTA
          sublw   b'000000101'     ;Check motor position
          bnz     drive2           ;Unmatch
          movf    mode,w           ;Read mode
          sublw   d'1'             ;Right ?
          bz      drive1           ;Yes. Right
          movlw   b'00001001'      ;No. Set Left data
          goto    drive_end        ;Jump to PORTA write
drive1
          movlw   b'00000110'      ;Set Right data
          goto    drive_end        ;Jump to PORTA write
;-------
drive2
          movf    porta,w          ;Read PORTA
          sublw   b'000000110'     ;Check motor position
          bnz     drive4           ;Unmatch
          movf    mode,w           ;Read mode
          sublw   d'1'             ;Right ?
          bz      drive3           ;Yes. Right
          movlw   b'00000101'      ;No. Set Left data
          goto    drive_end        ;Jump to PORTA write
drive3
          movlw   b'00001010'      ;Set Right data
          goto    drive_end        ;Jump to PORTA write
;-------
```

```
drive4
        movf    porta,w         ;Read PORTA
        sublw   b'000001010'    ;Check motor position
        bnz     drive6          ;Unmatch
        movf    mode,w          ;Read mode
        sublw   d'1'            ;Right ?
        bz      drive5          ;Yes. Right
        movlw   b'00000110'     ;No. Set Left data
        goto    drive_end       ;Jump to PORTA write
drive5
        movlw   b'00001001'     ;Set Right data
        goto    drive_end       ;Jump to PORTA write
;-------
drive6
        movf    porta,w         ;Read PORTA
        sublw   b'000001001'    ;Check motor position
        bnz     drive8          ;Unmatch
        movf    mode,w          ;Read mode
        sublw   d'1'            ;Right ?
        bz      drive7          ;Yes. Right
        movlw   b'00001010'     ;No. Set Left data
        goto    drive_end       ;Jump to PORTA write
drive7
        movlw   b'00000101'     ;Set Right data
        goto    drive_end       ;Jump to PORTA write
;-------
drive8
        movlw   b'00000101'     ;Compulsion setting

drive_end
        movwf   porta           ;Write PORTA
        goto    start           ;Jump to start

;*************  1msec Timer Subroutine  ****************
timer
        movlw   d'200'          ;Set loop count
        movwf   count2          ;Save loop count
tmlp    nop                     ;Time adjust
        nop                     ;Time adjust
        decfsz  count2,f        ;count - 1 = 0 ?
        goto    tmlp            ;No. Continue
        return                  ;Yes. Count end

;********************************************************
;               END of Stepper Motor controller
;********************************************************

        end
```

Appendix

B

Data Sheet

ANALOG DEVICES

Low Cost, Low Power Instrumentation Amplifier

AD620

FEATURES

EASY TO USE

Gain Set with One External Resistor (Gain Range 1 to 1000)

Wide Power Supply Range (±2.3 V to ±18 V)

Higher Performance than Three Op Amp IA Designs

Available in 8-Lead DIP and SOIC Packaging

Low Power, 1.3 mA max Supply Current

EXCELLENT DC PERFORMANCE ("B GRADE")

50 μV max, Input Offset Voltage

0.6 μV/°C max, Input Offset Drift

1.0 nA max, Input Bias Current

100 dB min Common-Mode Rejection Ratio (G = 10)

LOW NOISE

9 nV/√Hz, @ 1 kHz, Input Voltage Noise

0.28 μV p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS

120 kHz Bandwidth (G = 100)

15 μs Settling Time to 0.01%

APPLICATIONS

Weigh Scales

ECG and Medical Instrumentation

Transducer Interface

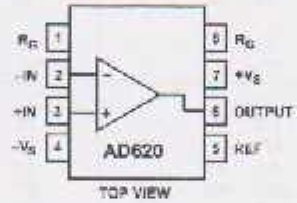
Data Acquisition Systems

Industrial Process Controls

Battery Powered and Portable Equipment

CONNECTION DIAGRAM

8-Lead Plastic Mini-DIP (N), Cerdip (Q) and SOIC (R) Packages



PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 1000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs, and offers lower power (only 1.3 mA max supply current), making it a good fit for battery powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 μV max and offset drift of 0.6 μV/°C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superβeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/√Hz at 1 kHz, 0.28 μV p-p in the 0.1 Hz to 10 Hz band, 0.1 pA/√Hz input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 μs to 0.01% and its cost is low enough to enable designs with one in-amp per channel.

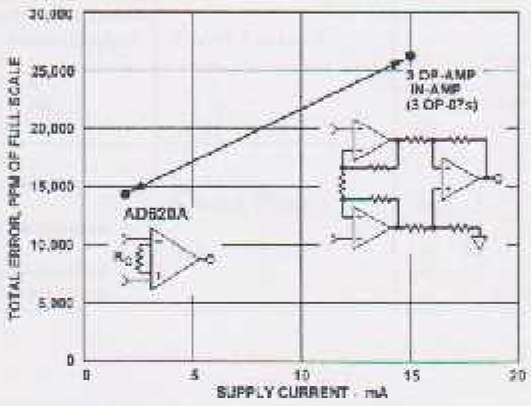


Figure 1. Three Op Amp IA Designs vs. AD620

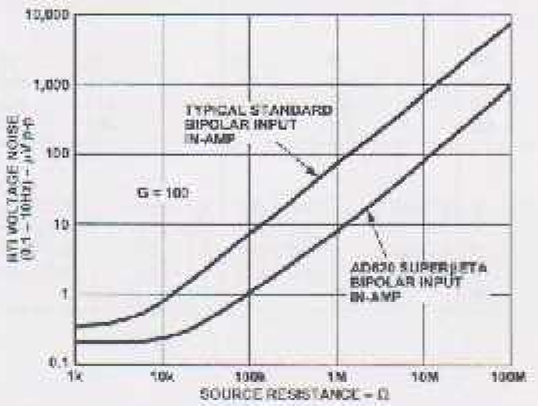


Figure 2. Total Voltage Noise vs. Source Resistance

REV. E

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781/329-4700 World Wide Web Site: http://www.analog.com
Fax: 781/326-8703

AD620–SPECIFICATIONS (Typical @ +25°C, V_S = ±15 V, and R_L = 2 kΩ, unless otherwise noted)

Model	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Units
GAIN	$G = 1 + (49.4\ k/R_G)$										
Gain Range		1		10,000	1		10,000	1		10,000	
Gain Error[2]	V_{OUT} = ±10 V										
G = 1			0.03	0.10		0.01	0.02		0.03	0.10	%
G = 10			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 100			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 1000			0.40	0.70		0.35	0.50		0.40	0.70	%
Nonlinearity,	V_{OUT} = –10 V to +10 V,										
G = 1–1000	R_L = 10 kΩ		10	40		10	40		10	40	ppm
G = 1–100	R_L = 2 kΩ		10	95		10	95		10	95	ppm
Gain vs. Temperature											
	G = 1			10			10			10	ppm/°C
	Gain >1[2]			–50			–50			–50	ppm/°C
VOLTAGE OFFSET	(Total RTI Error = $V_{OSI} + V_{OSO}/G$)										
Input Offset, V_{OSI}	V_S = ±5 V to ±15 V		30	125		15	50		30	125	µV
Over Temperature	V_S = ±5 V to ±15 V			185			85			225	µV
Average TC	V_S = ±5 V to ±15 V		0.3	1.0		0.1	0.6		0.3	1.0	µV/°C
Output Offset, V_{OSO}	V_S = ±15 V		400	1000		200	500		400	1000	µV
	V_S = ±5 V			1500			750			1500	µV
Over Temperature	V_S = ±5 V to ±15 V			2000			1000			2000	µV
Average TC	V_S = ±5 V to ±15 V		5.0	15		2.5	7.0		5.0	15	µV/°C
Offset Referred to the Input vs. Supply (PSR)	V_S = ±2.3 V to ±18 V										
G = 1		80	100		80	100		80	100		dB
G = 10		95	120		100	120		95	120		dB
G = 100		110	140		120	140		110	140		dB
G = 1000		110	140		120	140		110	140		dB
INPUT CURRENT											
Input Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
Over Temperature				2.5			1.5			4	nA
Average TC			3.0			3.0			8.0		pA/°C
Input Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
Over Temperature				1.5			0.75			2.0	nA
Average TC			1.5			1.5			8.0		pA/°C
INPUT											
Input Impedance											
Differential			10‖2			10‖2			10‖2		GΩ‖pF
Common-Mode			10‖2			10‖2			10‖2		GΩ‖pF
Input Voltage Range[3]	V_S = ±2.3 V to ±5 V	$-V_S + 1.9$		$+V_S - 1.2$	$-V_S + 1.9$		$-V_S - 1.2$	$-V_S + 1.9$		$+V_S - 1.2$	V
Over Temperature		$-V_S + 2.1$		$+V_S - 1.3$	$-V_S + 2.1$		$-V_S - 1.3$	$-V_S + 2.1$		$+V_S - 1.3$	V
	V_S = ±5 V to ±18 V	$-V_S + 1.9$		$+V_S - 1.4$	$-V_S + 1.9$		$-V_S - 1.4$	$-V_S + 1.9$		$+V_S - 1.4$	V
Over Temperature		$-V_S + 2.1$		$+V_S - 1.4$	$-V_S + 2.1$		$-V_S - 1.4$	$-V_S + 2.3$		$+V_S - 1.4$	V
Common-Mode Rejection Ratio DC to 60 Hz with 1 kΩ Source Imbalance	V_{CM} = 0 V to ±10 V										
G = 1		73	90		80	90		73	90		dB
G = 10		93	110		100	110		93	110		dB
G = 100		110	130		120	130		110	130		dB
G = 1000		110	130		120	130		110	130		dB
OUTPUT											
Output Swing	R_L = 10 kΩ,										
	V_S = ±2.3 V to ±5 V	$-V_S + 1.1$		$+V_S - 1.2$	$-V_S + 1.1$		$+V_S - 1.2$	$-V_S + 1.1$		$+V_S - 1.2$	V
Over Temperature		$-V_S + 1.4$		$+V_S - 1.3$	$-V_S + 1.4$		$-V_S - 1.3$	$-V_S + 1.6$		$+V_S - 1.3$	V
	V_S = ±5 V to ±18 V	$-V_S + 1.2$		$+V_S - 1.4$	$-V_S + 1.2$		$-V_S - 1.4$	$-V_S + 1.2$		$+V_S - 1.4$	V
Over Temperature		$-V_S + 1.6$		$+V_S - 1.5$	$-V_S + 1.6$		$-V_S - 1.5$	$-V_S + 2.3$		$+V_S - 1.5$	V
Short Current Circuit			±18			±18			±18		mA

Model	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Units
DYNAMIC RESPONSE											
Small Signal –3 dB Bandwidth											
G = 1			1000			1000			1000		kHz
G = 10			800			800			800		kHz
G = 100			120			120			120		kHz
G = 1000			12			12			12		kHz
Slew Rate		0.75	1.2		0.75	1.2		0.75	1.2		V/μs
Settling Time to 0.01%	10 V Step										
G = 1–100			15			15			15		μs
G = 1000			150			150			150		μs
NOISE											
Voltage Noise, 1 kHz	*Total RTI Noise* $= \sqrt{(e^2_{ni}) + (e_{no}/G)^2}$										
Input, Voltage Noise, e_{ni}			9	13		9	13		9	13	nV/√Hz
Output, Voltage Noise, e_{no}			72	100		72	100		72	100	nV/√Hz
RTI, 0.1 Hz to 10 Hz											
G = 1			3.0			3.0	6.0		3.0	6.0	μV p-p
G = 10			0.55			0.55	0.8		0.55	0.8	μV p-p
G = 100–1000			0.28			0.28	0.4		0.28	0.4	μV p-p
Current Noise	f = 1 kHz		100			100			100		fA/√Hz
0.1 Hz to 10 Hz			10			10			10		pA p-p
REFERENCE INPUT											
R_{IN}			20			20			20		kΩ
I_{IN}	V_{IN+}, $V_{REF} = 0$		+50	+60		+50	+60		+50	+60	μA
Voltage Range		$-V_S + 1.6$		$+V_S - 1.6$	$-V_S + 1.6$		$+V_S - 1.6$	$-V_S + 1.6$		$+V_S - 1.6$	V
Gain to Output			1 ± 0.0001			1 ± 0.0001			1 ± 0.0001		
POWER SUPPLY											
Operating Range[4]		±2.3		±18	±2.3		±18	±2.3		±18	V
Quiescent Current	$V_S = \pm 2.3$ V to ± 18 V		0.9	1.3		0.9	1.3		0.9	1.3	mA
Over Temperature			1.1	1.6		1.1	1.6		1.1	1.6	mA
TEMPERATURE RANGE											
For Specified Performance			–40 to +85			–40 to +85			–55 to +125		°C

NOTES

[1] See Analog Devices military data sheet for 883B tested specifications.

