Palestine Polytechnic University

College of Engineering and Technology

Electrical Engineering Department

Bachelor Thesis

Design and construction of left ventricular heart assisting model

Project Team

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Hebron - Palestine

May,2014

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According to the orientations of the supervisor on the project and the examined committee is by the agreement of a staffers all, sending in this project to the Electrical and Computer Engineering Department are in the College of the Engineering and the Technology by the requirements of the department for the step of the bachelor's degree.

Project Supervisor Signature

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Committee Signature

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Department Headmaster Signature

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الاهداء

قاسينا وسهرنا وتعبنا وها نحن اليوم وبحمد الله نطوي سهر الليالي وتعب السنين التي مضت ونقدم بين طيات الكتاب خلاصة مشوارنا....

اليك حبيبي وسيدي يا منارة العلم وهداية البشرية , يا من انقذتني برسالتك من ظلمات الجهل وكنت النجم الذي اهتدي به اذا ما اسود ليلي يا سيدي و نبي محمد صلى الله عليه وسلم....

الى اطيب قلب واجمل ابتسامة واعذب حديث , اليك امي يا من كنت شريكتي في سهري وتعبي

وحزني وفرحي أدامك الله تاجاً فوق روؤسنا يا من كنتي لي اماً واختاً وصديقة....

اليك يا من ضحيت بعمرك من اجلي وأثرت راحتي على راحتك وأحرقت شمعة أيامك وشبابك من

اجل ان تضعني على اول الطريق اليك ابي حفظك الله من كل شر وأطال في عمرك....

الي من حبهم سكن في اعماق قلبي الذين ادعو لهم لهم بالسر والعلن أن يحفظهم الله من كل شر

وأن يبقيهم نوراً لدربي وسنداً لي اليكم اخوتي واخواتي....

اليكم يا من وهبتكم لي الحياة وكنتم سنداً لي على طول الطريق يا من كنتم سبباً في زرع الابتسامة

على وجهي حتى في اصعب الظروف .... اصدقائي واحبابي....

اليهم جميعاً اهدي هذا العمل

والله ولي التوفيق

محمد ماهر الفاخوري
محمود جمال فراح
نبيل إسماعيل جويلس

شكر وتقدير

في مثل هذه اللحظات يتوقف اليراع ليفكر قبل أن يخط الحروف ليجمعها في كلمات ... تتبعثر الأحرف وعبثاً يحاول تجميعها في سطور

سطوراً كثيرة تمر في الخيال ولا يبقى لنا في نهاية المطاف إلا قليلاً من الذكريات وصور تجمعنا

برفاق كانوا إلى جانباً ...

فواجب علينا و وداعهم ونحن تخطو خطواتنا الأولى في غمار الحياة

ونخص بالجزيل الشكر والعرفان إلى كل من أشعل شمعة في دروب علمنا

وإلى من وقف على المنابر وأعطى من حصيلة فكره لينير دربنا

إلى الأساتذة الكرام في كلية الهندسة وقسم الهندسة الكهربائية ونخص بالذكر

المهندس سامي السلامين
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والمهندسة إيمان عوض

ونتوجه بالشكر الجزيل إلى

الدكتور رمزي القواسمي

والدكتور عبد الكريم داود

الذين قامو بالاشراف على هذا المشروع فلهم منّا كلّ التقدير وألاحترام ....

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Abstract

LVAD stands for Left Ventricular Assist Device. It is a mechanical device that circulates blood throughout the body when the heart is too weak to pump blood by its own.

LVAD is designed to perform the pumping function of the patient's left ventricle. The device is placed just below the diaphragm in the abdomen. It is attached to the left ventricle via one way valve, and the aorta, the main artery that carries oxygenated blood from the left ventricle to the hole body. The system includes a small controller and two batteries is attached by an external driveline.

A brushless dc pump push blood from left ventricle to aorta this pump is controlled by (ArduinoController). The system is synchronized with the patient's ECG , ECG provides information about the patient's physiological conditions, the external controller is connected to the internal pump through drive line. The System Controller has two power lead cables one for each side that have to be connected to batteries, the speed of the pump, battery level and many physiological parameter are monitored of displayed on the LCD screen.

ملخص المشروع

(LVAD) جهاز مساعد البطين الايسر , هو عبارة عن جهاز الكتروميكانيكي صممّ ليساعد احد البطينين أو كلاهما لضخ الدم إلى ارجاء الجسم , فهو لايحل محل القلب وإنما يعمل كمساعد له, بعض هذه الاجهزة تستخدم على المدى القصير كعملية عبور إلى ان يتم الحصول على قلب مانح (متبرّع) أو إلى ان يتعافى المريض من نوبة قلبية اقتضت مساعدة الجهاز في عملية تنظيم ضخ الدم,في حين ان هناك بعض من تلك الاجهزة تستخدم على المدى الطويل ,كحال المرضى الذين يعانون من فشل القلب المزمن ولايستطيعون ان يخضعوا لعملية زرع قلب نظرا لأحد العوامل التي تحول دون ذلك كأمراض الكلى وأمراض الانسداد الرئوي المزمن وغيرها .

يتكون النظام من مضخة ميكانيكية تعمل على تدفق الدم من الأدين الايسر الى الشريان الابهر وذلك ضمن متحكم دقيق يعمل على معالجة عدد نبضات القلب للمريض بحيث يقوم من خلال معرفة عدد النبضات بالتحكم بكمية التدفق الذي يحتاجها الجسم , يحصل المريض على المعلومات الكاملة عن حالته و اداء النظام من خلال شاشة عرض تقوم بعرض سرعة نبضات القلب و سرعة المضخة وايضاً حالة المريض ومعلمات اخرى , وفي حال حدث خلل او فقد لأشارة قلب المريض فأن النظام يقوم بالتحول الى نظام الأمان وهنالك تنبيه صوتي وكتابي بأن هنالك خلل ما ويعمل النظام بتدفق دم متوسط ليبقي المريض على قيد الحياة .

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Chapter Five: Design and Analysis of the system.

Chapter Six: Implementation, Experiments and results.

Abbreviation Table

Description	Abbreviations
Electrocardiography	ECG
Beat per minute	bpm
Revolution per minute	rpm
Radian per second	Rad/s
Constant coefficient	cc
Liquid-crystal display	LCD
Atrioventricular	AV node
Senatorial	SA node
Common mode rejection ratio	CMMR
Litter per minute	l/min
Time of contraction	TC
Common Mode Rejection Ratio	CMRR

1

Chapter One

Introduction

1.1 Overview.

1.2 Project objectives.

1.3 Literature review.

1.4 Time plan.

1.5 Project cost.

1.1 Overview

LVAD stands for Left Ventricular Assist Device. It is a mechanical device that circulates blood throughout the body when the heart is too weak to pump blood by itself. It is sometimes called a “heart pump “or “VAD.”

LVAD is designed to cover the pumping function of the patient’s left ventricle. The device is placed just below the diaphragm in the abdomen. It is attached to the left ventricle, and the aorta, the main artery that carries oxygenated blood from the left ventricle to the entire body. An external, wearable system that includes a small controller and two batteries is attached by an external driveline.

The wearable system is either worn under or on top of clothing; the appropriate set point for the pump rotational speed depends on these loads, which vary dynamically with time. The lower limit to pump speed is determined by the requirement to maintain adequate blood perfusion and to avoid regurgitate flow and unsatisfactory blood flow dynamics.

The highest pump speed is limited by induction of suction in the left ventricle, which occurs when the VAD attempts to pump more blood from the ventricle than is available. Suction can be deleterious to the myocardium, blood, and lungs.

1.2 Project Objectives

- Design a control system that control a centrifugal pump, the pump controlled by (Arduino microcontroller), it pumps the blood from left ventricle to aorta, the system synchronize with ECG signal of the patient.

1.3 Literature Review

In July 2009 in England, surgeons removed a donor heart that had been implanted in a toddler next to her native heart, after her native heart had recovered. This technique suggests mechanical assist device, such as an LVAD, can take some or all the work away from the native heart and allow it time to heal.[1]

In July 2009, 18-month follow-up results from the HeartMate II Clinical Trial concluded that continuous-flow LVAD provides effective hemodynamic support for at least 18 months in patients awaiting transplantation, with improved functional status and quality of life. [1]

Heidelberg University Hospital reported in July 2009 that the first HeartAssist5, known as the modern version of the DeBakey VAD, was implanted there. The HeartAssist5 weighs 92 grams, is made of titanium and plastic, and serves to pump blood from the left ventricle into the aorta. [1]

A phase 1 clinical trial is underway (as of August 2009), consisting of patients with coronary artery bypass grafting and patients in end-stage heart failure who have a left ventricular assist device. The trial involves testing a patch, called Anginera(TM) that contains cells that secrete hormone-like growth factors that stimulate other cells to grow. The patches are seeded with heart muscle cells and then implanted onto the heart with the goal of getting the muscle cells to start communicating with native tissues in a way that allows for regular contractions. [1]

In September 2009, a New Zealand news outlet, Stuff, reported that in another 18 months to two years, a new wireless device will be ready for clinical trial that will power VADs without direct contact. If successful, this may reduce the chance of infection as a result of the power cable through the skin. [1]

Heart Ware International announced in August 2009 that it had surpassed 50 implants of their Heart Ware Ventricular Assist System in their ADVANCE Clinical Trial, an FDA-approved IDE study. The study is to asses the system as bridge-to-transplantation system for patients with end-stage heart failure. The study, Evaluation of the Heart Ware LVAD System for the Treatment of Advance Heart Failure, is a multi-center study that started in May 2009. [1]

One device gained CE Mark approval for use in the EU and began clinical trials in the US (VentrAssist). As of June 2007 these pumps had been implanted in over 100 patients. In 2009, Ventracor was placed into the hands of Administrators due to financial problems and was later that year liquidated. No other companies purchased the technology, so as a result the VentrAssist device was essentially defunct. Around 30–50 patients worldwide remain supported on VentrAssist devices as of January 2010. [1]

The Heart ware HVAD works similarly to the VentrAssist – albeit much smaller and not requiring an abdominal pocket to be implanted into. The device has obtained CE Mark in Europe and is currently in clinical trials in the USA. Recently, it was shown that the Heart ware HVAD can be implanted through limited access without sternotomy.[1]

In a small number of cases left ventricular assist devices, combined with drug therapy, have enabled the heart to recover sufficiently for the device to be able to be removed (explanted).[1]

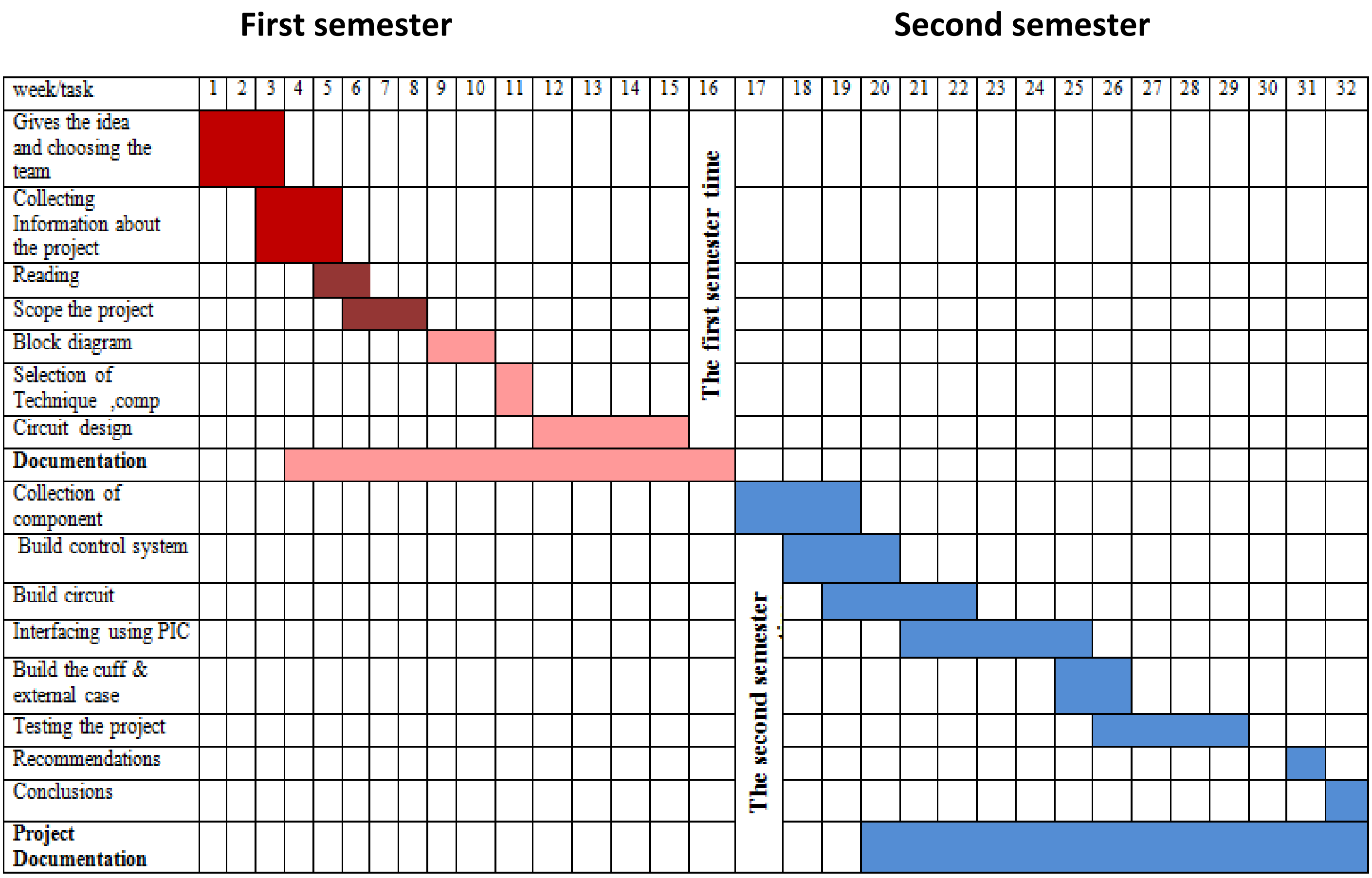
1.5 The Budget of the project

Task	Cost ($)
Research	40
Transportations	40
Copy from library	15
Printing papers	40
LVAD pump	200

Arduino	100
Electrical control valve	20
LCD	80
Circuit accessories	150
Batteries	300
Plastic Body	300
Batteries and control Bag	100

1.4 Time line

Time table of our project during one year from 1/9/2013 to 25/5/2014



2

Chapter Two

Anatomy of the heart

2.1 Anatomy of the heart.

2.2 Circulatory system.

2.3 Physiology of the heart.

2.4 Electrical conduction system.

2.5 Common causes heart failure.

2.1 Anatomy of the heart

The heart is a hollow muscle that pumps approximately 4.7-5.7 litres of blood per minute throughout the blood vessels to various parts of the body.

2.1.1 Structure of the heart:

The heart has four separate compartments or chambers. The upper chamber on each side of the heart, which is called an atrium, receives and collects the blood coming to the heart. The atrium then delivers blood to the powerful lower chamber, called a ventricle, which pumps blood away from the heart through powerful, rhythmic contractions, see Figure 2.1.

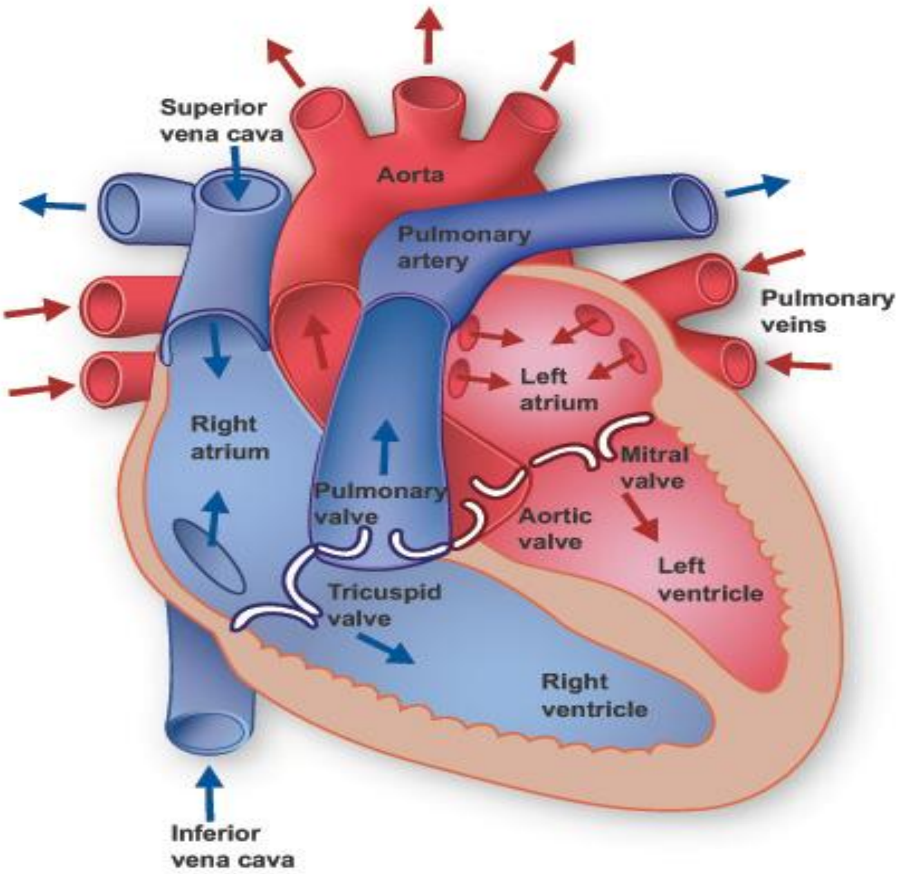


Figure 2.1: Structure of the heart

The human heart is actually two pumps in one. The right side receives oxygen-poor blood from the various regions of the body and delivers it to the lungs. In the lungs, oxygen is absorbed in the blood. The left side of the heart receives the oxygen-rich blood from the lungs and delivers it to the rest of the body.[2][3]

The wall of the heart consists of three layers:

- The epicardium: the outer, visceral layer serous pericardium.
- The muocardium: the middle, thick layer of cardiac muscle.
- Endocardum: the inner, thin layer.

2.2 Circulatory system

The circulatory system is an organ system that permits blood and lymph circulation to transport nutrients (such as amino acids and electrolytes), oxygen, carbon dioxide, hormones, blood cells, etc. to and from cells in the body to nourish it and help to fight diseases, stabilize body temperature and pH, and to maintain homeostasis.[2]

The circulatory system divided in tow type:

- Pulmonary circulation
- Systemic circulation.

2.2.1 Pulmonary circulation

The pulmonary circulatory system is the portion of the cardiovascular system in which deoxygenated blood is pumped away from the right ventricle via the pulmonary artery, to the lungs and returned, oxygenated, to the left atrium via the pulmonary vein.

Deoxygenated blood from the superior and inferior vena cava, enters the right atrium of the heart and flows through the tricuspid valve (right atrioventricular valve) into the right ventricle, from which it is then pumped through the pulmonary semi lunar valve into the pulmonary artery to the lungs. Gas exchange occurs in the lungs, whereby CO_2 is released from the blood, and oxygen is absorbed. The pulmonary vein returns the now oxygen-rich blood to the left atrium.[3]

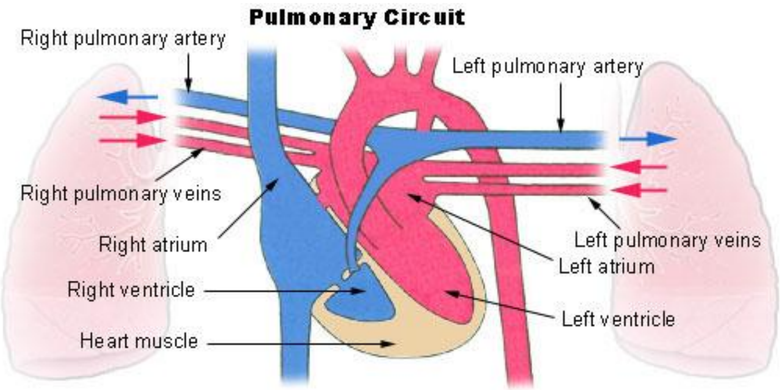


Figure 2.2: Pulmonary circulation

2.2.2 Systemic circulation

Systemic circulation is the circulation of the blood to all parts of the body except the lungs. Systemic circulation is the portion of the cardiovascular system which transports oxygenated blood away from the heart through the aorta from the left ventricle where the blood has been previously deposited from pulmonary circulation, to the rest of the body, and returns deoxygenated blood back to the heart. Systemic circulation is, distance-wise, much longer than pulmonary circulation, transporting blood to every part of the body.[3]

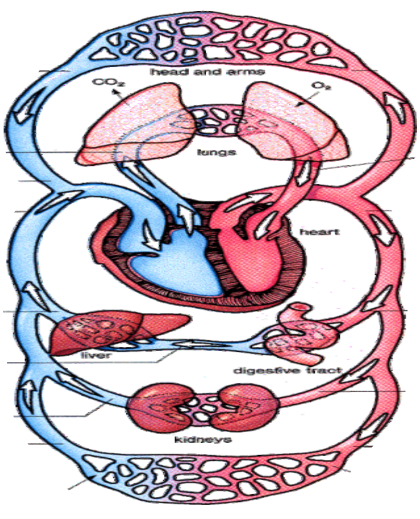


Figure 2.3: Systemic circulation

2.3 Physiology of the heart

2.3.1 Systole

The contraction of the cardiac muscle tissue in the ventricles is called systole. When the ventricles contract, they force the blood from their chambers into the arteries leaving the heart. The left ventricle empties into the aorta and the right ventricle into the pulmonary artery. The increased pressure due to the contraction of the ventricles is called systolic pressure.[3]

2.3.2 Diastole

The relaxation of the cardiac muscle tissue in the ventricles is called diastole. When the ventricles relax, they make room to accept the blood from the atria. The decreased pressure due to the relaxation of the ventricles is called diastolic pressure.[3]

2.4 Electrical Conduction System

The heart is composed primarily of muscle tissue. A network of nerve fibers coordinates the contraction and relaxation of the cardiac muscle tissue to obtain an efficient, wave-like pumping action of the heart.

The Sinoatrial Node (often called the SA node or sinus node) serves as the natural pacemaker for the heart. Nestled in the upper area of the right atrium, it sends the electrical impulse that triggers each heartbeat. The impulse spreads through the atria, prompting the cardiac muscle tissue to contract in a coordinated wave-like manner.

The impulse that originates from the senatorial node strikes the Atrioventricular node (or AV node) which is situated in the lower portion of the right atrium. The atrioventricular node in turn sends an impulse through the nerve network to the ventricles, initiating the same wave-like contraction of the ventricles.

The electrical network serving the ventricles leaves the atrioventricular node through the Right and Left Bundle Branches. These nerve fibers send impulses that cause the cardiac muscle tissue to contract.[2][3]

1. Sinoatrial node (SA node)
2. Atrioventricular node (AV node)
3. Common AV Bundle
4. Right & Left Bundle Branches

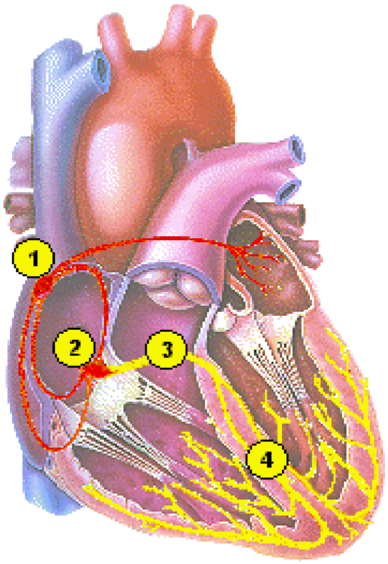


Figure 2.4: Electrical Conduction System

2.5 Heart failure

Definition: Heart failure is a clinical syndrome characterized by systemic perfusion inadequate to meet the body's metabolic demands as a result of impaired cardiac pump function.

2.5 Common Causes Heart Failure

- Coronary Heart Disease

CHD is a condition in which a waxy substance called plaque (plak) builds up inside the coronary arteries. These arteries supply oxygen-rich blood to your heart muscle

- High Blood Pressure

. Blood pressure is the force of blood pushing against the walls of the arteries. If this pressure rises and stays high over time, it can weaken your heart and lead to plaque buildup.

Blood pressure is considered high if it stays at or above 140/90 mmHg over time.

- Diabetes

Diabetes is a disease in which the body's blood glucose (sugar) level is too high. In diabetes, the body doesn't make enough insulin or doesn't use its insulin properly. Over time, high blood sugar levels can damage and weaken the heart muscle and the blood vessels around the heart, leading to heart failure.[2][3]

Other diseases and conditions also can lead to heart failure, such as:

- Cardiomyopathy or heart muscle disease. Cardiomyopathy may be present at birth or caused by injury or infection.
- Heart valve disease. Problems with the heart valves may be present at birth or caused by infection, heart attack, or damage from heart disease.
- Arrhythmias or irregular heartbeats. These heart problems may be present at birth or caused by heart disease or heart defects.
- Congenital heart defects. These problems with the heart's structure are present at birth.

Other factors also can injure the heart muscle and lead to heart failure. Examples include:

- Treatments for cancer, such as radiation and chemotherapy
- Thyroid disorders (having either too much or too little thyroid hormone in the body
- Alcohol abuse or cocaine and other illegal drug use
- HIV/AIDS
- Too much vitamin E

3

Chapter Three

Lift Ventricle Assistant Device (LVAD).

3.1 LVAD Components.

3.2 LVAD Generations.

3.3 LVAD Control.

3.4 The Control problem for LVAD.

3.1 LVAD Component.

In general, all LVADs include the following parts (Figure 3.1):

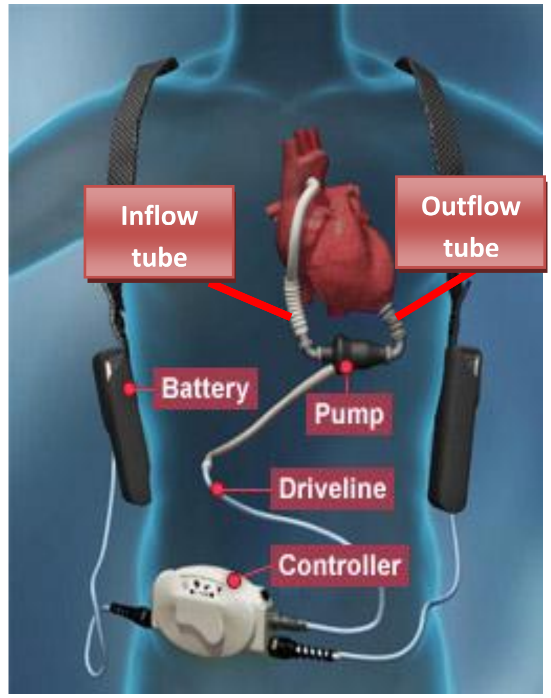


Figure 3.1: LVAD Components

- **Pump:**

  This is the part of the device that is attached to your heart. It helps your heart pump blood to your body

- **Driveline:**

  The driveline connects the pump to the controller, and contains the necessary power and electronic cables. It exits through your skin, on either the right or left side of your abdomen.[4][5]

- **Tubes**:

  - **Outflow tube** :

    Attached to the aorta (the large artery that carries blood away from the heart)

  - **Inflow tube**:

    Attached to the bottom of the left ventricle

- **Controller:**

  The controller is the "brain" of the LVAD. It operates the pump and has lights, messages, and/or alarms that indicate when the batteries need to be changed and alert you if there are any problems with your system.[4][5]

- **Batteries:**

  Batteries are one option for powering your LVAD. The batteries are charged using a device specific battery charger. Your controller and/or batteries will show you how much power the batteries have left and alert you when they need to be changed. When you are outside of your home you'll need to have extra fully charged batteries with you. Depending on your specific LVAD device, the batteries may be in a pack along with the controller or carried in a holster over your shoulders.[4][5]

AC (Electrical) Power Sources:

When you are sleeping or about to sleep, you will need to connect your LVAD to the device-specific electrical power source to eliminate the chance of battery power loss while sleeping. The electrical power source should include a backup battery (possibly internal) in case there is a power outage. Your device may also come with a **DC** adaptor, which will allow you to power your LVAD in a car.[4][5]

3.2 LVAD Generation.

This is a heterogeneous group consisting of devices developed in different periods, employing different drive mechanisms, inspired by different principles. It is best to review them under three generation groups:

1-First generation:

These are implanted, pulsatile, electric-driven, bulky, pusher-plate displacement pumps connected to a wearable, control and battery unit by a driveline piercing the skin, allowing discharge to home on support. The first FDA " Food & Drag Accusation" approved devices for permanent use (destination therapy) are from this group. These two well- known devices are the Novacor (World Heart, Inc., Oakland, CA) and HeartMate VE (Thoratec Laboratories Corp, Pleasanton, CA) electrically-driven version of (HeartMate) systems.[6]

They were used extensively for both bridging and permanent purposes on an outpatient basis. The main drawbacks of the Novacor system was anticoagulation necessity and a relatively high incidence of thromboembolic events while infection and technical problems were more commonly observed problems with the HeartMate system. The blood-device interface of the HeartMate pump incorporates titanium microspheres and the flexible diaphragm is covered with textured polyurethane. This unique structure promotes the formation of a pseudo-intimal layer densely attached to the interior surface of the device, and may be responsible for the low thromboembolic risk (less than 5%) associated with the HeartMate despite the lack of anticoagulation . The Novacor device, on the other hand has an excellent mechanical reliability, however mandates strict anticoagulation with Coumadin and aspirin. [6]

With growing experience, it is realized that the LVAD driveline piercing the skin to connect the implanted pump to an extracorporeal control and battery unit is problematic in many ways, including infectious complications and technical problems.

To overcome such problems associated with this driveline, a wireless Transcutaneous Energy Transfer System (TETS) has been developed. Many newly developing fully implantable devices of different genres are expected to use this new technology.[6]

2-Second generation:

These are mainly named as “axial flow pumps”. Employing the “Archimedes’ screw” principle, these pumps use electrical energy to rotate an axle on which a turbine or propeller system is mounted to propose liquids forwardly. A very high rotation rate makes it possible to pump large amount of blood in accordance with the body needs.[6]

These systems consist of a much smaller pump with fewer moving parts and less blood-contacting surface than pusher-plate devices. However, the system works on high rotational speeds, heat is generated, hemolysis with damage to the blood cells and thrombi may occur.
Anemia and platelet damage along with the activation of contact coagulation system may ensue. All these can interfere with device function, and cause thromboembolic complications. In addition, the flow they provide is non-pulsatile the contribution from the patient’s own heart

“less pulsatile”, and this non-physiological condition, although well tolerated by mammalian organisms after a period of adaptation, may cause compromises and distorting effects in bar

receptor activity, catecholamine release, lymphatic pump, renal cortical blood flow, fluid shift and vascular wall structure integrity in the early period of implantation.
With the use of these devices, myocardial oxygen consumption is reported to decrease by 20% and coronary perfusion pressure is expected to increase.[6]

Since there is no one-way valve mechanism employed on these devices, any device malfunction leads to develop the equivalent of wide-open aortic insufficiency. Among these devices are the HeartMate II (formerly Nimbus) (Thoratec Laboratories Corp, Pleasanton, CA), Micromed **DeBakey VAD** (MicroMed Cardiovascular, Inc Houston, Texas), Berlin Heart INCOR (Berlin Heart GmbH, Germany) and Jarvik 2000 FlowMaker (Jarvik Heart, Inc., New York, NY) systems, weighing between 53 and 176 g rams.

DeBakey VAD: This axial flow pump was developed by Doctors. Michael E. DeBakey and George P. Noon with the collaboration of engineers in 1988 , and licensed in 1996 with the first clinical application in 1998. Since then it is used extensively mainly in Europe, with a longest assist period
over 500 days. It is also the first successful long-term left ventricular assist device implanted in Turkey in 2001 at Yuksek Ihtisas Hospital of Turkey. Initially three devices were implanted in this clinic and two were successfully bridged to transplantation; one is still alive. In this group a relatively new device.[6]

3-Third generation:

These are mainly implantable centrifugal pumps developed for long-term use. Many devices in this group are newly developed or in development stage.

Examples from this heterogeneous group are the Dura Heart (Terumo Heart, Inc., Michigan), VentrAssist (Ventracor, Australia), CorAide (Arrow International, Pennsylvania), Heart Ware HVAD (HeartWare, Inc., Massachusetts) and Levacor (World Heart, Inc., Oakland, CA) systems.[6]

These pumps all use centrifugal energy to propulse blood but they somehow differ from each other in many aspects such as their implantation characteristics, dimensions, interrelation between the moving parts, working principles and device-blood interface. They have been subjected to vigorous pressures. Strict anticoagulation and anti-platelet treatment are mandatory. In 2001, ABIOCOR saw its first clinical application and the FDA approved it for commercial approval under a Humanitarian Device Exemption in September, 2006. A new generation, smaller and durable model, AbioCor II is reported to be under development using ABIOMED and Penn State experiences animal ,preclinical and clinical test .[6]

First Generation	The main drawbacks of this generation was anticoagulation necessity and a relatively high incidence of thromboembolic events.
Second Generation	**1.** These systems consist of a much smaller pump with fewer moving parts**.** **2.** The system works on high rotational speeds, heat is generated, hemolysis with damage to the blood cells and thrombi may occur.
Third Generation	These are implantable centrifugal pumps developed for **long-term use .**

Table 3.1 : The main points of each generation

3.3 LVAD Control.

Previous work on pulsatile assist devices and total artificial hearts has suggested that reasonably simple models can be used to represent the major hemodynamic pressures and flows in the heart. We have investigated the model shown in (Figure 3.1). [7]

A second order windkessel model was used to describe the impedance of the systemic circulation. Cardiac contractility was modeled using a time-varying capacitor. The pulmonary circulation and right side of the heart, because they operate at low pressures, were simply represented by a capacitor. An extended Kalman filter using only pump input parameters can be used to estimate the systemic circulation model parameters. However, an accurate estimate of preload, such as atrial pressure, requires an additional measurement. Approaches to estimate atrial pressure are currently being investigated. [7]

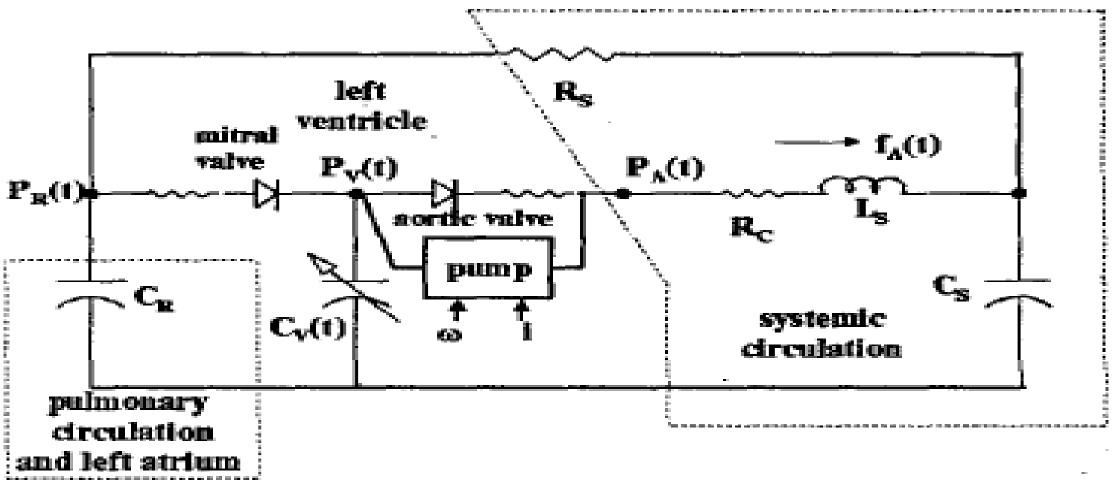


Figure 3.2:Electric analog model of the cardiovascular system and assist device.

