A LIE DETECTOR

By

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FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

December 2005

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Norhidayah Ahmad Sobri

ABSTRACT

This project is about a lie detector and how it can respond to the physiological reaction in human body. Basically there are three different systems which will react to the physiological changes. The first system use to sense the changes due to human electrical skin resistance. As people are exposing to the stress situation, it is believe that they will sweat more especially between fingers and palm. This will cause skin resistance to become low than normal. Dry skin is said to have a resistance in Mega Ohm while for the moist skin, the resistive value might be in the range of few Kilo Ohm. Simple circuit act as a skin resistance sensor is implemented by using a voltage comparator. Based on the physiological changes, heart rate will be faster than normal when people are under stress and so do the blood pressure. According to the human biological, normal heart rate is stated as 75 beats per minute (bpm) while blood pressure is 120/80 mmHg. During the study, it is realized that both of the systems (heart rate monitoring and blood pressure monitoring system) are possible to use the same circuit for monitoring or even measuring purposes. This is because, variations in both the heart rate and the blood cause expansion and contraction of the arteries and veins throughout the body. So, the second system design is to detect both parameters by using only one device. As the heart beat increases as well as the blood pressure, the value for respiration rate also increases proportionally as we breathe faster because there are more oxygen needed as the heart pumps the blood faster.

ACKNOWLEDGEMENTS

First and foremost, thanks to Allah, The Most Merciful as without His guidance and blessings, the author would not be able to finish this project. The author wish to express an appreciation to the supervisor, Pn Salina bt Mohmad for patiently guiding and share the idea with the author throughout the process of completing this project. The kindness and cooperation given for these two semesters are highly appreciated. The author would also like to thanks Dr Nazir Ahmed, a sudden supervisor who has been very kind to supervise and share his knowledge in order to complete the project.

An acknowledge appreciation also goes to Ms Nasreen Badruddin as the coordinator of Final Year Project and not forgetting the other lecturers as well for their management and coordination.

The author also would like to express a deepest appreciation towards Miss Siti Hawa Tahir, the lab technician for being so helpful and share all the knowledge with the author during these two semesters. Last but not least, thank you very much to all the author friends for being so helpful of sharing the ideas, knowledge and understanding to accomplish this Final Year Project.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background

In our daily life, people tell lies and deceive others for many reasons. Some people might think deception is one of their hobbies and a fun activity to do. Lying is a common defense mechanism used to avoid trouble with the law, bosses or authority figures. Somehow, there is a job which required people to tell lies. For example, we always claimed spies as the world's best liars. Sometimes in whatever condition, people can easily detect when the other people is lying but at other times it maybe not.

John Larson, a University of California medical student invented the modern lie detector in 1921. The theory is that when a person lies, it causes a certain amount of stress that result in several involuntary physiological reactions. Despite, its nickname, it does not detect lies but can only detect whether deceptive behavior is being displayed during a test [1].

Since centuries ago, polygraphs are used as a lie detector which can monitor a person's physiological reactions. Based on the understanding about physiology, there is a changed in human body when they are facing great stress or depression. These changes are called physiological reactions. Basically, polygraph only detects about four changes that occurred, which are electro-dermal activity or electrical skin resistance, heart rate, blood pressure and respiratory rate.

1.2 Problem Statement

For crime cases or even in daily life, it is very difficult for us to detect when a person is lying. Usually, when a person deceives other person, the body will undergo a specific circumstance which is called a physiological reaction due to the stress that they faced. These give great changes to the pulse rate (heart beats), blood pressure, respiratory rate and how much the hands perspire (sweating). These four changes can be used as references to detect lie.

In the market today, the common device used is a polygraph. This old fashion device can measure all the four changes but this equipment somehow is too big, complicated and expensive with a computer connected to it to display the results. Therefore, based on the overall view of a few problems stated earlier, the main purpose of this study is to make a concise research on enhancing the features of a lie detector.

1.3 Objective and Scope of Study

The main objective of this project is to enhance the features of a lie detector. It is required to come out with a simple and small device which can replace the present lie detector.

Perhaps, this device can be used for various purposes such as in monitoring and measuring the blood pressure and heart rate and not only to detect lies. Furthermore, it is also can be used by different group of users such as individual, in business environment as well as in crime investigation by the police and also the military.

As for the main scope, the study is needed to be carried out about the physiological reactions in the human body when they tell lies (in stress condition). The physiological reactions will cover four main changes in the body which are electro-dermal activity or electrical skin resistance, heart rate, blood pressure changes and respiration rate.

CHAPTER 2
LITERATURE REVIEW

The idea that lying could be identified in recordings of physiological phenomena apparently originated by an Italian named Lombroso [2], who discovered that blood pressure and heart rate will increase during lying.

Since it is invented, the most common lie detector that had been used is called a polygraph. In fact, polygraph examinations are designed to look for the responses going on in a person's body when that person is subjected to stress, such as the stress that deal with deception. According to polygrapher, Dr. Bob Lee, the exams are not able to specifically detect if a person is lying. But there are certain physiological responses that most of the people undergo when attempting to deceive another person. For many years, polygraphs are the instruments with little needles scribbling lines on a single strip of scroll paper as in **Figure 1**. These are called analog polygraphs.

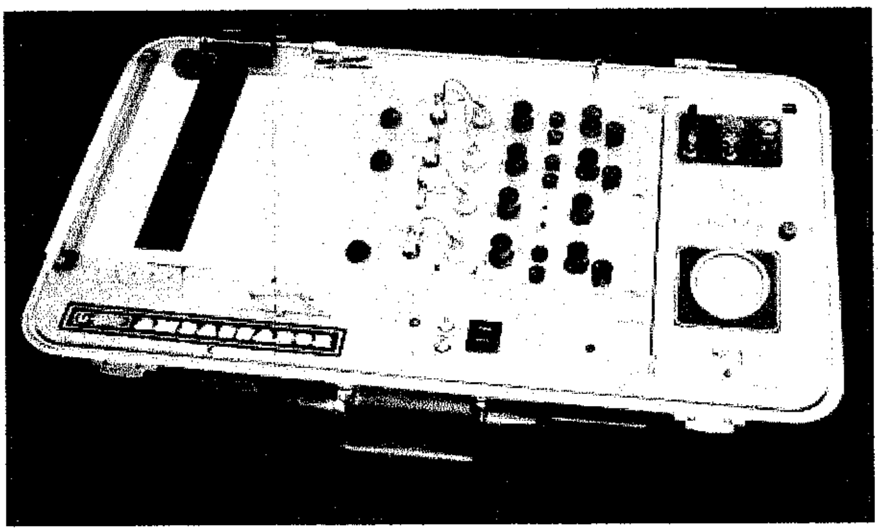

Figure 1 : Analog Polygraph Instrument [3]

In today world, most polygraph tests are administered with digital equipment. The scrolling paper has been replaced with sophisticated algorithms and computer monitor [3]. When you sit down in the chair for a polygraph exam as in **Figure 2**, several tubes and wires will be connected to the body in specific locations to monitor physiological activities. Deceptive behavior is supposed to trigger certain physiological changes that can be detected by a polygraph and a trained examiner.

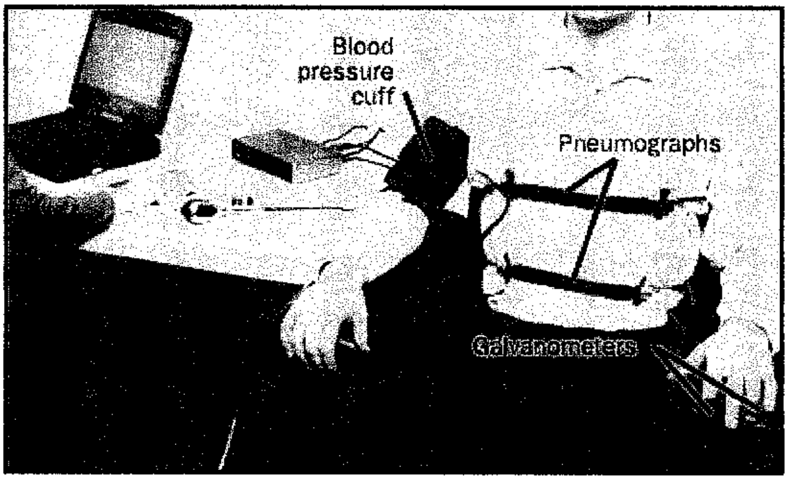

Figure 2 : Polygraph test [3]

Physiological reactions occur in a person body when that person is subjected to stress, such as the stress associated with deception. There are four physiological reactions that will be discussed in this project; electro-dermal activity or galvanic skin response, heart rate, blood pressure and respiration rate monitoring.

2.1 Electro-dermal Activity/Electrical Skin Resistance

This is basically the measurement of the skin resistance on the hand. The finger tips and palm are the most porous areas on the body and are a good place to look for sweat as in **Figure 3**. Based on theory, there are two types of sweat glands which are eccrine and apocrine. The eccrine is the most numerous types that are found all over the body, particularly on the palms of the hands, soles of the feet and forehead. Besides, the apocrine is mostly confined to the armpits and the anal-genital area. They typically end in hair follicles rather than pores. The idea is that, people sweat more when they are placed under stress and person's skin resistance changes when they sweat. The dry skin gives resistance about a few Mega Ohm whereas the moist skin reduced the resistance by a factor of ten or maybe more which is about Kilo Ohm. Usually in order to test the resistance level, fingerplates from copper or aluminum are attached to fingers or palm. These plates measure the skin ability to conduct electricity. In the electro-dermal activity, skin resistance response (SRR) and skin resistance level (SRL) are expressed as a component of alternating current and direct current changes. The galvanic skin response is measured most conveniently at the palms of the hand, where the body has the highest concentration of sweat glands. The measurement is made using a dc current source. Silver to silver or copper to copper electrodes are used to measure and record the galvanic skin response or electrical skin resistance.

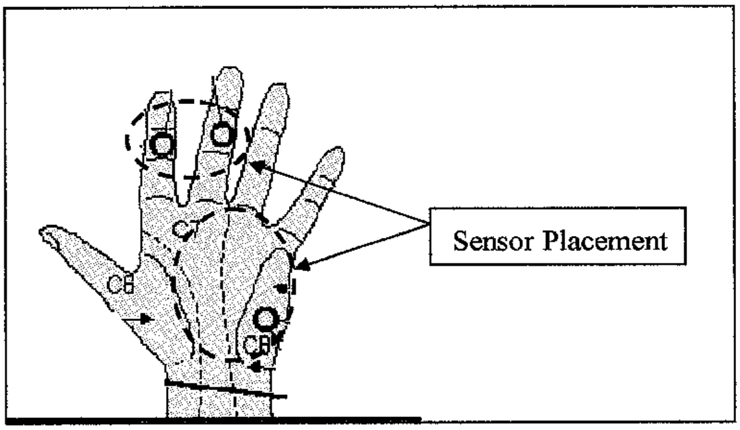

Figure 3 : Sensor Placement

2.2 Heart Rate Monitoring

When people tell deception, these will be an automatic reaction where the heart beat become faster than normal. In our heart, there is a group of cells which can charge particles separately. The normal heart beat is 72 beats per minute while for people under stress, is said that the heart rate will be double. In the heart there are cells called peacemaker cells, which can create the electrical impulse that causes the heart to beat. There are two nerves that help in controlling the heart rate: the sympathetic nervous system and the parasympathetic nervous system. Heart rate will increase when the sympathetic nervous system works and increase the force of contraction.

Heart rate is derived by the amplification of the electrocardiograph (ECG) signal and by measuring either the average or instantaneous time intervals. There are two common techniques used to calculate the heart rate:

$$\boxed{\frac{Beats}{Min} = \frac{60}{T}}$$

- *Average calculation* This is the oldest and most popular technique. An average rate is calculated by counting the number of pulses in a given time. Actually, the calculation for this method does not show changes in the time between beats and thus does not represent the true picture of the heart's response to the stress.
- *Beat to beat calculation* This is done by measuring the time (T) in seconds, between two consecutive pulses and converting this time into beats/min by using the formula below.

The measurement of the heart rate or pulse rate is basically based on the theory of each time the heart muscle contracts, blood is ejected from the ventricles and pulse of pressure is transmitted through the circulatory system. This pressure pulse causes vessel-wall displacement, which is measurable at various points. The pulse can be felt by placing the finger tip over the radial artery in the wrist or some other location where an artery seems just below the skin [4].

As the technology grows, devices like stethoscope used to monitor heartbeats acoustically and there are the other devices that monitor the light modulation resulting from the pulsing flow of blood. **Figure 4** below show the graph on how the various tissues and bones can absorb light transmitted through the body. As blood flows through the circulatory system, it changes density because of the heart's pumping pressure. This change also changes the absorption rate of light, effectively modulating the light absorption. The total light absorption is a combination of modulated and constant absorption which is similar to a small AC noise riding a top a DC voltage.

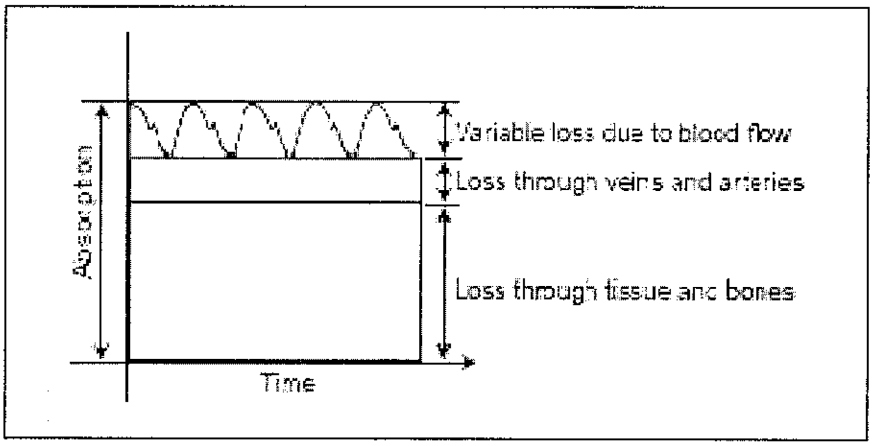

Figure 4 : Various absorption light transmitted through the body [5]

By comparing the intensity of light that makes its way out (X_{OUT}) to that which comes in (X_{IN}) gives the percentage of light that has passed through the body. As the arterial system expands and contracts, it affects the level of light absorption. The measurement of heart rate normally made at the area of earlobes and fingers because they are relatively thin [5].

2.3 Blood Pressure Monitoring

There are two numbers in blood pressure readings which are systolic and diastolic. A typical reading for a normal person is 120/80 which indicates that 120 is the measurement of the maximum output pressure of the heart (systolic), while 80 indicates the pressure in the system when the heart is relaxed (diastolic). Normally, when people are under stress, hormones like adrenaline will be release into the blood and this cause certain blood vessels to constrict and it results in a high blood pressure.

The first blood pressure measurement was made with a very simple sensor. In 1733, the Reverend Stephen Hales [6] introduced glass tubes into the carotid arteries of horses and measured the height of the blood column that arose in the tube. Rapid advances in technology throughout the centuries have brought dynamic changes in the advancement of medical devices, particularly blood pressure sensor. The development of indirect blood pressure measurement was discovered by a Russian surgeon Korotkov in 1905 [7]. He discovered that if one increased the pressure in the cuff to above systolic pressure levels and then slowly decreased the cuff pressure while listening to the sounds from the artery, one could associate the sound characteristics with the corresponding pressure levels in the vessel. Several methods for non-invasive or indirect blood pressure measurement have been developed based on the sphygmomanometer cuff method.

2.4 Respiration Rate

The respiratory rate will change due to how fast people can breathe. Usually, when people tell lies to others, their rate of breathing will became faster compared to the normal rate. In analog polygraph, two pneumographs, rubber tubes filled with air, are placed around the subject's chest and abdomen. When the chest or abdominal muscles expand, the air inside the tubes is displaced. It is attached to a mechanical arm, which is connected to an ink-filled pen that makes marks on the scrolling paper when the subject takes a breath. When an analog polygraph is replaced by a digital polygraph, it still used the pneumographs, but employs transducers to convert the energy of the displaced air into electronic signals.