[2] Does not include effects of external resistor R_G.

[3] One input grounded. G = 1.

[4] This is defined as the same supply range which is used to specify PSR.

Specifications subject to change without notice.

BSOLUTE MAXIMUM RATINGS[1]

pply Voltage . . . . ±18 V
ernal Power Dissipation[2] . . . . 650 mW
put Voltage (Common Mode) . . . . $\pm V_S$
fferential Input Voltage . . . . ±25 V
tput Short Circuit Duration . . . . Indefinite
rage Temperature Range (Q) . . . . –65°C to +150°C
rage Temperature Range (N, R) . . . . –65°C to +125°C
erating Temperature Range
AD620 (A, B) . . . . –40°C to +85°C
AD620 (S) . . . . –55°C to +125°C
ad Temperature Range
(Soldering 10 seconds) . . . . +300°C

TES
resses above those listed under Absolute Maximum Ratings may cause perma-
nt damage to the device. This is a stress rating only; functional operation of the
vice at these or any other conditions above those indicated in the operational
ction of this specification is not implied. Exposure to absolute maximum rating
nditions for extended periods may affect device reliability.
ecification is for device in free air:
Lead Plastic Package: θ_{JA} = 95°C/W
Lead Cerdip Package: θ_{JA} = 110°C/W
Lead SOIC Package: θ_{JA} = 155°C/W

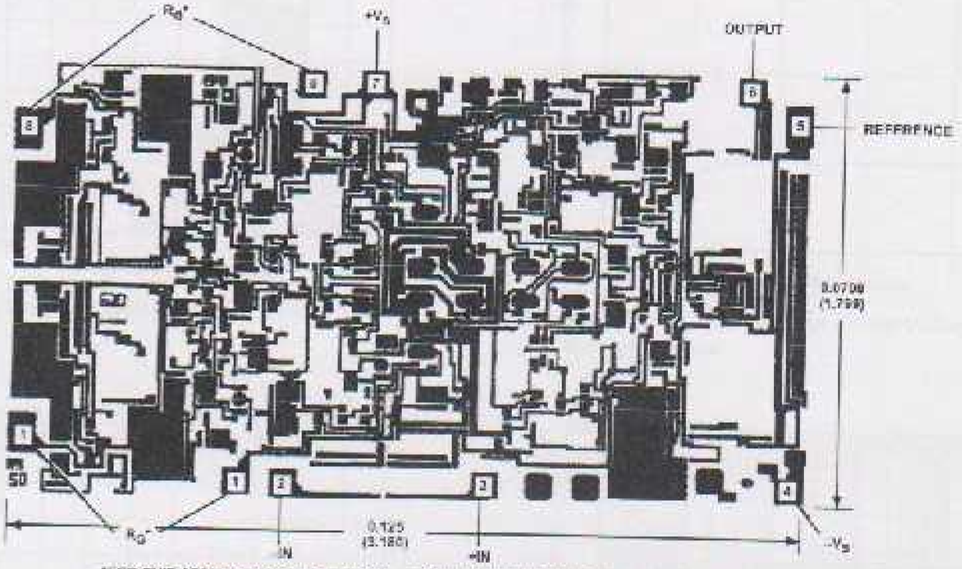
ORDERING GUIDE

Model	Temperature Ranges	Package Options*
AD620AN	–40°C to +85°C	N-8
AD620BN	–40°C to +85°C	N-8
AD620AR	–40°C to +85°C	SO-8
AD620AR-REEL	–40°C to +85°C	13" REEL
AD620AR-REEL7	–40°C to +85°C	7" REEL
AD620BR	–40°C to +85°C	SO-8
AD620BR-REEL	–40°C to +85°C	13" REEL
AD620BR-REEL7	–40°C to +85°C	7" REEL
AD620ACHIPS	–40°C to +85°C	Die Form
AD620SQ/883B	–55°C to +125°C	Q-8

*N = Plastic DIP; Q = Cerdip; SO = Small Outline.

METALIZATION PHOTOGRAPH

Dimensions shown in inches and (mm).
Contact factory for latest dimensions.



*FOR CHIP APPLICATIONS: THE PADS $1R_G$ AND $8R_G$ MUST BE CONNECTED IN PARALLEL TO THE EXTERNAL GAIN REGISTER R_G. DO NOT CONNECT THEM IN SERIES TO R_G. FOR UNITY GAIN APPLICATIONS WHERE R_G IS NOT REQUIRED, THE PADS $1R_G$ MAY SIMPLY BE BONDED TOGETHER, AS WELL AS THE PADS $8R_G$.

AUTION
SD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily
cumulate on the human body and test equipment and can discharge without detection.
though the AD620 features proprietary ESD protection circuitry, permanent damage may
cur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD
ecautions are recommended to avoid performance degradation or loss of functionality.

Typical Characteristics (@ +25°C, V_S = ±15 V, R_L = 2 kΩ, unless otherwise noted)

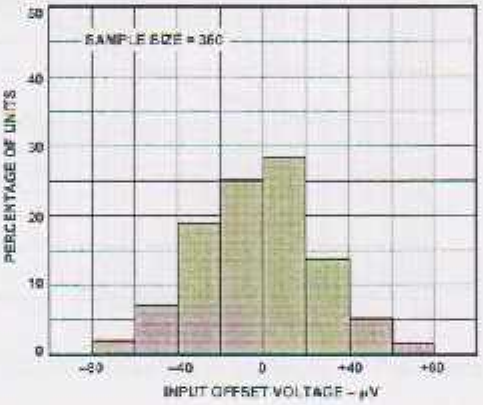


Figure 3. Typical Distribution of Input Offset Voltage

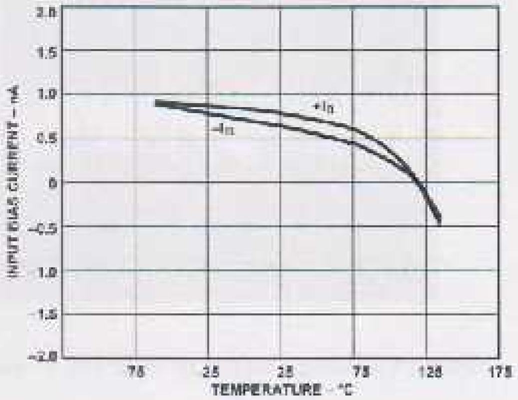


Figure 6. Input Bias Current vs. Temperature

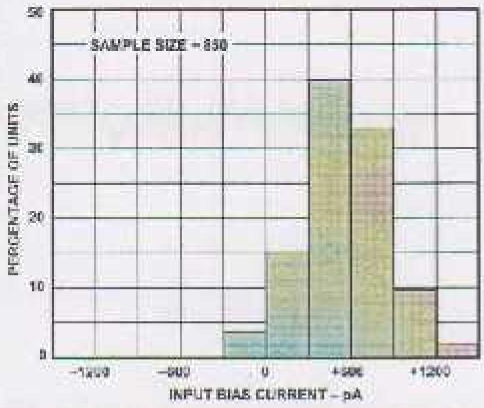


Figure 4. Typical Distribution of Input Bias Current