The intelligent control supervisor performs several tasks. It determines the patient's level of activity and hence demands for blood flow. It calculates the pressure set-points, using the systemic impedance. It monitors the estimated model parameters and determines whether they are within acceptable ranges and whether the rates of parameter change are reasonable. It selects the control algorithm to use, based on the measurements available, reliability of the patient model being estimated, and the past history of the patient. Finally, the supervisor compares model parameters and pump parameters with the past history of the system to detect hardware failures or changes in the patient that would prevent the assist device from delivering adequate output.[7]

We have proposed the control architecture diagrammed in (Figure 3.2)A local control algorithm built into the pump maintains pump speed at a reference value. The reference speed is determined by one of several algorithms (optimal, or default), depending on the patient's physical condition, device status, and confidence that accurate measurements or estimates of hemodynamic variables are available. Each algorithm relies on a greater amount of information than the algorithm below it in the structure and provides better performance, if the information is accurate.[7]

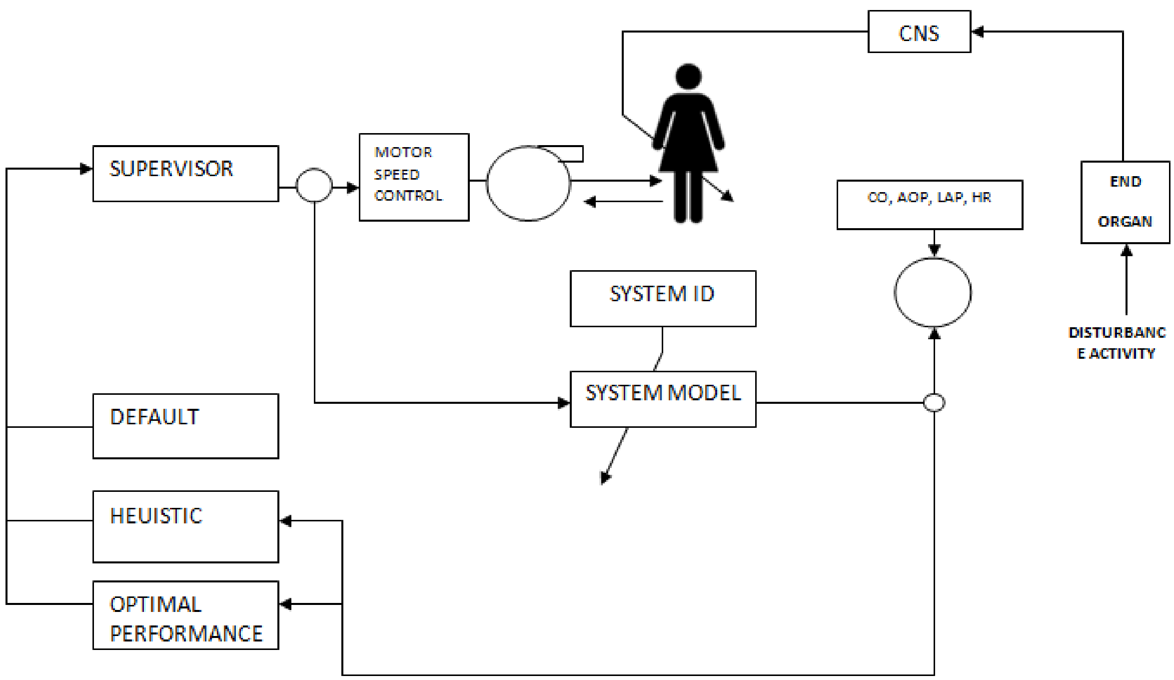


Figure 3.3: Hierarchical control architecture for axial pump ventricular assist system.

The default control mode can be used in the event of extensive sensor failure, software failure, or uncertainty concerning the reliability of control actions or functioning of the assist device itself. The default mode provides a constant pump speed that is low enough in most cases to avoid suction while still providing a nominal flow output. This mode attempts to provide safe operation of the device without requiring any sensory information, state variables or model parameter estimates. However, it generates a low cardiac output without the capability of responding to changes in the required demand, and it may result in adverse regurgitate flow through the pump circuit.[7][14]

3.4 The Control Problem for previous LVAD generations.

LVADs that are used in critical care settings are typically operated in open-loop fashion but are continuously supervised by a human operator. Control adjustments are made by the operator during stable conditions to achieve desired pressure, flow, andor rate of pressure change. When the patient's condition changes due, for example, to change in blood volume status, inotropic level, or stress, the pump operates sub-optimally until the operator is able to identify the changes and make suitable adjustments. Within a range near the selected operating point, nominal control is attained by the intrinsic properties of the patient's circulation.

The amount of blood delivered to the pump from the venous system is usually governed by demand, although in patients with left-ventricular assistance alone, failure of the right ventricle can result in a critically low level of venous return. The arterial pressure is regulated somewhat by innate feedback control of the systemic resistance. In the event of an unacceptable hemodynamic condition, the operator must decide if the device requires adjustment or if a clinician is required to intervene to treat the patient. The operator thereby provides both feedback control and fault detection functions.[7][14]

The limitations of open-loop control become apparent as patients are rehabilitated and seek to adopt a normal, active lifestyle. The inability of the devices to respond automatically to changes in demand can dramatically impact the quality of life for these patients.

For successful long-term implantation, the need for a term implantation, the need for a human to monitor the device operation should be eliminated. To achieve this level of automatic operation, the control system for the VAD must be able to respond to changes in the demand for cardiac output. It should monitor the patient's status to recognize a change in the patient's requirements for support, and it should monitor its own operation to identify hardware failures, changes in assist device parameters, and uncontrollable situations and inappropriate or dangerous control commands by the controller. [7]

Finally, because of the poor reliability of current blood pressure and flow transducers for long-term use, device inputs (voltage and current) should be used to the greatest extent possible to estimate the hemodynamic state variables needed to control the device [7].

Many investigators have worked on control techniques for various types of VADs. Some of these investigators developed models to estimate hemodynamic variables needed to achieve physiologic control. **Pulsatile pumps** fill from venous return and then eject blood into the systemic circulation under positive pressure, using valves to assure one-way blood flow. The primary control problem is to specify the volume per cycle and pumping rate, usually controlling a blood pressure to maintain adequate hemodynamic.

Non-pulsatile pumps like the axial pump mentioned above pose a different control problem. Axial pumps run continuously, attempting to draw blood out of the ventricle and into the circulation. The pumps do not use valves, and it is possible for blood to flow backwards through the pump if the pump runs too slowly. Conversely, if the pump runs too fast, it may attempt to pump more blood from the ventricle than is available, causing kinking of the connecting canulae or negative pressure in the ventricle. [7]

Obtaining information regarding the status of the patient's cardiovascular system is critical in implementing these control strategies. In order to use the multi-objective optimization approach, the penalties on output variables as functions of pump speed must also be known.
These functions cannot be measured directly in patients except for those with intensive monitoring, but it may be possible to estimate them in an individual patient by using a model of the patient's cardiovascular system and the assist device. Because the patient's cardiovascular status can change over a time period of seconds, the model parameters must be updated rapidly. The calculation of the non-inferior set must also be performed rapidly.[7]

The suction detection indices that are used in the heuristic algorithm rely on instantaneous observations of the pump flow. Direct flow measurements are difficult to obtain reliably in a patient, and in practice it will be necessary to estimate these indices.

One approach to estimate the indices is to use a model of the pump such as the one referred to above. However, models that are currently available, while they provide good estimates of the overall flow waveform, do not provide adequate estimates of the subtle waveform changes that occur as suction is approached. This may be because the models do not adequately include the suction effect, and more sophisticated models will be necessary.[7]

The controller should respond to changes in demand for cardiac output. This desire for physiologic control has motivated the use of atrial and, to a lesser extent, arterial pressure control for assist devices have discussed the use of cardiac signals ("inotropic" pacemakers) and direct metabolic sensors in pacemaker control , and many of their conclusions are relevant to assist device control.

Cardiac signals may be of limited use in early implantation, since patients will often have abnormal cardiovascular status. However, if cardiac recovery is obtained, these signals will become of greater value. Direct metabolic sensors (such pH and O2 saturation) would be of value throughout implantation. acknowledge the potential contribution for multiple signals, but they caution against incorporating multiple sensors that do not contribute independent information, due to the increased complexity.[7]

The control system, as well as the assist device itself, must be reliable, and it must be able to react appropriately to hardware failures. Device and patient-adaptive cardiovascular models can be used to determine the reference pump speed and to evaluate device performance, and the hierarchical control structure can decide which model approach to use. However, obtaining adequate information to identify the models in real time remains a significant challenge.[7]

4

Chapter Four

Electrocardiography (ECG).

4.1 The origin of an electrocardiograph.

4.2 ECG waveforms and intervals.

4.3 ECG leads connection.

4.4 ECG simulation.

4.1 The origin of an Electrocardiograph .

The electrocardiogram (ECG) is a graphic recording of electric potentials generated by the heart .The signals are detected by means of metal electrodes attached to the extremities and chest wall and are then amplified and recorded by the electrocardiograph, ECG leads actually display the instantaneous differences in potential between these electrodes.

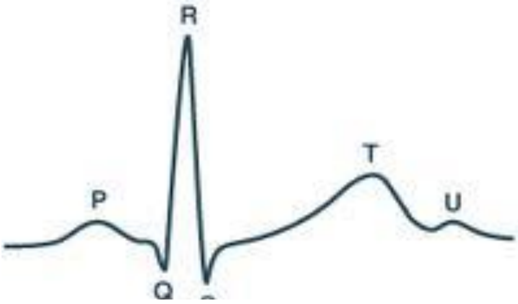


Figure 4.1: Normal Electrocardiograph (ECG) Signal

Depolarization of the heart is the initiating event for cardiac contraction. The electric currents that spread through the heart are produced by three components: cardiac pacemaker cells, specialized conduction tissue, and the heart muscle itself .The ECG, however, records only the depolarization (stimulation) and repolarization (recovery) potentials generated by the atrial and ventricular myocardium.
The depolarization stimulus for the normal heartbeat originates in the sinoatrial (SA) node (Figure 4.2), or sinus node, a collection of pacemaker cells. These cells fire spontaneously; that is, they exhibit automaticity.

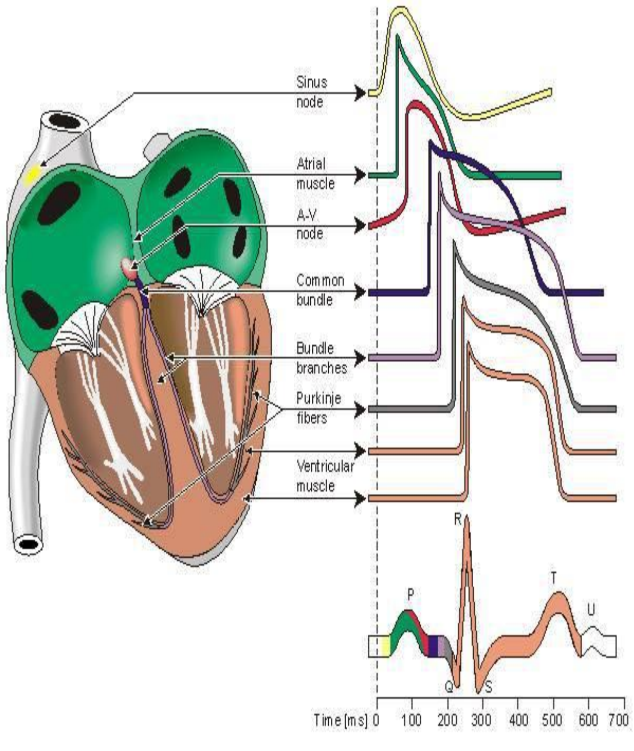


Figure 4.2: Electrocardiograph (ECG) creation .

The first phase of cardiac electrical activation is the spread of the depolarization wave through the right and left atria, followed by atrial contraction. Next, the impulse stimulates pacemaker and specialized conduction tissues in the atrioventricular (AV) nodal and His-bundle areas; together, these two regions constitute the AV junction.

The bundle of His bifurcates into two main branches, the right and left bundles, which rapidly transmit depolarization wavefronts to the right and left ventricular myocardium by way of Purkinje fibers. The main left bundle bifurcates into two primary subdivisions, a left anterior fascicle and a left posterior fascicle. The depolarization wavefronts then spread through the ventricular wall, from endocardium to epicardium, triggering ventricular.

4.2 ECG waveforms and intervals.

The ECG waveforms are labeled alphabetically, beginning with the P wave, which represents atrial depolarization (Figure 4.3). The QRS complex represents ventricular depolarization, and the ST-T-U complex (ST segment wave, and U wave) represents ventricular repolarization. The J point is the junction between the end of the QRS complex and the beginning of the ST segment. Atrial repolarization is usually too low in amplitude to be detected, but it may become apparent in such conditions as acute pericarditis or atrial infarction.

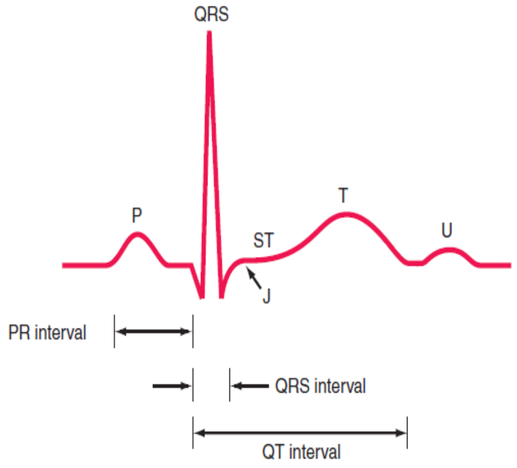


Figure 4.3: Basic ECG waveforms and intervals .

The QRS-T waveforms of the surface ECG correspond in a general way with the different phases of simultaneously obtained ventricular action potentials, the intracellular recordings from single myocardial fibers. The rapid upstroke (phase 0) of the action potential corresponds to the onset of QRS.

The plateau (phase 2) corresponds to the isoelectric ST segment, and active repolarization (phase 3) to the inscription of the T wave. Factors that decrease the slope of phase 0 by impairing the influx of Na tend to increase QRS duration.

The conditions that prolong phase increase the QT interval. In contrast, shortening of ventricular repolarization (phase 2), as by digitalis administration or hypercalcemia, abbreviates the ST segment.

4.3 ECG leads connection.

The 12 conventional ECG leads record the difference in potential between electrodes placed on the surface of the body. These leads are divided into two groups: six limb (extremity) leads and six chest (precordial) leads .The limb leads record potentials transmitted onto the frontal plane (Figure 4.4 A), and the chest leads record potentials transmitted onto the horizontal plane (Figure 4.4B).

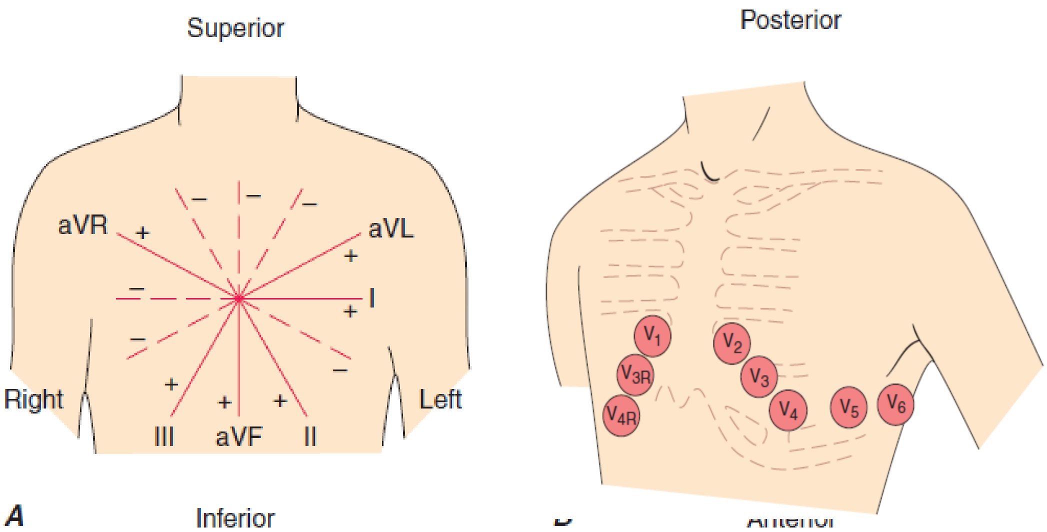


Figure 4.4 : The six frontal plane (A) and six horizontal plane (B) leads

The six limb leads are further subdivided into three standard “bipolar” leads (I, II, and III) and three augmented “unipolar” leads (aVR, aVL, and aVF).
Each standard lead measures the difference in potential between electrodes at two extremities: lead I = left arm – right arm voltages, lead II = left leg – right arm, and lead III = left leg – left arm.The unipolar leads measure the voltage (V) at one locus relative to an electrode that has approximately zero potential.

Thus, aVR = right arm, aVL = left arm, and aVF = left leg (foot).

The owercase a indicates that these unipolar potentials are electrically augmented by 50%. The right leg electrode functions as a ground.

Figure 4.5 shows the 12 lead waveform.

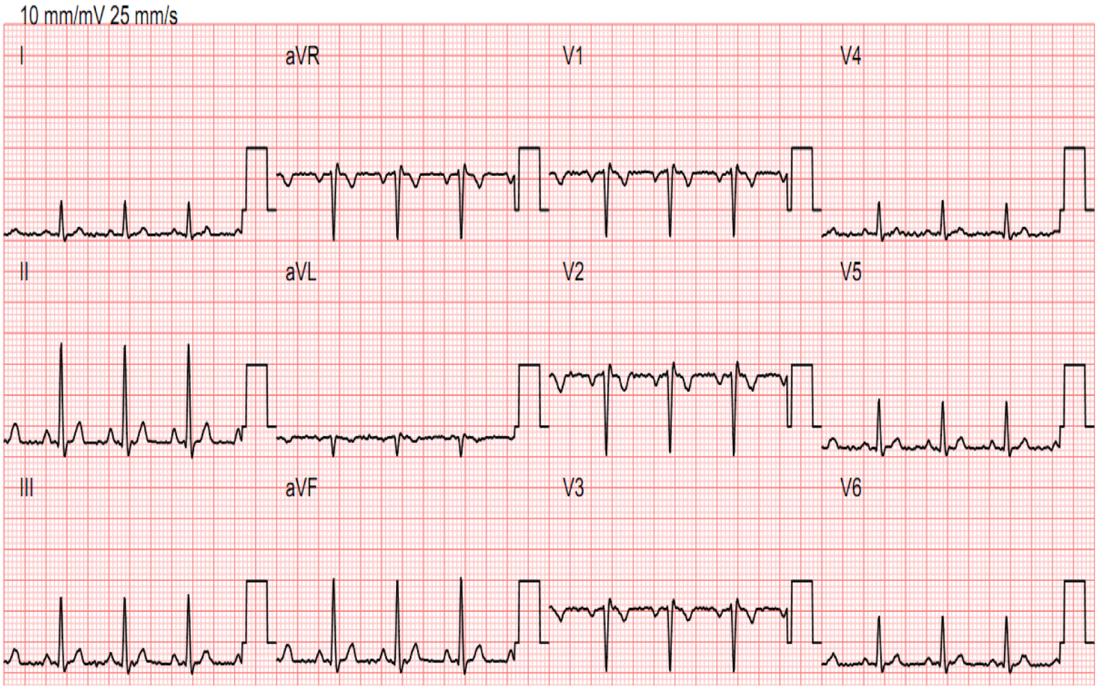


Figure 4.5: 12 lead waveform .

As illustrated in Figure 4.5 all the ECG components are clearly seen in Lead II, so the experimental part of the project will be implemented and tested using three cases of the heart condition using lead II, and the conditions is :

The first case **Normal ECG Rate (100 – 60 rpm)** (Figure 4.6 a) .

The second case **Fast ECG Rate(>100 rpm) Tachycardia**(Figure 4.6 b).

The third case **Slow ECG Rate (<60 rpm)Bradycardia** (Figure 4.6 c).

Figure 4.6 a: Normal ECG .

Figure 4.6b: Tachycardia ECG.

Figure 4.6c: Bradycardia ECG.

4.4 ECG Simulation.

Because abnormal ECG waves can't be recorded directly from pationts with cardiovascular diseas , and for the practical reasors it is easily to simulate these pathologies (Tachycardia and Bradycardia) , ECG simulator will be used.

ECG simulator is designed to give the ECG signal by using different lead connection , and with variable hrart rate. (Figure 4.7)

Figure 4.7 ECG Simulator.

5

Chapter Five

Design and Analysis the System

5.1 The general system.

5.2 The analysis part of the system.

5.3 System controller.

5.4 Pump and electrical circuits.

5.5 Chopper circuit.

5.6 LCD display

5.7 The final project circuit

5.1 The General System

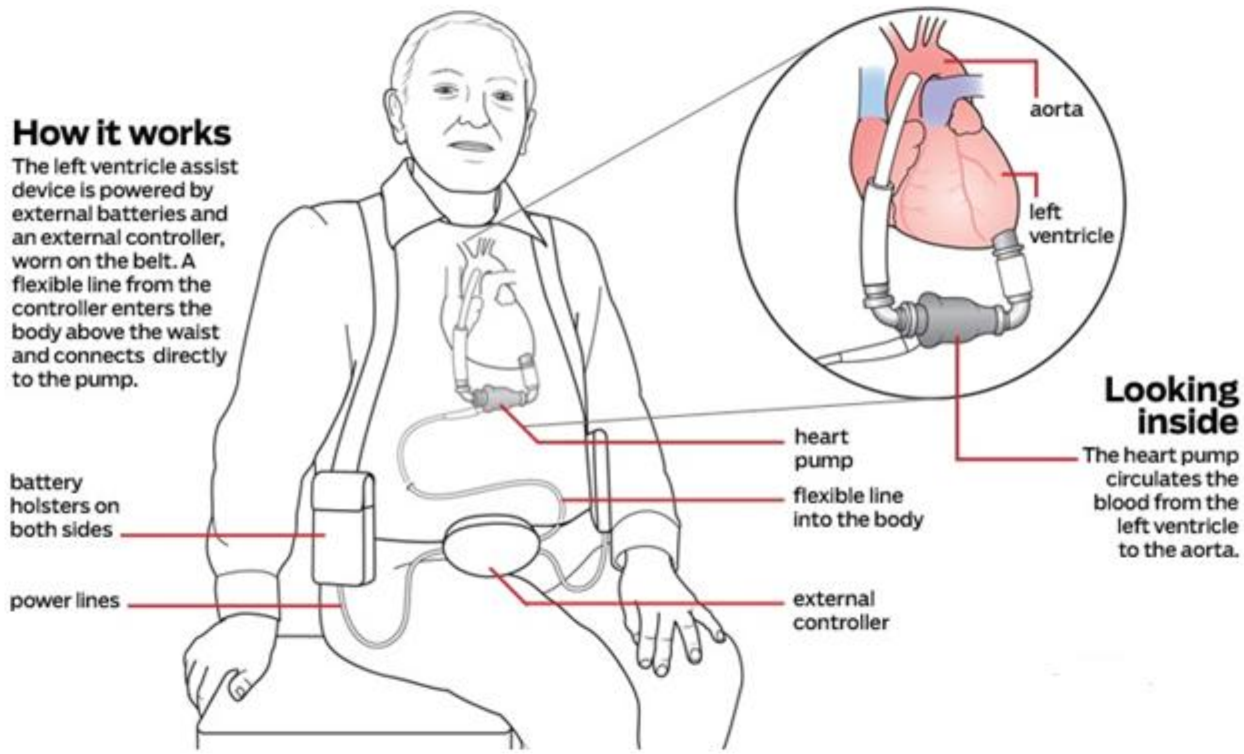


Figure 5.1: General system

The Left Ventricular Assist Device (LVAD) system is designed to support systemic circulation of blood when the natural heart is unable to maintain adequate perfusion with conventional therapy. To accomplish support, the IVAD system shunts blood from the natural heart and then pumps blood to the arterial system in a pulsatile manner at normal arterial pressures see Figure 5.1 .[14]

5.1.1 System Description

The designed LVAD System work synchronously with the other chambers of the heart, so any changes in heart beat Consequents by a fast response from the System. The system consists of three major subsystems:

1) ECG subsystem.

2) Controller subsystem.

3) Blood pumping subsystem.

The Signal come from ECG Simulator to conditional circuit AD620, and enter to the Arduino Controller to be analyzed such that to limit the R wave, after detecting the R wave the electrical valve will open to let the blood pass to the pump, the pump will flow the blood to Aorta after that the blood go back to left atrium and so on .

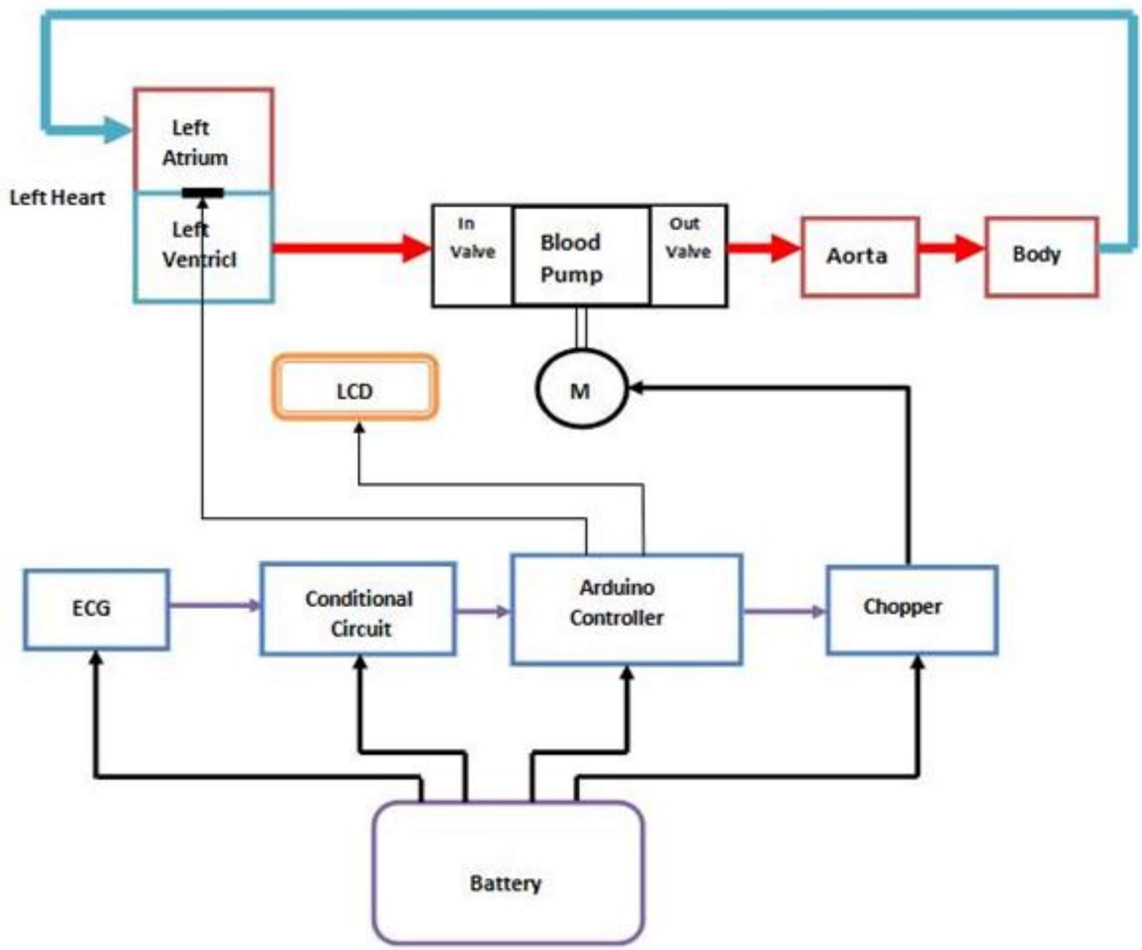


Figure 5.2: General Block diagram

5.2 The Analysis Part of the System:

5.2.1 ECG subsystem:

1) Simulator

Figure 5.3: ECG simulator

Because abnormal ECG waves can't be recorded directly from pations with cardiovascular diseas , and for the practical reasors it is easily to simulate these pathologies (Tachycardia and Bradycardia) , ECG simulator will be used.

2) Conditional Circuit:

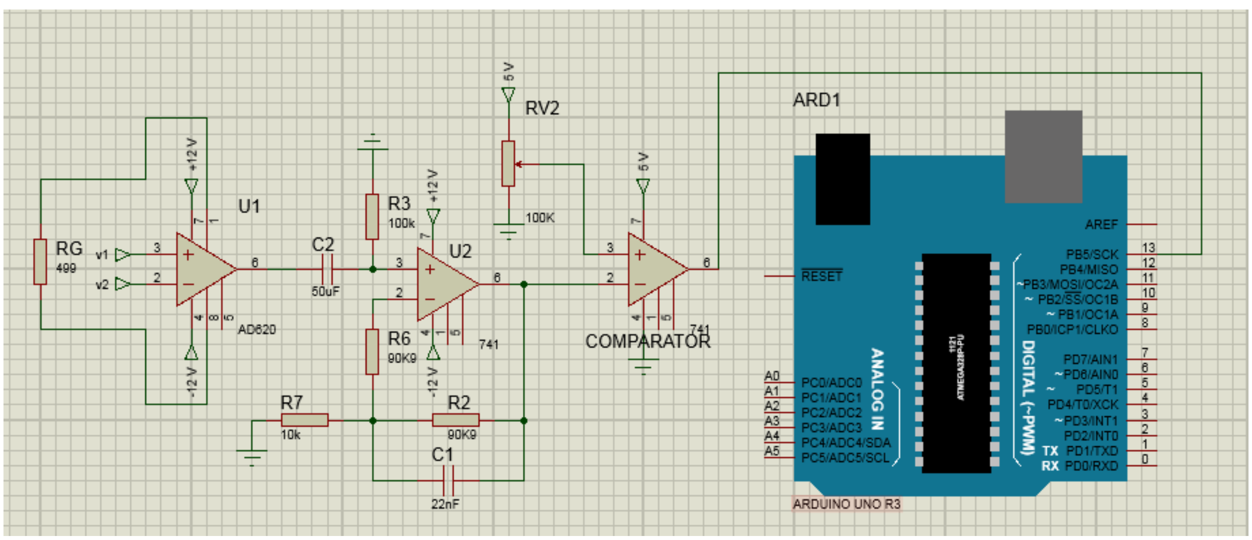


Figure 5.4: Conditional circuit , band pass filter and comparator circuit with Arduino

Conditional circuit consists of:

1) AD620 Instrumentation amplifier IC.
2) Band Pass Filter (LM741).
3) Comparator (LM741)

1) Instrumentation Amplifier (AD620).

Instrumentation amplifiers offer a unique combination of differential inputs, high input impedance, and excellent precision and noise specifications. Using both zero-drift and traditional topologies, Linear Technology's instrumentation amps feature high precision, low drift and excellent Common Mode Rejection Ratio(CMRR).

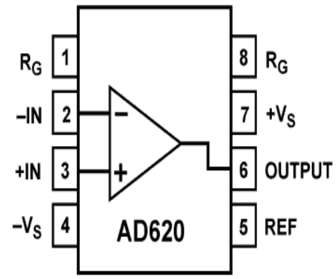


Figure 5.5:AD 620 Top view

Like all Linear Technology devices, our instrumentation amplifiers are unique in offering fully specified, tested and guaranteed performance for key parameters over the full operating temperature range, enabling high reliability designs.

$$\text{Gain} = 1 + \frac{49.4\ \text{K}}{\text{R gain}} \qquad \textbf{(5.1)}$$

$$\text{R gain} = \frac{49.4\ \text{k}}{\text{Gain}-1} \qquad \textbf{(5.2)}$$

We use Gain = 100

So R gain = 499 Ω

Figure 5.6:AD 620

2) Band Pass Filter (BPF)

The band Pass Filter (Fig 5.3) is consist of two stages, high pass filter (FcH=0.5 Hz) and low pass filter (Fcl=150Hz).

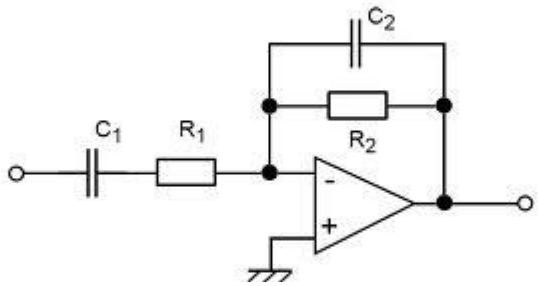


Figure 5.7: Band Pass Filter

The BPF is a RC circuit with operational amplifier (LM 741) Figure (5.7).

FcH = 0.5 Hz

$$FcH = \frac{1}{2\pi R2C2} \quad \text{(5.3)}$$

C2 = 100µF

R2 = 3.2 k Ω

Fcl = 150 Hz

$$.FcL = \frac{1}{2\pi R1C1}$$

C1 = 5µF

R1= 212 Ω

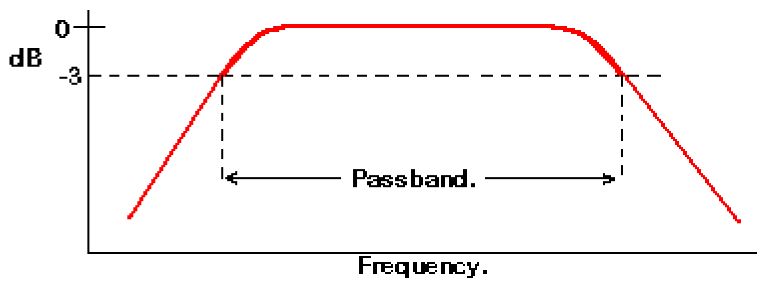


Figure 5.8: Band Pass Filter curve

3) comparator circuit.

The LM 741 work as comparator by supplied it with 5v and GND, reference voltage on positive pin and the output of Band Pass Filter on negative pin , when the R wave of ECG signal passes the output of LM741 is GND unless the output is 5v Vcc .

