Palestine Polytechnic University

College of Engineering

Electrical Engineering Department

Design of a Non-Invasive Diabetes Measurement System Using Impedance Plethysmography

Project Team

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Abstract:

Measuring the bioelectrical impedance value for a human tissue can be used to determine many vital variables as fat and salt inside the body tissue, Some recent studies suggest there is a relationship between the bioelectrical impedance and the percentage of glucose in the blood, therefore this opens the way for the development of a new techniques for determining the blood glucose percentage by measuring the bioelectrical impedance.

This project includes three phases:

The first phase is a design a system to measure the rate of diabetes in the blood non-invasively (without need to the blood sample), through the using of bioelectrical impedance technique, this system depends on using of constant current source that passes the current from one point to another on the human body, then we have to measure the voltage difference between these two points, next we have to measure bioelectrical impedance between them by using Ohm's law.

The second phase includes the construction of mathematical equation describe the relationship between obtained values by the bioelectrical impedance system and the obtained values by traditional system, this must done by examination the diabetes for a sample of patients (ranging from 30 to 40 patients) by the two systems to build tables that compare between the two system values and then analyze these tables by numerical analysis laws in order to derive a mathematical equation describes the relationship between the two systems.

The third phase includes the showing of the measurement result by substitution the values of our system in the mathematical equation that we have obtained in the previous phase.

مُـلـخـص

يُتيح قياس نسبة المقاومة الكهربائية الحيوية لجسم الإنسان إمكانية تقدير وقياس عدد من المتغيرات الهامة لتشخيص الحالة الصحية للإنسان مثل قياس نسبة الدهون و الأملاح داخل أنسجة الجسم البشري، وتشير عدد من الدراسات الحديثة إلى وجود علاقة بين قيمة المقاومة الكهربائية الحيوية للجسم مع نسبة السكر في الدم، وهو الأمر الذي يفتح المجال لتطوير طرق جديدة لقياس نسبة السكر في الدم دون الحاجة إلى عينات الدم التي يشكل الحصول عليها من جسم المريض عملية مزعجة ومؤلمة وقد تتسبب في انتقال الأمراض المعدية إليه عن طريق الدم وخصوصا أنها عملية يومية .

يمكن تقسيم هذا المشروع إلى ثلاث مراحل :

المرحلة الأولى: تشمل تصميم وبناء نظام جديد لقياس نسبة السكر في الدم دون الحاجة لعينات الدم من خلال قياس قيمة المقاومة الكهربائية الحيوية للجسم التى تتغير بتغير نسبة السكر في الدم، حيث يقوم هذا النظام على استخدام مصدر تيار ثابت (يعمل على إنتاج تيار ذي قيمة ثابتة) حيث سيمر هذا التيار من نقط إلى أخرى على جسم الإنسان، ثم يتم بعد ذلك قياس فرق الجهد بين هاتين النقطتين ويتبع ذلك حساب قيمة المقاومة بين هاتين النقطتين باستخدام قانون أوم حيث تمثل هذه القيمة مقدار المقاومة الكهربائية الحيوية لأنسجة الجسم بين هاتين النقطتين.

المرحلة الثانية: تشمل عملية بناء علاقة رياضية واضحة بين قيم قراءات نظام المقاومة الكهربائية الحيوية وبين قيم القراءات بواسطة الطرق التقليدية ويتم ذلك بإجراء فحص السكري على عينة من المرضى (تتراوح ما بين ٣٠ الى ٤٠ مريض) بواسطة النظامين لبناء جداول للمقارنة بينهما ومن ثم تحليل هذه الجداول بواسطة قوانين التحليل العددي بهدف إشتقاق مُعادلة رياضية تصف العلاقة بين قراءات كل من النظامين.

المرحلة الثالثة: تشمل إظهار نتيجة القياس وذلك بعد تعويض قيم قراءات نظامنا المذكور أعلاه في المعادلة الرياضية التي حصلنا عليها في المرحلة السابقة.

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Introduction

Chapter One

Introduction

1.1 Introduction

Diabetes is one of the most dangerous and deadliest diseases to human health, this disease spread dramatically in the countries of the Mediterranean basin, because of the dietary habits of the people of this region, where the population of these areas depends on eating large amounts of starches and carbohydrates daily.

Perhaps the most notable disadvantages of this disease lies in the serious complication that affects the patient's body where it is usually the cause of many other diseases such as kidney failure and gangrene .

Perhaps the biggest problem faced by patients is a measure of the percentage of sugar they have, where it is required to obtain a sample of blood and thus harming themselves by perforating the skin by painful, inhumane and ways may they has serious complications.

There are more than one method for measuring the glucose of the blood, the first one was to convert the sugar in blood into PH, this idea was easy to apply, but there was one problem , that is the materials used to convert the sugar into PH of companies and didn't allow to give their secret to anyone, and the other method, which was called chemical reaction, this method also was easy, but we faced a problem in the chemical materials, that materials not available, and we have to recommend for it and that will take a long time, in addition it may be not found.

But there is a major problem facing all the methods currently used. This problem is the need to withdraw a blood sample from the patient to do a test, the obtain of the sample is carried out through repeated acupuncture for tissue of the patient, but this is very annoying operation to him and makes the patient often avoids doing the test, in addition to the wounds that caused by acupuncture may cause transfer serious diseases and infectious to the patient through the blood.

Finally, we are motivated to design a non-invasively method (without need to the blood sample) bioelectrical impedance technology; this method is easy and don't harm the patient.

Our final project is to design and build glucose devices that can measure a user's blood, and it does consist three phases:

- The first phase is a design of system to measure the rate of diabetes in the blood non-invasively (without need to the blood sample), through the using of bioelectrical impedance technique, this system depends on using of constant current source that passes the current from one point to another on the human body, then we have to measure the voltage difference between these two points, next we have to measure bioelectrical impedance between them by using Ohm's law.

- The second phase includes the construction of mathematical equation describe the relationship between obtained values by the bioelectrical impedance system and the obtained values by traditional system, this must done by examination the diabetes for a sample of patients (ranging from 30 to 40 patients) by the two systems to build tables that compare between the two system values and then analyze these tables by numerical analysis laws in order to derive a mathematical equation describes the relationship between the two systems.

- The third phase includes the showing of the measurement result by substitution the values of our system in the mathematical equation that we have obtained in the previous phase.

1.2 Project objectives

The measuring of the glucose in the blood by conventional methods is very unpleasant for the patient because they require tingling and hurting the patient body which might cause pain, suffering wounds and infection. Our goal is to design a new easy and safe method to measure the glucose without need to withdrawal of a blood sample from the patient body.

1.3 Project importance

Around the world, tens millions are afflicted with diabetes, with billions Dollars being spent annually in diabetes related treatment. The development of a non-invasive system to measure glucose could improve the life of diabetic patients by allowing them to comfortably and painlessly measure their blood sugar. Impedance plethysmography of the finger can be used to measure blood resistivity, which may correlate to blood glucose levels and other physiological metrics.

The importance this method comes from the following:

- It's non-invasive.
- Safe.
- Simple to use.
- Test can be repeated.
- The patient doesn't require special preparation.

1.4 Project content

Our report is divided into five chapter, these chapter is:

Chapter one: Introduction

Introduction to talk about the project objectives, importance, time plan and cost plan.

Chapter two: Physiological background

Diabetes definition, reasons and statistics, regulation of glucose in blood and reasons of monitoring glucose.

Chapter three: Measurement of glucose in blood

Introduction to methods of measuring blood glucose, reference intervals, the use of the spectrophotometer, Beer's Law and the bioelectrical impedance method.

Chapter four: Project conceptual design

General block diagram and circuit design.

Chapter five: Results and conclusions.

Conclusion, results and discussions.

1.5 Time plan

Table 1.1

Time scheduling

Time (week)	Activity
5	Study blood sugar physiology
7	Study blood sugar measurements
8	Literature review
10	Design the schematic block diagram
11	Design theory
12	Theoretical report ready
13	Discussion for project

1.6 Cost

Table 1.2

Economical study

Component	Cost (NIS)
Electrode leads	240
PCB	500
1N4001 Diodes (2)	10
Capacitors	23
Resistors	26
AD620 (2)	90
LM339 (2)	16
TL084	8
LM741 (4)	20
NE555	5
Total Cost	938

Chapter 2

Physiological Background

2.1 Introduction

2.2 Regulation of Glucose

2.3 Reasons of monitoring glucose

2.4 What is diabetes?

2.5 Diabetes Statistics

Chapter Two

Physiological Background

2.1 Introduction

Glucose is a form of simple sugar, which is carbohydrate. Our cells need it for energy. Glucose is important for cellular respiration. Chemically, glucose is made up of six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. Naturally, Glucose can be found in planets and is one of the products need for photosynthesis. Glucose is found in fungi and starchy plants. Animals synthesize glucose in the liver and kidneys. Commercially, glucose is found in food products such as corn, rice, wheat products, and potatoes.

