Palestine Polytechnic University

College of Engineering & Technology
Electrical & Computer Engineering Department

Graduation Project

Pulse Difference Time (PDT) measuring device for diagnosing sleep apnea

Project Team

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Hebron – Palestine

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Prepared by:

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This report is submitted in partial fulfillment of the requirements for the

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Project Supervisor: Dr.Ramzi Qawassmi.

Electrical and Computer Engineering Department

Palestine Polytechnic University

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جامعة بوليتكنك فلسطين

الخليل – فلسطين

كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية و الحاسوب

اسم المشروع

تشخيص ضيق التنفس أثناء النوم عن طرق جهاز الفرق بين النبضات

أسماء الطلبة

أيام الرجبي، **نور دويفش**، شريهان العمله

بناء على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية و الحاسوب وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة الأجهزة الطبية.

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First all praise is to Allah who gave us the ability to complete this project with a satisfying degree of perfection.

We would like to thank our parents who taught to be good person who work hard to achieve our aim, thanks to palestine polytechnic university, & every body shared to success our project.

Abstract

Sleep apnea is a serious sleep disorder that occurs when a persons breathing is interrupted during sleep.

Typical breathing rates occur anywhere from 10-20 breathes per minute. During sleep apnea, the tongue blocks the airway and a 10-30 second pause in breathing occurs, causing the sufferer to miss one to two breathes, so we use Pulse differences time method to measure indirectly the presence of the disorder and its severity in a sleep lab.

Pulse difference time (PDT) is a noninvasive method of measuring respiratory changes in persons with breathing sleep disorders. It is measured by use of both an ECG machine and photoplethysmograph technique. An ECG machine generates a signal based on the depolarization of the heart while the photoplethysmograph measures the pressure wave, or pulse at the tip of the finger. A value for pulse difference time is given by calculating the difference in time between the peak of the R wave from the ECG and the peak of the pressure wave from the plethysmogram.

The main goal of the project is to create device that can record electrical signals from ECG and plethysmograph leads, improving the signal by including an instrumentation amplifier and by modifying existing software to better detection the peaks of the stored voltage data. And help doctors to treatment sleep apnea.

الملخص

ضيق التنفس في حالة النوم هي حالة من النوم الغير طبيعي تحدث للإنسان نتيجة التأخر في التنفس.
معدل التنفس الطبيعي عند الإنسان تكون ما بين ١٠ إلى ٢٠ مره في الدقيقة، أما في حالة ضيق التنفس يقل معدل التنفس بضياع نفس أو اثنين في فتره زمنيه ما نتيجة لوجود جسيم ما يغلق المجاري التنفسية أو لأسباب أخرى، لذا يتم استخدام تقنية pulse difference time لقياس وجود وشدة ضيق التنفس أثناء النوم بطريقة غير مباشره.

PDT طريقه غير جراحيه يتم من خلالها قياس التغير في معدل التنفس عند الأشخاص المصابين بضيق التنفس أثناء النوم، و هو الفرق ما بين الزمن اللازم للحصول على موجة (QRS) من تقنية (ECG) و الزمن اللازم للوصول إلى ذروة إشارة ضغط الدم باستخدام تقنية (plethysmogram).

في هذا المشروع سنعرض نظام يمكن أي يقيس هذا الزمن باستخدام دائرتين رئيسيتين، الأولى نسجل بها إشارة القلب الكهربائية باستخدام تقنيه (electrocardiograph) والثانية نسجل بها إشارة ضغط الدم باستخدام تقنيه(plethysmograph).

الهدف من هذا المشروع هو الحصول على جهاز يتم من خلاله اخذ الإشارتين السابقتين ومن ثم معالجتهما باستخدام برامج الحاسوب للحصول على الموجه المطلوبة بأقل تشويش ممكن بالتالي تحديد(PDT) التي تساعد الطبيب في علاج الحالة المرضية.

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Chapter 1

Introduction

1.1 Overview.

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1.6 Project Contents.

1.1 Overview

Our final project is aimed to design and build a simple device for measuring pulse difference time (PDT). The device consisted of two main circuits one for recording electrocardiogram (ECG) signal and the other for recording blood pressure (BP).

The objectives that can be summarized as follows:

1- Design and build ECG and plethysmography systems.
2- Use data acquisition system (DAQ) to convert signal from analog form to digital one.
3- Systems will be connected to laptop computer.
4- The received signals will be processed by using Matlab.

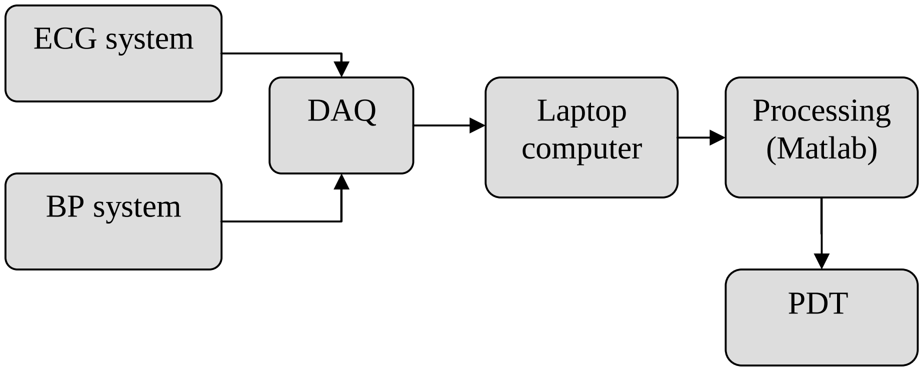

Fig1.1: General PDT system block diagram

1.2 Project Objectives

The main objectives of the project are:

1. To study the physiology of blood pressure and cardiac conduction system.
2. To show how blood pressure and ECG waveform are benefit for apnea diagnosing.
3. Design and build ECG and photoplythesmograph systems.
4. To design a software program with use of Mat Lab for processing the ECG and BP signals.

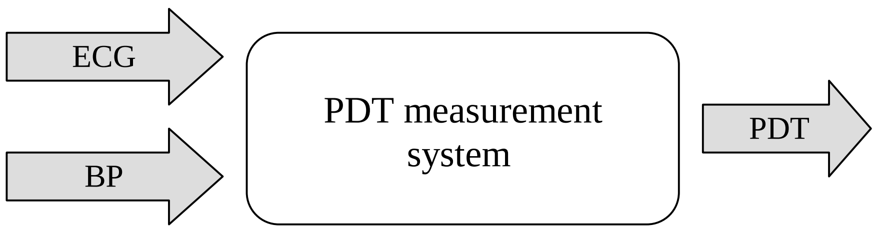

Fig1.2: Simple PDT block diagram

1.3 Literature Review

Sleep apnea is a sleep disorder characterized by pauses in breathing during sleep. There are three distinct forms of sleep apnea: central, obstructive, and complex (i.e., a combination of central and obstructive) constituting 0.4%, 84% and 15% of cases respectively .[5]

1. Since the most common type of apnea is the obstructive sleep apnea, the early reports in the medical literature described individuals who were very severel congestive heart failure .

   The management of obstructive sleep apnea was revolutionized with the introduction of continuous positive airway pressure (CPAP), first described in 1981 by Colin Sullivan and associates in Sydney, Australia.

   The first models were bulky and noisy but the design was rapidly improved and by the late 1980s CPAP was widely adopted. The availability of an effective treatment stimulated an aggressive search for affected individuals and led to the establishment of hundreds of specialized clinics dedicated to the diagnosis and treatment of sleep disorders. [5]

2. Polysomnography (PSG) is a multi-parametric test used in the study of sleep, the test result is called a polysomnogram.

   Polysomnography is used to diagnose many types of sleep disorders including REM behavior disorder, parasomnias, and sleep apnea.

Increasingly, polysomnography is being supplemented or replaced by Actigraphy in cases where longitudinal or large scale data sets need to be generated, or when PSG is not a cost-efficient option. [5]

3. Normal pulse transit time (PTT) range from 250-350 milliseconds; a significant variation in this time can help identify sleep apnea in two ways.
   First, as blood pressure decreases the arterial wall stiffness decreases. As stiffness decreases, it causes the pulse to take a longer time to reach the finger, causing on increase in PTT. This increase helps to diagnose sleep apnea.
   Second, the increase of blood pressure as the obstruction clears increases arterial wall. The increases in stiffness increases blood pressure, causing pulse transit time to decrease. Decreases in PTT in patients with sleep apnea can range from 15 to 50 milliseconds. Any decrease over 50 milliseconds is anatomically impossible. This decrease in PTT can help diagnose the severity of the apnea. [8]

4. PWTT (pulse wave transit time) is a parameter used to indicate changes in BP. its measuring by using the photoplethysmograph (PPG) sensor in an earlobe and measure ECG using the ECG monitoring device made on the chest. The measurement device for detecting pulse wave consists of infrared LED for transmitted light illumination, photodiode as light detector, amplifier and filter. The components of circuit contain 0.5Hz high pass, 60Hz notch and 10Hz low pass filter. ECG measurement device consists of multiplexer, amplifier, filter, and micro-controller and RF module. After amplification and filtering, ECG signal and pulse wave is fed through micro-controller. [10]

1.4 The importance of the project.

PDT device is important since it provides a signal which used to diagnoses the apnea problems.

- ✓ Simple to use and it is safe.
- ✓ Non invasive method.
- ✓ Use two methods to get the output signal, so it is easer in comparison with previous studies.
- ✓ Small and comfortable.

1.5 Time Plan.

Table1.1: Project Time

week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gives idea	*	*														
Collection data.		*	*	*	*	*	*	*	*	*	*	*				
Make circuit.				*	*	*	*	*	*	*	*	*	*	*	*	
Analysis.						*	*	*	*	*	*	*	*			
Writing.			*	*	*	*	*	*	*	*	*	*	*	*	*	
Presentation.																*

Table1.2: Project Cost.

Component	Quantity	Cost ($)
Electrode wire	1	0
PPG sensor	1	0
AD620	2	10
LM358	10	10
Resistance	....	15
Capacitors	.....	15
Others	......	10
Total cost	....	60

1.6 Project Content.

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Chapter Two: Theoretical and Physiological Background.

Chapter Three: Project Conceptual Design.

Chapter Four: Implementation and Testing.

Chapter Five: Conclusion and Future work.

Chapter 2

Theoretical and Physiological Background

2.1 Cardiac Conduction System.

2.2 Blood Pressure Measurement.

2.3 Photoplethysmography Method.

2.4 Sleep Apnea.

2.5 Pulse Difference Time.

2.1 Cardiac Conduction System.

Human heart is composed of myocardium. When action potential occurs, it will lead to a myocardial contraction then heart pumps blood to whole body. In the meantime, the current resulting from action potential will spread from heart to whole body unequally. It explains why we can catch the signal from the different parts of human body by surface electrodes. The measured waveform is called electrocardiogram (ECG).

A lead is composed by potential waveforms recorded from the electrodes placed on different parts of body. Baised on cardiac potential axis , there are six standard leads, including lead I , lead II , lead III, aVr , aVl , aVf , the right foot is usually considered as a reference ground ; since its potential amplitude changes less than all other reference points because it farthest from heart .

The systole of heart is not completely controlled by automatic nervous system, but originally by the specialized cells in sinoartial node (SAN) which works as pacemaker. The potential from (SAN) will spread to all atria & make it contracted, then atria pumps the blood into the ventricles. In the meantime, passing through the atrioventricular node (AVN) between the ventricle and atrium, action potential will center to all areas of the ventricles via Purkinje fibers, and then makes it contracted.
Finally, ventricle pumps the blood to the arteries. [4]

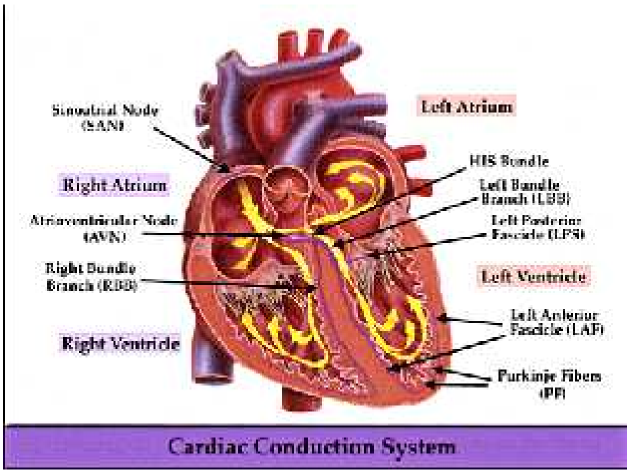


Fig 2.1.1: Cardiac Conduction System.[11]

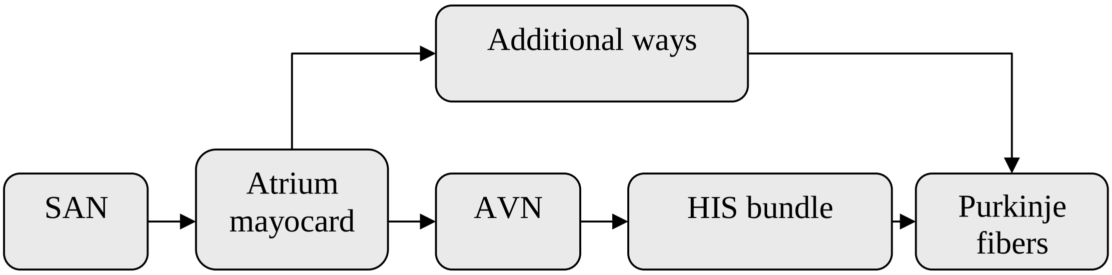


Fig 2.1.2: Cardiac Conduction System Block Diagram.

- SAN is a section of nodal tissue that is located in the upper of the right atrium, is referred as the pacemaker of the heart.

- AVN is a section of nodal tissue that lies on the right side of the partition that divides the arterial, near the bottom of the right atrium.

- Purkinji fibres are fibre branches that extend from the atrioventicular bundle. They relay cardiac impulses to the ventricular causing the ventricles to contract.

- HIS bundle is pat of the specialized conduction system .The HIS bundle rapidly conducts electrical impulses from the AVN to the ventricles. Disease in the HIS bundle can produce a form of bradycardia (too slow heart rate) called heart block.

Einthoven triangle (Bipolar leads):

Willem Eitnthoven invented the ECG to measure heartbeats in 1901, for which he was awarded the Nobel Prize in Medicine in 1924. With each heartbeat, the cardiac tissue releases ions that depolarize the tissue. This creates a voltage of about 1 mV that can be measured with various leads attached at the body.

Einthoven's recording is known as the "three lead" ECG, with measurements taken from three points on the body (defining Einthoven triangle, an equilateral triangle with the heart at the centre). [5]

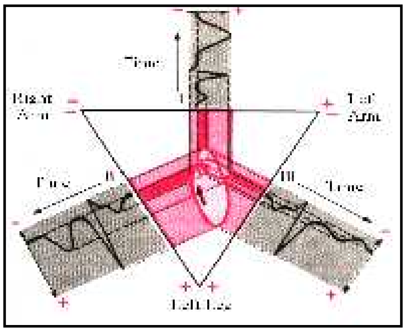


Fig 2.1.3: Einthoven Triangle.[11]

Each lead has a differ shape of wave:

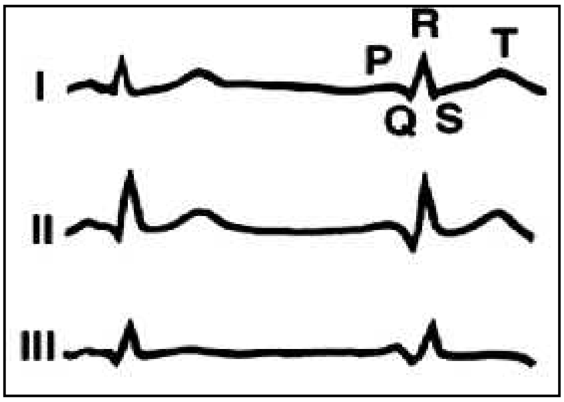


Fig 2.1.4: ECG waves.[4]

ECG waveform:

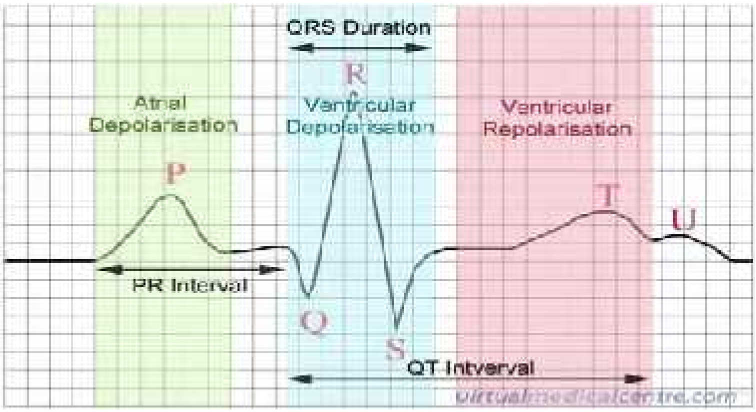


Fig 2.1.5: ECG Waveform.[11]

Figure 2.1.5 shows a normal ECG which consist of a P wave, QRS wave and T wave. P wave is a current caused by the depolarization of atria contraction., QRS is the current caused by the depolarization before ventricular contraction. And at last T wave, by ventricular repolarization.

Table 2.1: ECG Component Duration and Amplitude.

Duration of ECG component (sec)			
P -wave	PQ- wave	QRS -wave	QT- wave
Less0.1 sec	Less0.2	Less0.12	0.32-39
Amplitude of ECG component (mV)			
P- wave	Q -wave	R+S	T -wave
Less0.25	1-4	1-0	1-0

ECG Medical electrodes:

The physical shape of an electrode depends upon its application

- Metalic Plate electrodes.
  Used as limb electrode.

- Suction electrodes.
  Used on the patient chest.

- Needle electrodes.
  Is used in open heart surgery.

- Ag-AgCl electrodes.
  Is used for long time recordings and continuous recordings.

We use conductive paste, adhesive tape, and alcohol to avoid signal noise production & artificial movement.

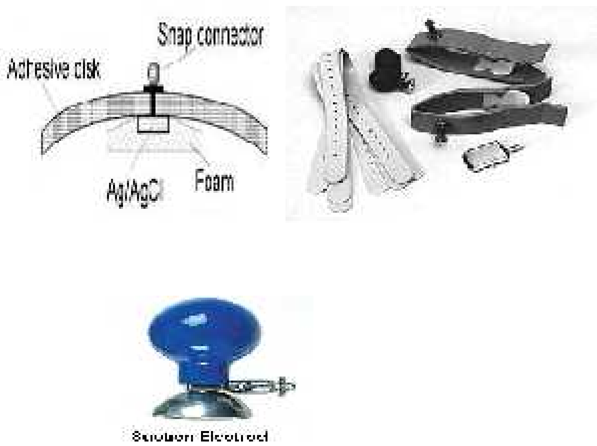


Fig 2.1.6: Differ Shape of Electrodes.[4]

2.2 Blood Pressure Measurement. [3]

Blood Pressure (BP) is a measure of the force or pressure exerted by the blood on the arteries.

BP is comprised of two numbers:

1- Systolic pressure.
2- Diastolic pressure.

The left and right ventricles are the primary pumping chambers of the heart. During relaxation of the ventricles (ventricular diastole) the artioventricular valves open and the semilunar valves close, allowing the ventricles to fill with blood. During contraction of the ventricles (ventricular systole) the atrioventicular valves close and the semilunar valves open, allowing the ventricles to eject into the arteries.

- Systolic pressure (the max value) is the highest arterial pressure reached during ventricular systole.
- Diastolic pressure (the min value) is the lowest arterial pressure reached during ventricular diastole.
- Blood Pressure (BP) = systolic pressure – diastolic pressure.
- Mean arterial pressure (MAP) = (BP/3) +diastolic pressure.
- MAP: is pressure between systolic & diastolic pressure that converts BP into a continues pressure that determine the average rate of blood flow from left ventricle to right atrium.

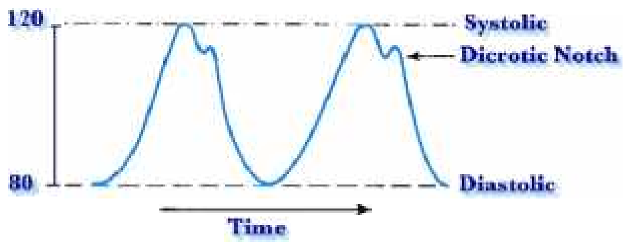


Fig 2.2.1: Blood Pressure Wave.

Blood pressure measurement methods:

We can measure the BP in two ways:

1- **Oscillometric Method** :

- It is noninvasive and indirect method, depend on oscillation signal and cuff pressure signal.
- In this method we use pressure electronic sensor to find systolic and diastolic pressure.

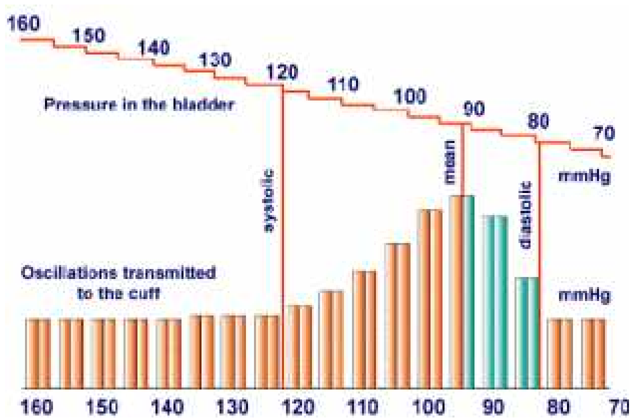


Fig 2.2.2: Oscillometric method.[11]

2- **Sphygmomanometer Method** :

- Non-invasive method depend on human hear.
- In this method we use cuff, pump and stethoscope.
- The pump inflation the cuff until we not hearing any sound , then we can take he systolic pressure at the first sound after deflation (blood laminar flow), and we can take the diastolic pressure at the last sound we can hear it , the normal range is between (80/120) mmHg.

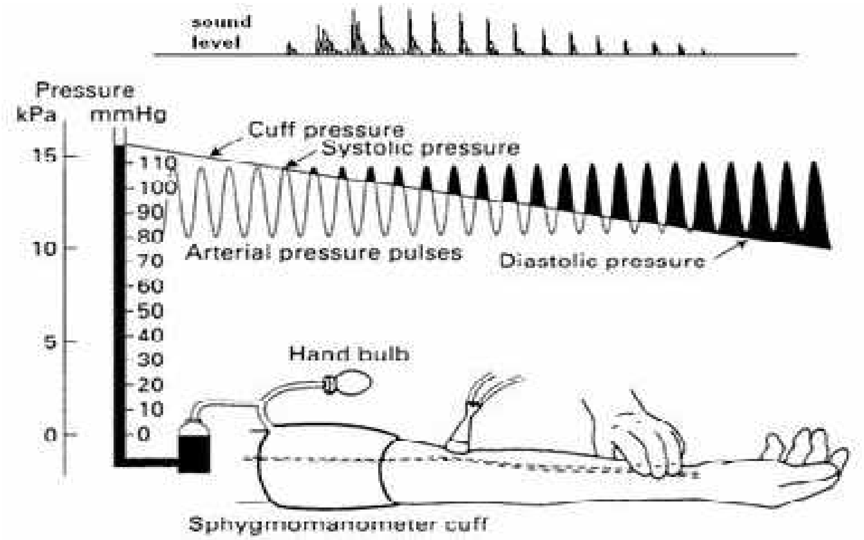


Fig 2.2.3: Sphygmomanometer Method.[3]

Factors that affect on blood pressure:

- Resistance of the blood vessels.
- Viscosity of the blood.
- Vessels length and diameter.
- Cardiac output physiology.

2.3 Photoplethysmography Method.

Photoplethysmography (PPG) is a non invasive technique that can be used for monitoring or measured different vital parameter which depends on measuring vessel volume as: vessel volume, SPO_2, blood pressure, heart rate ....etc.[6]

These methods depend on the optical properties of the previous parameters.

PPG construction:

- The light source (LED).
- Photo detector (photodiode, phototransistor, or photo resistance).

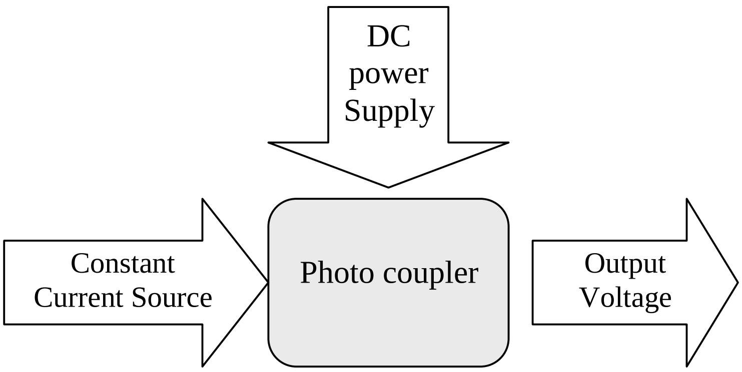


Fig 2.3.1: Simple Diagram of PPG.

- A beam of light is directed to the part of the tissue which is measured.
- Changes in light intensity causes proportional changes in the resistance of photocell (Δ R = Δ light intensity), then photocell produce (Δ Voltage) at the output terminal.
- The arterial pulse changing the optical density of the blood.
- Light from LED is reflected into photocell.
- PPG indicate the optical density of the blood, does not indicate volume changes.

PPG advantages:

- ✓ Simple method.
- ✓ Pulse velocity measurement.
- ✓ Indicate of the existence of a pulse in a finger.
- ✓ Determination of heart rate (HR).

PPG disadvantages:

- ✓ Very sensitive to motion artifacts.

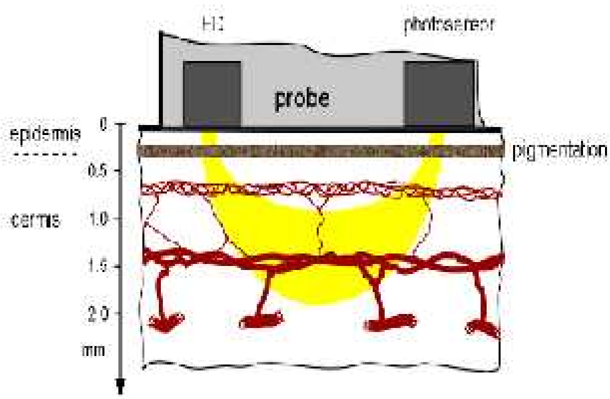


Fig 2.3.2: BP photo coupler.

There are two different types of PPG probes that can be used for arterial blood measurements:

1. *Reflection probes*

   The light emitting and sensitive parts are located side by side in one probe. The photo sensors detect the light, which is backscattered from the tissue of the skin. Due to the body's anatomy, the PPG sensors can only detect the pulse waves in areas that contain many arterial-venous anastomoses such as the fingers, toes, earlobes, or some regions of the face.

2. *Transmission probes*

   In these probes the photo sensors are located on the opposite side as the light emitting parts. The tissue is located between them. This limits the field of application to locations where the light can penetrate all the way through the tissue (fingers, toes, earlobes). In contrast to the reflection probe, the main sources of pulsation also contain the large vessels making these sensors especially useful for peripheral blood pressure measurements.

2.4 Sleep Apnea.

Sleep apnea is a serious sleep disorder that occurs when a persons breathing is interrupted during sleep. [5]

Typical breathing rates occur anywhere from 10-20 breathes per minute. During sleep apnea, the tongue blocks the airway and a 10-30 second pause in breathing occurs, causing the sufferer to miss one to two breathes.

There are three distinct forms of sleep apnea: central, obstructive, and complex (i.e., a combination of central and obstructive) constituting 0.4%, 84% and 15% of cases respectively.

1. Central sleep apnea causes pauses in breathing by the lack of effort in breathing. This is due to the failure of neurons in sending signals to indicate inhalation.

2. Obstructive sleep apnea is where the air path inside the throat is blocked by an object, such as the tongue. As the muscles relax during sleep, the tongue can block the airway, which causes the patient to enter a lighter sleep stage or possibly cause the patient to awaken. Most patients suffering from obstructive apnea have trouble getting into a deep sleep state. Even though the light sleep time may be numerous, it is still not as effective as deep sleep.

3. Mixed apnea is the combination of central and obstructive sleep apnea. While obstructive sleep apnea takes place during sleep, central sleep apnea is often developed. Patients experience problems breathing and constantly wake up from sleep because of long-term obstructive apnea.

Most people who have sleep apnea don't know they have it because it only occurs during sleep. People who have small airways in their noses, throats, or mouths also are more likely to have sleep apnea. Smaller airways may be due to the shape of these structures or allergies or other medical conditions that cause congestion in these areas.

In children, sleep apnea can cause hyperactivity, poor school performance, and aggressiveness. Children who have sleep apnea also may have unusual sleeping positions, and may breathe through their mouths instead of their noses during the day.

Risk factors for sleep apnea:

- Smoking.
- High blood pressure.
- Heart failure.
- Overweigh.
- Smaller airways.
- Being male, men are twice as likely to have sleep apnea as women are.
- Brain tumers.
- Family history.

Diagnosis sleep apnea:

- Medical and family history.
- Physical exam.
- Results from sleep studies.

A sleep study is the most accurate test for diagnosing sleep apnea; a sleep study is often done in a sleep lab as apart of hospital which uses:

- ✓ Polysomnogram(PSG), this test record brain activity, eye movement, breathing and heart rate, amount of oxygen in blood, and how much air moves in and out the lungs at sleeping.
- ✓ Electroencephalogram (EEG), to measure and record brain wave activity.
- ✓ Electromyogram (EMG), to record muscle activity such as in face, teeth grinding, and leg movement.
- ✓ Electrooculogram (EOG), to record eye movements, these movements are important in determining the different sleep stages.
- ✓ Electrocardiogram (ECG), to record heart rate and rythm.
- ✓ Nasal air flow sensor to record air flow.
- ✓ Snore microphone to record snoring activity.

Specific types of treatment:

1. Breathing devices as CPAP, and dental devices.
2. Surgery.
3. Currently, there are no medicines to treat sleep apnea.

CPAP (continuous positive airway pressure), is a treatment in which a mask is worn over the nose and/or mouth at sleep. The mask is hooked up to a machine that delivers a continuous flow of air into the nostrils. The positive pressure from air flowing into the nostrils helps keep the airways open so that breathing is not impaired.