5.3 System controller

5.3.1 Arduino Controller

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board.[15]

The Arduino platform has become quite popular with people just starting out with electronics, and for good reason , see Figure 5.3.3.[15] Unlike most previous programmable circuit boards, the Arduino does not need a separate piece of hardware (called a programmer) in order to load new code onto the board – you can simply use a USB cable. Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program. Finally, Arduino provides a standard form factor that breaks out the functions of the micro-controller into a more accessible package

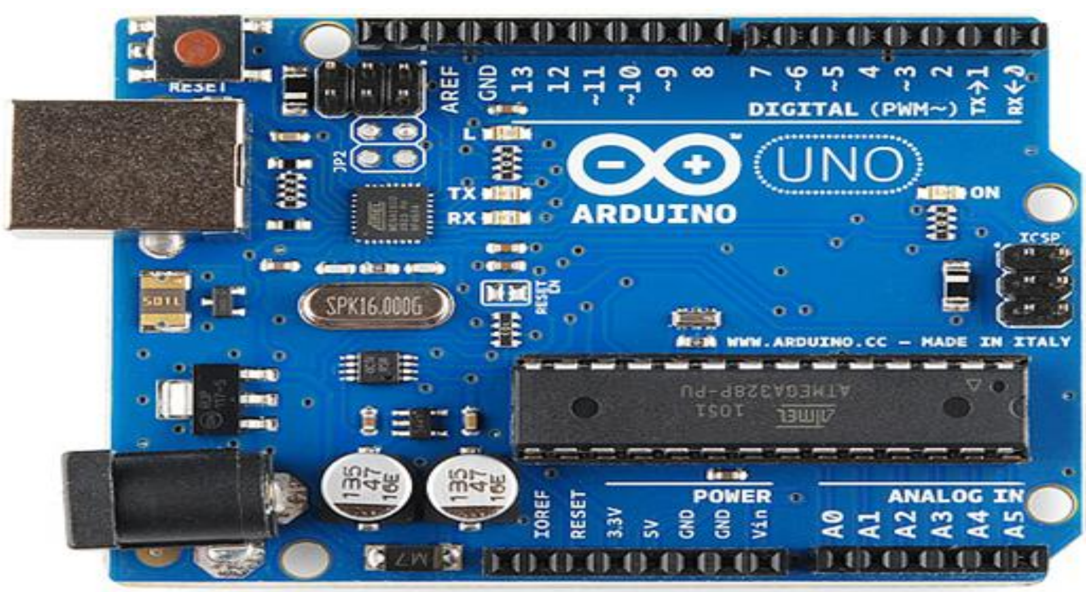
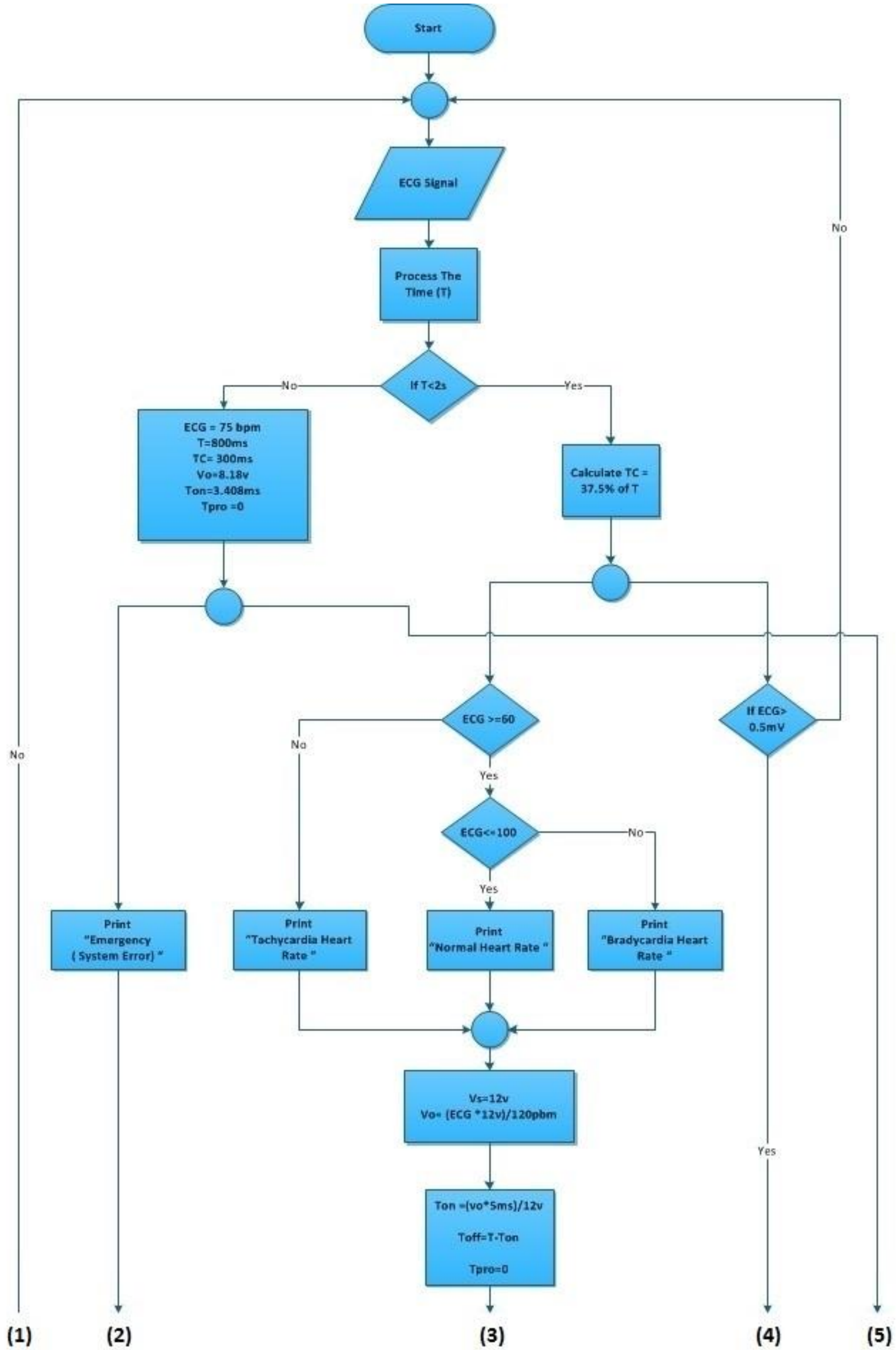
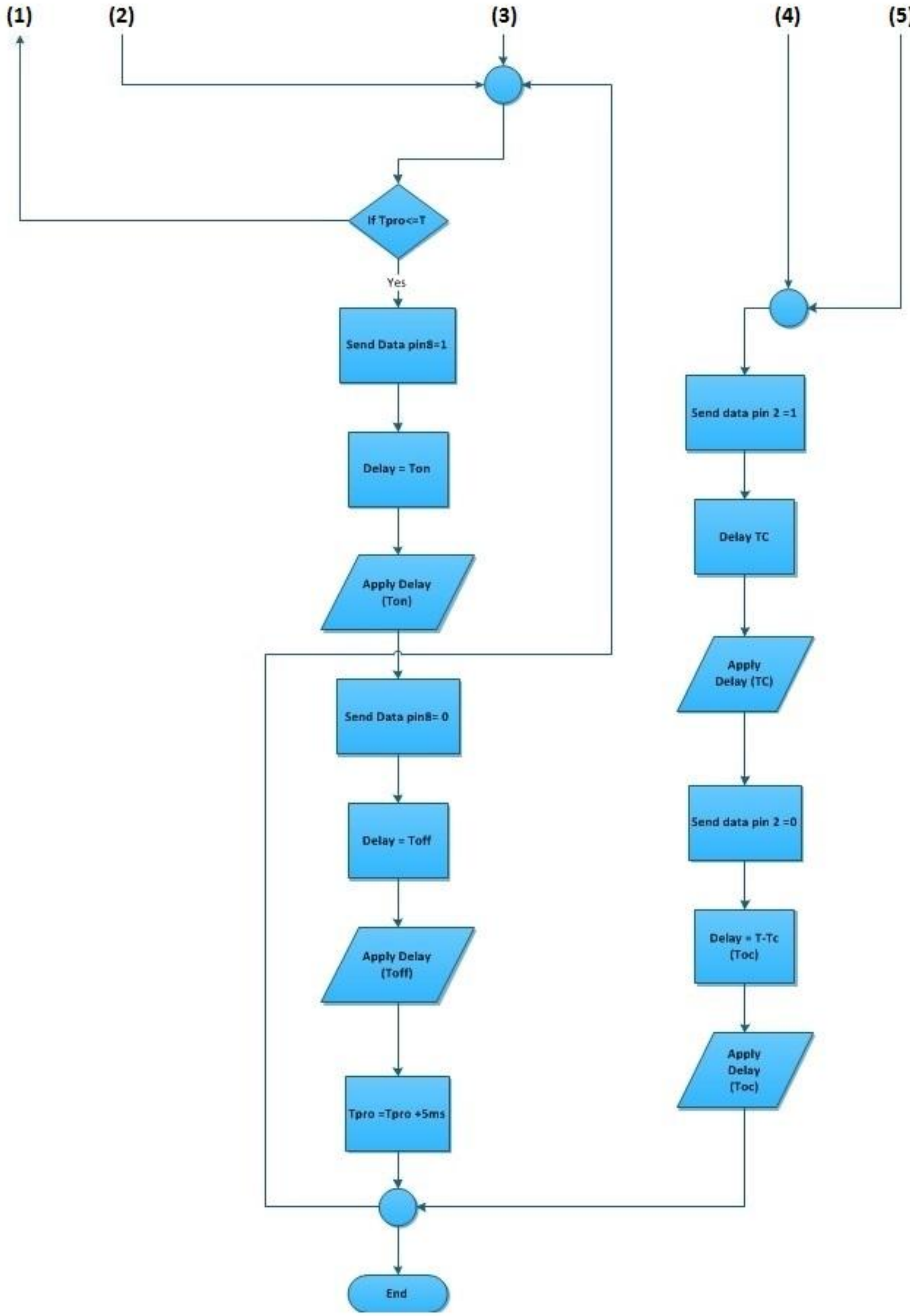


Figure 5.9: Arduino microcontroller

5.3.2 The flow chart of the control program




(1)
(2)
(3)
(4)
(5)
If Tpro<=T
Yes
Send Data pin8=1
Delay = Ton
Apply Delay (Ton)
Send Data pin8= 0
Delay = Toff
Apply Delay (Toff)
Tpro =Tpro +5ms
Send data pin 2 =1
Delay TC
Apply Delay (TC)
Send data pin 2 =0
Delay = T-Tc (Toc)
Apply Delay (Toc)
End

5.4 System Pump and valves

5.4.1 IVAD Blood Pump.

The central part of the IVAD system is the blood pump, which can be used as a left, right, or biventricular assist device. The pump has a titanium alloy case Containing an elastomeric, blood-pumping sac, the blood sac is compressed by applying pressure from a pneumatic driver, thus ejecting blood from the sac. Similarly, the blood sac is expanded by applying vacuum from the driver, thus allowing the pre-load volumes to fill the sac with blood. Mechanical valves mounted in the inflow and outflow ports of the blood pump control the direction of blood flow. The blood pump has an effective stroke volume of 65 ml and, depending on various conditions, will pump approximately 6.5 L/min at a rate of 100 bpm.[1]

Figure 5.10: LVAD pump

5.4.2 Inflow and outflow cannula

The IVAD is connected to the patient's heart and great vessels with cannula. a cannula is inserted into the atrium or ventricle to provide inflow to the IVAD. Blood is returned to the patient with an arterial cannula anastomosed onto the ascending aorta or the main pulmonary artery.[1][12]

How the LVAD pump works [1]

A complete LVAD cycle is as follow:

1) Blood fills the 65cc blood sac by pre-load pressures.
2) A signal is transmitted via the gray electrical lead or signal processor lead to from controller.

3) Air pressure is sent to the pump via the pneumatic lead to compress the blood sac and eject the blood from the pump into the outflow cannula (systole). The air pressure is applied for a predetermined amount of time, usually 300 msec.
4) Vacuum is applied to the pneumatic lead to remove the air to assist the pre-load pressure to fill the pump (diastole).

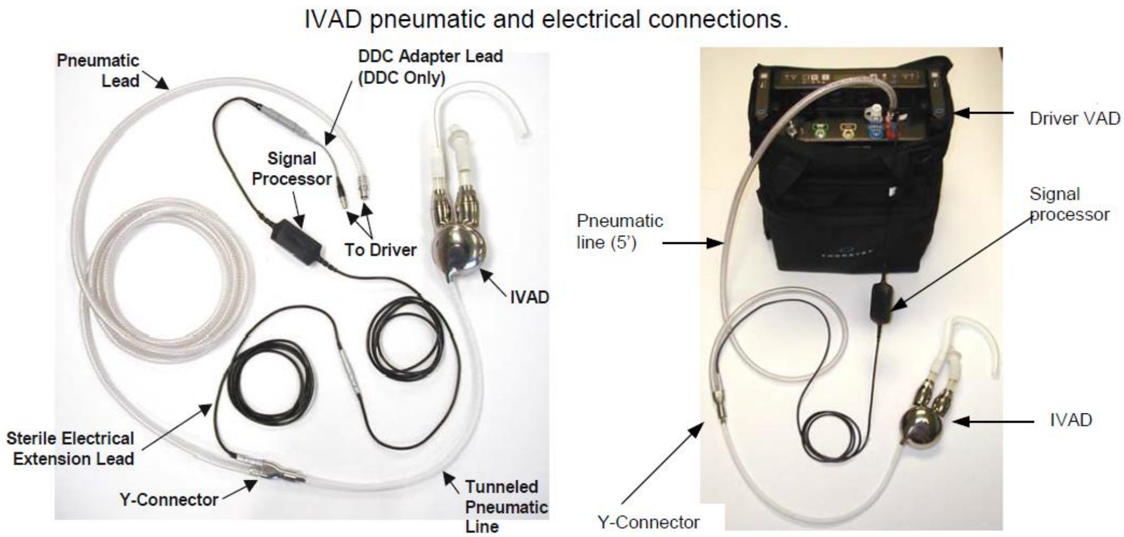


Figure 5.11: LVAD pneumatic and electrical component

We Estimate some information for this pump and take the voltage Equal 12 V, and the current 1.5 A. This pump at 12 V DC gives 7.15 Liter per minute.

5.4.3 Electrical Valve

When using LVAD the blood bypass the heart valve, so in order to control the blood flow from left atrium to left ventricle the electrical blood valve is necessary to use for this purpose.

A solenoid valve (HLPC IP65) is an electromechanically operated valve. The valve is controlled by an electric current through a solenoid: in the case of a two-port valve the flow is switched on or off, sees appendices.

Figure 5.12: Electrical valve

5.4.4 Electrical Valve Circuit:

The following circuit Figure 5.13 controls the electrical valve (ASCO388) between the left atrium and left ventricle.

A 5v pulse signal connected through R5=1K to the base in the NPN transistor which act as a switch to open or close the electrical valve.

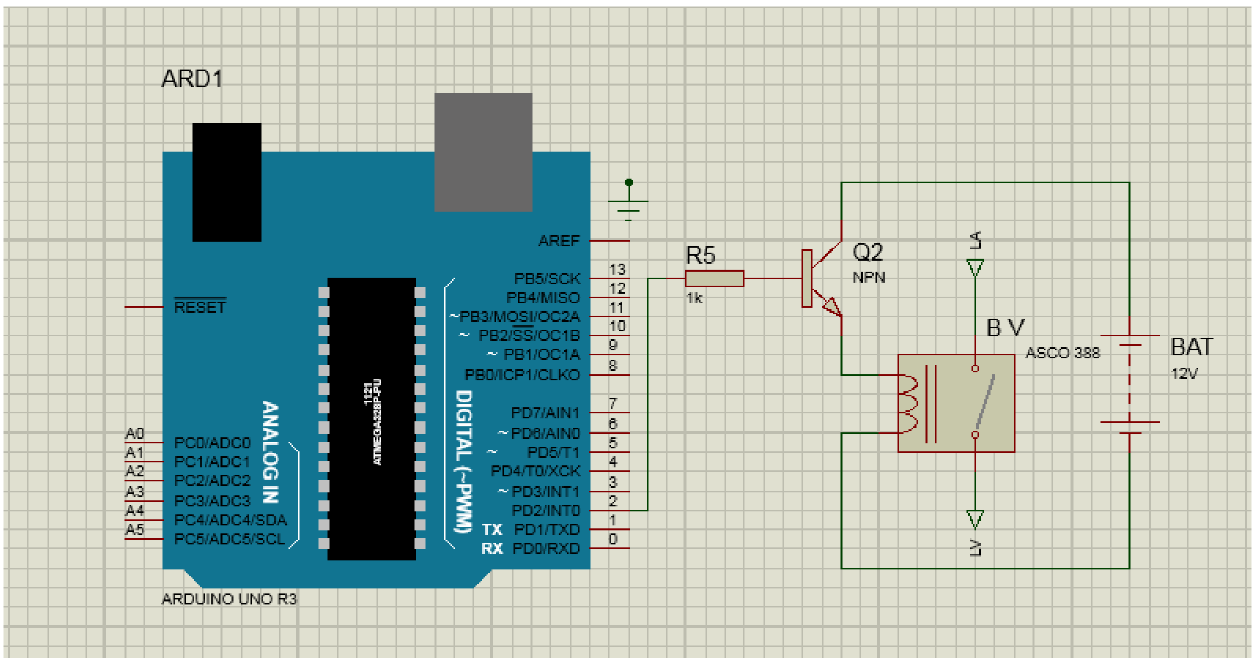


Figure 5.13:control the electrical valve using microcontroller

5.5 Chopper Circuit

DC motor control in a high performance manner. The DC motor control system is designed and performed using a chopper circuit. Using chopper as a converter the speed of DC motor is controllable. The chopper firing circuit gets signal from controller and then by supplying variable voltage to the armature of the motor the desired speed chopper is achieved. There are two different types of control loops, current controller and speed controller. The controller used is Proportional-Integral type.

Using this controller the delay is removed and fast control is achieved. Separately excited DC motor is designed and the complete layout of DC drive mechanism is achieved. The current and speed controller is designed and in order to get stable and high speed control of DC motor, the speed controller is optimized using modulus hugging method .

High performance motor derives are necessary parts of industrial applications. A motor drive system with high performance has special characteristics such as good dynamic speed command tracking and load regulating response. DC motors are well known for their excellent control of speed for acceleration and deceleration.

In a DC motor the power supply directly connects to the field of the motor and causes a precise voltage control which is essential for applications which need control of speed and torque. Because of various advantages such as simplicity,

ease of application, reliability and favorable cost, DC drives have long been a backbone of industrial applications. In comparison with AC drive systems DC drives are less and are normally cheaper for low horsepower ratings. DC motors are identified as adjustable speed machines for many years and a wide range of options have evolved for this purpose. Adjustable speed AC drives would be more complex and expensive. D.C motor is considered as a SISO (Single Input and Single Output) system which has torque/speed characteristics and is compatible with most mechanical loads.[16]

By proper adjustment of the terminal voltage the mentioned characteristic makes a D.C motor controllable over a wide range of speeds. In this article controlling DC motor speed using Chopper as power converter and PI as speed and current controller is investigated. A chopper is a static power electronic device that converts fixed dc input voltage to a variable dc output voltage. Chopper systems have smooth control capability and are highly efficient and fast in response. A chopper can be used to step down or step up the fixed dc input voltage like a transformer.

5.5.2 Principle of chopper operation

A chopper is a "on" or "off" semiconductor switch which is so high in speed. It connects source to load and disconnect the load from source at a fast speed. As shown in Fig1. During the period Ton, chopper is on and load voltage is equal to source voltage Vs. During the period Toff, load voltage is zero and chopper is off. In this manner, a chopped dc voltage is produced at the load terminals.[16]

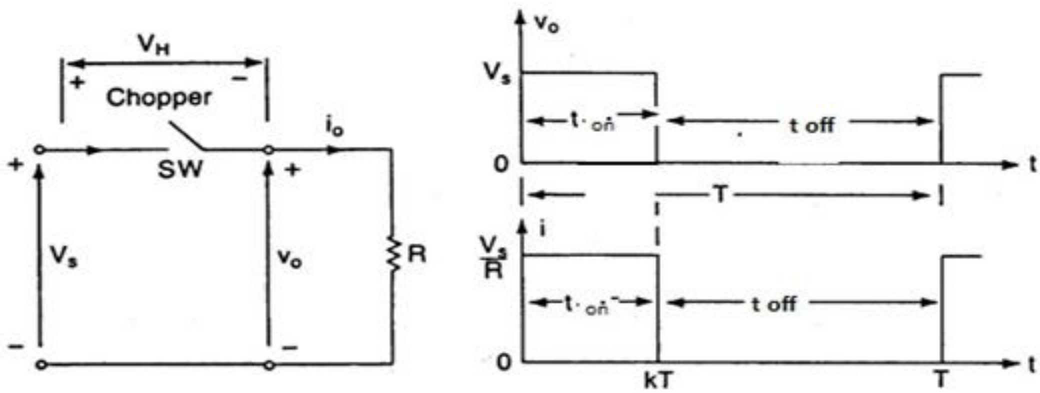


Figure 5.14:chopper circuit

5.5.3 Chopper Equations

Average voltage,

V_o = (Ton/T)*Vs …………………………………………………………………… (5.4)

And Total Time Period

(α) = (Ton/T)……………………………………………………………………...(5.5)

∴ $(V_o)_{avg}$= (Ton/T)*Vs=αV_s ……………………………………………………..(5.6)

Where,

Ton=on-time.

Toff=off-time.

T=Ton+Toff = Chopping period.

$V_o = f * T_{on} * V_s$………………………………………………………………………….. **(5.7)**

[Here, f=1/T=chopping frequency]

Variable Frequency Operation

It is also known as frequency modulation control as frequency (f=1/T) is varied by keeping on time (Ton) as constant or off time (Toff) as constant.

Principle of frequency modulation may be illustrated in for different duty cycles.

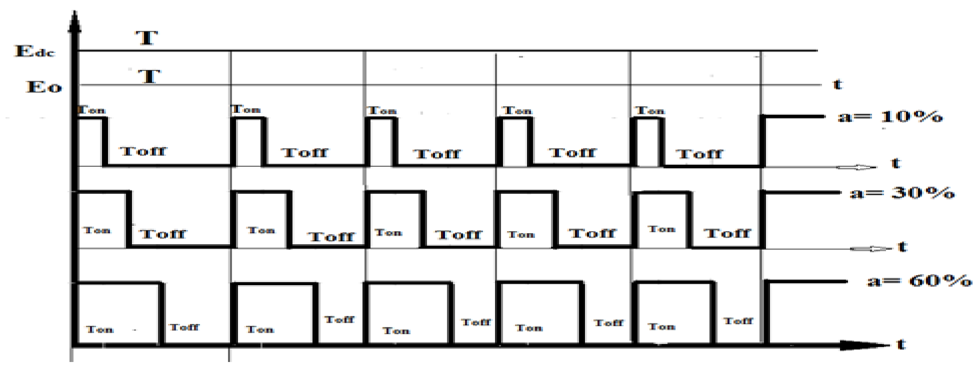


Figure 5.15: Pulse width modulation control [16]

5.3.4 Circuit of DC Chopper and Motor Pump

In figure 5.16 , output pin PB8 give 5v pulse signal connected through R1 to NPN transistor (BD139) which as act as chopper to control in output voltage of motor .

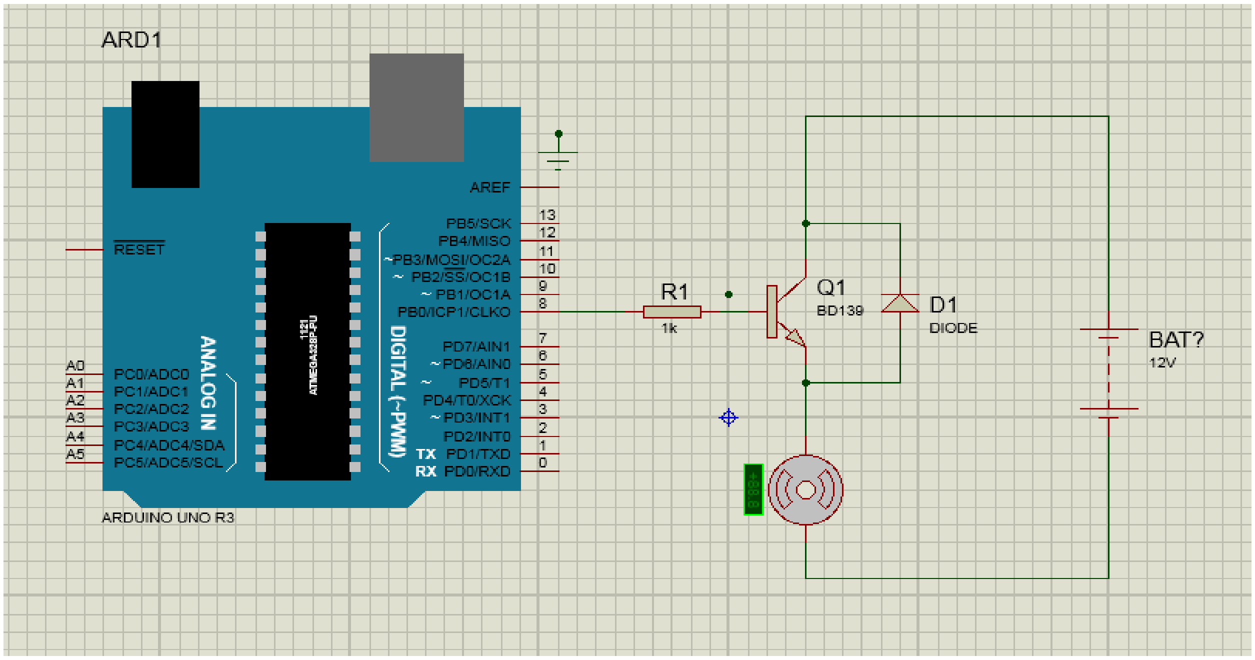


Figure 5.16: Circuit of DC Chopper and Motor Pump

The DC Chopper circuit in Figure 5.12 consists of:

1) Transistor (TIP 122).

2) Resistance 1K ohm.

3) 12 v Power Supply (Battery)

4) DC Motor (LVAD Blood Pump)

5) Freewheel diode .

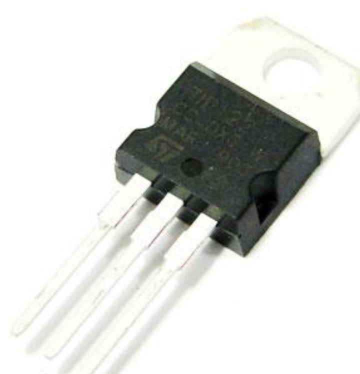


Figure 5.17: Transistor (TIP 122)

- Transistor (BD139).

- Collector-Emitter Volt (Vceo): 100V
- Collector-Base Volt (Vcbo): 100V
- Collector Current (Ic): 5A
- Type: NPN

  - See Appendix.

5.5.4 Calculations:

There is three major cases in the system [19] :

1) Tachycardia Heart Rate > 100 bpm .

2) Normal Heart Rate between 60 to 100 bpm.

3) Bradycardia Heart Rate < 60 bpm.

The speed of the motor depends on the heart beat, we will calculate the time between two R waves to know the case which the heart works in and duo to this time we can calculate the number of beats per minute.

The Time of contraction (TC) of the LVAD for every case equal [13] :

1) Normal Heart Rate at 75 bpm >> TC=300 ms.
2) Tachycardia Heart Rate at 110 bpm >> TC=204.6 ms.
3) Bradycardia Heart Rate at 40 bpm >> TC=562.5 ms.

The standard time in the rate of 75 bpm of the total ECG equal:

$T_{ECG} = \frac{60\ s}{75\ bpm} = 800$ ms………………………………………………………………..….**(5.8)**

TC =300 ms .

Constant coefficient (cc) = $\frac{800\ ms}{300\ ms} = 2.6667$ ………………………………………………..**(5.9)**

Or

Total TC in 1 min = 300ms $\times$75 pbm = 22.5 s……………………………………………**(5.10)**

Constant coefficient = $60s \div 22.5s$ = 2.6667

- Constant coefficient for every Rate equal **2.667.**

5.5.5 Equation for Calculate the Ton of Chopper circuit:

Time between ECG signal $\mathbf{T_{ECG}}$ **,** this time we calculate by Arduino Controller , we need this Time to know any case the system should work .

- $\#bpm = \frac{60}{Tecg}$
- $Vo = \frac{\#bpm \times 12}{110}$
- $Ton = \frac{Vo \times T}{Vs}$
- $T = \frac{1}{f}$, $f = 200\ HZ$ >> T =5ms

The frequency of chopper circuit (f) is choosing 200 HZ, because this frequency appropriate to our system and components.

Where: $\mathbf{T_{ECG}}$ = time between two ECG signal.

#bpm = number of beat per minute.

Vo = voltage of motor.

Ton = Time base to control chopper.

T = Total Time.

F = Chopper Frequency.

❖ **Equations of the pump and motor speed :**

- $Q = A \times v$ ……………………………………………………………………**(5.11)**
- $A = \pi r^2$ ……………………………………………………………………**(5.12)**
- $n = \frac{v}{R}$ ……………………………………………………………………**(5.13)**
- $n\ real\ of\ pump = n \times cc$ ……………………………………………………**(5.14)**

- Where: **Q** = flow rate volume/time.

A = cross section area to out flow tube of pump.

v = velocity of blood. ***n*** = speed of motor.

R = radius of tube. **cc** = constant coefficient.

r = radius of out tube.

a) When the Heartbeat in Normal 1 (60 bpm)case :

The average value of heart rate in Tachycardia is at 60 bpm give the flow of the blood in $\frac{60\times6.5}{100}$ = 3.9 L/min.

Q= $3.9\ \times 10^{-3}\ \mathrm{m}^3/\mathrm{min}$.

The total period of the normal ECG cycle (60 bpm) is 1000 ms TC= 375 ms .

❖ **Chopper calculation :**

- Vo = $\frac{60\ \mathrm{bpm}\times 12\ \mathrm{v}}{120\ \mathrm{bpm}}$ = 6.0 v

- Ton = $\frac{6.0\ \mathrm{v}\times 5\mathrm{ms}}{12\ \mathrm{v}}$ = 2.5 ms

❖ **Pump calculation :**

- v = $\frac{\mathrm{Q}}{\mathrm{A}}$, A= $\pi\times\ 0.8^2 = 0.000201\ M^2$

  v = $\frac{3.9\times10^{-3}}{2.01\times10^{-4}\ M^2} = 19.40298\ \mathrm{m/min}$

- $n = \frac{24.378\ \ m/min}{2.5\times10^{-2}} = 776.119$ rpm

n : The speed of the motor at 60 s continuously , but there is an electric valve that let the blood pass after R wave for 300 ms , so we make some equation to know the real speed for the motor

- Total TC in 1 min $=$ 375ms ×60 bpm =22.5 s
- Cc = $\frac{1\ min}{Total\ TC}$**……………………………………………………………………….(5.15)**
- Cc = $\frac{1\ min}{Total\ TC} = 60s \div 22.5s$ = 2.667

✓ n real of pump = 975.124 × 2.667 = 2069.9093 rpm.

b) When the Heartbeat in Normal 2 (90 bpm)case :

The average value of heart rate in Tachycardia is at 90 bpm give the flow of the blood in $\frac{90\times6.5}{100}$ = 5.85 L/min.

Q= $5.85 \times 10^{-3}\ \mathrm{m}^3/\mathrm{min}$.

The total period of the normal ECG cycle (90 bpm) is 666 ms TC= 250 ms .

❖ **Chopper calculation :**

- Vo = $\frac{90\ \mathrm{bpm}\times12\ \mathrm{v}}{120\ \mathrm{bpm}}$ = 9.0 v
- Ton = $\frac{9.0\ \mathrm{v}\times5\mathrm{ms}}{12\ \mathrm{v}}$ = 3.75 ms

❖ **Pump calculation :**

- v = $\frac{Q}{A}$, A= $\pi\times\ 0.8^2 = 0.000201\ M^2$

  v = $\frac{5.85\times10^{-3}}{2.01\times10^{-4}\ M^2} = 29.104477\ \mathrm{m/min}$

- $n = \frac{24.378\ \ m/min}{2.5\times10^{-2}}$ = 1164.179 rpm

n : The speed of the motor at 60 s continuously , but there is an electric valve that let the blood pass after R wave for 300 ms , so we make some equation to know the real speed for the motor

- Total TC in 1 min = 250 ms ×90 bpm =22.5 s
- Cc = $\frac{1\ min}{Total\ TC}$**……………………………………………………………………….(5.15)**
- Cc = $\frac{1\ min}{Total\ TC} = 60s \div 22.5s$ = 2.667

✓ n real of pump = 1164.179 rpm × 2.667 = 3104.865 rpm.

c) **In the Tachycardia case :**

The average value of heart rate in Tachycardia is at 120 bpm give the flow of the blood in $\frac{120\times6.5}{100}$ = 7.8 L/min.

Q = $7.8\times10^{-3}\ \mathrm{m^3/min}$.

The total period of the normal ECG cycle (60 bpm) is 800msec TC= 375msec . so, in the case of Tachycardia (120 bpm) the TC = 187.5 ms .

❖ **Chopper calculation :**

- Vo = 12 v
- Ton = T = 5ms

❖ **Pump calculation :**

- v = $\frac{Q}{A}$, A= $\pi\times\ 0.8^2 = 0.000201\ m^2$

  v = $\frac{7.8\times10^{-3}\ \mathrm{m^3}}{2.01\times10^{-4}\ \ \mathrm{m^2}} =$ 38.805 m/min

- $n = \frac{38.805\ \mathrm{m/min}}{2.5\times10^{-2}\ m} =$ 1552.238 rpm
- Total TC in 1 min $=$ 204.6ms ×110 pbm =22.5 s
- Cc = $\frac{1\ min}{Total\ TC}$**…………………………………………………………………(5.16)**
- Cc = $\frac{1\ min}{Total\ TC} = 60s \div 22.5s$ = 2.667

✓ n real of pump= 1552.238 rpm × 2.667 = 4139.82 rpm

d) In the Bradicardia case :

The average value of heart rate in **Bradicardia** is at 30 bpm give the flow of the blood in $\frac{30\times6.5}{100}$ = 1.95 L/m.

Q = $1.95\times10^{-3}\ \mathrm{m^3/min.}$

The total period of the Bradiacrdia ECG cycle (30 bpm) TC = 750 ms .

❖ **Chopper calculation :**

- Vo = $\frac{30\ \mathrm{bpm}\times12\ \mathrm{v}}{120\ \mathrm{bpm}}$ = 3.0 V.
- Ton = $\frac{3.0\mathrm{v}\times5\mathrm{ms}}{12\ \mathrm{v}}$ = 1.25 ms

❖ **Pump calculation :**

- v = $\frac{Q}{A}$,   A= $\pi\times\ 0.8^2=0.000201\ M^2$

  v = $\frac{1.95\ \times10^{-3}\ \mathrm{m^3/min.}}{2.01\times10^{-4}\ \ m^2}$ = 9.7014 m/min

- n = $\frac{9.7014\ m/min}{2.5\times10^{-2}\ m}$ = 388.059 rpm
- Total TC in 1 min = 562.5ms ×40 pbm =22.5 s
- Cc = $\frac{1\ min}{Total\ TC}=60s\div22.5s$ = 2.667

✓ n real of pump = 390.05 rpm × 2.667 = 1034.955 rpm.

e) Emergence case :

If there is an error occur such as losing ECG signal of the patient , the system will operate in 75 bpm as programmed in microcontroller .

The average value of heart rate in emergence is at 75 bpm give the flow of the blood in $\frac{75\times6.5}{120}$ = 4.0625 L/min.

Q= $4.0625\ \times 10^{-3}\ \mathrm{m}^3/\mathrm{min}$.

The total period of the normal ECG cycle (75bpm) is 800msec TC= 300msec .

❖ **Chopper calculation :**

- Vo = $\frac{75\ \mathrm{bpm}\times 12\ \mathrm{v}}{120\ \mathrm{bpm}}$ = 7.5 V
- Ton = $\frac{7.5\ \mathrm{v}\times 5\mathrm{ms}}{12\ \mathrm{v}}$ = 3.125 ms

❖ **Pump calculation :**

- v = $\frac{Q}{A}$, A= $\pi\times\ 0.8^2 = 0.000201\ M^2$

  v = $\frac{4.0625\times10^{-3}}{2.01\times10^{-4}\ M^2} = 20.2114\ \mathrm{m/min}$

- n = $\frac{20.2114\ \ m/min}{2.5\times10^{-2}}$ = 808.457 rpm.

- Total TC in 1 min $=$ 300ms ×75 bpm =22.5 s
- Cc = $\frac{1\ min}{Total\ TC}$**…………………………………………………………………………(5.15)**
- Cc = $\frac{1\ min}{Total\ TC} = 60s \div 22.5s$ = 2.667

n real of pump = 808.457 rpm × 2.667 = 2156.156 rpm

5.6 LCD Display

LCD use to display Power and medical information about statues of patient , it's Important to be To keep abreast of the status of the patient and how the device works . see **Figure** 5.14, LCD 16*4 display used in project ,see appendix.

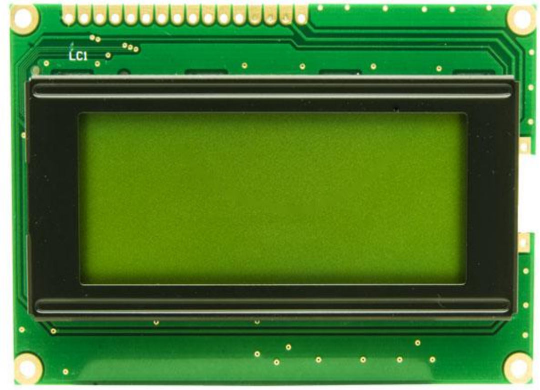


Figure 5.18: LCD Display

5.6.1 Connection Circuit:

This Figure shows the connection wires to the LCD,
VSS ,VDD,VEE the power of the LCD see Appendix A
D4,D5,D6,D7 is the data from Arduino

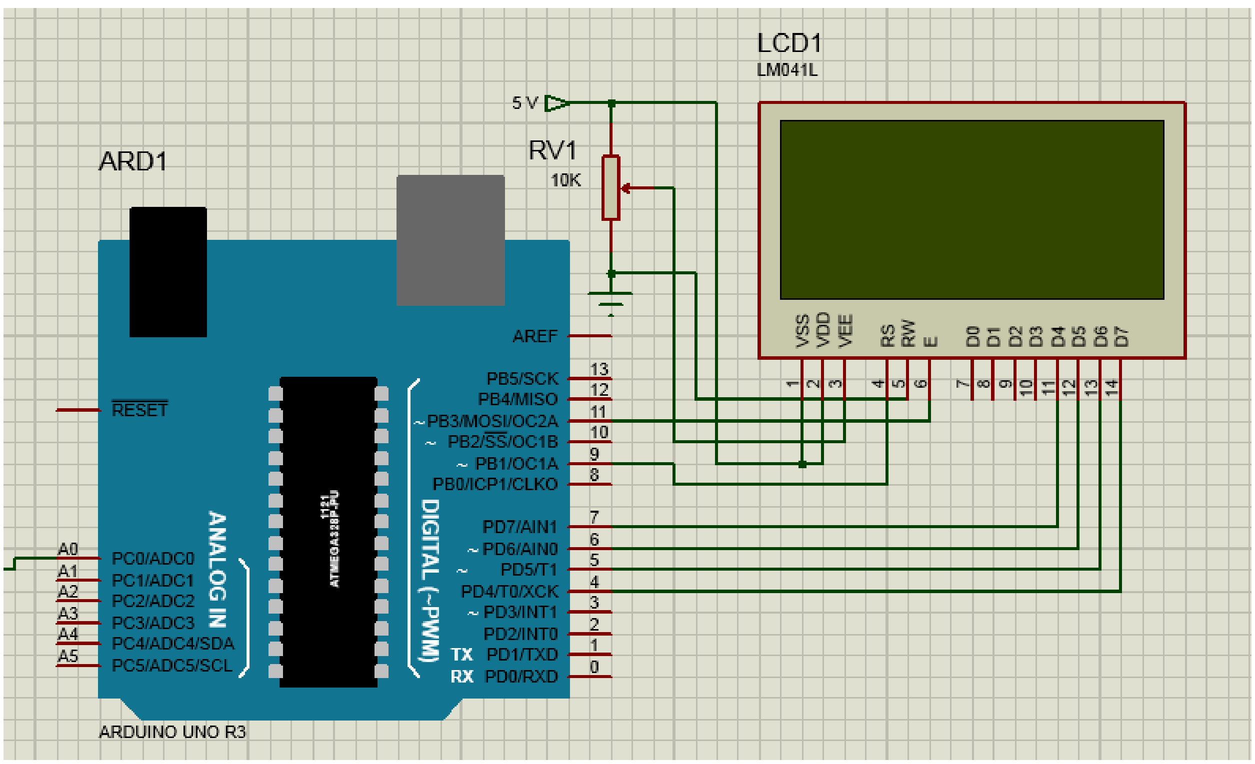


Figure 5.19: Connection circuit

5.6 Batteries

The system designed to operate with at least two batteries

1) Two External Battery 12v.