CHAPTER 3
METHODOLOGY

Flow chart in **Figure 5** shows the step taken by the student in order to complete the project. The first step includes the study and research on physiological reactions in human body. Then, the student proceeds to the next step which is research about the current lie detector used in the market today. Next stage is the design of the overall system for a lie detector which includes the process of finding the components, design and constructs the circuit and also troubleshooting process. And the last stage is to display the result using the selected components.

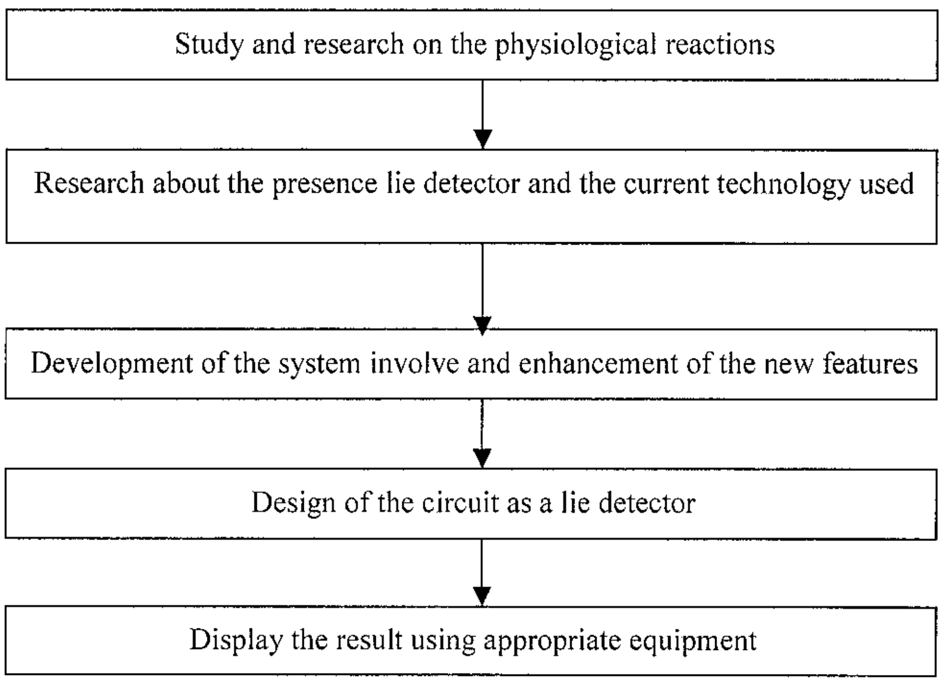

Figure 5 : Flow chart for the project

Figure 6 below shows the flow chart of the design system. Actually, student is dividing the whole system into three small block design. First system is to check and measure the electrical skin resistance. The second system is the combination of heart rate and blood pressure monitoring system which the output will be display on just one LCD display. And the last system is for measuring and monitoring the respiration rate of the subject.

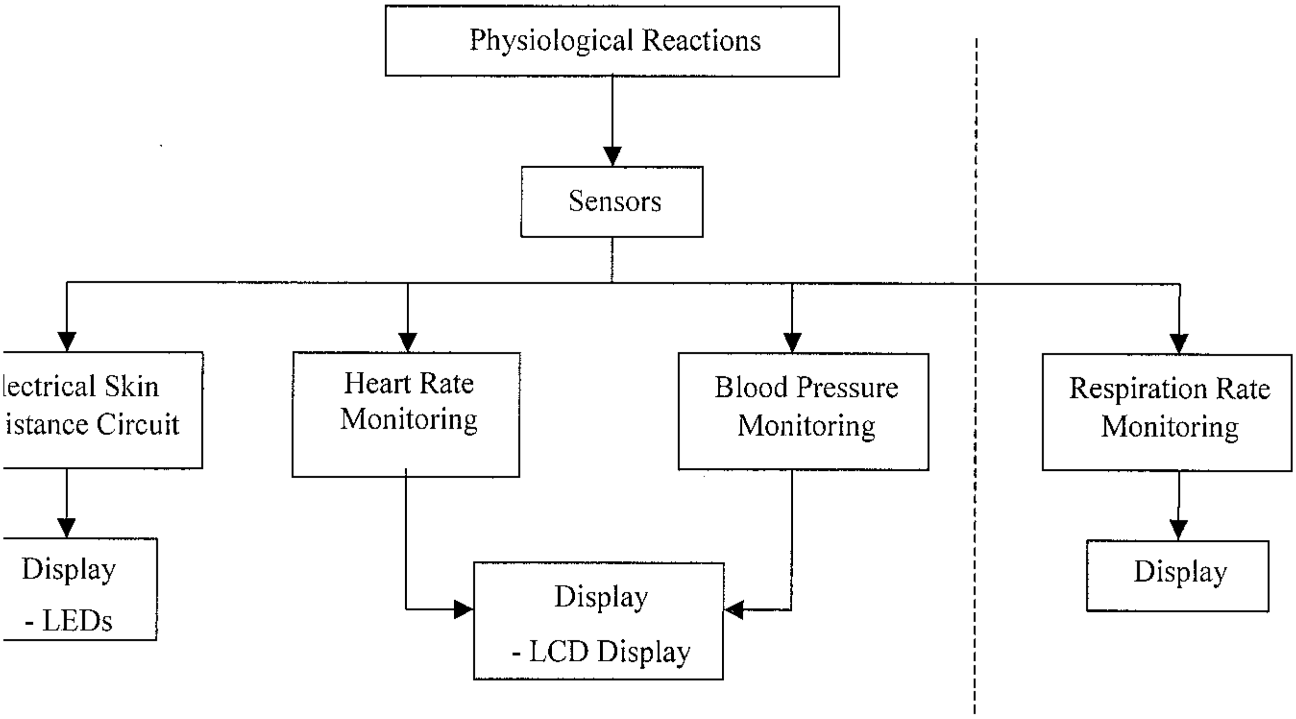

Figure 6 : Combination of the Overall System Design

The project required software's and hardware's during the process of implementation the device. Table 1 below shows the listed item which will be used in designing the first system which is Electrical Skin Resistance.

Table 1 : List of software and hardware for Electrical Skin Resistance monitoring device

SOFTWARE	HARDWARE
1. Electronic Workbench (EWB)	1. resistors
2. Pspice	2. transistors
3. MultiSim	3. power supply
	4. LEDs
	5. wires
	6. multimeter
	7. variable resistor
	8. copper plates

CHAPTER 4
RESULT AND DISCUSSION

As mentioned in the previous chapter, there are four physiological reactions which will take placed in human body when they are facing stresses. The hand will perspire more than usual; the blood pressure will be higher since there is more blood will be pumping into the heart and heart beat will be faster as rate of blood pumped to the heart is faster than normal. And the respiration rate also will increases proportional to the other reactions. The measurement and detection of these reactions are studied in this chapter.

From **Figure 6**, it shows that the overall system design is divided into three blocks based on the reactions occurs. Actually, until this stage student only manage to complete the design circuit for the first reaction which is Electrical Skin Resistance. Although the circuit is able to produce the output, it still needs some improvement for future use. The result for the circuit testing and further discussion will be in the next section. As for the blood pressure and heart rate monitoring system, student manages to complete the research and there is one system that is proposed. Student will discuss about the system hardware on the incoming section. The third reaction which student took in account is the respiration rate. But, unfortunately, there is no further research and study had been done due to time constrains. Student would not be capable to show the result of the project because the project is still under progress.

4.1 Electro-dermal Activity/Electrical Skin Resistance

Theory of physiology stated that people who tell lie always in a stress condition. It is believed that, people's hand will perspire more when they are in stress mode or when facing with the uncontrollable situations. Due to the amount of sweat being produced, the skin resistance will change. The first experiment done is to check the skin resistance value when palm in a normal condition (no sweat produced). When two probes which are conductive material (copper or aluminum) are placed on the palm, the resistance value from the ohm meter shows about 1-2 M ohm. In order to measure the resistance for moist skin (when sweat is produced), probes were left on the palm and again the reading from the ohm meter is taken. Ohm meter showed that the value drop until 1-0.2 K ohm. Student is having difficulties while taken the reading because the values do fluctuate all the time.

The circuit in **Figure** 7 below shows an electrical skin resistance circuit which will be used as a part of a lie detector.

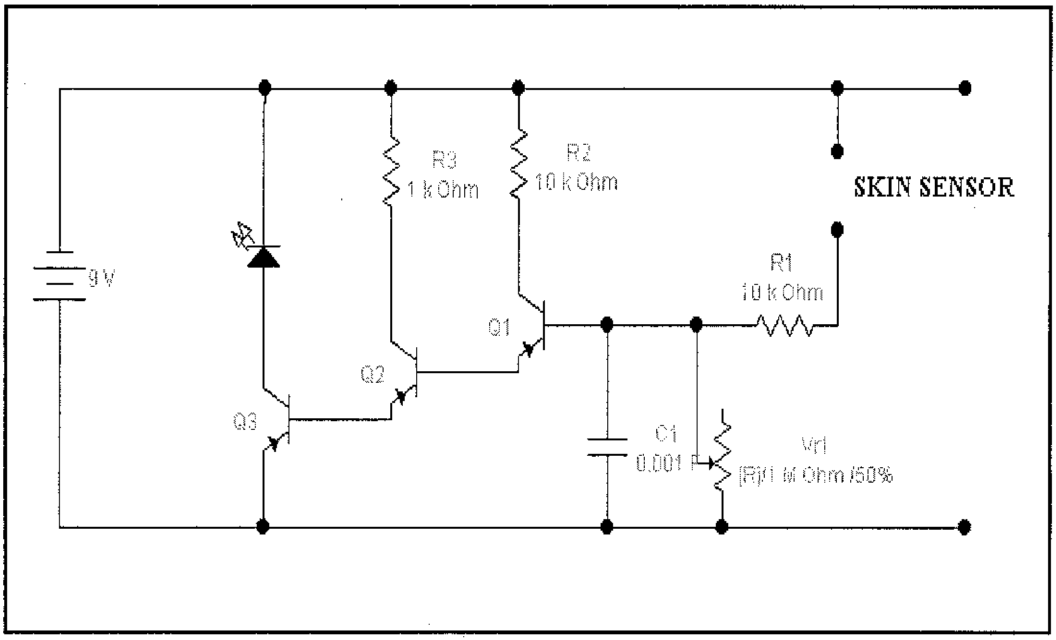

Figure 7 : Schematics diagram for Electrical Skin Resistance

From **Figure 7**, firstly the skin sensor is placed on the hand touching the skin which is on the palm. Then, variable resistor is adjusted until the LED just stops lighting. When the palm starts to perspire, the value for resistance of the circuit will decrease and automatically the LED will be emitting back. Notices that, there is no specific time for the LED to emit back since perspiring rate among people are different. Student is using copper plates as the skin sensor (for testing purpose). It is shows in **Figure 8.**

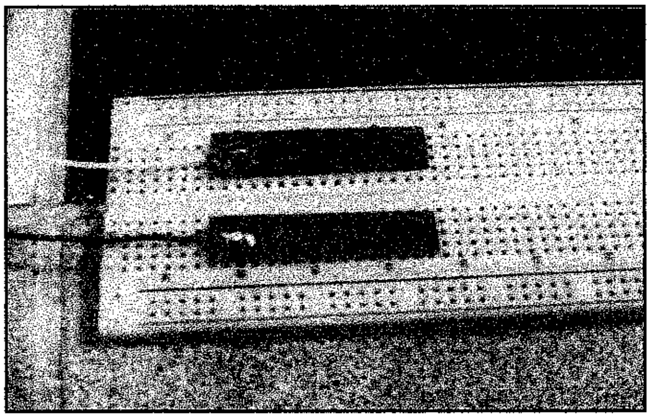

Figure 8 : Copper plates as skin sensor

In real situation, probes as in **Figure 8** will be placed as in **Figure 9** in order to get more accuracy of reading.

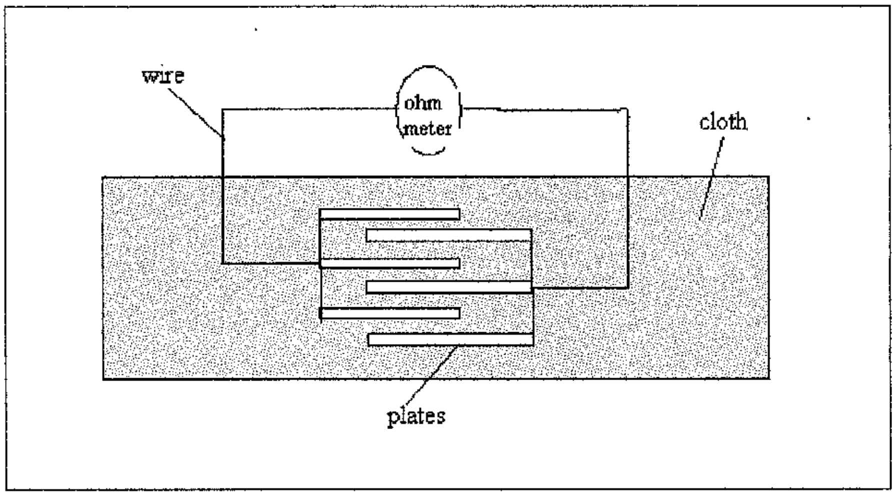

Figure 9 : Placement of plates for skin sensor

The result for the experiment is shows in all the figures below:

1. When the sensor is placed on the palm, the LED will emit as the circuit is complete (no open circuit).

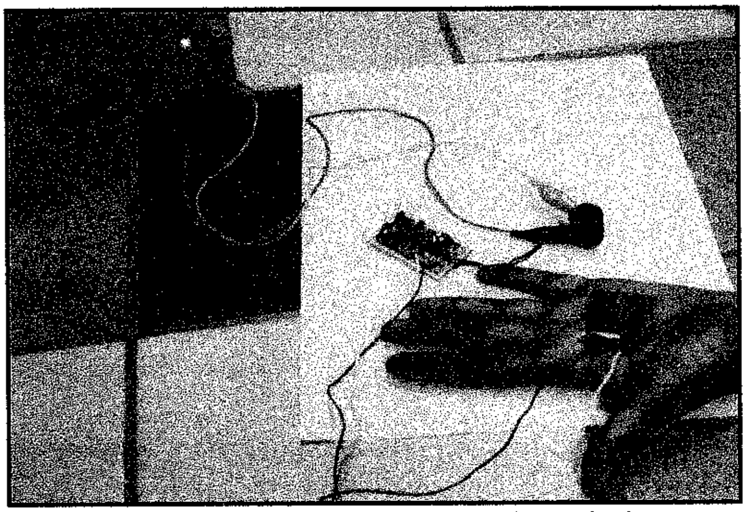

Figure 10 : Picture of how experiment is done

2. Variable resistor is adjusted until the LED stops emit and this is the initial condition before the circuit is use.

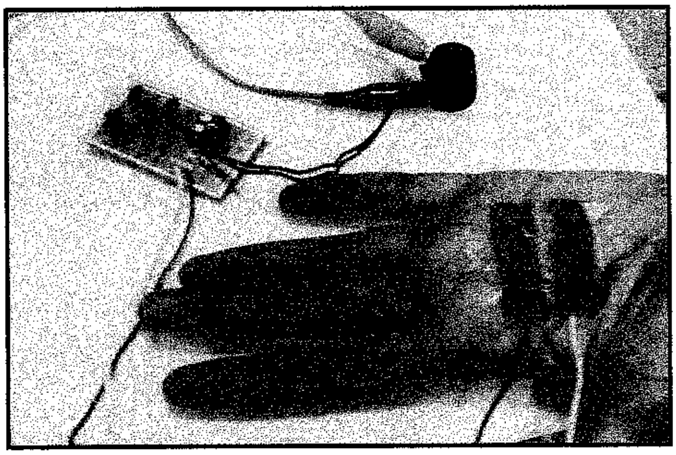

Figure 11 : Initial condition of the circuit

3. When palm produce sweat, the LED will emit back as the resistance of the circuit is decrease.

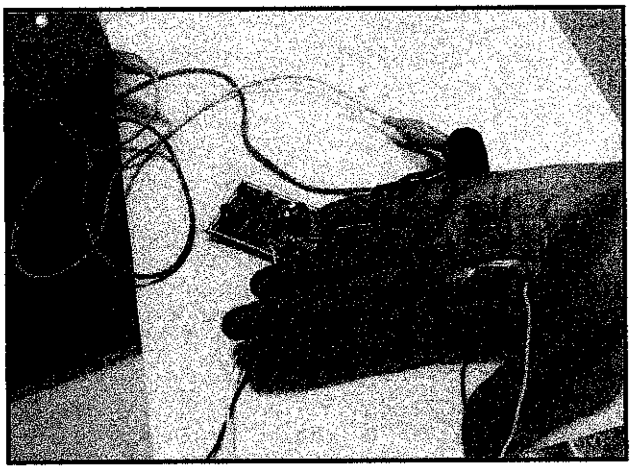

Figure 12 : The LED on

4.2 Heart Rate and Blood Pressure Monitoring

As stated earlier in the beginning of the chapter, for this system student only manage to do a study on the proposed design because of some reason. During the previous semester, student planned to construct different circuit for these two systems. Somehow, while doing a study and research for the blood pressure monitoring system, it is realized that both of the systems (heart rate monitoring and blood pressure monitoring system) are possible to use the same circuit for monitoring or even measuring purposes. This is because, both heart rate and blood pressure measurement relating to the theory of expansion and contraction of the arteries and veins throughout the body.