Dental appliance can be made that help keep the airway open during sleep .such devices can be specifically designed by dentists with special expertise in treating sleep apnea.

2.5 Pulse Difference Time.

Pulse difference time (PDT) is a noninvasive method of measuring respiratory changes (for persons) with breathing sleep disorders. PDT is the measure of the time it takes for the pulse pressure wave to go from the heart to the periphery.

It is measured by use of both an ECG machine and a photoplethysmogram. An ECG machine generates a curve based on the depolarization of the heart while the plethysmographic measures the pressure wave, or pulse, at the tip of the finger. Value for pulse difference time is given by calculating the difference in time between the peak of the R wave from the ECG and the peak of the pressure wave from the oximeter.

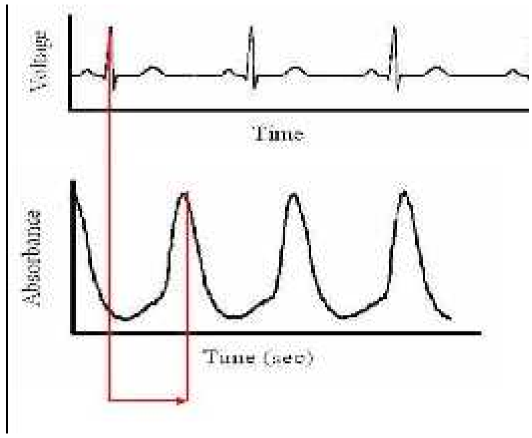


Fig 2.5.1: Calculation of pulse difference time from ECG and plethysmogram graphs.

Chapter 3

Project Conceptual Design

3.1 Measurement System Elements.

3.2 Project Objectives.

3.3 Project Design Block Diagrams.

- 3.3.1 ECG Block Diagram.
- 3.3.2 Plethysmograph Block Diagram.

3.4 Theoretical Background about Project Components.

3.5 Project Circuit Diagram.

- 3.5.1 ECG Circuit.
- 3.5.2 Plethysmograph Circuit.

3.1 Measurement System Elements. [4]

Measurement is the operation of determining the value of quantity as heart rate, blood pressure... etc.

Measurement system (MS) has an input of the true value of the variable being measured and output of the measured value of that variable.

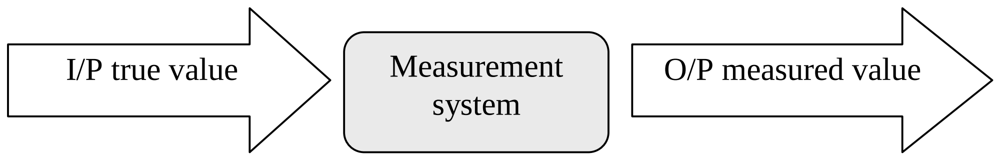


Fig 3.1.1: Simple MS Block Diagram.

Functional elements of MS:

1. Sensor.

Convert physical value to electrical value, as thermometer, thermocouple.

2. Signal conditioner.

Puts the output form the sensor into a suitable condition for processing so that it can be displayed or handled by a control system, as OPAMP, Wheatstone bridges.

3.Signal processor.

Processes the signal so that it is suitable for display, as Analog-to-digital converters, filters.

4. Data presentation.

Represents the measured value in a form which enables an observer to recognize it, as recorder, scale of meter.

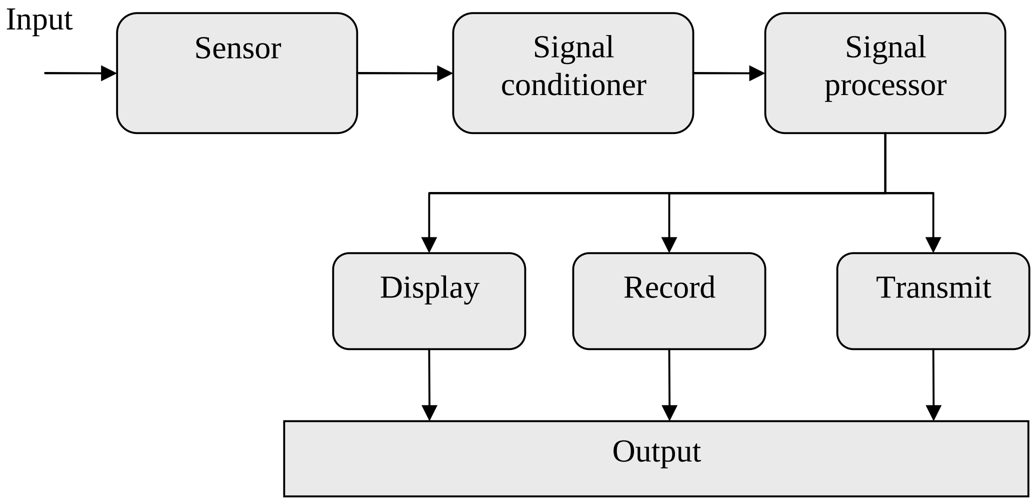


Fig 3.1.2: MS block diagram.

3.2 Project Objectives.

The main objectives of the project are:

1. To design and implement ECG and PPG system.
2. To design a software program with use of lab view and Matlab for processing the ECG and BP signals.

3.3 Project Design Block Diagrams.

In this project we going to describe the general block diagram of ECG system and PPG system.

3.3.1 ECG Block Diagram.

The following figure (3.3.1) shows the block diagram of ECG system.

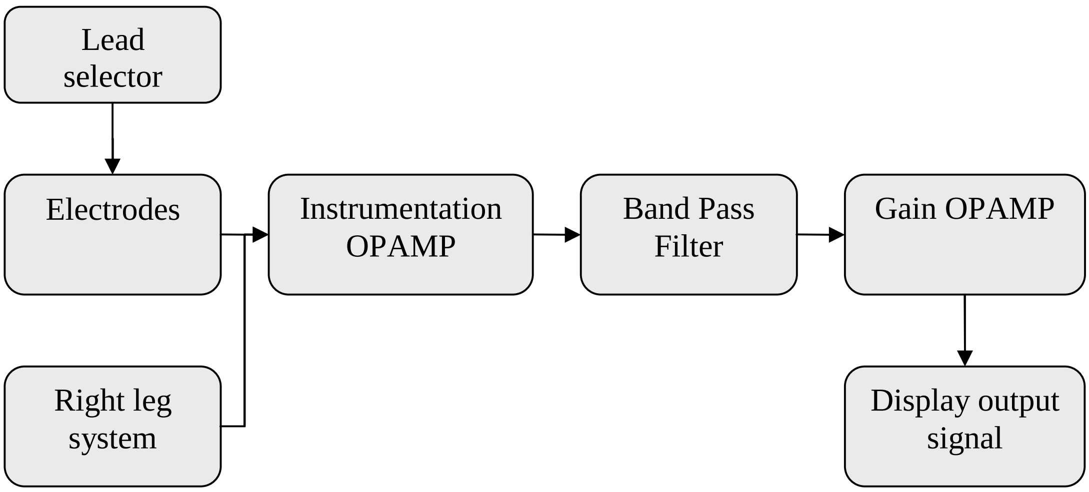


Fig 3.3.1: ECG Block Diagram

3.3.2 Plethysmograph Block Diagram.

The following figure(3.3.2) shows the block diagram of PPG system.

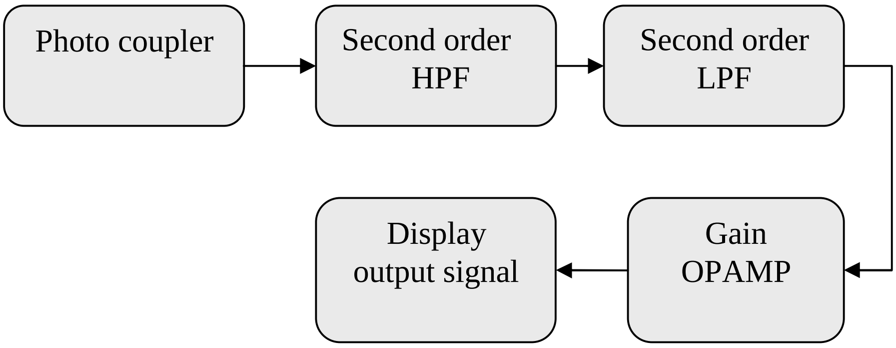


Fig 3.3.2: Plethysmogram Block Diagram.

3.4 Theoretical Background about project components.

For ECG block diagram*:*

- ***DC power supply source :***

  Used to feed AD620 with positive (+9V) and negative(-9V) DC voltage and feed LM358 with positive voltage(+9V).

- ***Lead II:***

The electrocardiograph signal can be measured at any point of the human skin. In the chest, the signal amplitude, of adults, can reach up to 5mV and so very easy to measure.

The type of signal acquired depends on the position of the electrodes on body, the best position of the electrodes to collect signals with the maximum amplitude are represented in figure3.4.1.

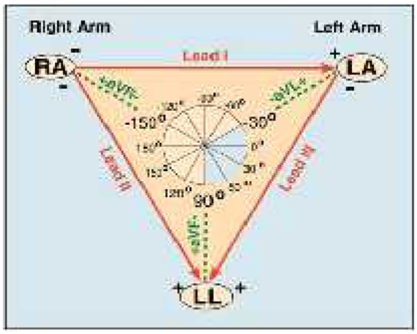


Fig 3.4.1: Leads Distance.

- ***Electrodes:***

A transducer that convert ionic current to an electric current, that is attached to the skin to detect the potentials.

Metallic plate electrodes are used for long time and continuous recordings.

Fig 3.4.2: Limb Electrodes

.

- ***Right leg system: (as shown in appendix)***

- ***Instrumentation OPAMP:***

In this project AD620 is used to reject the common signal from ECG signal because it has the following features: high CMRR, high input impedance and variable gain.

- ***Band Pass Filter (BPF):***

The circuit contain high pass filter (HPF) and low pass filter (LPF), from HPF low critical frequency can be found, and from LPF high critical frequency can be found .

BPF is used to pass frequency in a range from low critical frequency to high critical frequency. The frequency range in this project from (0.1-100) Hz

- ***Gain OPAMP:***

A non-inverting OPAMP used to amplify the signal. where the gain expressed as :

$$Av = 1 + \frac{Rf}{Rin}$$

- ***Display :***

The output signal will be displayed using oscilloscope.

All ICs used in our circuits are LM358 since:

- ✓ Large dc voltage gain:100db.
- ✓ Wide power supply range.
- ✓ Multi OPAMP in one IC.
- ✓ Low input offset voltage:2mV.
- ✓ Very low supply current drain:500μA.

For plethysmograph circuit:

- ***DC power supply source:***

Used to feed photo coupler circuit with a constant current source. In this project infrared diode will be used as transmitter & photo-transistor as receiver.

- ***Photo coupler:***

Infrared will be used as transmitter (λ = 880nm), & photo-transistor (λ =800nm) as receiver, infrared photo coupler used to detect the volume changes in capillaries of fingers and to obtain pulse further. Infrared photo coupler can avoid the interfaces of light.

- ***Second order HPF :***

High pass filter used to pass the frequency range up to (0.1) Hz, and amplify the signal. HPF Used to eliminate the DC drift voltage due to the tremble of finger.

- ***Second order LPF:***

Is used to eliminate the interference of power source and avoid the noise of high frequency. The second order LPF pass frequency range less (Fc = 45Hz).

- ***Gain OPAMP:***

A non inverting OPAMP is used to amplify the signal, where the gain expressed as :

$$Av = 1 + \frac{Rf}{Rin}$$

- ***Display:***

  Display the out put signal using oscilloscope.

3.5 Project Circuit Diagram.

3.5.1 ECG circuit.

❖ ***Instrumentation OPAMP:***

- ✓ Rg = 49.9kΩ/G-1 .
- ✓ G = 100.

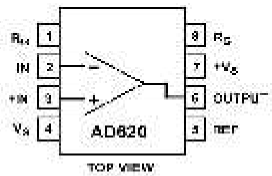


Fig 3.5.1.1: Instrumentation OPAMP.

❖ ***Band Pass Filter (BPF):***

Band pass filter is used to pass frequency in a range from low critical frequency to high critical frequency. The frequency range in this design from (0.1-100) Hz used for measurement purposes.

We can calculating high critical frequency from inverting side of OP-AMP :

$$Fch = 1/(2\pi R_6 C_1).$$

And we can calculating low critical frequency from the non-inverting side of OP-AMP:

$$Fcl = 1/(2\pi R_5 C).$$

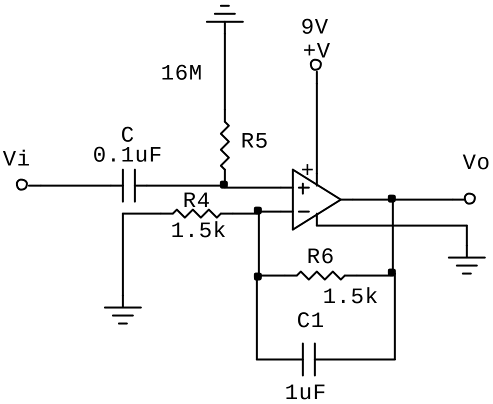


Fig3.5.1.2: Band Pass Filter Circuit.

❖ ***Gain circuit.***

A non-inverting OP-AMP will be used as gain amplifier to amplify the signal in a suitable range, suppose the gain = 5.

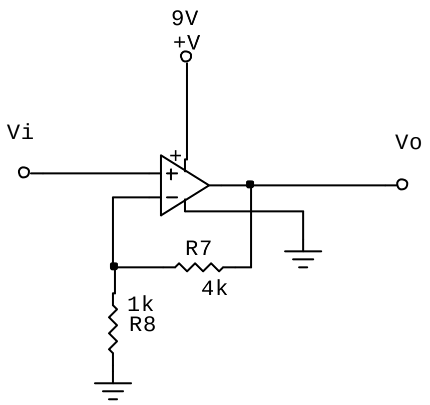


Fig 3.5.1.3: Non inverting OPAMP Circuit**.**

3.5.2 Plethysmograph Circuit.

- ***Photo-coupler***.
  - ✓ Infrared and red LED will be used as transmitter.
  - ✓ Phototransistor will be used as receiver.

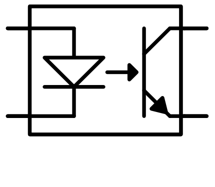


Fig 3.5.2.1: Simple Block Diagram of Photo coupler.

- ***Second Order HPF.***
  - ✓ $Av = 1 + R_{10}/R_{11}$.
  - ✓ Fc= 1/ $(2\pi\sqrt{CCR8R9})$= 0.1Hz.

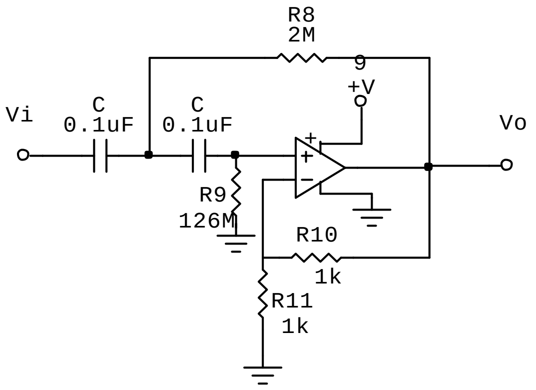


Fig 3.5.2.2: Second Order HPF Circuit.

- ***Second Order LPF:***
  - ✓ Fc = 1/ $(2\pi\sqrt{CCR13R12})$= 45Hz.
  - ✓ Total gain = $(1 + R_{14}/R_{15}) = 2$.

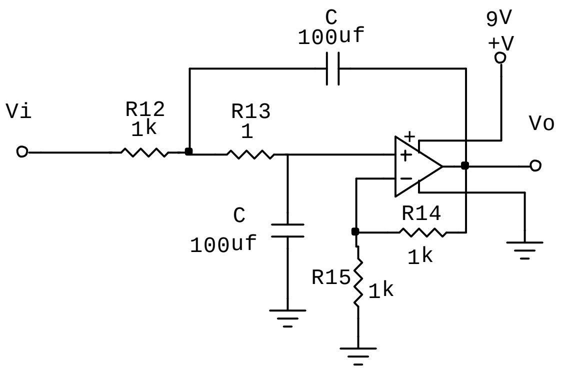


Fig 3.5.2.3: Second Order LPF Circuit.

- ***Gain OPAMP.***

  - ✓ A noninverting OPAMP will be used.
  - ✓ $Av = 1 + (R_f / R_{in}) = 1 + (R1/R_2) = 101$.

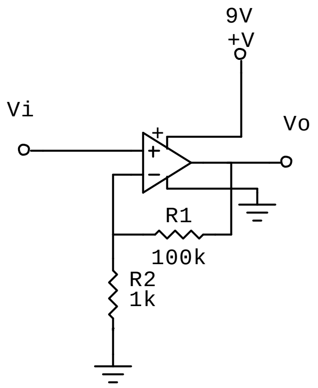


Fig 3.5.2.4: Non inverting Gain OPAMP Circuit.

Chapter 4

Device Implementation and Testing

4.1 Project Implementation.

4.2 Hardware Component Testing.

4.3 Software Component Testing.

4.4 DAQ connection.

4.5 Signal Processing.

4.5.1 PDT measurement using Matlab.

This chapter demonstrates the methods and procedures used to implement, test, and examine the instrument operation and behavior.

4.1 Project Implementation.

The implementation process is synchronized with the testing operation, since each implementation phase will take many testing steps to ensure that are no errors.

The actual project implementation was a hardware and soft ware prototype. The detailed description of each circuit implementation will be mentioned in the next sections.

4. 2 Hardware Component Testing.

We started to test each component of the project to ensure its functionality. Electrode lead testing was done by connecting each branch to each pin in electrode cable by using digital multi meter (DMM) and get sound means no short and its working.

4.2.1 Power Supply Testing.

At first we tested the power supply without connecting to the circuit. In any case, the design for the power supply was successful and give the required results. Its provide positive volts and other negative needed for ICs works.

Fig 4.2.1: Power supply testing.

4.2.2 Instrumentation OP-AMP Testing.

Buffer amplifier and pre-amplifier are connected with power supply , then the electrodes and lead wires were connected to the circuit and the signal recorded on the oscilloscope as shown in figure 4.2.2

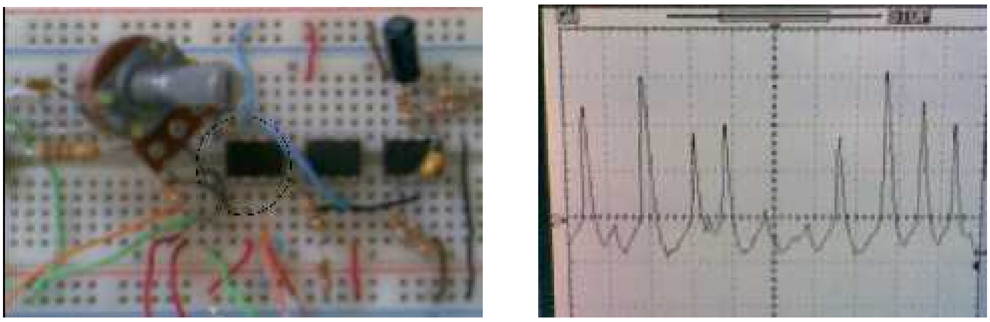


Fig4.2.2: Instrumentation OPAMP testing.

4.2.3 Band Pass Filter Testing.

The band pass filter connected with suitable resistance and capacitors and connecting to the power supply, then recorded the signal by electrodes leads wire on the oscilloscope as in the figure 4.2.3

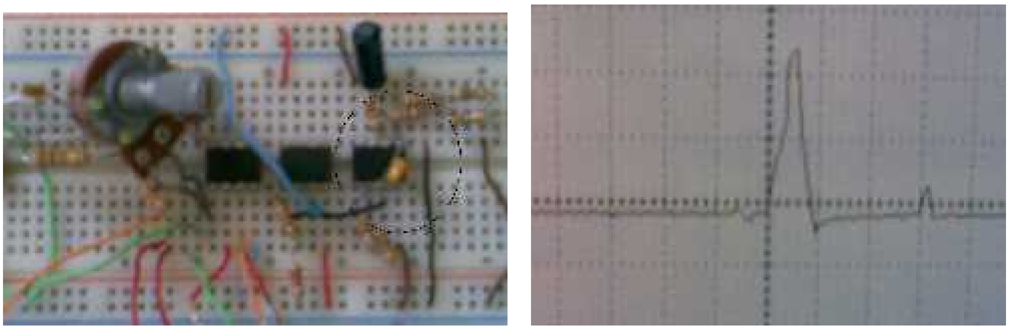


Fig 4.2.3: Band pass filter testing.

4.2.4 Gain OP-AMP Testing.

The gain amplifier is connected with suitable resistance and connected with the power circuit, then recorded signal on oscilloscope as shown in figure 4.2.4.

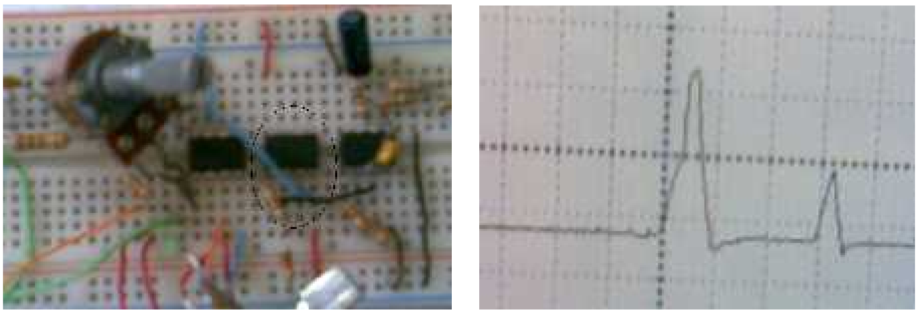


Fig 4.2.4: Gain OPAMP testing.

4.2.5 Photo coupler Sensor Connecting.

Pin 1, 4, 6, 8 - no connection.

Pin 2 - anode of the IR LED, cathode of the red LED - usually red wire.

Pin 3 - cathode of the IR LED, anode of the red LED - usually black wire.

Pin 5 - phototransistor anode - usually white wire.

Pin 7 - shield, connects to copper shield over the phototransistor.

Pin 9 - phototransistor cathode - usually green wire.

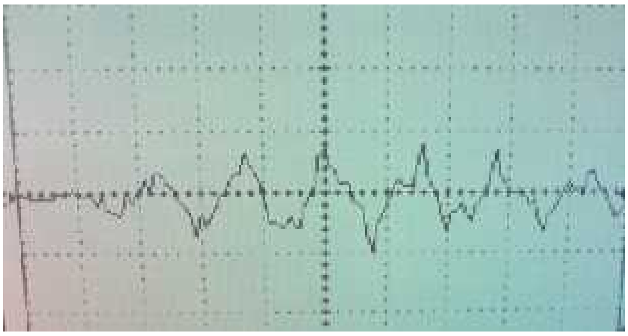


Fig 4.2.5: Photo coupler sensor testing.

4.2.6 Second Order High Pass Filter and Gain OPAMP.

The high pass filter is connected with suitable resistance and capacitors and connecting to power supply , then recorded signal on oscilloscope as shown in figure 4.2.6.

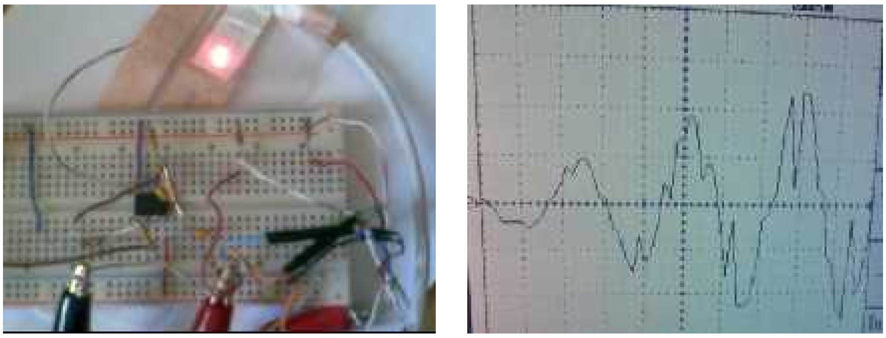


Fig 4.2.6:Second order HPF and gain OPAMP testing.

4.2.7 Second Order Low Pass Filter.

The low pass filter is connected with suitable resistance and power supply, then recorded signal on the oscilloscope as shown in figure 4.2.7.

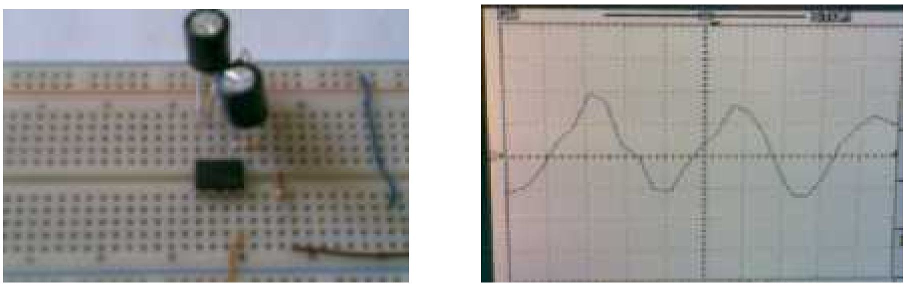


Fig 4.2.7: Second order LPF testing.

4.3 Software Component Testing.

Crocodile program is a method used to examine each stages of ECG and PPG circuits as shown.

4.3.1 Instrumentation circuit.

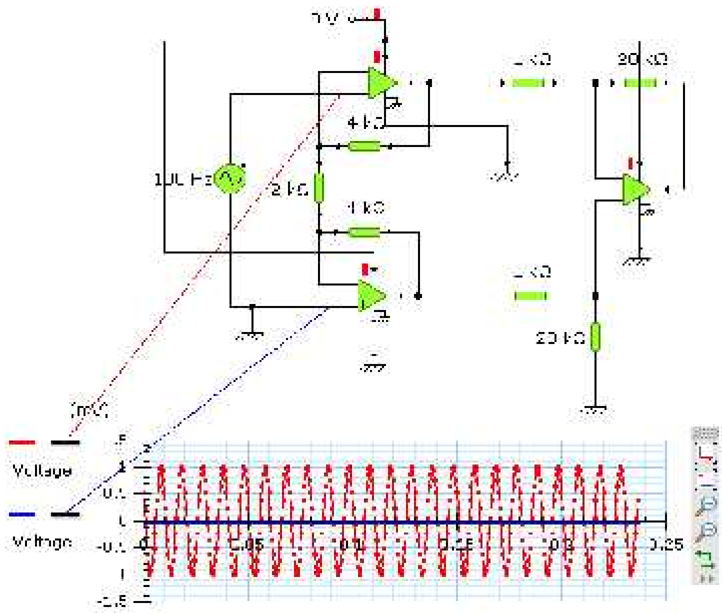


Fig 4.3.1.a:Instrumentation circuit inputs.

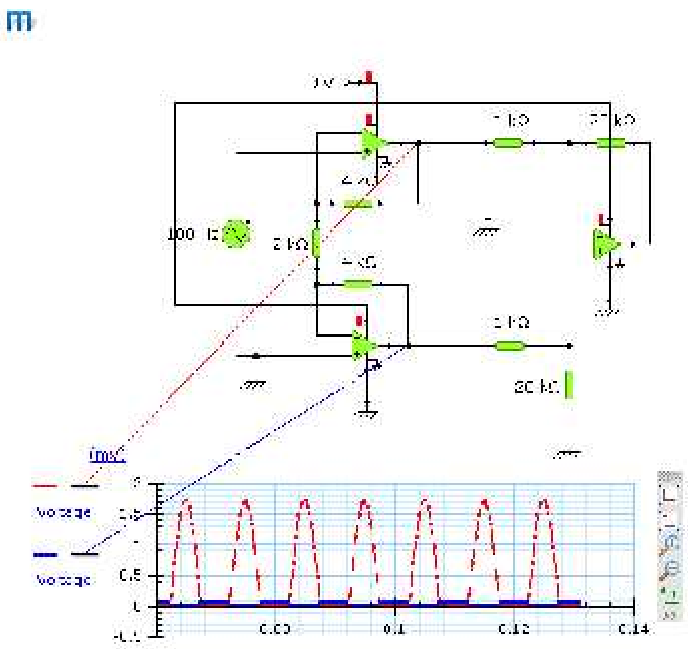


Fig 4.3.1.b:Noninverting circuit outputs.

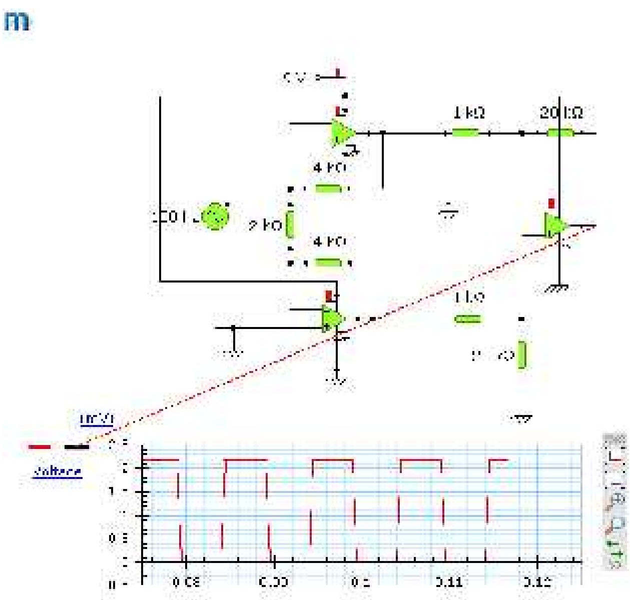


Fig 4.3.1.c:Instrumentation output.