Glucose is energy source for the body. It is the main source of energy for the brain, and when glucose levels are low, person's mental abilities may be impaired. Since glucose is distributed through our bodies by our blood streams, where it meet and reacts with insulin, ingesting too much glucose will overwhelm body. When the body's glucose level is too high, the body becomes hyperglycemic which means you have too much sugar and too little insulin. Hyperglycemia and diabetes are disorders that result when the body cannot regulate glucose and/or insulin levels, and can happen after years of consuming too much glucose. People who consume too little glucose (usually by not eating enough food in general) become hyperglycemic. This results in low energy levels and can lead to fainting [1].

2.2 Regulation of Glucose

The human body wants blood glucose (blood sugar) maintained in a very narrow range. Insulin and glucagon are the hormones which make this happen. Both insulin and glucagon are secreted from pancreas, and thus are referred to as pancreatic endocrine hormones. Figure 2.2 shows the intimate relationship both insulin and glucagon have to each other. Note that the pancreas serves as the

central player in this scheme. It is production of insulin and glucagon by the pancreas which ultimately determines if a patient has diabetes, hypoglycemia, or some other sugar problems. Insulin and glucagon are hormones secreted by islet cells within the pancreas. They are both secreted in response to blood sugar levels, but in opposite fashion.

Insulin is normally secreted by the beta cells (a type of islet cell) of the pancreas. The stimulus for insulin secretion is a high blood glucose...it's as simple as that! Although there is always a low level of insulin secreted by the pancreas, the amount secreted into the blood increases as the blood glucose rises. Similarly, as blood glucose falls, the amount of insulin secreted by the pancreatic islets goes down. Insulin has an effect on a number of cells, including muscle, red blood cells, and fat cells. In response to insulin, these cells absorb glucose out of the blood, having the net effect of lowering the high blood glucose levels into the normal range.

As shown in **Figure 2.1**. Glucagon is secreted by the alpha cells of the pancreatic islets in much the same manner as insulin, except in the opposite direction. If blood glucose is high, then no glucagon is secreted. When blood glucose goes Low, however, (such as between meals, and during exercise) more and more glucagon is secreted. Like insulin, glucagon has an effect on many cells of the body, but most notably the liver. The effect of glucagon is to make the liver release the glucose it has stored in its cells into the bloodstream, with the net effect of increasing blood glucose. Glucagon also induces the liver (and some other cells such as muscle) to make glucose out of building blocks obtained from other nutrients found in the body (eg, protein).

Our bodies desire blood glucose to be maintained between 70 mg/dl and 110 mg/dl (mg/dl means milligrams of glucose in 100 milliliters of blood). As shown in **Table 2.1** the glucose below 70 is termed "hypoglycemia". Above 110 can be normal if you have eaten within 2 to 3 hours. Even after you have eaten, however, your glucose should be below 180. Above 180 is termed "hyperglycemia" (too much glucose in the blood). If you have two blood sugar measurements above 200 after drinking a sugar-water drink (glucose tolerance test), then you are diagnosed with diabetes [2].

Table 2.1

Blood Sugar Range

Elevated Blood Sugar Range	Risk of Complications
Above 800 mg/dl	Life threatening acute risk
400 mg/dl – 800 mg/dl	Very high risk
250 mg/dl – 400 mg/dl	High risk
180 mg/dl – 250 mg/dl	Moderate risk
110 mg/dl – 180 mg/dl	Low risk
70 mg/dl – 110 mg/dl	Normal risk

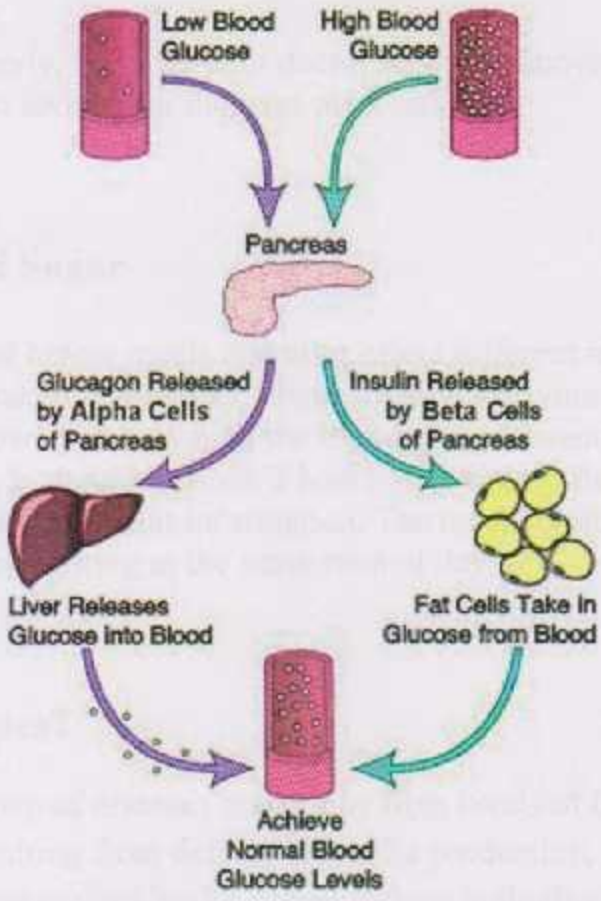

Figure 2.1: Roles if insulin and glucagon. [3]

2.3 Reasons of monitoring glucose

There are many reasons that may encourage to monitor glucose in blood:

1. Monitoring shows you what your blood glucose is doing at the best of times, while you are feeling good in your usual routine. This allows you to interpret the readings under more unusual circumstances. It also lets you to catch any changes in your glucose as time goes by.
2. It shows you how your blood glucose varies over the course of the day, indicating trends.
3. It shows you what happens to your blood glucose when there is a change in physical activity, such as playing sports.
4. It shows you what is happening to your blood glucose in times of illness.
5. It shows you what happens to your glucose when there is a change in medication (for diabetes or any other illness), and where further changes need to be made.
6. If recorded properly, it shows your doctor all of the above so that he can better advise you about your diabetes medications.

2.3.1 Testing Blood Sugar

Testing the blood before meals and after offers different information. As a general rule, readings taken before meals indicate how low your glucose can get. Testing after meals shows you how high the blood glucose went, due to the absorption of the food. It should be done 2 hours after eating. Both pre-meal and post-meal testing supply important information. The most common mistake people make in testing is always testing at the same time of day [4].

2.4 What the diabetes?

Diabetes is a group of diseases marked by high levels of blood glucose, also called blood sugar, resulting from defects in insulin production, insulin action, or both. Diabetes can cause serious health complications including heart disease blindness, kidney failure, and lower-extremity amputations. But the people with diabetes can take step to control the disease and lower risk of complications.

2.4.1 The symptoms of diabetes

People who think they might have diabetes must visit a physician for diagnosis.

They might have SOME or NONE of the following symptoms:

- Frequent urination
- Excessive thirst
- Unexplained weight loss
- Extreme hunger
- Sudden vision changes
- Tingling or numbness in hands or feet
- Feeling very tired much of the time
- Very dry skin
- Sores that are slow to heal
- More infection than usual

2.4.2 Types of Diabetes

Type 1 Diabetes

The body does not produce insulin. Some people may refer to this type as insulin-dependent diabetes, juvenile diabetes, or early-onset diabetes. People usually develop type 1 diabetes before their 40th year, often in early adulthood or teenage years. Type 1 diabetes is nowhere near as common as type 2 diabetes. Approximately 10% of all diabetes cases are type 1. [5]

Patients with type 1 diabetes will need to take insulin injections for the rest of their life. They must also ensure proper blood-glucose levels by carrying out regular blood tests and following a special diet.

Between 2001 and 2009, the prevalence of type 1 diabetes among the under 20s in the USA rose 23%, according to SEARCH for Diabetes in Youth data issued by the CDC (Centers for Disease Control and Prevention). [6]

Type 2 Diabetes

The body does not produce enough insulin for proper function, or the cells in the body do not react to insulin (insulin resistance).Approximately 90% of all cases of diabetes worldwide are of this type.