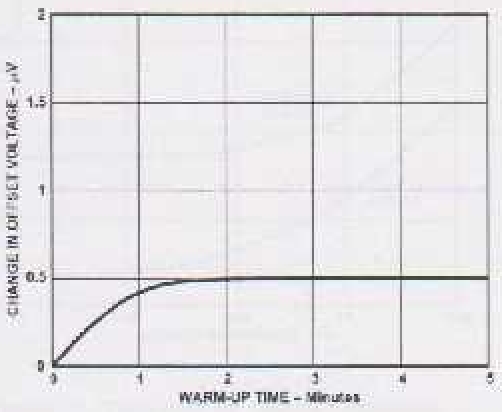


Figure 7. Change in Input Offset Voltage vs. Warm-Up Time

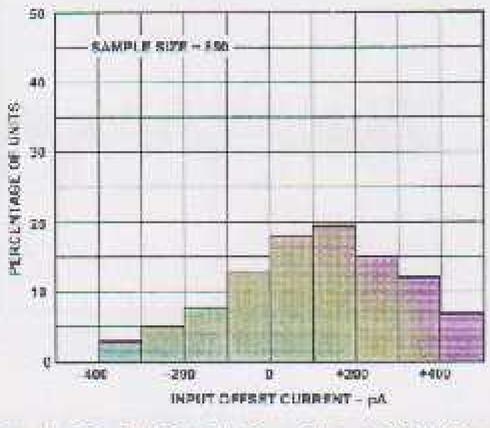


Figure 5. Typical Distribution of Input Offset Current

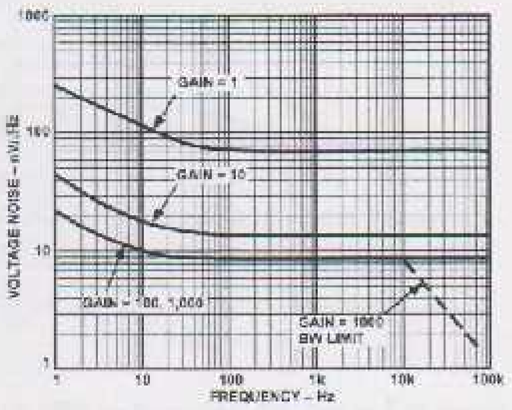


Figure 8. Voltage Noise Spectral Density vs. Frequency, (G = 1–1000)

AD620–Typical Characteristics

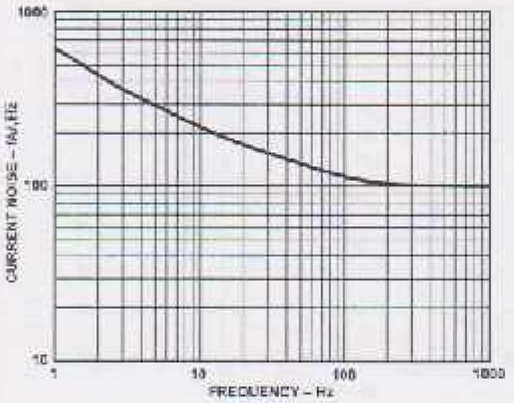


Figure 9. Current Noise Spectral Density vs. Frequency

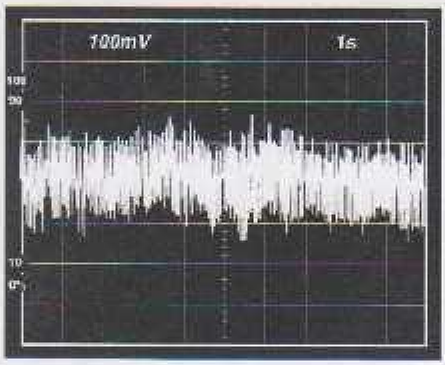


Figure 11. 0.1 Hz to 10 Hz Current Noise, 5 pA/Div

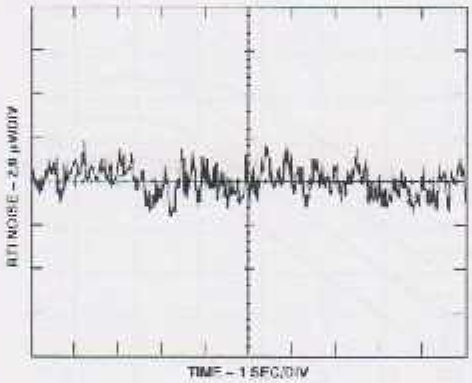


Figure 10a. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1)

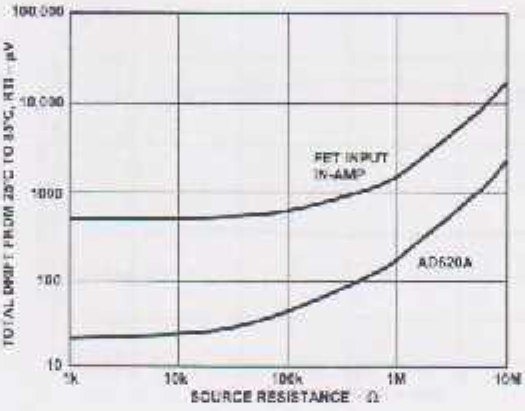


Figure 12. Total Drift vs. Source Resistance

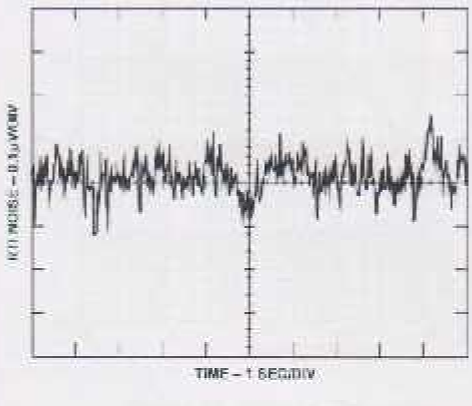


Figure 10b. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1000)

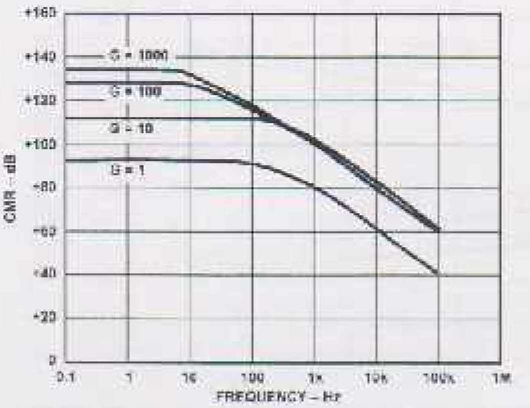


Figure 13. CMR vs. Frequency, RTI, Zero to 1 kΩ Source Imbalance

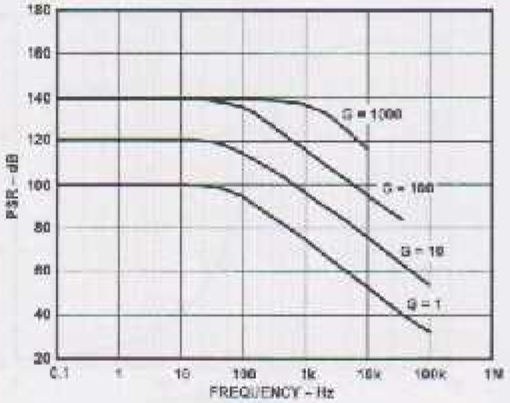


Figure 14. Positive PSR vs. Frequency, RTI (G = 1–1000)

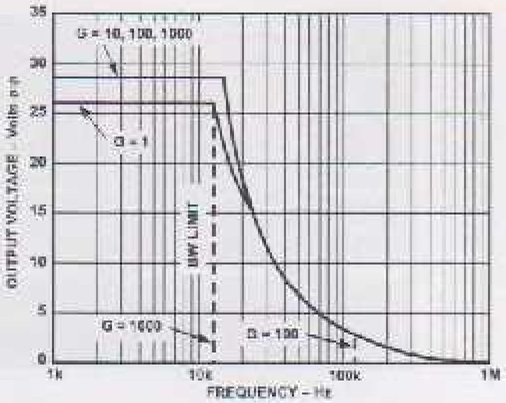


Figure 17. Large Signal Frequency Response

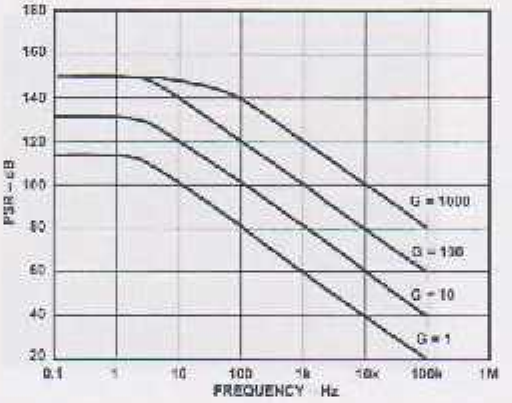


Figure 15. Negative PSR vs. Frequency, RTI (G = 1–1000)

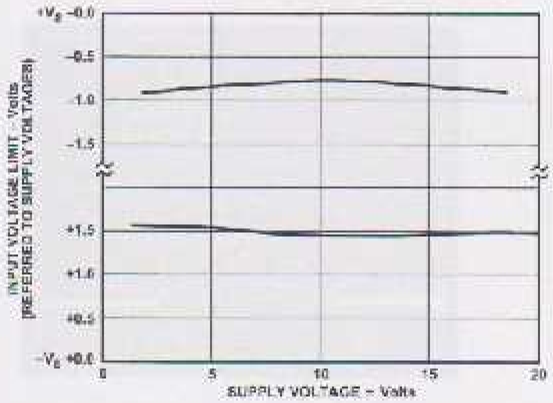


Figure 18. Input Voltage Range vs. Supply Voltage, G = 1

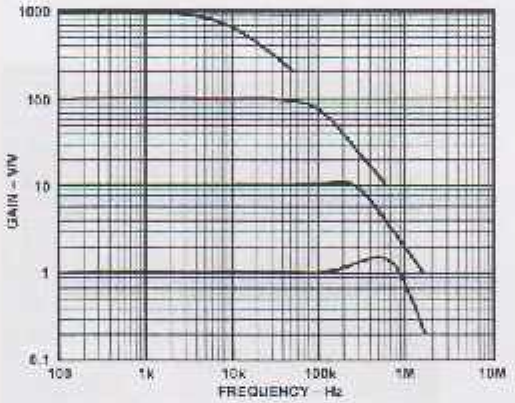


Figure 16. Gain vs. Frequency

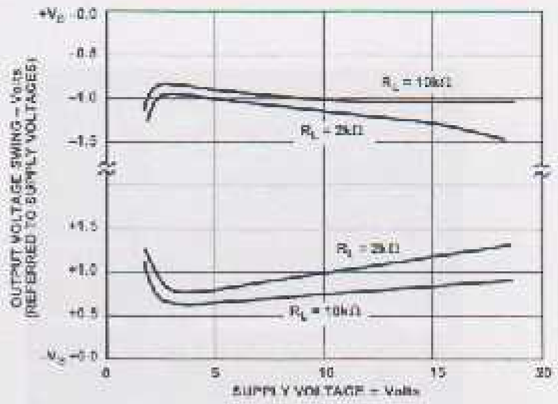


Figure 19. Output Voltage Swing vs. Supply Voltage, G = 10

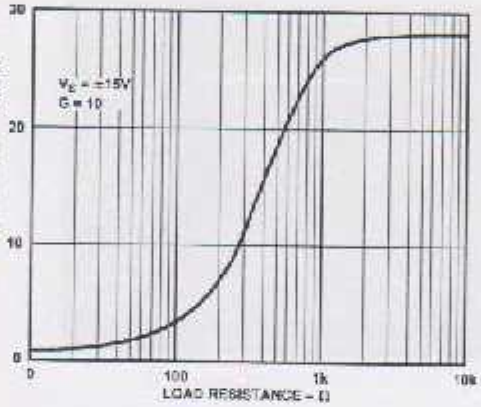


Figure 20. Output Voltage Swing vs. Load Resistance

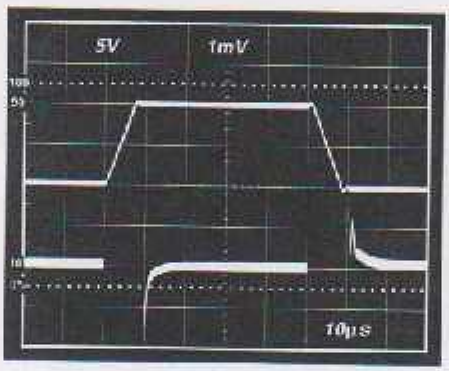


Figure 21. Large Signal Pulse Response and Settling Time G = 1 (0.5 mV = 0.01%)

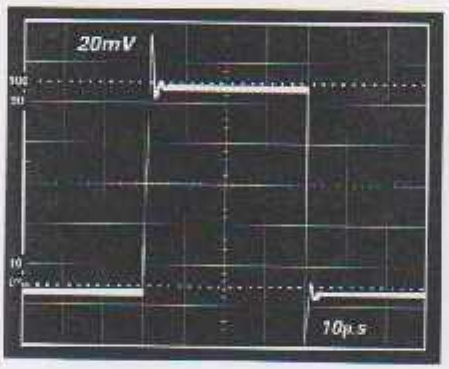


Figure 22. Small Signal Response, G = 1, R_L = 2 kΩ, C_L = 100 pF

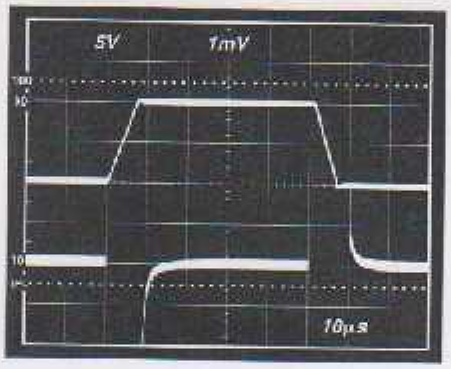


Figure 23. Large Signal Response and Settling Time, G = 10 (0.5 mV = 0.01%)

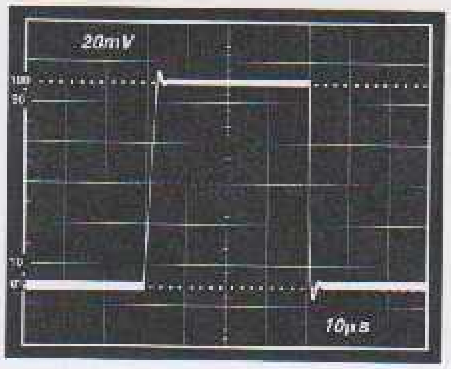


Figure 24. Small Signal Response, G = 10, R_L = 2 kΩ, C_L = 100 pF

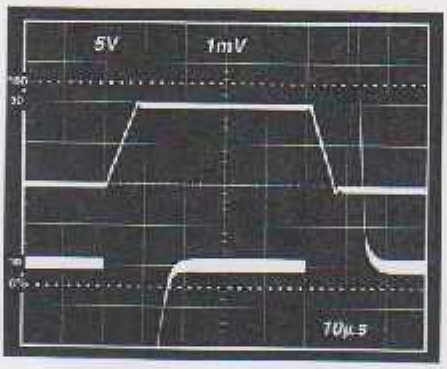


Figure 25. Large Signal Response and Settling Time, G = 100 (0.5 mV = 0.01%)

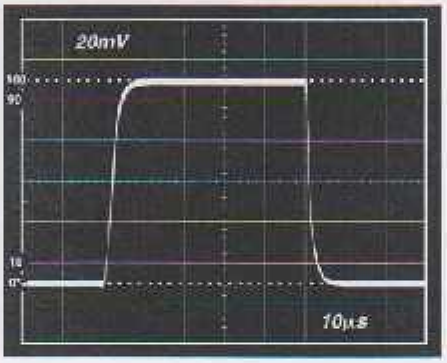


Figure 26. Small Signal Pulse Response, G = 100, R_L = 2 kΩ, C_L = 100 pF

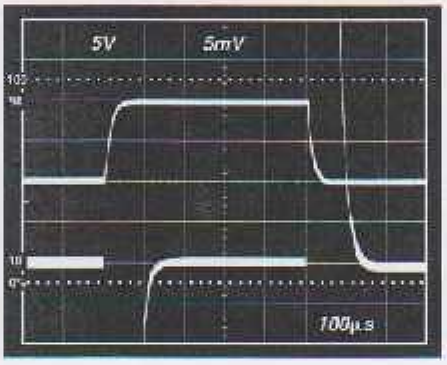


Figure 27. Large Signal Response and Settling Time, G = 1000 (0.5 mV = 0.01%)

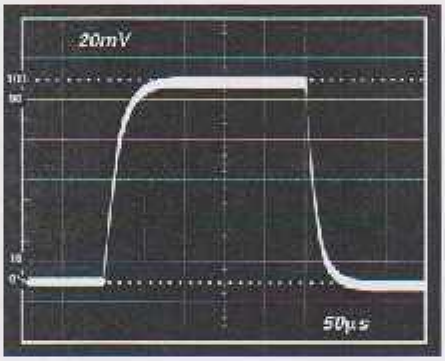


Figure 28. Small Signal Pulse Response, G = 1000, R_L = 2 kΩ, C_L = 100 pF

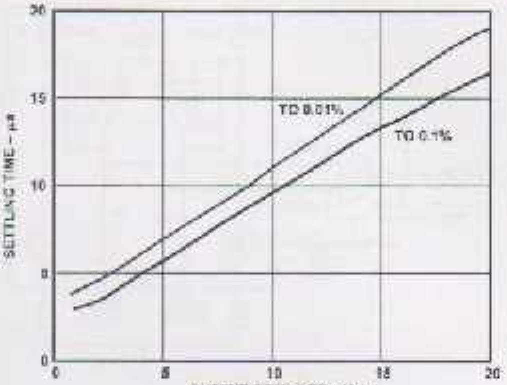


Figure 29. Settling Time vs. Step Size (G = 1)

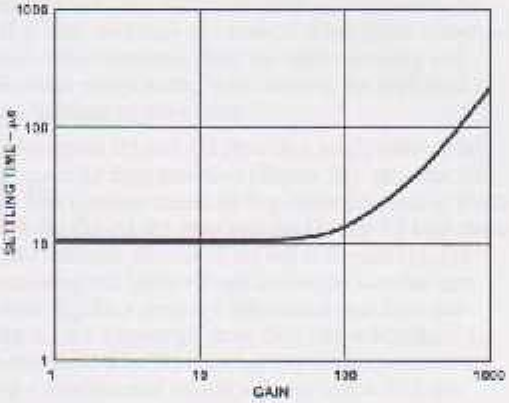


Figure 30. Settling Time to 0.01% vs. Gain, for a 10 V Step

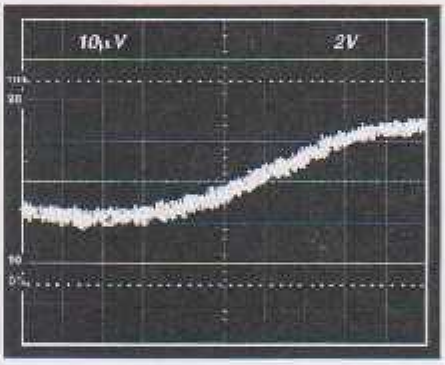


Figure 31a. Gain Nonlinearity, G = 1, R_L = 10 kΩ (10 µV = 1 ppm)