4.3.2 Band pass filter circuit.

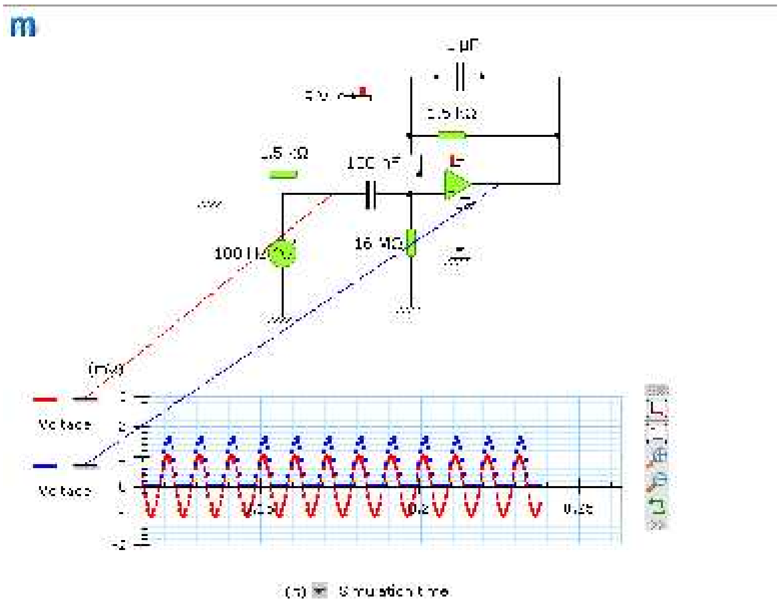


Fig 4.3.2.a:Band pass filter output at (f =100Hz).

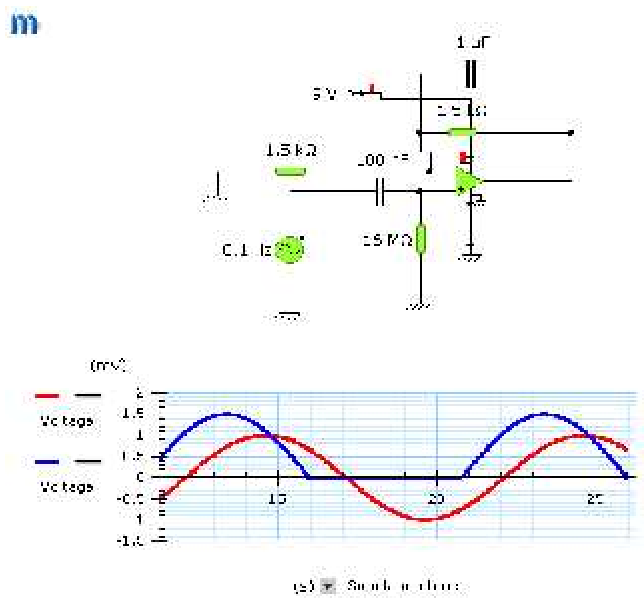


Fig 4.3.2.b: Band pass filter input and output at (f = 0.1Hz).

4.3.3 Gain circuit.

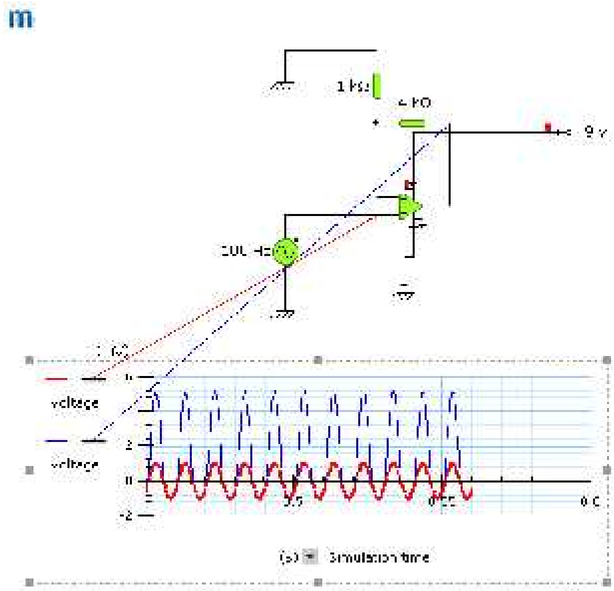


Fig 4.3.3: Gain circuit input and output.

4.3.4 Second order high pass filter.

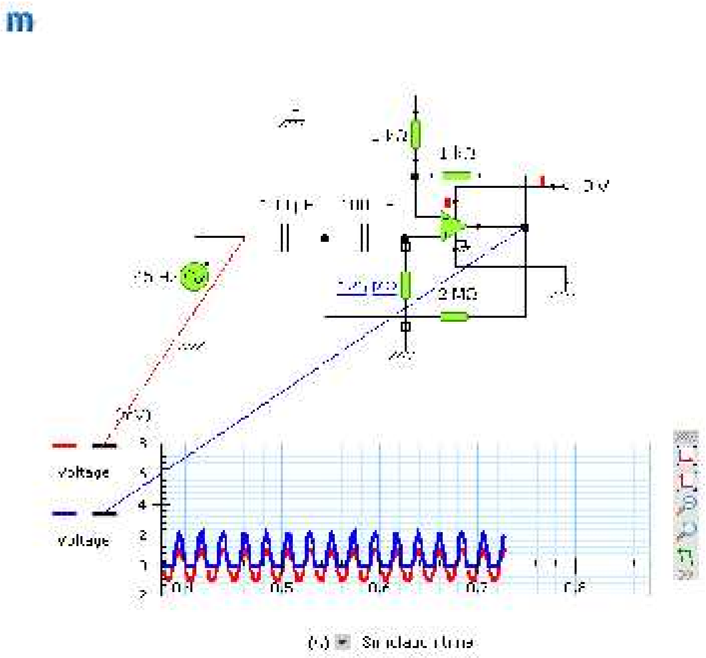


Fig 4.3.4:Second order high pass filter input and output.

4.3.5 Gain circuit.

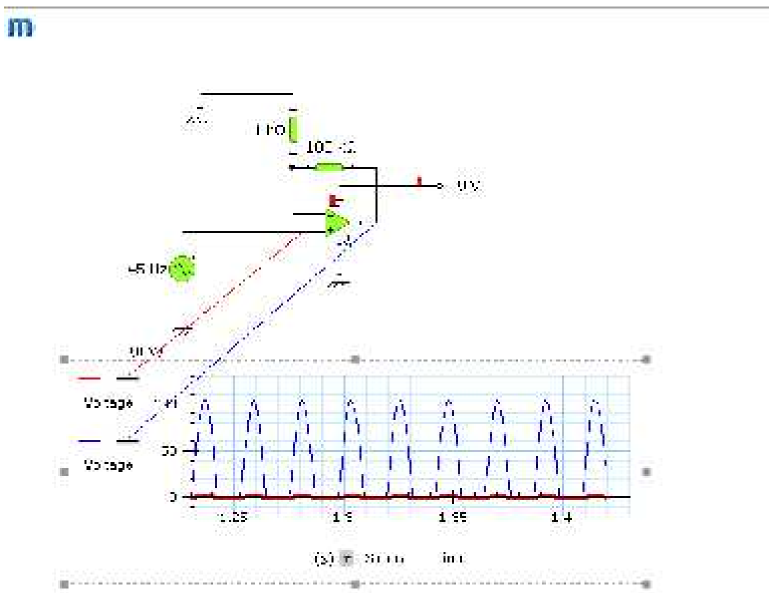


Fig 4.3.5: Gain circuit input and output.

4.3.6 Second order low pass filter.

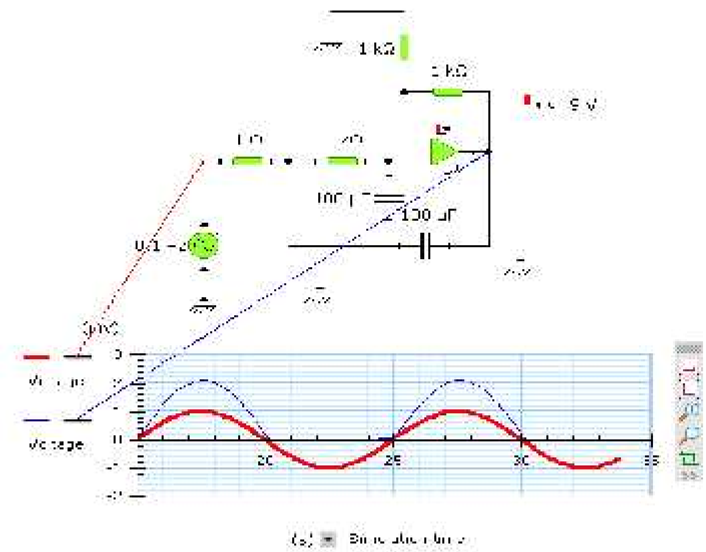


Fig 4.3.6:Second order low pass filter input and output

4.4 DAQ connection.

4.4.1 NI 6034 E card.

Data acquisition involves gathering signals from measurement sources and digitizing the signal for storage, analysis, and presentation on a PC . *DAQ hardware* acts as the interface between the computer and the outside world. It primarily functions as a device that includes:

1.Analog Input/Output.

2.Digital Input/Output.

3.Counter/Timers.

4.Multifunction - a combination of analog, digital, and counter operations on a signal device.

NI 6034 E card has many important features as:

- Have 16 analog inputs at 200kS/s, with 16 bit resolution.
- 2 analog output, each with 16 bit resolution.
- 8 digital input/output lines which are compatible with both 5V TTL & CMOS.
- Tow 24 bit counter/timer, with 20MHz frequency.
- Digital Triggering.
- 4 analog input signal ranges.

Fig 4.4: NI 6034 E**.**

4.4.2 Lab VIEW program.

Lab VIEW (short for **L**aboratory **V**irtual **I**nstrumentation **E**ngineering **W**orkbench).

Lab VIEW is a graphical programming system that is designed for data acquisition, data analysis, and instrument control.

In our project we will deal with a Lab VIEW program to save the signals as a (TXT file) then analysis these signals to measure PDT .

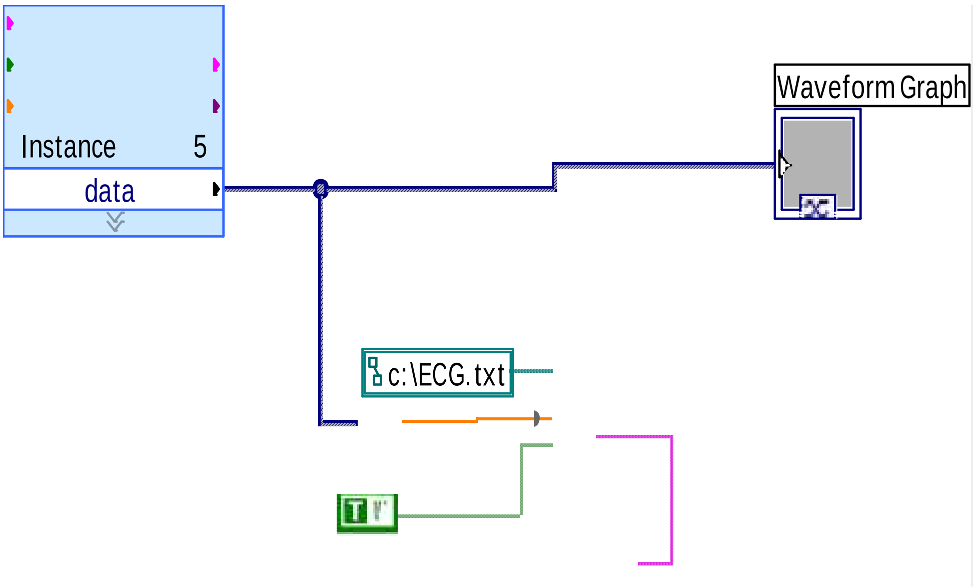


Fig 4.4.2: Process block diagram in Lab VIEW .

4.5 Signal Processing.

After interring the signals to the PC, its needs processing to monitoring the signals, measuring the peaks value and PDT .

Matlab is a programming language that used to find the pulse difference time between R-peak in ECG and the max peak value in PPG.

4.5.1 PDT measurement using Matlab.

The signal processing aims to monitoring the ECG and PPG signals which produced by the PDT system, measuring the peaks value of ECG and PPG signals then find the PDT for each pulses, and finally check the apnea at specific time.

Matlab testing:

- *The function call:*

```
%%%%%% ECG and PPG calling
g=load('C:\Documents and Settings\ecg2.txt');
h=load('C:\Documents and Settings\ppg2.txt');
numOfMax=4;
DataRange=200;
sampelsRate=0.02;
[Timediff]=ayam(g,h,numOfMax,DataRange,sampelsRate)
```

- *The main function:*

```
function[Timediff]=ayam(ecgdat,ppgdat,numOfMax,DataRange,sampelsRate)
%function for measuring pulse difference time.
%Input:ecgdat:ECG signal.
%       ppgdat:PPG signal.
%       numOfMax:number of R-waves which needed to find PDT values.
%       DataRange:number of  amples for each ECG an PPG data which
used to find PDT values.
%       sampelsRate:the step value.
%Output:Timediff:Pulse Difference Time (PDT) between max peak of ECG
and
%        max peak of PPG

g=ecgdat;
h=ppgdat;

plot(sampelsRate*(1:length(g(1:DataRange))),g(1:DataRange),'b')
hold on
plot(sampelsRate*(1:length(h(1:DataRange))),h(1:DataRange),'r')
grid on
[wert ind]=sort(g(1:DataRange));
maxIndField =sortrows([ind(end-numOfMax+1:end) wert(end-
numOfMax+1:end)]);
[maxh indh]=max(h(1:maxIndField(1,1)));
maxIndFieldH(1,: )=[indh maxh];
maxh=0;indh=0;
d=length(maxIndField(:,1));
for j=1:d-1
    if(-maxIndField(j,1)+maxIndField(j+1,1)<5)
      if(maxIndField(j,2)>maxIndField(j+1,2))
         maxIndField(j+1,: )=[];
         d=length(maxIndField(:,1));
      else
         maxIndField(j+1,: )=[];
         d=length(maxIndField(:,1));
      end
```

```
    end
end
for i=1:length(maxIndField)-1
   [maxh indh]=max(h(maxIndField(I,1)+1:maxIndField(i+1,1)));
    maxIndFieldH(i+1,: )=[indh+maxIndField(I,1) maxh];
    maxh=0;indh=0;
end
Timediff=(maxIndField(:,1)-maxIndFieldH(:,1))*sampelsRate;
```

Result **:**

The PDT values at the first four R-waves.

```
Timediff =
    0.0400
    0.9400
         0
    0.3200
```

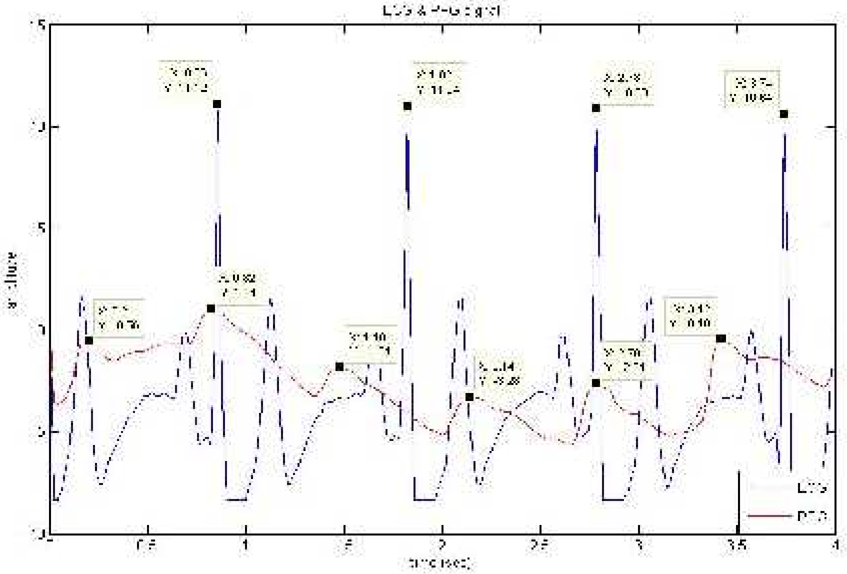


Fig 4.5.1: PDT values at first 4 values.

Chapter 5

Conclusion and Future Work

5.1 Conclusions.

5.2 Faced Problems.

5.3 Future Works.

5.1 Conclusions.

Knowledge and practical experiences were gained by developing this project. There are many important points to be mentioned:

1. This project was a challenge for us, we used everything we had learned in our classes to solve the problems and come up with solutions to design the circuits.

2. We can build and design simple device to pick up ECG signal and blood pressure signal, then processing these signals to take PDT as output form.

3. We learned how to manage our time and organize a team work.

4. PDT device is a medical device, small, comfortable instrument that is able to conduct sleep studies.

5. The current instrument is inefficient for home use; since it is non portable device and need memory card to store data for along time.

5.2 Faced Problems.

The idea of the project started with determination of the objectives, collecting data about the project, starting the system design that follows with the implementation stage. It is expectedly that many problems will appear.

In our cases many problems has been faced:

1. ECG is very small, many noise which needs amplification and filtration, this problem has been overcome by using instrumentation amplifier and band pass filter.

2. Earth looping problems.

3. Working on the bread board is not accurate in biosignal working.

4. To detect PDT, patients need to participate in sleep studies at sleep centers. Furthermore, sleep centers are not specifically for sleep apnea studies.

5. Found SpO2 data sheet.

5.3 Future Works.

A lot of ideas can be utilized to enhance the current work.
Here some of them:

1. Use other software program to display the signals.

2. Use other programming language for PDT measurement.

3. Design and build laboratory device for measuring other biosignals.

4. Use memory chip to store the ECG and PPG values for long time at sleep time.

5. Future work should be focused on determining if can we use a rechargeable battery in the system to get a smaller size, light weight and portable.

6. PDT device allow families to conduct the test at home so make the patient feel more comfortable.

7. Improving the software and minimizing the circuit will attempt to be rectified by numerous design additions in order to use them in other applications, such as psychological analysis.

References

Books:

[1] Floyd, "Electronic Devices", 6-th edition, Simon & Schustor.

[2] Malvino, "Electronic principles", Sixth edition, 1999.

[3] Medical instrumentation application & design, second edition, John G. Webster.

[4] Introduction to biomedical equipment technology, forth edition, Joseph J. Curr & John M. Brown.

Web Sites:

[5] www.nhlbi.nih.gov.

[6] www.sine.ni.com.

[7] www.medis-de.com.

[8] www.homepages.cae.wisc.edu.

[9] www. datasheet.com.

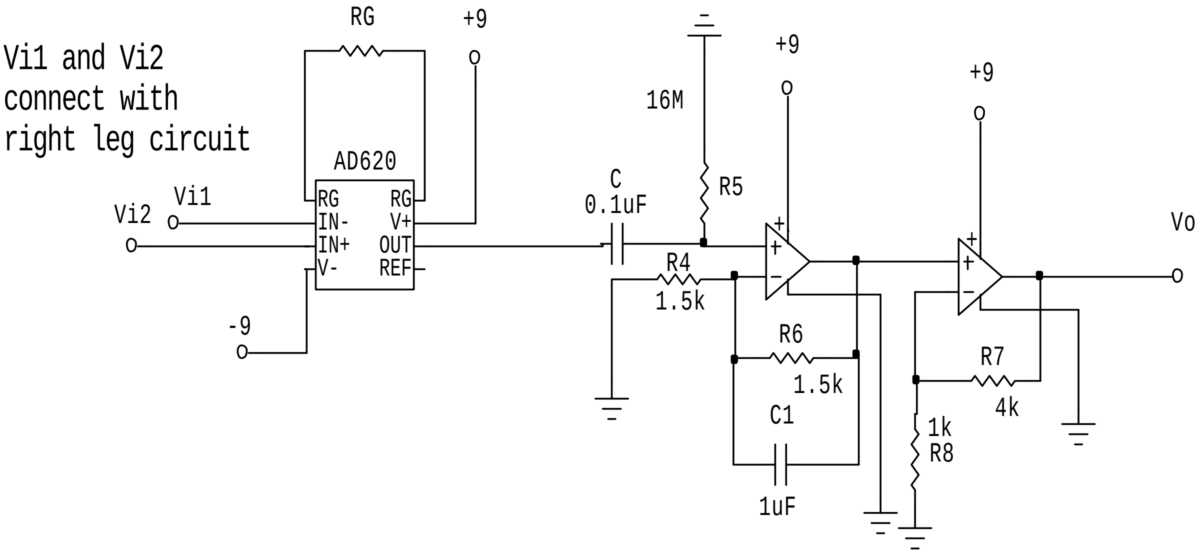
[10] Continuous Blood Pressure Monitoring using Pulse Wave Transit Time (PWTT) , Gu-Young Jeong, Kee-Ho Yu and Nam-Gyun Kim, Department of Mechatronics Engineering, Chonbuk National University, Jeonju, Korea.

[11] www.images.google.com

Appendices A

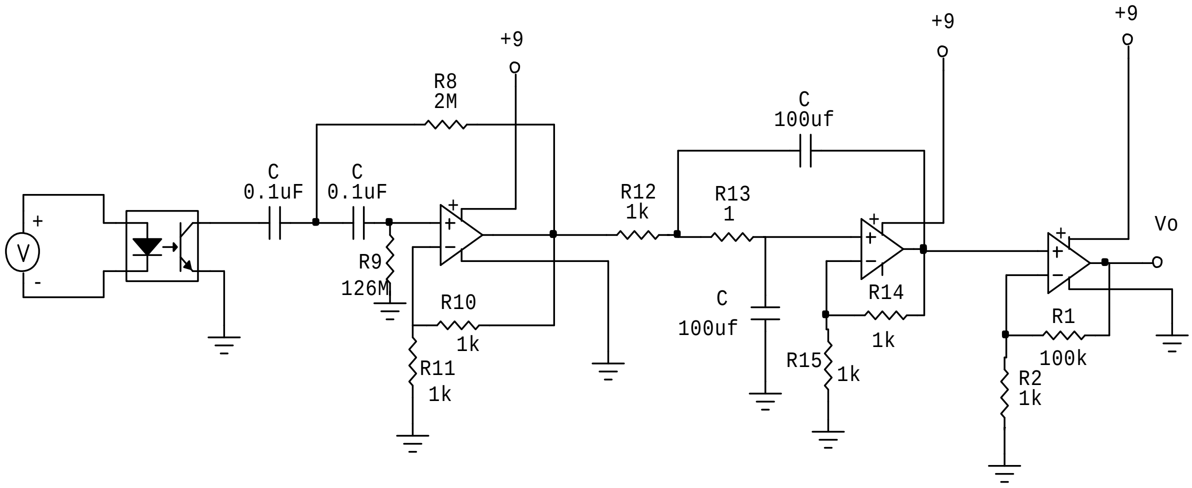
1. ECG circuit.
2. Plethysmograph circuit.
3. Right leg circuit.

ECG circuit.

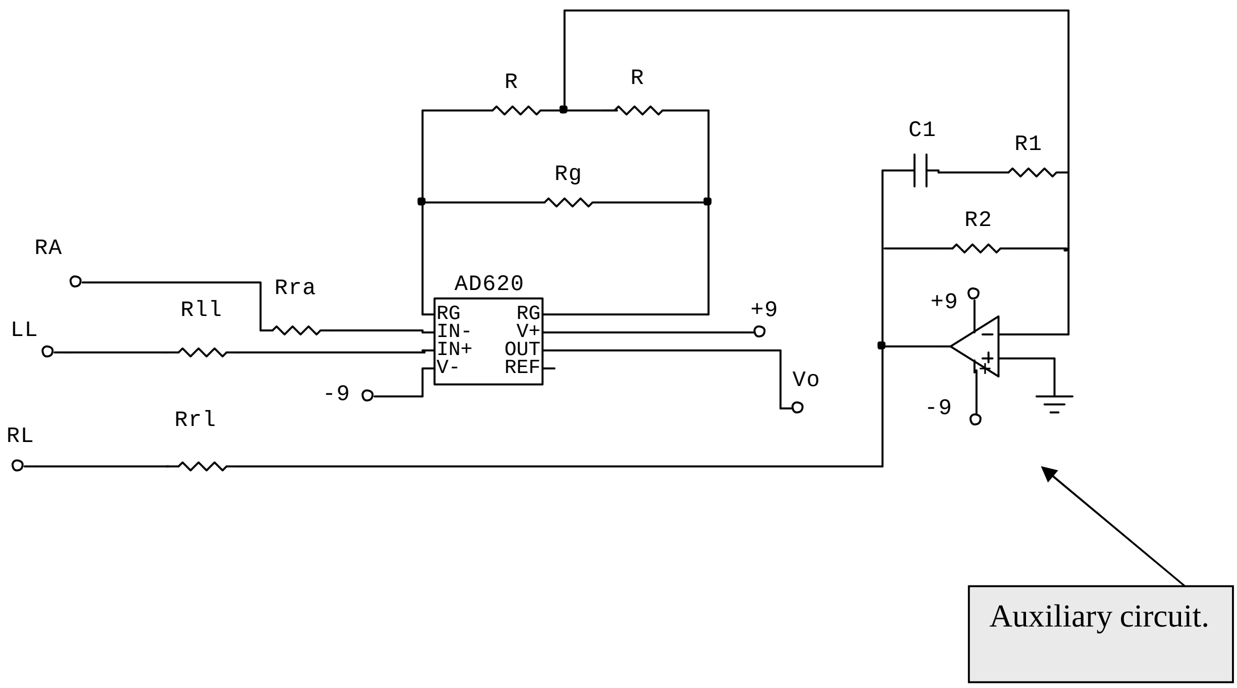


Vi1 and Vi2
connect with
right leg circuit
RG
+9
AD620
RG
IN-
IN+
V-
RG
V+
OUT
REF
Vi1
Vi2
-9
C
0.1uF
16M
R5
R4
1.5k
+9
R6
1.5k
C1
1uF
+9
R7
4k
1k
R8
Vo

Photoplethysmogaph circuit.



Right leg circuit.



In many modern electrocardiographic systems, the patient is not grounded at all. Instead, the right leg electrode is connected to the output of an auxiliary OPAMP .

The common mode voltage on the body is sensed by the tow (R), inverted, amplified, and fed back to the right leg . this negative feedback drives the common mode voltage to a low value. The body displacement current flows not to ground but rather to the OPAMP output circuit. This reduces the pickup as far as the ECG amplifier is connected and effectively grounds the patient.

Appendices B

Datasheets

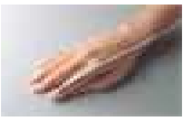
1. **AD620**

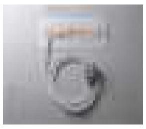
2. **LM358**

3. **NI PCI-6034E**

BM-200 Series :

o BM Sensors provide a cost-effective.
o Compatible with major leading manufactures of patient monitoring systems.
o Simplified design allows for quick setup and easy checking.
o Advanced high quality of LED provides superior performance of signal tracking.
o Latex free rubber based adhesive coated tape provides good adhesion to skin but removes cleanly without causing skin trauma.





Sensor type	disposable
Sensor details	adhesive wrap
Patient weight	<3 kg. or >40 kg.
Typical application	neonate foot or adult finger

Recommended Use: Disposable.
Patient Size: < 3kg or > 40kg Neonatal/Adult.
Preferred Application: Lateral aspect of foot or Index finger.

Advantage:

* Self-adhesive application.
* Pre-formed for easy application.
* Optimal performance in motion situation.
* Single patient use supports infection control management.
* Fast and easy application for spot checking and short duration continuous use.

2. BM-200

o Application : Adult/Neonatal
- Preferred application sites are index finger and foot below the toes with the cable running along sole of foot
- Alternative sites are palm of hand and other fingers

o Usage : Disposable
o Shape : Adhesive Type
o SpO2 Accuracy : 70~100% �2 digit
o LED Specification
- Red & Infrared, nominal

o Photodiode Specification
- Active Area : 5mm2
- Responsibility : 0.18Min (0.21 typical) @436nm

National Semiconductor

October 2005

LM158/LM258/LM358/LM2904 Low Power Dual Operational Amplifiers

General Description

The LM158 series consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

The LM358 and LM2904 are available in a chip sized package (8-Bump micro SMD) using National's micro SMD package technology.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

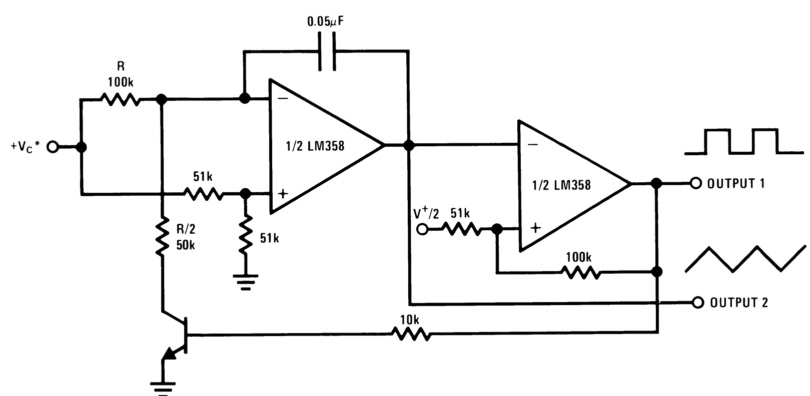
Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Available in 8-Bump micro SMD chip sized package, (See AN-1112)
- Internally frequency compensated for unity gain
- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz (temperature compensated)
- Wide power supply range:
  — Single supply: 3V to 32V
  — or dual supplies: ±1.5V to ±16V
- Very low supply current drain (500 µA) — essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing

Voltage Controlled Oscillator (VCO)



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Absolute Maximum Ratings (Note 9)

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

	LM158/LM258/LM358 LM158A/LM258A/LM358A	LM2904
Supply Voltage, V^+	32V	26V
Differential Input Voltage	32V	26V
Input Voltage	−0.3V to +32V	−0.3V to +26V
Power Dissipation (Note 1)		
Molded DIP	830 mW	830 mW
Metal Can	550 mW	
Small Outline Package (M)	530 mW	530 mW
micro SMD	435mW	
Output Short-Circuit to GND		
(One Amplifier) (Note 2)		
$V^+ \leq 15V$ and $T_A = 25^\circ C$	Continuous	Continuous
Input Current (V_{IN} < −0.3V) (Note 3)	50 mA	50 mA
Operating Temperature Range		
LM358	0˚C to +70˚C	−40˚C to +85˚C
LM258	−25˚C to +85˚C	
LM158	−55˚C to +125˚C	
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C
Lead Temperature, DIP		
(Soldering, 10 seconds)	260˚C	260˚C
Lead Temperature, Metal Can		
(Soldering, 10 seconds)	300˚C	300˚C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260˚C	260˚C
Small Outline Package		
Vapor Phase (60 seconds)	215˚C	215˚C
Infrared (15 seconds)	220˚C	220˚C

See AN-450 “Surface Mounting Methods and Their Effect on Product Reliability” for other methods of soldering surface mount devices.