2) Internal Battery 5v .

· Each side of the Driver has a slot for a battery.

· Each battery provides to 8 hours (LVAD)when fully charged [12].

5.7 The final project circuit

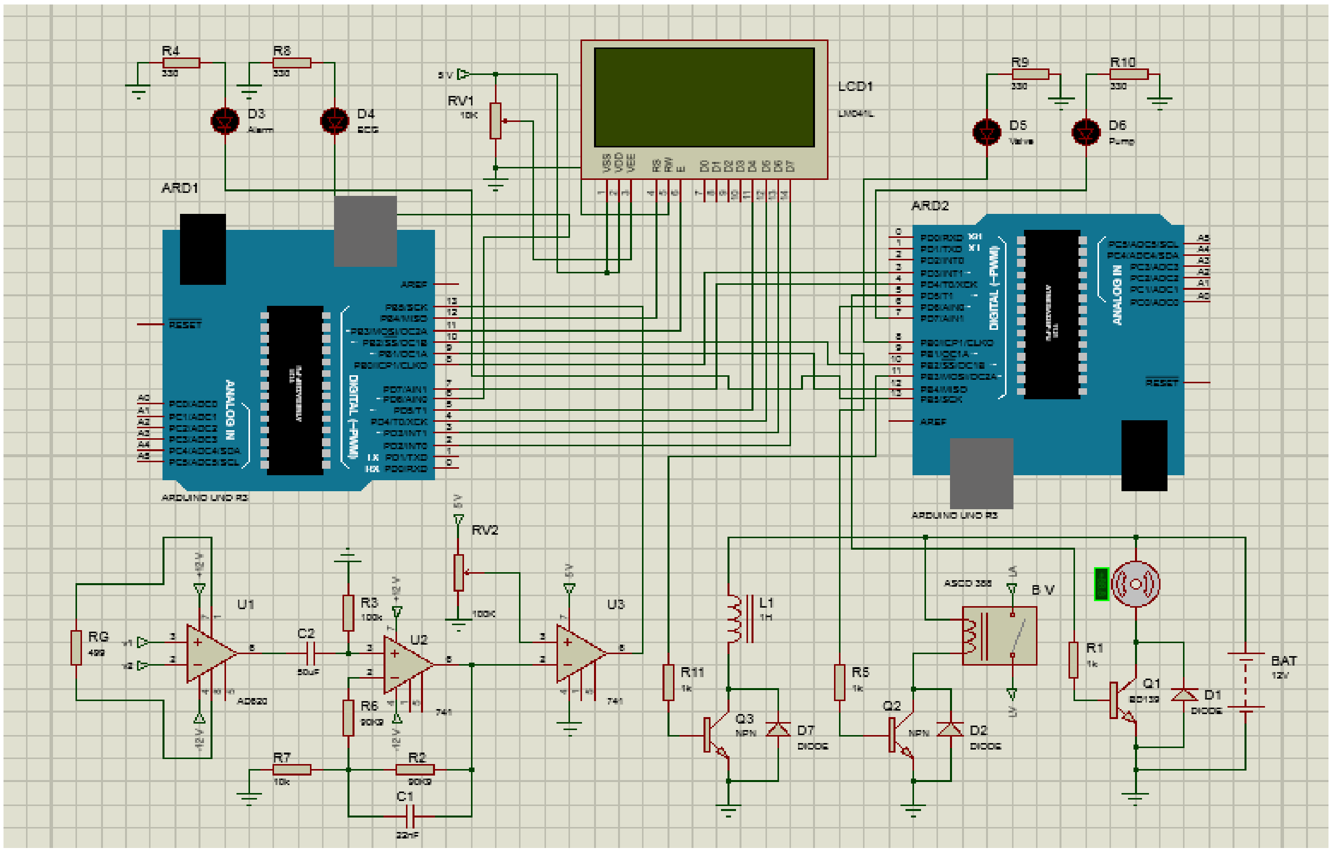


Figure 5.20: Project circuit

6

Chapter six

Implementation, Experiments and results

6.1 Introduction.

6.2 System components and circuits.

6.3 Testing and results.

6.1 Introduction

Practical implementation of the project has been done in the second semester, and this implementation started by implementing each individual subsystem. After completing this implementation, the individual subsystem are connected together to accomplish the project as one unit.

6.2 System components and circuits

In following section, it will show the primary circuit of the system before implemented on the printed board.

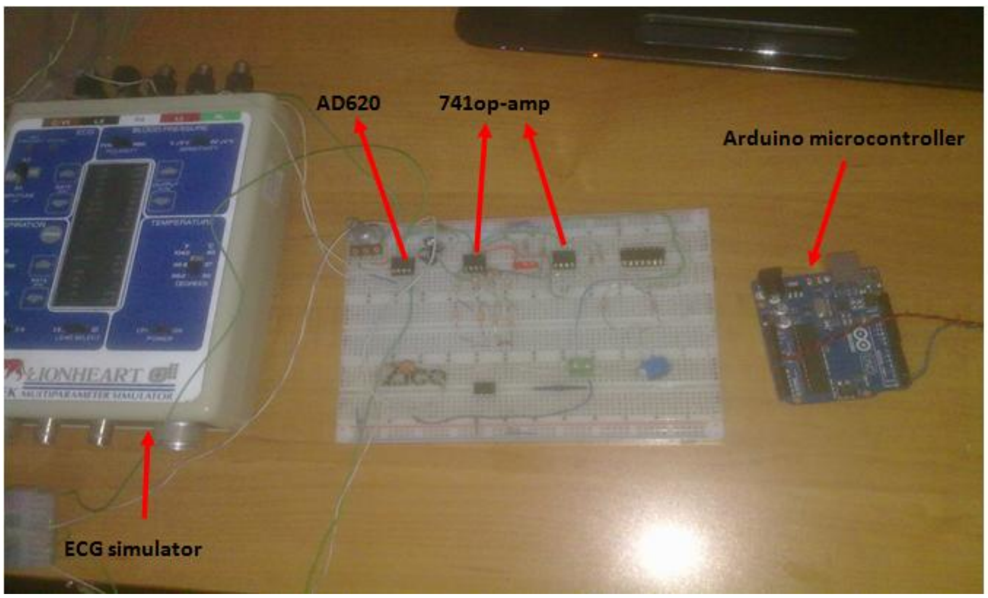


Figure 6.1: Main components

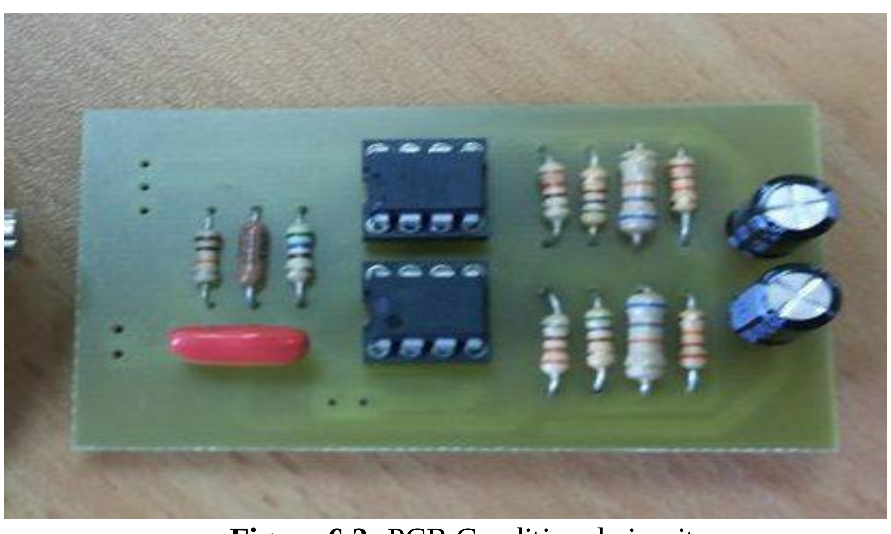


Figure 6.2: PCB Conditional circuit

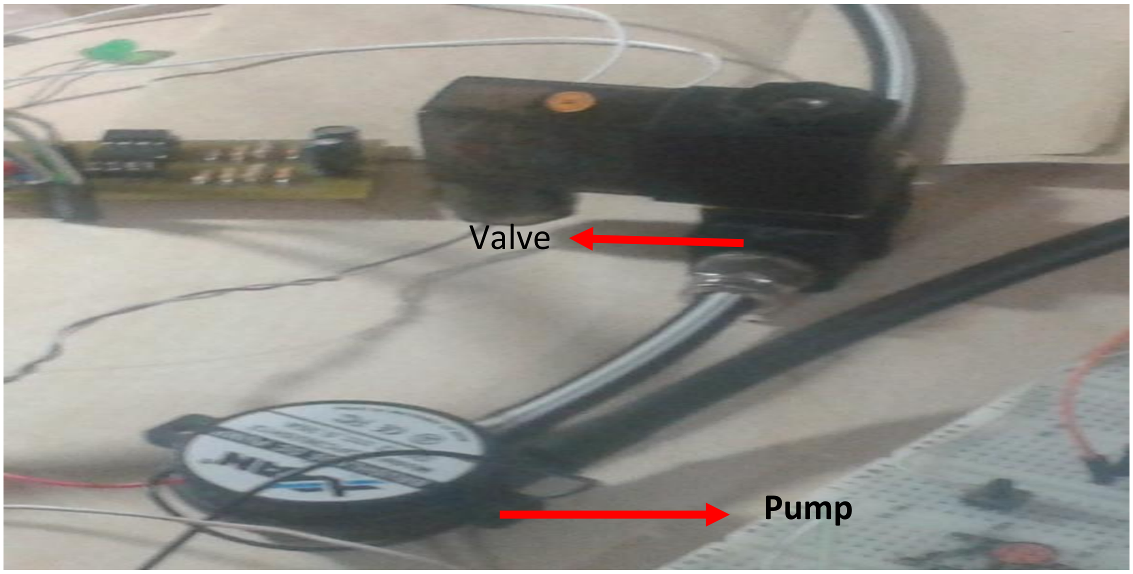


Figure 6.3: The pump and valve of system

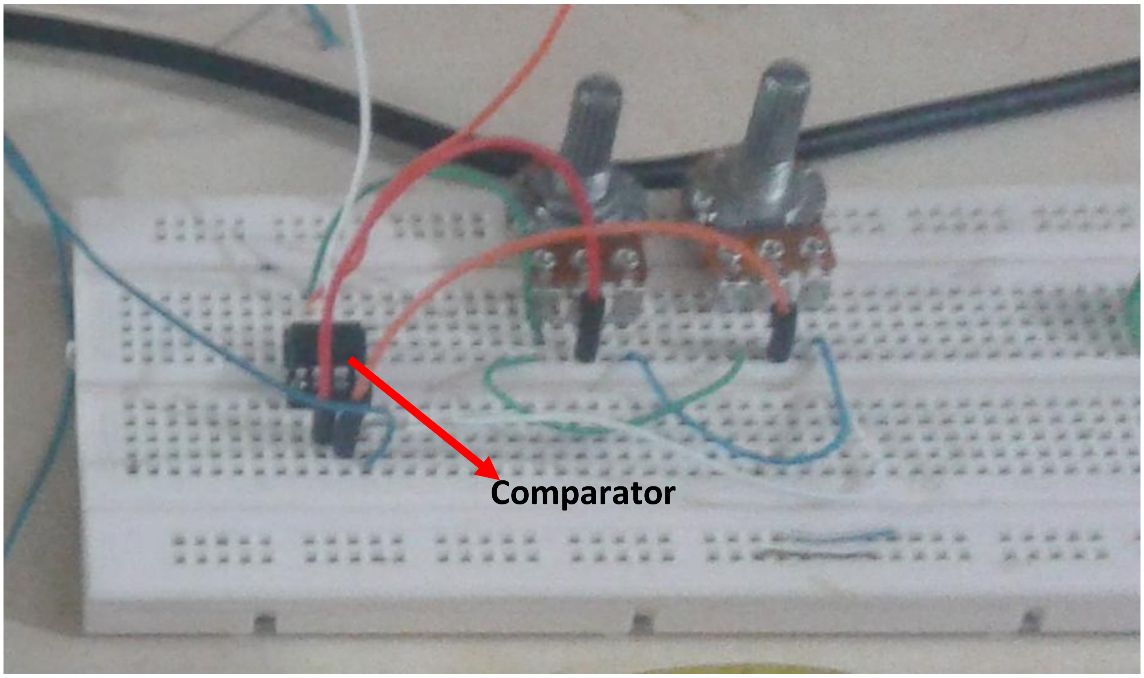


Figure 6.4: Detecting R wave circuits

After testing each part of the system successfully, all the parts of the system has been built in one printed circuit as shown in the figure

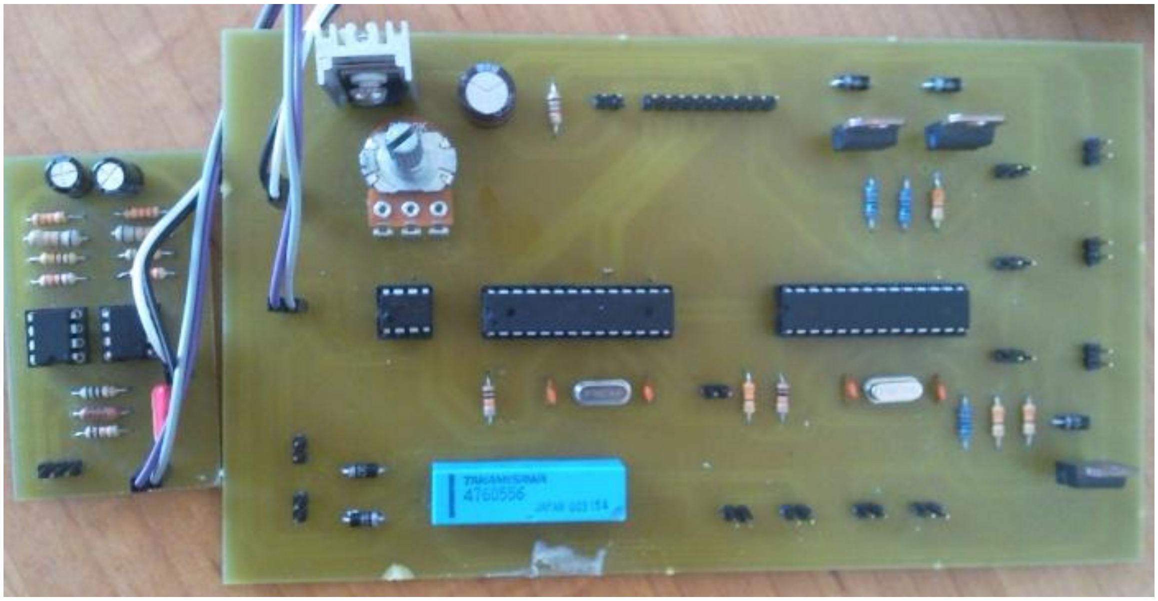


Figure 6.5: system printed circuit

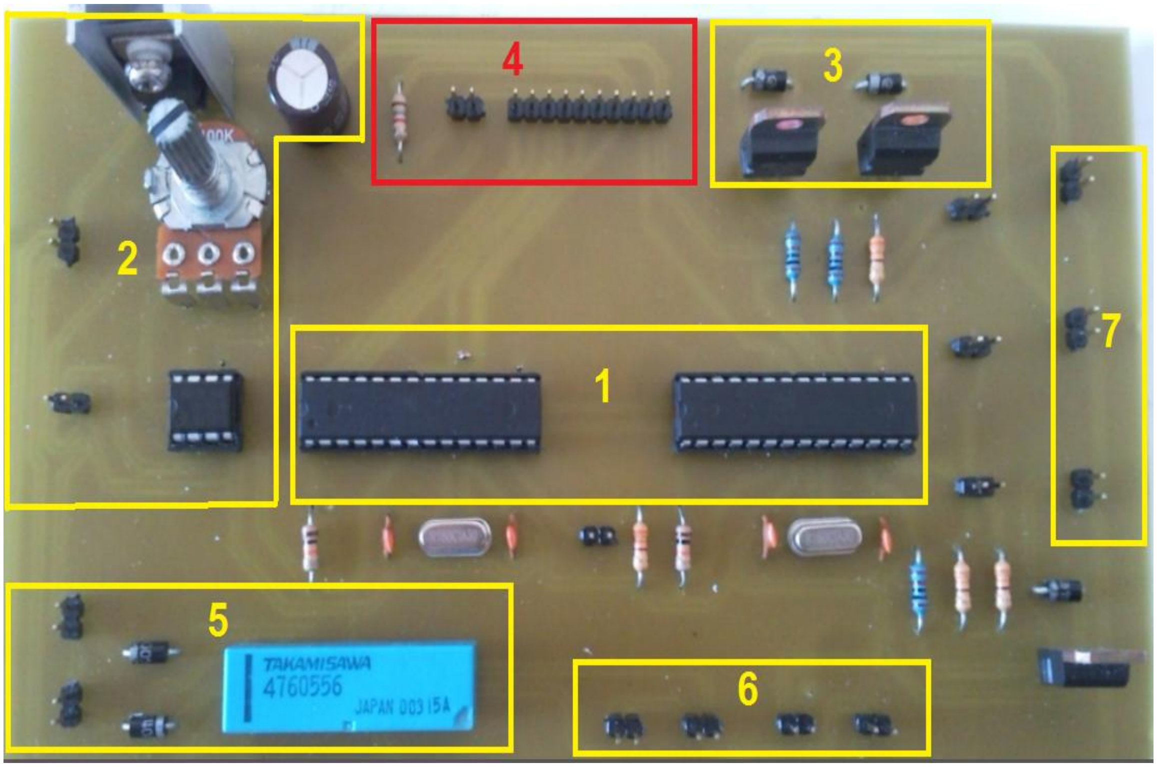


Figure 6.6:PCB component

1. The first rectangular representing the two IC's of Arduino microcontroller, work in parallel process.
2. The second rectangular representing the R wave detecting circuit which consists of comparator and the potentiometer in the addition of that we have the DC rectification circuit with regulator LM7805.
3. These components in the third rectangular is representing two transistors used in chopper circuit.
4. The fourth rectangular is representing the pins of LCD and its power pins too.
5. The fifth rectangular is representing dual relay and diodes for protection.
6. The sixth rectangular is representing the start,stop,reset and the power pins.
7. The fifth rectangular is representing the pump, valve and bell pins.

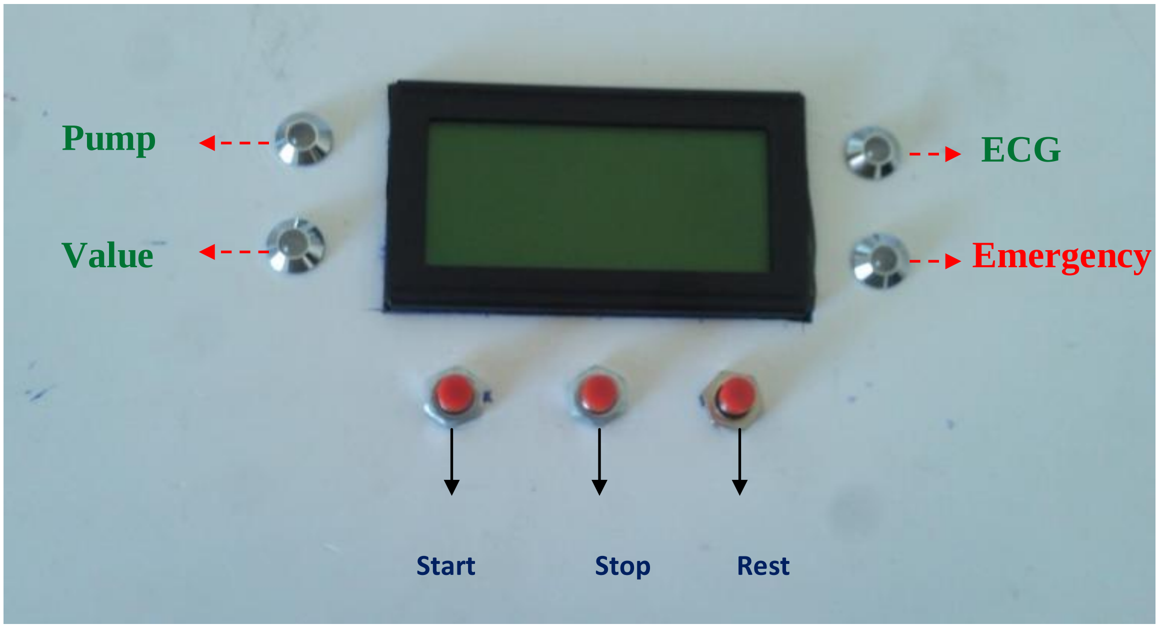


Figure 6.7: The cover of the device

6.3 System testing and results

6.3.1 The conditional circuit signals

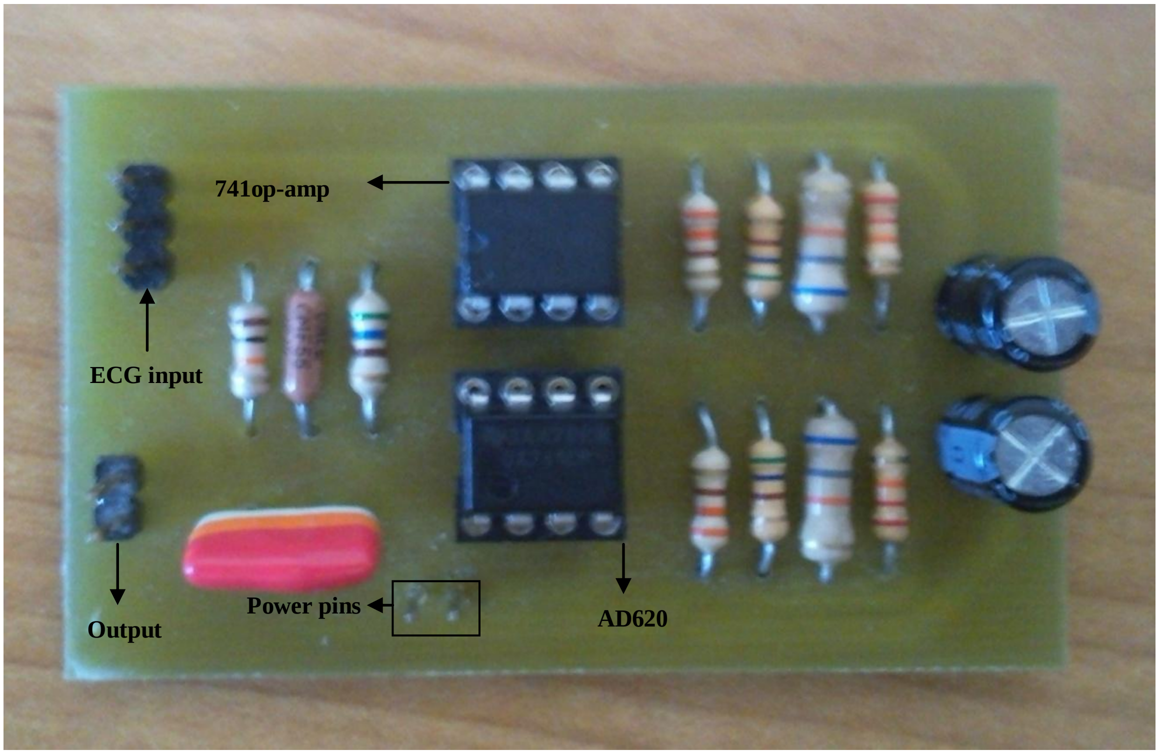


Figure 6.8: conditional circuit component

The output ECG signals from the conditional circuit are as follow:

Figure 6.9: ECG signal on 30bpm mode

Figure 6.10: ECG signal on 60bpm mode

Figure 6.11: ECG signal on 90bpm mode

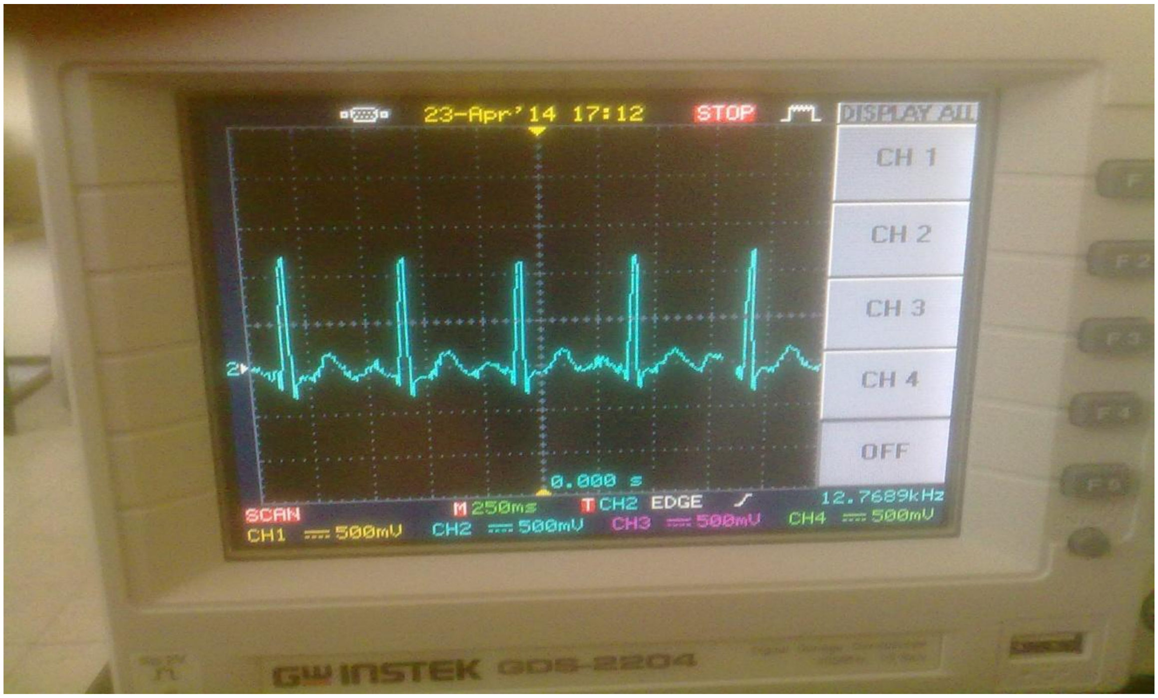


Figure 6.12: ECG signal on 120bpm mode

6.3.2 Results

Beat per minute	Blood flow	Pump voltage	Pump speed	Mode(case)
30 bpm	1.95 L/min.	3.0V	1035 rpm	Bradycardia
60 bpm	3.9 L/min.	6.0V	2070 rpm	Normal 1
90 bpm	5.85 L/min.	9.0V	3105 rpm	Normal 2
120 bpm	7.8 L/min.	12.0V	4140 rpm	Tachycardia
75 bpm	4.06 L/min.	7.5V	2156 rpm	Emergency

Note:

The circuit below shows the designed circuit on the proteus software by the project team, before convert it to PCB.

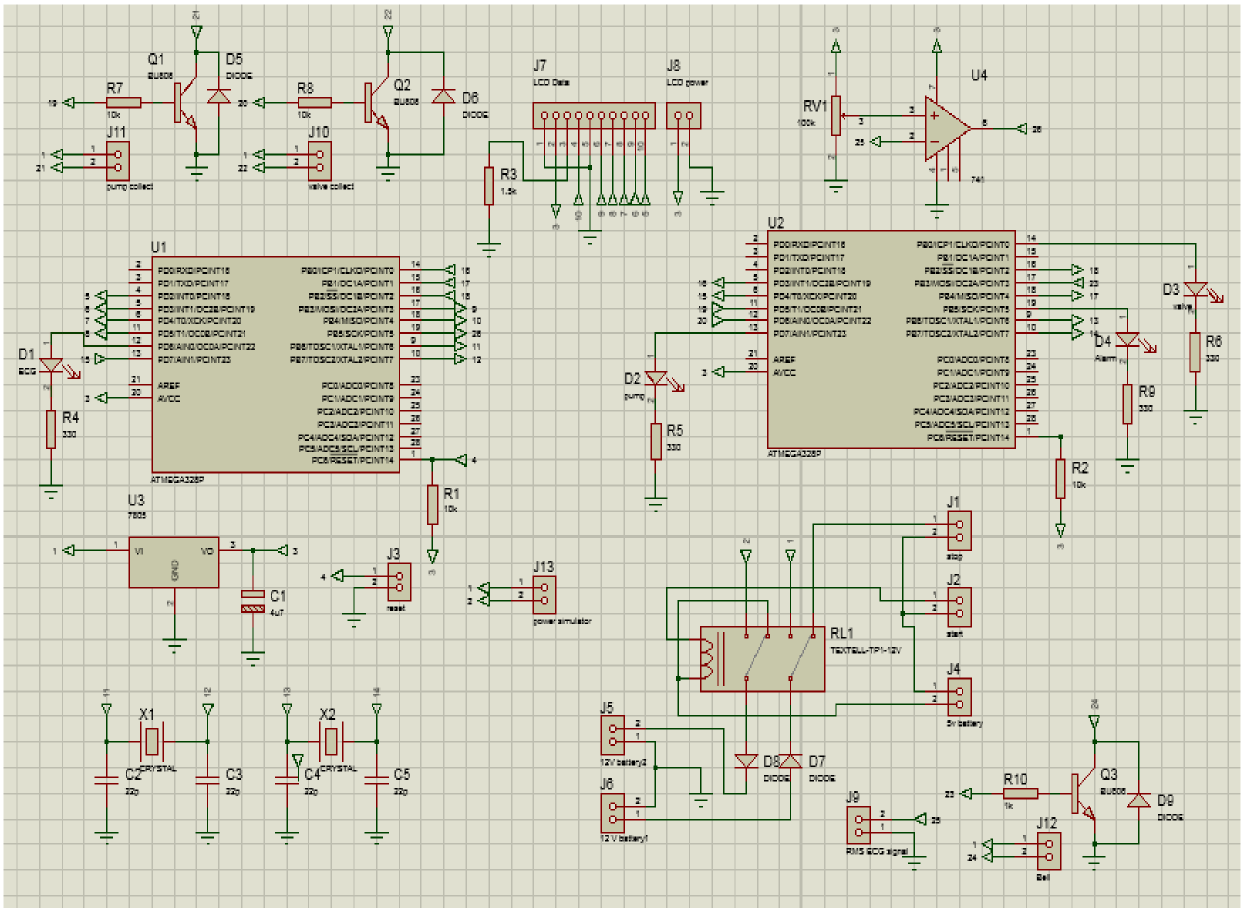


Figure 6.12: The system circuit (schematic first stage)

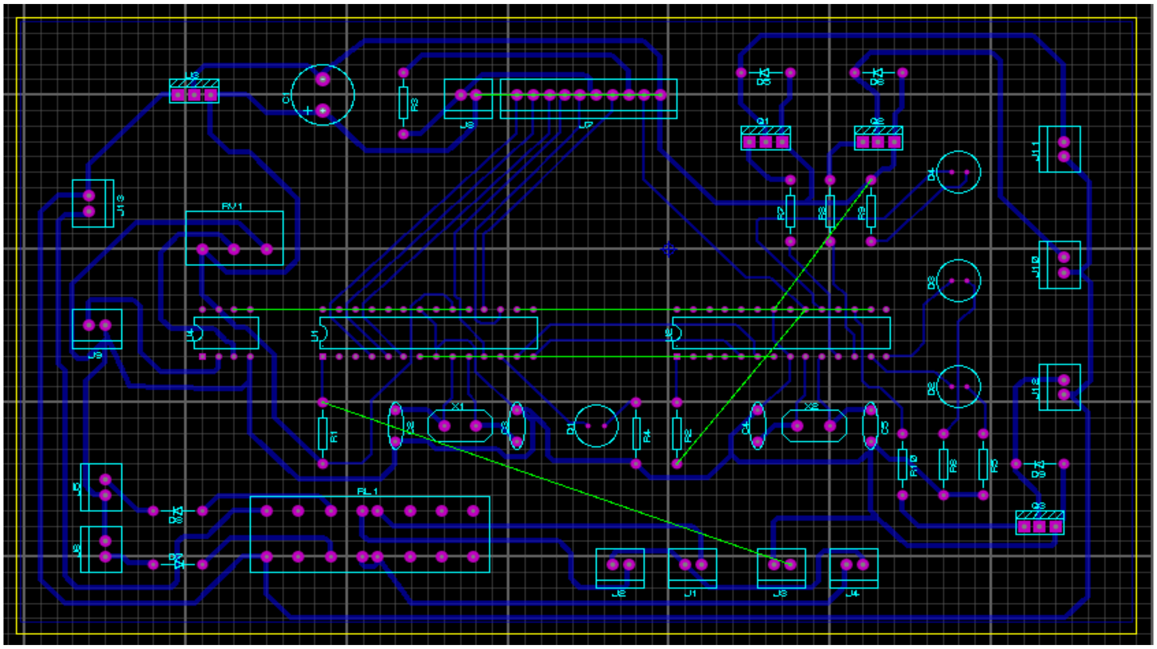


Figure 6.13: The system circuit (layout second stage)

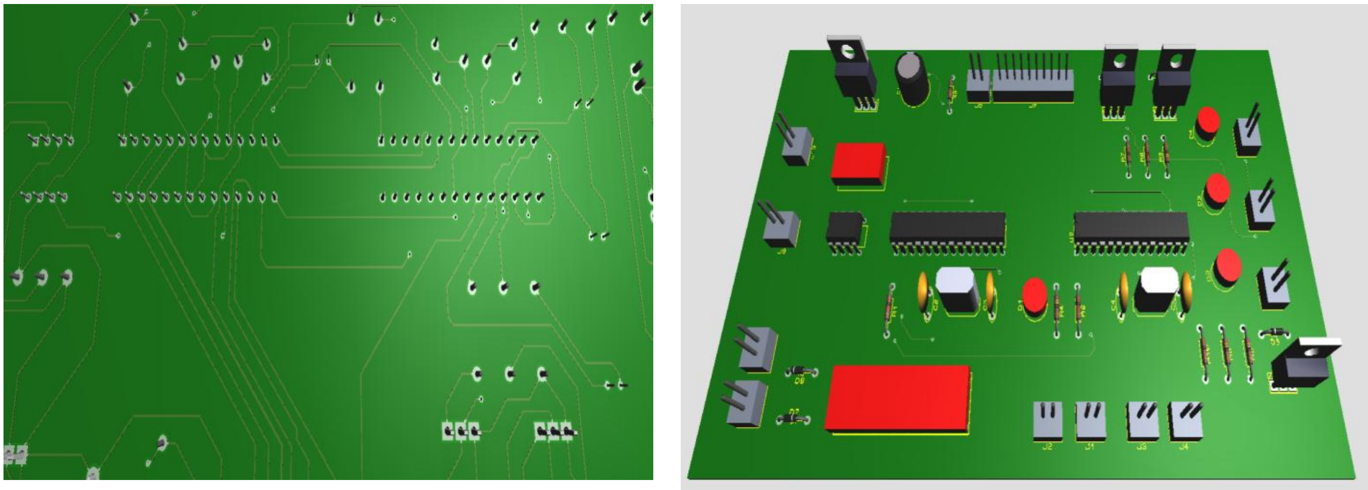


Figure 6.14: The system circuit (3D last stage)

7

Chapter Seven

Recommendation, Challenges and Conclusions.

7.1 Recommendations.

7.2 Challenges.

7.3 Conclusions.

7.1 Recommendations:

In this project a left ventricular heart assisting device has been designed and built to support the blood pumping from left ventricle to aorta, it can be improved by studying the air bubbles and vibration which made while the pumping circulation.

7.2 Challenges:

While designing the system, there are many challenge were faced, such as:

- Some of required components for the project are not available in the local market; such as circulation pump.
- Importing a plastic body from Turkey.
- Some of the project components are expensive.
- Lack of knowledge in the local hospital about the left ventricular heart assistant device.
- Detecting the R wave from the ECG signal.