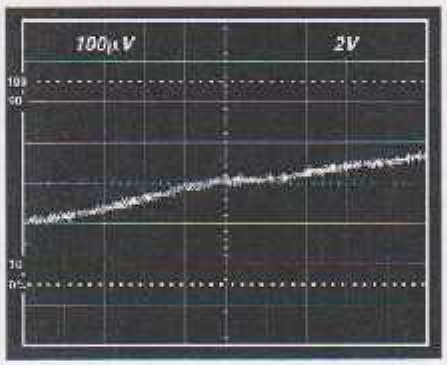


Figure 31b. Gain Nonlinearity, G = 100, R_L = 10 kΩ (100 µV = 10 ppm)

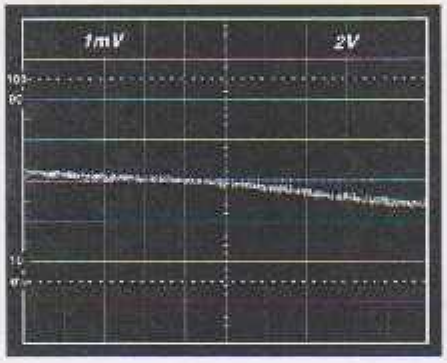


Figure 31c. Gain Nonlinearity, G = 1000, R_L = 10 kΩ (1 mV = 100 ppm)

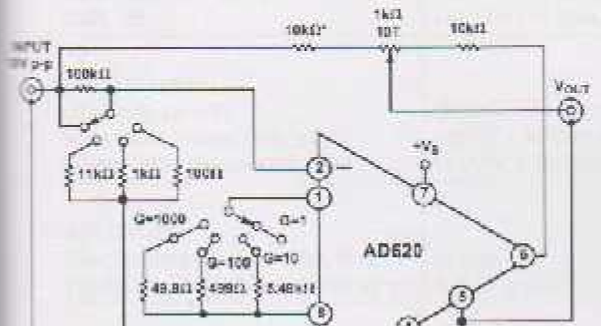


Figure 32. Settling Time Test Circuit

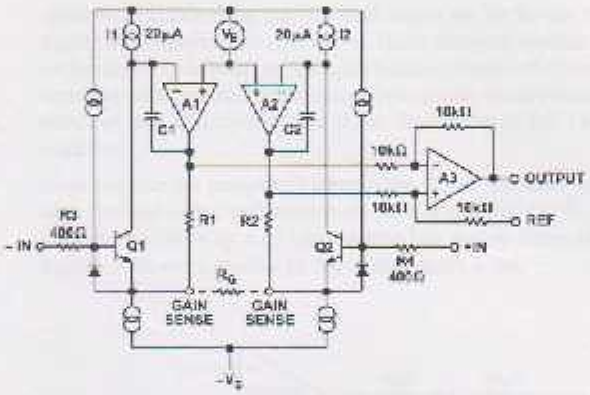


Figure 33. Simplified Schematic of AD620

THEORY OF OPERATION

The AD620 is a monolithic instrumentation amplifier based on a modification of the classic three op amp approach. Absolute value trimming allows the user to program gain *accurately* (to 0.15% at G = 100) with only one resistor. Monolithic construction and laser wafer trimming allow the tight matching and tracking of circuit components, thus ensuring the high level of performance inherent in this circuit.

The input transistors Q1 and Q2 provide a single differential-pair bipolar input for high precision (Figure 33), yet offer 10× lower Input Bias Current thanks to Superβeta processing. Feedback through the Q1-A1-R1 loop and the Q2-A2-R2 loop maintains constant collector current of the input devices Q1, Q2 thereby impressing the input voltage across the external gain setting resistor R_G. This creates a differential gain from the inputs to the A1/A2 outputs given by $G = (R1 + R2)/R_G + 1$. The unity-gain subtracter A3 removes any common-mode signal, yielding a single-ended output referred to the REF pin potential.

The value of R_G also determines the transconductance of the preamp stage. As R_G is reduced for larger gains, the transconductance increases asymptotically to that of the input transistors. This has three important advantages: (a) Open-loop gain is boosted for increasing programmed gain, thus reducing gain-related errors. (b) The gain-bandwidth product (determined by C1, C2 and the preamp transconductance) increases with programmed gain, thus optimizing frequency response. (c) The input voltage noise is reduced to a value of 9 nV/√Hz, determined mainly by the collector current and base resistance of the input devices.

The internal gain resistors, R1 and R2, are trimmed to an absolute value of 24.7 kΩ, allowing the gain to be programmed accurately with a single external resistor.

The gain equation is then

$$G = \frac{49.4\ k\Omega}{R_G} + 1$$

so that

$$R_G = \frac{49.4\ k\Omega}{G - 1}$$

Make vs. Buy: A Typical Bridge Application Error Budget

The AD620 offers improved performance over "homebrew" three op amp IA designs, along with smaller size, fewer components and 10× lower supply current. In the typical application, shown in Figure 34, a gain of 100 is required to amplify a bridge output of 20 mV full scale over the industrial temperature range of –40°C to +85°C. The error budget table below shows how to calculate the effect various error sources have on circuit accuracy.