ESD Tolerance (Note 10)	250V	250V

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 5), $T_A = 25^\circ C$		1	2		2	3		2	5	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^\circ C$, $V_{CM} = 0V$, (Note 6)		20	50		45	100		45	150	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$		2	10		5	30		3	30	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 7) (LM2904, $V^+ = 26V$), $T_A = 25^\circ C$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps										
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2		0.5	1.2	mA

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 5) , $T_A = 25^\circ C$		2	7		2	7	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^\circ C$, $V_{CM} = 0V$, (Note 6)		45	250		45	250	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$		5	50		5	50	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 7) (LM2904, $V^+ = 26V$), $T_A = 25^\circ C$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps							
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2	mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25^\circ C$, $R_L \geq 2\ k\Omega$, (For $V_O = 1V$ to 11V)	50	100		25	100		50	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25^\circ C$, $V_{CM} = 0V$ to $V^+ - 1.5V$	70	85		65	85		70	85		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to 30V (LM2904, $V^+ = 5V$ to 26V), $T_A = 25^\circ C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25^\circ C$ (Input Referred), (Note 8)		−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ C$	20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25^\circ C$, $V_O = 2V$	10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25^\circ C$, $V_O = 200\ mV$, $V^+ = 15V$	12	50		12	50		12	50		μA
Short Circuit to Ground		$T_A = 25^\circ C$, (Note 2), $V^+ = 15V$		40	60		40	60		40	60	mA
Input Offset Voltage		(Note 5)			4			5			7	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7	15		7	20		7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			30			75			100	nA
Input Offset Current Drift		$R_S = 0\Omega$		10	200		10	300		10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	100		40	200		40	300	nA
Input Common-Mode Voltage Range		$V^+ = 30\ V$, (Note 7) (LM2904, $V^+ = 26V$)	0		$V^+ - 2$	0		$V^+ - 2$	0		$V^+ - 2$	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions		LM158A			LM358A			LM158/LM258			Units
				Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = +15V$ (V_O = 1V to 11V) $R_L \geq 2$ kΩ		25			15			25			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$)	$R_L = 2$ kΩ	26			26			26			V
			$R_L = 10$ kΩ	27	28		27	28		27	28		V
	V_{OL}	$V^+ = 5V$, $R_L = 10$ kΩ			5	20		5	20		5	20	mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$		10	20		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$		10	15		5	8		5	8		mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM358			LM2904			Units
			Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25^\circ C$, $R_L \geq 2$ kΩ, (For V_O = 1V to 11V)	25	100		25	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25^\circ C$, V_{CM} = 0V to $V^+ - 1.5V$	65	85		50	70		dB
Power Supply Rejection Ratio		V^+ = 5V to 30V (LM2904, V^+ = 5V to 26V), $T_A = 25^\circ C$	65	100		50	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25^\circ C$ (Input Referred), (Note 8)		−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ C$	20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25^\circ C$, $V_O = 2V$	10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25^\circ C$, V_O = 200 mV, $V^+ = 15V$	12	50		12	50		μA
Short Circuit to Ground		$T_A = 25^\circ C$, (Note 2), $V^+ = 15V$		40	60		40	60	mA
Input Offset Voltage		(Note 5)			9			10	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7			7		μV/°C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			150		45	200	nA
Input Offset Current Drift		$R_S = 0\Omega$		10			10		pA/°C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	500		40	500	nA
Input Common-Mode Voltage Range		V^+ = 30 V, (Note 7) (LM2904, $V^+ = 26V$)	0		$V^+ - 2$	0		$V^+ - 2$	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions		LM358 Min	LM358 Typ	LM358 Max	LM2904 Min	LM2904 Typ	LM2904 Max	Units
Large Signal Voltage Gain		$V^+ = +15V$ (V_O = 1V to 11V) $R_L \geq 2\ k\Omega$		15			15			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$)	$R_L = 2\ k\Omega$	26			22			V
			$R_L = 10\ k\Omega$	27	28		23	24		V
	V_{OL}	$V^+ = 5V$, $R_L = 10\ k\Omega$			5	20		5	100	mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$		5	8		5	8		mA

Note 1: For operating at high temperatures, the LM358/LM358A, LM2904 must be derated based on a +125˚C maximum junction temperature and a thermal resistance of 120˚C/W for MDIP, 182˚C/W for Metal Can, 189˚C/W for Small Outline package, and 230˚C/W for micro SMD, which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM258/LM258A and LM158/LM158A can be derated based on a +150˚C maximum junction temperature. The dissipation is the total of both amplifiers — use external resistors, where possible, to allow the amplifier to saturate or to reduce the power which is dissipated in the integrated circuit.

Note 2: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circucits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Note 3: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V^+voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than −0.3V (at 25˚C).

Note 4: These specifications are limited to $-55˚C \leq T_A \leq +125˚C$ for the LM158/LM158A. With the LM258/LM258A, all temperature specifications are limited to $-25˚C \leq T_A \leq +85˚C$, the LM358/LM358A temperature specifications are limited to $0˚C \leq T_A \leq +70˚C$, and the LM2904 specifications are limited to $-40˚C \leq T_A \leq +85˚C$.

Note 5: $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ −1.5V) at 25˚C. For LM2904, V^+ from 5V to 26V.

Note 6: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

Note 7: The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25˚C). The upper end of the common-mode voltage range is V^+ −1.5V (at 25˚C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+.

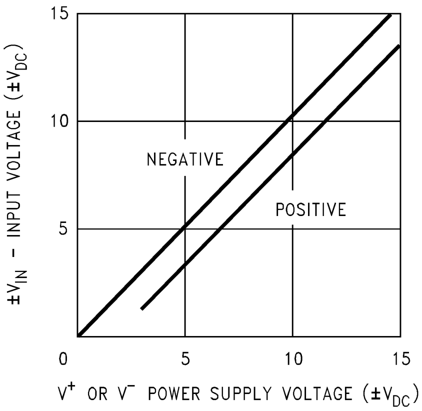
Note 8: Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

Note 9: Refer to RETS158AX for LM158A military specifications and to RETS158X for LM158 military specifications.

Note 10: Human body model, 1.5 kΩ in series with 100 pF.

Typical Performance Characteristics

Input Voltage Range



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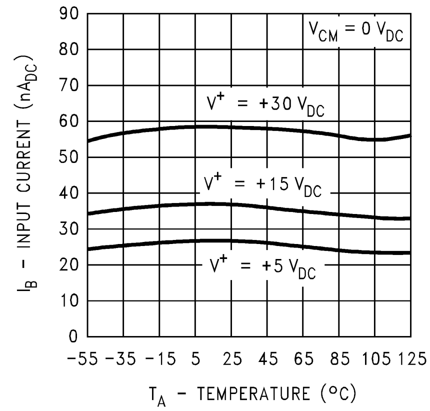
Input Current



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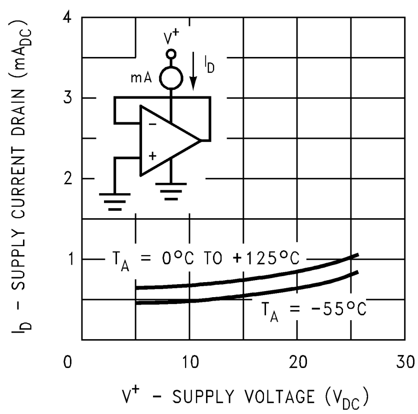
Supply Current



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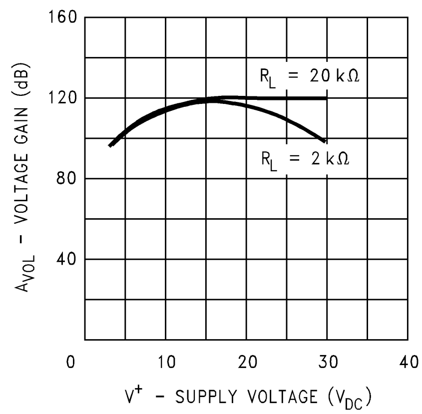
Voltage Gain



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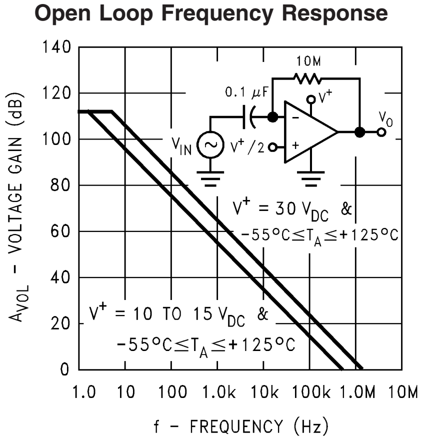
Open Loop Frequency Response



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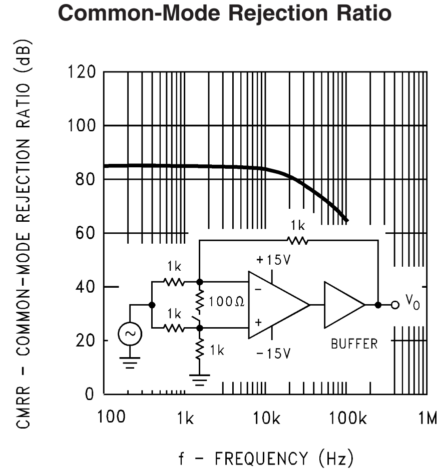
Common-Mode Rejection Ratio



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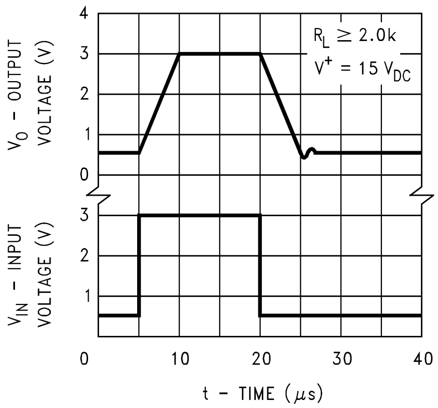
Typical Performance Characteristics (Continued)

Voltage Follower Pulse Response



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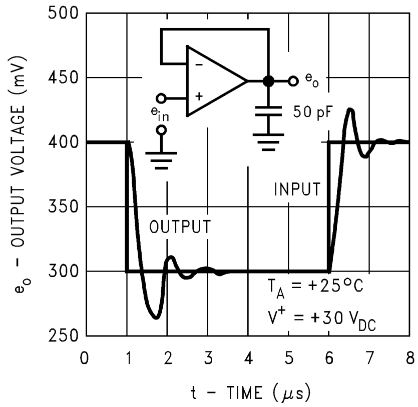
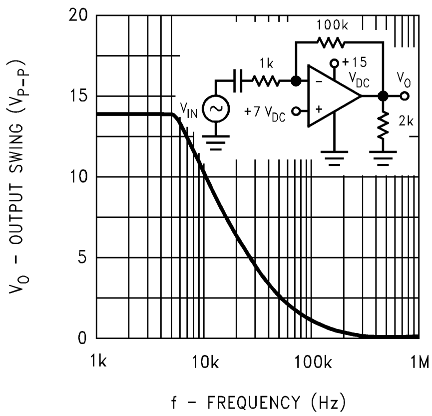
Voltage Follower Pulse Response (Small Signal)



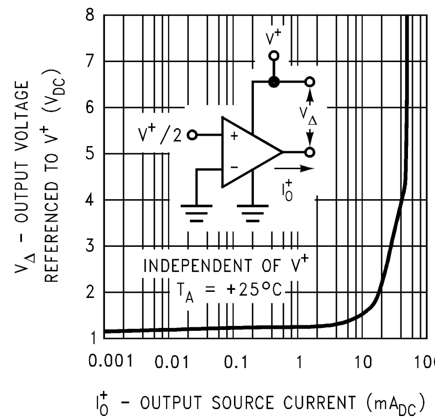
00778741

Large Signal Frequency Response



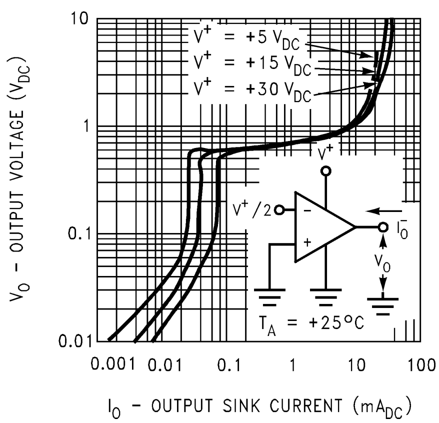
00778742

Output Characteristics Current Sourcing



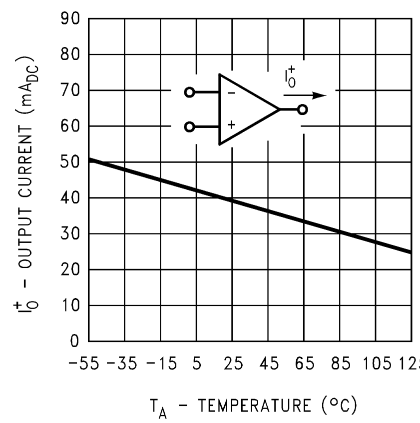
00778743

Output Characteristics Current Sinking



00778744

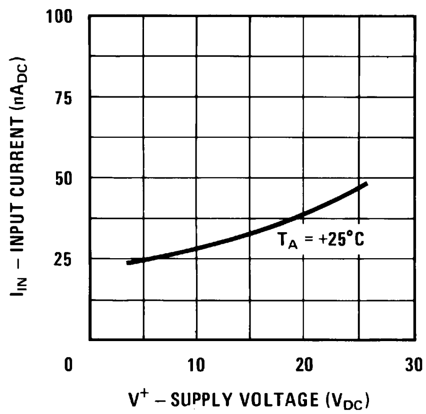
Current Limiting



00778745

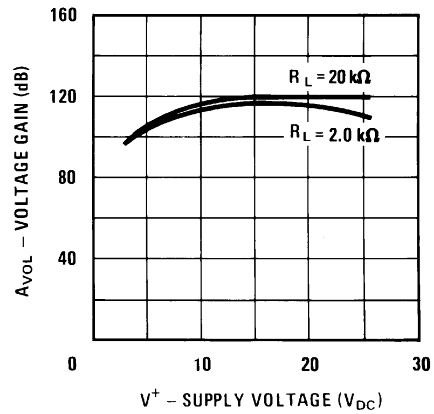
Typical Performance Characteristics (Continued)

Input Current (LM2902 only)



00778746

Voltage Gain (LM2902 only)



00778747

Application Hints

The LM158 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25˚C amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC}.

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accomodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than –0.3 V_{DC} (at 25˚C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply current drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion. Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accomodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

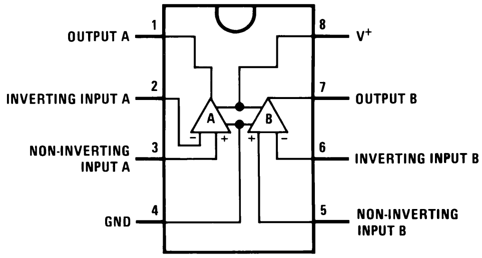
The bias network of the LM158 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of 3 V_{DC} to 30 V_{DC}.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive function temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25˚C provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

Connection Diagrams

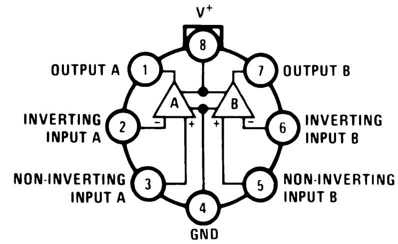
DIP/SO Package



00778702

Top View

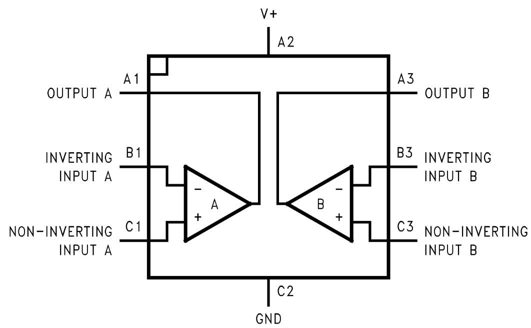
Metal Can Package



00778701

Top View

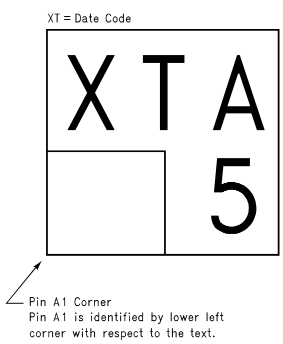
8-Bump micro SMD



00778755

Top View
(Bump Side Down)

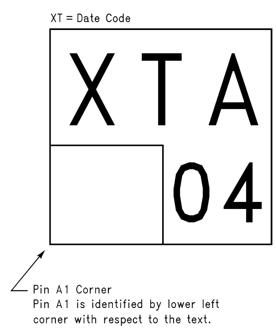
LM358BP micro SMD Marking Orientation



00778756

Top View

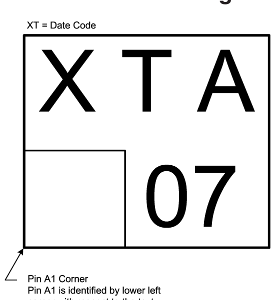
LM2904IBP micro SMD Marking Orientation



00778757

Top View

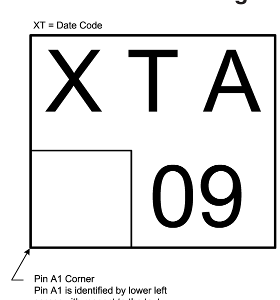
LM358TP micro SMD Marking Orientation



00778758

Top View

LM2904ITP micro SMD Marking Orientation



00778759

Top View

Ordering Information

Package	Temperature Range				NSC Drawing
	−55˚C to 125˚C	−25˚C to 85˚C	0˚C to 70˚C	−40˚C to 85˚C	
SO-8			LM358AM LM358AMX LM358M LM358MX	LM2904M LM2904MX	M08A
8-Pin Molded DIP			LM358AN LM358N	LM2904N	N08E
8-Pin Ceramic DIP	LM158AJ/883(Note 11) LM158J/883(Note 11) LM158J LM158AJLQML(Note 12) LM158AJQMLV(Note 12)				J08A
TO-5, 8-Pin Metal Can	LM158AH/883(Note 11) LM158H/883(Note 11) LM158AH LM158H LM158AHLQML(Note 12) LM158AHLQMLV(Note 12)	LM258H	LM358H		H08C
8-Bump micro SMD			LM358BP LM358BPX	LM2904IBP LM2904IBPX	BPA08AAB 0.85 mm Thick
8-Bump micro SMD Lead Free			LM358TP LM358TPX	LM2904ITP LM2904ITPX	TPA08AAA 0.50 mm Thick
14-Pin Ceramic SOIC	LM158AWG/883				WG10A

Note 11: LM158 is available per SMD #5962-8771001

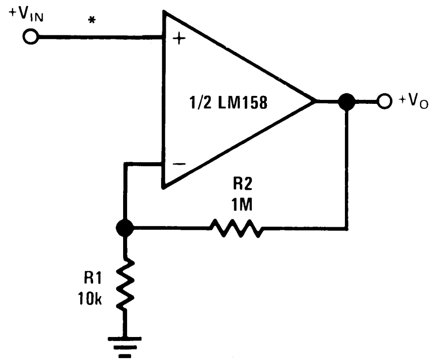
LM158A is available per SMD #5962-8771002

Note 12: See STD Mil DWG 5962L87710 for Radiation Tolerant Devices

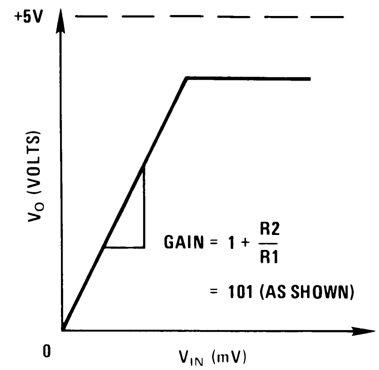
Typical Single-Supply Applications

($V^+ = 5.0\ V_{DC}$)

Non-Inverting DC Gain (0V Output)



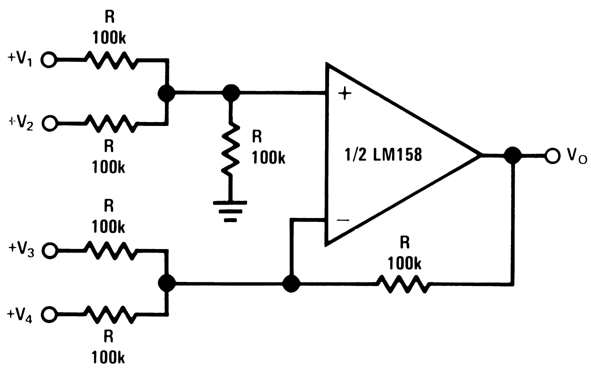
00778706



00778707

*R not needed due to temperature independent I_{IN}

DC Summing Amplifier ($V_{IN'S} \geq 0\ V_{DC}$ and $V_O \geq 0\ V_{DC}$)

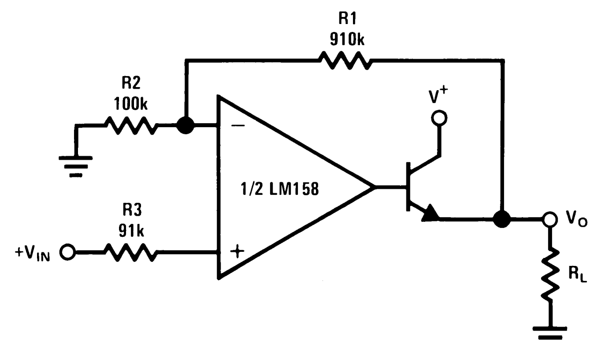


00778708

Where: $V_O = V_1 + V_2 - V_3 - V_4$

$(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_O > 0\ V_{DC}$

Power Amplifier



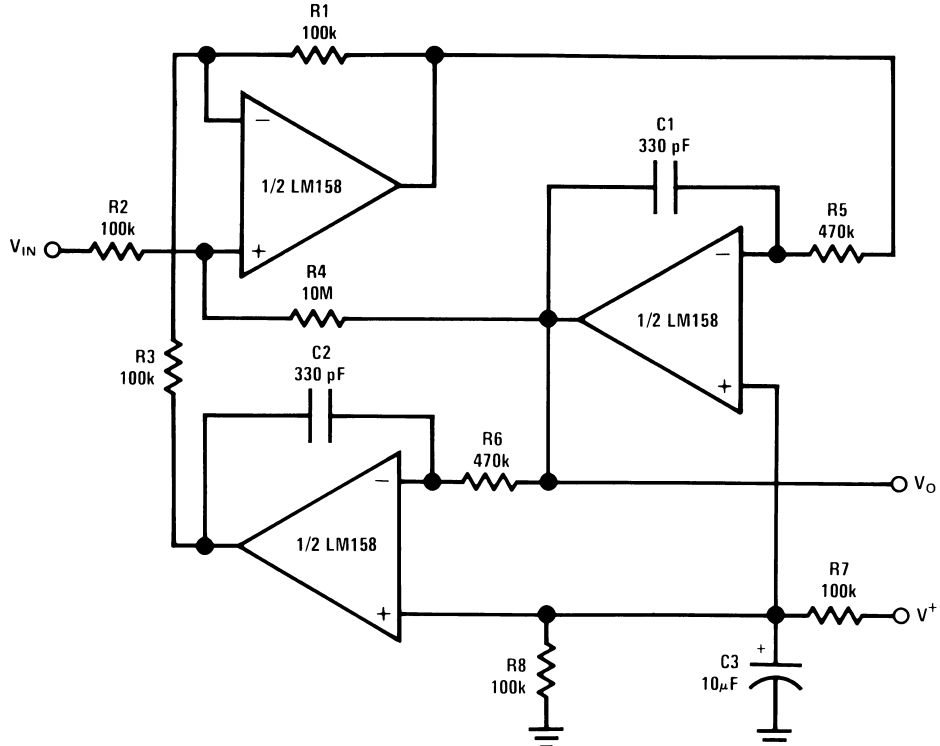
00778709

$V_O = 0\ V_{DC}$ for $V_{IN} = 0\ V_{DC}$

$A_V = 10$

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

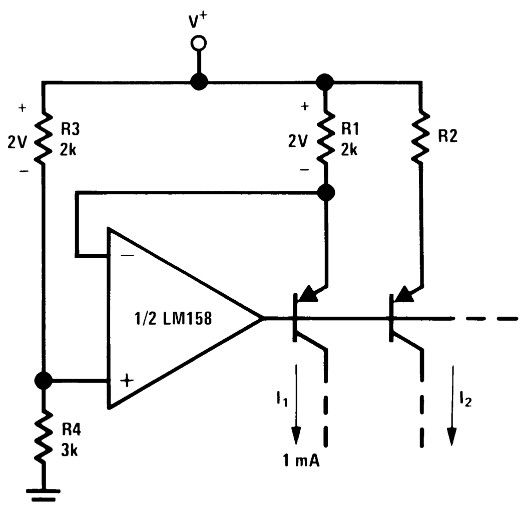
"BI-QUAD" RC Active Bandpass Filter



00778710

$f_o = 1$ kHz
Q = 50
$A_V = 100$ (40 dB)

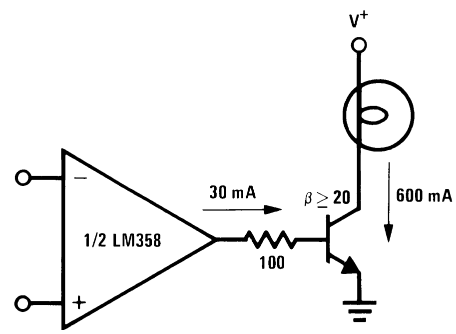
Fixed Current Sources



00778711

$$I_2 = \left(\frac{R1}{R2}\right) I_1$$

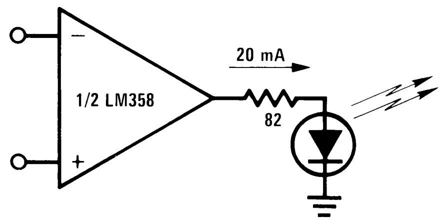
Lamp Driver



00778712

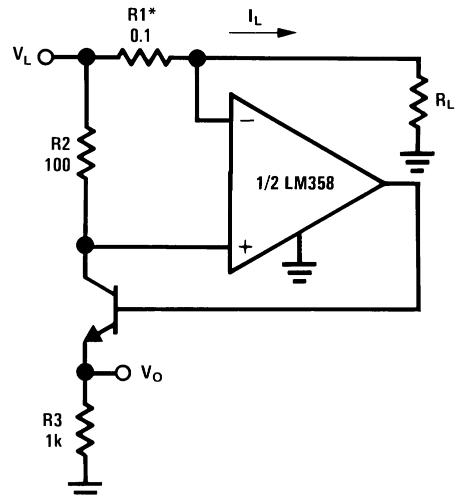
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

LED Driver



00778713

Current Monitor



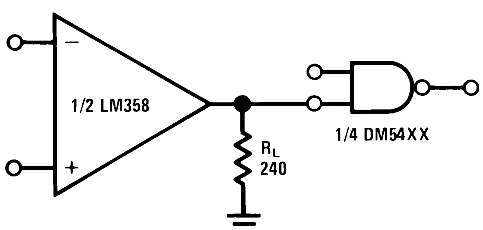
00778714

$$V_O = \frac{1V\ (I_L)}{1A}$$

*(Increase R1 for I_L small)

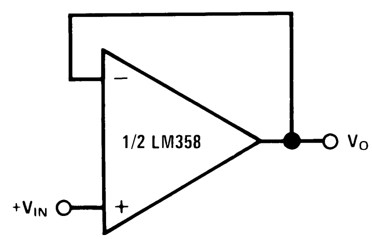
$V_L \le V^+ - 2V$

Driving TTL



00778715

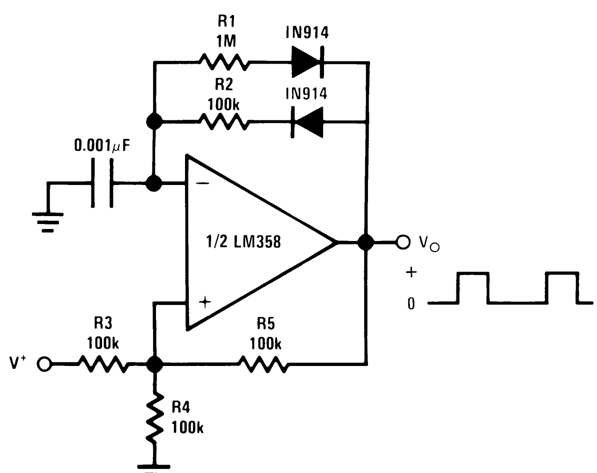
Voltage Follower



00778717

$V_O = V_{IN}$

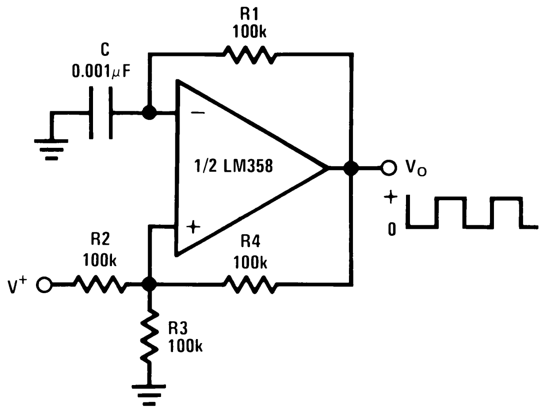
Pulse Generator



00778716

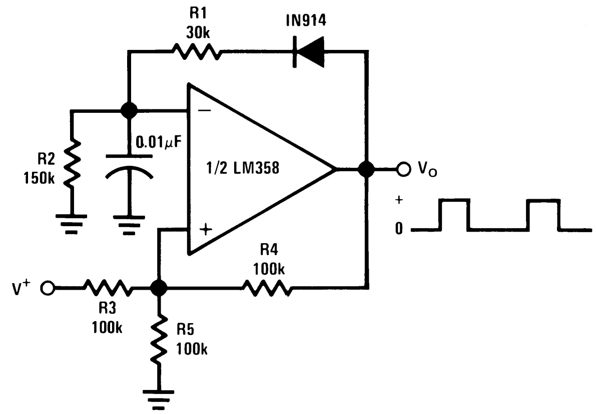
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Squarewave Oscillator