Biologically, during the systolic phase, the heart will contract and pushing the blood into the arteries, capillaries and veins. Blood will flow back to the heart from the veins during the diastolic phase. This will give effects to the level of pressure reading taken.

Basically, this blood pressure monitor device can measure user's blood pressures and heart rate through an inflatable hand cuff. The device is consisted of three main parts which cover the external hardware (cuff, motor, valve, and LCD), analog circuit, and microcontroller. The rough illustration for the system is as in **Figure 13**.

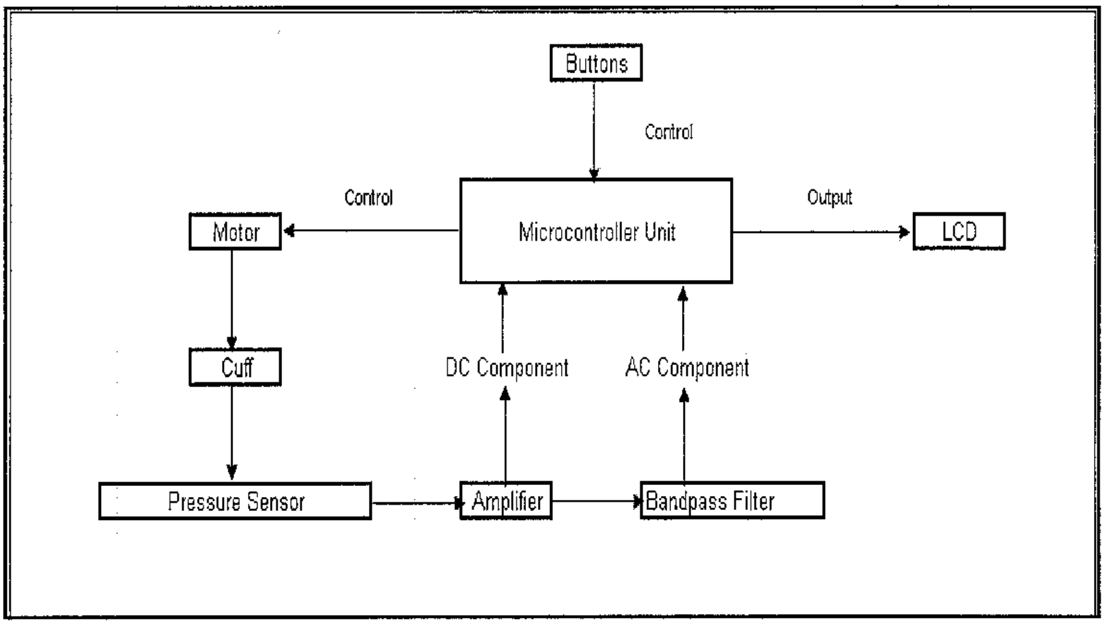

Figure 13 : Operation of the heart rate and blood pressure monitoring device

The operation of the system is control by the button. Microcontroller is the main unit that controls all the operations such as motor and valve control, A/D conversion, and measurement as well. The results then are shown through LCD screen.

For analog design stage, there are two main components that are used which are an amplifier and the band-pass filter. Actually analog circuit is used to amplify both the AC and DC components from the output signal of pressure transducer. The output voltage of pressure transducer ranges from 0 to 40 mV. But in the design system, the arm cuff will be pumping to only 160mmHg which is approximately to 18mV. Thus, the amplifier is used in order to amplify the DC output voltage. Then the signal will passed to the band-pass filter. The filter is designed to attenuate any signal that is out of the pass band. The AC component from the band-pass filter is the most important in order to determine when to capture the systolic and diastolic pressure and when to determine the heart rate of the user.

In hardware design, there are four design stages which are pressure transducer, DC amplifier, band-pass filter and AC coupling stage.

1. **Pressure Transducer**

   The proposed design is using the MPX2050 pressure transducer to sense the pressure from the arm cuff. The pressure transducer produces the output voltage proportional to the applied differential input pressure. Somehow, student is still doing the research on the equipment; MPX2050 pressure transducer.

2. **DC Amplifier**

   The purpose of using the DC amplifier is to amplify the output voltage from pressure transducer which is very small for further processing. The proposed instrumentation amplifier is AD620. Gain for this instrument is determined by using equation

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

3. **Band-pass Filter**

   For this stage design, cascaded of two active band-pass filter is used. Reason for using two stages is that the overall band-pass stage would provide a large gain and the frequency response of the filter will have sharper cut off than using only one active band-pass filter.

4. **AC Coupling Stage**

   In order to get the DC bias level, AC coupling stage is used. This bias level will help in processing the AC signal using on the ADC in the microcontroller.

All of the hardware stages are combined in one analog circuit as in the **Figure 14** below.

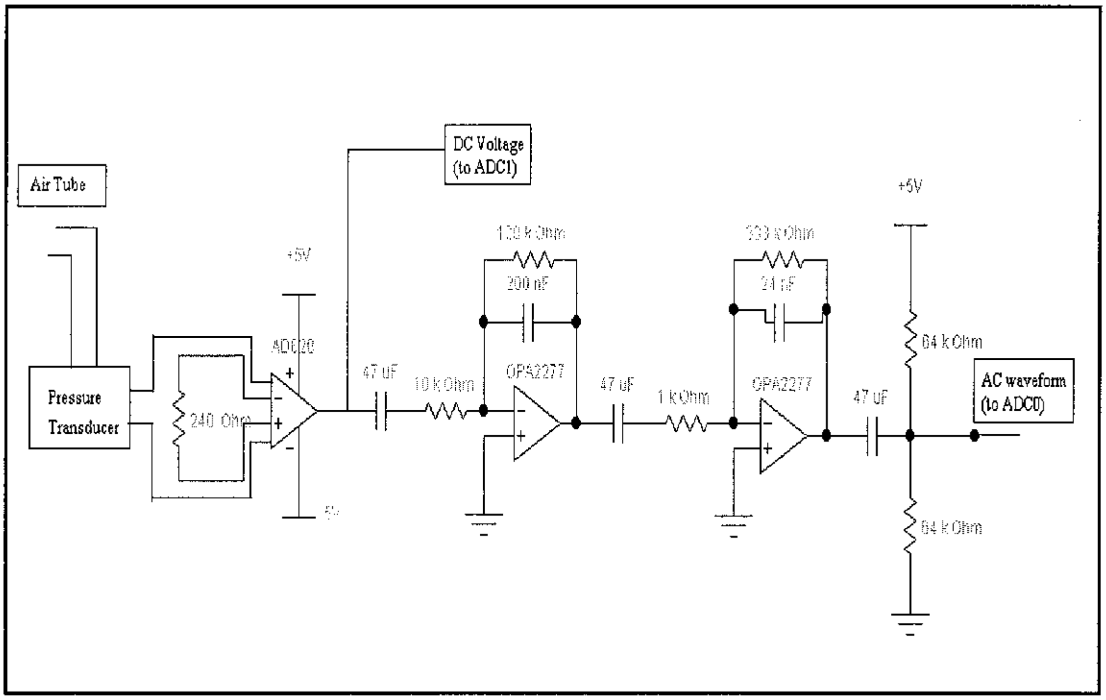

Figure 14 : Schematics of Analog Circuit

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Relevancy to the Objective

As for the conclusion, the objective to design a simple and small circuit is achieved even though the student manages to complete the first portion of the system only. The circuit which had being constructed still needs an improvement for a better used. Besides, all the circuit designed hopefully can also be used in the biomedical world as one of the equipment to monitor the heart rate, blood pressure or respiration rate and not only as a lie detector.

5.2 Suggested Future Work for Expansion and Continuation

For continuation of work, student will try to improve the circuit for electrical skin resistance. After completed the experiment for the electrical skin resistance, student found out that the circuit still need an improvement for a better use. Perhaps, there will be a switch attach as a reset button in order to set back the circuit to an initial condition especially after a question by a question. Moreover, student also should take note on the placement of the sensor in order to obtain a correct and precise result.

It is recommended that the other two system to be finish in time in order to test the functionality of the overall systems. Maybe for a future use, the system can be run together with the questions in order to detect lie.

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APPENDICES

APPENDIX A

Project Gantt chart

PROJECT GANTT CHART

No.	Detail/ Week	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Circuit construction on the breadboard	▒													
2.	Troubleshoot the circuit (the one that use two LEDs)		▒												
3.	Progress Report 1			●											
4.	Design new circuit for electrical skin resistance				▒	▒									
5.	Research for new design of Blood Pressure and Heart Rate monitoring system						▒								
6.	Progress Report 2							●							
7.	Project work continue (electrical skin resistance circuit)								▒	▒	▒	▒			
8.	Final Draft Report												●		
9.	Project work continue													▒	
10.	Final Report Soft Cover														●
11.	Technical Report														
12.	Oral Presentation														
13.	Final Report														

APPENDIX B

PNP Transistor Datasheet

FAIRCHILD
SEMICONDUCTOR®

MPS751

Silicon PNP Transistor (Note 1)

- Low Saturation Voltage

1

TO-92

1. Emitter 2. Base 3. Collector

Absolute Maximum Ratings T_C=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	-60	V
I_C	Collector Current (DC)	2	A
P_C	Collector Dissipation (T_a=25°C) (Note 2, 3)	625	mW
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 55 ~ 150	°C

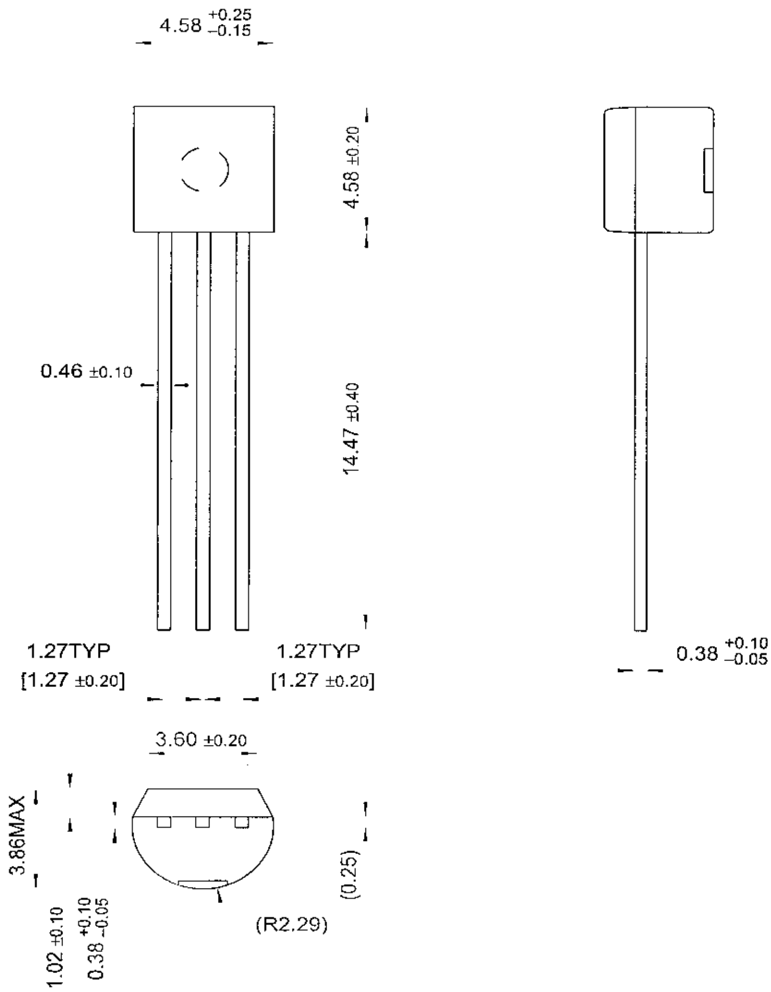
Electrical Characteristics T_C=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
BV_{CBO}	Collector-Base Voltage	I_C = 100μA	-80			V
BV_{CEO}	Collector-Emitter Voltage	I_C = 10mA	-60			V
BV_{EBO}	Emitter-Base Voltage	I_E = 10μA	-5			V
I_{CBO}	Collector Cut-off Current	V_{CB} = 30V			100	nA
I_{EBO}	Emitter Cut-off Current	V_{EB} = 3V			100	nA
h_{FE}	DC Current Gain	V_{CE} = 2V, I_C = 50mA V_{CE} = 2V, I_C = 500mA V_{CE} = 2V, I_C = 1A V_{CE} = 2V, I_C = 2A	75 75 75 40			
V_{CE}(sat)	Collector-Emitter Saturation Voltage	I_C = 2A, I_B = 200mA I_C = 1A, I_B = 100mA			0.5 0.3	V
V_{BE}(sat)	Base-Emitter Saturation Voltage	I_C = 1A, I_B = 100mA			1.2	V
V_{BE}(on)	Base-Emitter On Voltage	V_{CE} = 5V, I_C = 2mA			1	V
f_T	Current gain Bandwidth Product	V_{CE} = 5V, I_C = 50mA f = 100MHz	75			MHz

Notes:
1. These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.
2. These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.
3. These ratings are based on a maximum junction temperature of 150degrees C.

Package Dimensions

TO-92



Dimensions in Millimeters

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Bottomless™	FAST®	LittleFET™	Power247™	SuperSOT™-3
CoolFET™	FASTr™	MicroFET™	PowerTrench®	SuperSOT™-6
CROSSVOLT™	FRFET™	MicroPak™	QFET™	SuperSOT™-8
DOME™	GlobalOptoisolator™	MICROWIRE™	QS™	SyncFET™
EcoSPARK™	GTO™	MSX™	QT Optoelectronics™	TinyLogic™
E^2CMOS™	HiSeC™	MSXPro™	Quiet Series™	TruTranslation™
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PRODUCT STATUS DEFINITIONS

Definition of Terms

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

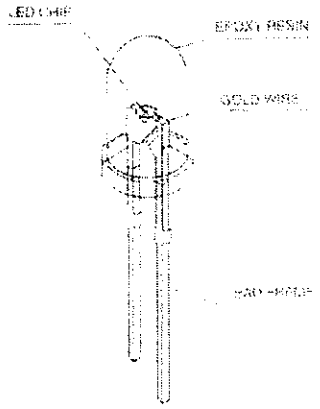
APPENDIX C

Light Emitting Diode

Overall Description

A Light Emitting Diode (LED) is a solid-state component that uses electricity to make light. LEDs produce no significant waste heat and have lives so long that they basically don't burn out.

LEDs come in a huge array of sizes, shapes, and colors.



This drawing, from the Photron catalog, shows the anatomy of a common LED

The part that actually makes the light is the "die", or "chip". The "lead frame" holds the chip and extends out of the package to provide electrical connection. The whole thing is encapsulated in an epoxy plastic package that may be colored or shaped.

This is the schematic symbol for a LED. Expect plenty of artistic variation, such as a triangle that it filled in or hollow, differing number of arrows coming out of it, and sometimes the greek letter Lambda alongside.

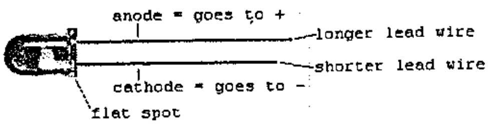
The "triangle" side is the "Anode". This connects to the positive side of your power supply.

The "flat" side is the "Cathode". This connects to the negative side of the power.