Some people may be able to control their type 2 diabetes symptoms by losing weight, following a healthy diet, doing plenty of exercise, and monitoring their blood glucose levels. However, type 2 diabetes is typically a progressive disease - it gradually gets worse - and the patient will probably end up have to take insulin, usually in tablet form.

Overweight and obese people have a much higher risk of developing type 2 diabetes compared to those with a healthy body weight. People with a lot of visceral fat, also known as central obesity, belly fat, or abdominal obesity, are especially at risk. Being overweight/obese causes the body to release chemicals that can destabilize the body's cardiovascular and metabolic systems.

Gestational Diabetes This type affects females during pregnancy. Some women have very high levels of glucose in their blood, and their bodies are unable to produce enough insulin to transport all of the glucose into their cells, resulting in progressively rising levels of glucose. Diagnosis of gestational diabetes is made during pregnancy.

The majority of gestational diabetes patients can control their diabetes with exercise and diet. Between 10% to 20% of them will need to take some kind of blood-glucose-controlling medications. Undiagnosed or uncontrolled gestational diabetes can raise the risk of complications during childbirth. The baby may be bigger than he/she should be.

Scientists from the National Institutes of Health and Harvard University found that women whose diets before becoming pregnant were high in animal fat and cholesterol had a higher risk for gestational diabetes, compared to their counterparts whose diets were low in cholesterol and animal fats.

Other Types of diabetes result from specific genetic condition, such as maturity-onset diabetes of youth; medications, infection, pancreatic disease, and other illnesses such types of diabetes account for 1 to 5 percent of all diagnosed cases.

2.4.2 The treatment of diabetes

Healthy eating, physical activity, and insulin injections are the basic therapies for type 1 diabetes. The amount of insulin take must be balanced with food intake and the daily activities. Blood glucose levels must be closely monitored through frequent blood glucose testing.

Healthy eating, physical activity, and blood glucose testing are the basic therapies for type 2 diabetes. In addition, many people with type 2 diabetes require oral medication, insulin, or both to control their blood glucose levels.

People with diabetes must take responsibility for their day-to-day care, and keep blood glucose levels from going too lower or too high.

People with diabetes should see a health care provider who will monitor their diabetes control and help them learn to manage their diabetes. In addition people with diabetes may see endocrinologists, who may specialize in diabetes care, ophthalmologists for eye examinations; podiatrists for routine foot care, and dietitians and diabetes educators who teach the skills needed for daily diabetes management.

2.5 Diabetes Statistics

1. Diabetes currently affects 246 million people worldwide and is expected to affect 380 million by 2025
2. In 2007, the five countries with the largest numbers of people with of diabetes are India (40.9 million), China (39.8 million), the United States (19.2 million), Russia (9.6 million) and Germany (7.4 million).
3. In 2007, the five countries with the highest diabetes prevalence in the adult population are Nauru (30.7%), UEA (19.5%), Saudi Arabia (16.7%), Bahrain (15.2%), and Kuwait (14.4%).
4. Each year a further 7 million people develop diabetes.
5. Each year 3.8 million deaths are attributable to diabetes. An even greater number die from cardiovascular disease made worse by diabetes-related lipid disorders and hypertension.
6. Every 10 seconds a person dies from diabetes-related causes.
7. Every 10 seconds two people develop diabetes.

8. Diabetes is the fourth leading causes of global death by disease.
9. Up to 80% of type 2 diabetes preventable by adopting a healthy diet, and increasing physical activity.
10. Diabetes is the leading cause of kidney failure in developed countries and is responsible for huge dialysis costs.
11. Type 2 diabetes has become the most frequent condition in people with kidney failure in countries of the Western world. The reported incidence varies between 30% and 40% in countries such as Germany and the USA.
12. Diabetic retinopathy is the leading causes of vision loss in adults of working age (20 to 65 years) in industrialized countries.
13. On average, people with type 2 diabetes will die 5-10 years before people without diabetes, mostly due to cardiovascular disease.
14. Cardiovascular disease is major cause of death in diabetes, accounting for some 50% of all diabetes fatalities, and much disability. [7]

Chapter 3

Measurement of Glucose in Blood

3.1 Introduction

3.2 Methods of measuring blood glucose

3.3 Reference intervals

3.4 The use of the spectrophotometer and Beer's Law

3.5 The Bioelectrical impedance method

Chapter Three

Measurement of Glucose in Blood

3.1 Introduction

Many analytical procedures are used to measure blood glucose levels. In the past, analyses were often performed with relatively nonspecific methods that resulted in falsely elevated values. Almost all commonly used techniques are now enzymatic methods.

In individuals with a normal hematocrit, fasting whole blood glucose concentration is approximately 12% to 15 % lower than plasma glucose. Although the glucose concentration is the water phase of red blood cells and plasma is similar (the erythrocyte plasma membrane is freely permeable to glucose), the water content of plasma (93%) is approximately 12% higher than that of whole blood. In most clinical laboratories, plasma or serum is used for the majority of glucose determines, whereas most methods for self-monitoring of glucose use whole blood. During fasting, capillary blood glucose level is only about 2 to 5 mg/dl higher than that of venous blood. After glucose load, however, capillary blood glucose concentrations are 20 to 70 mg/dl (mean 30 mg/dl) greater than concurrently drawn venous blood samples. [8]

3.2 Methods of measuring blood glucose

3.2.1 Hexokinase Methods

Principle: Glucose is phosphorylated by ATP in the presence of hexokinase and Mg^{+2}. The glucose-6-phosphate formed is oxidized by (G-6-PD) to 6-phosphogluconate in the presence of Nicotinamide-adenenine Dinucleotide Phosphate ($NADP^{+}$). The amount of reduced NADP (NADPH) produced is directly proportional to the amount of glucose in the sample and is measured by

absorbanc at 340 nm. G-6-PD derived from yeast is used in the assay with $NADP^+$ as the cofactor. Nicotinamide-adenine dinucleotide (NAD^+) is the cofactor if bacterial G-6-PD is used, and the NADH produced is also measured at 340 nm.

$$\text{Glucose} + \text{ATP} \xrightarrow{\text{hexokinase}} \text{glucose 6-phosphate} + \text{ADP}$$

$$\text{Glucose 6-phosphate} + NAD^+ \xrightarrow{\text{G-6-PD}} \text{6-phosphogluconate} + \text{NADH} + H^+$$

A generally accepted reference methods based on this principle has been developed and validated. Serum or plasma is deproteinated by the addition of solutions of barium hydroxide ($Ba[OH]_2$) and zinc sulfate ($ZnSO_4$). The clear supernatant is mixed with a reagent containing ATP, NAD^+, hexokinase, and G-6-PD; the mixture is incubated at 25 °C until the reaction is complete, and the NADH is measured. Calibrators and blanks are carried through the entire procedure, including the deproteination step.

Although highly accurate and precise, the reference method is too exating and time consuming for routine use in a clinical laboratory. An alternative approach is to apply the reaction use in a clinical laboratory. An alternative approach is to apply the reaction directly to serum or plasma and to use a specimen blank to correct for interfering substances that absorb at 340 nm.

Either serum or plasma may be used. NaF, with an anticoagulant such as EDTA, heparin, oxalate, or citrate, may be used. Hemolyzed specimens containing more than 0.5 g of hemoglobin per deciliter are unsatisfactory because phosphate esters and enzymes released from red blood cells interfere with the assay. Other sources of interference include drugs, bilirubin, and lipemia (triglyceride level > 500 mg/dl causes a positive interference).

Absorbances of sample or calibrator reaction mixture are measured after the reaction have continued to the point of completion (equilibrium reaction). Although concentration may be calculated directly, based on the molar absorptivity of NADPH or NADH, inclusion of a set of calibrators is recommended to detect

possible deterioration of enzymes, ATP, BADP$^+$, or NAD$^-$. All of which are unstable. Reagents may also contain substances that with the coenzymes.

Presence of these substances can be evaluated by measuring the increase in absorbance of observed in a reagent blank. The highest calibrator the increase in linearity of response and the adequacy of the enzyme reagent. The procedure is linear from 0 to 500 mg/dl. Glucose concentration that exceed 500 mg/dl should be diluted with isotonic saline and reassayed.

Hexokinase procedures in which indicator reactions produce colored products are also available, enabling absorbance to be measured in the visible range. An oxidation-reaction system containing phenazine methosulfate and a substituted tetrazolium compound.

2- (p-idoopheny1) -3-p- nitropheny1 -5-pheny1tetrazolium chloride (INT), is reacted with NADPH formed in the reaction. The reduced INT is colored with maximum absorbance 520 nm.