Regardless of the system in which it is being used, the AD620 provides greater accuracy, and at low power and price. In simple systems, absolute accuracy and drift errors are by far the most significant contributors to error. In more complex systems with an intelligent processor, an autogain/autozero cycle will remove all absolute accuracy and drift errors leaving only the resolution errors of gain nonlinearity and noise, thus allowing full 14-bit accuracy.

Note that for the homebrew circuit, the OP07 specifications for input voltage offset and noise have been multiplied by $\sqrt{2}$. This is because a three op amp type in-amp has two op amps at its inputs, both contributing to the overall input error.

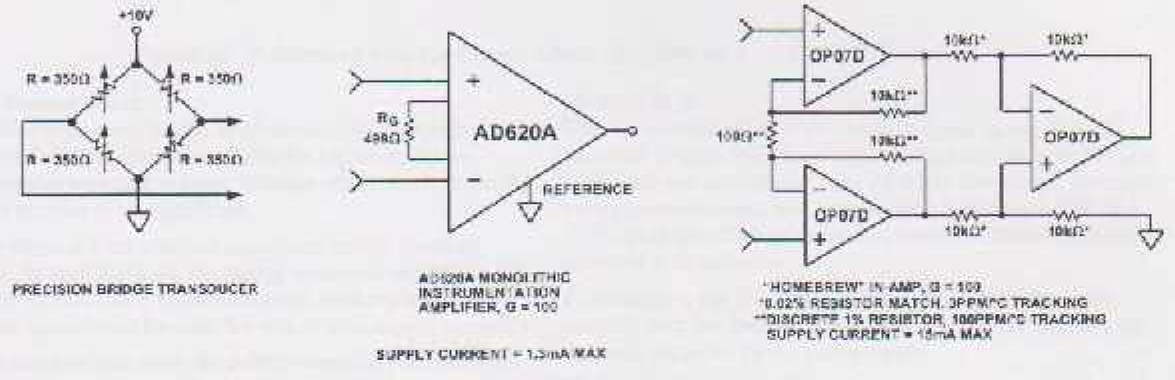


Figure 34. Make vs. Buy

Table I. Make vs. Buy Error Budget

Error Source	AD620 Circuit Calculation	"Homebrew" Circuit Calculation	Error, ppm of Full Scale AD620	Homebrew
ABSOLUTE ACCURACY at T_A = +25°C				
Input Offset Voltage, µV	125 µV/20 mV	(150 µV × $\sqrt{2}$)/20 mV	6,250	10,607
Output Offset Voltage, µV	1000 µV/100/20 mV	((150 µV × 2)/100)/20 mV	500	150
Input Offset Current, nA	2 nA × 350 Ω/20 mV	(6 nA × 350 Ω)/20 mV	18	53
CMR, dB	110 dB→3.16 ppm, × 5 V/20 mV	(0.02% Match × 5 V)/20 mV/100	791	500
		Total Absolute Error	7,558	11,310
DRIFT TO +85°C				
Gain Drift, ppm/°C	(50 ppm + 10 ppm) × 60°C	100 ppm/°C Track × 60°C	3,600	6,000
Input Offset Voltage Drift, µV/°C	1 µV/°C × 60°C/20 mV	(2.5 µV/°C × $\sqrt{2}$ × 60°C)/20 mV	3,000	10,607
Output Offset Voltage Drift, µV/°C	15 µV/°C × 60°C/100/20 mV	(2.5 µV/°C × 2 × 60°C)/100/20 mV	450	150
		Total Drift Error	7,050	16,757
RESOLUTION				
Gain Nonlinearity, ppm of Full Scale	40 ppm	40 ppm	40	40
Typ 0.1 Hz–10 Hz Voltage Noise, µV p-p	0.28 µV p-p/20 mV	(0.38 µV p-p × $\sqrt{2}$)/20 mV	14	27
		Total Resolution Error	54	67
		Grand Total Error	14,662	28,134

G = 100, V_S = ±15 V.

(All errors are min/max and referred to input.)

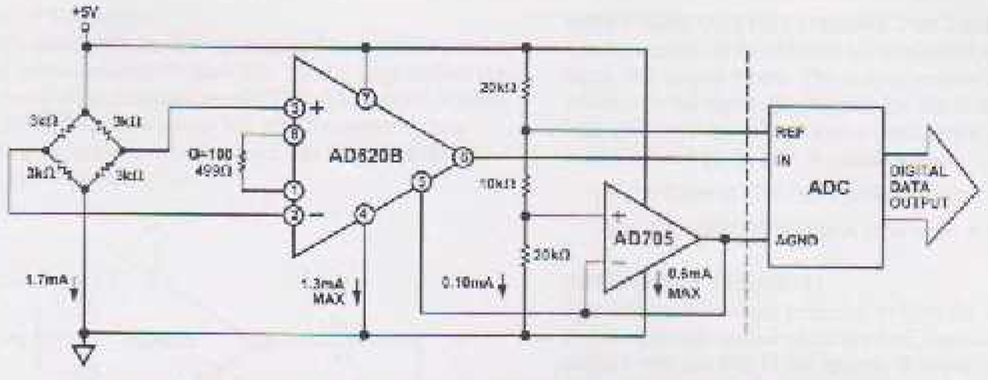


Figure 35. A Pressure Monitor Circuit which Operates on a +5 V Single Supply

Pressure Measurement

Although useful in many bridge applications such as weigh scales, the AD620 is especially suitable for higher resistance pressure sensors powered at lower voltages where small size and low power become more significant.

Figure 35 shows a 3 kΩ pressure transducer bridge powered from +5 V. In such a circuit, the bridge consumes only 1.7 mA. Adding the AD620 and a buffered voltage divider allows the signal to be conditioned for only 3.8 mA of total supply current.

Small size and low cost make the AD620 especially attractive for voltage output pressure transducers. Since it delivers low noise and drift, it will also serve applications such as diagnostic non-invasive blood pressure measurement.

Medical ECG

The low current noise of the AD620 allows its use in ECG monitors (Figure 36) where high source resistances of 1 MΩ or higher are not uncommon. The AD620's low power, low supply voltage requirements, and space-saving 8-lead mini-DIP and SOIC package offerings make it an excellent choice for battery powered data recorders.

Furthermore, the low bias currents and low current noise coupled with the low voltage noise of the AD620 improve the dynamic range for better performance.

The value of capacitor C1 is chosen to maintain stability of the right leg drive loop. Proper safeguards, such as isolation, must be added to this circuit to protect the patient from possible harm.

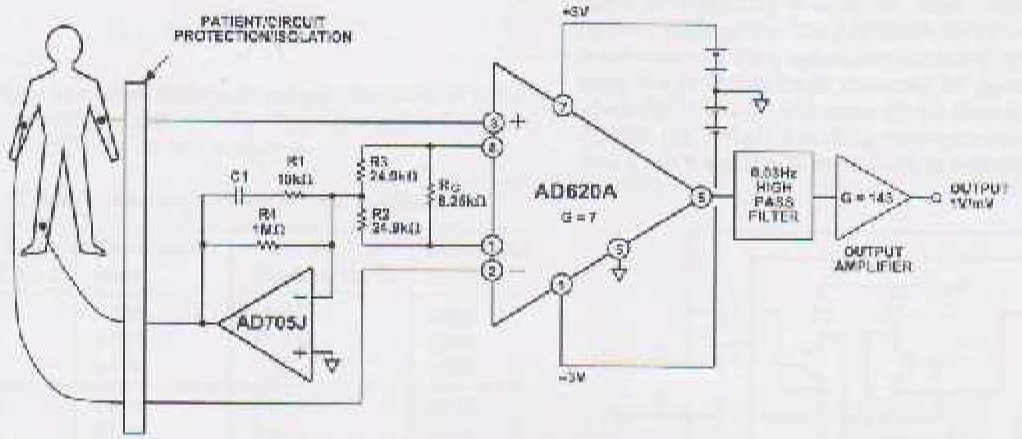


Figure 36. A Medical ECG Monitor Circuit

Precision V-I Converter

The AD620, along with another op amp and two resistors, makes a precision current source (Figure 37). The op amp buffers the reference terminal to maintain good CMR. The output voltage V_X of the AD620 appears across R1, which converts it to a current. This current less only, the input bias current of the op amp, then flows out to the load.

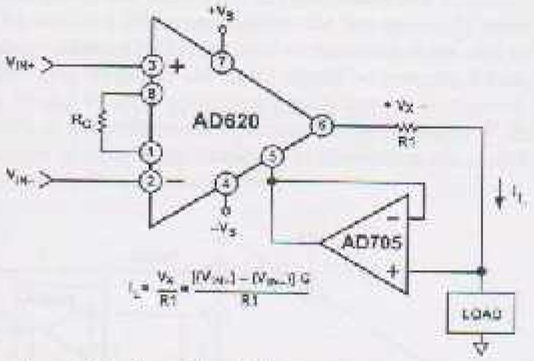


Figure 37. Precision Voltage-to-Current Converter (Operates on 1.8 mA, ±3 V)

GAIN SELECTION

The AD620's gain is resistor programmed by R_G, or more precisely, by whatever impedance appears between Pins 1 and 8. The AD620 is designed to offer accurate gains using 0.1%–1% resistors. Table II shows required values of R_G for various gains. Note that for G = 1, the R_G pins are unconnected ($R_G = \infty$). For any arbitrary gain R_G can be calculated by using the formula:

$$R_G = \frac{49.4\ k\Omega}{G - 1}$$

To minimize gain error, avoid high parasitic resistance in series with R_G; to minimize gain drift, R_G should have a low TC—less than 10 ppm/°C—for the best performance.

Table II. Required Values of Gain Resistors

1% Std Table Value of R_G, Ω	Calculated Gain	0.1% Std Table Value of R_G, Ω	Calculated Gain
49.9 k	1.990	49.3 k	2.002
12.4 k	4.984	12.4 k	4.984
5.49 k	9.998	5.49 k	9.998
2.61 k	19.93	2.61 k	19.93
1.00 k	50.40	1.01 k	49.91
499	100.0	499	100.0
249	199.4	249	199.4
100	495.0	98.8	501.0
49.9	991.0	49.3	1,003

INPUT AND OUTPUT OFFSET VOLTAGE

The low errors of the AD620 are attributed to two sources, input and output errors. The output error is divided by G when referred to the input. In practice, the input errors dominate at high gains and the output errors dominate at low gains. The total V_{OS} for a given gain is calculated as:

Total Error RTI = input error + (output error/G)

Total Error RTO = (input error × G) + output error

REFERENCE TERMINAL

The reference terminal potential defines the zero output voltage, and is especially useful when the load does not share a precise ground with the rest of the system. It provides a direct means of injecting a precise offset to the output, with an allowable range of 2 V within the supply voltages. Parasitic resistance should be kept to a minimum for optimum CMR.