Polarity

It is important to remember that LEDs are polarized. If you hook LEDs up backwards, they won't work, and might be damaged. There are several ways to determine the polarity of a LED:

- If the package is round, look for a flat spot on the edge of the LED package. The lead wire nearest this flat spot is probably the cathode.
- If the LED is new (not cut out of some old device), the longer lead wire is usually the Anode.
- The most reliable method of identification is to read the instructions or data sheet, if available.



In summary:

anode	cathode
hooks to + supply	hooks to - supply
longer lead wire	shorter lead wire
case stays round	flat spot on case

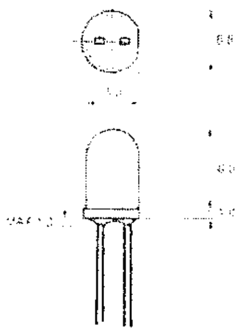
LED Selection

There is a nearly infinite assortment of LEDs to choose from. Some selection factors are:

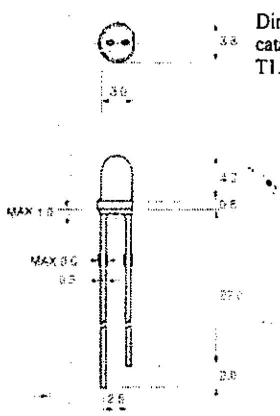
- size
- shape
- color of emitted light
- color of the case
- brightness
- beam pattern (spread)

Size and Shape

LEDs come in a huge variety of sizes and shapes. Perhaps the most common size is called "T1 3/4". His smaller brother is "T1".



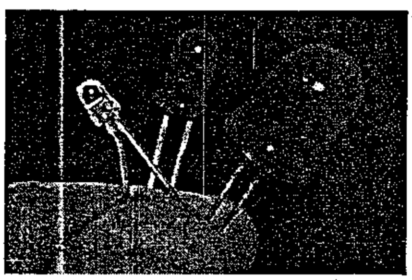
Dimensioned drawing, from the Photron catalog, of the standard LED size called T1 3/4. All dimensions are in mm.



Dimensioned drawing, from the Photron catalog, of the standard LED size called T1. All dimensions are in mm.

Note that the drawings of T1 and T1 3/4 both show one wire longer than the others, and one side of the package with a flat spot on it. These are important indicators of device polarity. If you apply power backwards, the LED will not function, and can be destroyed.

When it comes to LED performance, "size doesn't matter". You might have a huge LED, the size of a gumdrop, and the chip inside is the same one that is normally built into a much smaller case. If you want something bright, get one that is specified as high brightness, or has a large MCD rating.



Three red LEDs, in sizes T1, T1 3/4, and 10mm.

Some common round LED sizes:

name	slang	diameter
T1	miniature	3mm
T1 3/4	standard	5mm
	jumbo	8mm
		10mm

Light Color

The color of the plastic case around a LED chip doesn't always indicate the color of the light coming out.

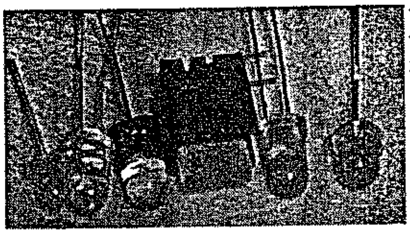
When a LED emits a "pure spectral color", the color can be objectively described in terms of the wavelength of the emitted light. This is usually specified in nanometers (nm).

LEDs emitting other colors, such as purples and pinks, are often described by their position on the CIE chromaticity diagram.

LEDs sold through electronic surplus outlets, a common source for hobbiests, may not be so precise. You might find them described as "red", "crimson", "orange", "yellow", "amber".

Light from LEDs tends to be monochromatic. Exceptions are (a) LASER LEDs, which are also coherent, and (b) LEDS that produce interesting colors via secondary emission from phosphors.

Case Color



The color of the LED case sometimes has little to do with the color of light coming out of it. These are all green LEDs. Even the yellow one. :-)

Cases described as "milky" or "diffuse" will spread the light around more.

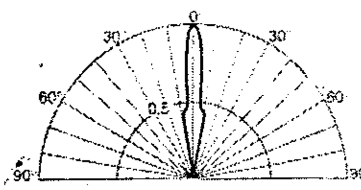
Brightness

LEDs sold through electronic surplus outlets, a common source for hobbiests, are seldom uniformly rated for brightness. Instead, you might find local teminology like "bright", "super bright", and "ultra bright". I have never seen a merchant selling "rather dim" LEDs.

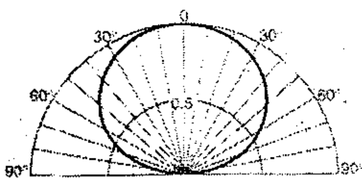
The better sources rate their LEDs in millicandella (mcd), a measure of luminous intensity. A higher number is a brighter LED.

Beam Pattern

The light coming out of a LED doesn't always shoot out in a straight line. There is a pattern to it.



This radiation diagram shows the output of a blue LED with a water-clear case (Photron PL-BA31). Most of the light is shooting straight out the front of the package.



This radiation diagram shows the output of a green LED with a diffused colored case (Photron PL-GB574G).

If you have the manufacturer's part number for a LED, you can probably look up information about the beam pattern - at the very least a viewing angle.

If you are buying LEDs surplus and the part number is unknown, just remember that a "milky" or "diffused" case will spread the beam more, affording a wider viewing angle, but at a reduced intensity.

All LEDs Are Not Created Equal

In the section on LED Selection, I described some of the ways that LEDs can differ. But I feel the need to hammer home the point that if you are building a project that calls for a "yellow LED", and that's what you ask for, you could get something that is very different from the original. Perhaps your yellow LED will work as well, or even better. But without more specifications, it will probably be different.

The following table was compiled from the web sites of Hosfelt Electronics and Jameco Electronics, two companies that offer a wide range of LEDs at competetive prices. The information was collected 24 September 2004, and will certainly be out of date by the time that you read this. But it does a good job of pointing out the range of options.

I looked only for yellow LEDs. I tried to use only LEDs with lenses that are clear or transparent yellow. The prices are for just one LED, but when purchased in quantities of 10. There may well be errors: Hosfelt provided less technical information, but Jameco provided details that sometimes conflicted with the basic description of the part.

vendor	*part number*	*price*	*brightness*	*test current*	*voltage*	*size*	*lens color*	*wavelength*	*mcd/penny*
Hosfelt	25-342	$3.49	23000mcd	20mA	1.9-2.5V	10mm	water clear	590nm	66
Hosfelt	25-408	$1.45	9500mcd	20mA	2-2.4V	5mm	clear	587nm	66
Hosfelt	25-335	$.75	8000mcd	20mA	2.1-2.5V	5mm	colorless, transparent	?nm	107
Jameco	197641	$.62	7800mcd	20mA	2.3V	oval	transparent yellow	590nm	126
Jameco	215597	$.55	5000mcd	20mA	2.2V	5mm	water clear	?nm	91
Hosfelt	25-357	$.49	3600mcd	20mA	2.1-2.5V	5mm	water clear	?nm	73
Jameco	197675	$.36	2800mcd	20mA	2.8V	5mm	water clear	592nm	78
Hosfelt	25-337	$.45	2000mcd	20mA	2.1-2.5V	5mm	water clear	?nm	45
Jameco	152792	$.24	1040mcd	20mA	2.1V	5mm	?	593nm	44
Jameco	206501	$.19	700mcd	20mA	2.2V	5mm	transparent yellow	595nm	37
Hosfelt	25-275	$.12	550mcd	30mA	2V	5mm	colorless	?nm	46
Jameco	206480	$.14	450mcd	20mA	2.3V	3mm	transparent yellow	595nm	32
Jameco	253796	$.24	150mcd	20mA	2.2v	5mm	?clear	585nm	6
Hosfelt	25-414	$.04	80mcd	10mA	2V	3mm	yellow	?nm	20
Hosfelt	25-285	$.10	80mcd	30mA	2V	3mm	?clear	?nm	8
Jameco	175695	$.15	60mcd	10mA	2.1V	5mm	water clear	585nm	4
Hosfelt	25-411	$.05	50mcd	20mA	2.5V	5mm	clear	?nm	10
Hosfelt	25-328	$.06	40mcd	10mA	2.1V	3mm	?	585nm	7
Jameco	136493	$.19	38mcd	20mA	2.3V	5mm	water clear	589nm	2

To summarize, by just checking two vendors, I found 19 different kinds, with properties ranging:

- brightness 38mcd- 23000mcd
- wavelength 585nm - 595nm
- voltage 1.9V - 2.8V
- current 10mA - 30mA
- size 3mm - 10mm
- cost $.04- $3.49

Special LEDs

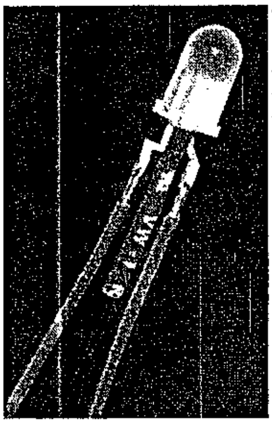
There are various special LEDs on the market:

- resistor LEDs - Contain their own current-limiting resistor.
- blinkers - Contain a timer chip that makes them automatically flash on and off.
- multichip - Contain more than one LED of the same color. Takes more power, but lights brighter.
- nonpolarized - Contains two LED chips of the same color, back-to-back. Lights up the same when voltage is positive, negative, or AC.
- multicolor - Contains two or more LED chips that light different colors.

Multicolor LEDs

Multicolor LEDs contain two or more LED chips that light different colors.

The most common type has one red chip and one green chip. There are two common types of packaging: a three-lead package that allows independent access to the two LED chips, and a two-lead package that connects the two chips back-to back (to change color, reverse polarity).



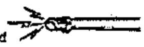
This T1 3/4 package contains two LED chips.

Apply power to one wire and the package lights green.
Apply power to the other, and it glows red.
Apply power to both, and the package glows yellow.

Self-Flashing LEDs

Self-flashing LEDs are packaged in a normal LED case, but include an integrated circuit that makes the LED flash on and off.

Built-in flashing unit 3 - 5 Vdc operation	CAT#	1-99	100	1000
T-1 3/4 (5mm) RED - diffused High Brightness	LED-4	2 for .90	.40	.30
T-1 3/4 (5mm) GREEN - diffused	LED-4G	.50	.45	.40
T-1 3/4 (5mm)YELLOW - diffused	LED-4Y	.50	.45	.40
SPECIAL - RED T-1 3/4 - water clear	LED-84	3 for $1.00	.25	.18
T-1 (3mm) RED - diffused	LED-72R	.65	.55	.45
T-1 (3mm) GREEN - diffused	LED-72G	.75	.65	.55
T-1 (3mm) YELLOW - diffused	LED-72Y	.75	.65	.55



This section of the All Electronics catalog offers several different kinds of self-flashing LEDs [January 2004].

APPENDIX D

Variable Resistor

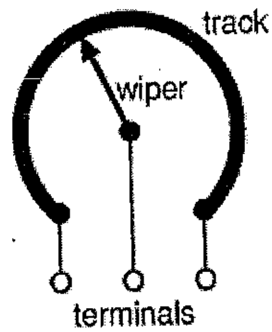
ELECTRONICS CLUB
Kelsey Park School

ariable Resistors

ıstruction | LIN & LOG | Rheostat | Potentiometer | Presets

›nstruction

riable resistors consist of a resistance **track** with connections at both ɔds and a **wiper** which moves along the track as you turn the spindle. The ck may be made from carbon, cermet (ceramic and metal mixture) or a il of wire (for low resistances). The track is usually rotary but straight track rsions, usually called sliders, are also available.

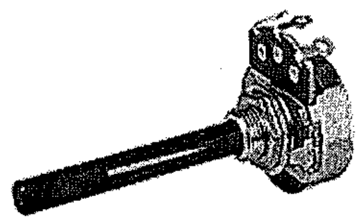


ıriable resistors may be used as a rheostat with **two** connections (the ɔer and just one end of the track) or as a potentiometer with all **three** nnections in use. Miniature versions called presets are made for setting circuits which will not require further adjustment.

ıriable resistors are often called **potentiometers** in books and catalogues. ıey are specified by their maximum resistance, linear or logarithmic track, ıd their physical size. The standard spindle diameter is 6mm.

ıe resistance and type of track are marked on the body:
4K7 LIN means 4.7 kΩ linear track.
1M LOG means 1 MΩ logarithmic track.

ome variable resistors are designed to be mounted directly on the circuit ɔard, but most are for mounting through a hole drilled in the case ɔntaining the circuit with stranded wire connecting their terminals to the rcuit board.



Standard Variable Resistor
Photograph © Rapid Electronics

.inear (LIN) and Logarithmic (LOG) tracks

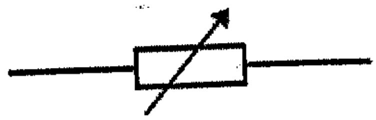
.inear (LIN) track means that the resistance changes at a constant rate as you move the wiper. This is the tandard arrangement and you should assume this type is required if a project does not specify the type of track. ᵓresets always have linear tracks.

.ogarithmic (LOG) track means that the resistance changes slowly at one end of the track and rapidly at the ɔther end, so halfway along the track is **not** half the total resistance! This arrangement is used for volume loudness) controls because the human ear has a logarithmic response to loudness so fine control (slow change) s required at low volumes and coarser control (rapid change) at high volumes. It is important to connect the ends ɔf the track the correct way round, if you find that turning the spindle increases the volume rapidly followed by littl further change you should swop the connections to the ends of the track.

Rheostat

This is the simplest way of using a variable resistor. **Two terminals** are used: one connected to an end of the track, the other to the moveable wiper. Turning the spindle changes the resistance between the two terminals from zero up to the maximum resistance.

eostats are often used to **vary current**, for example to control the
ghtness of a lamp or the rate at which a capacitor charges.



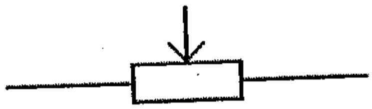
Rheostat Symbol

ie rheostat is mounted on a printed circuit board you may find that all three
ninals are connected! However, one of them will be linked to the wiper terminal.
s improves the mechanical strength of the mounting but it serves no function
ctrically.

---

otentiometer

ariable resistors used as potentiometers have all **three terminals**
nnected.

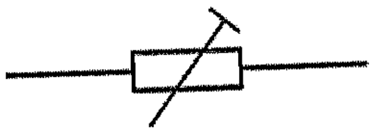


Potentiometer Symbol

iis arrangement is normally used to **vary voltage**, for example to set the
vitching point of a circuit with a sensor, or control the volume (loudness) in
ı amplifier circuit. If the terminals at the ends of the track are connected
cross the power supply then the wiper terminal will provide a voltage which
an be varied from zero up to the maximum of the supply.

'resets

'hese are miniature versions of the standard variable resistor. They are
lesigned to be mounted directly onto the circuit board and adjusted only when
he circuit is built. For example to set the frequency of an alarm tone or the
sensitivity of a light-sensitive circuit. A small screwdriver or similar tool is
'equired to adjust presets.

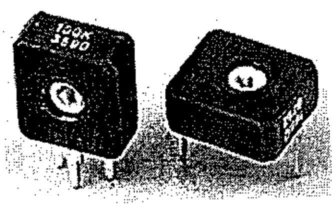


Preset Symbol

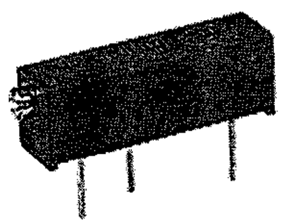
Presets are much cheaper than standard variable resistors so they are
sometimes used in projects where a standard variable resistor would normally
be used.

Multiturn presets are used where very precise adjustments must be made. The screw must be turned many times (10+) to move the slider from one end of the track to the other, giving very fine control.

Preset
(open style)



Presets
(closed style)



Multiturn preset

Photographs © Rapid Electronics

Home | Capacitor | Connector | Diode | IC | Lamp | LED | Relay | Resistor | Switch | Transistor | Variable Resistor | Other

- Electronics Club Home Page
- Site Map

APPENDIX E

Pressure Transducer MPX2050 Datasheet

50 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPX2050 SERIES

0 to 50 kPa (0 to 7.25 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2050 series device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output — directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin–film resistor network integrated on–chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

Features

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage
- Differential and Gauge Options
- ±0.25% Linearity (MPX2050)

Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non–Invasive Blood Pressure Measurement

Figure 1 shows a block diagram of the internal circuitry on the stand–alone pressure sensor chip.