7.3 Conclusions

- In this project many information about the physiology of circulation system, heart parts and heart frailer.
- The project is divided in two systems :
  1. The artificial heart and pumping system.
  2. The controlling and synchronization system.
- A scientific paper has been written for this project.

The Thoratec pump is the best and the appropriate for this project, but this kind of pumps doesn't available in the mart so we chose to work on X-Fan pump close in characteristics of the thoratec pump, the table below is showing the characteristics of each of them.

Table 7.1: Characteristics of the pumps

Beat per minute	Thoratec LVAD Blood Pump.	X-Fan Brushless DC Pump
30 bpm	1035 rpm	625 rpm
60 bpm	2070 rpm	1250 rpm
90 bpm	3105 rpm	1875 rpm
120 bpm	4140 rpm	2500 rpm
75 bpm	2156 rpm	1302 rpm

Appendices

References

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Low Cost Low Power Instrumentation Amplifier

AD620

FEATURES

Easy to use
- **Gain set with one external resistor**
  - **(Gain range 1 to 10,000)**
- **Wide power supply range (±2.3 V to ±18 V)**
- **Higher performance than 3 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

Table 1. Next Generation Upgrades for AD620

Part	Comment
AD8221	Better specs at lower price
AD8222	Dual channel or differential out
AD8226	Low power, wide input range
AD8220	JFET input
AD8228	Best gain accuracy
AD8295	+2 precision op amps or differential out
AD8429	Ultra low noise

CONNECTION DIAGRAM

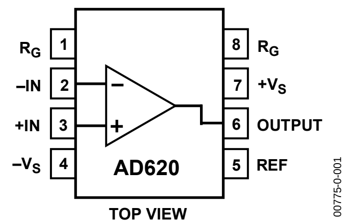

Figure 1. 8-Lead PDIP (N), CERDIP (Q), and SOIC (R) Packages

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. 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, and 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.

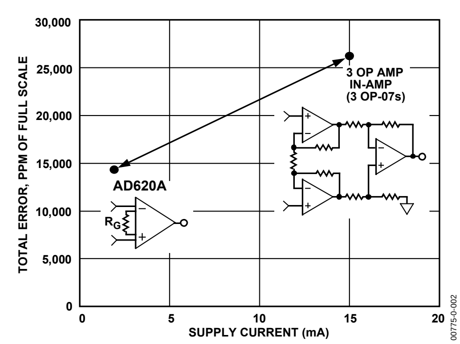

Figure 2. Three Op Amp IA Designs vs. AD620

Rev. H

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 **www.analog.com**
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IMPORTANT LINKS for the AD620*

Last content update 01/08/2014 09:49 am

Looking for a high performance in-amp with lower noise, wider bandwidth, and fast settling time? Consider the **AD8421**

Looking for a high performance in-amp with lower power and a rail-to-rail output? Consider the **AD8422**.

DOCUMENTATION

AD620: Military Data Sheet

AN-282: Fundamentals of Sampled Data Systems

AN-244: A User's Guide to I.C. Instrumentation Amplifiers

AN-245: Instrumentation Amplifiers Solve Unusual Design Problems

AN-671: Reducing RFI Rectification Errors in In-Amp Circuits

AN-589: Ways to Optimize the Performance of a Difference Amplifier

A Designer's Guide to Instrumentation Amplifiers (3rd Edition)

UG-261: Evaluation Boards for the AD62x, AD822x and AD842x Series

ECG Front-End Design is Simplified with MicroConverter

Low-Power, Low-Voltage IC Choices for ECG System Requirements

Ask The Applications Engineer-10

Auto-Zero Amplifiers

High-performance Adder Uses Instrumentation Amplifiers

Protecting Instrumentation Amplifiers

Input Filter Prevents Instrumentation-amp RF-Rectification Errors

The AD8221 - Setting a New Industry Standard for Instrumentation Amplifiers

ADI Warns Against Misuse of COTS Integrated Circuits

Space Qualified Parts List

Applying Instrumentation Amplifiers Effectively: The Importance of an Input Ground Return

Leading Inside Advertorials: Applying Instrumentation Amplifiers Effectively–The Importance of an Input Ground Return

DESIGN TOOLS, MODELS, DRIVERS & SOFTWARE

In-Amp Error Calculator

These tools will help estimate error contributions in your instrumentation amplifier circuit. It uses input parameters such as temperature, gain, voltage input, and source impedance to determine the errors that can contribute to your overall design.

In-Amp Common Mode Calculator

AD620 SPICE Macro-Model

AD620A SPICE Macro-Model

AD620B SPICE Macro-Model

AD620S SPICE Macro-Model

AD620 SABER Macro-Model Conv, 10/00

EVALUATION KITS & SYMBOLS & FOOTPRINTS

View the Evaluation Boards and Kits page for documentation and purchasing

Symbols and Footprints

PRODUCT RECOMMENDATIONS & REFERENCE DESIGNS

CN-0146: Low Cost Programmable Gain Instrumentation Amplifier Circuit Using the ADG1611 Quad SPST Switch and AD620 Instrumentation Amplifier

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Quality and Reliability
Lead(Pb)-Free Data

SAMPLE & BUY

AD620

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SPECIFICATIONS

Typical @ 25°C, V_S = ±15 V, and R_L = 2 kΩ, unless otherwise noted.

Table 2.

Parameter	Conditions	AD620A			AD620B			AD620S[1]			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
GAIN	G = 1 + (49.4 kΩ/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
Overtemperature	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
Overtemperature	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
Overtemperature				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
Overtemperature				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
Overtemperature		−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
Overtemperature		−V_S + 2.1		+V_S − 1.4	−V_S + 2.1		+V_S + 2.1	−V_S + 2.3		+V_S − 1.4	V

Parameter	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Unit
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
Overtemperature		$-V_S$ + 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
Overtemperature		$-V_S$ + 1.6		$+V_S$ − 1.5	$-V_S$ + 1.6		$+V_S$ − 1.5	$-V_S$ + 2.3		$+V_S$ − 1.5	V
Short Circuit Current			±18			±18			±18		mA
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 = ±2.3 V to ±18 V		0.9	1.3		0.9	1.3		0.9	1.3	mA
Overtemperature			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

[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 that is used to specify PSR.

ABSOLUTE MAXIMUM RATINGS

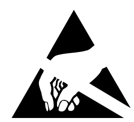
Table 3.

Parameter	Rating
Supply Voltage	±18 V
Internal Power Dissipation[1]	650 mW
Input Voltage (Common-Mode)	$\pm V_S$
Differential Input Voltage	25 V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range (Q)	−65°C to +150°C
Storage Temperature Range (N, R)	−65°C to +125°C
Operating Temperature Range	
AD620 (A, B)	−40°C to +85°C
AD620 (S)	−55°C to +125°C
Lead Temperature Range	
(Soldering 10 seconds)	300°C

[1] Specification is for device in free air:
8-Lead Plastic Package: θ_{JA} = 95°C
8-Lead CERDIP Package: θ_{JA} = 110°C
8-Lead SOIC Package: θ_{JA} = 155°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other condition s above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

TYPICAL PERFORMANCE CHARACTERISTICS

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

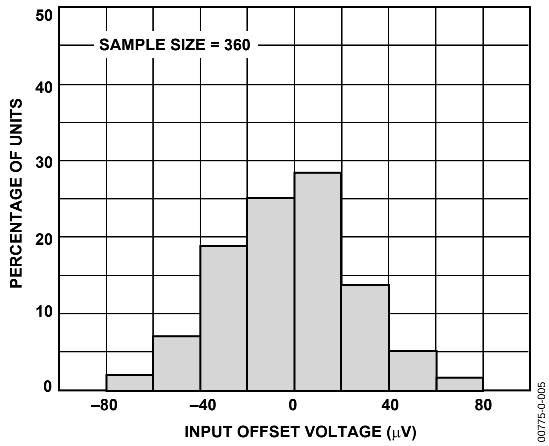


Figure 3. Typical Distribution of Input Offset Voltage

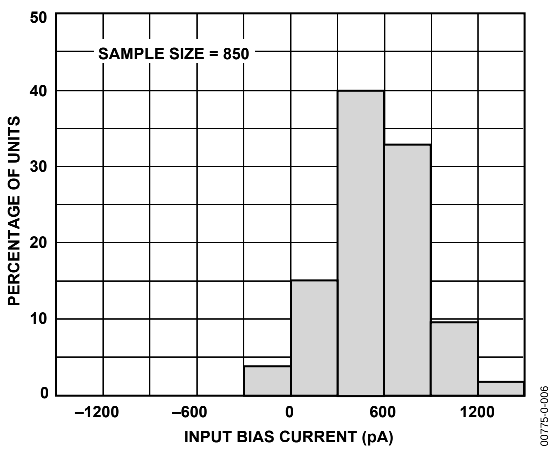


Figure 4. Typical Distribution of Input Bias Current

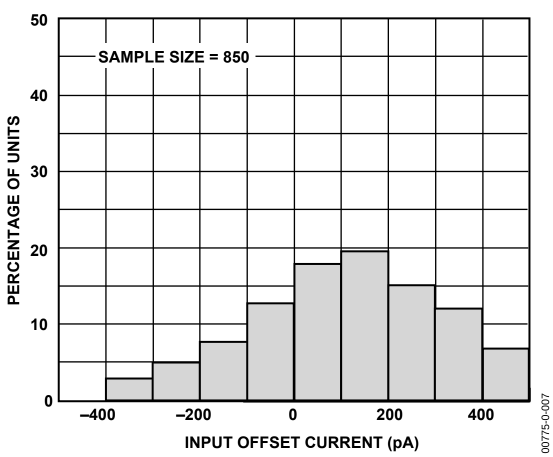


Figure 5. Typical Distribution of Input Offset Current

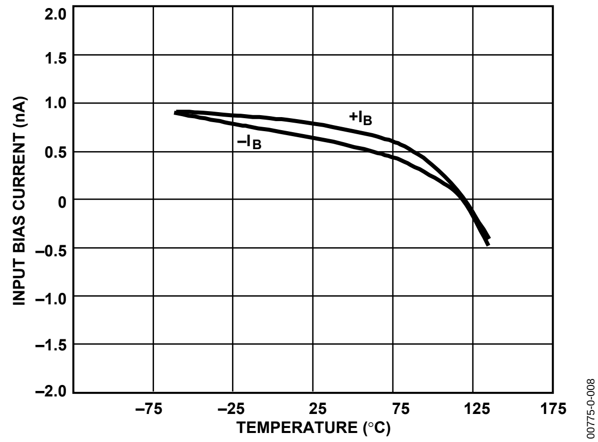


Figure 6. Input Bias Current vs. Temperature

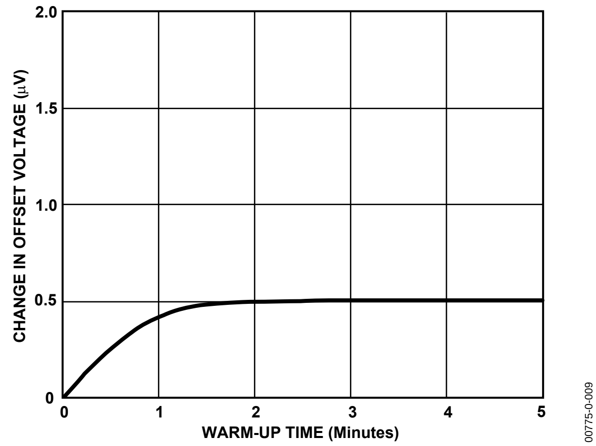


Figure 7. Change in Input Offset Voltage vs. Warm-Up Time

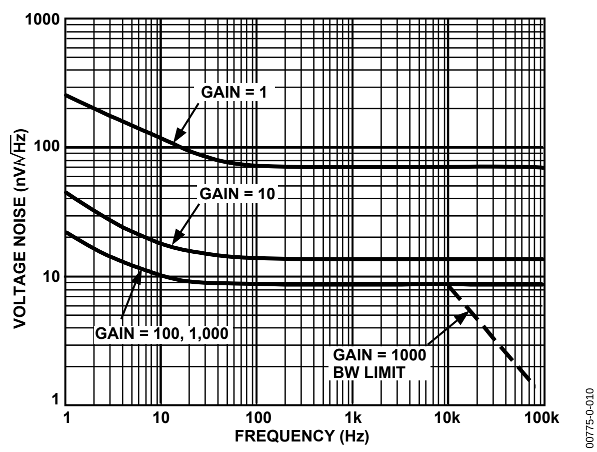


Figure 8. Voltage Noise Spectral Density vs. Frequency (G = 1–1000)

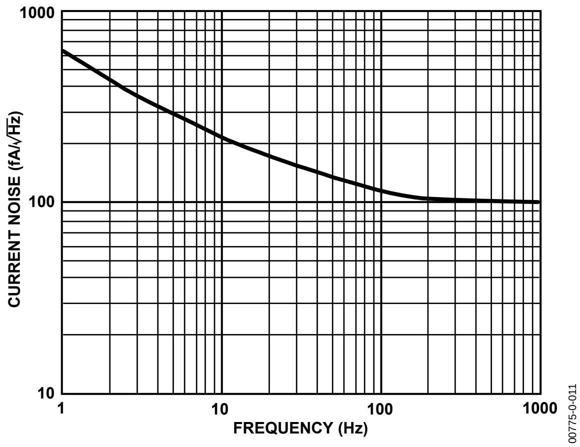


Figure 9. Current Noise Spectral Density vs. Frequency

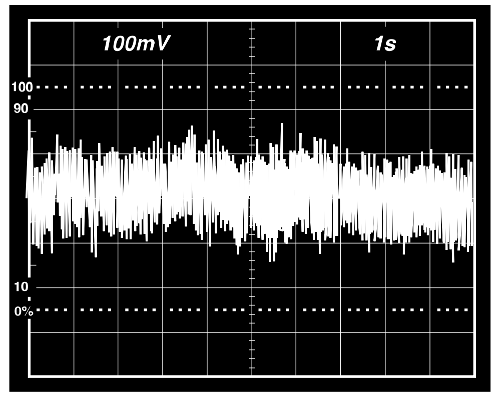


Figure 12. 0.1 Hz to 10 Hz Current Noise, 5 pA/Div

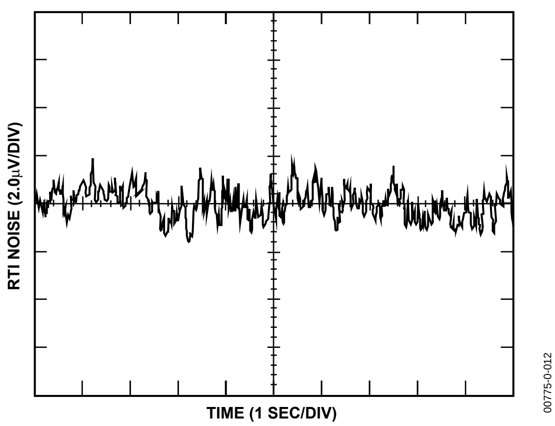


Figure 10. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1)

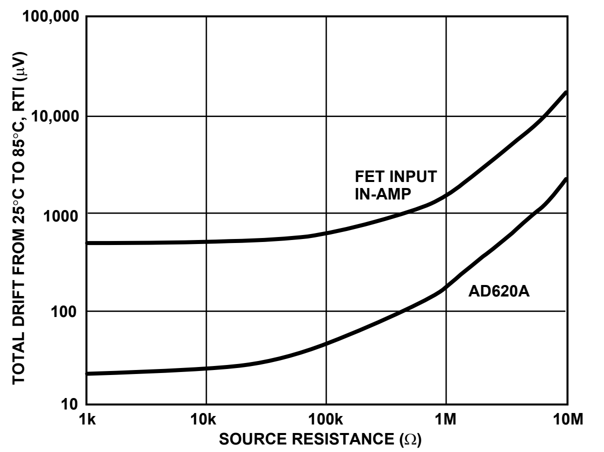


Figure 13. Total Drift vs. Source Resistance

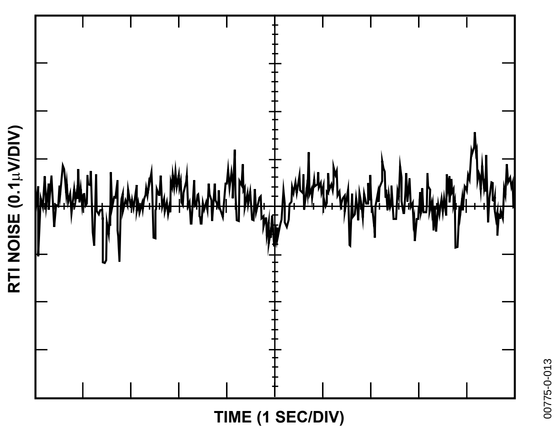


Figure 11. 0.1 Hz to 10 Hz RTI Voltage Noise (G = 1000)

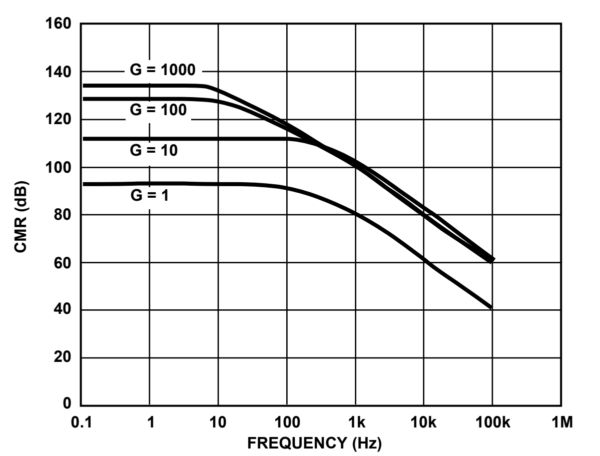


Figure 14. Typical CMR vs. Frequency, RTI, Zero to 1 kΩ Source Imbalance

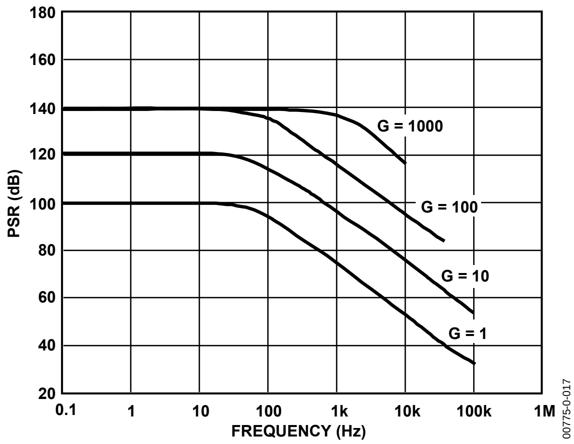


Figure 15. Positive PSR vs. Frequency, RTI (G = 1–1000)

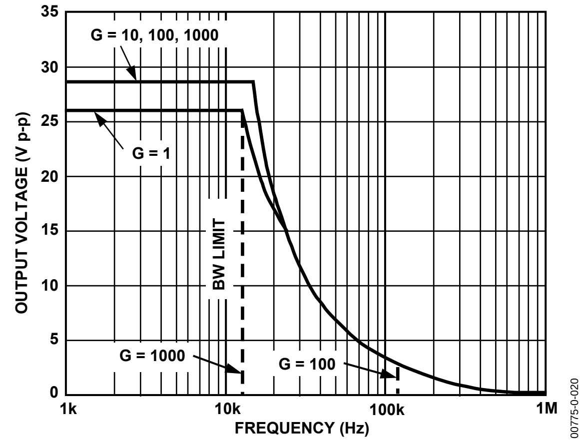


Figure 18. Large Signal Frequency Response

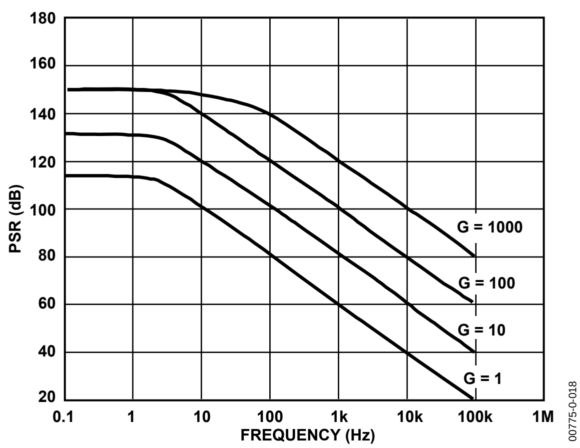


Figure 16. Negative PSR vs. Frequency, RTI (G = 1–1000)

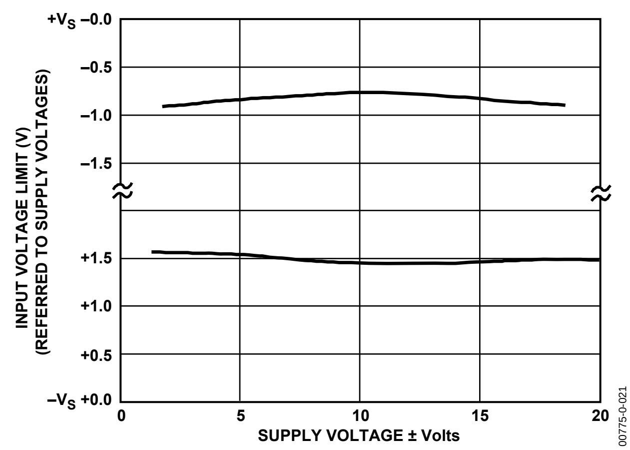


Figure 19. Input Voltage Range vs. Supply Voltage, G = 1

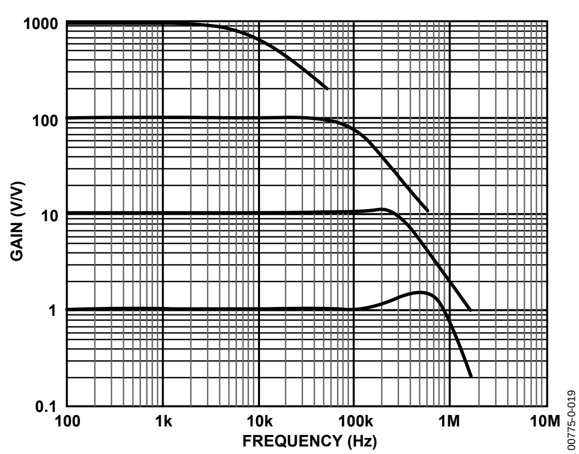


Figure 17. Gain vs. Frequency

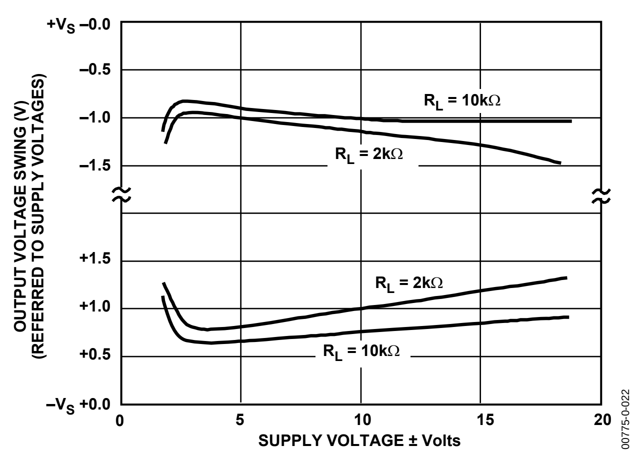


Figure 20. Output Voltage Swing vs. Supply Voltage, G = 10

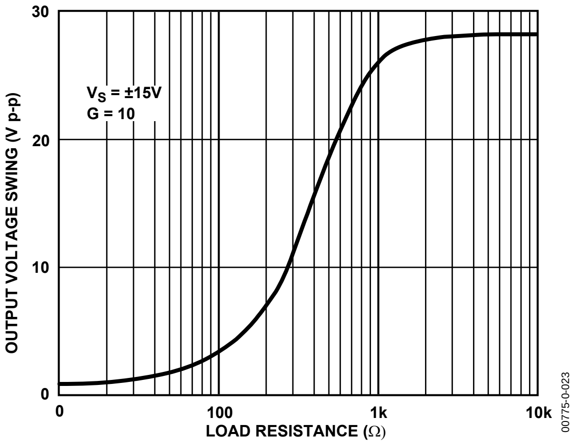


Figure 21. Output Voltage Swing vs. Load Resistance

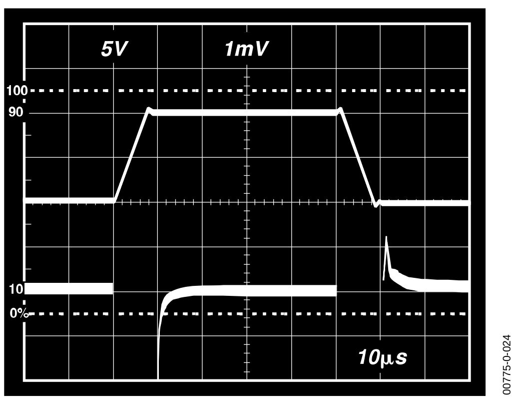


Figure 22. Large Signal Pulse Response and Settling Time G = 1 (0.5 mV = 0.01%)

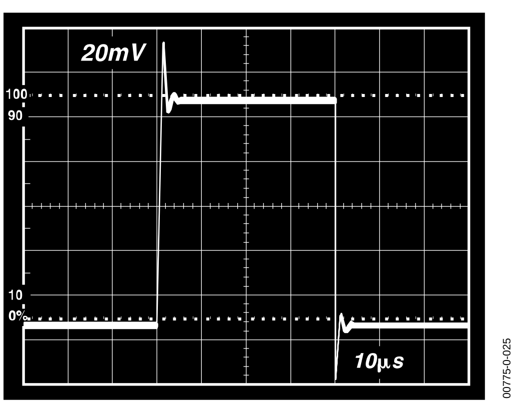


Figure 23. Small Signal Response, G = 1, R_L = 2 kΩ, C_L = 100 pF

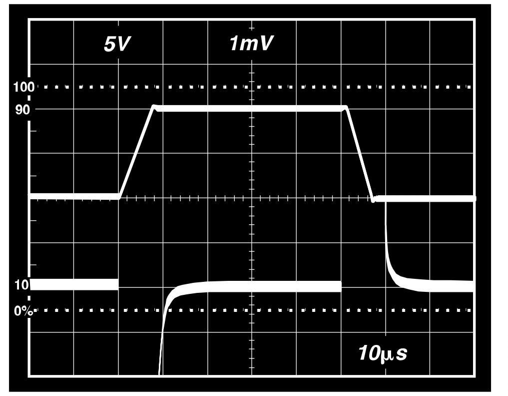


Figure 24. Large Signal Response and Settling Time, G = 10 (0.5 mV = 0.01%)

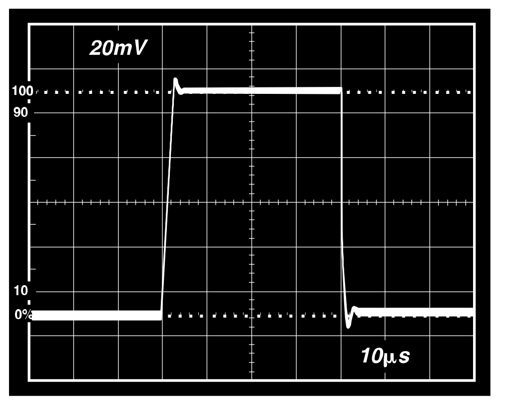


Figure 25. Small Signal Response, G = 10, R_L = 2 kΩ, C_L = 100 pF

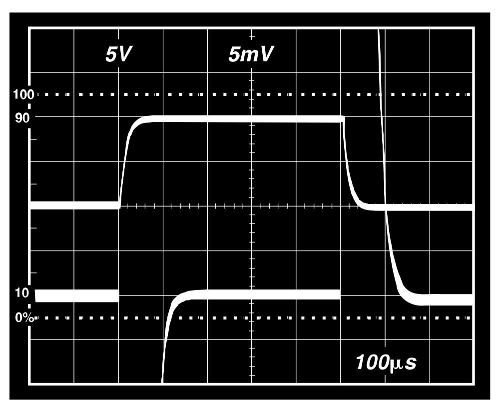


Figure 26. Large Signal Response and Settling Time, G = 100 (0.5 mV = 0.01%)

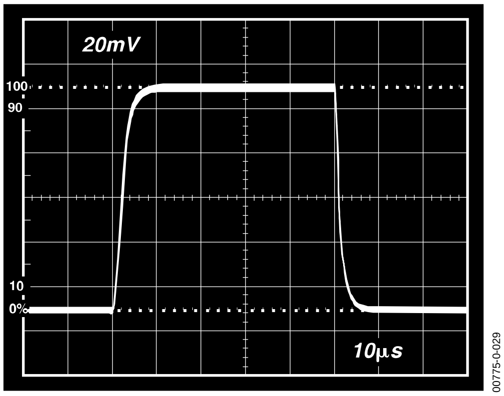


Figure 27. Small Signal Pulse Response, G = 100, R_L = 2 kΩ, C_L = 100 pF

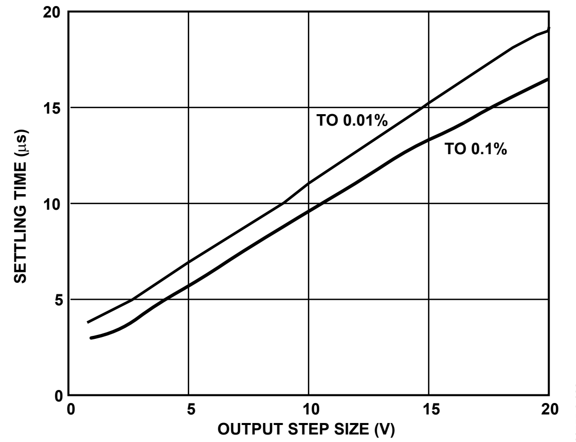


Figure 30. Settling Time vs. Step Size (G = 1)

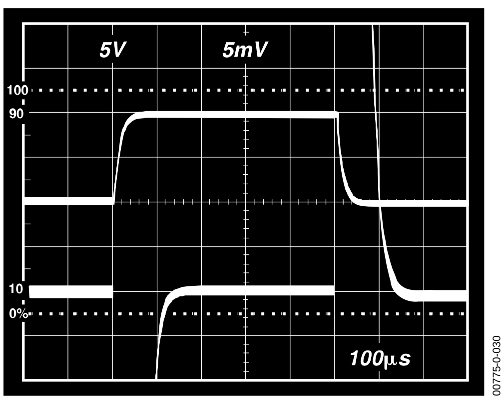


Figure 28. Large Signal Response and Settling Time,
G = 1000 (0.5 mV = 0.01%)

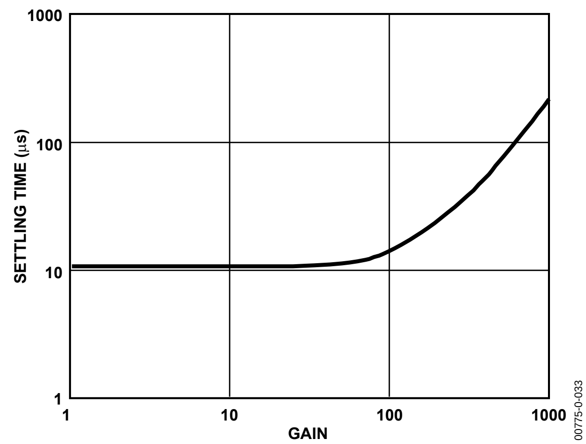


Figure 31. Settling Time to 0.01% vs. Gain, for a 10 V Step

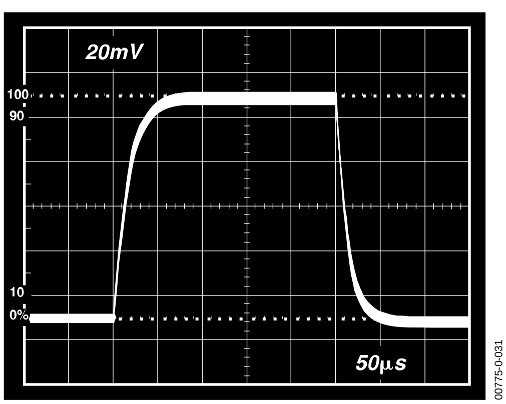


Figure 29. Small Signal Pulse Response, G = 1000, R_L = 2 kΩ, C_L = 100 pF

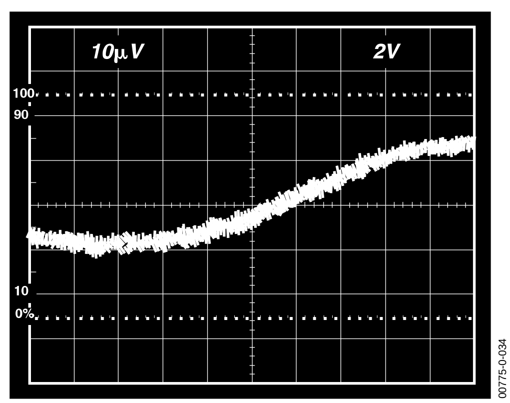


Figure 32. Gain Nonlinearity, G = 1, R_L = 10 kΩ (10 μV = 1 ppm)

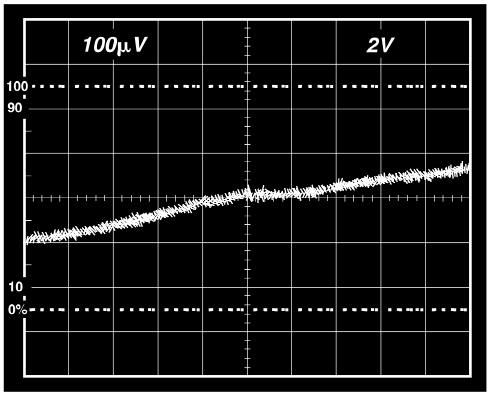


Figure 33. Gain Nonlinearity, G = 100, R_L = 10 kΩ (100 µV = 10 ppm)

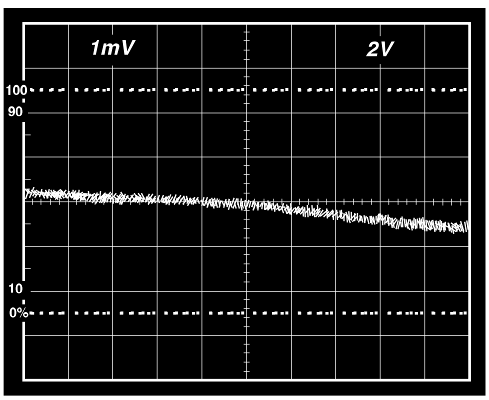


Figure 34. Gain Nonlinearity, G = 1000, R_L = 10 kΩ (1 mV = 100 ppm)

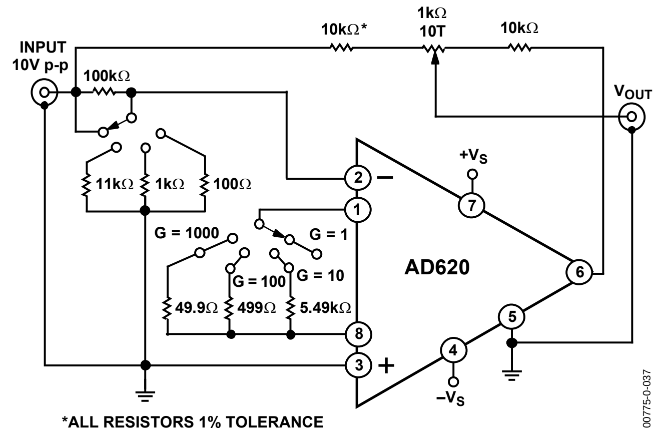


Figure 35. Settling Time Test Circuit

THEORY OF OPERATION

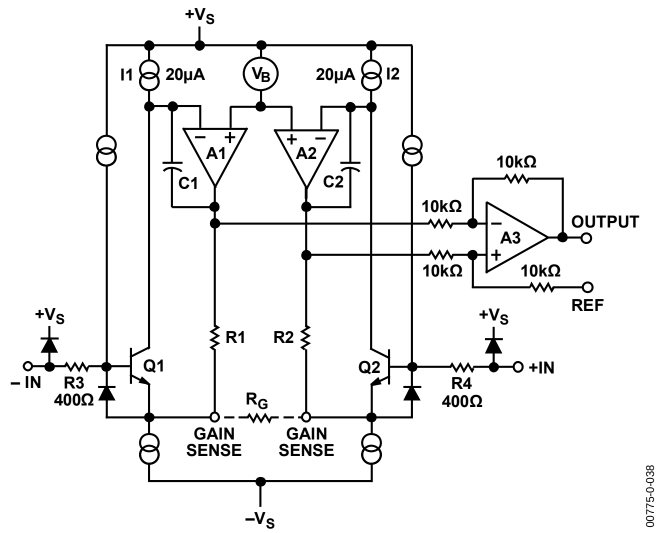


Figure 36. Simplified Schematic of AD620

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 36), 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 and 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 subtractor, 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 and 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

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

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

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 37, 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. Table 4 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 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 removes 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 √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.