3.2.2 Glucose Oxidase Methods

Principle: The enzyme glucose oxidase catalyzes the oxidation of glucose to gluconic acid and hydrogen peroxide (H_2O_2):

$$\text{Glucose} + 2\,H_2O + O_2 \xrightarrow{\text{glucose oxidase}} \text{glucose acid} + 2H_2O$$

Addition of the enzyme peroxidase and a chromogenic oxygen accepter, such as o-dianisidine , results in the formation of a colored compound that can be measured :

$$\underset{\text{(Colorless)}}{\text{o-Dianisidine}} + H_2O_2 \xrightarrow{\text{peroxidase}} \underset{\text{(Colored)}}{\text{oxidized o-dianisidine}} + H_2O$$

Glucose oxidase is highly specific for β-D-glucose since 36% and 64% of glucose in solution are in the α- and β-forms, respectively, complete reaction requires mutarotation of the α - to β- form. Some commercial preparations of glucose oxidase contain an enzyme, mutarotase, which accelerates this reaction. Otherwise, extended incubation time allows spontaneous conversion.

The second step, involving peroxidase, is much less specific than the glucose oxidase reaction. Various substances, such as uric acid, bilirubin, hemoglobin, tetracycline, and glutathione, inhibit the reaction (presumably by empeting with the chromogen for H_2O_2, producing lower values). Some glucose oxidase preparations contain catalase as a contaminate; ctalase activity decomposes proxide and decreases the final color obtained. Calibrators and unknowns should be analyzed simultaneously under conditions in which the rate of oxidation is proportional to glucose concentration.

Modification some instrument use a polarographic electrode that measures the rate of oxygen consumption after the sample is added to a solution containing glucose oxidase. Because this measurement involves only the first reaction shown earlier, interferences encountered in the peroxidase step are eliminated. To prevent formation of oxygen from H_2O_2 by catalase present in some preparations of glucose oxidase, H_2O_2 is removed by two additional reactions:

$$H_2O_2 + C2H2OH \xrightarrow{\text{catalase}} CH_3CHO + 2\,H_2O$$

ethanol acetaldehyde

$$H_2O_2 + 2H^+ + 2I^- \xrightarrow{\text{molybdate}} I_2 + 2\,H_2O$$

The latter reaction is effective even when catalase activity has diminished on storage of regents. The procedure can be applied directly to urine, serum, plasma , or CSF. However, this approach cannot be used for the determination of glucose in whole blood because blood cells consume oxygen.

3.2.3 Glucose Oxidase Methods

principle : The enzyme glucose dehydrogenase (β-D- glucose:NAD oxidoreductase) catalyzes the oxidation of glucose to gluconolactone:

$$\text{Glucose} + NAD^{+} \xrightarrow{\text{glucosedehydrogenase}} \text{D-glucose-δ-lactone} + NADH + H^{+}$$

Mutarotase is added to sgorten the time necessary to reach equilibrium. The amount of NADH generated is proportional to the glucose concentration. The reaction appears to be highly specific for glucose, shows no interference from common anticoagulants and substances normally found in serum, and provides resultsbin close agreement with gexokinase procedures.

3.3 Reference intervals

Although glucose can be assayed by a number of different analytical procedures, reference intervals do not vary significantly among methods. The following values shown should apply to virtually all currently used glucose assays.

Table 3.1

The references intervals for some samples

Sample (plasma/serum)	Fasting Glucose (mg/dl)
Children	70-105
Premature neonates	25-80
Term neonates	30-90
Whole blood	60-95
CSF	40-75 (60% of plasma value)
Random	<30
24-hr	<500 mg/24hr

Plasma glucose levels show no sex difference. Plasma glucose values increase with age: approximately 2 mg/dl per decade for fasting levels; 4 mg/dl ped decade for postprandial levels; and 8 to 13 mg/dl per decade after a glucose challenge. The plasma values and must always be compared with concurrently measured plasma values for adequate clinical interpretation.

3.4 The Use of the Spectrophotometer and Beer's Law

Scientists use many methods to determine the identity and quantity of a substance in samples. Spectroscopy is a simple and powerful method for performing both qualitative and quantitative analyses. Each chemical species has a unique spectral fingerprint based on where electrons are located with respect to the nucleus. For example, a solution of sodium ions sprayed into a flame will change the flame's color to a bright yellow, while a solution of lithium ions will cause the flame to burn a deep red color.

These flame tests reveal the solution's emission spectrum – the wavelength (or color) of light revealed by the flame is due to excited electrons within atoms and ions in the solution relaxing to a lower energy state, emitting photons. A photon is a packet of light energy, the first indication that light may have particle-like properties. The flame provides the energy used to excite the electrons within the metal ions. The wavelength of radiation emitted can then be used to determine the energy lost by the electron as it relaxes.

Since electrons can occupy only discrete energy states, the way radiation interacts with matter can indicate its chemical identity. Chemists commonly use absorbance spectroscopy, or how a substance absorbs photons of light, to obtain both qualitative (identity) and quantitative (amount) information. The quantitative measurement is achieved because each photon of light absorbed corresponds to the excitation of a single electron.

Of course, in the laboratory, analyses are performed on large numbers of atoms or molecules, therefore a relationship must be established to obtain quantitative information. Initial spectrophotometric studies measured

transmittance, which is defined as the fraction of light that passes through the sample:

$$T = \frac{I}{Io} \qquad \ldots\ldots\ldots\ldots \qquad (3.1)$$

%T= T x 100

Where:

Io: is the intensity of the light passing through the solvent.

I : is the intensity of light that passes through the sample solution.

Percent transmittance (%T) is simply the transmittance fraction multiplied by 100. A more useful quantity in performing analyses is the absorbance or the negative log of transmittance

(**A = – log T**).

A linear relationship exists between absorbance and concentration known as Beer's Law

(**A = α b c**), where:

b : is the length of the path traveled by light through the sample.

c : is the concentration

α : is a molar absorptivity constant that depends on both wavelength and substance.

This linear relationship between concentration and absorbance allows scientists to use spectroscopy for quantitative measurements of unknown samples.

3.5 Bioelectrical impedance method

Measuring the bioelectrical impedance value for a human tissue can be used to measure many vital variables as fat and salt inside the body tissue, Some recent studies suggest there is a relationship between the bioelectrical impedance and the percentage of glucose in the blood, therefore this opens the way for the development of a new technique for measuring the blood glucose percentage by measuring the bioelectrical impedance [9].

Four electrode impedance plethysmography uses two electrodes to pass current through the tissue and two electrodes to measure the voltage output across the finger. For this project, the finger will be inserted downward into a tube similar to that shown in **Figure 3.1.** The electrode at the top, near the base of the finger, is the current input. The electrode at the bottom acts as the ground where the current exits the system. The two center electrodes measure the voltage across the middle section of the finger. By passing current through the finger (which provides resistance), the resulting voltage drop can be measured across these electrodes.

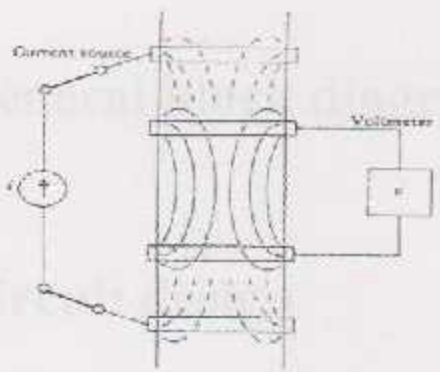

Figure 3.1: Four electrode impedance plethysmography

The voltage measurements obtained will vary depending upon physiological changes in a blood and due to the blood pulse itself. It is expected that these measurements will be small. In order to observe and analyze the signal, the wires from the middle electrodes are connected to a circuit where the signal will be amplified and processed. Finally, the voltage output can be used to calculate the impedance and resistivity of the blood in the finger. It is thought that the resistivity can be correlated with different blood compositions [10].

Chapter 4

Project conceptual design and Implementation

4.1 Introduction

4.2 General block diagram

4.3 Circuit design

Chapter Four

Project conceptual design and Implementation

4.1 Introduction

The project target is to design and build a finger impedance plethysmograph to measure blood resistivity. in order to accomplish this, we have to design and build data acquisition device to acquire the signal from the finger. This device should mechanically immobilize the test subjects' finger such as that motion artifacts are kept to a minimum. This device should be able to detect the electrical potential (voltage) change across the finger so that the change in resistance may determine. It should be able to detect the velocity-dependent change in blood resistivity due to arterial blood pulsations.