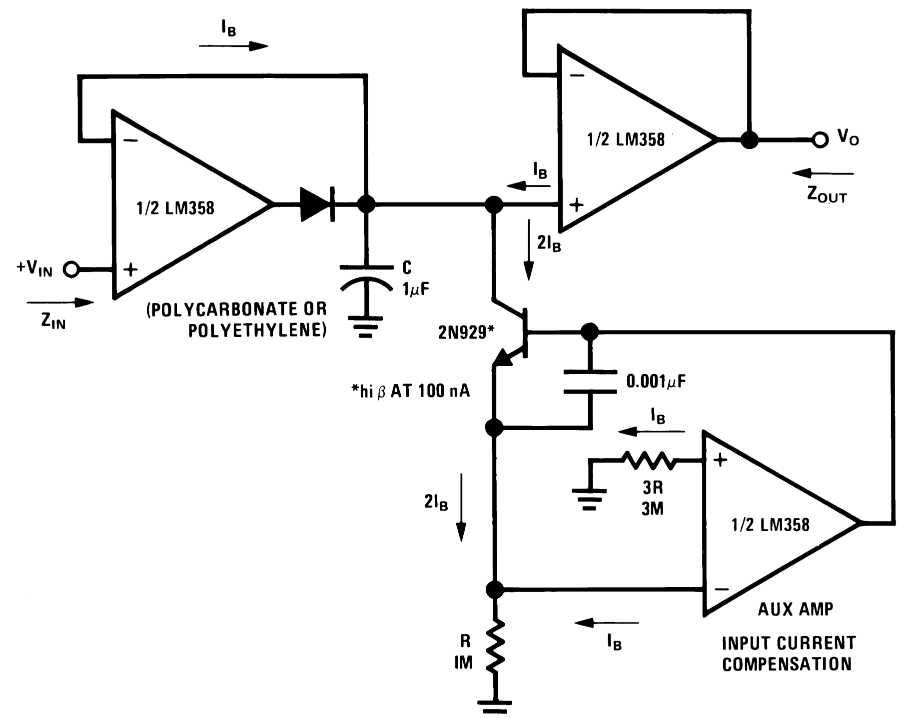
00778718

Pulse Generator



00778719

Low Drift Peak Detector

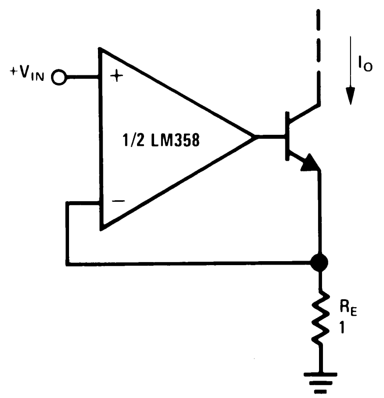


00778720

HIGH Z_{IN}
LOW Z_{OUT}

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

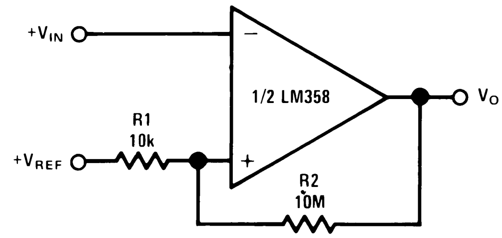
High Compliance Current Sink



00778721

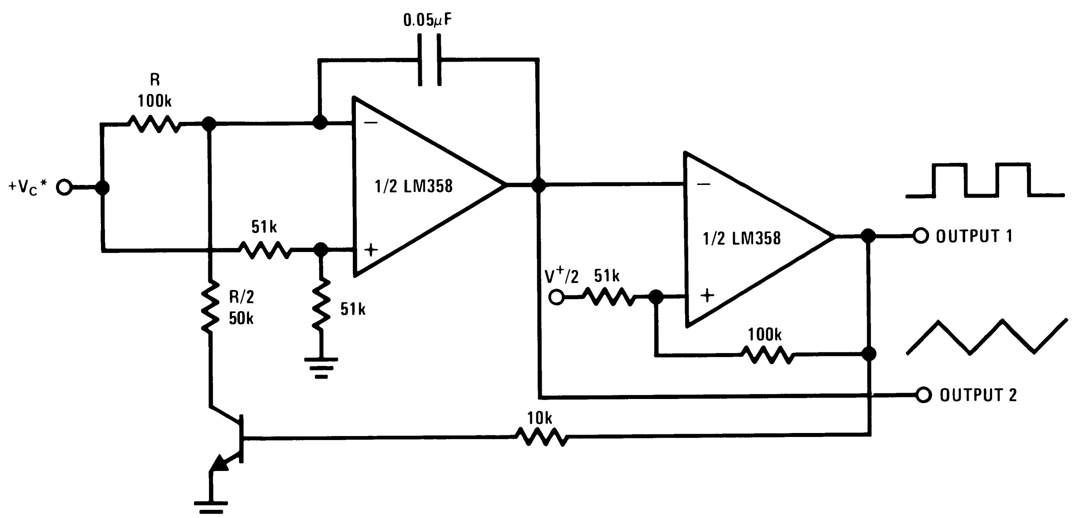
I_O = 1 amp/volt V_{IN}
(Increase R_E for I_O small)

Comparator with Hysteresis



00778722

Voltage Controlled Oscillator (VCO)

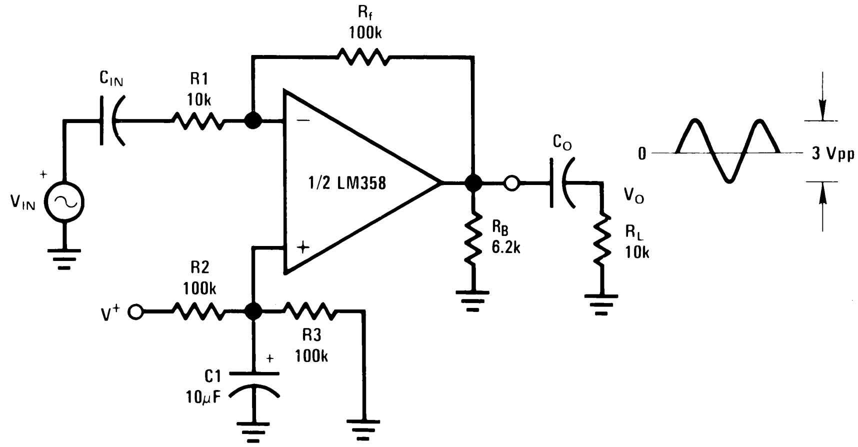


00778723

*WIDE CONTROL VOLTAGE RANGE: 0 $V_{DC} \leq V_C \leq 2\ (V^+ - 1.5V_{DC})$

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

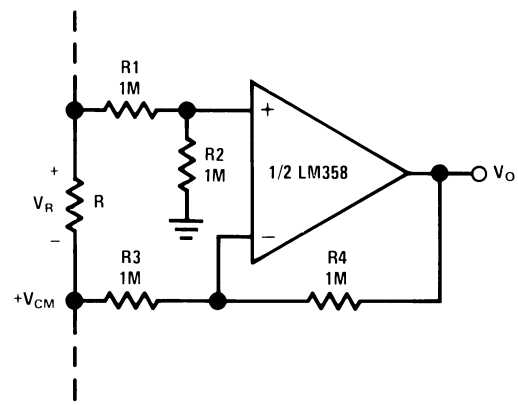
AC Coupled Inverting Amplifier



00778724

$$A_V = \frac{R_f}{R1} \quad \text{(As shown, } A_V = 10\text{)}$$

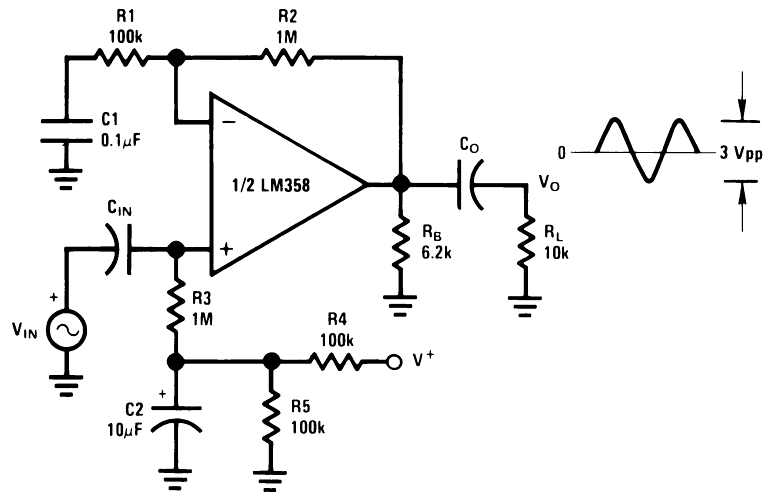
Ground Referencing a Differential Input Signal



00778725

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

AC Coupled Non-Inverting Amplifier

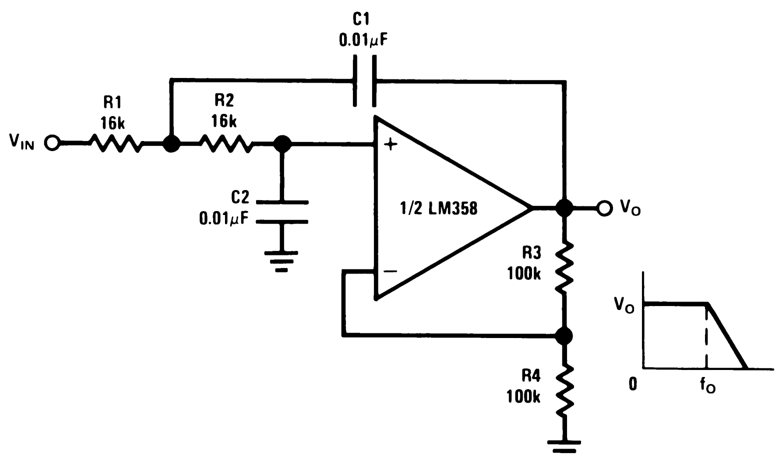


00778726

$$A_V = 1 + \frac{R2}{R1}$$

A_v = 11 (As Shown)

DC Coupled Low-Pass RC Active Filter

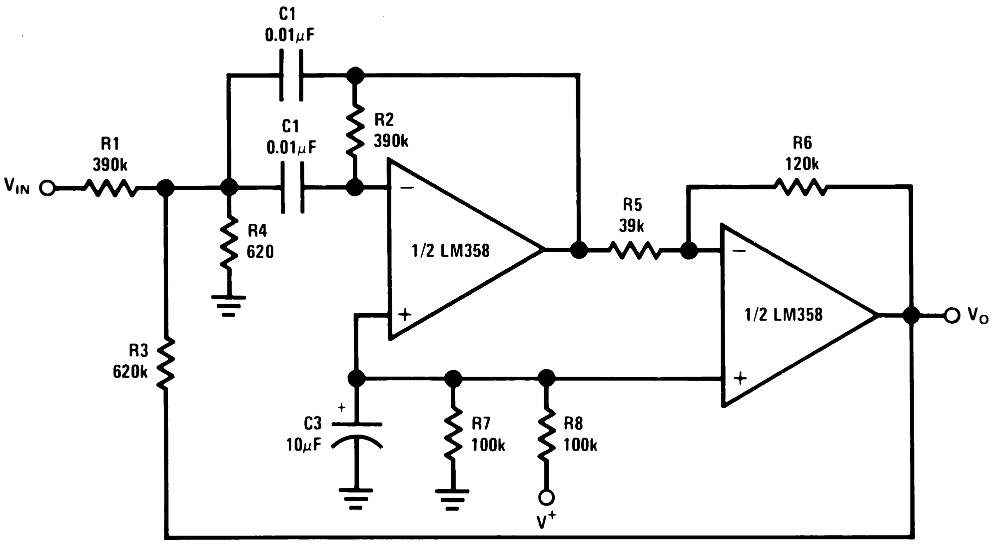


00778727

f_o = 1 kHz
Q = 1
A_V = 2

Typical Single-Supply Applications (V^+ = 5.0 V_{DC}) (Continued)

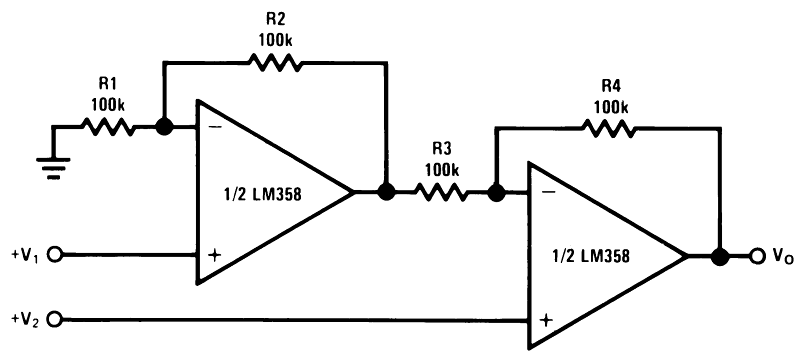
Bandpass Active Filter



00778728

f_O = 1 kHz
Q = 25

High Input Z, DC Differential Amplifier



00778729

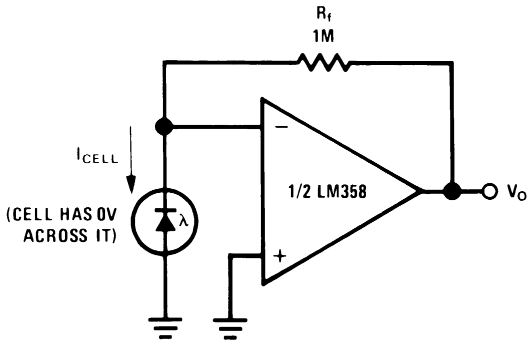
For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$V_O = 1 + \frac{R4}{R3} (V_2 - V_1)$

As Shown: $V_O = 2 (V_2 - V_1)$

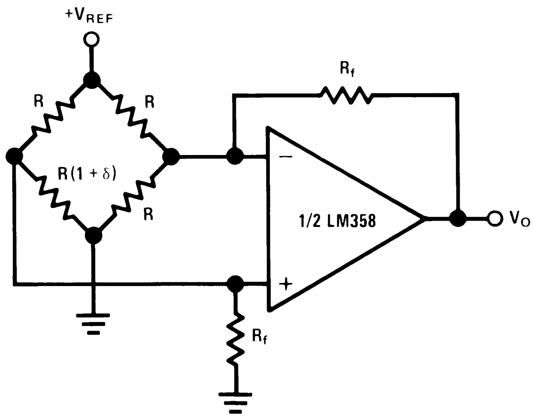
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Photo Voltaic-Cell Amplifier



00778730

Bridge Current Amplifier

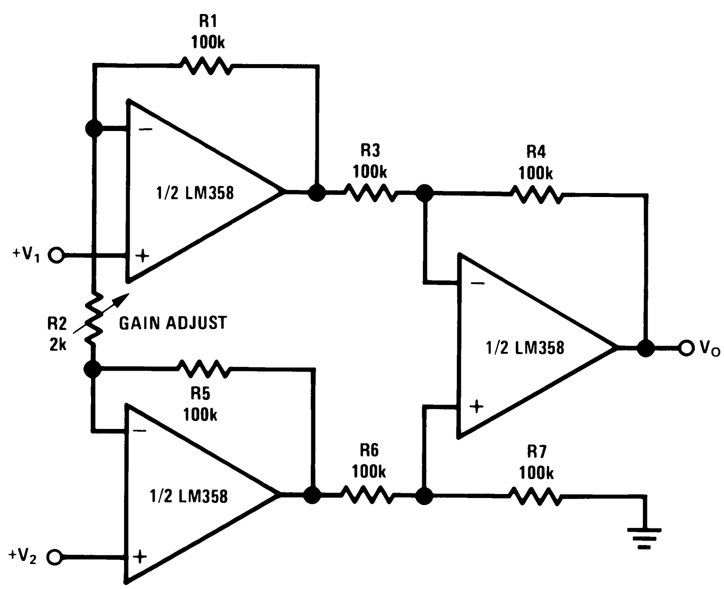


00778733

For $\delta << 1$ and $R_f >> R$

$$V_O \cong V_{REF}\left(\frac{\delta}{2}\right)\frac{R_f}{R}$$

High Input Z Adjustable-Gain DC Instrumentation Amplifier



00778731

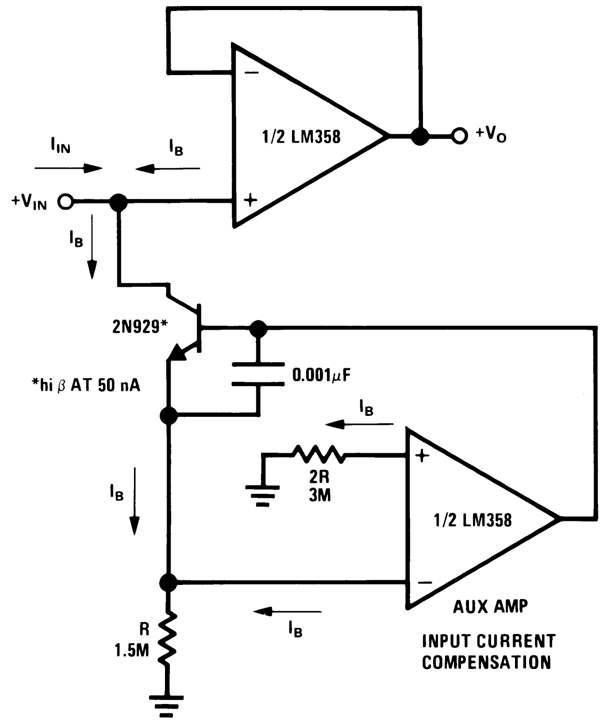
If R1 = R5 & R3 = R4 = R6 = R7 (CMRR depends on match)

$$V_O = 1 + \frac{2R1}{R2}\left(V_2 - V_1\right)$$

As shown $V_O = 101\ (V_2 - V_1)$

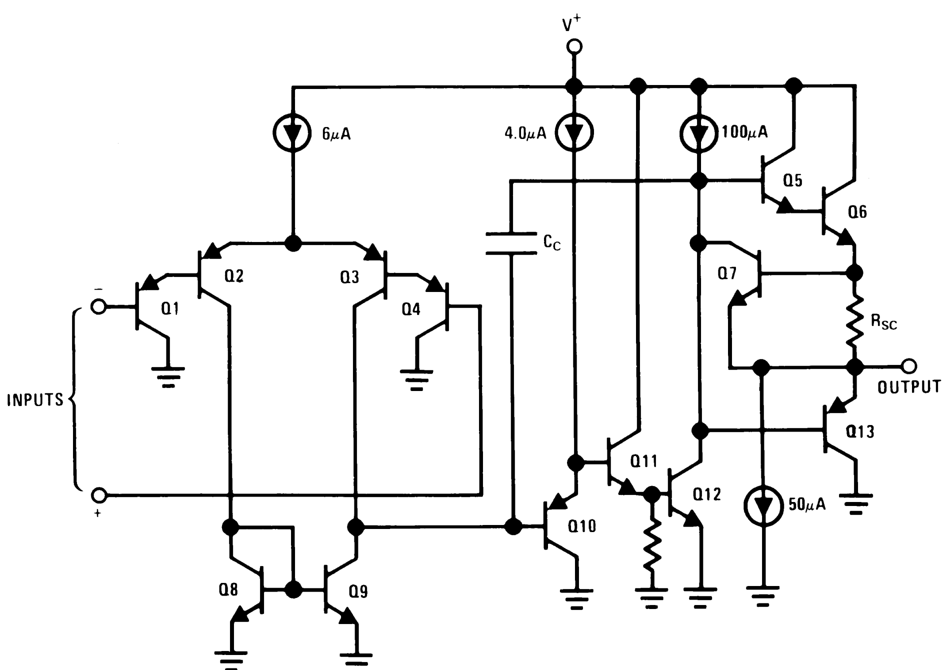
Typical Single-Supply Applications (V^+ = 5.0 V_{DC}) (Continued)

Using Symmetrical Amplifiers to Reduce Input Current (General Concept)



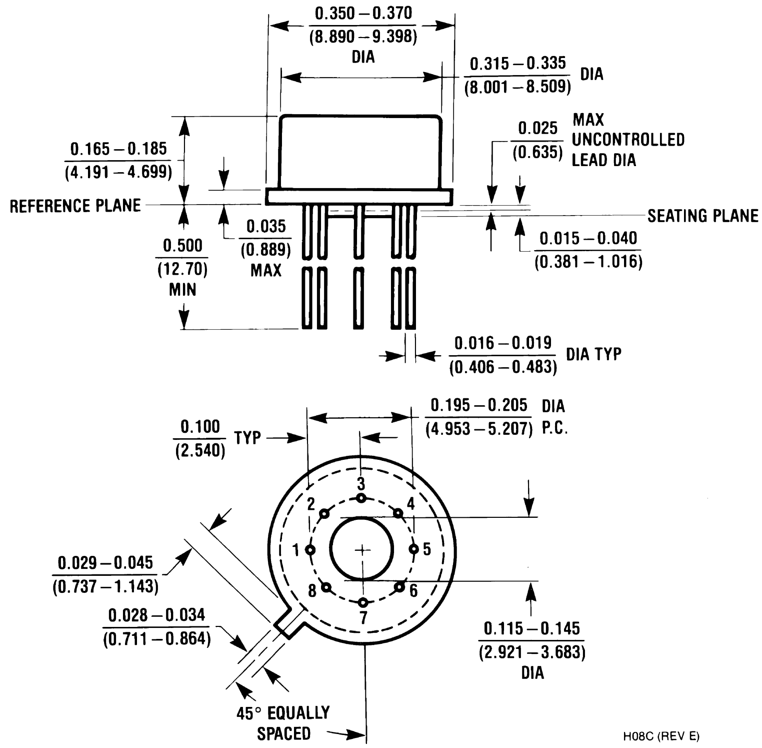
00778732

Schematic Diagram (Each Amplifier)

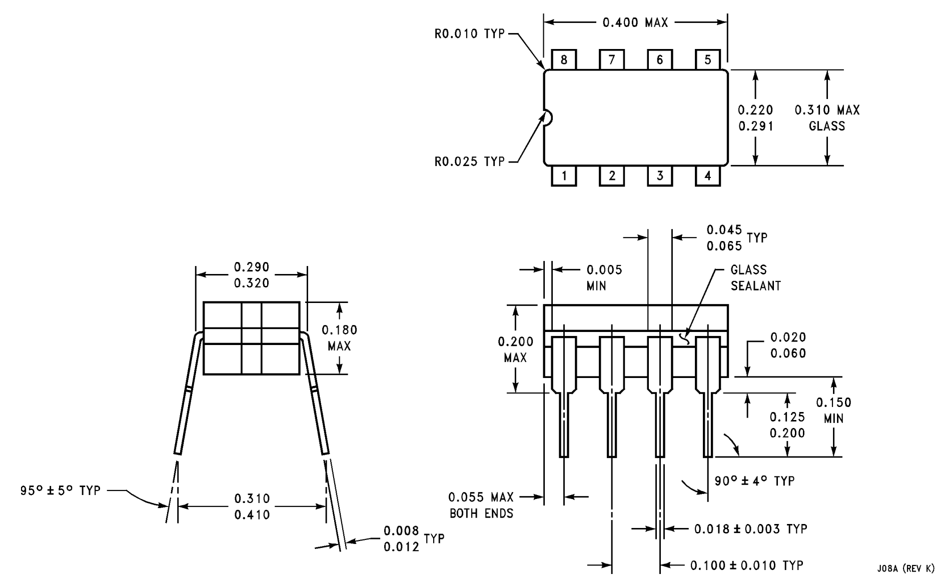


00778703

Physical Dimensions inches (millimeters) unless otherwise noted

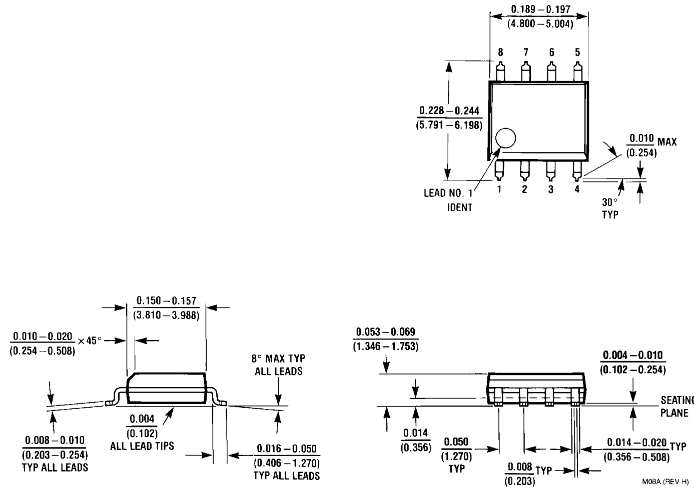


Metal Can Package (H)
NS Package Number H08C

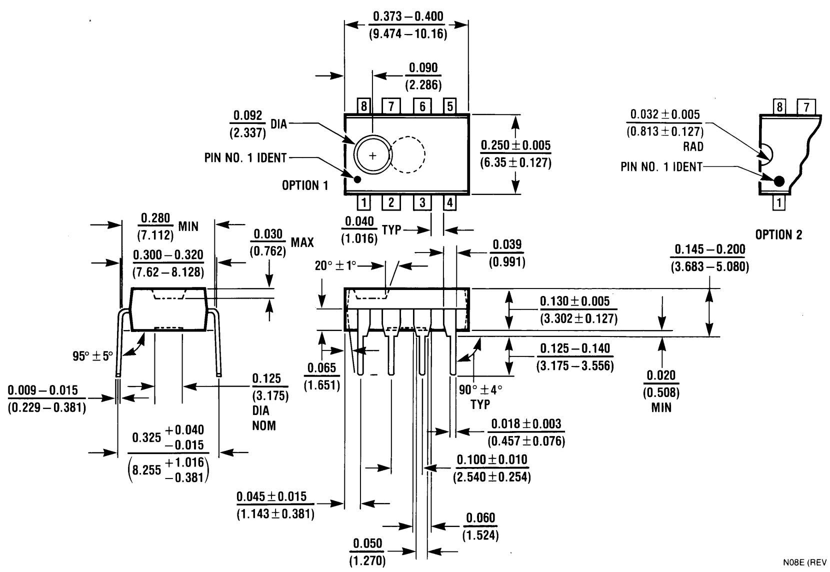


Cerdip Package (J)
NS Package Number J08A

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

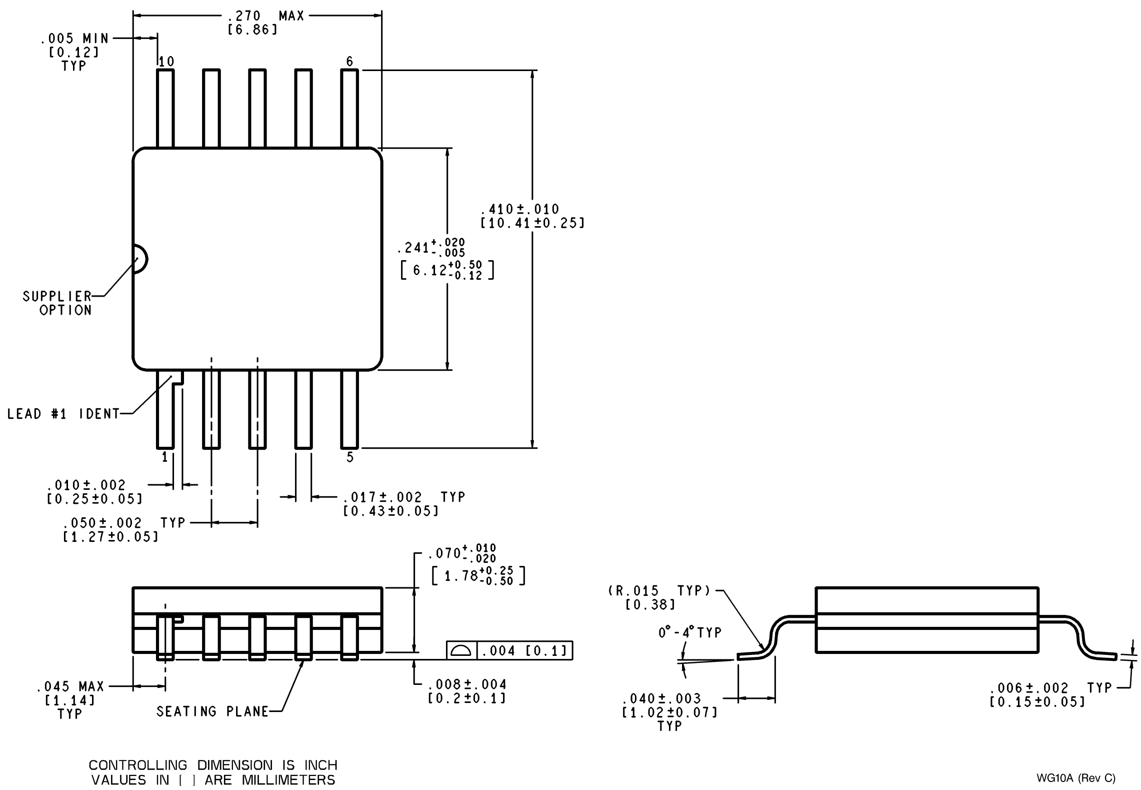


SOIC Package (M)
NS Package Number M08A



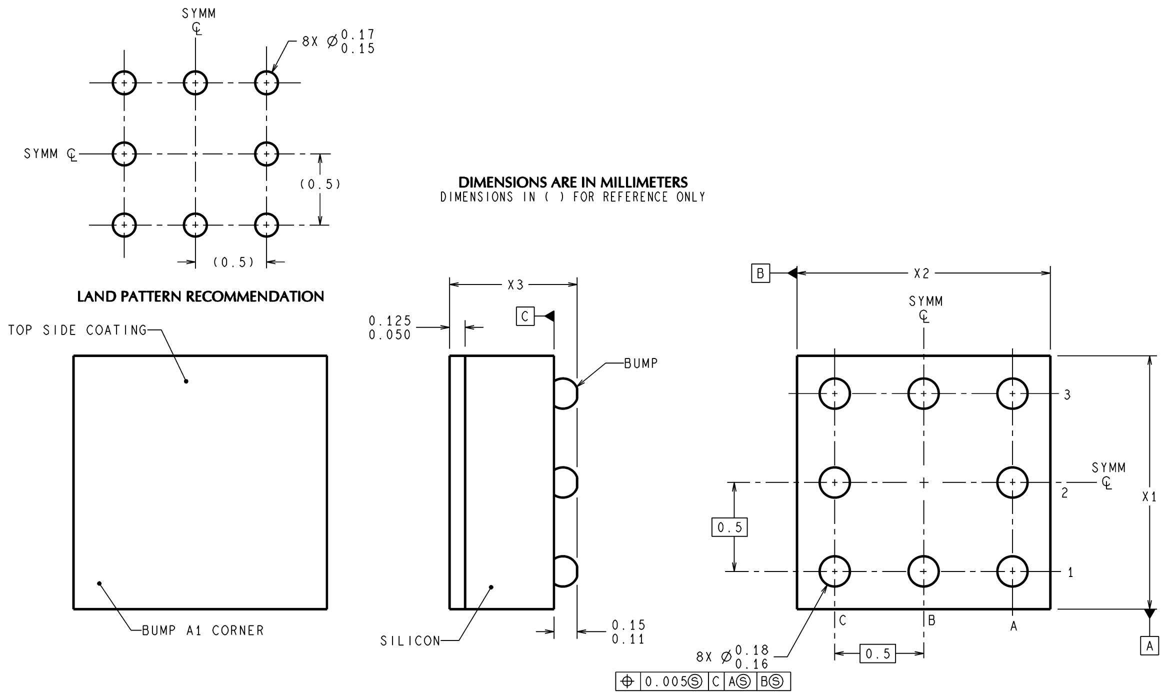
Molded Dip Package (N)
NS Package Number N08E