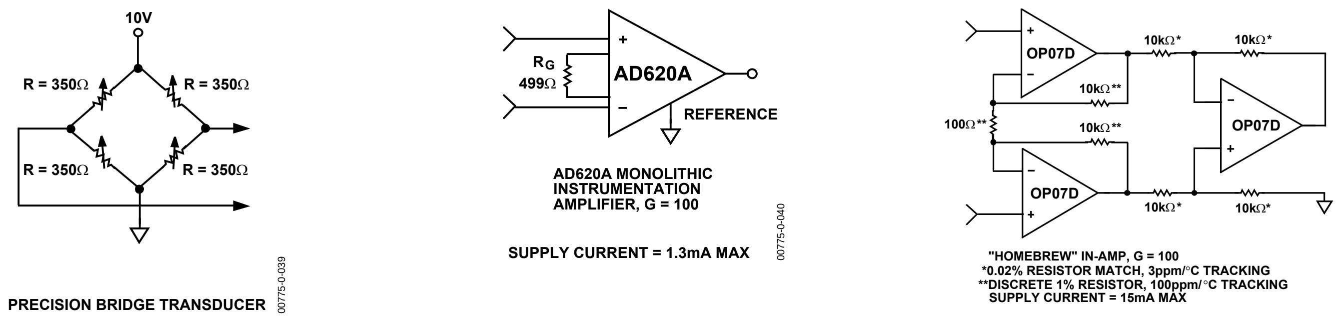


Figure 37. Make vs. Buy

Table 4. 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 × √2)/20 mV	6,250	10,607
Output Offset Voltage, µV	1000 µV/100 mV/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	7,559	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 × √2 × 60°C)/20 mV	3,000	10,607
Output Offset Voltage Drift, µV/°C	15 µV/°C × 60°C/100 mV/20 mV	(2.5 µV/°C × 2 × 60°C)/100 mV/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 to 10 Hz Voltage Noise, µV p-p	0.28 µV p-p/20 mV	(0.38 µV p-p × √2)/20 mV	14	27
		Total Resolution Error	54	67
		Grand Total Error	14,663	28,134

G = 100, V_S = ±15 V.
(All errors are min/max and referred to input.)

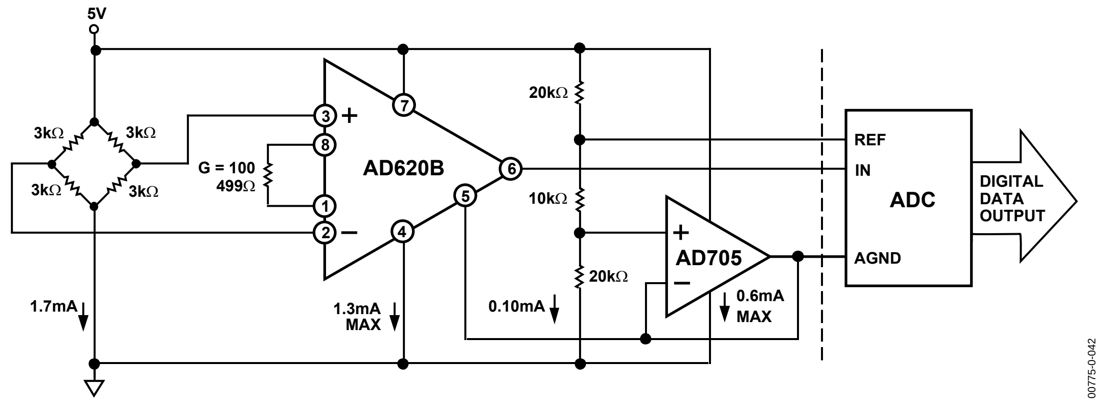


Figure 38. A Pressure Monitor Circuit that Operates on a 5 V Single Supply

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 38 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 also serves applications such as diagnostic noninvasive blood pressure measurement.

Medical ECG

The low current noise of the AD620 allows its use in ECG monitors (Figure 39) 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.

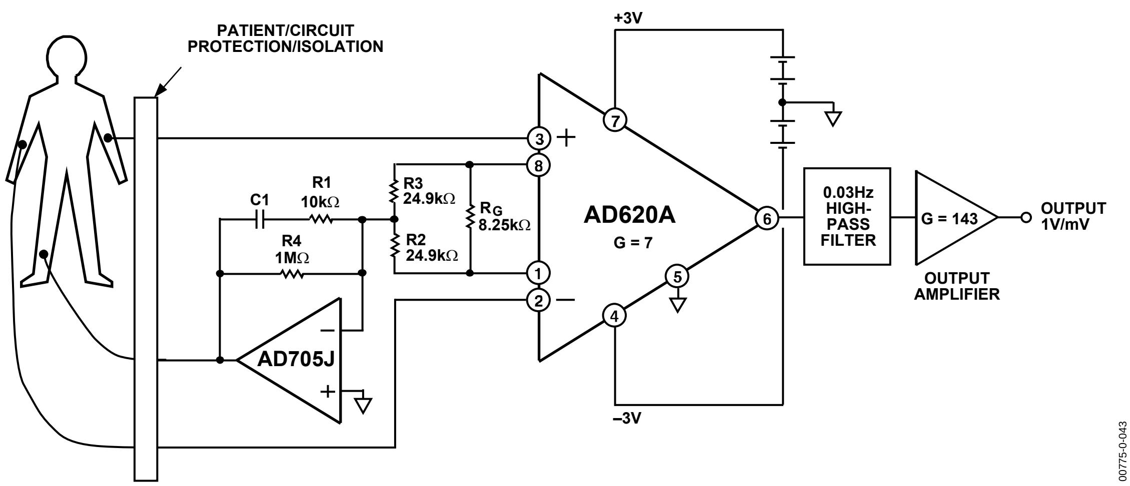


Figure 39. A Medical ECG Monitor Circuit

Precision V-I Converter

The AD620, along with another op amp and two resistors, makes a precision current source (Figure 40). 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.

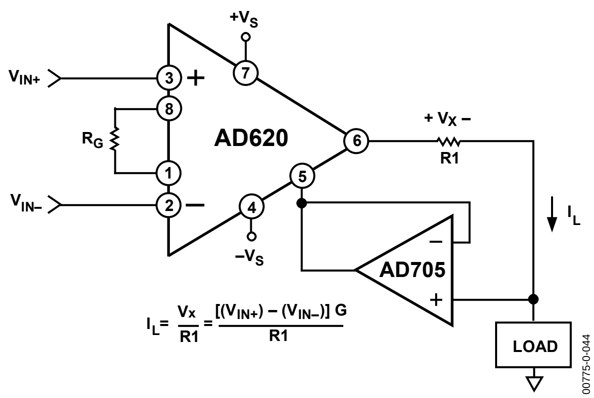


Figure 40. Precision Voltage-to-Current Converter (Operates on 1.8 mA, ±3 V)

GAIN SELECTION

The AD620 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% to 1% resistors. Table 5 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 5. 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	1,003.0

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 safely withstands an input current of ±60 mA for several hours at room temperature. This is true for all gains and power on and off, which is useful if the signal source and amplifier are powered separately. For longer time periods, the input current should not exceed 6 mA.

For input voltages beyond the supplies, a protection resistor should be placed in series with each input to limit the current to 6 mA. These can be the same resistors as those used in the RFI filter. High values of resistance can impact the noise and AC CMRR performance of the system. Low leakage diodes (such as the BAV199) can be placed at the inputs to reduce the required protection resistance.

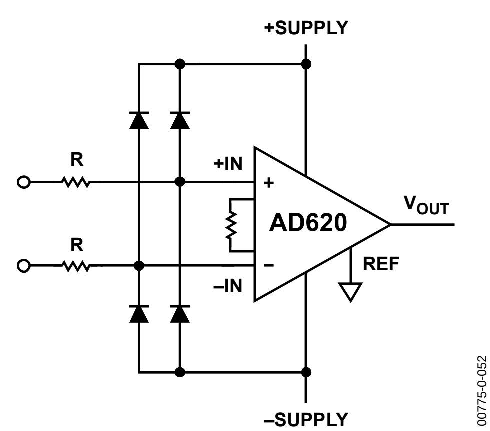


Figure 41. Diode Protection for Voltages Beyond Supply

RF INTERFERENCE

All instrumentation amplifiers rectify small out of band signals. The disturbance may appear as a small dc voltage offset. High frequency signals can be filtered with a low pass R-C network placed at the input of the instrumentation amplifier. Figure 42 demonstrates such a configuration. The filter limits the input signal according to the following relationship:

$$FilterFreq_{DIFF} = \frac{1}{2\pi R(2C_D + C_C)}$$

$$FilterFreq_{CM} = \frac{1}{2\pi R C_C}$$

where $C_D \geq 10C_C$.

C_D affects the difference signal. C_C affects the common-mode signal. Any mismatch in $R \times C_C$ degrades the AD620 CMRR. To avoid inadvertently reducing CMRR-bandwidth performance, make sure that C_C is at least one magnitude smaller than C_D. The effect of mismatched C_Cs is reduced with a larger C_D:C_C ratio.

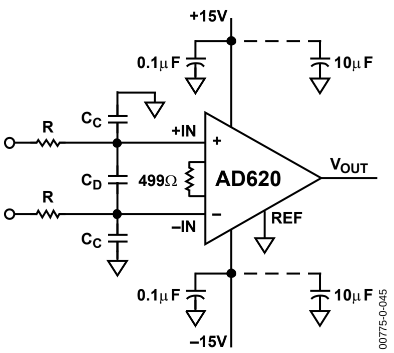


Figure 42. Circuit to Attenuate RF Interference

COMMON-MODE REJECTION

Instrumentation amplifiers, such as 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; for best CMR over frequency, the shield should be properly driven. Figure 43 and Figure 44 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.

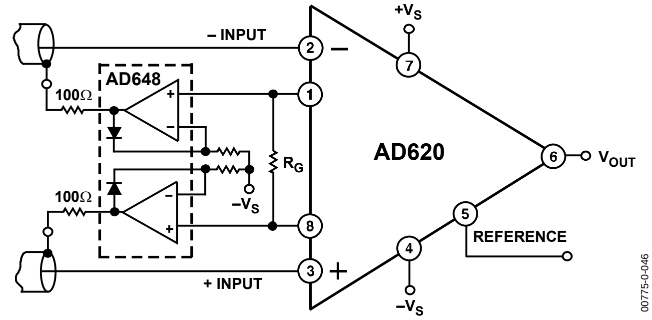


Figure 43. Differential Shield Driver

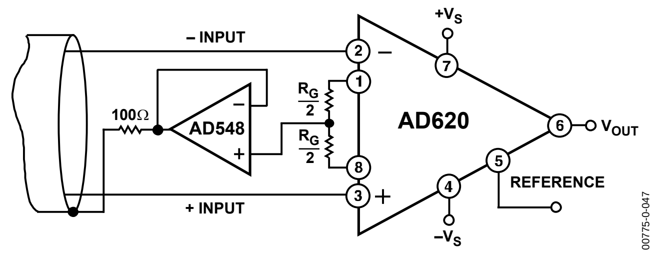


Figure 44. Common-Mode Shield Driver

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."

To isolate low level analog signals from a noisy digital environment, many data-acquisition components have separate analog and digital ground pins (Figure 45). 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 shown in Figure 45.

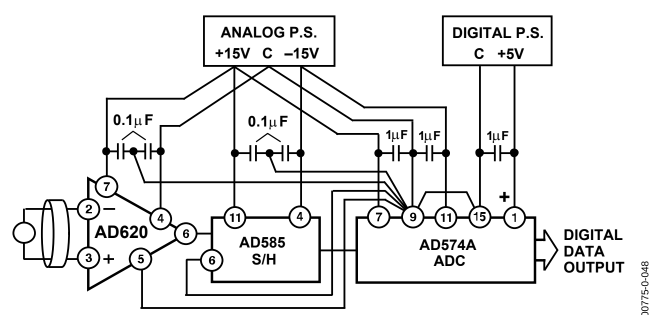


Figure 45. Basic Grounding Practice

GROUND RETURNS FOR INPUT BIAS CURRENTS

Input bias currents are those currents necessary to bias the input transistors of an amplifier. There must be a direct return path for these currents. Therefore, when amplifying "floating" input sources, such as transformers or ac-coupled sources, there must be a dc path from each input to ground, as shown in Figure 46, Figure 47, and Figure 48. Refer to *A Designer's Guide to Instrumentation Amplifiers* (free from Analog Devices) for more information regarding in-amp applications.

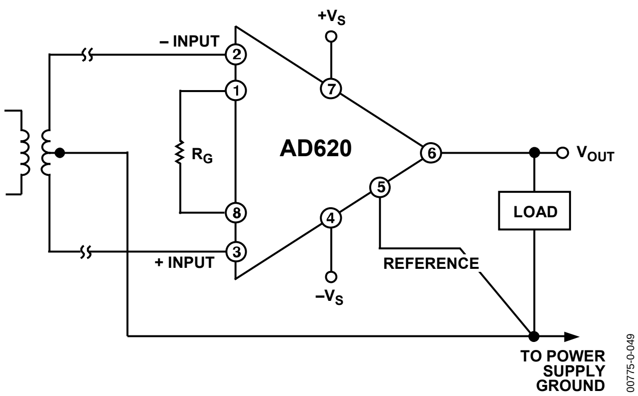


Figure 46. Ground Returns for Bias Currents with Transformer-Coupled Inputs

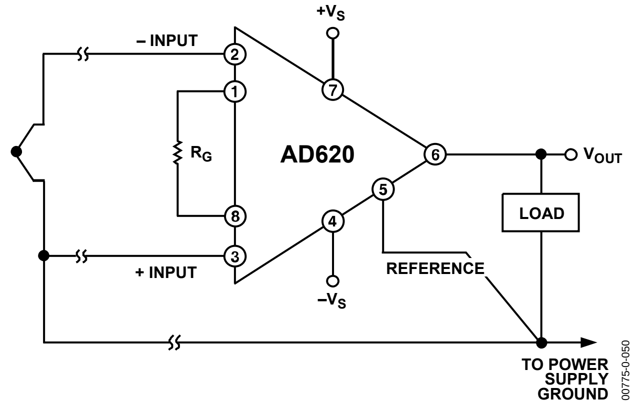


Figure 47. Ground Returns for Bias Currents with Thermocouple Inputs

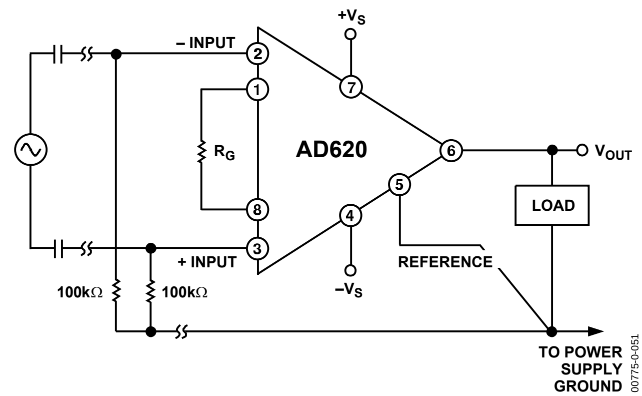


Figure 48. Ground Returns for Bias Currents with AC-Coupled Inputs

AD620ACHIPS INFORMATION

Die size: 1803 μm × 3175 μm

Die thickness: 483 μm

Bond Pad Metal: 1% Copper Doped Aluminum

To minimize gain errors introduced by the bond wires, use Kelvin connections between the chip and the gain resistor, R_G, by connecting Pad 1A and Pad 1B in parallel to one end of R_G and Pad 8A and Pad 8B in parallel to the other end of R_G. For unity gain applications where R_G is not required, Pad 1A and Pad 1B must be bonded together as well as the Pad 8A and Pad 8B.

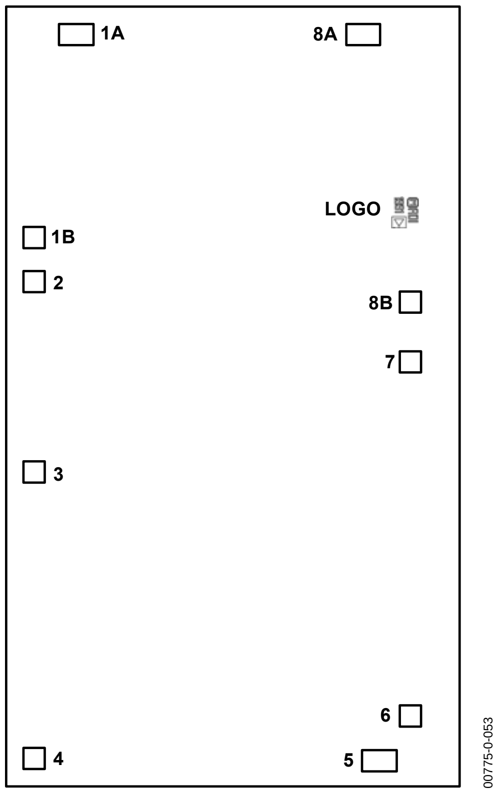


Figure 49. Bond Pad Diagram

Table 6. Bond Pad Information

Pad No.	Mnemonic	Pad Coordinates[1]	
		X (μm)	Y (μm)
1A	R_G	−623	+1424
1B	R_G	−789	+628
2	−IN	−790	+453
3	+IN	−790	−294
4	$-V_S$	−788	−1419
5	REF	+570	−1429
6	OUTPUT	+693	−1254
7	$+V_S$	+693	+139
8A	R_G	+505	+1423
8B	R_G	+693	+372

[1] The pad coordinates indicate the center of each pad, referenced to the center of the die. The die orientation is indicated by the logo, as shown in Figure 49.

OUTLINE DIMENSIONS

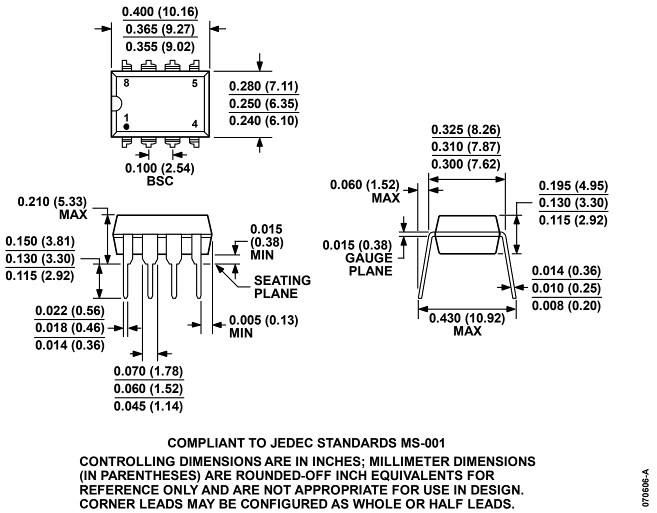


Figure 50. 8-Lead Plastic Dual In-Line Package [PDIP]
Narrow Body (N-8).
Dimensions shown in inches and (millimeters)

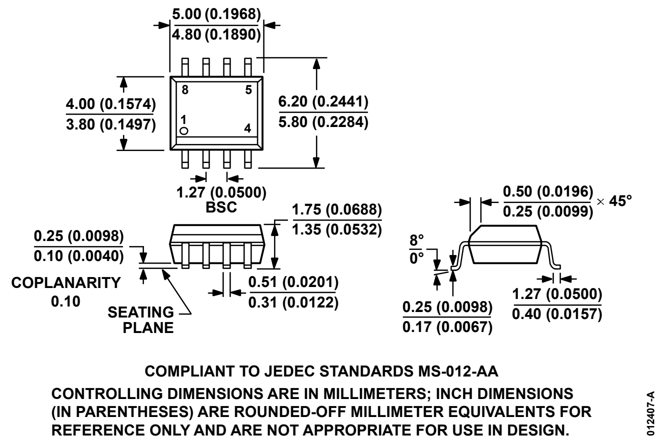


Figure 52. 8-Lead Standard Small Outline Package [SOIC_N]
Narrow Body (R-8)
Dimensions shown in millimeters and (inches)

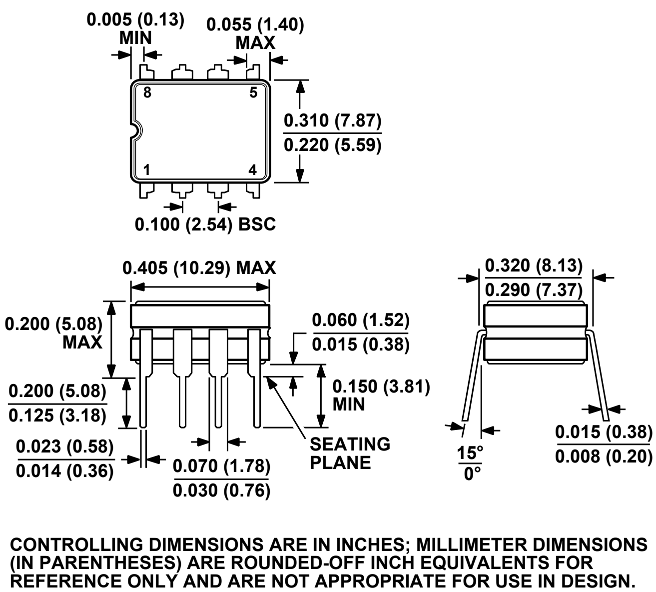


Figure 51. 8-Lead Ceramic Dual In-Line Package [CERDIP]
(Q-8)
Dimensions shown in inches and (millimeters)

ORDERING GUIDE

Model[1]	Temperature Range	Package Description	Package Option
AD620AN	−40°C to +85°C	8-Lead PDIP	N-8
AD620ANZ	−40°C to +85°C	8-Lead PDIP	N-8
AD620BN	−40°C to +85°C	8-Lead PDIP	N-8
AD620BNZ	−40°C to +85°C	8-Lead PDIP	N-8
AD620AR	−40°C to +85°C	8-Lead SOIC_N	R-8
AD620ARZ	−40°C to +85°C	8-Lead SOIC_N	R-8
AD620AR-REEL	−40°C to +85°C	8-Lead SOIC_N, 13" Tape and Reel	R-8
AD620ARZ-REEL	−40°C to +85°C	8-Lead SOIC_N, 13" Tape and Reel	R-8
AD620AR-REEL7	−40°C to +85°C	8-Lead SOIC_N, 7" Tape and Reel	R-8
AD620ARZ-REEL7	−40°C to +85°C	8-Lead SOIC_N, 7" Tape and Reel	R-8
AD620BR	−40°C to +85°C	8-Lead SOIC_N	R-8
AD620BRZ	−40°C to +85°C	8-Lead SOIC_N	R-8
AD620BR-REEL	−40°C to +85°C	8-Lead SOIC_N, 13" Tape and Reel	R-8
AD620BRZ-RL	−40°C to +85°C	8-Lead SOIC_N, 13" Tape and Reel	R-8
AD620BR-REEL7	−40°C to +85°C	8-Lead SOIC_N, 7" Tape and Reel	R-8
AD620BRZ-R7	−40°C to +85°C	8-Lead SOIC_N, 7" Tape and Reel	R-8
AD620ACHIPS	−40°C to +85°C	Die Form	
AD620SQ/883B	−55°C to +125°C	8-Lead CERDIP	Q-8

[1] Z = RoHS Compliant Part.

C00775–0–7/11(H)

DIODES INCORPORATED

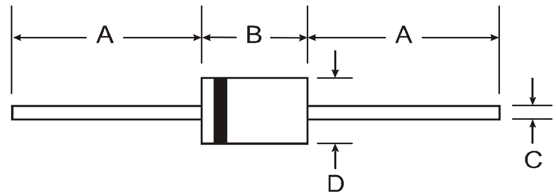
1N4001 - 1N4007

1.0A RECTIFIER

Please click here to visit our online spice models database.

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- **Lead Free Finish, RoHS Compliant (Note 3)**



Dim	DO-41 Plastic	
	Min	**Max**
A	25.40	—
B	4.06	5.21
C	0.71	0.864
D	2.00	2.72
All Dimensions in mm		

Mechanical Data

- Case: DO-41
- Case Material: Molded Plastic. UL Flammability Classification Rating 94V-0
- Moisture Sensitivity: Level 1 per J-STD-020D
- Terminals: Finish - Bright Tin. Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Mounting Position: Any
- Ordering Information: See Page 2
- Marking: Type Number
- Weight: 0.30 grams (approximate)

Maximum Ratings and Electrical Characteristics @T_A = 25°C unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

Characteristic	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current (Note 1) @ T_A = 75°C	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms single half sine-wave superimposed on rated load	I_{FSM}	30							A
Forward Voltage @ I_F = 1.0A	V_{FM}	1.0							V
Peak Reverse Current @T_A = 25°C at Rated DC Blocking Voltage @ T_A = 100°C	I_{RM}	5.0 50							µA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range	T_J, T_{STG}	-65 to +150							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1.0 MHz and applied reverse voltage of 4.0V DC.
3. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied, see EU Directive 2002/95/EC Annex Notes.

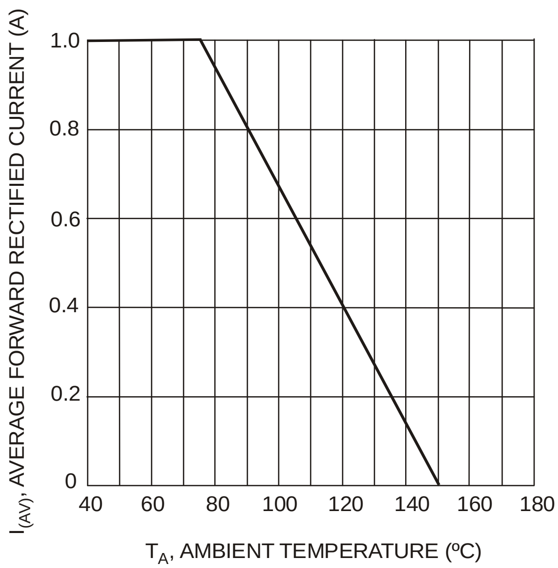


Fig. 1 Forward Current Derating Curve

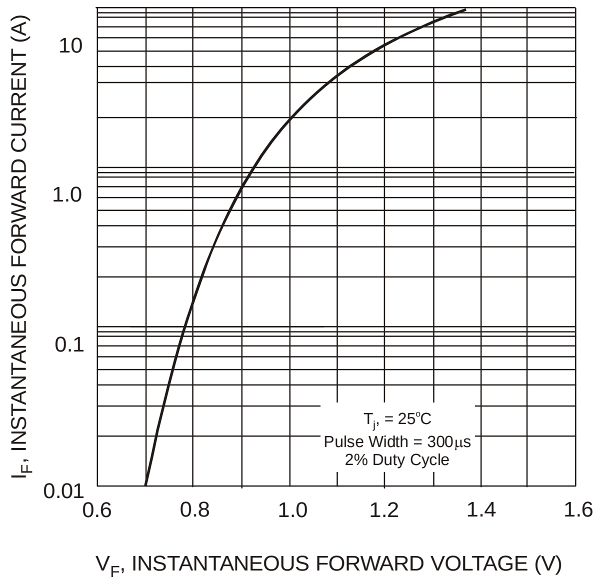


Fig. 2 Typical Forward Characteristics

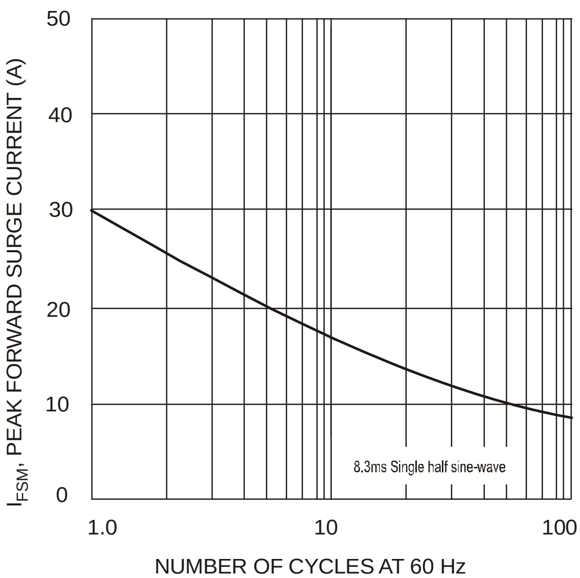


Fig. 3 Max Non-Repetitive Peak Fwd Surge Current

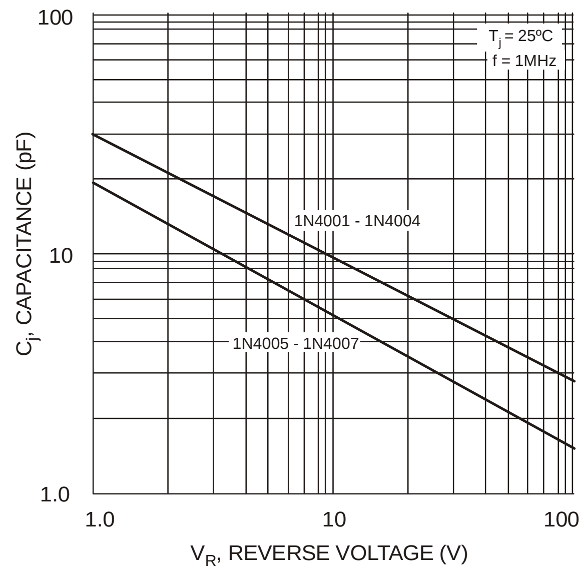


Fig. 4 Typical Junction Capacitance

Ordering Information (Note 4)

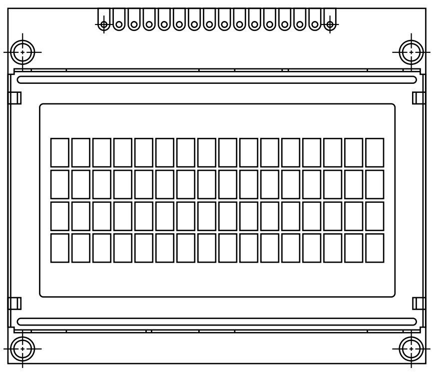
Device	Packaging	Shipping
1N4001-B	DO-41 Plastic	1K/Bulk
1N4001-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4002-B	DO-41 Plastic	1K/Bulk
1N4002-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4003-B	DO-41 Plastic	1K/Bulk
1N4003-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4004-B	DO-41 Plastic	1K/Bulk
1N4004-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4005-B	DO-41 Plastic	1K/Bulk
1N4005-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4006-B	DO-41 Plastic	1K/Bulk
1N4006-T	DO-41 Plastic	5K/Tape & Reel, 13-inch
1N4007-B	DO-41 Plastic	1K/Bulk
1N4007-T	DO-41 Plastic	5K/Tape & Reel, 13-inch

Notes: 4. For packaging details, visit our website at http://www.diodes.com/datasheets/ap02008.pdf.

IMPORTANT NOTICE

LIFE SUPPORT

16 x 4 Character LCD



FEATURES

- Type: Character
- Display format: 16 x 4 characters
- Built-in controller: ST 7066 (or equivalent)
- Duty cycle: 1/16
- 5 x 8 dots includes cursor
- + 5 V power supply (also available for + 3 V)
- B/L to be driven by pin 1, pin 2, pin 15, pin 16 or A and K
- N.V. optional for + 3 V power supply
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

Pb Pb-free
RoHS COMPLIANT

MECHANICAL DATA

ITEM	STANDARD VALUE	UNIT
Module Dimension	70.6 x 60.0	mm
Viewing Area	60.0 x 32.6	
Dot Size	0.55 x 0.55	
Dot Pitch	0.60 x 0.60	
Mounting Hole	65.6 x 50.0	
Character Size	2.95 x 4.75	

ABSOLUTE MAXIMUM RATINGS

ITEM	SYMBOL	STANDARD VALUE			UNIT
		MIN.	TYP.	MAX.	
Power Supply	V_{DD} to V_{SS}	- 0.3	-	7.0	V
Input Voltage	V_I	- 0.3	-	V_{DD}	

Note

- V_{SS} = 0 V, V_{DD} = 5.0 V

ELECTRICAL CHARACTERISTICS

ITEM	SYMBOL	CONDITION	STANDARD VALUE			UNIT
			MIN.	TYP.	MAX.	
Input Voltage	V_{DD}	V_{DD} = + 5 V	4.7	5.0	5.3	V
		V_{DD} = + 3 V	2.7	3.0	5.3	
Supply Current	I_{DD}	V_{DD} = + 5 V	-	1.65	-	mA
Recommended LC Driving Voltage for Normal Temperature Version Module	V_{DD} to V_0	- 20 °C	5.0	5.1	5.7	V
		0 °C	4.6	4.8	5.2	
		25 °C	4.1	4.5	4.7	
		50 °C	3.9	4.2	4.5	
		70 °C	3.7	3.9	4.3	
EL Power Supply Current	I_{EL}	V_{EL} = 110 V_{AC}, 400 Hz	-	-	5.0	mA

OPTIONS

PROCESS COLOR						BACKLIGHT			
TN	STN Gray	STN Yellow	STN Blue	FSTN B&W	STN Color	None	LED	EL	CCFL
x	x	x	x	x		x	x	x	

For detailed information, please see the “Product Numbering System” document.

DISPLAY CHARACTER ADDRESS CODE

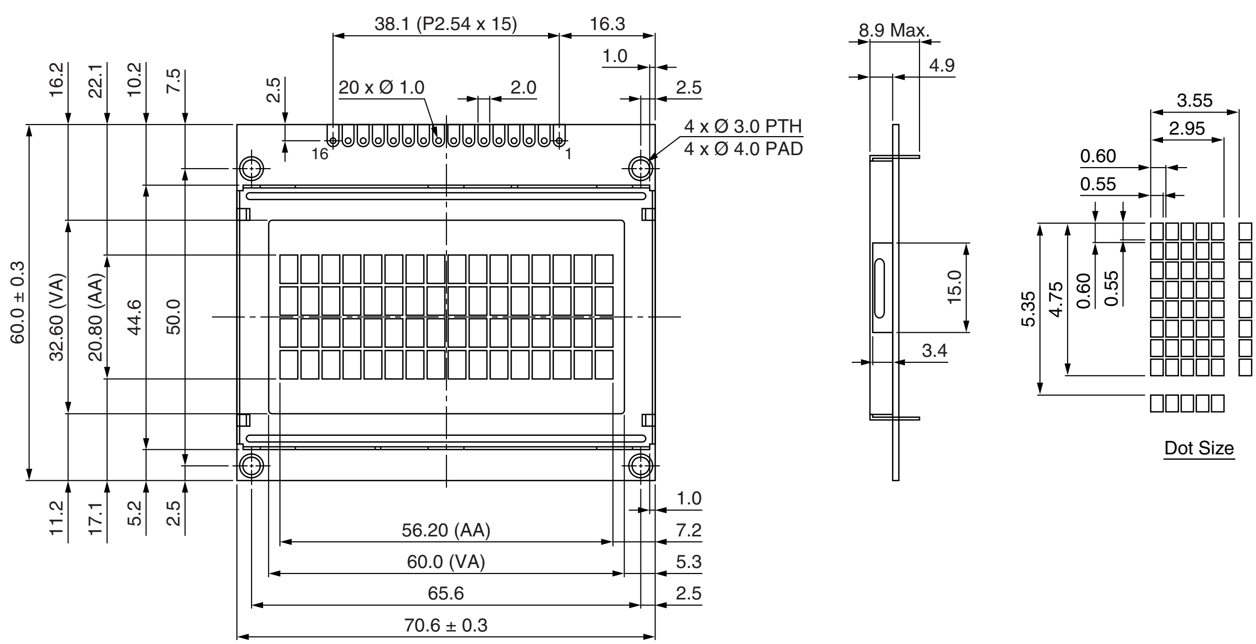
Display Position

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
DD RAM Address	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F
DD RAM Address	40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F
DD RAM Address	10	11	12	13	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F
DD RAM Address	50	51	52	53	54	55	56	57	58	59	5A	5B	5C	5D	5E	5F

INTERFACE PIN FUNCTION

PIN NO.	SYMBOL	FUNCTION
1	V_{SS}	Ground
2	V_{DD}	+ 3 V or + 5 V
3	V_0	Contrast adjustment
4	RS	H/L register select signal
5	$R/\overline{W}$	H/L read/write signal
6	E	H → L enable signal
7	DB0	H/L data bus line
8	DB1	H/L data bus line
9	DB2	H/L data bus line
10	DB3	H/L data bus line
11	DB4	H/L data bus line
12	DB5	H/L data bus line
13	DB6	H/L data bus line
14	DB7	H/L data bus line
15	A/V_{EE}	+ 4.2 V for LED (R_A = 0 Ω)/negative voltage output
16	K	Power supply for B/L (0 V)

DIMENSIONS in millimeters



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National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

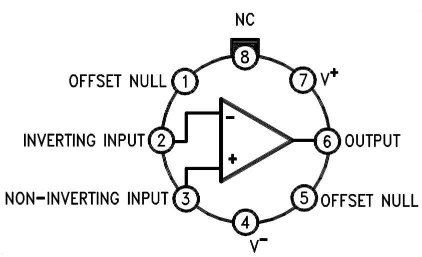
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

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.