In addition, we will need to build an electrical circuit to perform signal processing and analysis. This circuit should be capable of rectifying the alternating current (AC) signal from the finger data acquisition device and modulate it into a direct current (DC) signal to be analyzed.

The circuit should be capable of discerning or visually displaying the voltage changes caused by correlated changes in blood resistivity. As an added feature, this circuit may contain an automatic reset function capable of adjusting one of the differential amplifier inputs to that of the output from the data acquisition (finger holder) device. This will allow the device to easily accommodate fingers having different electrical resistances and will prevent having to manually adjust voltages using a potentiometer to match independences with each new test subject or finger position.

4.2 General block diagram

Figure 4.1 shows the general block diagram of our project, which contains the following parts:

- Constant Current Source.
- Preamp Instrumentation Amplifier Stage.
- High Gain Instrumentation Amplifier stage.
- Sample and Hold.
- Low Pass Filter and Additional Signal Processing.
- Automatic Reset.

The following block diagram showing the constant current source, electrode configuration and signal pathway:

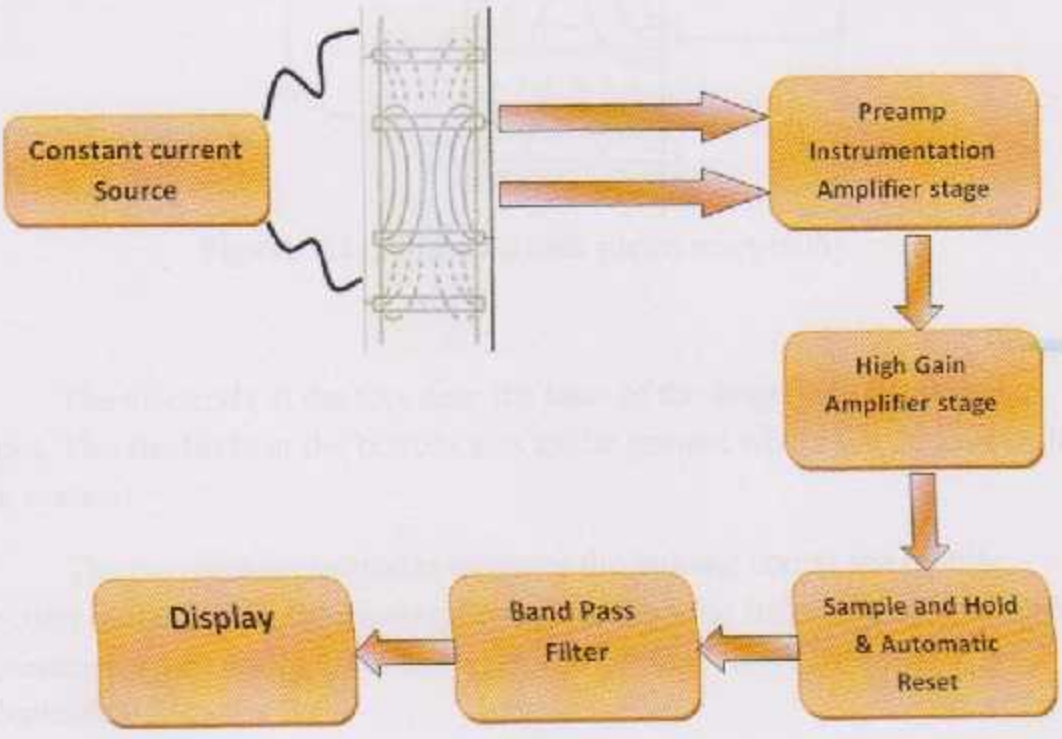

Figure 4.1: General block diagram

4.3 Circuit design

4.3.1 Constant current Source

The project design begins with a constant current source, which uses to pass constant current value through the finger by using tow electrodes as shown in **figure 4.2**

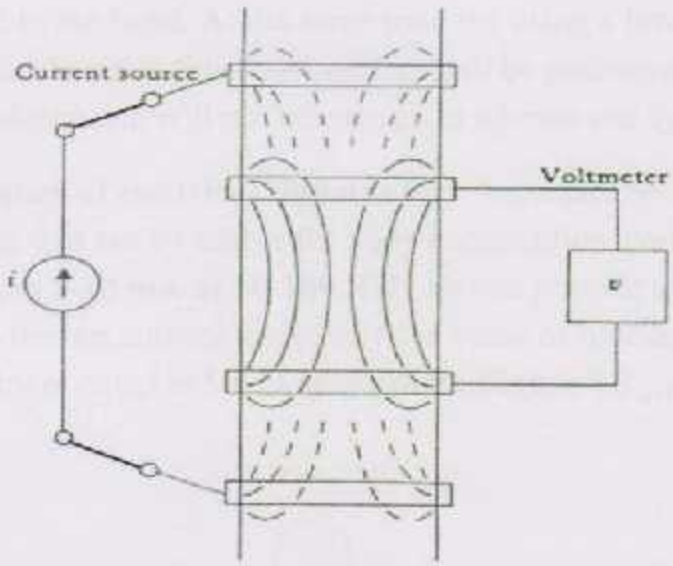

Figure 4.2: Four electrode plethysmography

The electrode at the top, near the base of the finger, is the current input. The electrode at the bottom acts as the ground where the current exits the system.

The two center electrodes measure the voltage across the middle section of the finger. By passing current through the finger (which provides resistance), the resulting voltage drop can be measured across these electrodes.

We will talk about voltage measurement extensively later, but now let us talk about **constant current source**. In this part from our design we have to take in account tow important factors:

- **The value of current.**
- **The Frequency of electrical signal.**

The value of current is very important because the high value mean less safety. electricity is only being applied across the finger, high current could create direct threat to the heart. At the same time the using a law value of current is Unhelpful, because this small current will be consumed by the bioelectrical impedance and will not be enough to operate our system.

The Frequency of electrical signal is very important because using of low frequencies will not be usable for body composition evaluation. . A current ranging from **1-10 mA at 50-100 KIIz** should provide a safe current that will not harm the test subject, especially the value of bioelectrical impedance for a finger equal to 500Ω as shown in **Figure 4.3** [11]

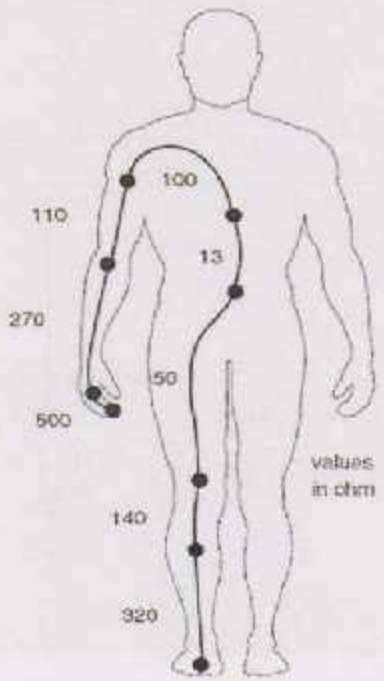

Figure 4.3: Values of body impedance of relevant parts of a body. [12]

4.3.2 The circuit of Constant current Source

The circuit of Constant current Source contains two main parts; the first is the feed source and it's consist Wien bridge oscillator, while the second consist a circuit designed to generate constant current value between the terminal of the load regardless of its resistance value.

- **Wien bridge oscillator**

  - The resonance of the frequency should be 75 KHz.
  - The input voltage value should be 12v.