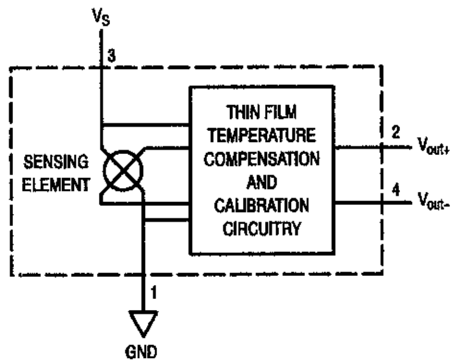
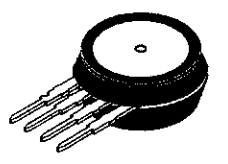


Figure 1. Temperature Compensated Pressure Sensor Schematic

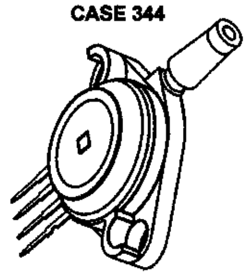
VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

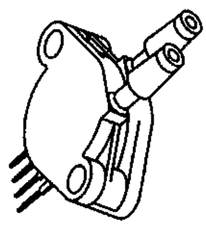
The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).



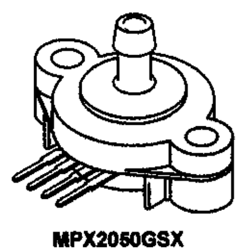
MPX2050D
CASE 344



MPX2050GP
CASE 344B



MPX2050DP
CASE 344C



MPX2050GSX
CASE 344F

PIN NUMBER			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

NOTE: Pin 1 is noted by the notch in the lead.

REV 8

(IMUM RATINGS(NOTE)

Rating	Symbol	Value	Unit
ximum Pressure (P1 > P2)	P_{max}	200	kPa
rage Temperature	T_{stg}	–40 to +125	°C
erating Temperature	T_A	–40 to +125	°C

E: Exposure beyond the specified limits may cause permanent damage or degradation to the device.

RATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
ssure Range(1)		P_{OP}	0	—	50	kPa
pply Voltage(2)		V_S	—	10	16	Vdc
pply Current		I_o	—	6.0	—	mAdc
l Scale Span(3)	MPX2050	V_{FSS}	38.5	40	41.5	mV
set(4)	MPX2050	V_{off}	–1.0	—	1.0	mV
nsitivity		ΔV/ΔP	—	0.8	—	mV/kPa
earity(5)	MPX2050	—	–0.25	—	0.25	$\%V_{FSS}$
essure Hysteresis(5) (0 to 50 kPa)		—	—	±0.1	—	$\%V_{FSS}$
nperature Hysteresis(5) (–40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
nperature Effect on Full Scale Span(5)		TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
nperature Effect on Offset(5)		TCV_{off}	–1.0	—	1.0	mV
ut Impedance		Z_{in}	1000	—	2500	Ω
tput Impedance		Z_{out}	1400	—	3000	Ω
sponse Time(6) (10% to 90%)		t_R	—	1.0	—	ms
arm–Up		—	—	20	—	ms
set Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

ES:
. 1.0 kPa (kiloPascal) equals 0.145 psi.
. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self–heating.
. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
. Accuracy (error budget) consists of the following:
- Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
- Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
- Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
- TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
- TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.

. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

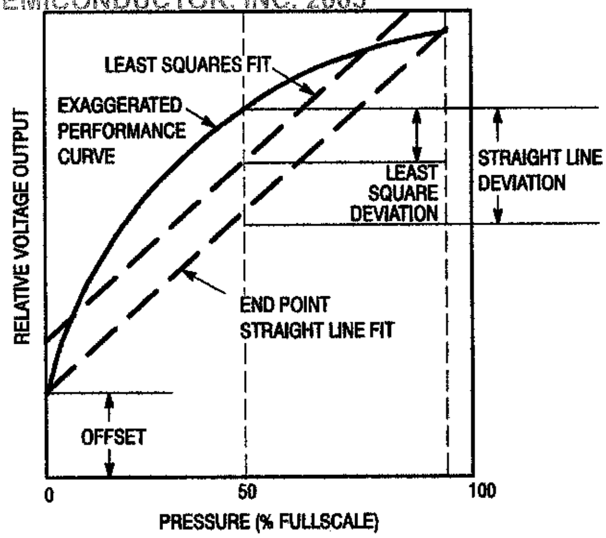


Figure 2. Linearity Specification Comparison

ON–CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPX2050 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full–Scale Span and Offset are very small and are shown under Operating Characteristics.

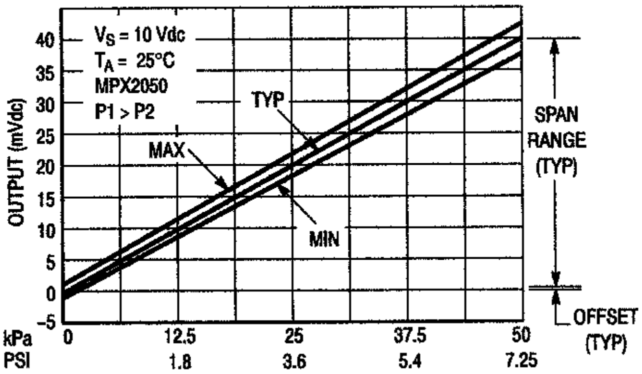


Figure 3. Output versus Pressure Differential

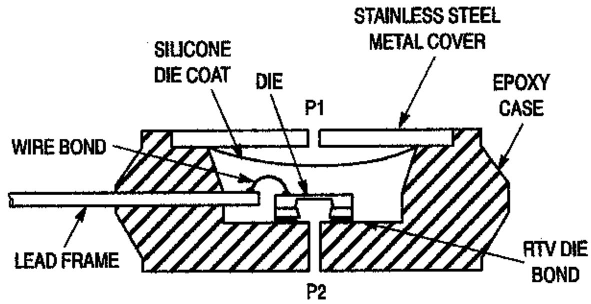


Figure 4. Cross–Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2050 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

›torola designates the two sides of the pressure sensor ıe Pressure (P1) side and the Vacuum (P2) side. The sure (P1) side is the side containing the silicone gel h isolates the die. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

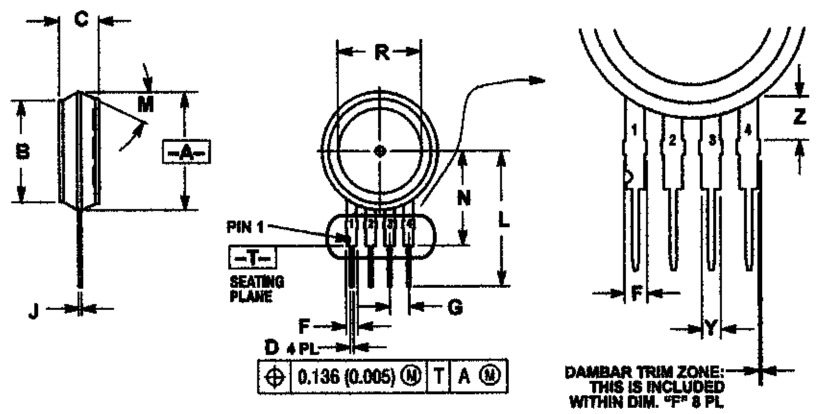
Part Number	Case Type	Pressure (P1) Side Identifier
'X2050D	344	Stainless Steel Cap
'X2050DP	344C	Side with Part Marking
'X2050GP	344B	Side with Port Attached
'X2050GSX	344F	Side with Port Attached

)ERING INFORMATION

PX2050 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic ıent package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure ıections.

›evice Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
ısic Element	Differential	344	MPX2050D	MPX2050D
ırted Elements	Differential, Dual Port	344C	MPX2050DP	MPX2050DP
	Gauge	344B	MPX2050GP	MPX2050GP
	Gauge Axial PC Mount	344F	MPX2050GSX	MPX2050D

PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

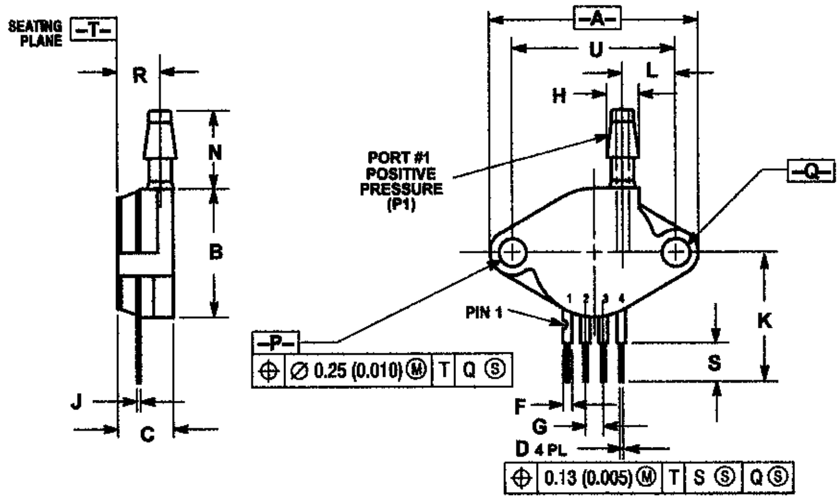
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
Y	0.048	0.052	1.22	1.32
Z	0.106	0.118	2.68	3.00

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

STYLE 2:
PIN 1. V_{CC}
2. – SUPPLY
3. + SUPPLY
4. GROUND

STYLE 3:
PIN 1. GND
2. -VOUT
3. VS
4. +VOUT

CASE 344–15
ISSUE Z



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
2. CONTROLLING DIMENSION: INCH.

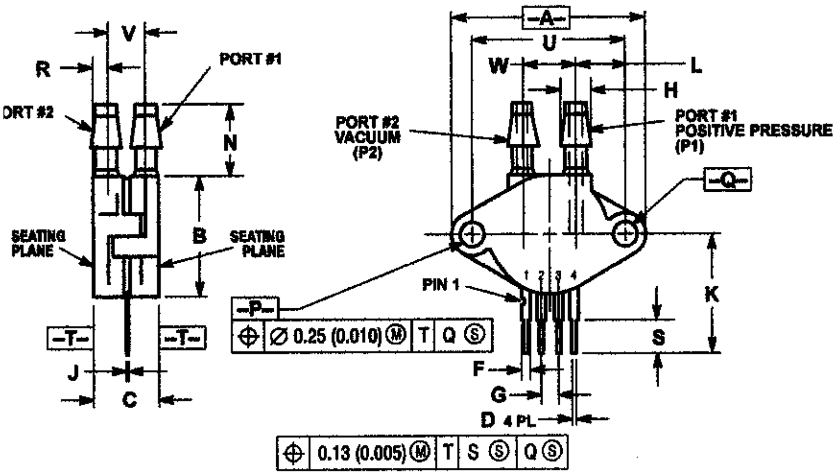
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 344B–01
ISSUE B

Freescale Semiconductor, Inc.

PACKAGE DIMENSIONS — CONTINUED

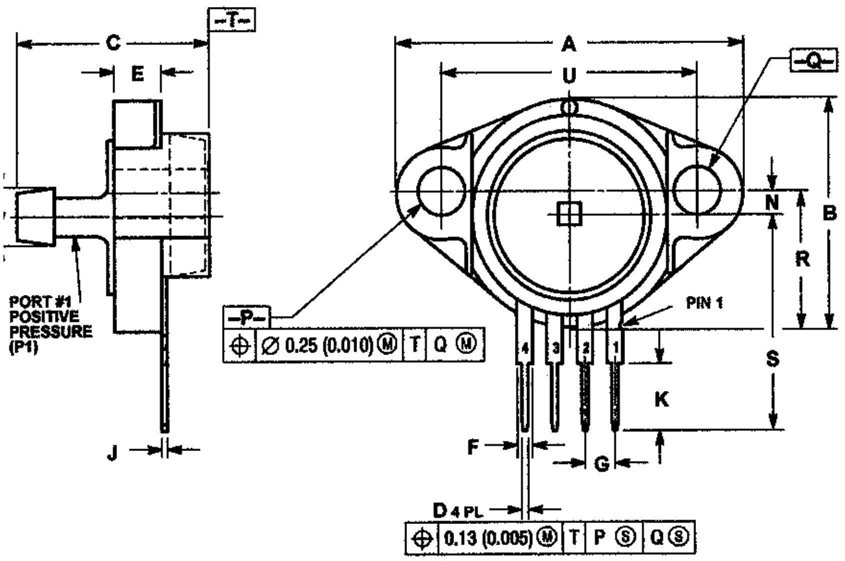


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.248	0.278	6.30	7.06
W	0.310	0.330	7.87	8.38

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 344C–01
ISSUE B



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.016	0.020	0.41	0.51
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.92

STYLE 1:
PIN 1. GROUND
2. V (+) OUT
3. V SUPPLY
4. V (–) OUT

CASE 344F–01
ISSUE B

APPENDIX F

DC Amplifier AD620 Datasheet

ANALOG DEVICES

Low Cost, Low Power Instrumentation Amplifier

AD620

FEATURES

EASY TO USE
Gain Set with One External Resistor
(Gain Range 1 to 1000)
Wide Power Supply Range (±2.3 V to ±18 V)
Higher Performance than Three Op Amp IA Designs
Available in 8-Lead DIP and SOIC Packaging
Low Power, 1.3 mA max Supply Current

EXCELLENT DC PERFORMANCE ("B GRADE")
50 µV max, Input Offset Voltage
0.6 µV/°C max, Input Offset Drift
1.0 nA max, Input Bias Current
100 dB min Common-Mode Rejection Ratio (G = 10)

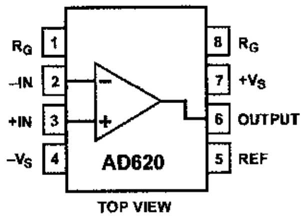
LOW NOISE
9 nV/√Hz, @ 1 kHz, Input Voltage Noise
0.28 µV p-p Noise (0.1 Hz to 10 Hz)

EXCELLENT AC SPECIFICATIONS
120 kHz Bandwidth (G = 100)
15 µs Settling Time to 0.01%

APPLICATIONS
Weigh Scales
ECG and Medical Instrumentation
Transducer Interface
Data Acquisition Systems
Industrial Process Controls
Battery Powered and Portable Equipment