Connection Diagrams

Metal Can Package

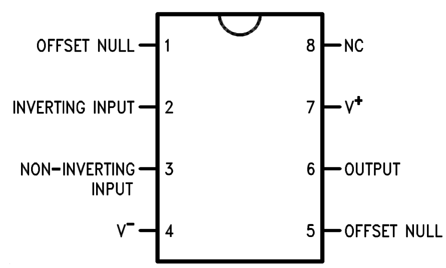


DS009341-2

Note 1: LM741H is available per JM38510/10101

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

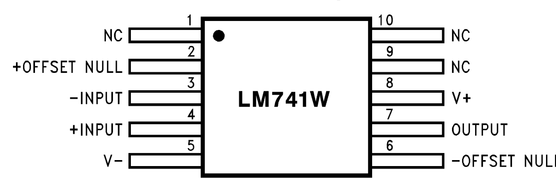
Dual-In-Line or S.O. Package



DS009341-3

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

Ceramic Flatpak

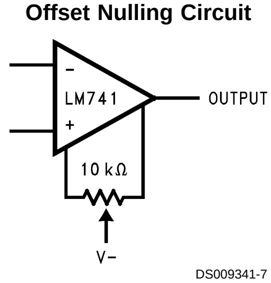


DS009341-6

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



DS009341-7

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.

	LM741A	LM741	LM741C
ESD Tolerance (Note 8)	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										
	$R_S \le 10$ kΩ					1.0	5.0		2.0	6.0	mV
	$R_S \le 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \le T_A \le T_{AMAX}$										
	$R_S \le 50\Omega$			4.0							mV
	$R_S \le 10$ kΩ						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/˚C
Input Offset Voltage Adjustment Range	T_A = 25˚C, V_S = ±20V	±10				±15			±15		mV
Input Offset Current	T_A = 25˚C		3.0	30		20	200		20	200	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			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
	$T_{AMIN} \le T_A \le T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	T_A = 25˚C, V_S = ±20V	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \le T_A \le T_{AMAX}$, V_S = ±20V	0.5									MΩ
Input Voltage Range	T_A = 25˚C							±12	±13		V
	$T_{AMIN} \le T_A \le T_{AMAX}$				±12	±13					V

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$T_A = 25^\circ C$, $R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V$, $V_O = \pm 15V$	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	$T_A = 25^\circ C$	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	$T_A = 25^\circ C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		µs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	$T_A = 25^\circ C$	0.437	1.5								MHz
Slew Rate	$T_A = 25^\circ C$, Unity Gain	0.3	0.7			0.5			0.5		V/µs
Supply Current	$T_A = 25^\circ C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25^\circ C$										
	$V_S = \pm 20V$		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 2: "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.

Electrical Characteristics (Note 5) (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100˚C/W	100˚C/W	170˚C/W	195˚C/W
θ_{jC} (Junction to Case)	N/A	N/A	25˚C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

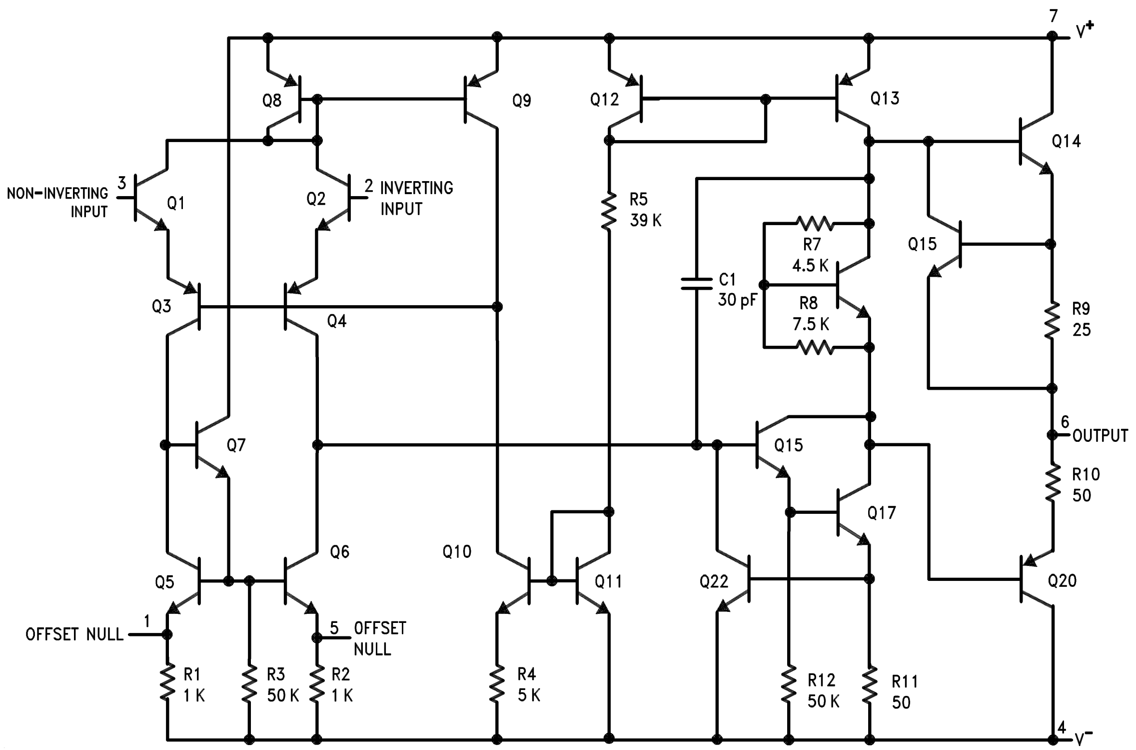
Note 5: Unless otherwise specified, these specifications apply for V_S = ±15V, −55˚C ≤ T_A ≤ +125˚C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0˚C ≤ T_A ≤ +70˚C.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

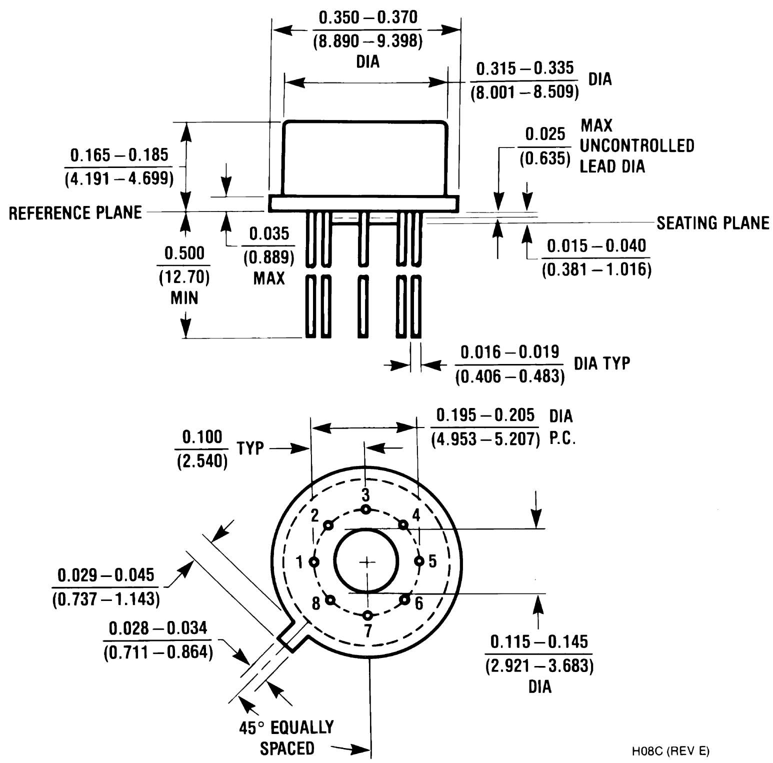
Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram

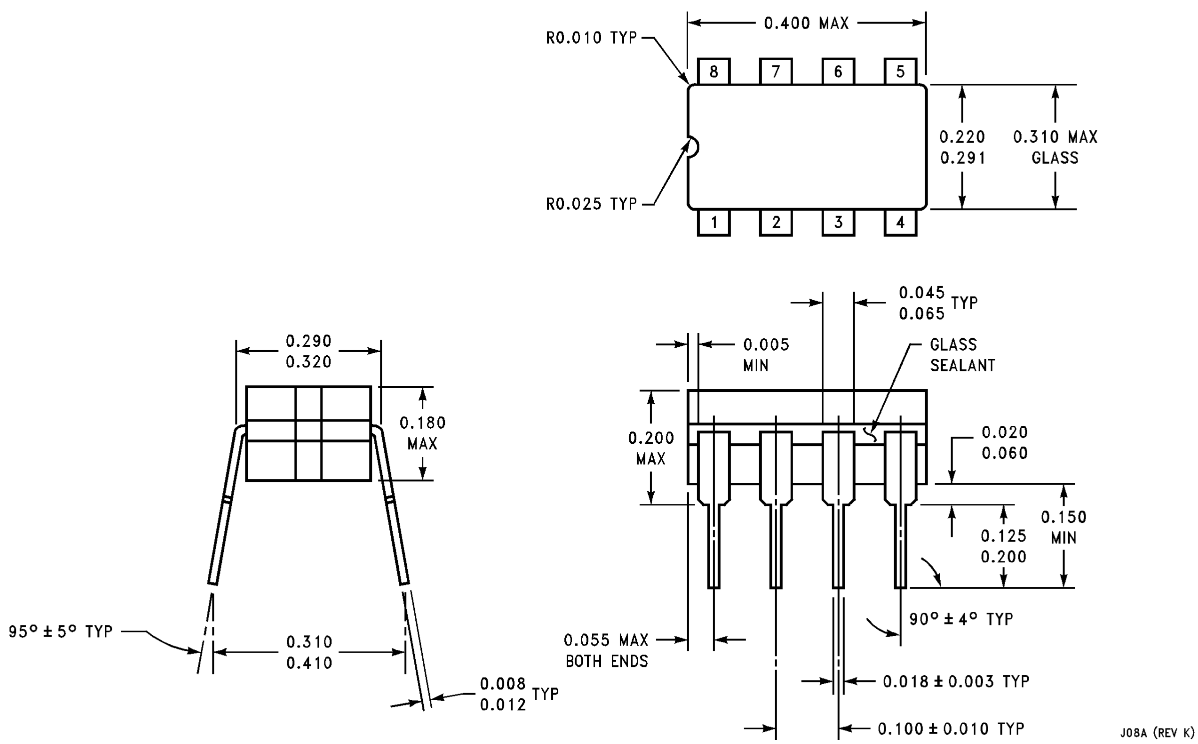


DS009341-1

Physical Dimensions inches (millimeters) unless otherwise noted

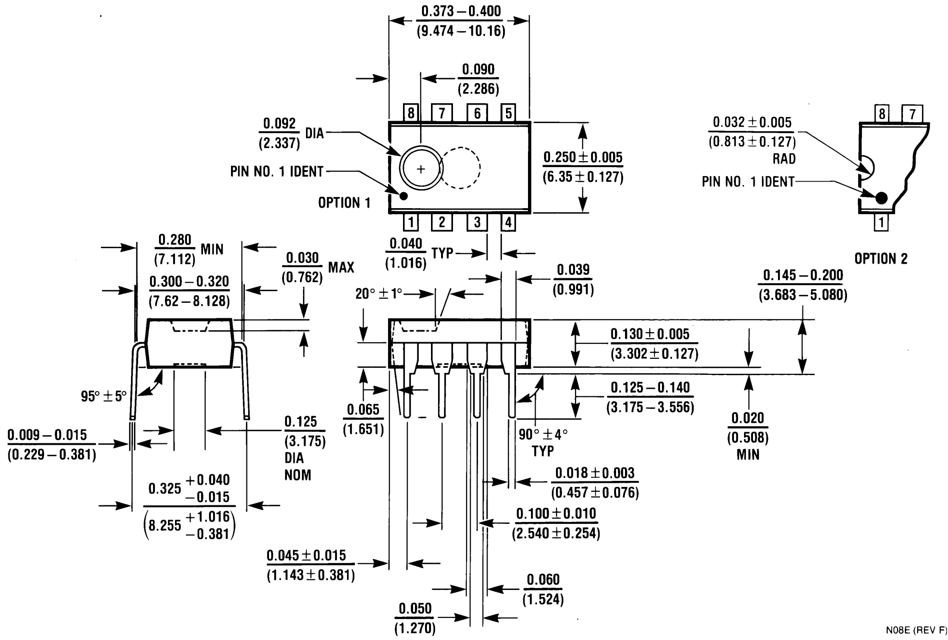


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741AH-MIL or LM741CH
NS Package Number H08C

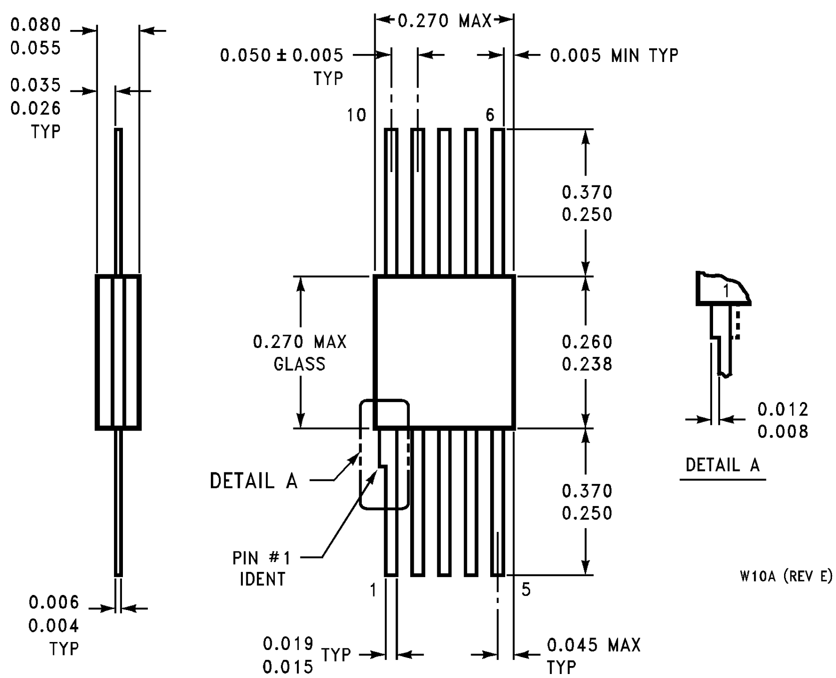


Ceramic Dual-In-Line Package (J)
Order Number LM741J/883
NS Package Number J08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Dual-In-Line Package (N)
Order Number LM741CN
NS Package Number N08E



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883, LM741WG-MPR or LM741WG/883
NS Package Number W10A

Notes

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Fax: 81-3-5639-7507

FAIRCHILD SEMICONDUCTOR®

August 2013

LM78XX / LM78XXA
3-Terminal 1 A Positive Voltage Regulator

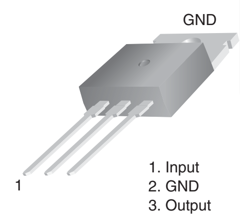
Features

- Output Current up to 1 A
- Output Voltages: 5, 6, 8, 9, 10, 12, 15, 18, 24 V
- Thermal Overload Protection
- Short-Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The LM78XX series of three-terminal positive regulators is available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down, and safe operating area protection. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed-voltage regulators, these devices can be used with external components for adjustable voltages and currents.

TO-220 (Single Gauge)



Ordering Information[1]

Product Number	Output Voltage Tolerance	Package	Operating Temperature	Packing Method
LM7805CT	±4%	TO-220 (Single Gauge)	-40°C to +125°C	Rail
LM7806CT				
LM7808CT				
LM7809CT				
LM7810CT				
LM7812CT				
LM7815CT				
LM7818CT				
LM7824CT				
LM7805ACT	±2%		0°C to +125°C	
LM7809ACT				
LM7810ACT				
LM7812ACT				
LM7815ACT				

Note:

1. Above output voltage tolerance is available at 25°C.

Block Diagram

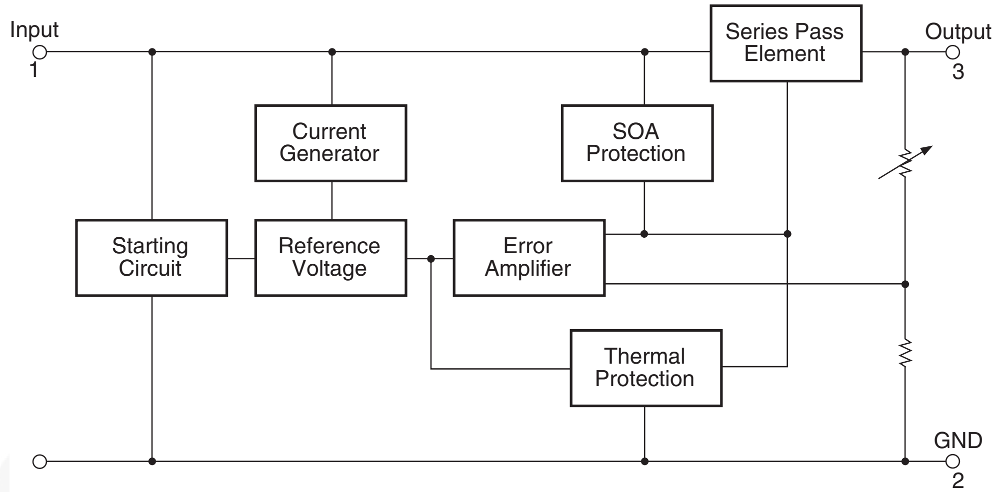


Figure 1. Block Diagram

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at $T_A = 25°C$ unless otherwise noted.

Symbol	Parameter		Value	Unit
V_I	Input Voltage	V_O = 5 V to 18 V	35	V
		V_O = 24 V	40	
$R_{θJC}$	Thermal Resistance, Junction-Case (TO-220)		5	°C/W
$R_{θJA}$	Thermal Resistance, Junction-Air (TO-220)		65	°C/W
T_{OPR}	Operating Temperature Range	LM78xx	-40 to +125	°C
		LM78xxA	0 to +125	
T_{STG}	Storage Temperature Range		- 65 to +150	°C

Electrical Characteristics (LM7805)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 10 V, C_I = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		4.80	5.00	5.20	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 7 V to 20 V		4.75	5.00	5.25	
Regline	Line Regulation(2)	T_J = +25°C	V_I = 7 V to 25 V		4.0	100.0	mV
			V_I = 8 V to 12 V		1.6	50.0	
Regload	Load Regulation(2)	T_J = +25°C	I_O = 5 mA to 1.5 A		9.0	100.0	mV
			I_O = 250 mA to 750 mA		4.0	50.0	
I_Q	Quiescent Current	T_J =+25°C			5.0	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.03	0.50	mA
		V_I = 7 V to 25 V			0.30	1.30	
$\Delta V_O/\Delta T$	Output Voltage Drift(3)	I_O = 5 mA			-0.8		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			42.0		µV/V_O
RR	Ripple Rejection(3)	f = 120 Hz, V_I = 8 V to 18 V		62.0	73.0		dB
V_{DROP}	Dropout Voltage	T_J = +25°C, I_O = 1 A			2.0		V
R_O	Output Resistance(3)	f = 1 kHz			15.0		mΩ
I_{SC}	Short-Circuit Current	T_J = +25°C, V_I = 35 V			230		mA
I_{PK}	Peak Current(3)	T_J = +25°C			2.2		A

Notes:

2. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
3. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7806)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 11 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		5.75	6.00	6.25	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 8.0 V to 21 V		5.70	6.00	6.30	
Regline	Line Regulation(4)	T_J = +25°C	V_I = 8 V to 25 V		5.0	120	mV
			V_I = 9 V to 13 V		1.5	60.0	
Regload	Load Regulation(4)	T_J = +25°C	I_O = 5 mA to 1.5 A		9.0	120.0	mV
			I_O = 250 mA to 750 mA		3.0	60.0	
I_Q	Quiescent Current	T_J =+25°C			5.0	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 8 V to 25 V				1.3	
$\Delta V_O/\Delta T$	Output Voltage Drift(5)	I_O = 5 mA			-0.8		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			45.0		µV/V_O
RR	Ripple Rejection(5)	f = 120 Hz, V_I = 8 V to 18 V		62.0	73.0		dB
V_{DROP}	Dropout Voltage	T_J = +25°C, I_O = 1 A			2.0		V
R_O	Output Resistance(5)	f = 1 kHz			19.0		mΩ
I_{SC}	Short-Circuit Current	T_J = +25°C, V_I = 35 V			250		mA
I_{PK}	Peak Current(5)	T_J = +25°C			2.2		A

Notes:

4. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
5. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7808)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 14 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		7.7	8.0	8.3	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 10.5 V to 23 V		7.6	8.0	8.4	
Regline	Line Regulation(6)	T_J = +25°C	V_I = 10.5 V to 25 V		5.0	160.0	mV
			V_I = 11.5 V to 17 V		2.0	80.0	
Regload	Load Regulation(6)	T_J = +25°C	I_O = 5 mA to 1.5 A		10.0	160.0	mV
			I_O = 250 mA to 750 mA		5.0	80.0	
I_Q	Quiescent Current	T_J =+25°C			5.0	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.05	0.50	mA
		V_I = 10.5 V to 25 V			0.5	1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift(7)	I_O = 5 mA			-0.8		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			52.0		µV/V_O
RR	Ripple Rejection(7)	f = 120 Hz, V_I = 11.5 V to 21.5 V		56.0	73.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C			2.0		V
R_O	Output Resistance(7)	f = 1 kHz			17.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			230		mA
I_{PK}	Peak Current(7)	T_J = +25°C			2.2		A

Notes:

6. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
7. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7809)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 15 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		8.65	9.00	9.35	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 11.5 V to 24 V		8.60	9.00	9.40	
Regline	Line Regulation(8)	T_J = +25°C	V_I = 11.5 V to 25 V		6.0	180.0	mV
			V_I = 12 V to 17 V		2.0	90.0	
Regload	Load Regulation(8)	T_J = +25°C	I_O = 5 mA to 1.5 A		12.0	180.0	mV
			I_O = 250 mA to 750 mA		4.0	90.0	
I_Q	Quiescent Current	T_J =+25°C			5.0	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 11.5 V to 26 V				1.3	
$\Delta V_O/\Delta T$	Output Voltage Drift(9)	I_O = 5 mA			-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			58.0		µV/V_O
RR	Ripple Rejection(9)	f = 120 Hz, V_I = 13 V to 23 V		56.0	71.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C			2.0		V
R_O	Output Resistance(9)	f = 1 kHz			17.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			250		mA
I_{PK}	Peak Current(9)	T_J = +25°C			2.2		A

Notes:

8. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
9. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7810)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 16 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		9.6	10.0	10.4	V
		I_O = 5 mA to 1 A, $P_O \le$ 15 W, V_I = 12.5 V to 25 V		9.5	10.0	10.5	
Regline	Line Regulation(10)	T_J = +25°C	V_I = 12.5 V to 25 V		10	200	mV
			V_I = 13 V to 25 V		3	100	
Regload	Load Regulation(10)	T_J = +25°C	I_O = 5 mA to 1.5 A		12	200	mV
			I_O = 250 mA to 750 mA		4	400	
I_Q	Quiescent Current	T_J =+25°C			5.1	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 12.5 V to 29 V				1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift(11)	I_O = 5 mA			-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			58.0		µV/V_O
RR	Ripple Rejection(11)	f = 120 Hz, V_I = 13 V to 23 V		56.0	71.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C			2.0		V
R_O	Output Resistance(11)	f = 1 kHz			17.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			250		mA
I_{PK}	Peak Current(11)	T_J = +25°C			2.2		A

Notes:

10. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
11. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7812)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 19 V, C_I = 0.33 µF,C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		11.5	12.0	12.5	V
		I_O = 5 mA to 1 A, P_O ≤ 15 W, V_I = 14.5 V to 27 V		11.4	12.0	12.6	
Regline	Line Regulation[12]	T_J = +25°C	V_I = 14.5 V to 30 V		10	240	mV
			V_I = 16 V to 22 V		3	120	
Regload	Load Regulation[12]	T_J = +25°C	I_O = 5 mA to 1.5 A		11	240	mV
			I_O = 250 mA to 750 mA		5	120	
I_Q	Quiescent Current	T_J =+25°C			5.1	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.1	0.5	mA
		V_I = 14.5 V to 30 V			0.5	1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift[13]	I_O = 5 mA			-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			76.0		µV/V_O
RR	Ripple Rejection[13]	f = 120 Hz, V_I = 15 V to 25 V		55.0	71.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C			2.0		V
R_O	Output Resistance[13]	f = 1 kHz			18.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			230		mA
I_{PK}	Peak Current[13]	T_J = +25°C			2.2		A

Notes:

12. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
13. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7815)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 23 V, C_I = 0.33 µF,C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		14.40	15.00	15.60	V
		I_O = 5 mA to 1 A, P_O ≤ 15 W, V_I = 17.5 V to 30 V		14.25	15.00	15.75	
Regline	Line Regulation[14]	T_J = +25°C	V_I = 17.5 V to 30 V		11	300	mV
			V_I = 20 V to 26 V		3	150	
Regload	Load Regulation[14]	T_J = +25°C	I_O = 5 mA to 1.5 A		12	300	mV
			I_O = 250 mA to 750 mA		4	150	
I_Q	Quiescent Current	T_J =+25°C			5.2	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 17.5 V to 30 V				1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift[15]	I_O = 5 mA			-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			90.0		µV/V_O
RR	Ripple Rejection[15]	f = 120 Hz, V_I = 18.5 V to 28.5 V		54.0	70.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J =+25°C			2.0		V
R_O	Output Resistance[15]	f = 1 kHz			19.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			250		mA
I_{PK}	Peak Current[15]	T_J = +25°C			2.2		A

Notes:

14. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
15. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7818)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 27 V, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		17.3	18.0	18.7	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 21 V to 33 V		17.1	18.0	18.9	
Regline	Line Regulation(16)	T_J = +25°C	V_I = 21 V to 33 V		15	360	mV
			V_I = 24 V to 30 V		5	180	
Regload	Load Regulation(16)	T_J = +25°C	I_O = 5 mA to 1.5 A		15	360	mV
			I_O = 250 mA to 750 mA		5	180	
I_Q	Quiescent Current	T_J =+25°C			5.2	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 21 V to 33 V				1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift(17)	I_O = 5 mA			-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			110		μV/V_O
RR	Ripple Rejection(17)	f = 120 Hz, V_I = 22 V to 32 V		53.0	69.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J =+25°C			2.0		V
R_O	Output Resistance(17)	f = 1 kHz			22.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J =+25°C			250		mA
I_{PK}	Peak Current(17)	T_J =+25°C			2.2		A

Notes:

16. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
17. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7824)

Refer to the test circuit, -40°C < T_J < 125°C, I_O = 500 mA, V_I = 33 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		23.00	24.00	25.00	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 27 V to 38 V		22.80	24.00	25.25	
Regline	Line Regulation(18)	T_J = +25°C	V_I = 27 V to 38 V		17	480	mV
			V_I = 30 V to 36 V		6	240	
Regload	Load Regulation(18)	T_J = +25°C	I_O = 5 mA to 1.5 A		15	480	mV
			I_O = 250 mA to 750 mA		5	240	
I_Q	Quiescent Current	T_J =+25°C			5.2	8.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.1	0.5	mA
		V_I = 27 V to 38 V			0.5	1.0	
$\Delta V_O/\Delta T$	Output Voltage Drift(19)	I_O = 5 mA			-1.5		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			6.0		µV/V_O
RR	Ripple Rejection(19)	f = 120 Hz, V_I = 28 V to 38 V		50.0	67.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C			2.0		V
R_O	Output Resistance(19)	f = 1 kHz			28.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			230		mA
I_{PK}	Peak Current(19)	T_J = +25°C			2.2		A

Notes:

18. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
19. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7805A)

Refer to the test circuit, 0°C < T_J < 125°C, I_O = 1 A, V_I = 10 V, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		4.9	5.0	5.1	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 7.5 V to 20 V		4.8	5.0	5.2	
Regline	Line Regulation[20]	V_I = 7.5 V to 25 V, I_O = 500 mA			5.0	50.0	mV
		V_I = 8 V to 12 V			3.0	50.0	
		T_J = +25°C	V_I = 7.3 V to 20 V		5.0	50.0	
			V_I = 8 V to 12 V		1.5	25.0	
Regload	Load Regulation[20]	T_J = +25°C, I_O = 5 mA to 1.5 A			9.0	100.0	mV
		I_O = 5 mA to 1 A			9.0	100.0	
		I_O = 250 mA to 750 mA			4.0	50.0	
I_Q	Quiescent Current	T_J =+25°C			5.0	6.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 8 V to 25 V, I_O = 500 mA				0.8	
		V_I = 7.5 V to 20 V, T_J = +25°C				0.8	
$\Delta V_O/\Delta T$	Output Voltage Drift[21]	I_O = 5 mA			-0.8		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			10.0		$\mu V/V_O$
RR	Ripple Rejection[21]	f = 120 Hz, V_O = 500 mA, V_I =8 V to 18 V			68.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J =+25°C			2.0		V
R_O	Output Resistance[21]	f = 1 kHz			17.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J =+25°C			250		mA
I_{PK}	Peak Current[21]	T_J =+25°C			2.2		A

Notes:

20. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
21. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7809A)

Refer to the test circuit, 0°C < T_J < 125°C, I_O = 1 A, V_I = 15 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C		8.82	9.00	9.16	V
		I_O = 5 mA to 1 A, $P_O \leq$ 15 W, V_I = 11.2 V to 24 V		8.65	9.00	9.35	
Regline	Line Regulation(22)	V_I = 11.7 V to 25 V, I_O = 500 mA			6.0	90.0	mV
		V_I = 12.5 V to 19 V			4.0	45.0	
		T_J = +25°C	V_I = 11.5 V to 24 V		6.0	90.0	
			V_I = 12.5 V to 19 V		2.0	45.0	
Regload	Load Regulation(22)	T_J = +25°C, I_O = 5 mA to 1.5 A			12.0	100.0	mV
		I_O = 5 mA to 1 A			12.0	100.0	
		I_O = 250 mA to 750 mA			5.0	50.0	
I_Q	Quiescent Current	T_J = +25°C			5.0	6.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A				0.5	mA
		V_I = 12 V to 25 V, I_O = 500 mA				0.8	
		V_I = 11.7 V to 25 V, T_J = +25°C				0.8	
$\Delta V_O/\Delta T$	Output Voltage Drift(23)	I_O = 5 mA			-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C			10.0		$\mu V/V_O$
RR	Ripple Rejection(23)	f = 120 Hz, V_O = 500 mA, V_I =12 V to 22 V			62.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C			2.0		V
R_O	Output Resistance(23)	f = 1 kHz			17.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C			250		mA
I_{PK}	Peak Current(23)	T_J = +25°C			2.2		A

Notes:

22. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
23. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7810A)

Refer to the test circuit, 0°C < T_J < 125°C, I_O = 1 A, V_I = 16 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C	9.8	10.0	10.2	V
		I_O = 5 mA to 1 A, P_O ≤ 15 W, V_I = 12.8 V to 25 V	9.6	10.0	10.4	
Regline	Line Regulation[24]	V_I = 12.8 V to 26 V, I_O = 500 mA		8.0	100.0	mV
		V_I = 13 V to 20 V		4.0	50.0	
		T_J = +25°C, V_I = 12.5 V to 25 V		8.0	100.0	
		T_J = +25°C, V_I = 13 V to 20 V		3.0	50.0	
Regload	Load Regulation[24]	T_J = +25°C, I_O = 5 mA to 1.5 A		12.0	100.0	mV
		I_O = 5 mA to 1 A		12.0	100.0	
		I_O = 250 mA to 750 mA		5.0	50.0	
I_Q	Quiescent Current	T_J =+25°C		5.0	6.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.5	mA
		V_I = 12.8 V to 25 V, I_O = 500 mA			0.8	
		V_I = 13 V to 26 V, T_J = +25°C			0.5	
$\Delta V_O/\Delta T$	Output Voltage Drift[25]	I_O = 5 mA		-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C		10.0		µV/V_O
RR	Ripple Rejection[25]	f = 120 Hz, V_O = 500 mA, V_I =14 V to 24 V		62.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J =+25°C		2.0		V
R_O	Output Resistance[25]	f = 1 kHz		17.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J =+25°C		250		mA
I_{PK}	Peak Current[25]	T_J =+25°C		2.2		A

Notes:

24. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
25. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7812A)

Refer to the test circuit, 0°C < T_J < 125°C, I_O = 1 A, V_I = 19 V, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C	11.75	12.00	12.25	V
		I_O = 5 mA to 1 A, P_O ≤ 15 W, V_I = 14.8 V to 27 V	11.50	12.00	12.50	
Regline	Line Regulation(26)	V_I = 14.8 V to 30 V, I_O = 500 mA		10.0	120.0	mV
		V_I = 16 V to 22 V		4.0	120.0	
		T_J = +25°C, V_I = 14.5 V to 27 V		10.0	120.0	
		T_J = +25°C, V_I = 16 V to 22 V		3.0	60.0	
Regload	Load Regulation(26)	T_J = +25°C, I_O = 5 mA to 1.5 A		12.0	100.0	mV
		I_O = 5 mA to 1 A		12.0	100.0	
		I_O = 250 mA to 750 mA		5.0	50.0	
I_Q	Quiescent Current	T_J = +25°C		5.0	6.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.5	mA
		V_I = 14 V to 27 V, I_O = 500 mA			0.8	
		V_I = 15 V to 30 V, T_J = +25°C			0.8	
$\Delta V_O/\Delta T$	Output Voltage Drift(27)	I_O = 5 mA		-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C		10.0		μV/V_O
RR	Ripple Rejection(27)	f = 120 Hz, V_O = 500 mA, V_I =14 V to 24 V		60.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J = +25°C		2.0		V
R_O	Output Resistance(27)	f = 1 kHz		18.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J = +25°C		250		mA
I_{PK}	Peak Current(27)	T_J = +25°C		2.2		A

Notes:

26. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
27. These parameters, although guaranteed, are not 100% tested in production.

Electrical Characteristics (LM7815A)

Refer to the test circuit, 0°C < T_J < 125°C, I_O = 1 A, V_I = 23 V, C_I = 0.33 µF, C_O = 0.1 µF, unless otherwise specified.

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
V_O	Output Voltage	T_J = +25°C	14.75	15.00	15.30	V
		I_O = 5 mA to 1 A, P_O ≤ 15 W, V_I = 17.7 V to 30 V	14.40	15.00	15.60	
Regline	Line Regulation(28)	V_I = 17.4 V to 30 V, I_O = 500 mA		10.0	150.0	mV
		V_I = 20 V to 26 V		5.0	150.0	
		T_J = +25°C, V_I = 17.5 V to 30 V		11.0	150.0	
		T_J = +25°C, V_I = 20 V to 26 V		3.0	75.0	
Regload	Load Regulation(28)	T_J = +25°C, I_O = 5 mA to 1.5 A		12.0	100.0	mV
		I_O = 5 mA to 1 A		12.0	100.0	
		I_O = 250 mA to 750 mA		5.0	50.0	
I_Q	Quiescent Current	T_J =+25°C		5.2	6.0	mA
ΔI_Q	Quiescent Current Change	I_O = 5 mA to 1 A			0.5	mA
		V_I = 17.5 V to 30 V, I_O = 500 mA			0.8	
		V_I = 17.5 V to 30 V, T_J = +25°C			0.8	
$\Delta V_O/\Delta T$	Output Voltage Drift(29)	I_O = 5 mA		-1.0		mV/°C
V_N	Output Noise Voltage	f = 10 Hz to 100 kHz, T_A = +25°C		10.0		µV/V_O
RR	Ripple Rejection(29)	f = 120 Hz, V_O = 500 mA, V_I =18.5 V to 28.5 V		58.0		dB
V_{DROP}	Dropout Voltage	I_O = 1 A, T_J =+25°C		2.0		V
R_O	Output Resistance(29)	f = 1 kHz		19.0		mΩ
I_{SC}	Short-Circuit Current	V_I = 35 V, T_J =+25°C		250		mA
I_{PK}	Peak Current(29)	T_J =+25°C		2.2		A

Notes:

28. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty is used.
29. These parameters, although guaranteed, are not 100% tested in production.