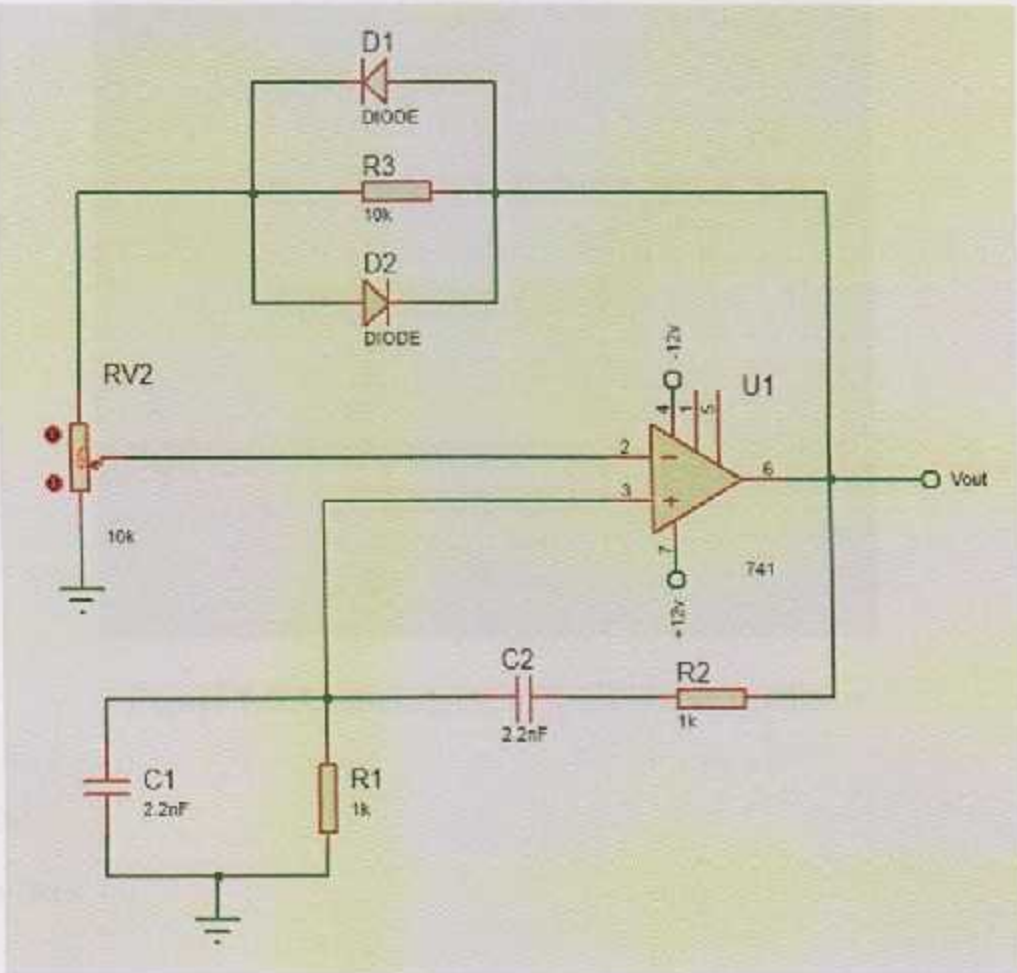

Figure 4.4: Wien bridge oscillator

$$F_0=1/2\pi RC \qquad \ldots\ldots\ldots\ldots \qquad (4.1)$$

$R_1=R_2$, $C_1=C_2$

Let C=2.2nF

$75kH=1/2\pi*R*1nF$

$R_1=R_2=1\ k\ \Omega$

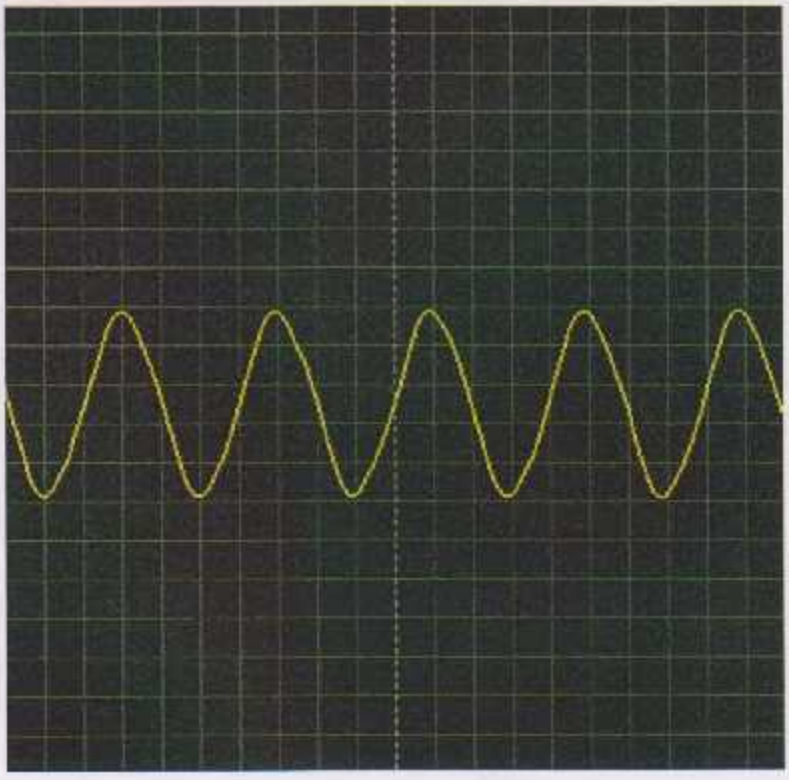

Figure 4.5: Output signal of wien bridge oscillator

*Scale

Volts/Div = 1 v

- **Inverting amplifier**

By using a inverting amplifier in this stage, the passing current through the human finger will be constant (equal I_{in}) , regardless of the finger resistance value. The goal is to pass a 5 mA current through the finger by using the following laws.

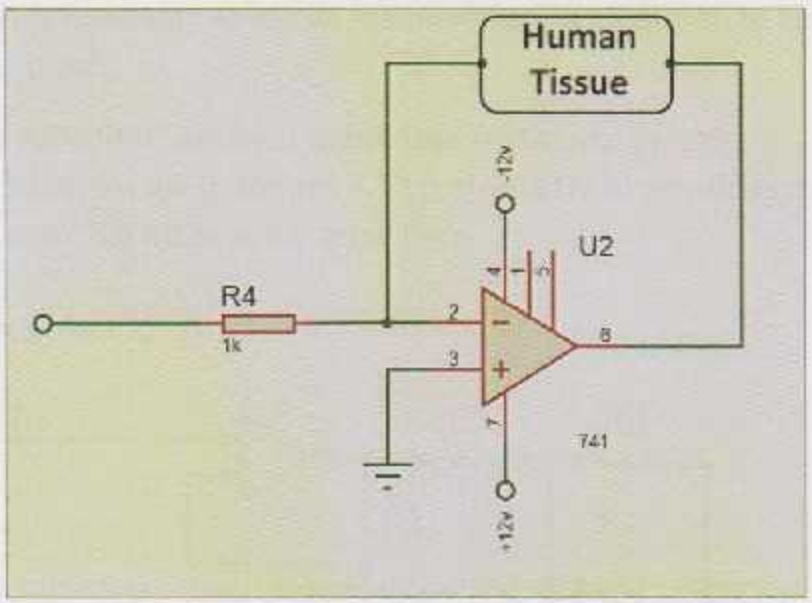

Figure 4.6: Constant current circuit design.

$$V_{in} = 5 \text{ v}$$

$$I_{in} = 5 \text{ mA} = \frac{5 \text{ v}}{R4}$$

$$R_1 = 1 \text{ k}\Omega$$

4.3.3 Preamp Instrumentation Amplifier stage

The voltage signals from across the finger are expected to be very small and could be buried within a substantial amount of noise. Because of this, a circuit must be designed that both amplifies the small voltage difference across the finger and filters out any noise that corrupts the signal. Therefore it is necessary to use an instrumentation amplifier, to canceling the noise as much.

Two AD620 IC are used rather than traditional preamp instrumentation, shown in **Figure 4.7** because AD620 amplifies the signal as well as it cancel the noise at the same time.

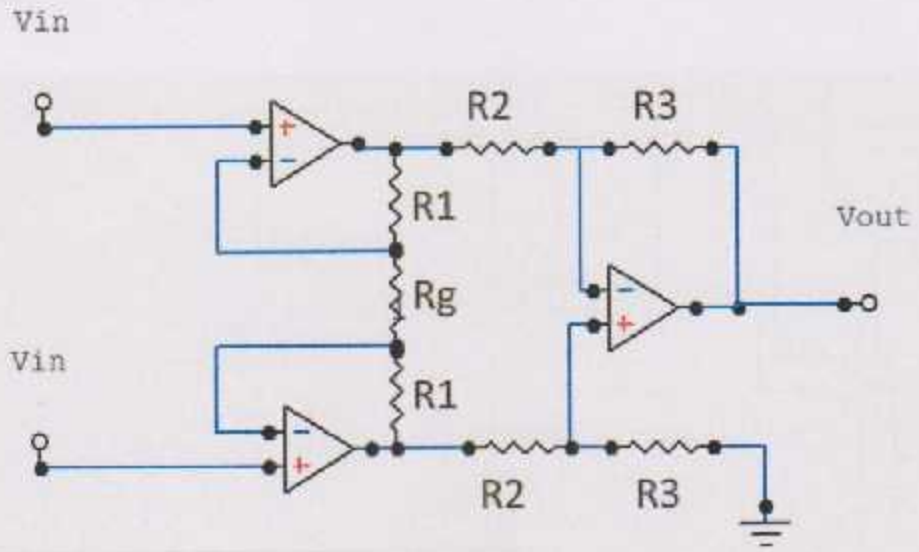

Figure 4.7: Instrumentation Amplifier internal design

$$G = 1 + (49.4\ k/Rg \qquad \ldots\ldots\ldots \qquad (4.2)$$

$$10 = 1 + (49.4\ k/Rg)$$

$$Rg = 5.5\ k\Omega$$

4.3.4 "Sample & hold" & "reset" circuit design

Because of using a high gain; any movement of the finger or any heartbeat would saturate the amplifier. This sensitivity of the measurements requires the need for automatic reset and sample and hold circuit.