CONNECTION DIAGRAM

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



ODUCT DESCRIPTION

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

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

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

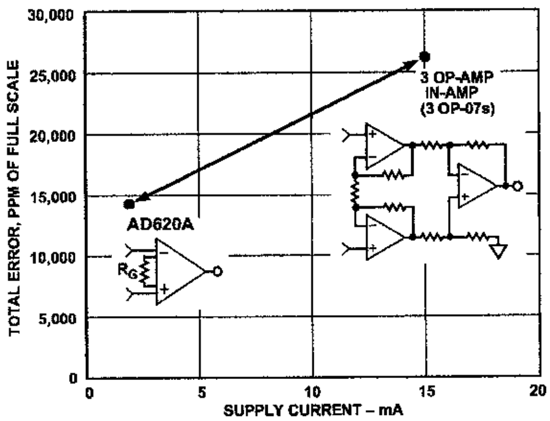


Figure 1. Three Op Amp IA Designs vs. AD620

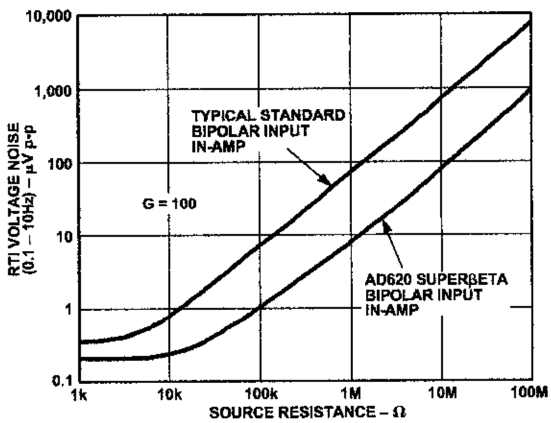


Figure 2. Total Voltage Noise vs. Source Resistance

:V. E

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

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

	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Units
	G = 1 + (49.4 k/R_G)										
tange		1		10,000	1		10,000	1		10,000	
ırror[2]	V_{OUT} = ±10 V										
: 1			0.03	0.10		0.01	0.02		0.03	0.10	%
: 10			0.15	0.30		0.10	0.15		0.15	0.30	%
: 100			0.15	0.30		0.10	0.15		0.15	0.30	%
: 1000			0.40	0.70		0.35	0.50		0.40	0.70	%
ıearity,	V_{OUT} = –10 V to +10 V,										
: 1–1000	R_L = 10 kΩ		10	40		10	40		10	40	ppm
: 1–100	R_L = 2 kΩ		10	95		10	95		10	95	ppm
s. Temperature											
	G =1			10			10			10	ppm/°C
	Gain >1[2]			–50			–50			–50	ppm/°C
3E OFFSET	(Total RTI Error = V_{OSI} + V_{OSO}/G)										
Offset, V_{OSI}	V_S = ±5 V to ±15 V		30	125		15	50		30	125	μV
:r Temperature	V_S = ±5 V to ±15 V			185			85			225	μV
:rage TC	V_S = ±5 V to ±15 V		0.3	1.0		0.1	0.6		0.3	1.0	μV/°C
t Offset, V_{OSO}	V_S = ±15 V		400	1000		200	500		400	1000	μV
	V_S = ±5 V			1500			750			1500	μV
:r Temperature	V_S = ±5 V to ±15 V			2000			1000			2000	μV
:rage TC	V_S = ±5 V to ±15 V		5.0	15		2.5	7.0		5.0	15	μV/°C
Referred to the											
ut vs.											
›ply (PSR)	V_S = ±2.3 V to ±18 V										
3 = 1		80	100		80	100		80	100		dB
3 = 10		95	120		100	120		95	120		dB
3 = 100		110	140		120	140		110	140		dB
3 = 1000		110	140		120	140		110	140		dB
CURRENT											
Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
:r Temperature				2.5			1.5			4	nA
:rage TC			3.0			3.0			8.0		pA/°C
Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
:r Temperature				1.5			0.75			2.0	nA
:rage TC			1.5			1.5			8.0		pA/°C
Impedance											
ferential			10‖2			10‖2			10‖2		GΩ‖pF
mmon-Mode			10‖2			10‖2			10‖2		GΩ‖pF
Voltage Range[3]	V_S = ±2.3 V to ±5 V	$-V_S$ + 1.9		$+V_S$ – 1.2	$-V_S$ + 1.9		$+V_S$ – 1.2	$-V_S$ + 1.9		$+V_S$ – 1.2	V
er Temperature		$-V_S$ + 2.1		$+V_S$ – 1.3	$-V_S$ + 2.1		$+V_S$ – 1.3	$-V_S$ + 2.1		$+V_S$ – 1.3	V
	V_S = ±5 V to ±18 V	$-V_S$ + 1.9		$+V_S$ – 1.4	$-V_S$ + 1.9		$+V_S$ – 1.4	$-V_S$ + 1.9		$+V_S$ – 1.4	V
er Temperature		$-V_S$ + 2.1		$+V_S$ – 1.4	$-V_S$ + 2.1		$+V_S$ – 1.4	$-V_S$ + 2.3		$+V_S$ – 1.4	V
ıon-Mode Rejection											
tio DC to 60 Hz with											
Ω Source Imbalance	V_{CM} = 0 V to ±10 V										
G = 1		73	90		80	90		73	90		dB
G = 10		93	110		100	110		93	110		dB
G = 100		110	130		120	130		110	130		dB
G = 1000		110	130		120	130		110	130		dB
T											
ıt Swing	R_L = 10 kΩ,										
	V_S = ±2.3 V to ±5 V	$-V_S$ + 1.1		$+V_S$ – 1.2	$-V_S$ + 1.1		$+V_S$ – 1.2	$-V_S$ + 1.1		$+V_S$ – 1.2	V
er Temperature		$-V_S$ + 1.4		$+V_S$ – 1.3	$-V_S$ + 1.4		$+V_S$ – 1.3	$-V_S$ + 1.6		$+V_S$ – 1.3	V
	V_S = ±5 V to ±18 V	$-V_S$ + 1.2		$+V_S$ – 1.4	$-V_S$ + 1.2		$+V_S$ – 1.4	$-V_S$ + 1.2		$+V_S$ – 1.4	V
er Temperature		$-V_S$ + 1.6		$+V_S$ – 1.5	$-V_S$ + 1.6		$+V_S$ – 1.5	$-V_S$ + 2.3		$+V_S$ – 1.5	V
Current Circuit			±18			±18			±18		mA

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

)TES
:e Analog Devices military data sheet for 883B tested specifications.
oes not include effects of external resistor R_G.
ne input grounded. G = 1.
his is defined as the same supply range which is used to specify PSR.
ecifications subject to change without notice.

.UTE MAXIMUM RATINGS[1]

Voltage . . . . ±18 V
l Power Dissipation[2] . . . . 650 mW
'oltage (Common Mode) . . . . $\pm V_S$
ıtial Input Voltage . . . . ±25 V
Short Circuit Duration . . . . Indefinite
Temperature Range (Q) . . . . –65°C to +150°C
Temperature Range (N, R) . . . . –65°C to +125°C
ng Temperature Range
20 (A, B) . . . . –40°C to +85°C
20 (S) . . . . –55°C to +125°C
'emperature Range
lering 10 seconds) . . . . +300°C

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

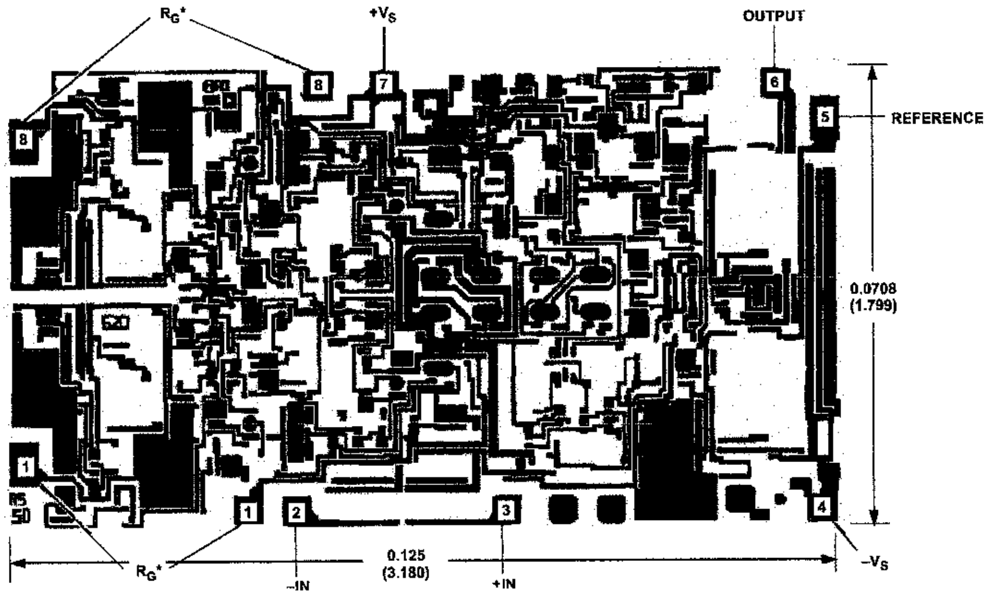
ORDERING GUIDE

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

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

METALIZATION PHOTOGRAPH

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



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

'ION

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

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

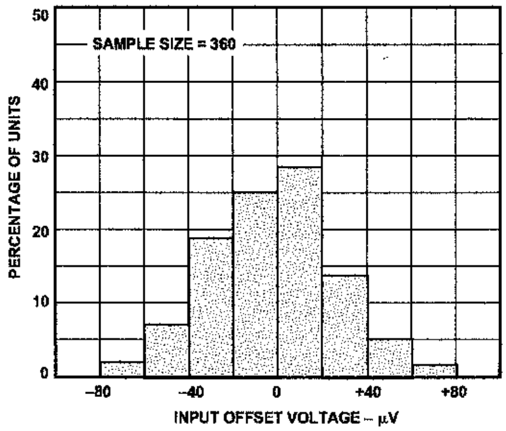


Figure 3. Typical Distribution of Input Offset Voltage

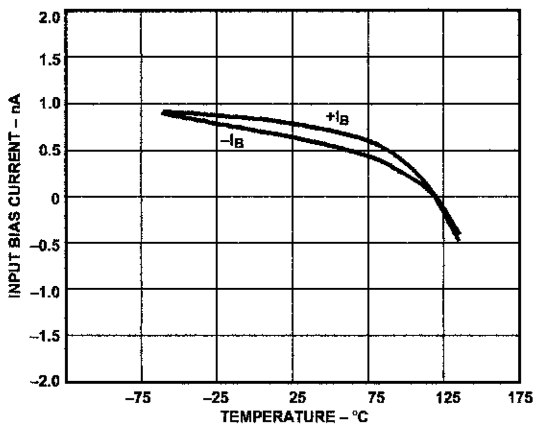


Figure 6. Input Bias Current vs. Temperature

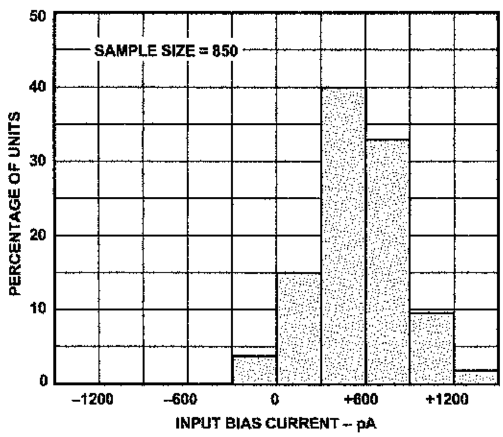


Figure 4. Typical Distribution of Input Bias Current

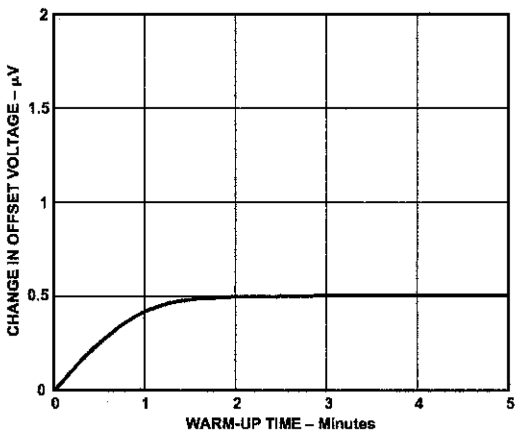


Figure 7. Change in Input Offset Voltage vs. Warm-Up Time

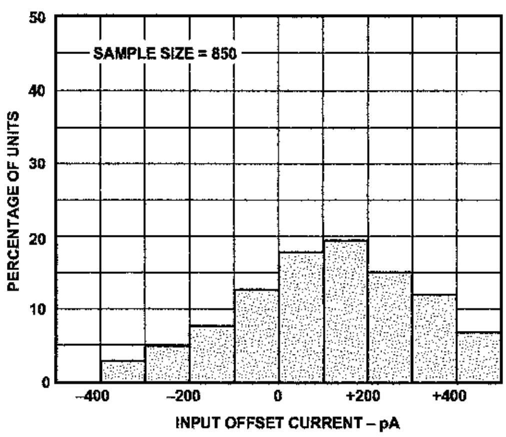


Figure 5. Typical Distribution of Input Offset Current

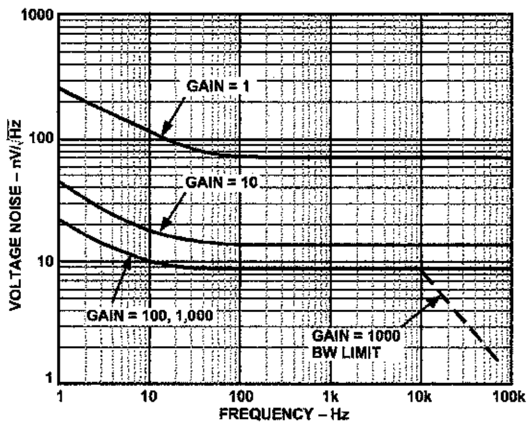
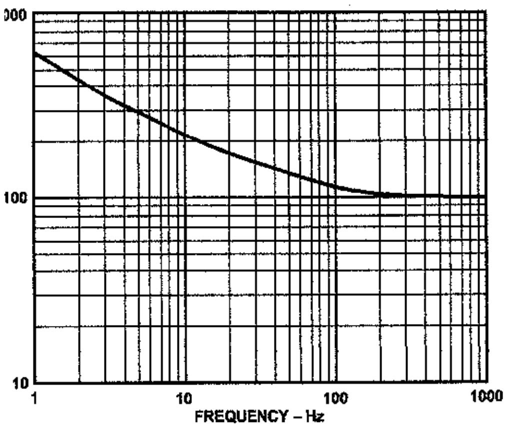


Figure 8. Voltage Noise Spectral Density vs. Frequency, (G = 1–1000)

0–Typical Characteristics



e 9. *Current Noise Spectral Density vs. Frequency*

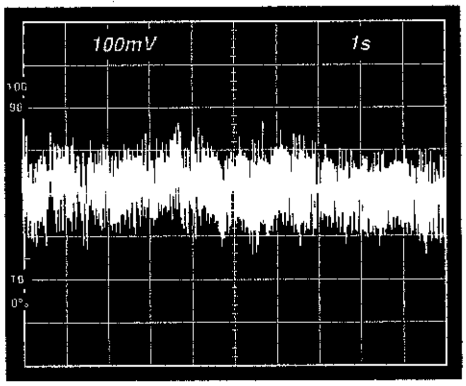
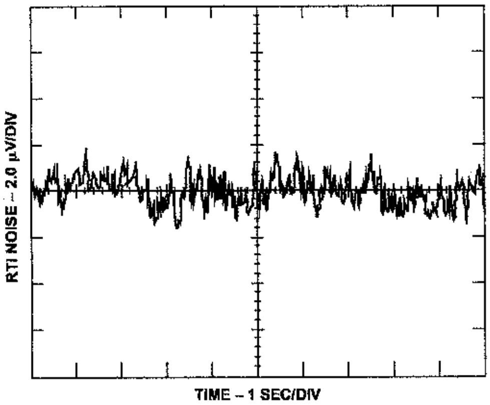


Figure 11. 0.1 Hz to 10 Hz Current Noise, 5 pA/Div



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

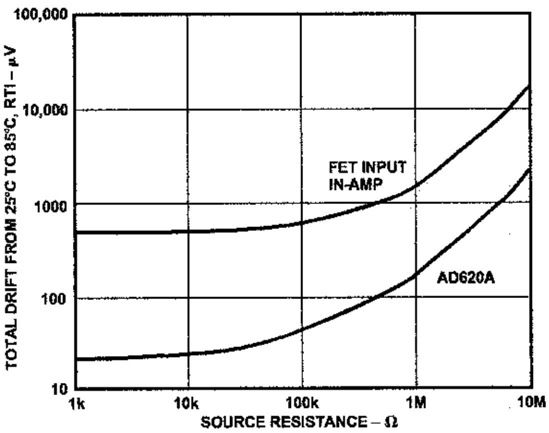
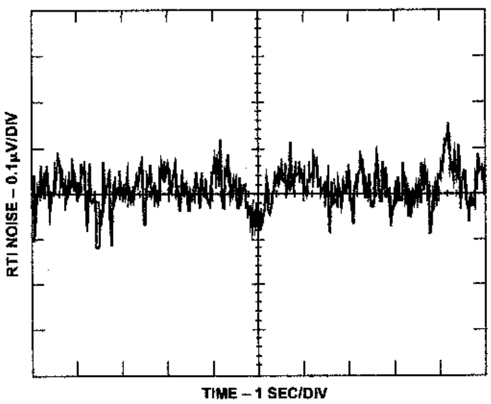