INPUT PROTECTION

The AD620 features 400 Ω of series thin film resistance at its inputs, and will safely withstand input overloads of up to ±15 V or ±60 mA for several hours. This is true for all gains, and power on and off, which is particularly important since the signal source and amplifier may be powered separately. For longer time periods, the current should not exceed 6 mA ($I_{IN} \leq V_{IN}/400\ \Omega$). For input overloads beyond the supplies, clamping the inputs to the supplies (using a low leakage diode such as an FD333) will reduce the required resistance, yielding lower noise.

RF INTERFERENCE

All instrumentation amplifiers can rectify out of band signals, and when amplifying small signals, these rectified voltages act as small dc offset errors. The AD620 allows direct access to the input transistor bases and emitters enabling the user to apply some first order filtering to unwanted RF signals (Figure 38), where $RC \approx 1/(2\ \pi f)$ and where $f \geq$ the bandwidth of the AD620; $C \leq 150$ pF. Matching the extraneous capacitance at Pins 1 and 8 and Pins 2 and 3 helps to maintain high CMR.

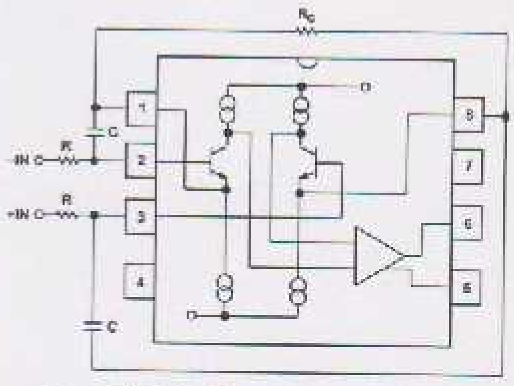


Figure 38. Circuit to Attenuate RF Interference

COMMON-MODE REJECTION

Instrumentation amplifiers like the AD620 offer high CMR, which is a measure of the change in output voltage when both inputs are changed by equal amounts. These specifications are usually given for a full-range input voltage change and a specified source imbalance.

For optimal CMR the reference terminal should be tied to a low impedance point, and differences in capacitance and resistance should be kept to a minimum between the two inputs. In many applications shielded cables are used to minimize noise, and for best CMR over frequency the shield should be properly driven. Figures 39 and 40 show active data guards that are configured to improve ac common-mode rejections by "bootstrapping" the capacitances of input cable shields, thus minimizing the capacitance mismatch between the inputs.

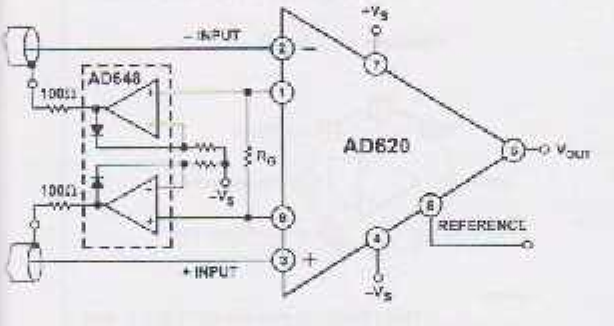


Figure 39. Differential Shield Driver

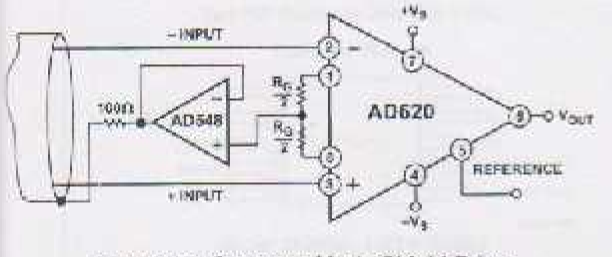


Figure 40. Common-Mode Shield Driver

GROUNDING

Since the AD620 output voltage is developed with respect to the potential on the reference terminal, it can solve many grounding problems by simply tying the REF pin to the appropriate "local ground."

In order to isolate low level analog signals from a noisy digital environment, many data-acquisition components have separate analog and digital ground pins (Figure 41). It would be convenient to use a single ground line; however, current through ground wires and PC runs of the circuit card can cause hundreds of millivolts of error. Therefore, separate ground returns should be provided to minimize the current flow from the sensitive points to the system ground. These ground returns must be tied together at some point, usually best at the ADC package as shown.

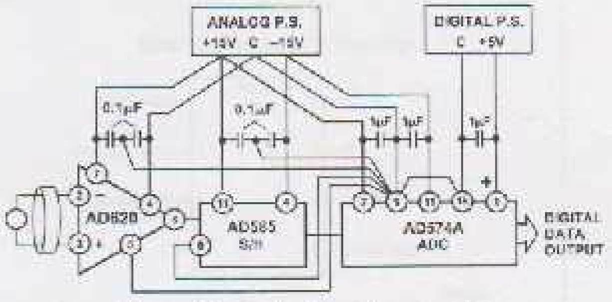


Figure 41. Basic Grounding Practice

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

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

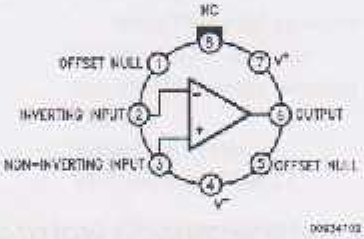
The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

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

Features

Connection Diagrams

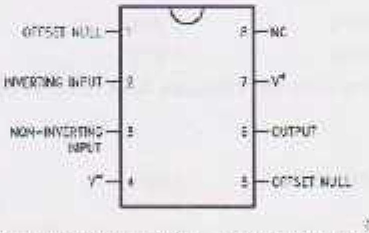
Metal Can Package



Note 1: LM741H is available per JM38510/10101

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

Dual-In-Line or S.O. Package



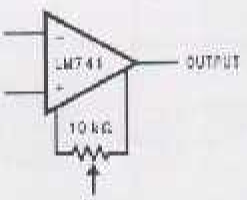
Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



 DS009341

Absolute Maximum Ratings (Note 2)

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

(Note 7)

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

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

surface mount devices

ESD Tolerance (Note 6)	400V	400V	400V

Electrical Characteristics (Note 5)

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

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A Min	LM741A Typ	LM741A Max	LM741 Min	LM741 Typ	LM741 Max	LM741C Min	LM741C Typ	LM741C Max	Units
Large Signal Voltage Gain	$T_A = 25°C$, $R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V$, $V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V$, $V_O = \pm 2V$	10									V/mV
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit	$T_A = 25°C$	10	25	35		25			25		mA
Current	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
Rejection Ratio	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
Ratio	$V_S = \pm 20V$ to $V_S = \pm 5V$										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10\ k\Omega$				77	96		77	96		dB
Transient Response	$T_A = 25°C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		µs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	$T_A = 25°C$	0.437	1.5								MHz
Slew Rate	$T_A = 25°C$, Unity Gain	0.3	0.7			0.5			0.5		V/µs
Supply Current	$T_A = 25°C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25°C$										
	$V_S = \pm 20V$		80	150							mW
	$V_S = \pm 15V$					50	85		50	85	mW
LM741A	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741	$V_S = \pm 15V$										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 3: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

PIC16F84A

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

High Performance RISC CPU Features:

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

Peripheral Features:

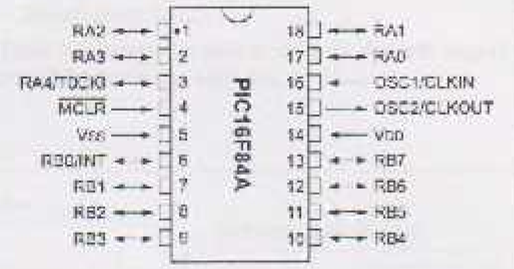
- 13 I/O pins with individual direction control
- High current sink/source for direct LED drive
  - 25 mA sink max. per pin
  - 25 mA source max. per pin
- TMR0: 8-bit timer/counter with 8-bit programmable prescaler

Special Microcontroller Features:

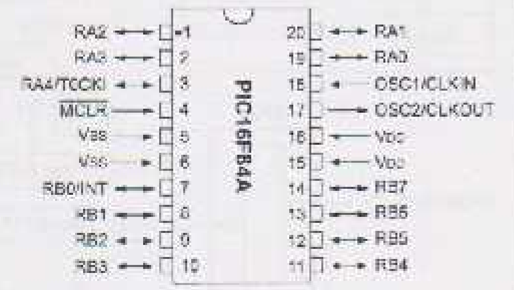
- 10,000 erase/write cycles *Enhanced* FLASH Program memory typical
- 10,000,000 typical erase/write cycles EEPROM Data memory typical
- EEPROM Data Retention > 40 years
- In-Circuit Serial Programming™ (ICSP™) - via two pins
- Power-on Reset (POR), Power-up Timer (PWRT), Oscillator Start-up Timer (OST)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

Pin Diagrams

PDIP, SOIC



SSOP



CMOS Enhanced FLASH/EEPROM Technology:

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

1.0 DEVICE OVERVIEW

This document contains device specific information for the operation of the PIC16F84A device. Additional information may be found in the PICmicro™ Mid-Range Reference Manual, (DS33023), which may be downloaded from the Microchip website. The Reference Manual should be considered a complementary document to this data sheet, and is highly recommended reading for a better understanding of the device architecture and operation of the peripheral modules.