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



Order Number LM158AWG/883
NS Package Number WG10A

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



BPA08XXX (Rev D)

NOTES: UNLESS OTHERWISE SPECIFIED

1. EPOXY COATING

2. 63Sn/37Pb EUTECTIC BUMP

3. RECOMMEND NON-SOLDER MASK DEFINED LANDING PAD.

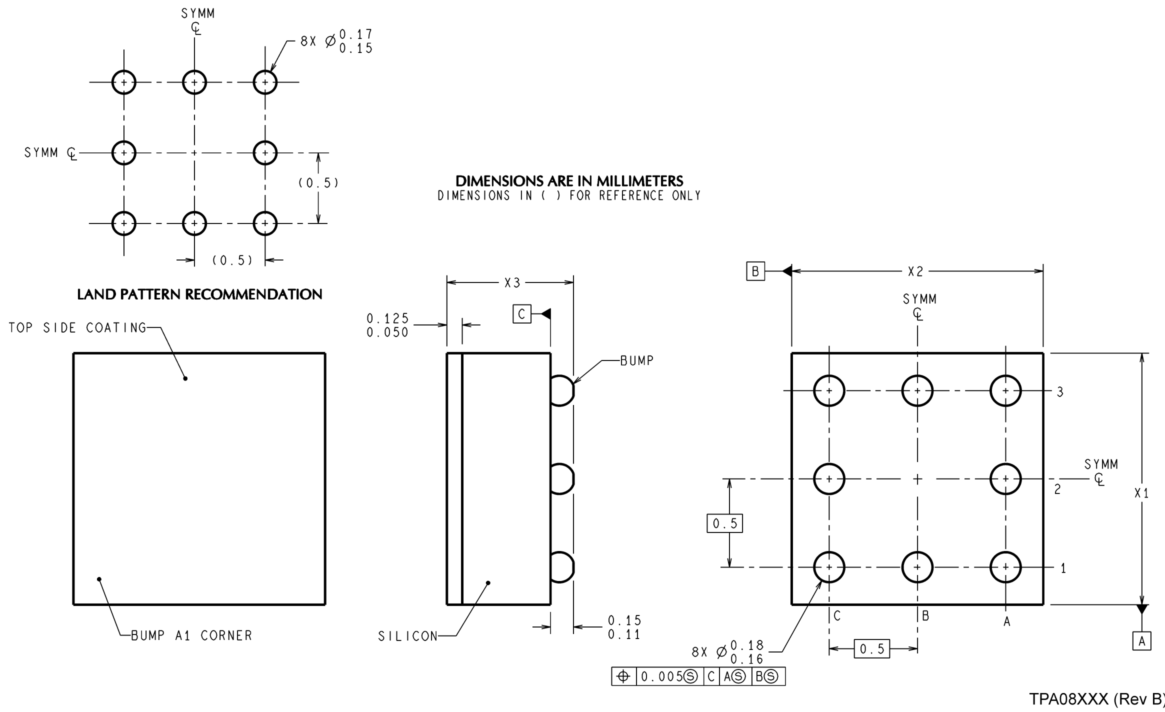
4. PIN A1 IS ESTABLISHED BY LOWER LEFT CORNER WITH RESPECT TO TEXT ORIENTATION REMAINING PINS ARE NUMBERED COUNTERCLOCKWISE.

5. XXX IN DRAWING NUMBER REPRESENTS PACKAGE SIZE VARIATION WHERE X_1 IS PACKAGE WIDTH, X_2 IS PACKAGE LENGTH AND X_3 IS PACKAGE HEIGHT.

6. REFERENCE JEDEC REGISTRATION MO-211, VARIATION BC.

8-Bump micro SMD
NS Package Number BPA08AAB
X_1 = 1.285 X_2 = 1.285 X_3 = 0.850

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



NOTES: UNLESS OTHERWISE SPECIFIED

1. EPOXY COATING
2. RECOMMEND NON-SOLDER MASK DEFINED LANDING PAD.
3. PIN A1 IS ESTABLISHED BY LOWER LEFT CORNER WITH RESPECT TO TEXT ORIENTATION REMAINING PINS ARE NUMBERED COUNTERCLOCKWISE.
4. XXX IN DRAWING NUMBER REPRESENTS PACKAGE SIZE VARIATION WHERE X_1 IS PACKAGE WIDTH, X_2 IS PACKAGE LENGTH AND X_3 IS PACKAGE HEIGHT.
5. REFERENCE JEDEC REGISTRATION MO-211, VARIATION BC.

8-Bump micro SMD Lead Free
NS Package Number TPA08AAA
X_1 = 1.285 X_2 = 1.285 X_3 = 0.500

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1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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Tel: 81-3-5639-7560

ANALOG DEVICES

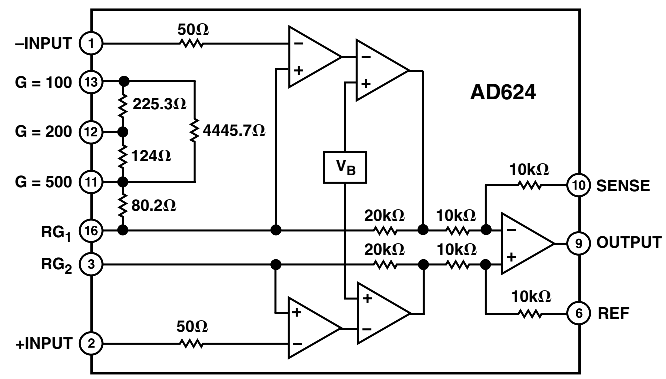
Precision Instrumentation Amplifier

AD624

FEATURES

Low Noise: 0.2 μV p-p 0.1 Hz to 10 Hz
Low Gain TC: 5 ppm max (G = 1)
Low Nonlinearity: 0.001% max (G = 1 to 200)
High CMRR: 130 dB min (G = 500 to 1000)
Low Input Offset Voltage: 25 μV, max
Low Input Offset Voltage Drift: 0.25 μV/°C max
Gain Bandwidth Product: 25 MHz
Pin Programmable Gains of 1, 100, 200, 500, 1000
No External Components Required
Internally Compensated

FUNCTIONAL BLOCK DIAGRAM



PRODUCT DESCRIPTION

The AD624 is a high precision, low noise, instrumentation amplifier designed primarily for use with low level transducers, including load cells, strain gauges and pressure transducers. An outstanding combination of low noise, high gain accuracy, low gain temperature coefficient and high linearity make the AD624 ideal for use in high resolution data acquisition systems.

The AD624C has an input offset voltage drift of less than 0.25 μV/°C, output offset voltage drift of less than 10 μV/°C, CMRR above 80 dB at unity gain (130 dB at G = 500) and a maximum nonlinearity of 0.001% at G = 1. In addition to these outstanding dc specifications, the AD624 exhibits superior ac performance as well. A 25 MHz gain bandwidth product, 5 V/μs slew rate and 15 μs settling time permit the use of the AD624 in high speed data acquisition applications.

The AD624 does not need any external components for pre-trimmed gains of 1, 100, 200, 500 and 1000. Additional gains such as 250 and 333 can be programmed within one percent accuracy with external jumpers. A single external resistor can also be used to set the 624's gain to any value in the range of 1 to 10,000.

PRODUCT HIGHLIGHTS

1. The AD624 offers outstanding noise performance. Input noise is typically less than 4 nV/√Hz at 1 kHz.
2. The AD624 is a functionally complete instrumentation amplifier. Pin programmable gains of 1, 100, 200, 500 and 1000 are provided on the chip. Other gains are achieved through the use of a single external resistor.
3. The offset voltage, offset voltage drift, gain accuracy and gain temperature coefficients are guaranteed for all pretrimmed gains.
4. The AD624 provides totally independent input and output offset nulling terminals for high precision applications. This minimizes the effect of offset voltage in gain ranging applications.
5. A sense terminal is provided to enable the user to minimize the errors induced through long leads. A reference terminal is also provided to permit level shifting at the output.

REV. C

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

AD624–SPECIFICATIONS (@ V_S = ±15 V, R_L = 2 kΩ and T_A = +25°C, unless otherwise noted)

Model	AD624A			AD624B			AD624C			AD624S			
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Units
GAIN													
Gain Equation (External Resistor Gain Programming)		$\left[\frac{40,000}{R_G}+1\right]\pm 20\%$			$\left[\frac{40,000}{R_G}+1\right]\pm 20\%$			$\left[\frac{40,000}{R_G}+1\right]\pm 20\%$			$\left[\frac{40,000}{R_G}+1\right]\pm 20\%$		
Gain Range (Pin Programmable)	1 to 1000			1 to 1000			1 to 1000			1 to 1000			
Gain Error													
G = 1			**±0.05**			**±0.03**			**±0.02**			**±0.05**	%
G = 100			**±0.25**			**±0.15**			**±0.1**			**±0.25**	%
G = 200, 500			**±0.5**			**±0.35**			**±0.25**			**±0.5**	%
Nonlinearity													
G = 1			±0.005			±0.003			±0.001			±0.005	%
G = 100, 200			±0.005			±0.003			±0.001			±0.005	%
G = 500			±0.005			±0.005			±0.005			±0.005	%
Gain vs. Temperature													
G = 1			5			5			5			5	ppm/°C
G = 100, 200			10			10			10			10	ppm/°C
G = 500			25			15			15			15	ppm/°C
VOLTAGE OFFSET (May be Nulled)													
Input Offset Voltage			**200**			**75**			**25**			**75**	µV
vs. Temperature			**2**			**0.5**			**0.25**			**2.0**	µV/°C
Output Offset Voltage			**5**			**3**			**2**			**3**	mV
vs. Temperature			**50**			**25**			**10**			**50**	µV/°C
Offset Referred to the Input vs. Supply													
G = 1	**70**			**75**			**80**			**75**			dB
G = 100, 200	**95**			**105**			**110**			**105**			dB
G = 500	**100**			**110**			**115**			**110**			dB
INPUT CURRENT													
Input Bias Current			**±50**			**±25**			**±15**			**±50**	nA
vs. Temperature		±50			±50			±50			±50		pA/°C
Input Offset Current			**±35**			**±15**			**±10**			**±35**	nA
vs. Temperature		±20			±20			±20			±20		pA/°C
INPUT													
Input Impedance													
Differential Resistance		10^9			10^9			10^9			10^9		Ω
Differential Capacitance		10			10			10			10		pF
Common-Mode Resistance		10^9			10^9			10^9			10^9		Ω
Common-Mode Capacitance		10			10			10			10		pF
Input Voltage Range[1]													
Max Differ. Input Linear (V_{DL})	±10			±10			±10			±10			V
Max Common-Mode Linear (V_{CM})		$12\ \mathbf{V} - \left(\frac{\mathbf{G}}{2} \times \mathbf{V_D}\right)$			$12\ \mathbf{V} - \left(\frac{\mathbf{G}}{2} \times \mathbf{V_D}\right)$			$12\ \mathbf{V} - \left(\frac{\mathbf{G}}{2} \times \mathbf{V_D}\right)$			$12\ \mathbf{V} - \left(\frac{\mathbf{G}}{2} \times \mathbf{V_D}\right)$		V
Common-Mode Rejection dc to 60 Hz with 1 kΩ Source Imbalance													
G = 1	**70**			**75**			**80**			**70**			dB
G = 100, 200	**100**			**105**			**110**			**100**			dB
G = 500	**110**			**120**			**130**			**110**			dB
OUTPUT RATING													
V_{OUT}, R_L = 2 kΩ		±10			±10			±10			±10		V
DYNAMIC RESPONSE													
Small Signal –3 dB													
G = 1		1			1			1			1		MHz
G = 100		150			150			150			150		kHz
G = 200		100			100			100			100		kHz
G = 500		50			50			50			50		kHz
G = 1000		25			25			25			25		kHz
Slew Rate		5.0			5.0			5.0			5.0		V/µs
Settling Time to 0.01%, 20 V Step													
G = 1 to 200		15			15			15			15		µs
G = 500		35			35			35			35		µs
G = 1000		75			75			75			75		µs
NOISE													
Voltage Noise, 1 kHz													
R.T.I.		4			4			4			4		nV/√Hz
R.T.O.		75			75			75			75		nV/√Hz
R.T.I., 0.1 Hz to 10 Hz													
G = 1		10			10			10			10		µV p-p
G = 100		0.3			0.3			0.3			0.3		µV p-p
G = 200, 500, 1000		0.2			0.2			0.2			0.2		µV p-p
Current Noise													
0.1 Hz to 10 Hz		60			60			60			60		pA p-p
SENSE INPUT													
R_{IN}	8	10	12	8	10	12	8	10	12	8	10	12	kΩ
I_{IN}		30			30			30			30		µA
Voltage Range	±10			±10			±10			±10			V
Gain to Output		1			1			1			1		%

Model	AD624A			AD624B			AD624C			AD624S			
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Units
REFERENCE INPUT													
R_{IN}	16	20	24	16	20	24	16	20	24	16	20	24	kΩ
I_{IN}		30			30			30			30		μA
Voltage Range	±10			±10			±10			±10			V
Gain to Output		1			1			1			1		%
TEMPERATURE RANGE													
Specified Performance	–25		+85	–25		+85	–25		+85	–55		+125	°C
Storage	–65		+150	–65		+150	–65		+150	–65		+150	°C
POWER SUPPLY													
Power Supply Range	**±6**	**±15**	**±18**	**±6**	**±15**	**±18**	**±6**	**±15**	**±18**	**±6**	**±15**	**±18**	V
Quiescent Current		3.5	5		3.5	5		3.5	5		3.5	5	mA

NOTES

[1]V_{DL} is the maximum differential input voltage at G = 1 for specified nonlinearity, V_{DL} at other gains = 10 V/G. V_D = actual differential input voltage.
Example: G = 10, V_D = 0.50. V_{CM} = 12 V – (10/2 × 0.50 V) = 9.5 V.

Specifications subject to change without notice.

Specifications shown in **boldface** are tested on all production unit at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in boldface are tested on all production units.

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage . . . . ±18 V
Internal Power Dissipation . . . . 420 mW
Input Voltage . . . . $±V_S$
Differential Input Voltage . . . . $±V_S$
Output Short Circuit Duration . . . . Indefinite
Storage Temperature Range . . . . –65°C to +150°C
Operating Temperature Range
AD624A/B/C . . . . –25°C to +85°C
AD624S . . . . –55°C to +125°C
Lead Temperature (Soldering, 60 secs) . . . . +300°C

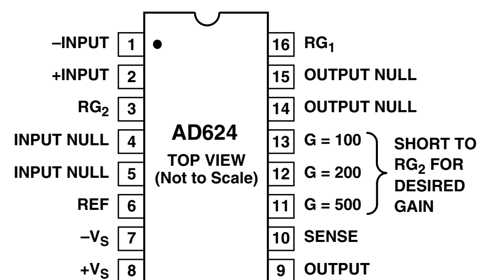
*Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute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

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD624AD	–25°C to +85°C	16-Lead Ceramic DIP	D-16
AD624BD	–25°C to +85°C	16-Lead Ceramic DIP	D-16
AD624CD	–25°C to +85°C	16-Lead Ceramic DIP	D-16
AD624SD	–55°C to +125°C	16-Lead Ceramic DIP	D-16
AD624SD/883B*	–55°C to +125°C	16-Lead Ceramic DIP	D-16
AD624AChips	–25°C to +85°C	Die	
AD624SChips	–25°C to +85°C	Die	

*See Analog Devices' military data sheet for 883B specifications.

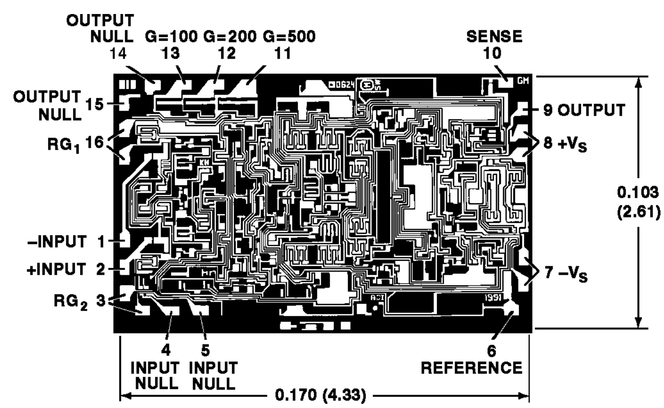
CONNECTION DIAGRAM



FOR GAINS OF 1000 SHORT RG_1 TO PIN 12 AND PINS 11 AND 13 TO RG_2

METALIZATION PHOTOGRAPH

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



PAD NUMBERS CORRESPOND TO PIN NUMBERS FOR THE D-16 16-LEAD CERAMIC PACKAGE

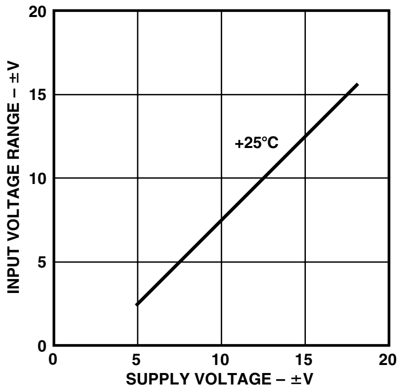


Figure 1. Input Voltage Range vs. Supply Voltage, G = 1

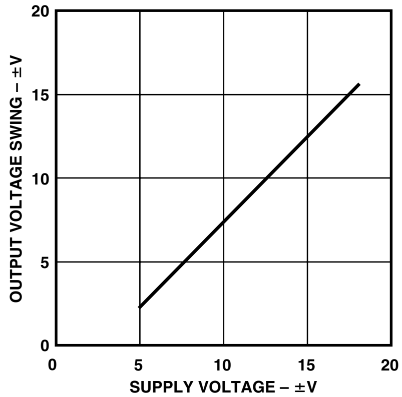


Figure 2. Output Voltage Swing vs. Supply Voltage

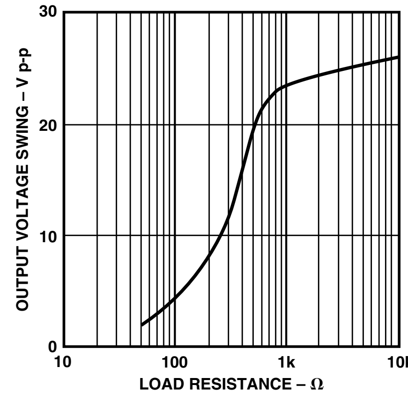


Figure 3. Output Voltage Swing vs. Load Resistance

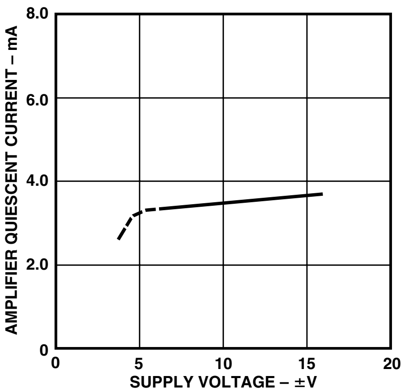


Figure 4. Quiescent Current vs. Supply Voltage

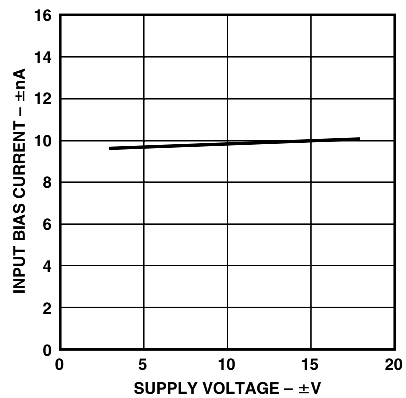


Figure 5. Input Bias Current vs. Supply Voltage

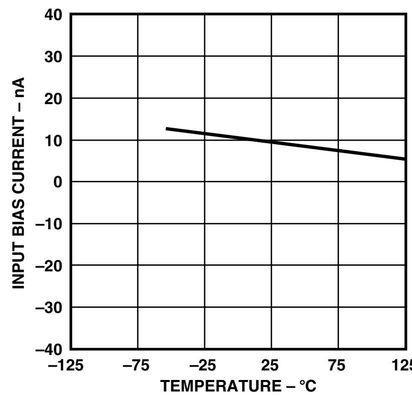


Figure 6. Input Bias Current vs. Temperature

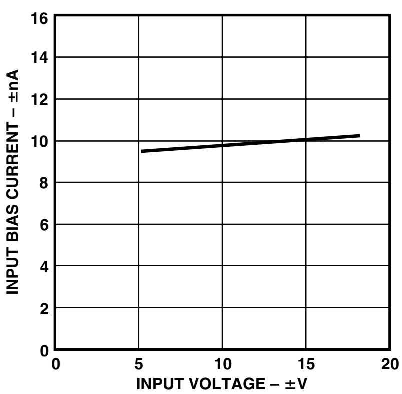


Figure 7. Input Bias Current vs. CMV

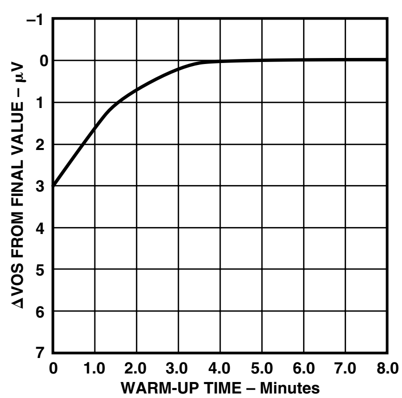


Figure 8. Offset Voltage, RTI, Turn On Drift

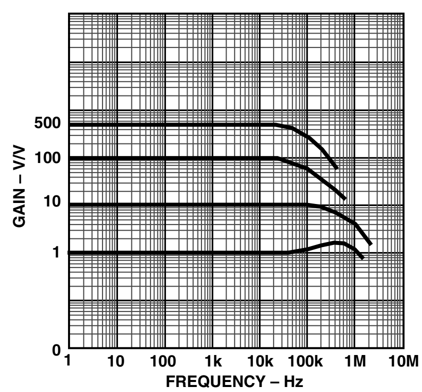


Figure 9. Gain vs. Frequency

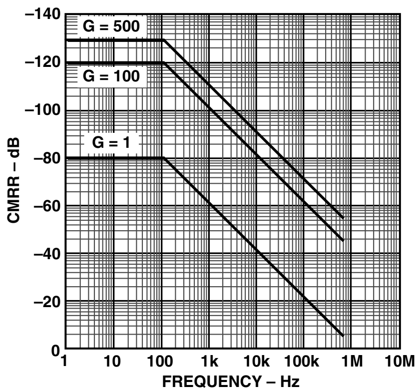


Figure 10. CMRR vs. Frequency RTI, Zero to 1k Source Imbalance

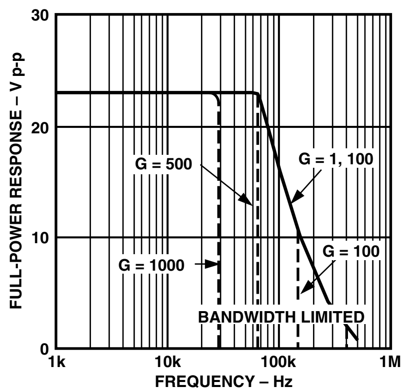


Figure 11. Large Signal Frequency Response

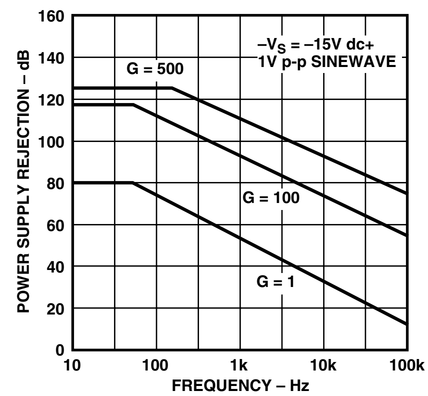


Figure 12. Positive PSRR vs. Frequency

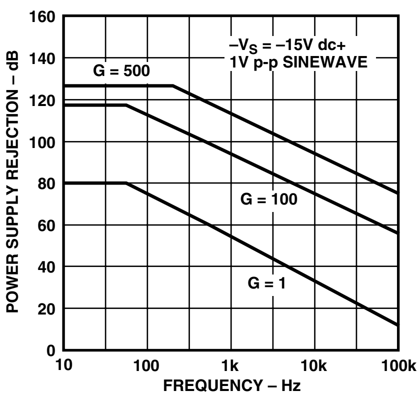


Figure 13. Negative PSRR vs. Frequency

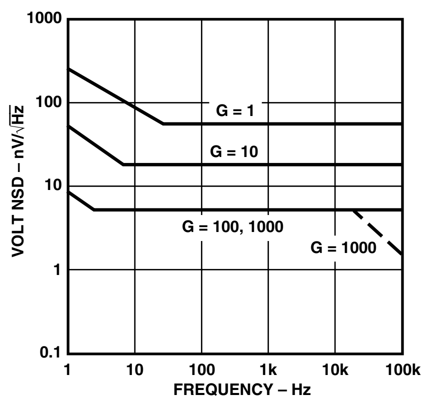


Figure 14. RTI Noise Spectral Density vs. Gain

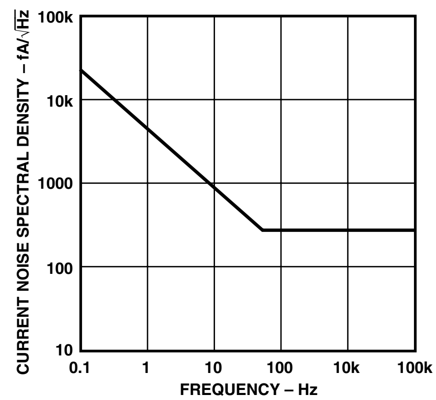


Figure 15. Input Current Noise

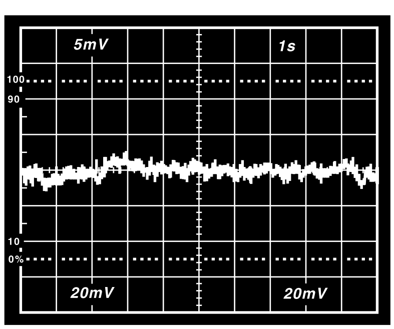


Figure 16. Low Frequency Voltage Noise, G = 1 (System Gain = 1000)

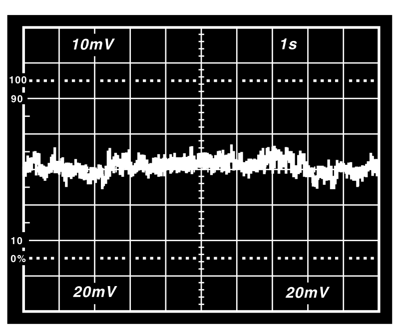


Figure 17. Low Frequency Voltage Noise, G = 1000 (System Gain = 100,000)

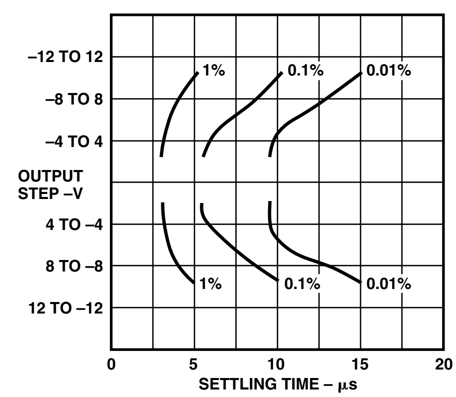


Figure 18. Settling Time, Gain = 1

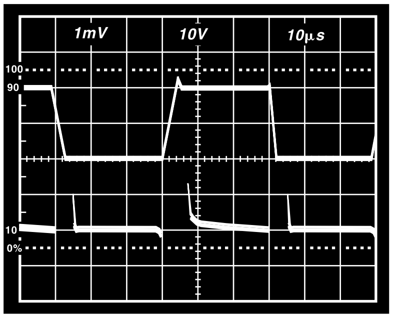


Figure 19. Large Signal Pulse Response and Settling Time, G = 1

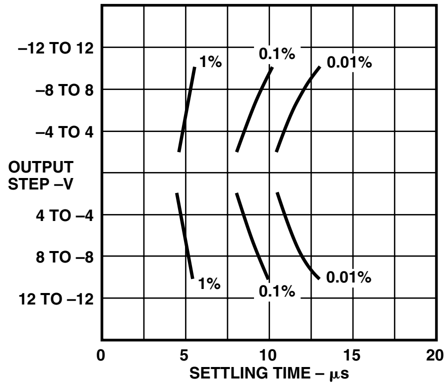


Figure 20. Settling Time Gain = 100

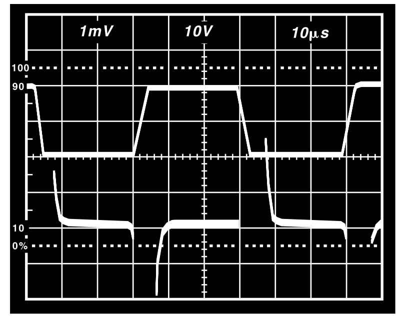


Figure 21. Large Signal Pulse Response and Settling Time, G = 100

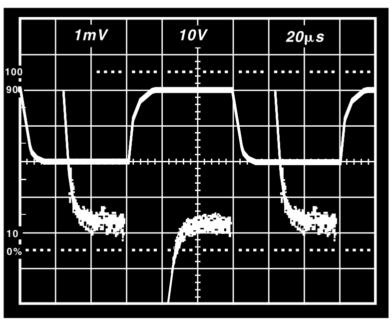


Figure 22. Range Signal Pulse Response and Settling Time, G = 500

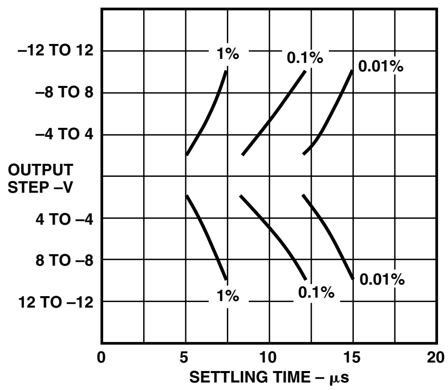


Figure 23. Settling Time Gain = 1000

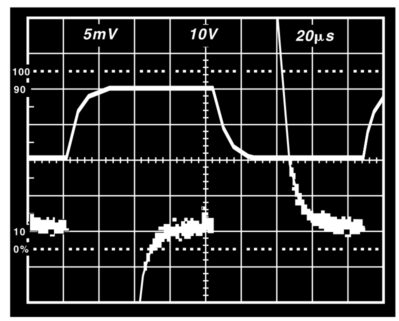


Figure 24. Large Signal Pulse Response and Settling Time, G = 1000

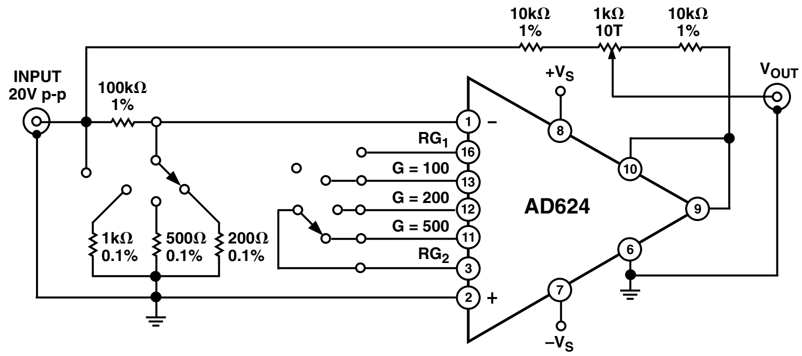


Figure 25. Settling Time Test Circuit

THEORY OF OPERATION

The AD624 is a monolithic instrumentation amplifier based on a modification of the classic three-op-amp instrumentation amplifier. Monolithic construction and laser-wafer-trimming allow the tight matching and tracking of circuit components and the high level of performance that this circuit architecture is capable of.