Figure 12. Total Drift vs. Source Resistance



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

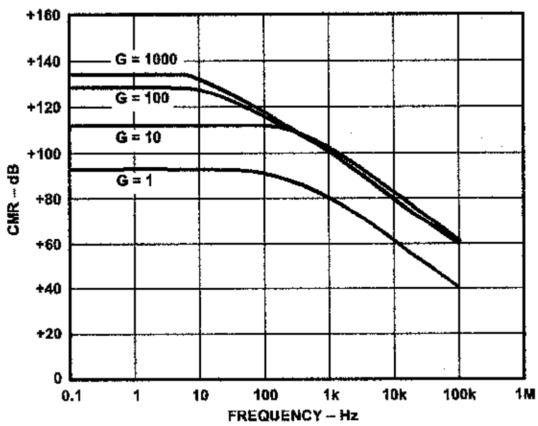
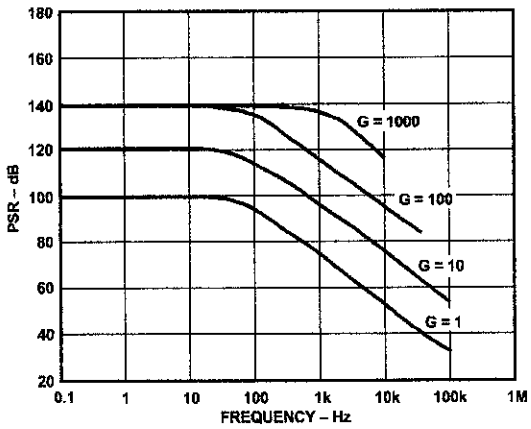


Figure 13. CMR vs. Frequency, RTI, Zero to 1 kΩ Source Imbalance



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

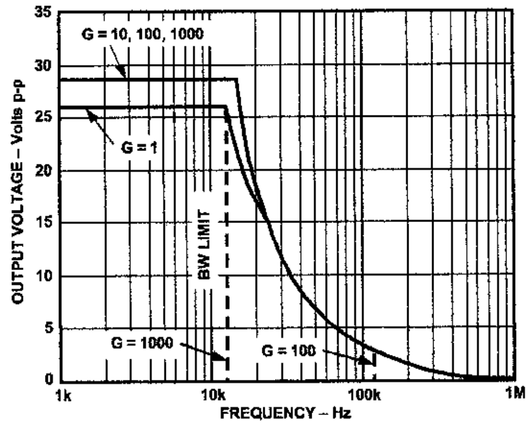
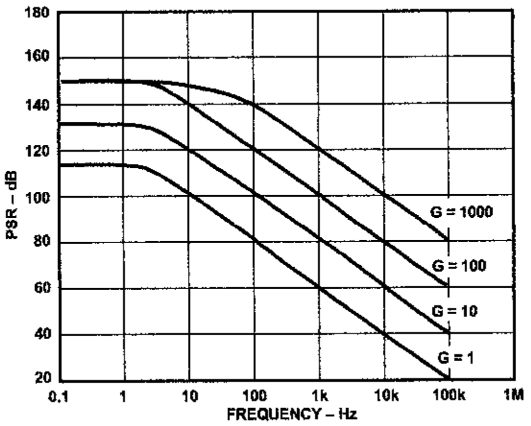


Figure 17. Large Signal Frequency Response



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

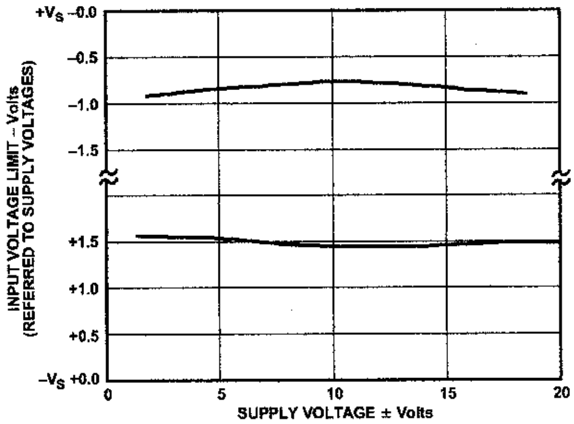


Figure 18. Input Voltage Range vs. Supply Voltage, G = 1

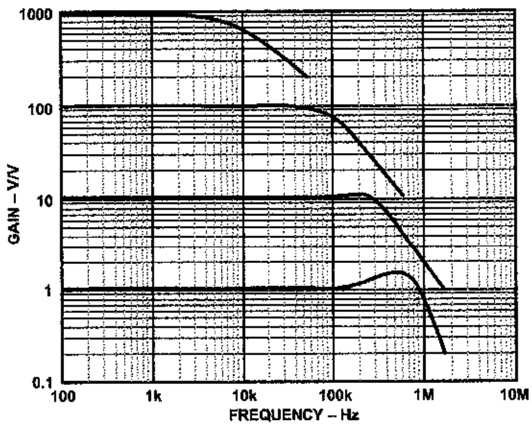


Figure 16. Gain vs. Frequency

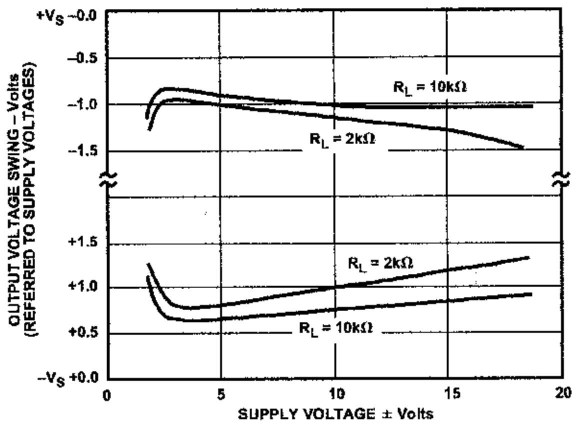
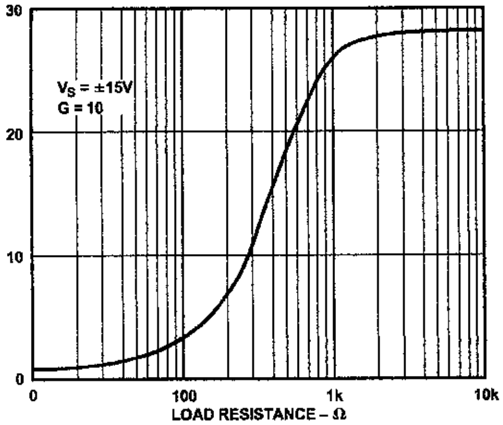


Figure 19. Output Voltage Swing vs. Supply Voltage, G = 10

0



re 20. Output Voltage Swing vs. Load Resistance

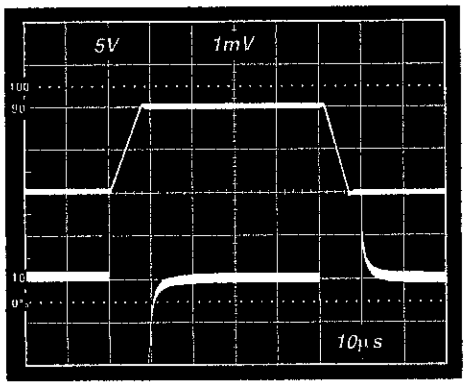
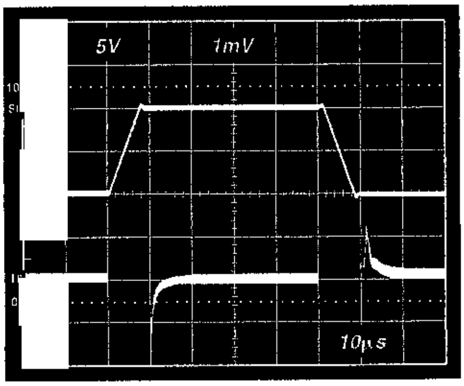


Figure 23. Large Signal Response and Settling Time, G = 10 (0.5 mV = 001%)



21. Large Signal Pulse Response and Settling Time 0.5 mV = 0.01%)

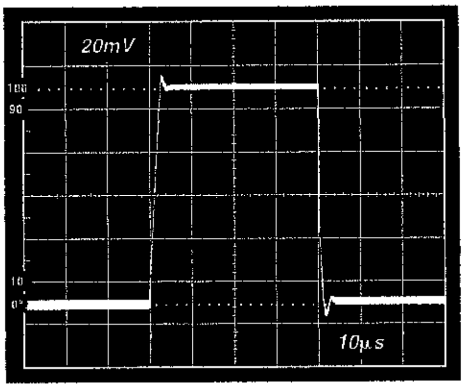
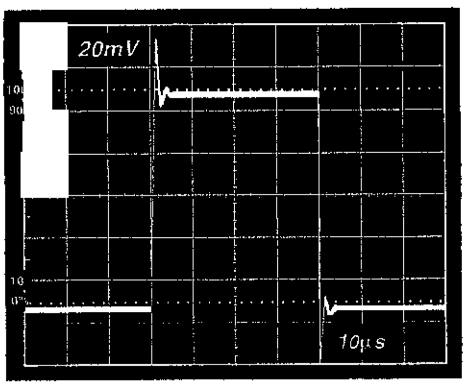


Figure 24. Small Signal Response, G = 10, R_L = 2 kΩ, C_L = 100 pF



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

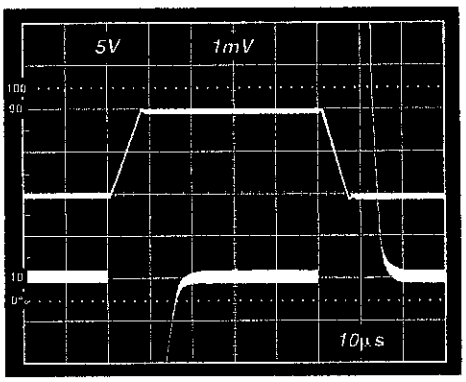


Figure 25. Large Signal Response and Settling Time, G = 100 (0.5 mV = 0.01%)

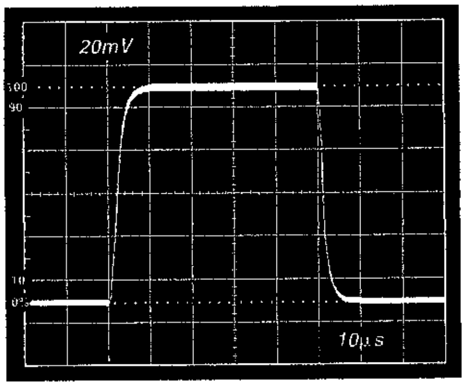


Figure 26. Small Signal Pulse Response, G = 100, R_L = 2 kΩ, C_L = 100 pF

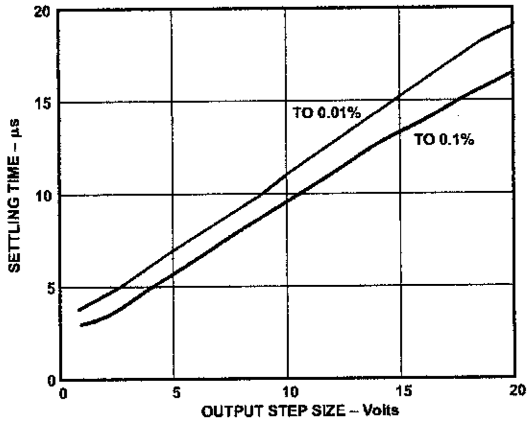


Figure 29. Settling Time vs. Step Size (G = 1)

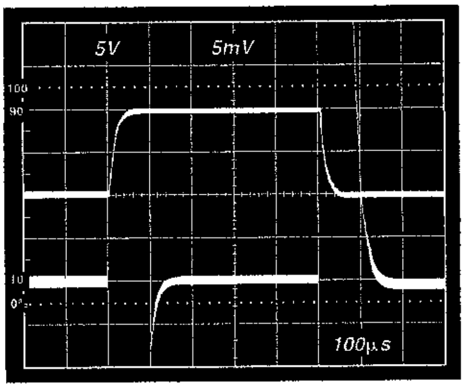


Figure 27. Large Signal Response and Settling Time, G = 1000 (0.5 mV = 0.01%)

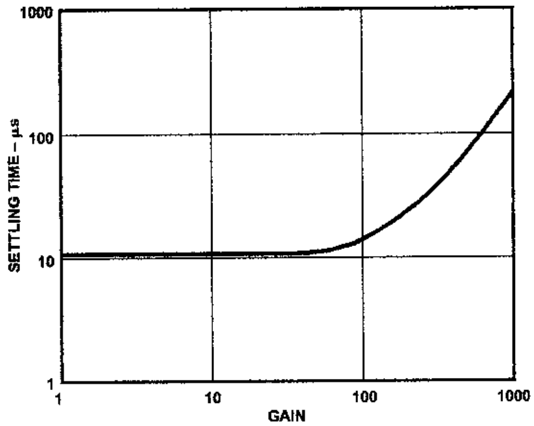


Figure 30. Settling Time to 0.01% vs. Gain, for a 10 V Step

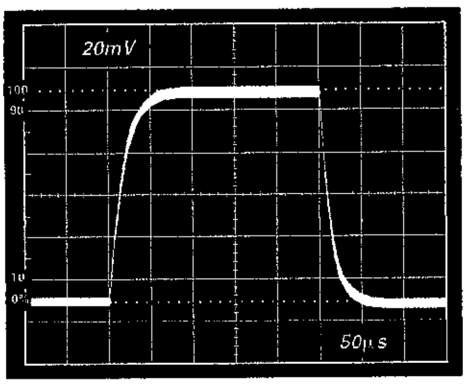


Figure 28. Small Signal Pulse Response, G = 1000, R_L = 2 kΩ, C_L = 100 pF

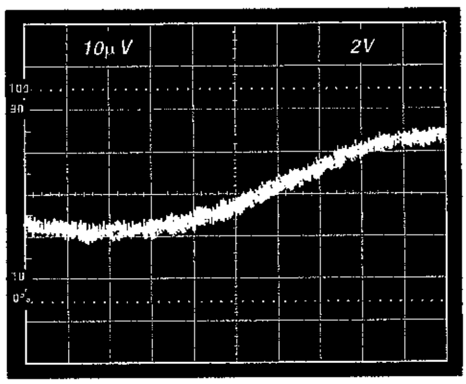
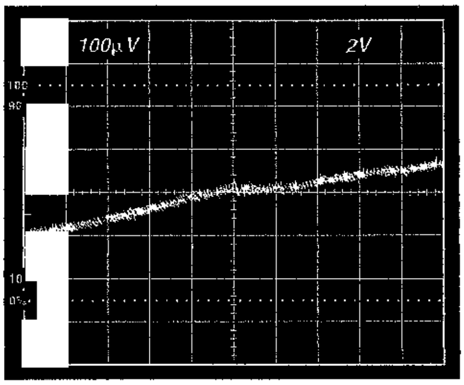
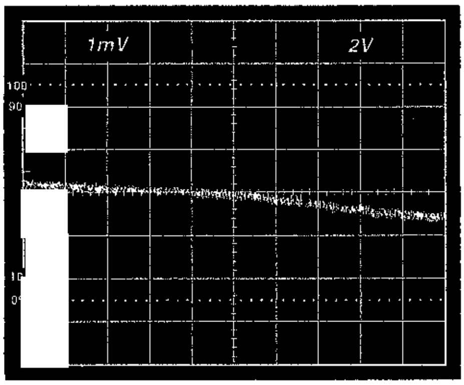


Figure 31a. Gain Nonlinearity, G = 1, R_L = 10 kΩ (10 µV = 1 ppm)



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



ıre 31c. Gain Nonlinearity, G = 1000, R_L = 10 kΩ
ıV = 100 ppm)

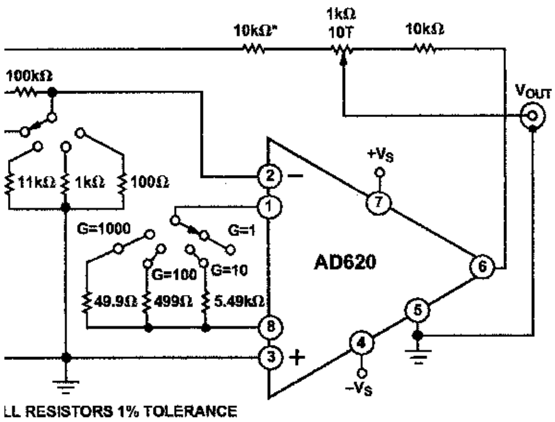


Figure 32. Settling Time Test Circuit

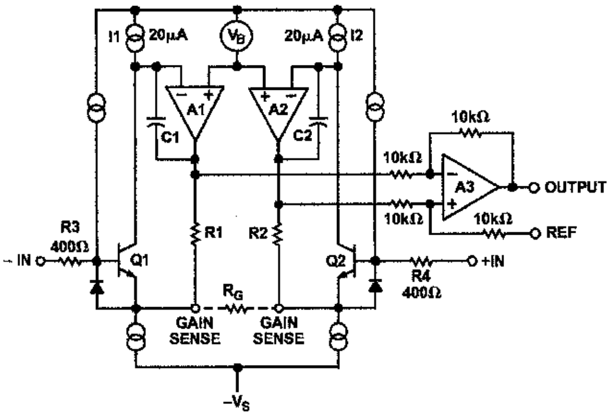


Figure 33. Simplified Schematic of AD620

THEORY OF OPERATION

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

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

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

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

The gain equation is then

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

so that

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

ıke vs. Buy: A Typical Bridge Application Error Budget
e AD620 offers improved performance over "homebrew" ee op amp IA designs, along with smaller size, fewer compo- ıts and 10× lower supply current. In the typical application, ıwn in Figure 34, a gain of 100 is required to amplify a bridge ːput of 20 mV full scale over the industrial temperature range -40°C to +85°C. The error budget table below shows how to culate the effect various error sources have on circuit accuracy.