Typical Performance Characteristics

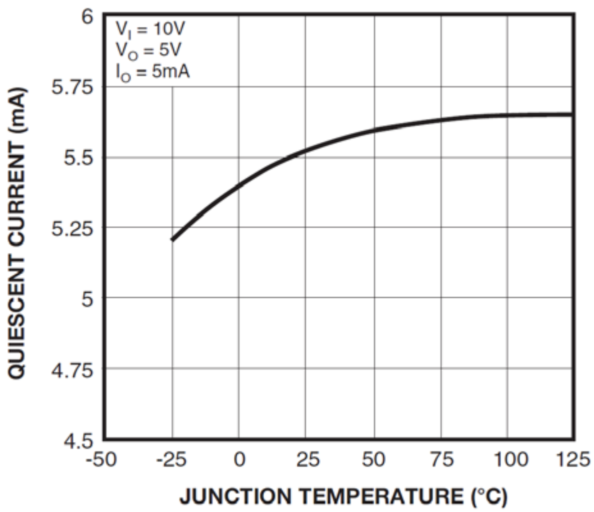


Figure 2. Quiescent Current

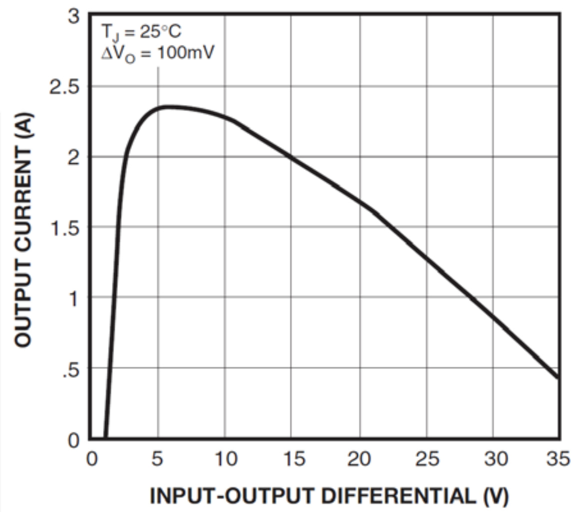


Figure 3. Peak Output Current

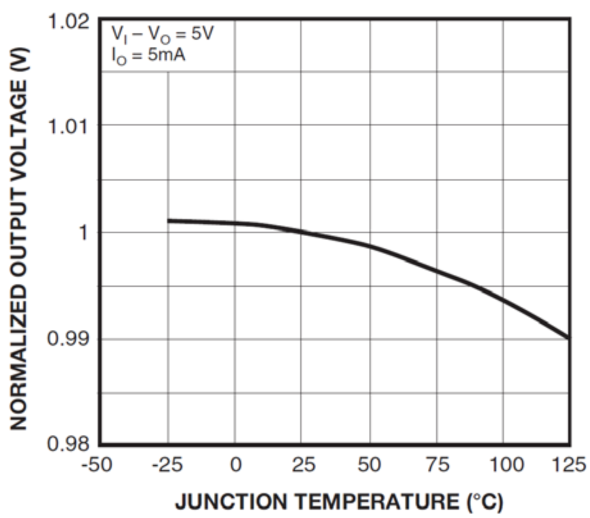


Figure 4. Output Voltage

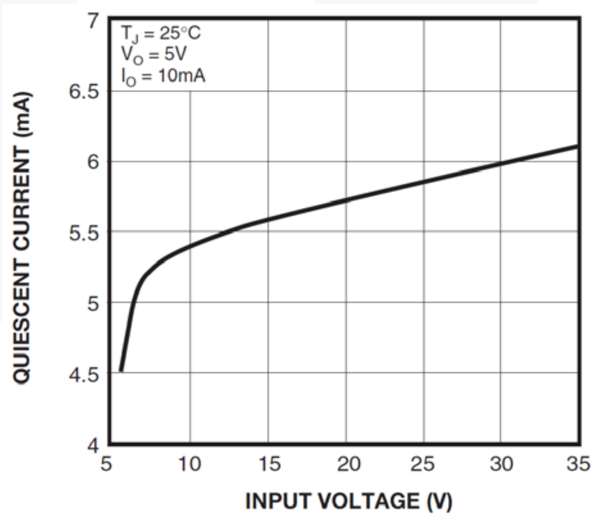


Figure 5. Quiescent Current

Typical Applications

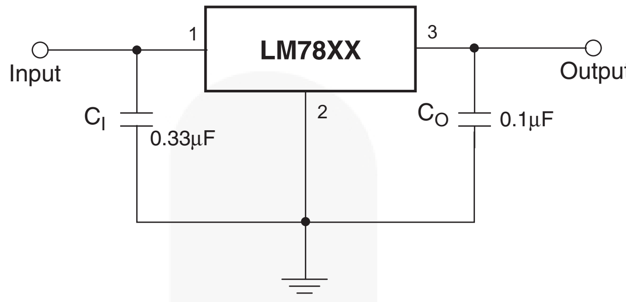


Figure 6. DC Parameters

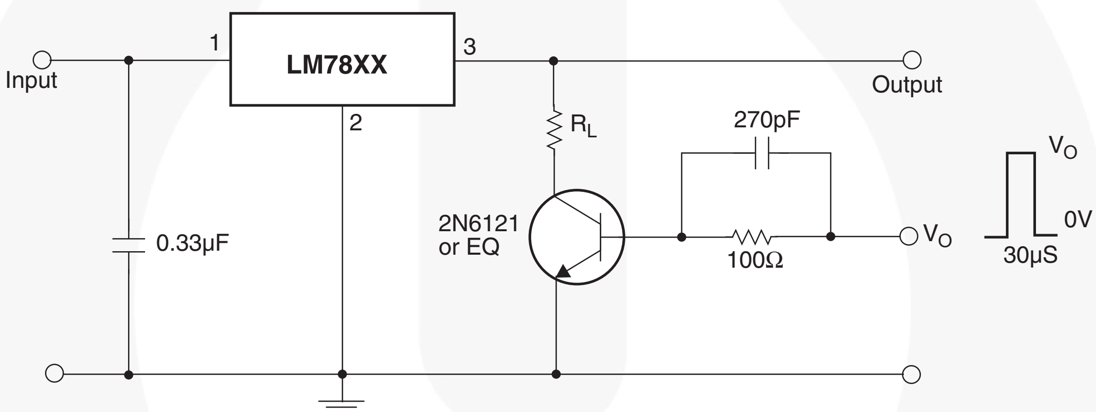


Figure 7. Load Regulation

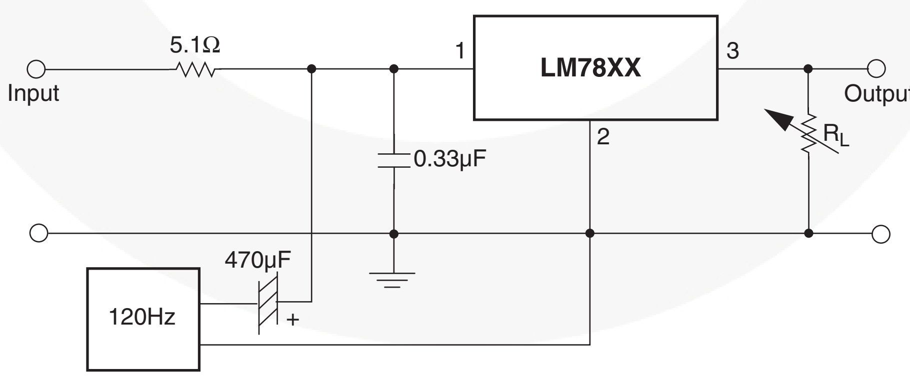


Figure 8. Ripple Rejection

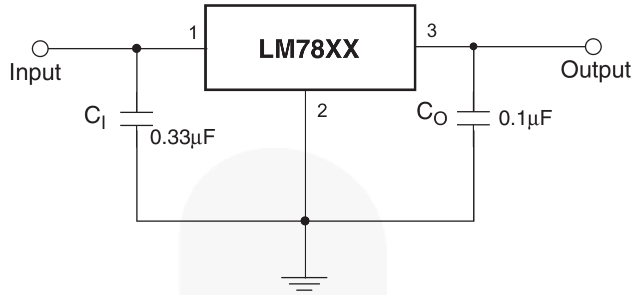
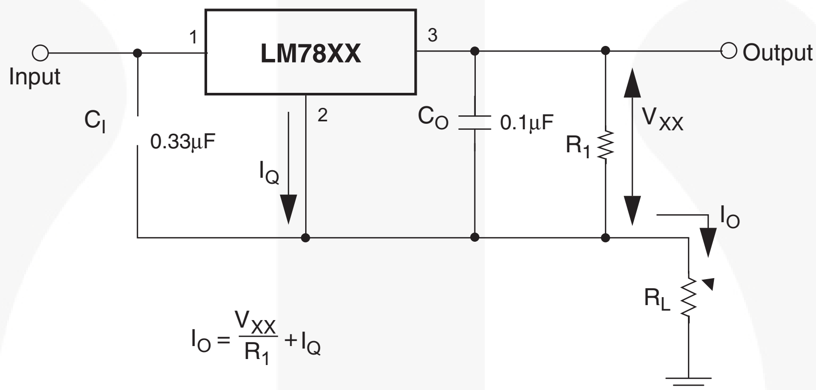


Figure 9. Fixed-Output Regulator



Notes:

29. To specify an output voltage, substitute voltage value for "XX". A common ground is required between the input and the output voltage. The input voltage must remain typically 2.0 V above the output voltage even during the low point on the input ripple voltage.

30. C_I is required if regulator is located an appreciable distance from power supply filter.

31. C_O improves stability and transient response.

Figure 10.

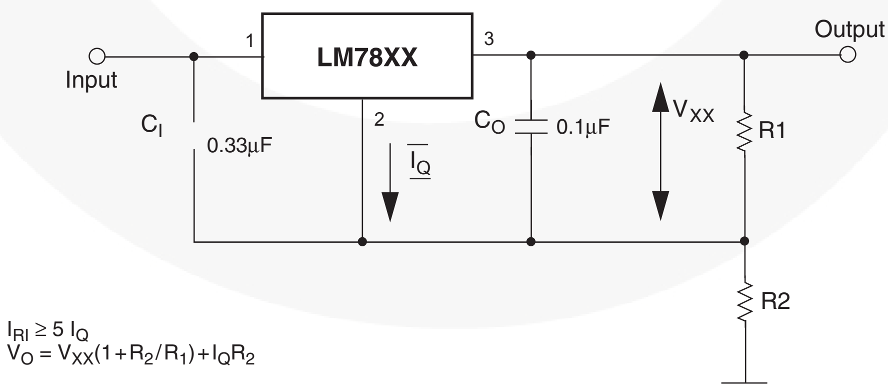


Figure 11. Circuit for Increasing Output Voltage

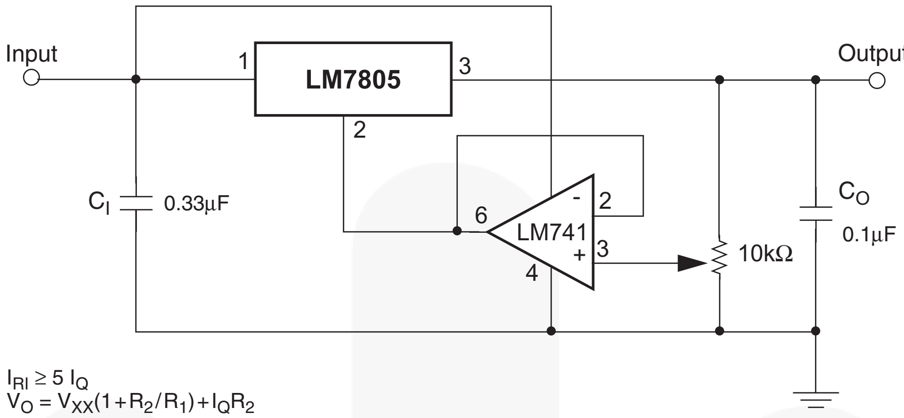


Figure 12. Adjustable Output Regulator (7 V to 30 V)

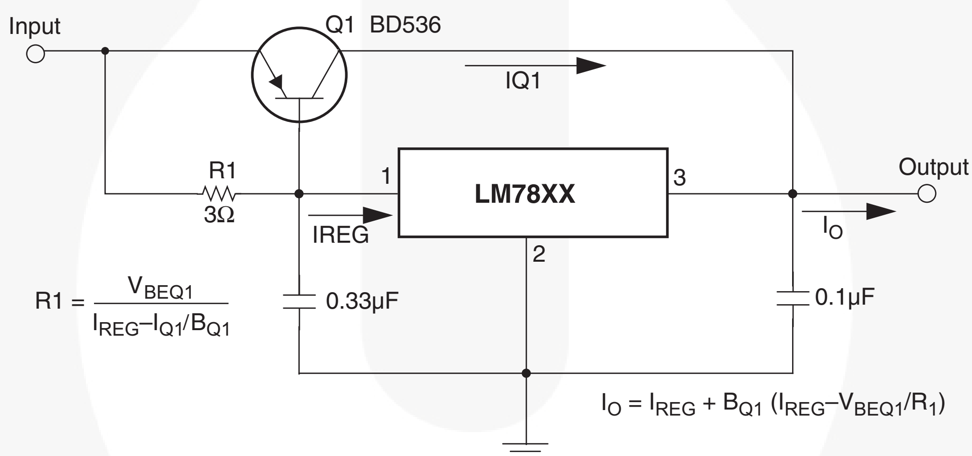


Figure 13. High-Current Voltage Regulator

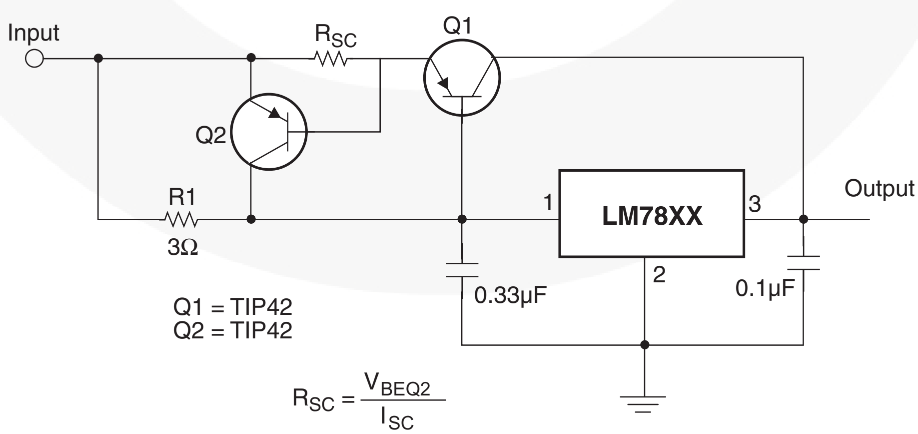


Figure 14. High Output Current with Short-Circuit Protection

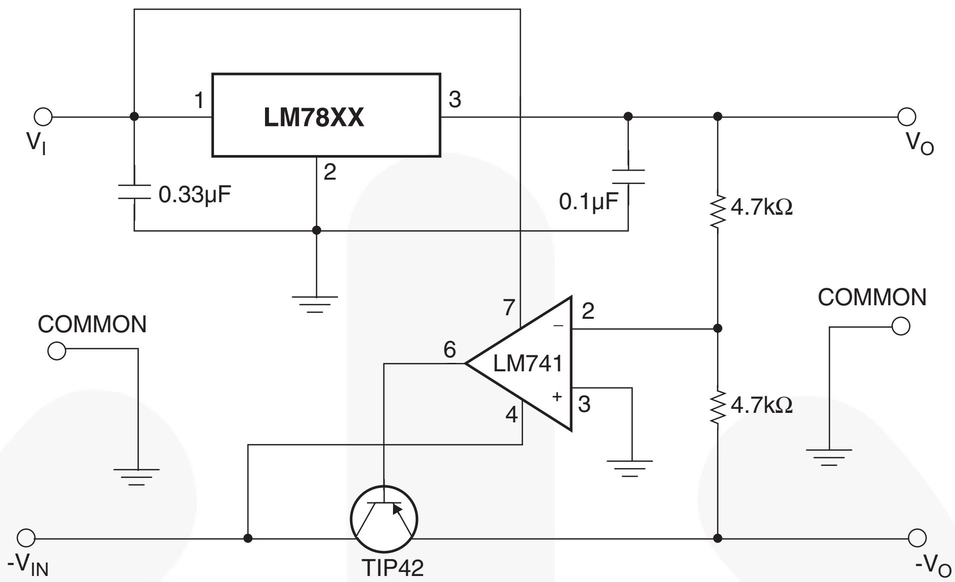


Figure 15. Tracking Voltage Regulator

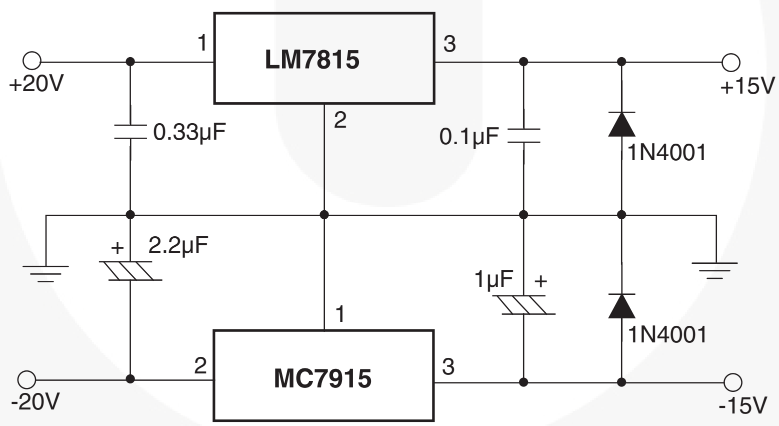


Figure 16. Split Power Supply (±15 V - 1 A)

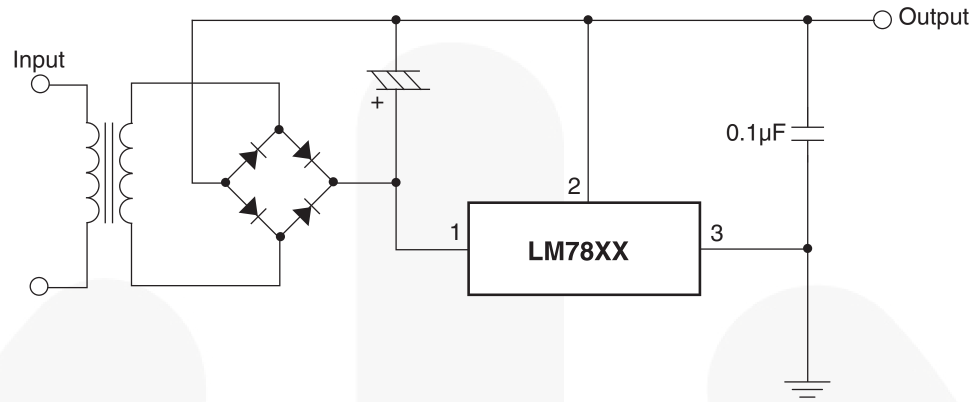


Figure 17. Negative Output Voltage Circuit

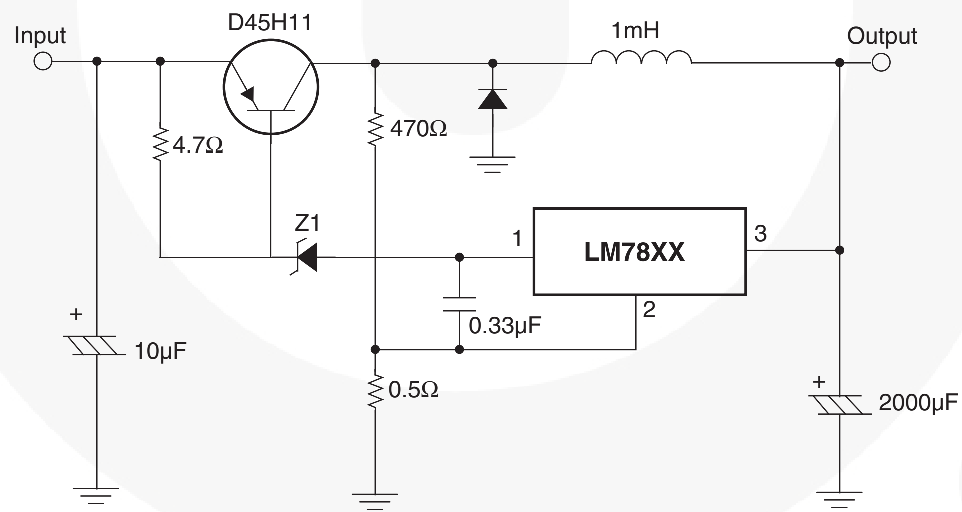


Figure 18. Switching Regulator

Physical Dimensions

TO-220 (SINGLE GAUGE)

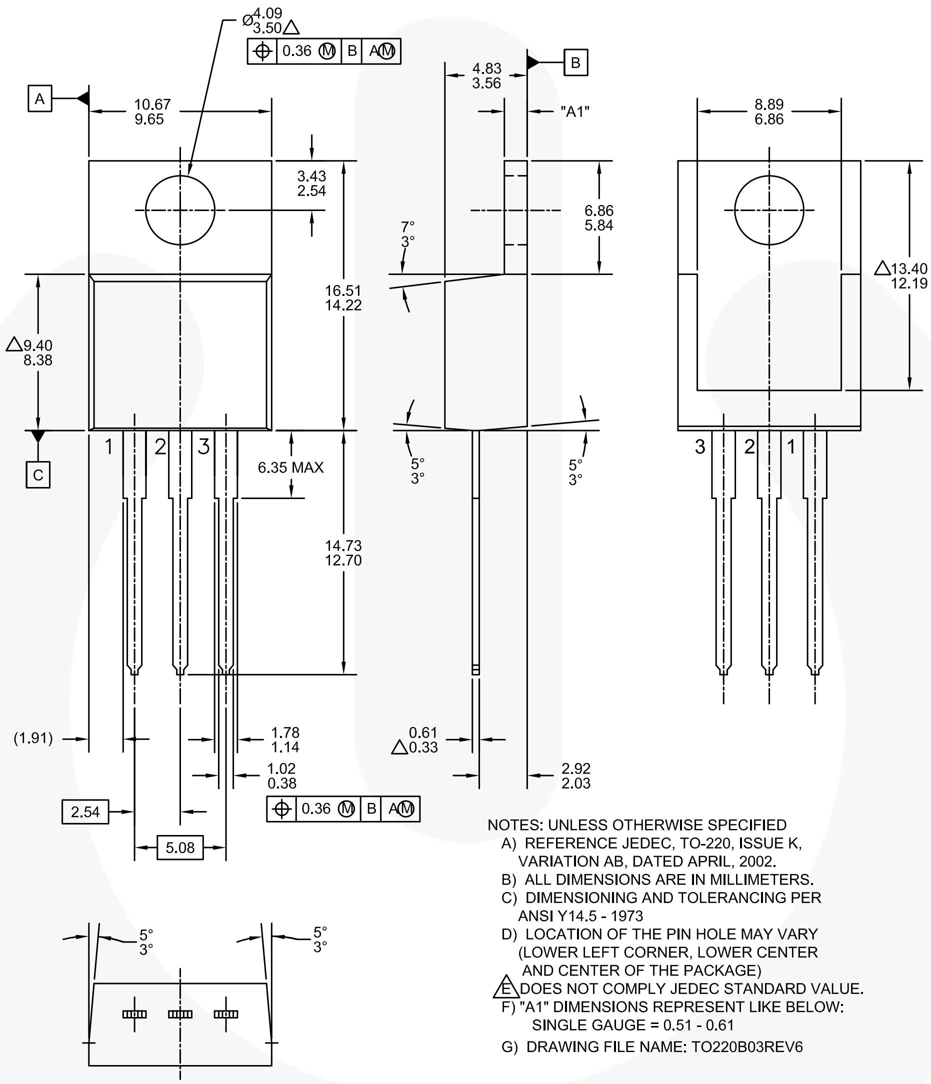


Figure 19. TO-220, MOLDED, 3-LEAD, JEDEC VARIATION AB (ACTIVE)

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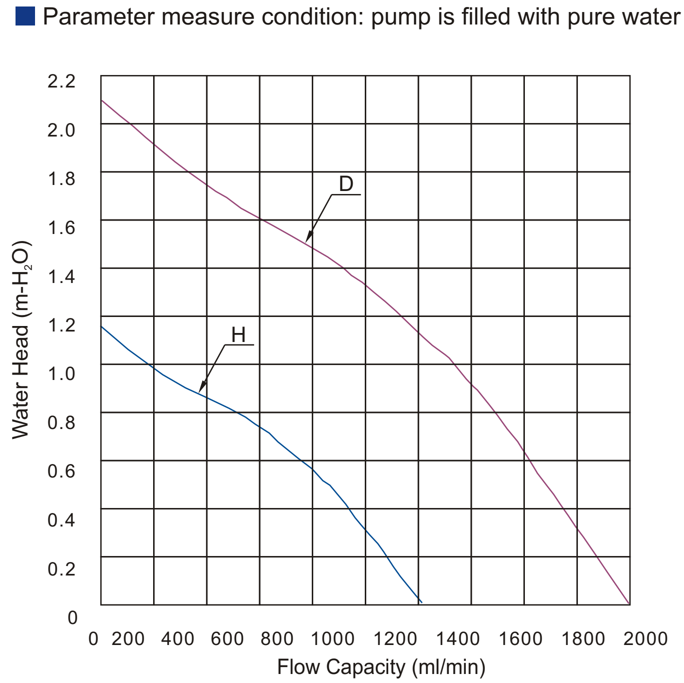
PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative / In Design	Datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	Datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design.
No Identification Needed	Full Production	Datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve the design.
Obsolete	Not In Production	Datasheet contains specifications on a product that is discontinued by Fairchild Semiconductor. The datasheet is for reference information only.

Rev. I65

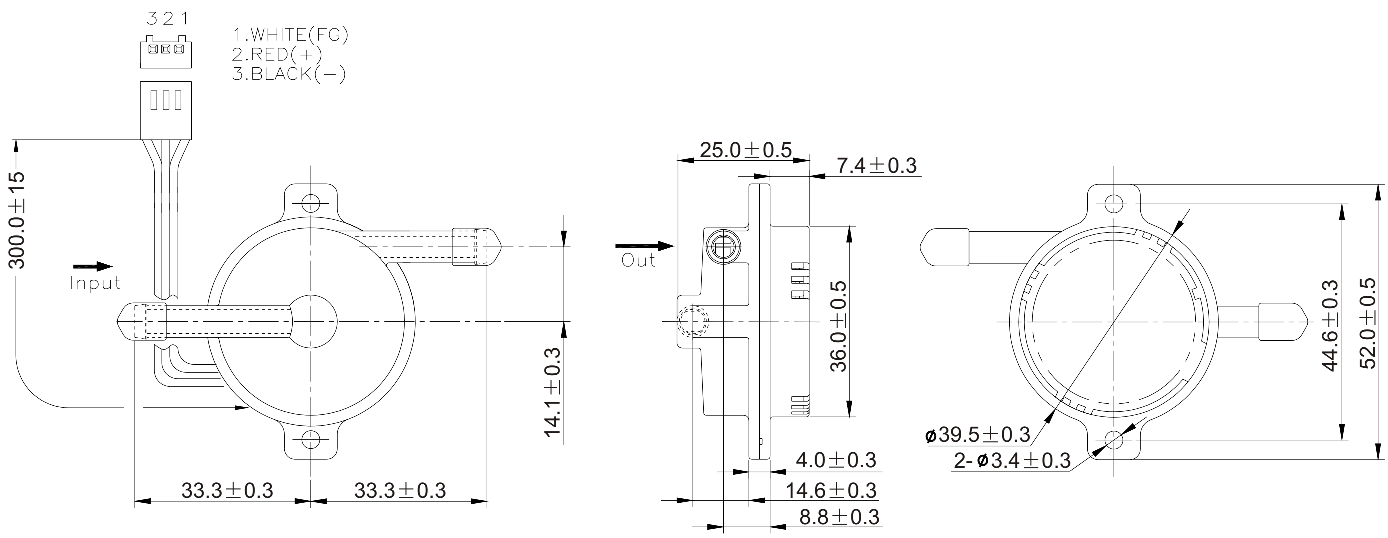


Application:

Use on liquid cooling system

Features:

Ceramic Shaft
High Performance
Mini Size
Low Noise
Low Vibration
Long Life



Unit: mm

Listed Model	Rated Voltage	Operation Voltage	Input Current	Speed	Flow Capacity	Water Head	Acoustical Noise	Operation Temperature	Weight
	VDC	VDC	A	RPM	ml/min	m-H_2O	dBA		g
RDPC3625D12	12	7.0～13.5	0.45	3,600	2,000	2.2	30	0～70	43
RDPC3625H12	12	6.0～13.8	0.30	2,600	1,200	1.1	25	0～70	

Notes: All readings are typical values at rated voltage.
Specifications subjected to change without notice.

Compact 2-Way Pinch Valves

For use with 3/32" OD to 3/8" OD Soft Tubing

ASCO

ASCO 388, 390, and 401 Series are 2-Way, normally closed and normally open, solenoid operated pinch valves designed to control the flow of corrosive or high purity fluids in medical equipment and analytical instruments. Pinch valves isolate the fluid from the valve components by locating soft tubing in the mechanism that "pinches" the tubing to block flow and releases to allow flow.

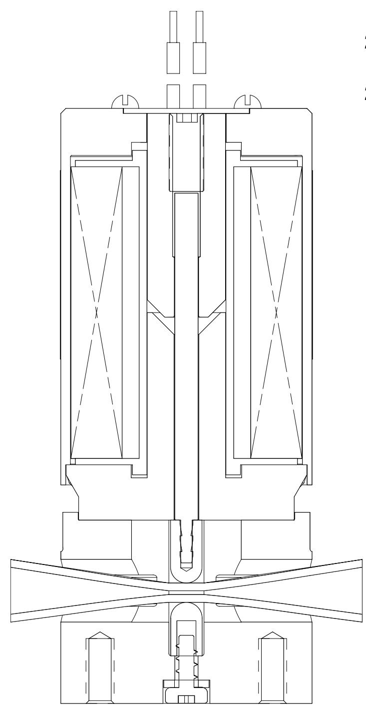
- Saves space in equipment with compact design.
- Large range of tubing sizes available for various flow and pressure requirements.
- Zero dead volume prevents cross-contamination

Construction

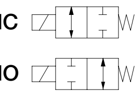
Valve Wetted Parts	
Recommended Tubing	VQM Max Hardness: 55 Shore A (12" tube supplied with each valve. Additional lengths available, see Pinch Valve Tubing Section)

Electrical

Standard Voltages	12 VDC, 24 VDC, 115 VAC (50/60 Hz)
Power Consumption **-DC** **-AC**	 2.5 to 10.0 Watts 4.0 to 12.0 Watts
Duty Cycle Rating	Continuous
Electrical Connection **-390** **-388, 401**	 26 AWG Hardwire, 15" long 22 AWG Hardwire, 15" long



2NC
2NO



Temperature Range:

Ambient:
32˚F to 77˚F (0˚C to 25˚C)

Approvals:

Meets applicable CE directives.

ASCO®

Specifications

Tubing ID (in)	Tubing OD (in)	Tubing Wall (in)	Operating Pressure (psi)		Catalog Number	Const. Ref.	Power (Watts)	Weight (oz)
			Min.	Max.				
2/2NC - Normally Closed								
1/32”	3/32”	1/32”	0	50	390NCxx150	1	2.5 (DC), 4.0 (AC)	2.5
1/16”	1/8”	1/32”	0	30	390NCxx330	1	2.5 (DC), 4.0 (AC)	2.5
1/16”	3/16”	1/16”	0	30	401NCxx430	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
3/32”	5/32”	1/32”	0	15	401NCxx515	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
1/8”	1/4”	1/16”	0	30	401NCxx830	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
3/16”	1/4”	1/32”	0	10	401NCxx1010	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
1/4”	5/16”	1/32”	0	10	388NCxx1110	3	10.0 (DC), 12.0 (AC)	16.0
1/4	3/8"	1/16"	0	15	388NCxx1215	3	10.0 (DC), 12.0 (AC)	16.0
2/2NO - Normally Open								
1/32”	3/32”	1/32”	0	50	390NOxx150	1	2.5 (DC), 4.0 (AC)	2.5
1/16”	1/8”	1/32”	0	30	390NOxx330	1	2.5 (DC), 4.0 (AC)	2.5
1/16”	3/16”	1/16”	0	30	401NOxx430	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
3/32”	5/32”	1/32”	0	15	401NOxx515	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
1/8”	1/4”	1/16”	0	30	401NOxx830	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
3/16”	1/4”	1/32”	0	10	401NOxx1010	2	4.5 (12DC), 5.3 (24DC), 6.8 (AC)	4.0
1/4”	5/16”	1/32”	0	10	388NOxx1110	3	10.0 (DC), 12.0 (AC)	16.0
1/4	3/8"	1/16"	0	15	388NOxx1215	3	10.0 (DC), 12.0 (AC)	16.0

Catalog Number Description and Options

390NC	xx	150
Catalog Number	**Voltage** 12 = 12VDC 24 = 24VDC 115 = 115VAC	**Catalog Number**

To Construct Catalog Number

- Select catalog number from specification table above.
- Insert desired voltage in place of “xx”; use 3 digits for 115 AC voltage.

Examples

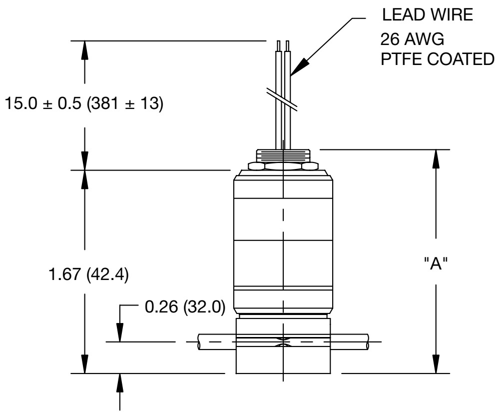
390NO12330 = 1/16" x 1/8" tubing, normally open, 12DC, 30 psi

401NC24830 = 1/8" x 1/4" tubing, normally closed, 24DC, 30 psi

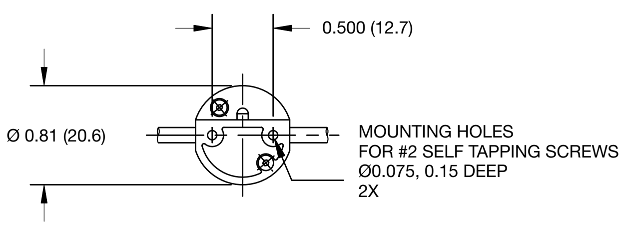
388NC1151215 = 1/4" x 3/8" tubing, normally closed, 115AC, 50/60 Hz, 15 psi

Dimensions: Inches (mm)

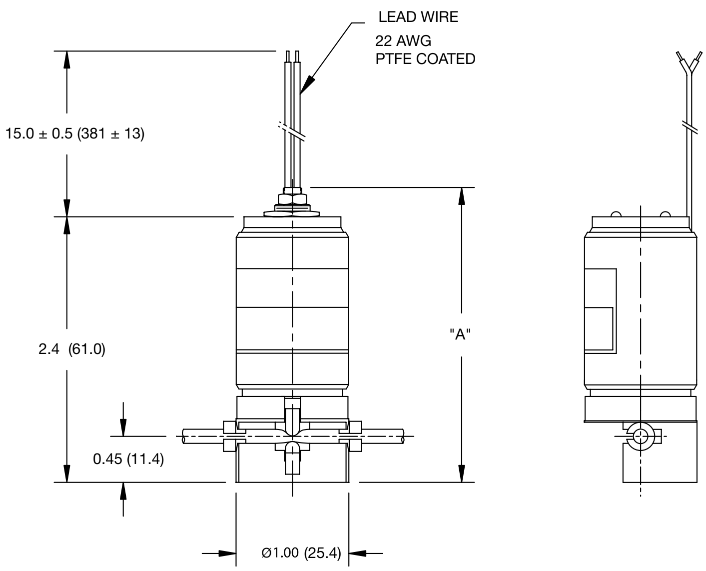
Const. Ref 1



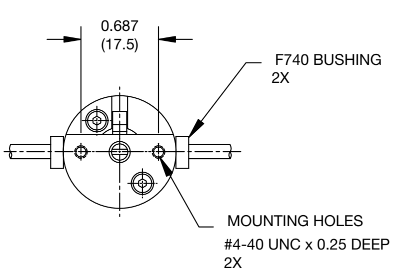
MODEL 390	
TYPE	DIM "A"
2 WAY NO	7.75 (44.5) MAX
2 WAY NC	1.90 (48.3) MAX



Const. Ref 2



MODEL 401	
TYPE	DIM "A"
2 WAY NO	2.45 (62.2) MAX
2 WAY NC	2.50 (63.5) MAX



Dimensions: Inches (mm)

Const. Ref 3

MODEL 388	
TYPE	DIM "A"
2 WAY NO	3.6 (91.4) MAX
2 WAY NC	4.00 (101.6) MAX