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

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

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

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

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

FIGURE 1-1: PIC16F84A BLOCK DIAGRAM

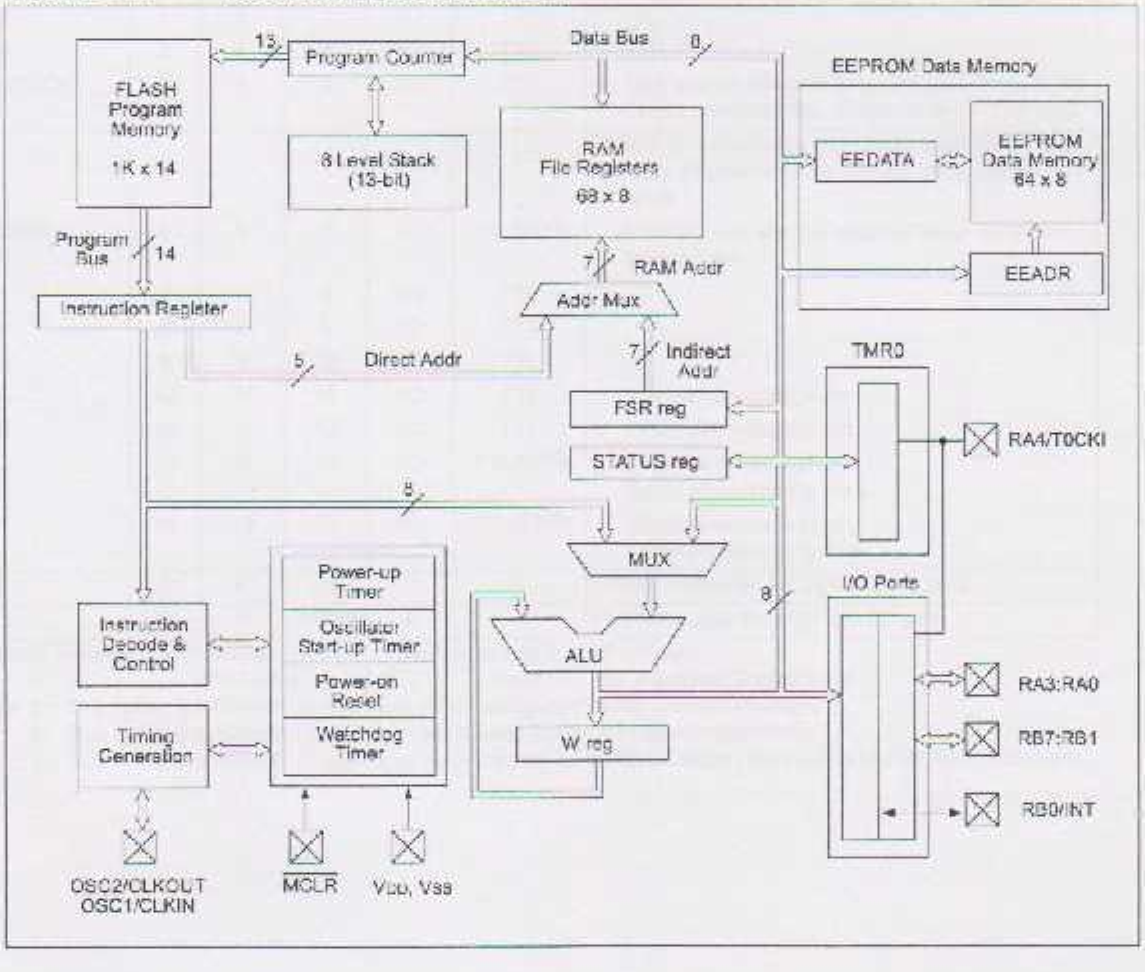


TABLE 1-1: PIC16F84A PINOUT DESCRIPTION

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

Legend: I= input O = Output I/O = Input/Output P = Power
— = Not used TTL = TTL Input ST = Schmitt Trigger input

Note 1: This buffer is a Schmitt Trigger input when configured as the external interrupt.
2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.
3: This buffer is a Schmitt Trigger input when configured in RC oscillator mode and a CMOS input otherwise.

2.3 Special Function Registers

The Special Function Registers (Figure 2-2 and Table 2-1) are used by the CPU and Peripheral functions to control the device operation. These registers are static RAM.

The special function registers can be classified into two sets, core and peripheral. Those associated with the core functions are described in this section. Those related to the operation of the peripheral features are described in the section for that specific feature.

TABLE 2-1: SPECIAL FUNCTION REGISTER FILE SUMMARY

Addr	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on Power-on RESET	Details on page
Bank 0											
00h	INDF	Uses contents of FSR to address Data Memory (not a physical register)								---- ----	11
01h	TMR0	8-bit Real-Time Clock/Counter								xxxx xxxx	20
02h	PCL	Low Order 8 bits of the Program Counter (PC)								0000 0000	11
03h	STATUS[2]	IRP	RP1	RP0	$\overline{TO}$	$\overline{PD}$	Z	DC	C	0001 1xxx	8
04h	FSR	Indirect Data Memory Address Pointer 0								xxxx xxxx	11
05h	PORTA[4]	—	—	—	RA4/T0CKI	RA3	RA2	RA1	RA0	---x xxxx	16
06h	PORTB[5]	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0/INT	xxxx xxxx	18
07h	—	Unimplemented location, read as '0'								—	—
08h	EEDATA	EEPROM Data Register								xxxx xxxx	13,14
09h	EEADR	EEPROM Address Register								xxxx xxxx	13,14
0Ah	PCLATH	—	—	—	Write Buffer for upper 5 bits of the PC[1]					---0 0000	11
0Bh	INTCON	GIE	EEIE	T0IE	INTE	RBIE	T0IF	INTF	RBIF	0000 000x	10
Bank 1											
80h	INDF	Uses Contents of FSR to address Data Memory (not a physical register)								---- ----	11
81h	OPTION_REG	$\overline{RBPU}$	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0	1111 1111	9
82h	PCL	Low order 8 bits of Program Counter (PC)								0000 0000	11
83h	STATUS[2]	IRP	RP1	RP0	$\overline{TO}$	$\overline{PD}$	Z	DC	C	0001 1xxx	8
84h	FSR	Indirect data memory address pointer 0								xxxx xxxx	11
85h	TRISA	—	—	—	PORTA Data Direction Register					---1 1111	16
86h	TRISB	PORTB Data Direction Register								1111 1111	18
87h	—	Unimplemented location, read as '0'								—	—
88h	EECON1	—	—	—	EEIF	WRERR	WREN	WR	RD	---0 x000	13
89h	EECON2	EEPROM Control Register 2 (not a physical register)								---- ----	14
0Ah	PCLATH	—	—	—	Write buffer for upper 5 bits of the PC[1]					---0 0000	11
0Bh	INTCON	GIE	EEIE	T0IE	INTE	RBIE	T0IF	INTF	RBIF	0000 000x	10

Legend: x = unknown, u = unchanged. - = unimplemented, read as '0', q = value depends on condition

Note 1: The upper byte of the program counter is not directly accessible. PCLATH is a slave register for PC<12:8>. The contents of PCLATH can be transferred to the upper byte of the program counter, but the contents of PC<12:8> are never transferred to PCLATH.

2: The $\overline{TO}$ and $\overline{PD}$ status bits in the STATUS register are not affected by a $\overline{MCLR}$ Reset.

3: Other (non power-up) RESETS include: external RESET through $\overline{MCLR}$ and the Watchdog Timer Reset.

4: On any device RESET, these pins are configured as inputs.

5: This is the value that will be in the port output latch.

TABLE 4-3: PORTB FUNCTIONS

Name	Bit	Buffer Type	I/O Consistency Function
RB0/INT	bit0	TTL/ST(1)	Input/output pin or external interrupt input. Internal software programmable weak pull-up.
RB1	bit1	TTL	Input/output pin. Internal software programmable weak pull-up.
RB2	bit2	TTL	Input/output pin. Internal software programmable weak pull-up.
RB3	bit3	TTL	Input/output pin. Internal software programmable weak pull-up.
RB4	bit4	TTL	Input/output pin (with interrupt-on-change). Internal software programmable weak pull-up.
RB5	bit5	TTL	Input/output pin (with interrupt-on-change). Internal software programmable weak pull-up.
RB6	bit6	TTL/ST(2)	Input/output pin (with interrupt-on-change). Internal software programmable weak pull-up. Serial programming clock.
RB7	bit7	TTL/ST(2)	Input/output pin (with interrupt-on-change). Internal software programmable weak pull-up. Serial programming data.

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

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

2: This buffer is a Schmitt Trigger input when used in Serial Programming mode.

TABLE 4-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTB

Address	Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on Power-on Reset	Value on all other RESETS
06h	PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0/INT	xxxx xxxx	uuuu uuuu
86h	TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	1111 1111	1111 1111
81h	OPTION_REG	RBPU	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0	1111 1111	1111 1111
0Bh,8Bh	INTCON	GIE	EEIE	T0IE	INTE	RBIE	T0IF	INTF	RBIF	0000 000x	0000 000u

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

TEXAS INSTRUMENTS

Application Report

SLAA223–November 2004

MSP430 Stepper Motor Controller

Greg Morton MSP430

ABSTRACT

This application report shows how to implement a controller for a stepper motor having bipolar windings using the MSP430F123 along with a pair of UC3717A Stepper Motor Drive ICs. Source code, schematic, bill of material, and board layout files are provided.

1 Stepper Motors

Stepper motors operate by sequentially energizing coils located in the stator. Depending upon the stepper motor's type: variable reluctance, permanent magnet, or hybrid, the rotor contains a toothed soft-iron core, permanent magnets, or both. What sets a stepper motor apart from other motor types is the ability to step (or turn) its rotor in small, precise increments and lock it in place.

Three configurations are typically found for wiring a stepper motor's windings; variable reluctance, unipolar, and bipolar. Each configuration requires different drive circuitry and its associated method of control. This application report focuses on controlling stepper motors with bipolar windings. Bipolar stepper motors are driven using an H-bridge circuit since current flow is bi-directional through the windings.

Based on its internal winding resistance, stepper motors are rated for maximum current at a particular voltage. Maximum torque is developed when maximum current is flowing through the windings. Operating at this voltage, however, is inefficient due to the ramp-up time it takes for current flow to overcome the winding's inherent inductance. Applying a voltage much higher than it's rated for to a stepper motor reduces this ramp-up time. To do this without overheating and destroying the motor, however, the winding current must still be limited to its maximum rated value. This is done by using a *chopper circuit* which controls the ratio of winding current *on* time to *off* time once the maximum current level is reached.

2 Implementation

2.1 Hardware

Figure 1 shows a block diagram of the MSP430 Stepper Motor Controller board. Although any MSP430 variant could have been used to implement a basic stepper motor controller using Timer A, the MSP430F123 was chosen since it contains a hardware UART for serial communications with a PC. Two UC3717A integrated circuits (ICs) provide the motor drive circuitry. Each UC3717A IC contains one H-bridge circuit for driving a single winding in a bipolar stepper motor. The UC3717A also contains a *chopper circuit* limiting the maximum current flowing through a motor's winding. To reduce external component count, the protection diodes required to clamp the inductive voltage spikes generated when switching current through a motor are also contained within the UC3717A.

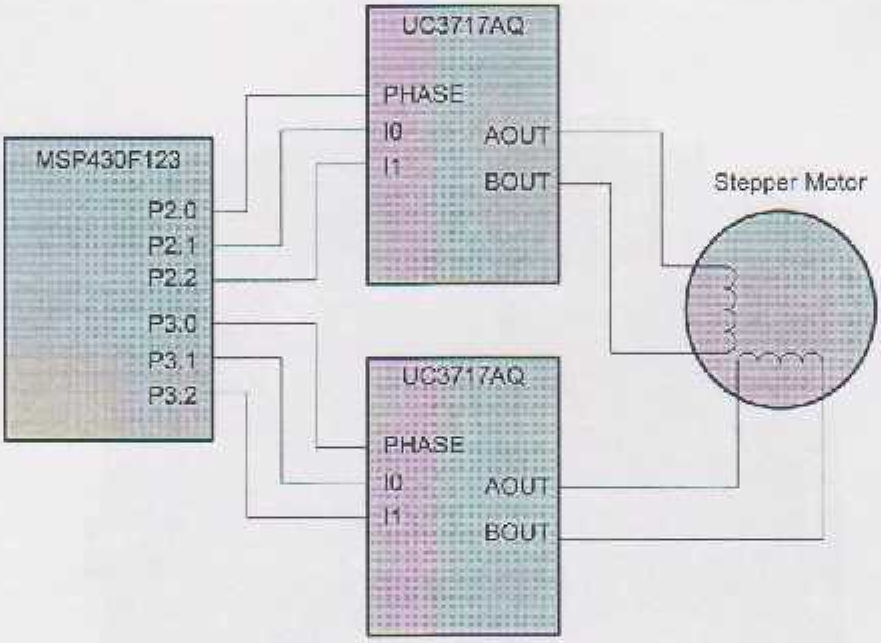


Figure 1. Block Diagram

Figure 2 shows a picture of the MSP430 Stepper Motor Controller board. Figure 4 shows the schematic. Port pins P2.0–P2.2 and P3.0–P3.2 on the MSP430 (U6) provide the control signals for the two UC3717A ICs (U1 and U5). Switches S1–S4 provide the inputs to the MSP430 to control the stepper motor. As an alternative, the stepper motor can also be controlled using a PC. A serial cable can be connected between connector J3 and a PC's serial port. U3 provides the RS-232 line driver/receiver required for level-shifting the RX and TX signals. The 32 kHz watch crystal, X1, provides the clock source for the MSP430's hardware UART. Connector J4 provides a convenient way to connect to a stepper motor. Connector J1 provides the JTAG connection for the MSP430 Flash Emulation Tool. DC power jack J2 enables the board to be powered by a +12V, 1.5A AD/DC adaptor. Battery holder B1 provides the option of powering the board with a +9V battery. Linear regulators U6 and U2 provide +5VDC and +3.3VDC respectively. Jumpers JP3 and JP4 provide an easy way to measure system current and motor current if desired. Jumper JP1 provides an easy way to monitor the UC3717A control signals with a scope. LEDs D1 and D2 are used to display operating modes.