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

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

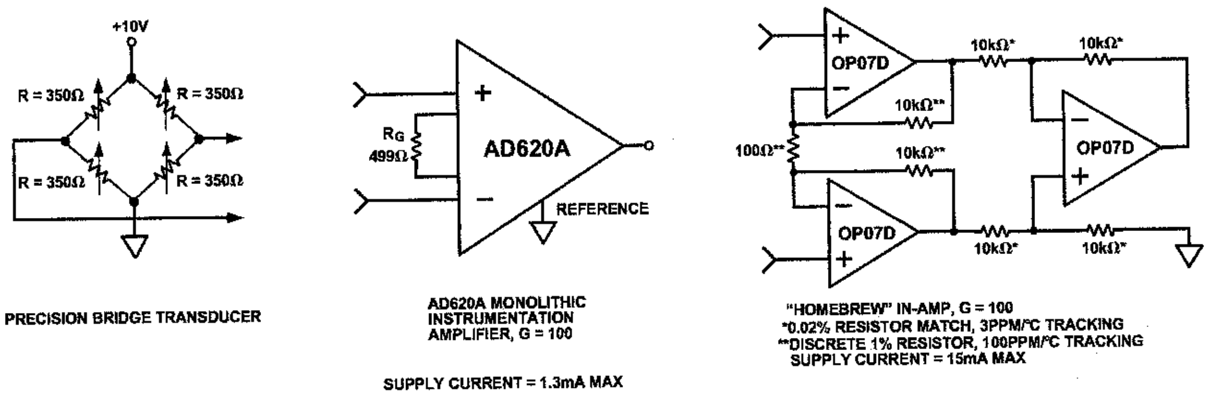


Figure 34. Make vs. Buy

Table I. Make vs. Buy Error Budget

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

· = 100, V_S = ±15 V.

ıll errors are min/max and referred to input.)

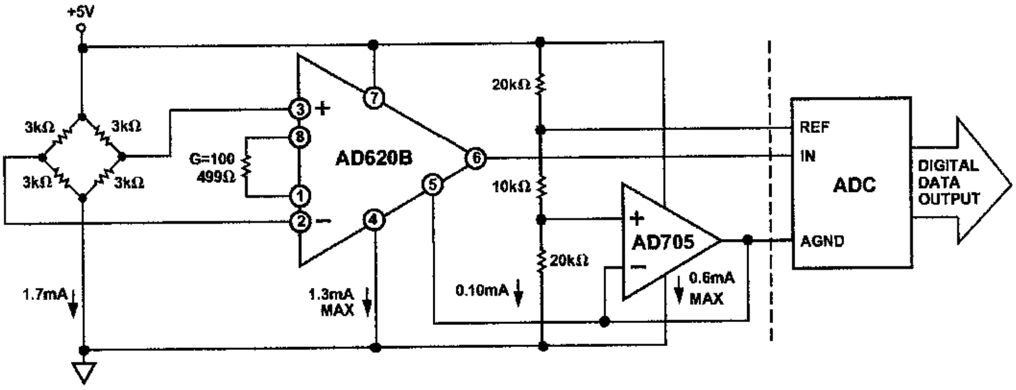


Figure 35. A Pressure Monitor Circuit which Operates on a +5 V Single Supply

'e Measurement

h useful in many bridge applications such as weigh he AD620 is especially suitable for higher resistance : sensors powered at lower voltages where small size and ver become more significant.

)5 shows a 3 kΩ pressure transducer bridge powered ; V. In such a circuit, the bridge consumes only 1.7 mA. the AD620 and a buffered voltage divider allows the) be conditioned for only 3.8 mA of total supply current.

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

Medical ECG

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

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

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

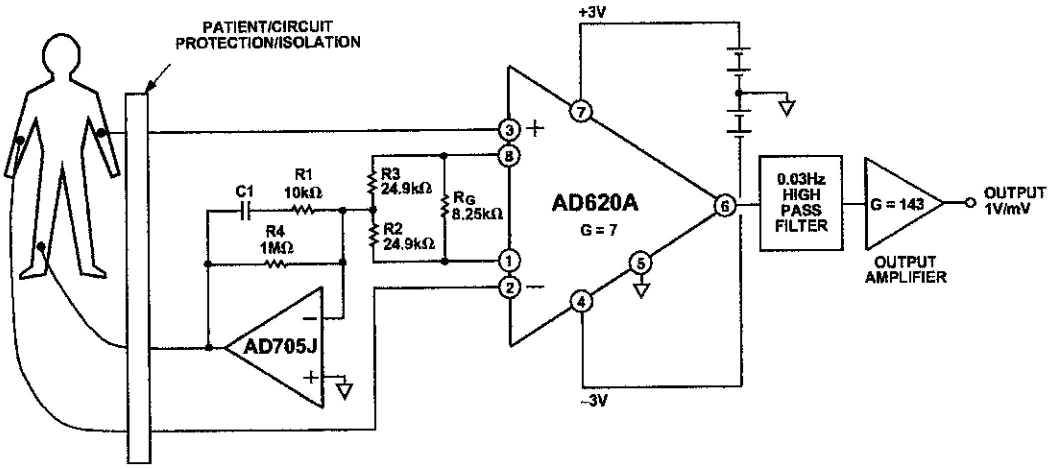


Figure 36. A Medical ECG Monitor Circuit

:cision V-I Converter

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

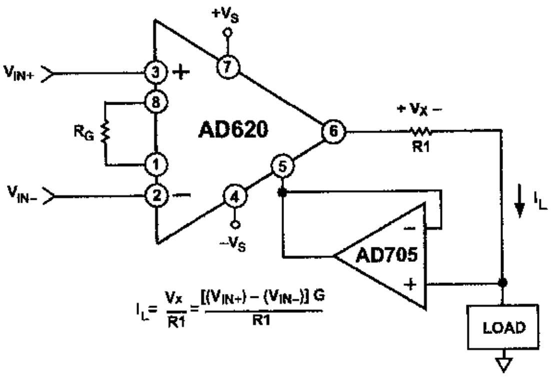


Figure 37. Precision Voltage-to-Current Converter (Operates on 1.8 mA, ±3 V)

ιIN SELECTION

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

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

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

Table II. Required Values of Gain Resistors

⁄₀ Std Table ılue of R_G, Ω	Calculated Gain	0.1% Std Table Value of R_G, Ω	Calculated Gain
49.9 k	1.990	49.3 k	2.002
12.4 k	4.984	12.4 k	4.984
5.49 k	9.998	5.49 k	9.998
2.61 k	19.93	2.61 k	19.93
1.00 k	50.40	1.01 k	49.91
499	100.0	499	100.0
249	199.4	249	199.4
100	495.0	98.8	501.0
49.9	991.0	49.3	1,003

INPUT AND OUTPUT OFFSET VOLTAGE

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

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

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

REFERENCE TERMINAL

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

INPUT PROTECTION

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

RF INTERFERENCE

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

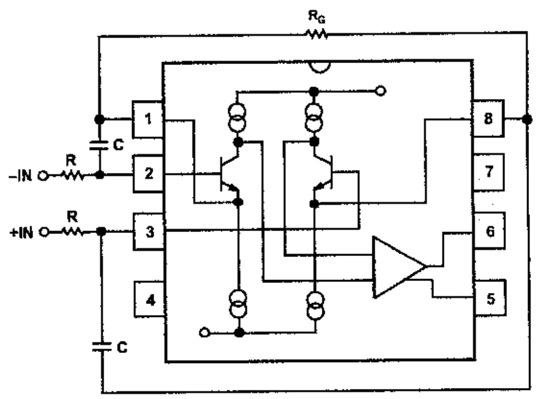


Figure 38. Circuit to Attenuate RF Interference

ON-MODE REJECTION

entation amplifiers like the AD620 offer high CMR, a measure of the change in output voltage when both re changed by equal amounts. These specifications are given for a full-range input voltage change and a speci- rce imbalance.

mal CMR the reference terminal should be tied to a low nce point, and differences in capacitance and resistance be kept to a minimum between the two inputs. In many ions shielded cables are used to minimize noise, and for IR over frequency the shield should be properly driven. 39 and 40 show active data guards that are configured ove ac common-mode rejections by "bootstrapping" the nces of input cable shields, thus minimizing the capaci- ismatch between the inputs.

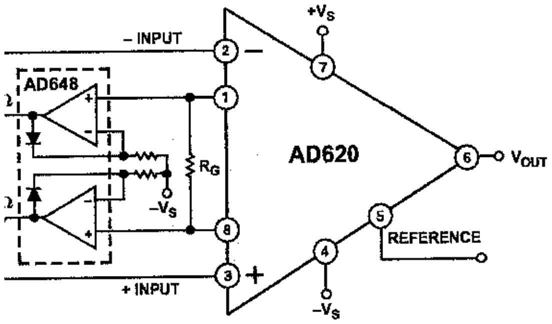


Figure 39. Differential Shield Driver

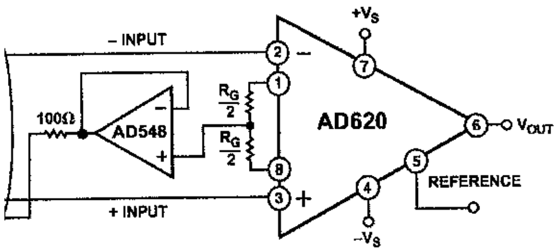


Figure 40. Common-Mode Shield Driver

GROUNDING

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

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

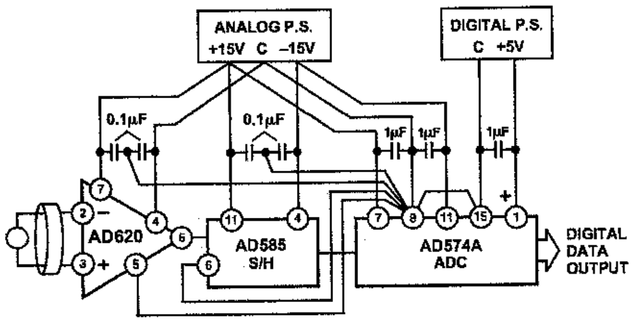


Figure 41. Basic Grounding Practice

OUND RETURNS FOR INPUT BIAS CURRENTS

ut bias currents are those currents necessary to bias the input ısistors of an amplifier. There must be a direct return path these currents; therefore, when amplifying "floating" input sources such as transformers, or ac-coupled sources, there must be a dc path from each input to ground as shown in Figure 42. Refer to the *Instrumentation Amplifier Application Guide* (free from Analog Devices) for more information regarding in amp applications.

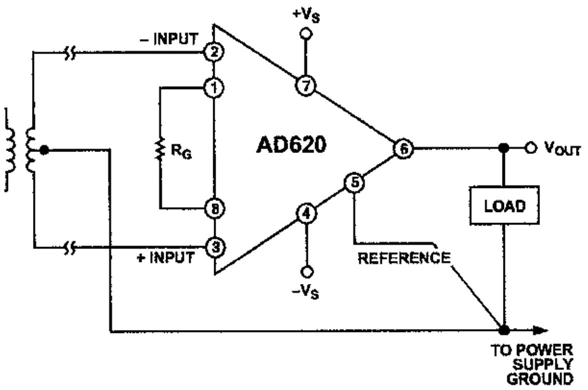


Figure 42a. Ground Returns for Bias Currents with Transformer Coupled Inputs

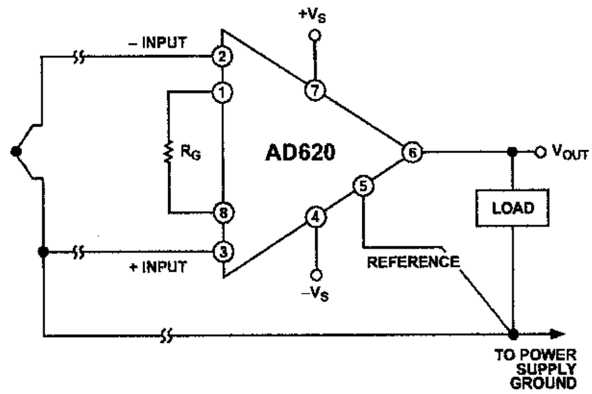


Figure 42b. Ground Returns for Bias Currents with Thermocouple Inputs

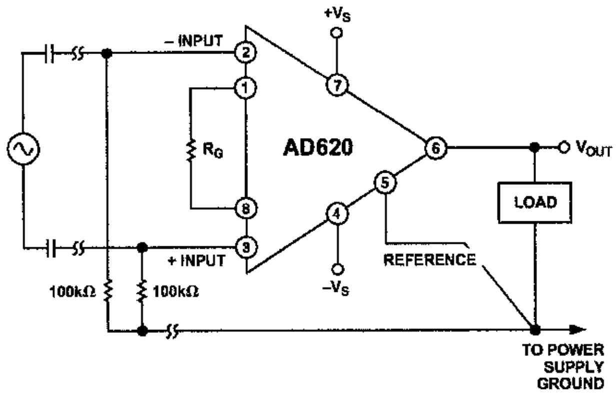


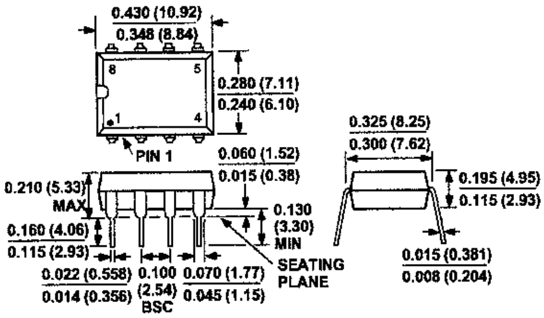
Figure 42c. Ground Returns for Bias Currents with AC Coupled Inputs

0

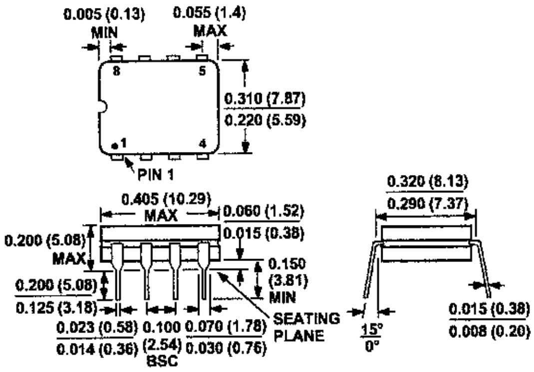
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

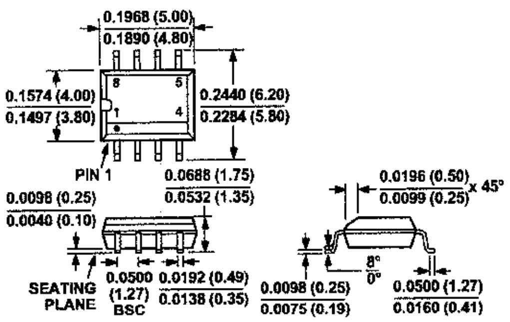
Plastic DIP (N-8) Package



Cerdip (Q-8) Package



SOIC (SO-8) Package



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PRINTED IN U.S.A.