A preamp section (Q1–Q4) develops the programmed gain by the use of feedback concepts. Feedback from the outputs of A1 and A2 forces the collector currents of Q1–Q4 to be constant thereby impressing the input voltage across R_G.

The gain is set by choosing the value of R_G from the equation, Gain $= \dfrac{40\,k}{R_G} + 1$. The value of R_G also sets the transconductance of the input preamp stage increasing it asymptotically to the transconductance of the input transistors as R_G is reduced for larger gains. This has three important advantages. First, this approach allows the circuit to achieve a very high open loop gain of 3×10^8 at a programmed gain of 1000 thus reducing gain related errors to a negligible 3 ppm. Second, the gain bandwidth product which is determined by C3 or C4 and the input transconductance, reaches 25 MHz. Third, the input voltage noise reduces to a value determined by the collector current of the input transistors for an RTI noise of 4 nV/$\sqrt{Hz}$ at G ≥ 500.

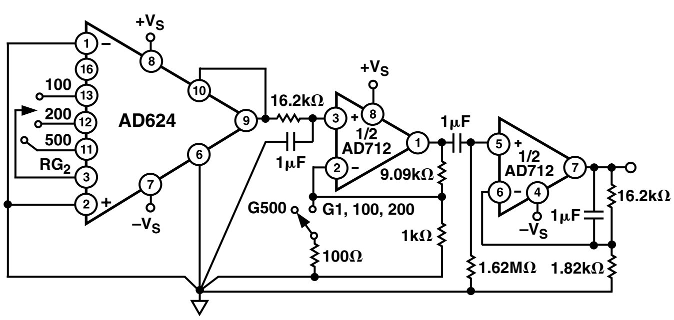


Figure 26. Noise Test Circuit

INPUT CONSIDERATIONS

Under input overload conditions the user will see R_G + 100 Ω and two diode drops (~1.2 V) between the plus and minus inputs, in either direction. If safe overload current under all conditions is assumed to be 10 mA, the maximum overload voltage is ~ ±2.5 V. While the AD624 can withstand this continuously, momentary overloads of ±10 V will not harm the device. On the other hand the inputs should never exceed the supply voltage.

The AD524 should be considered in applications that require protection from severe input overload. If this is not possible, external protection resistors can be put in series with the inputs of the AD624 to augment the internal (50 Ω) protection resistors. This will most seriously degrade the noise performance. For this reason the value of these resistors should be chosen to be as low as possible and still provide 10 mA of current limiting under maximum continuous overload conditions. In selecting the value of these resistors, the internal gain setting resistor and the 1.2 volt drop need to be considered. For example, to protect the device from a continuous differential overload of 20 V at a gain of 100, 1.9 kΩ of resistance is required. The internal gain resistor is 404 Ω; the internal protect resistor is 100 Ω. There is a 1.2 V drop across D1 or D2 and the base-emitter junction of either Q1 and Q3 or Q2 and Q4 as shown in Figure 27, 1400 Ω of external resistance would be required (700 Ω in series with each input). The RTI noise in this case would be

$$\sqrt{4\,KTR_{ext} + (4\,nV/\sqrt{Hz})^2} = 6.2\,nV/\sqrt{Hz}$$

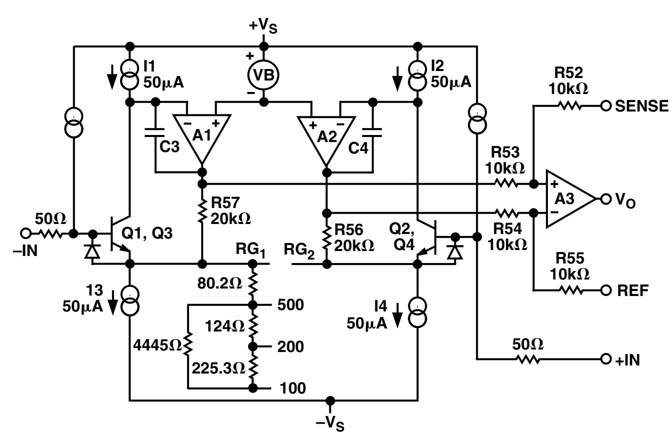


Figure 27. Simplified Circuit of Amplifier; Gain Is Defined as (R56 + R57)/(R_G) + 1. For a Gain of 1, R_G Is an Open Circuit.

INPUT OFFSET AND OUTPUT OFFSET

Voltage offset specifications are often considered a figure of merit for instrumentation amplifiers. While initial offset may be adjusted to zero, shifts in offset voltage due to temperature variations will cause errors. Intelligent systems can often correct for this factor with an autozero cycle, but there are many small-signal high-gain applications that don't have this capability.

Voltage offset and offset drift each have two components; input and output. Input offset is that component of offset that is directly proportional to gain i.e., input offset as measured at the output at G = 100 is 100 times greater than at G = 1. Output offset is independent of gain. At low gains, output offset drift is dominant, while at high gains input offset drift dominates. Therefore, the output offset voltage drift is normally specified as drift at G = 1 (where input effects are insignificant), while input offset voltage drift is given by drift specification at a high gain (where output offset effects are negligible). All input-related numbers are referred to the input (RTI) which is to say that the effect on the output is "G" times larger. Voltage offset vs. power supply is also specified at one or more gain settings and is also RTI.

By separating these errors, one can evaluate the total error independent of the gain setting used. In a given gain configuration both errors can be combined to give a total error referred to the input (R.T.I.) or output (R.T.O.) by the following formula:

Total Error R.T.I. = input error + (output error/gain)

Total Error R.T.O. = (Gain × input error) + output error

As an illustration, a typical AD624 might have a +250 µV output offset and a –50 µV input offset. In a unity gain configuration, the *total* output offset would be 200 µV or the sum of the two. At a gain of 100, the output offset would be –4.75 mV or: +250 µV + 100 (–50 µV) = –4.75 mV.

The AD624 provides for both input and output offset adjustment. This optimizes nulling in very high precision applications and minimizes offset voltage effects in switched gain applications. In such applications the input offset is adjusted first at the highest programmed gain, then the output offset is adjusted at G = 1.

GAIN

The AD624 includes high accuracy pretrimmed internal gain resistors. These allow for single connection programming of gains of 1, 100, 200 and 500. Additionally, a variety of gains including a pretrimmed gain of 1000 can be achieved through series and parallel combinations of the internal resistors. Table I shows the available gains and the appropriate pin connections and gain temperature coefficients.

The gain values achieved via the combination of internal resistors are extremely useful. The temperature coefficient of the gain is dependent primarily on the mismatch of the temperature coefficients of the various internal resistors. Tracking of these resistors is extremely tight resulting in the low gain TCs shown in Table I.

If the desired value of gain is not attainable using the internal resistors, a single external resistor can be used to achieve any gain between 1 and 10,000. This resistor connected between

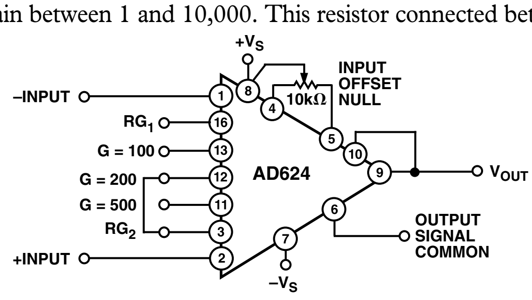


Figure 28. Operating Connections for G = 200

Table I.

Gain (Nominal)	Temperature Coefficient (Nominal)	Pin 3 to Pin	Connect Pins
1	–0 ppm/°C	–	–
100	–1.5 ppm/°C	13	–
125	–5 ppm/°C	13	11 to 16
137	–5.5 ppm/°C	13	11 to 12
186.5	–6.5 ppm/°C	13	11 to 12 to 16
200	–3.5 ppm/°C	12	–
250	–5.5 ppm/°C	12	11 to 13
333	–15 ppm/°C	12	11 to 16
375	–0.5 ppm/°C	12	13 to 16
500	–10 ppm/°C	11	–
624	–5 ppm/°C	11	13 to 16
688	–1.5 ppm/°C	11	11 to 12; 13 to 16
831	+4 ppm/°C	11	16 to 12
1000	0 ppm/°C	11	16 to 12; 13 to 11

Pins 3 and 16 programs the gain according to the formula

$$R_G = \frac{40k}{G-1}$$

(see Figure 29). For best results R_G should be a precision resistor with a low temperature coefficient. An external R_G affects both gain accuracy and gain drift due to the mismatch between it and the internal thin-film resistors R56 and R57. Gain accuracy is determined by the tolerance of the external R_G and the absolute accuracy of the internal resistors (±20%). Gain drift is determined by the mismatch of the temperature coefficient of R_G and the temperature coefficient of the internal resistors (–15 ppm/°C typ), and the temperature coefficient of the internal interconnections.

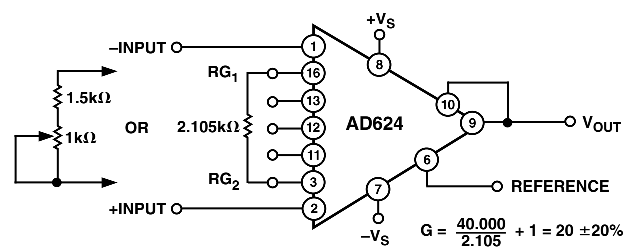


Figure 29. Operating Connections for G = 20

The AD624 may also be configured to provide gain in the output stage. Figure 30 shows an H pad attenuator connected to the reference and sense lines of the AD624. The values of R1, R2 and R3 should be selected to be as low as possible to minimize the gain variation and reduction of CMRR. Varying R2 will precisely set the gain without affecting CMRR. CMRR is determined by the match of R1 and R3.

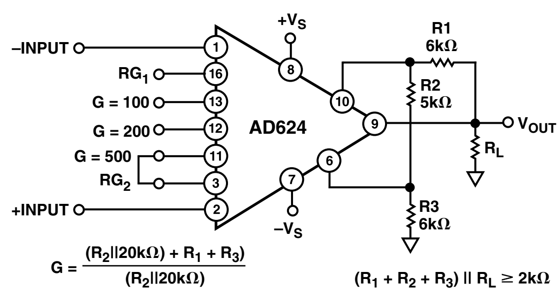


Figure 30. Gain of 2500

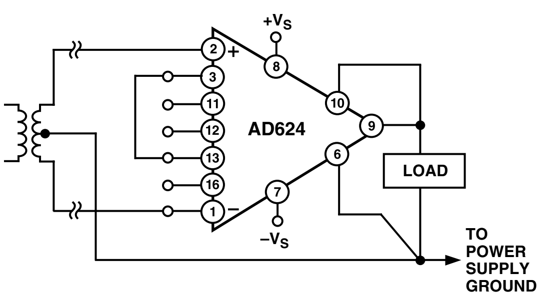
NOISE

The AD624 is designed to provide noise performance near the theoretical noise floor. This is an extremely important design criteria as the front end noise of an instrumentation amplifier is the ultimate limitation on the resolution of the data acquisition system it is being used in. There are two sources of noise in an instrument amplifier, the input noise, predominantly generated by the differential input stage, and the output noise, generated by the output amplifier. Both of these components are present at the input (and output) of the instrumentation amplifier. At the input, the input noise will appear unaltered; the output noise will be attenuated by the closed loop gain (at the output, the output noise will be unaltered; the input noise will be amplified by the closed loop gain). Those two noise sources must be root sum squared to determine the total noise level expected at the input (or output).

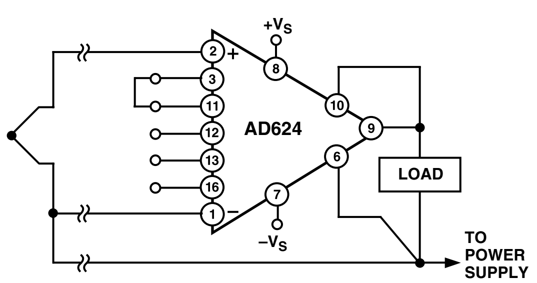
The low frequency (0.1 Hz to 10 Hz) voltage noise due to the output stage is 10 μV p-p, the contribution of the input stage is 0.2 μV p-p. At a gain of 10, the RTI voltage noise would be 1 μV p-p, $\sqrt{\left(\frac{10}{G}\right)^2 + \left(0.2\right)^2}$. The RTO voltage noise would be 10.2 μV p-p, $\sqrt{10^2 + \left(0.2(G)\right)^2}$. These calculations hold for applications using either internal or external gain resistors.

INPUT BIAS CURRENTS

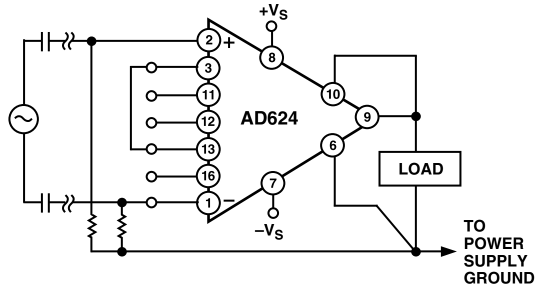
Input bias currents are those currents necessary to bias the input transistors of a dc amplifier. Bias currents are an additional source of input error and must be considered in a total error budget. The bias currents when multiplied by the source resistance imbalance appear as an additional offset voltage. (What is of concern in calculating bias current errors is the change in bias current with respect to signal voltage and temperature.) Input offset current is the difference between the two input bias currents. The effect of offset current is an input offset voltage whose magnitude is the offset current times the source resistance.



a. Transformer Coupled



b. Thermocouple



c. AC-Coupled

Figure 31. Indirect Ground Returns for Bias Currents

Although instrumentation amplifiers have differential inputs, there must be a return path for the bias currents. If this is not provided, those currents will charge stray capacitances, causing the output to drift uncontrollably or to saturate. Therefore, when amplifying "floating" input sources such as transformers and thermocouples, as well as ac-coupled sources, there must still be a dc path from each input to ground, (see Figure 31).

COMMON-MODE REJECTION

Common-mode rejection 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. "Common-Mode Rejection Ratio" (CMRR) is a ratio expression while "Common-Mode Rejection" (CMR) is the logarithm of that ratio. For example, a CMRR of 10,000 corresponds to a CMR of 80 dB.

In an instrumentation amplifier, ac common-mode rejection is only as good as the differential phase shift. Degradation of ac common-mode rejection is caused by unequal drops across differing track resistances and a differential phase shift due to varied stray capacitances or cable capacitances. In many applications shielded cables are used to minimize noise. This technique can create common-mode rejection errors unless the shield is properly driven. Figures 32 and 33 shows active data guards which are configured to improve ac common-mode rejection by "bootstrapping" the capacitances of the input cabling, thus minimizing differential phase shift.

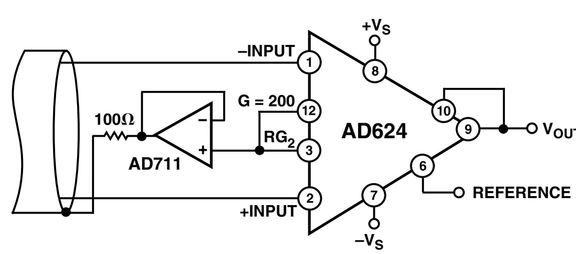


Figure 32. Shield Driver, G ≥ 100

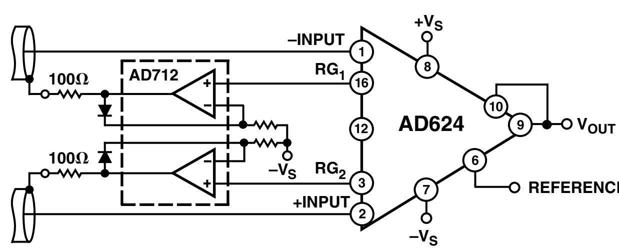


Figure 33. Differential Shield Driver

GROUNDING

Many data-acquisition components have two or more ground pins which are not connected together within the device. These grounds must be tied together at one point, usually at the system power supply ground. Ideally, a single solid ground would be desirable. However, since current flows through the ground wires and etch stripes of the circuit cards, and since these paths have resistance and inductance, hundreds of millivolts can be generated between the system ground point and the data acquisition components. Separate ground returns should be provided to minimize the current flow in the path from the most sensitive points to the system ground point. In this way supply currents and logic-gate return currents are not summed into the same return path as analog signals where they would cause measurement errors (see Figure 34).

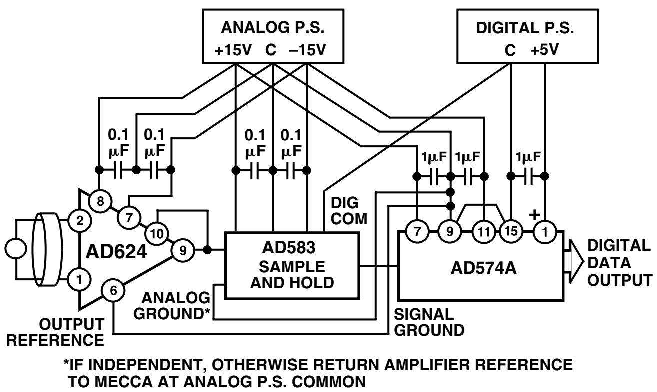


Figure 34. Basic Grounding Practice

Since the output voltage is developed with respect to the potential on the reference terminal an instrumentation amplifier can solve many grounding problems.

SENSE TERMINAL

The sense terminal is the feedback point for the instrument amplifier's output amplifier. Normally it is connected to the instrument amplifier output. If heavy load currents are to be drawn through long leads, voltage drops due to current flowing through lead resistance can cause errors. The sense terminal can be wired to the instrument amplifier at the load thus putting the IxR drops "inside the loop" and virtually eliminating this error source.

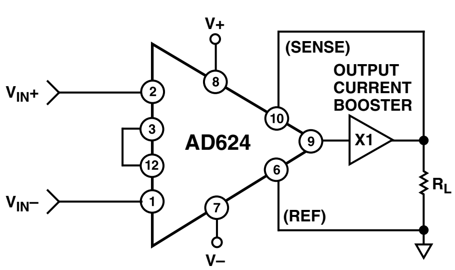


Figure 35. AD624 Instrumentation Amplifier with Output Current Booster

Typically, IC instrumentation amplifiers are rated for a full ±10 volt output swing into 2 kΩ. In some applications, however, the need exists to drive more current into heavier loads. Figure 35 shows how a current booster may be connected "inside the loop" of an instrumentation amplifier to provide the required current without significantly degrading overall performance. The effects of nonlinearities, offset and gain inaccuracies of the buffer are reduced by the loop gain of the IA output amplifier. Offset drift of the buffer is similarly reduced.

REFERENCE TERMINAL

The reference terminal may be used to offset the output by up to ±10 V. This is useful when the load is "floating" or does not share a ground with the rest of the system. It also provides a direct means of injecting a precise offset. It must be remembered that the total output swing is ±10 volts, from ground, to be shared between signal and reference offset.

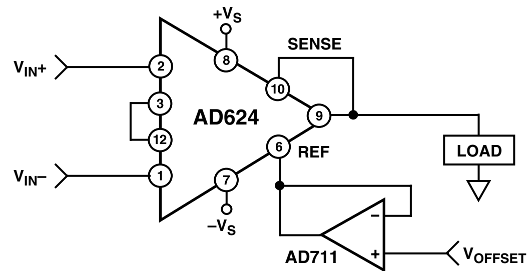


Figure 36. Use of Reference Terminal to Provide Output Offset

When the IA is of the three-amplifier configuration it is necessary that nearly zero impedance be presented to the reference terminal. Any significant resistance, including those caused by PC layouts or other connection techniques, which appears between the reference pin and ground will increase the gain of the noninverting signal path, thereby upsetting the common-mode rejection of the IA. Inadvertent thermocouple connections created in the sense and reference lines should also be avoided as they will directly affect the output offset voltage and output offset voltage drift.

In the AD624 a reference source resistance will unbalance the CMR trim by the ratio of 10 kΩ/R_{REF}. For example, if the reference source impedance is 1 Ω, CMR will be reduced to 80 dB (10 kΩ/1 Ω = 80 dB). An operational amplifier may be used to provide that low impedance reference point as shown in Figure 36. The input offset voltage characteristics of that amplifier will add directly to the output offset voltage performance of the instrumentation amplifier.

An instrumentation amplifier can be turned into a voltage-to-current converter by taking advantage of the sense and reference terminals as shown in Figure 37.

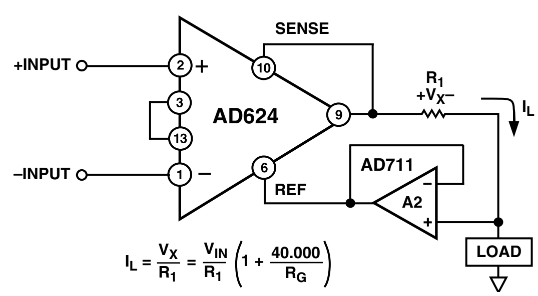


Figure 37. Voltage-to-Current Converter

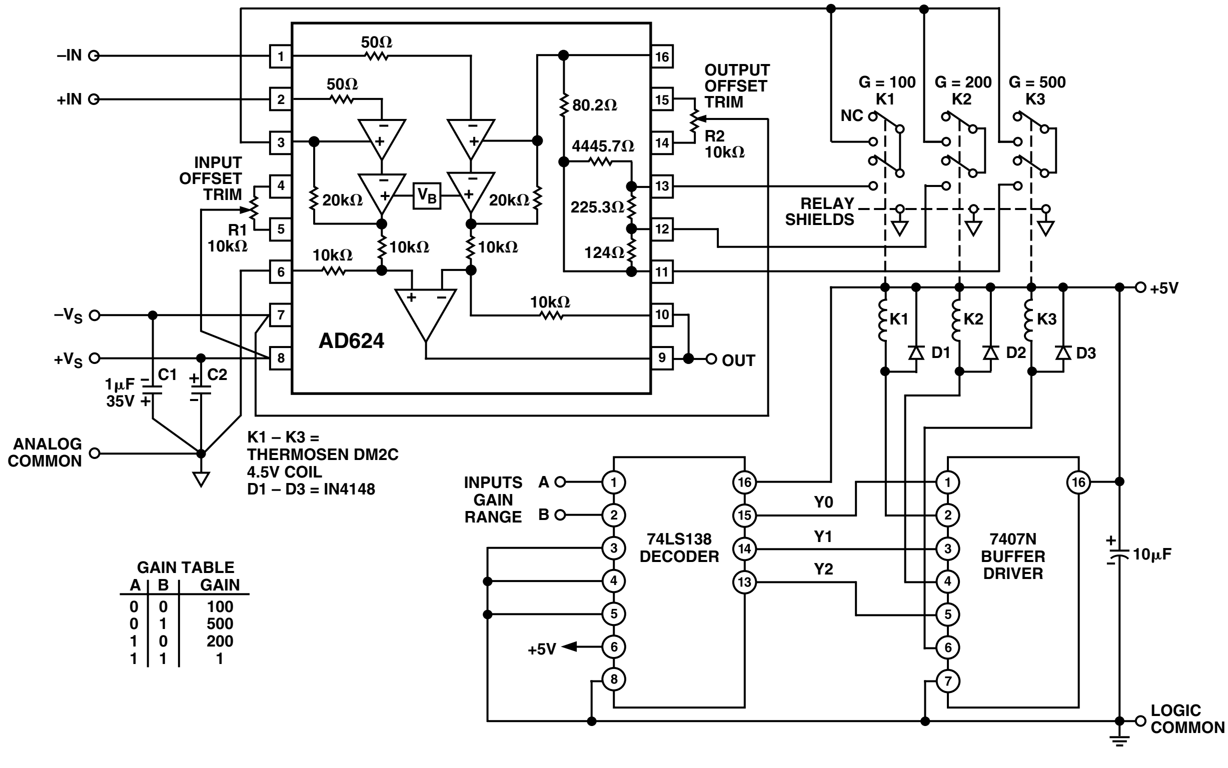


Figure 38. Gain Programmable Amplifier

By establishing a reference at the "low" side of a current setting resistor, an output current may be defined as a function of input voltage, gain and the value of that resistor. Since only a small current is demanded at the input of the buffer amplifier A2, the forced current I_L will largely flow through the load. Offset and drift specifications of A2 must be added to the output offset and drift specifications of the IA.

PROGRAMMABLE GAIN

Figure 38 shows the AD624 being used as a software programmable gain amplifier. Gain switching can be accomplished with mechanical switches such as DIP switches or reed relays. It should be noted that the "on" resistance of the switch in series with the internal gain resistor becomes part of the gain equation and will have an effect on gain accuracy.

A significant advantage in using the internal gain resistors in a programmable gain configuration is the minimization of thermocouple signals which are often present in multiplexed data acquisition systems.

If the full performance of the AD624 is to be achieved, the user must be extremely careful in designing and laying out his circuit to minimize the remaining thermocouple signals.

The AD624 can also be connected for gain in the output stage. Figure 39 shows an AD547 used as an active attenuator in the output amplifier's feedback loop. The active attenuation presents a very low impedance to the feedback resistors therefore minimizing the common-mode rejection ratio degradation.

Another method for developing the switching scheme is to use a DAC. The AD7528 dual DAC which acts essentially as a pair of switched resistive attenuators having high analog linearity and symmetrical bipolar transmission is ideal in this application. The multiplying DAC's advantage is that it can handle inputs of either polarity or zero without affecting the programmed gain. The circuit shown uses an AD7528 to set the gain (DAC A) and to perform a fine adjustment (DAC B).