The sample and hold circuit automatically resets the output once it moves outside a preset voltage range. This allows for the circuit to reset once the high gain amplification stage saturates.

Our design contain tow circuit, the first one is sample and hold, its contain FET transistor and buffer amplifier, and the second one in a reset circuit and it's contain comparator stage and 555 timer as the shown in **figure 4.8.**

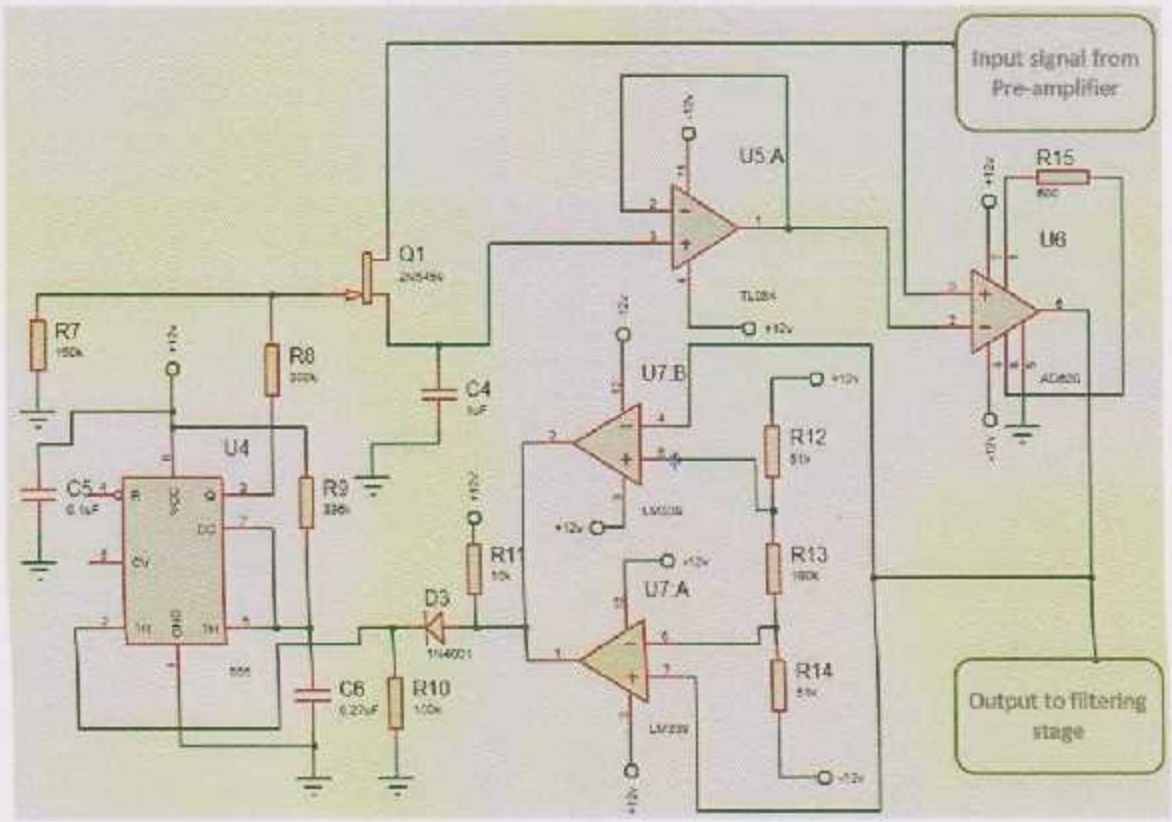

Figure 4.8: Sample and hold circuit design

- **Timer 555**

Very small duty cycle needed here, we chose it to be 0.1s

$$T_1=0.1$$

$$T_1 = 0.693\ (R_B)\ C \qquad \ldots\ldots\ldots\ldots \qquad (4.3)$$

$$T_1 = 0.693\ (R_8 + R_9)\ C$$

Let $C_5=0.27\mu F$

$R_B=0.1/0.693*0.27*10\text{^}-6$

$R_B=636\ k\Omega$

$R_8=300\ k\Omega$, $R_9=336\ k\Omega$

4.3.5 Band Pass filter circuit

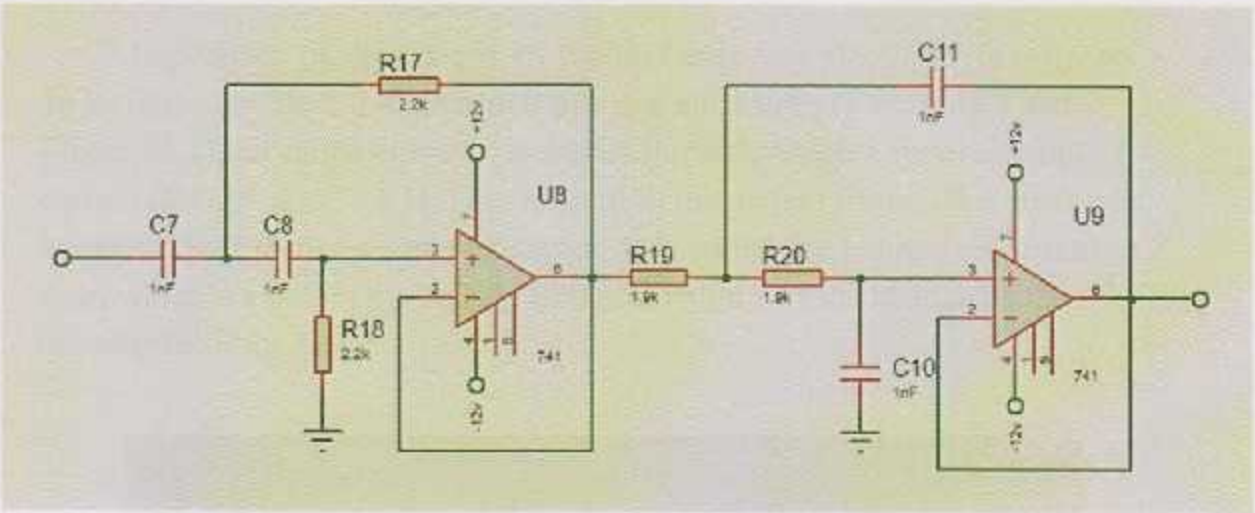

Figure 4.9: Band Pass circuit design

At this stage we need to pass a frequencies within a certain range [70 - 80] kHz and rejects (attenuates) frequencies outside that range; so we have to use a **Band Pass Filter Circuit** consist high and low pass filter circuits as shown in **figure 4.9**.

▶ Stage 1 (HPF)

$$fc=\frac{1}{2\pi\sqrt{(C7\,C8\,R17\,R18)}}$$

suppose $R_{17}=R_{18}$, $C_7=C_8=1$ nF

$$70\times10^{3}=\frac{1}{2\pi R(1\text{ nF})}$$

$R_{17}=R_{18}=2.2$ kΩ

▶ Stage 2 (LPF)

$$fc=\frac{1}{2\pi\sqrt{(C10\,C11\,R19\,R20)}}$$

suppose $R_{19}=R_{20}$, $C_{10}=C_{11}=1$ nF

$$80\times10^{3}=\frac{1}{2\pi R(1\text{ nF})}$$

$R_{19}=R_{20}=1.9$ kΩ

4.3.6 The electrodes

Impedance plethysmography method uses four electrodes in order to do its basic function, the outer pair of these electrodes (Electrode 1 and Electrode 2) are called current electrodes through which a small amount of current (0.5mA and 75 KHz) are entered to the patient tissue. The other pair of electrode (Electrode 3 and Electrode 4) is called the voltage electrodes from which we obtain the change in blood volume or the change of the impedance of the tissue.