A few external components are required by the UC3717A Stepper Motor Driver ICs. Components C10 and R4 for U1 and C9 and R8 for U5 set the *off* time for the UC3717A's chopper circuit. Components R3 and C8 for U1 and R7 and C12 for U5 form a low-pass filter to reduce switching transients appearing at the input to the UC3717A's *current sensor* section. Parallel resistors R1 and R2 for U1 and R5 and R6 for U5 provide a 1 ohm resistor for sensing current flowing through a stepper motor's windings. For a more detailed explanation, consult the UC3717A's data sheet [1].

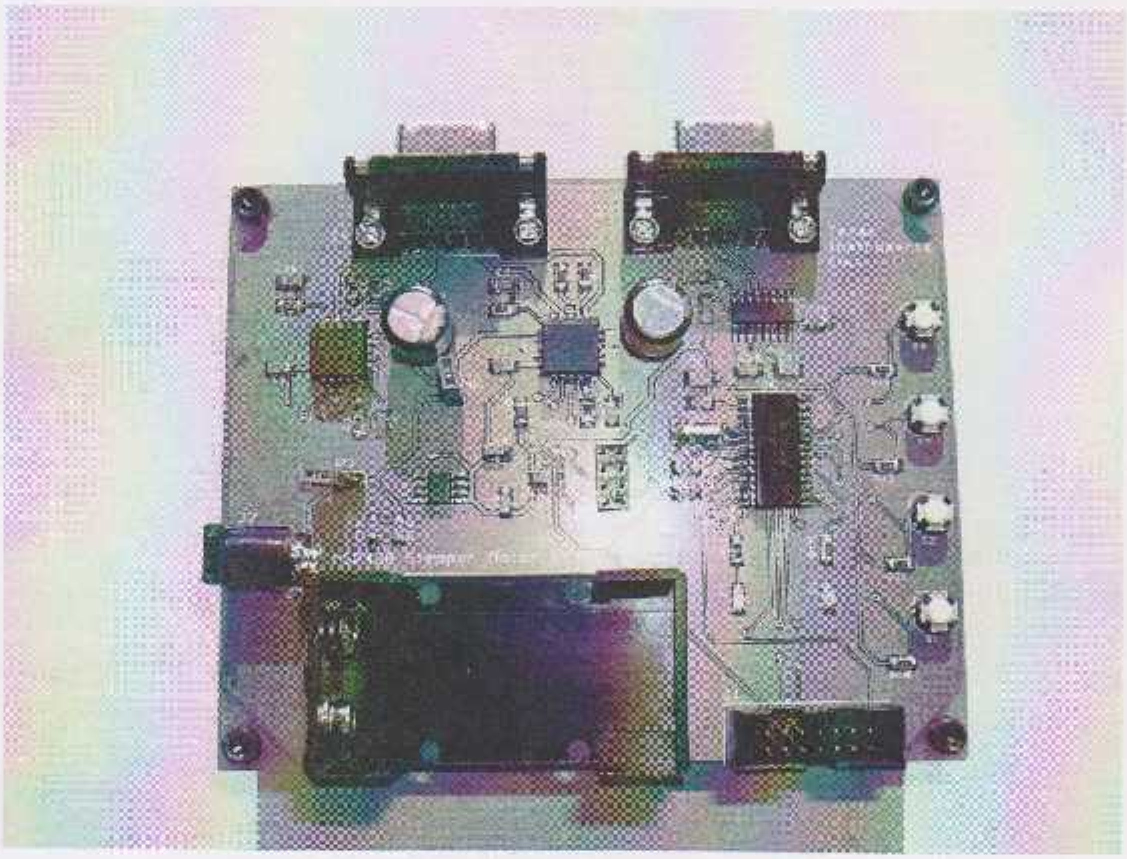


Figure 2. MSP430 Stepper Motor Controller Board

2.2 Software

Since most of the complexity with driving stepper motors involves limiting the winding current through the motor and the U3717A IC contains hardware to do this, the software implementation is relatively straight forward. For continuous mode operation, the MSP430's 16-bit Timer A is configured to generate an interrupt at the same rate as the motor is stepped. This is done by configuring Timer A for Up-mode and setting the maximum count in register TACCR0. Detailed information on Timer A operation can be found in [3]. Changing the value stored in TACCR0 changes the stepping rate. Stepping period equals 1/SMCLK frequency times the value stored in TACCR0. During the Timer A0 interrupt service routine (ISR) a state table lookup is performed to retrieve the next output state for the 6 port pins controlling the two UC3717A devices. The port pins are then updated and the state table index is incremented. Different state tables are used depending upon the direction the motor is stepped as well as the mode of operation; fullstepping or half-stepping. Figure 3 shows the stepping sequences for the various stepping modes and directions. During full-stepping I0 and I1 are held at a constant logic *0* state.

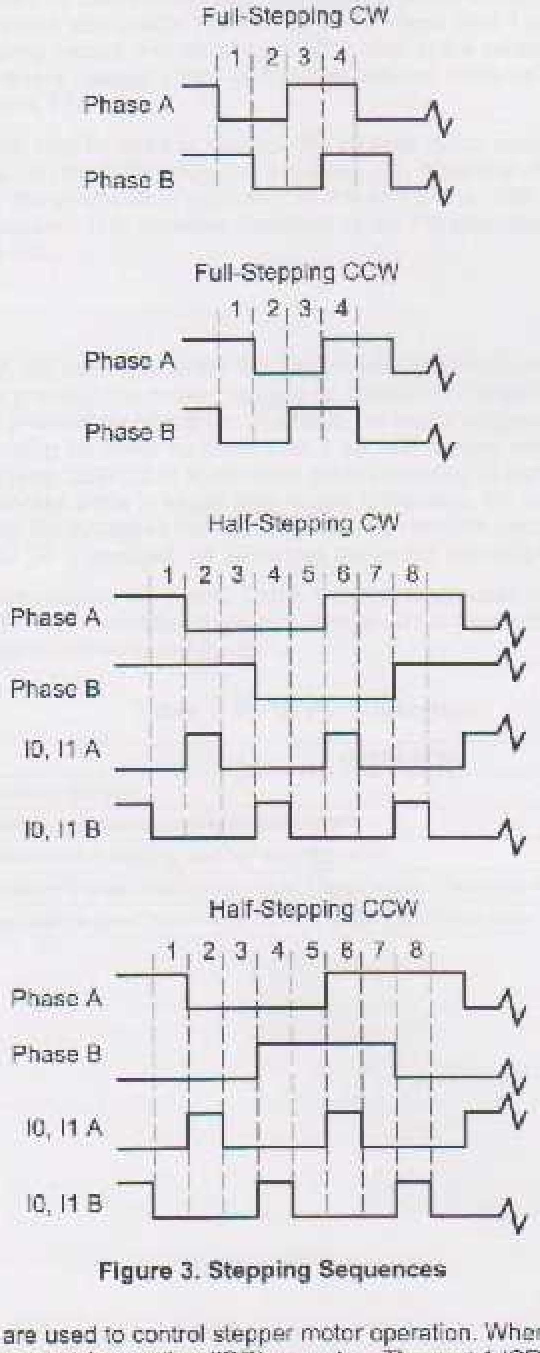


Figure 3. Stepping Sequences

Switches S1 through S4 are used to control stepper motor operation. Whenever any of the switches are pressed, the port 1 interrupt service routine (ISR) executes. The port 1 ISR disables port 1 interrupts and enables watchdog timer (WDT) interrupts. When enabled, the WDT ISR executes about once every 2 milliseconds. Each time the WDT ISR executes it checks the state of the switches. If switch S1, S3, or S4 is held in the *on* state for a *debounce count* of 5 consecutive interrupts or 10 milliseconds, then the operation associated with the particular switch is executed. Switch S2 works a little differently. If S2 is held in the *on* state for more than 10 milliseconds and less than 1 second, then the stepper motor toggles between continuous mode and step mode. Holding S2 *on* for more than 1 second toggles between fullstepping and half-stepping modes. For as long as S2 is held in the *on* state it will continue to toggle between stepping modes every second. Once all the switches are in the off state, the WDT ISR disables itself and re-enables the port 1 ISR.

The serial port on a PC can also be used to operate the stepper motor controller board. Each time the MSP430 receives a character, the UART RX ISR executes. If a *matching* character is received, then the operation associated with the character is executed. At the end of the UART RX ISR, it transmits back to the PC the character it received. This provides feedback to the PC user that the MSP430 received the character sent to it by the PC.

2.3 Operation

Four switches, S1 through S4, control how the Stepper Motor Controller board operates. S1 controls direction. Each time S1 is pressed the motor changes its direction of rotation. S2 controls how the motor is stepped. Each time S2 is pressed for less than 1 second, the motor toggles between continuous mode and single step mode. Holding S2 down for more than 1 second toggles the stepping sequence between full-stepping and half-stepping. LED D2 is illuminated while operating in half-stepping mode. Otherwise, D2 is off. LED D1 is illuminated while in single step mode. Otherwise, D1 is off. While operating in continuous mode, pressing S3 increases the motor's stepping rate, S4 decreases it. For single step mode, the motor steps as long as S3 is pressed. S4 advances the motor one step each time it is pressed.

When using a serial cable to control the board, Table 1 shows the operation performed when a character is received by the MSP430. LED operation does not change. D1 is illuminated while in single-step mode and D2 is illuminated while in half-stepping mode.

Table 1. Serial Port Operation

CHARACTER	OPERATION
D or d	Toggles motor's direction
C or c	Toggles between continuous mode and step mode
M or m	Toggles between full-stepping and half-stepping mode
F or f	Increases motor's speed (continuous mode) / single steps motor (step mode)
S or s	Decreases motor's speed (continuous mode) / single steps motor (step mode)

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