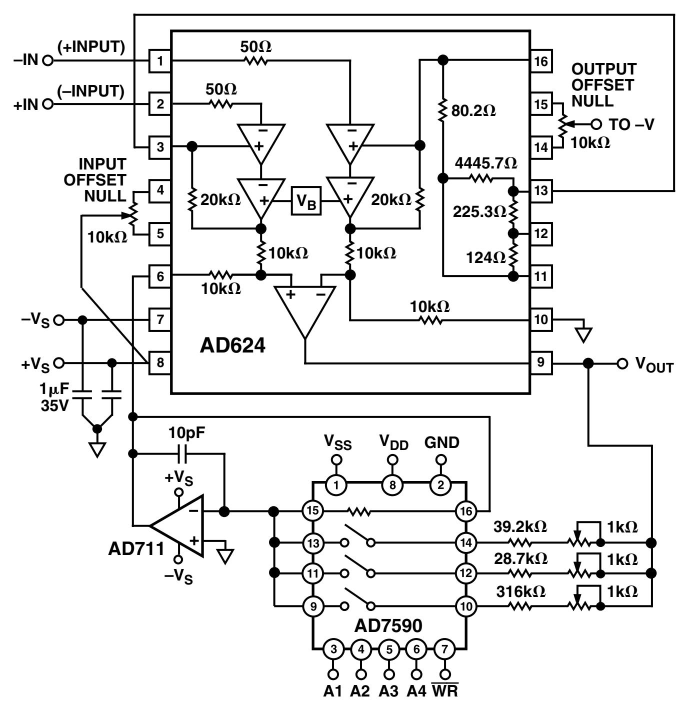


Figure 39. Programmable Output Gain

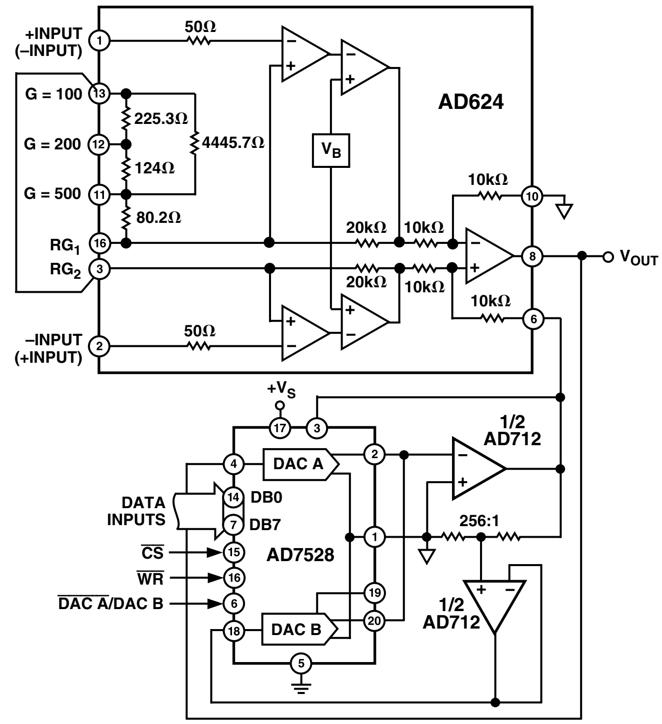


Figure 40. Programmable Output Gain Using a DAC

AUTOZERO CIRCUITS

In many applications it is necessary to provide very accurate data in high gain configurations. At room temperature the offset effects can be nulled by the use of offset trimpots. Over the operating temperature range, however, offset nulling becomes a problem. The circuit of Figure 41 shows a CMOS DAC operating in the bipolar mode and connected to the reference terminal to provide software controllable offset adjustments.

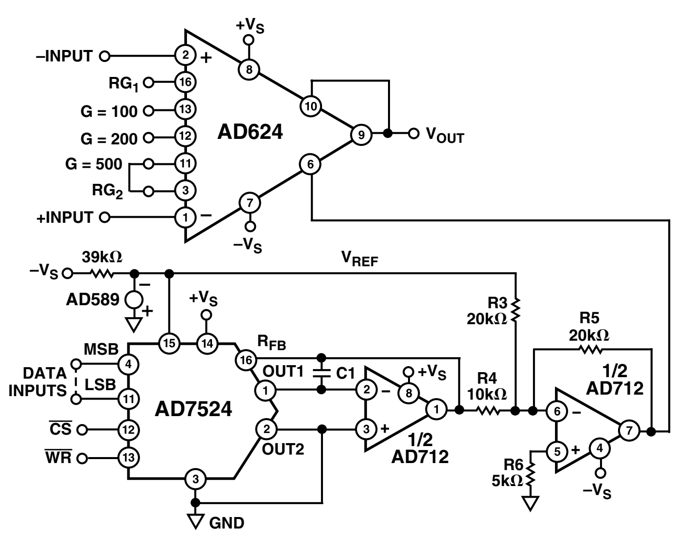


Figure 41. Software Controllable Offset

In many applications complex software algorithms for autozero applications are not available. For these applications Figure 42 provides a hardware solution.

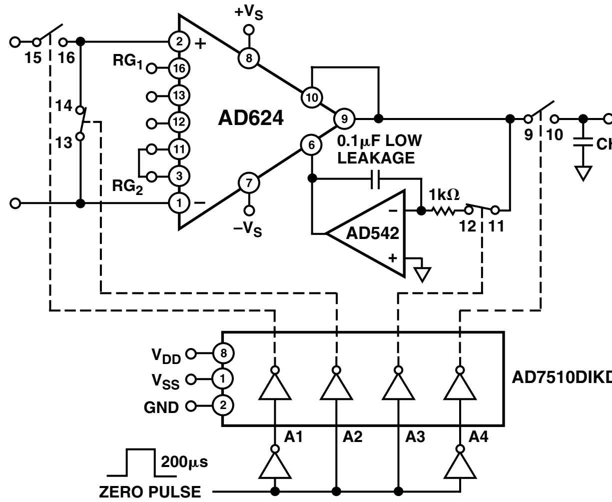


Figure 42. Autozero Circuit

The microprocessor controlled data acquisition system shown in Figure 43 includes includes both autozero and autogain capability. By dedicating two of the differential inputs, one to ground and one to the A/D reference, the proper program calibration cycles can eliminate both initial accuracy errors and accuracy errors over temperature. The autozero cycle, in this application, converts a number that appears to be ground and then writes that same number (8 bit) to the AD624 which eliminates the zero error since its output has an inverted scale. The autogain cycle converts the A/D reference and compares it with full scale. A multiplicative correction factor is then computed and applied to subsequent readings.

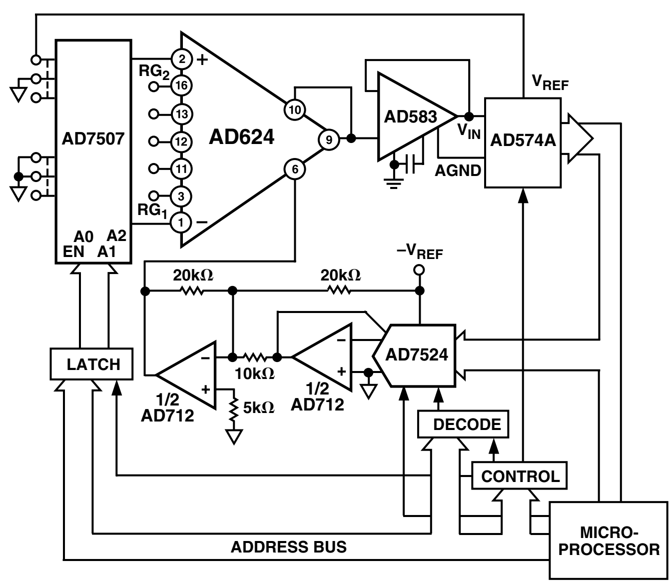
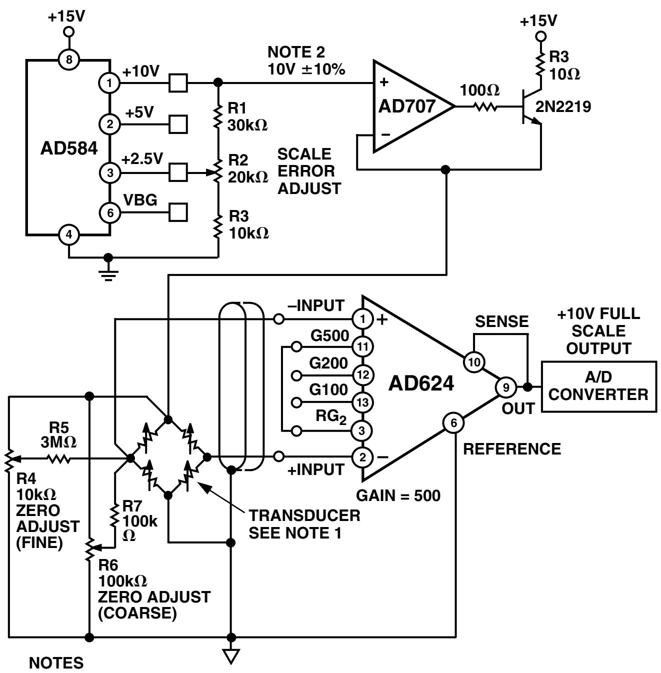


Figure 43. Microprocessor Controlled Data Acquisition System

WEIGH SCALE

Figure 44 shows an example of how an AD624 can be used to condition the differential output voltage from a load cell. The 10% reference voltage adjustment range is required to accommodate the 10% transducer sensitivity tolerance. The high linearity and low noise of the AD624 make it ideal for use in applications of this type particularly where it is desirable to measure small changes in weight as opposed to the absolute value. The addition of an autogain/autotare cycle will enable the system to remove offsets, gain errors, and drifts making possible true 14-bit performance.



NOTES
1. LOAD CELL TEDEA MODEL 1010 10kG. OUTPUT 2mV/V±10%.
2. R1, R2 AND R3 SELECTED FOR AD584. OUTPUT 10V ±10%.

Figure 44. AD624 Weigh Scale Application

AC BRIDGE

Bridge circuits which use dc excitation are often plagued by errors caused by thermocouple effects, l/f noise, dc drifts in the electronics, and line noise pickup. One way to get around these problems is to excite the bridge with an ac waveform, amplify the bridge output with an ac amplifier, and synchronously demodulate the resulting signal. The ac phase and amplitude information from the bridge is recovered as a dc signal at the output of the synchronous demodulator. The low frequency system noise, dc drifts, and demodulator noise all get mixed to the carrier frequency and can be removed by means of a low-pass filter. Dynamic response of the bridge must be traded off against the amount of attenuation required to adequately suppress these residual carrier components in the selection of the filter.

Figure 45 is an example of an ac bridge system with the AD630 used as a synchronous demodulator. The oscilloscope photograph shows the results of a 0.05% bridge imbalance caused by the 1 Meg resistor in parallel with one leg of the bridge. The top trace represents the bridge excitation, the upper middle trace is the amplified bridge output, the lower-middle trace is the output of the synchronous demodulator and the bottom trace is the filtered dc system output.

This system can easily resolve a 0.5 ppm change in bridge impedance. Such a change will produce a 6.3 mV change in the low-pass filtered dc output, well above the RTO drifts and noise.

The AC-CMRR of the AD624 decreases with the frequency of the input signal. This is due mainly to the package-pin capacitance associated with the AD624's internal gain resistors. If AC-CMRR is not sufficient for a given application, it can be trimmed by using a variable capacitor connected to the amplifier's RG_2 pin as shown in Figure 45.

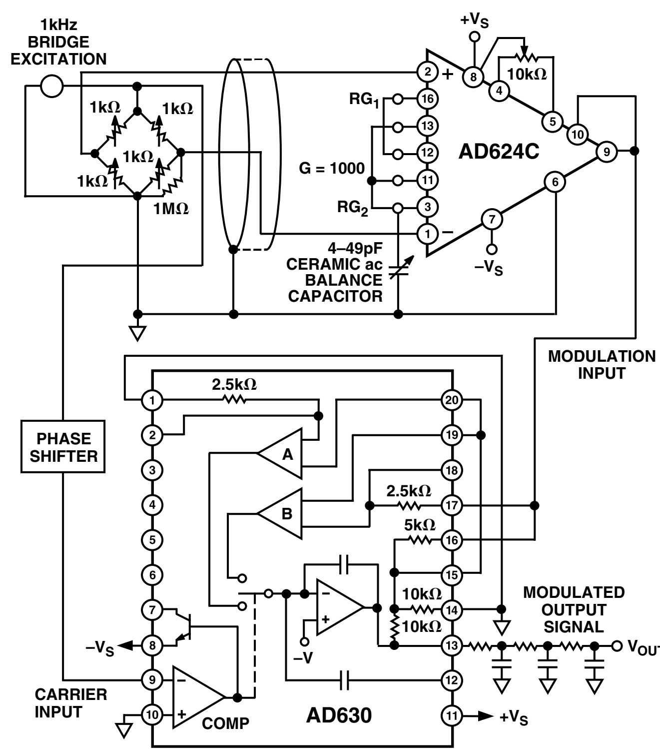


Figure 45. AC Bridge

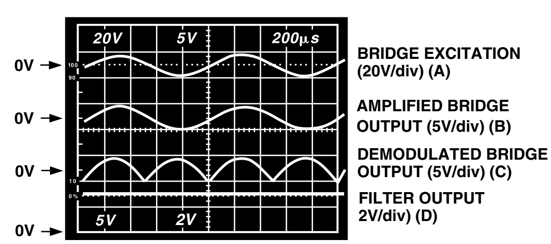


Figure 46. AC Bridge Waveforms

ERROR BUDGET ANALYSIS

To illustrate how instrumentation amplifier specifications are applied, we will now examine a typical case where an AD624 is required to amplify the output of an unbalanced transducer. Figure 47 shows a differential transducer, unbalanced by ≈5 Ω, supplying a 0 to 20 mV signal to an AD624C. The output of the IA feeds a 14-bit A to D converter with a 0 to 2 volt input voltage range. The operating temperature range is –25°C to +85°C. Therefore, the largest change in temperature ΔT within the operating range is from ambient to +85°C (85°C – 25°C = 60°C.)

In many applications, differential linearity and resolution are of prime importance. This would be so in cases where the absolute value of a variable is less important than changes in value. In these applications, only the irreducible errors (20 ppm = 0.002%) are significant. Furthermore, if a system has an intelligent processor monitoring the A to D output, the addition of an autogain/autozero cycle will remove all reducible errors and may eliminate the requirement for initial calibration. This will also reduce errors to 0.002%.

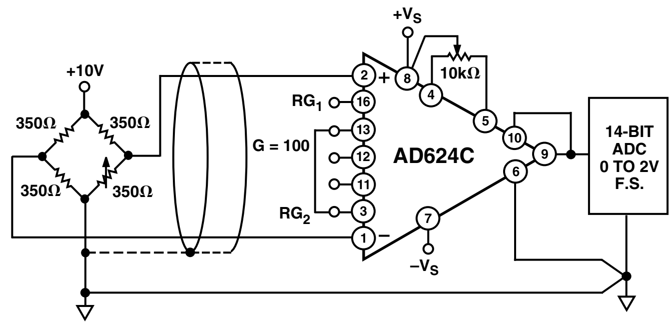


Figure 47. Typical Bridge Application

Table II. Error Budget Analysis of AD624CD in Bridge Application

Error Source	AD624C Specifications	Calculation	Effect on Absolute Accuracy at T_A = +25°C	Effect on Absolute Accuracy at T_A = +85°C	Effect on Resolution
Gain Error	±0.1%	±0.1% = 1000 ppm	1000 ppm	1000 ppm	–
Gain Instability	10 ppm	(10 ppm/°C) (60°C) = 600 ppm	–	600 ppm	–
Gain Nonlinearity	±0.001%	±0.001% = 10 ppm	–	–	10 ppm
Input Offset Voltage	±25 µV, RTI	±25 µV/20 mV = ±1250 ppm	1250 ppm	1250 ppm	–
Input Offset Voltage Drift	±0.25 µV/°C	(±0.25 µV/°C) (60°C)= 15 µV 15 µV/20 mV = 750 ppm	–	750 ppm	–
Output Offset Voltage[1]	±2.0 mV	±2.0 mV/20 mV = 1000 ppm	1000 ppm	1000 ppm	–
Output Offset Voltage Drift[1]	±10 µV/°C	(±10 µV/°C) (60°C) = 600 µV 600 µV/20 mV = 300 ppm	–	300 ppm	–
Bias Current–Source Imbalance Error	±15 nA	(±15 nA)(5 Ω) = 0.075 µV 0.075 µV/20mV = 3.75 ppm	3.75 ppm	3.75 ppm	–
Offset Current–Source Imbalance Error	±10 nA	(±10 nA)(5 Ω) = 0.050 µV 0.050 µV/20 mV = 2.5 ppm	2.5 ppm	2.5 ppm	–
Offset Current–Source Resistance Error	±10 nA	(10 nA) (175 Ω) = 1.75 µV 1.75 µV/20 mV = 87.5 ppm	87.5 ppm	87.5 ppm	–
Offset Current–Source Resistance–Drift	±100 pA/°C	(100 pA/°C) (175 Ω) (60°C) = 1 µV 1 µV/20 mV = 50 ppm	–	50 ppm	–
Common-Mode Rejection 5 V dc	115 dB	115 dB = 1.8 ppm × 5 V = 9 µV 9 µV/20 mV = 444 ppm	450 ppm	450 ppm	–
Noise, RTI (0.1 Hz–10 Hz)	0.22 µV p-p	0.22 µV p-p/20 mV = 10 ppm	–	–	10 ppm
		Total Error	3793.75 ppm	5493.75 ppm	20 ppm

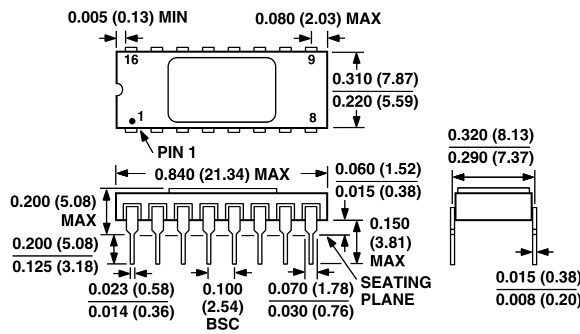
NOTE
[1]Output offset voltage and output offset voltage drift are given as RTI figures.

For a comprehensive study of instrumentation amplifier design and applications, refer to the *Instrumentation Amplifier Application Guide*, available free from Analog Devices.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

Side-Brazed Solder Lid Ceramic DIP (D-16)



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Low-Cost E Series Multifunction DAQ – 12 or 16-Bit, 200 kS/s, 16 Analog Inputs

NI E Series – Low-Cost

- 16 analog inputs at up to 200 kS/s, 12 or 16-bit resolution
- Up to 2 analog outputs at 10 kS/s, 12 or 16-bit resolution
- 8 digital I/O lines (TTL/CMOS); two 24-bit counter/timers
- Digital triggering
- 4 analog input signal ranges
- NI-DAQ driver that simplifies configuration and measurements

Families

- NI 6036E
- NI 6034E
- NI 6025E
- NI 6024E
- NI 6023E

Operating Systems

- Windows 2000/NT/XP
- Real-time performance with LabVIEW
- Others such as Linux® and Mac OS X

Recommended Software

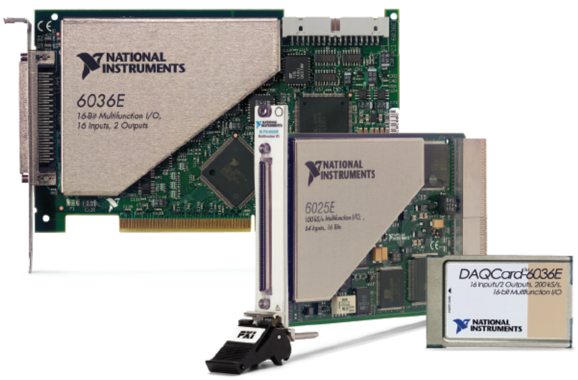
- LabVIEW
- LabWindows/CVI
- Measurement Studio
- VI Logger

Other Compatible Software

- Visual Basic, C/C++, and C#

Driver Software (included)

- NI-DAQ 7



Family	Bus	Analog Inputs	Input Resolution	Max Sampling Rate	Input Range	Analog Outputs	Output Resolution	Output Rate	Output Range	Digital I/O	Counter/Timers	Triggers
NI 6036E	PCI, PCMCIA	16 SE/8 DI	16 bits	200 kS/s	±0.05 to ±10 V	2	16 bits	10 kS/s[1]	±10 V	8	2, 24-bit	Digital
NI 6034E	PCI	16 SE/8 DI	16 bits	200 kS/s	±0.05 to ±10 V	0	–	–	–	8	2, 24-bit	Digital
NI 6025E	PCI, PXI	16 SE/8 DI	12 bits	200 kS/s	±0.05 to ±10 V	2	12 bits	10 kS/s[1]	±10 V	8	2, 24-bit	Digital
NI 6024E	PCI, PCMCIA	16 SE/8 DI	12 bits	200 kS/s	±0.05 to ±10 V	2	12 bits	10 kS/s[1]	±10 V	8	2, 24-bit	Digital
NI 6023E	PCI	16 SE/8 DI	12 bits	200 kS/s	±0.05 to ±10 V	0	–	–	–	8	2, 24-bit	Digital

[1] 10 kS/s typical when using the single DMA channel for analog output. 1 kS/s maximum when using the single DMA channel for either analog input or counter/timer operations. 1 kS/s maximum for PCMCIA DAQCard devices in all cases.

Table 1. Low-Cost E Series Model Guide

Overview and Applications

National Instruments low-cost E Series multifunction data acquisition devices provide full functionality at a price to meet the needs of the budget-conscious user. They are ideal for applications ranging from continuous high-speed data logging to control applications to high-voltage signal or sensor measurements when used with NI signal conditioning. Synchronize the operations of multiple devices using the RTSI bus or PXI trigger bus to easily integrate other hardware such as motion control and machine vision to create an entire measurement and control system.

Highly Accurate Hardware Design

NI low-cost E Series DAQ devices include the following features and technologies:

Temperature Drift Protection Circuitry – Designed with components that minimize the effect of temperature changes on measurements to less than 0.0010% of reading/°C.

Resolution-Improvement Technologies – Carefully designed noise floor maximizes the resolution.

Onboard Self-Calibration – Precise voltage reference included for calibration and measurement accuracy. Self-calibration is completely software controlled, with no potentiometers to adjust.

NI DAQ-STC – Timing and control ASIC designed to provide more flexibility, lower power consumption, and a higher immunity to noise and jitter than off-the-shelf counter/timer chips.

NI MITE – ASIC designed to optimize data transfer for multiple simultaneous operations using bus mastering with one DMA channel, interrupts, or programmed I/O.

NI PGIA – Measurement and instrument class amplifier that guarantees settling times at all gains. Typical commercial off-the-shelf amplifier components do not meet the settling time requirements for high-gain measurement applications.

PFI Lines – Eight programmable function input (PFI) lines that you can use for software-controlled routing of interboard and intraboard digital and timing signals.

RTSI or PXI Trigger Bus – Bus used to share timing and control signals between two or more PCI or PXI devices to synchronize operations.

RSE Mode – In addition to differential and nonreferenced single-ended modes, NI low-cost E Series devices offer the referenced single-ended (RSE) mode for use with floating-signal sources in applications with channel counts higher than eight.

Onboard Temperature Sensor – Included for monitoring the operating temperature of the device to ensure that it is operating within the specified range.

		Full-Featured E Series				Low-Cost E Series		Basic
Models		NI 6030E, NI 6031E, NI 6032E, NI 6033E	NI 6052E	NI 6070E, NI 6071E	NI 6040E	NI 6034E, NI 6036E	NI 6023E, NI 6024E, NI 6025E	PCI-6013, PCI-6014
Measurement Sensitivity[1] (mV)		0.0023	0.0025	0.009	0.008	0.0036	0.008	0.004
Nominal Range (V)								
Positive FS	**Negative FS**	**Absolute Accuracy (mV)**						
10	-10	1.147	4.747	14.369	15.373	7.560	16.504	8.984
5	-5	2.077	0.876	5.193	5.697	1.790	5.263	2.003
2.5	-2.5	–	1.190	3.605	3.859	–	–	–
2	-2	0.836	–	–	–	–	–	–
1	-1	0.422	0.479	1.452	1.556	–	–	–
0.5	-0.5	0.215	0.243	0.735	0.789	0.399	0.846	0.471
0.25	-0.25	–	0.137	0.379	0.405	–	–	–
0.2	-0.2	0.102	–	–	–	–	–	–
0.1	-0.1	0.061	0.064	0.163	0.176	–	–	–
0.05	-0.05	–	0.035	0.091	0.100	0.0611	0.106	0.069
10	0	0.976	1.232	6.765	7.269	–	–	–
5	0	1.992	2.119	5.391	5.645	–	–	–
2	0	0.802	0.850	2.167	2.271	–	–	–
1	0	0.405	0.428	1.092	1.146	–	–	–
0.5	0	0.207	0.242	0.558	0.583	–	–	–
0.2	0	0.098	0.111	0.235	0.247	–	–	–
0.1	0	0.059	0.059	0.127	0.135	–	–	–

Note: Accuracies are valid for measurements following an internal calibration. Measurement accuracies are listed for operational temperatures within ±1 °C of internal calibration temperature and ±10 °C of external or factory-calibration temperature. One-year calibration interval recommended. The Absolute Accuracy at Full Scale calculations were performed for a maximum range input voltage (for example, 10 V for the ±10 V range) after one year, assuming 100 pt averaging of data.

[1]Smallest detectable voltage change in the input signal at the smallest input range.

Table 2. E Series Analog Input Absolute Accuracy Specifications

		Full-Featured E Series				Low-Cost E Series		Basic
Models		NI 6030E, NI 6031E, NI 6032E, NI 6033E	NI 6052E	NI 6070E, NI 6071E	NI 6040E	NI 6034E, NI 6036E	NI 6023E, NI 6024E, NI 6025E	PCI-6013, PCI-6014
Nominal Range (V)								
Positive FS	**Negative FS**	**Absolute Accuracy (mV)**						
10	-10	1.430	1.405	8.127	8.127	2.417	8.127	3.835
10	0	1.201	1.176	5.685	5.685	–	–	–

Table 3. E Series Analog Output Absolute Accuracy Specifications

High-Performance, Easy-to-Use Driver Software

NI-DAQ is the robust driver software that makes it easy to access the functionality of your data acquisition hardware, whether you are a beginning or advanced user. Helpful features include:

Automatic Code Generation – DAQ Assistant is an interactive guide that steps you through configuring, testing, and programming measurement tasks and generates the necessary code automatically for NI LabVIEW, LabWindows/CVI, or Measurement Studio.

Cleaner Code Development – Basic and advanced software functions have been combined into one easy-to-use yet powerful set to help you build cleaner code and move from basic to advanced applications without replacing functions.

High-Performance Driver Engine – Software-timed single-point input (typically used in control loops) with NI-DAQ achieves rates of up to 50 kHz. NI-DAQ also delivers maximum I/O system throughput with a multithreaded driver.

Test Panels – With NI-DAQ, you can test all of your device functionality before you begin development.

Scaled Channels – Easily scale your voltage data into the proper engineering units using the NI-DAQ Measurement Ready virtual channels by choosing from a list of common sensors and signals or creating your own custom scale.

LabVIEW Integration – All NI-DAQ functions create the waveform data type, which carries acquired data and timing information directly into more than 400 LabVIEW built-in analysis routines for display of results in engineering units on a graph.

For information on applicable hardware for NI-DAQ 7, visit ni.com/dataacquisition.

Visit ni.com/oem for quantity discount information.

Recommended Accessories

Signal conditioning is required for sensor measurements or voltage inputs greater than 10 V. National Instruments SCXI is a versatile, high-performance signal conditioning platform, intended for high-channel-count applications. NI SCC products provide portable, flexible signal conditioning options on a per-channel basis. Both signal conditioning platforms are designed to increase the performance and reliability of your DAQ system, and are up to 10 times more accurate than terminal blocks (please visit **ni.com/sigcon** for more details). Refer to the table below for more information:

Sensor/Signals (>10 V)

System Description	DAQ Device	Signal Conditioning
High-performance	PCI-60xxE, PXI-60xxE, DAQCard-60xxE	SCXI
Low-cost, portable	PCI-60xxE, PXI-60xxE, DAQCard-60xxE	SCC

Signals (<10 V)[1]

System Description	DAQ Device	Terminal Block	Cable
Shielded	PCI-60xxE	SCB-68	SH6868-EP
Shielded	PXI-60xxE	TB-2705	SH6868-EP
Shielded	DAQCard-60xxE	SCB-68	SHC6868-EP
Low-cost	PCI-6025E/PXI-6025E	Two TBX-68s	SH1006868
Low-cost	PCI-60xxE/PXI-60xxE	CB-68LP	R6868
Low-cost	DAQCard-60xxE	CB-68LP	RC6868

[1]Terminal blocks do not provide signal conditioning (i.e., filtering, amplification, isolation, and so on), which may be necessary to increase the accuracy of your measurements.

Table 4. Recommended Accessories

Ordering Information

PCI

NI PCI-6036E 778465-01
NI PCI-6034E 778075-01
NI PCI-6025E 777744-01
NI PCI-6024E 777743-01
NI PCI-6023E 777742-01

PCMCIA

NI DAQCard-6036E 778561-01
NI DAQCard-6024E 778269-01

PXI

NI PXI-6025E 777798-01

Includes NI-DAQ driver software.

BUY NOW!

For complete product specifications, pricing, and accessory information, call (800) 813 3693 (U.S.) or go to **ni.com/dataacquisition**.

NI Services and Support

NI has the services and support to meet your needs around the globe and through the application life cycle – from planning and development through deployment and ongoing maintenance. We offer services and service levels to meet customer requirements in research, design, validation, and manufacturing. Visit **ni.com/services**.

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NI training is the fastest, most certain route to productivity with our products. NI training can shorten your learning curve, save development time, and reduce maintenance costs over the application life cycle. We schedule instructor-led courses in cities worldwide, or we can hold a course at your facility. We also offer a professional certification program that identifies individuals who have high levels of skill and knowledge on using NI products. Visit **ni.com/training**.

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In offices worldwide, our staff is local to the country, giving you access to engineers who speak your language. NI delivers industry-leading technical support through online knowledge bases, our applications engineers, and access to 14,000 measurement and automation professionals within NI Developer Exchange forums. Find immediate answers to your questions at **ni.com/support**.

We also offer service programs that provide automatic upgrades to your application development environment and higher levels of technical support. Visit **ni.com/ssp**.

Hardware Services

NI Factory Installation Services

NI Factory Installation Services (FIS) is the fastest and easiest way to use your PXI or PXI/SCXI combination systems right out of the box. Trained NI technicians install the software and hardware and configure the system to your specifications. NI extends the standard warranty by one year on hardware components (controllers, chassis, modules) purchased with FIS. To use FIS, simply configure your system online with **ni.com/pxiadvisor**.

Calibration Services

NI recognizes the need to maintain properly calibrated devices for high-accuracy measurements. We provide manual calibration procedures, services to recalibrate your products, and automated calibration software specifically designed for use by metrology laboratories. Visit **ni.com/calibration**.

Repair and Extended Warranty

NI provides complete repair services for our products. Express repair and advance replacement services are also available. We offer extended warranties to help you meet project life-cycle requirements. Visit **ni.com/services**.

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