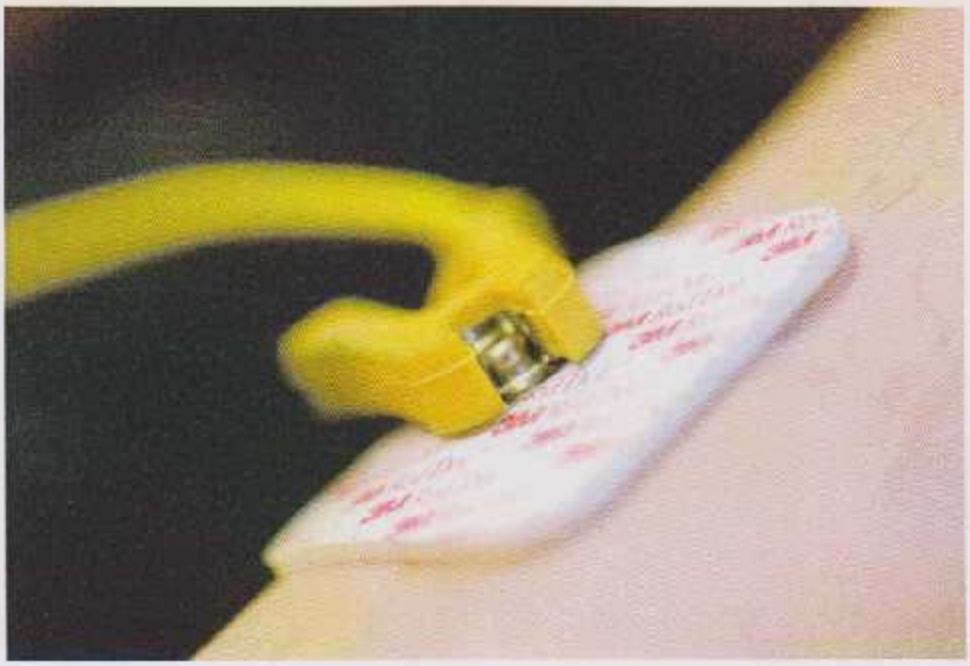

Figure 4.10: Floating disposable electrode

In our project we used a special type of ECG electrodes called floating disposable electrode. The principle of this electrode is to practically eliminate movement artifact by avoiding any direct contact of the electrolyte paste or jelly. In general disposable electrodes are of the floating type with simple snap connecters by which the leads, which are reusable, are attached.

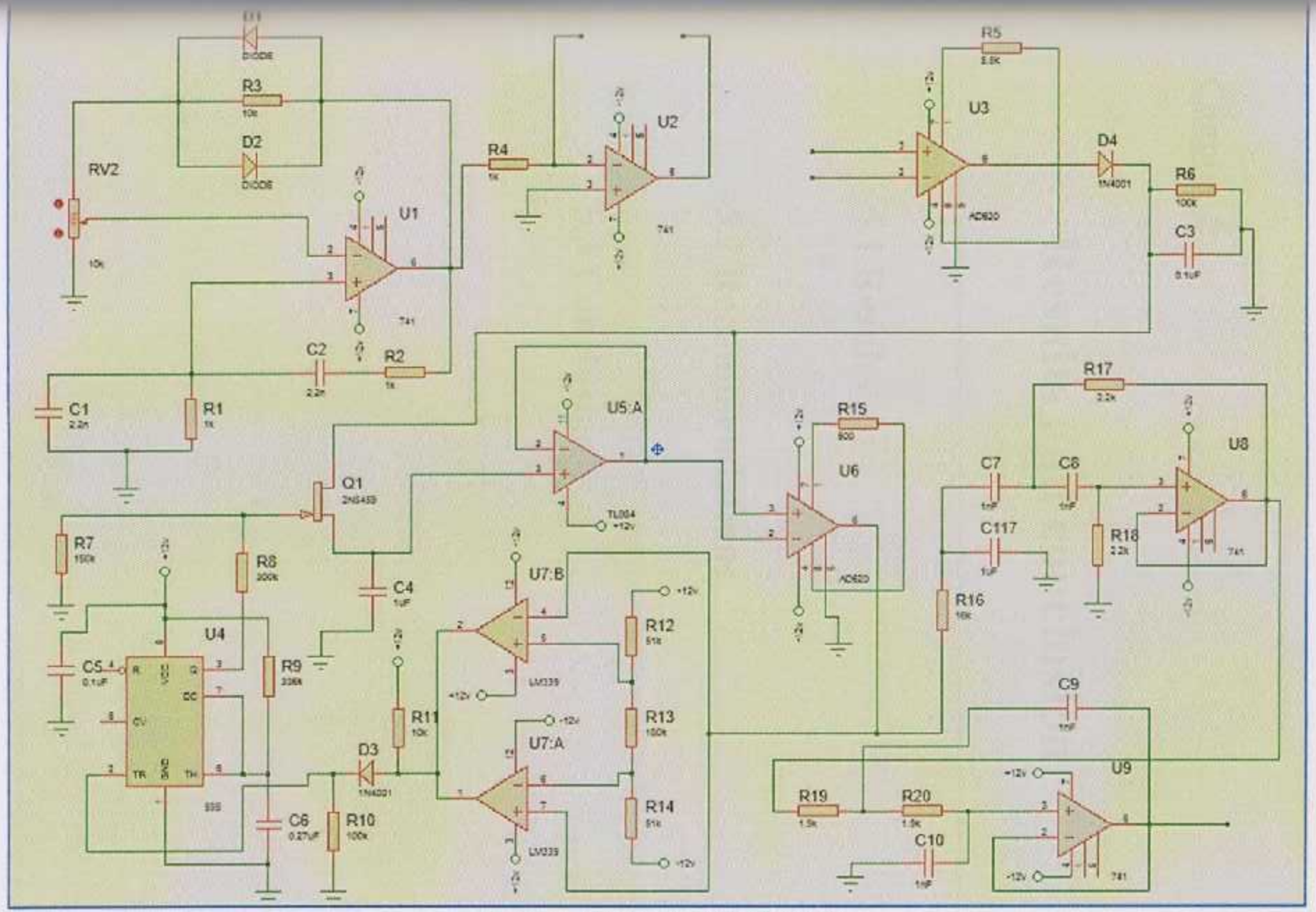

Figure 4.11: Simulated final circuit

Chapter 5

Results and conclusion

5.1 Results

5.2 Recommendations

5.3 Conclusion

Chapter Five

Results and conclusions

5.1 Results

1- Using a plethysmograph to measure blood impedance as it correlates to glucose concentration is a complicated and largely unproven technology. Accordingly, it is important that we have tested each stage of the device to find the source of any error in the final output.

2- The output of wien bridge oscillator was sinusoidal signal with amplitude 5 v (1volt/Div) as shown in **Figure 5.1**, as well as can be adjusted by change the value of potentiometer.

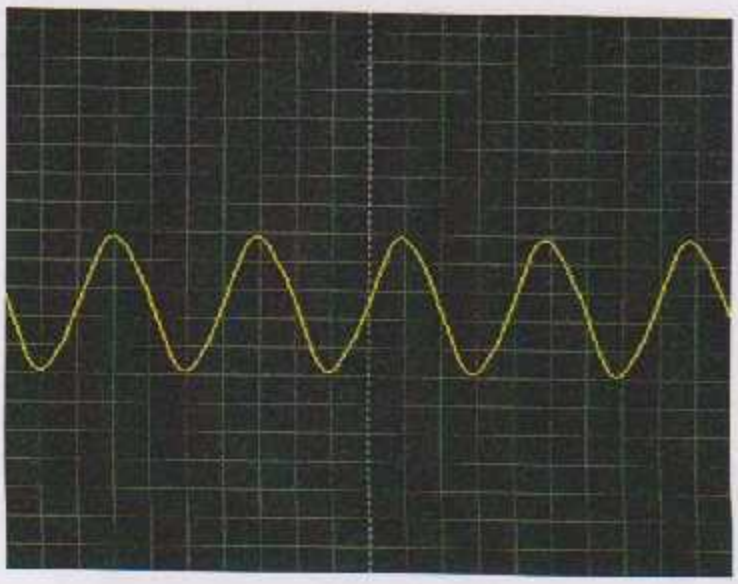

Figure 5.1: Output signal of wien bridge oscillator

3- First, the voltage across the two current input electrodes and the two voltage output electrodes was observed to ensure that the finger electrode device was working.

4- Once the output of the amplifier is saturated, the sample and hold circuit will reset the circuit back to the baseline value. As shown in **Figure 5.2**.

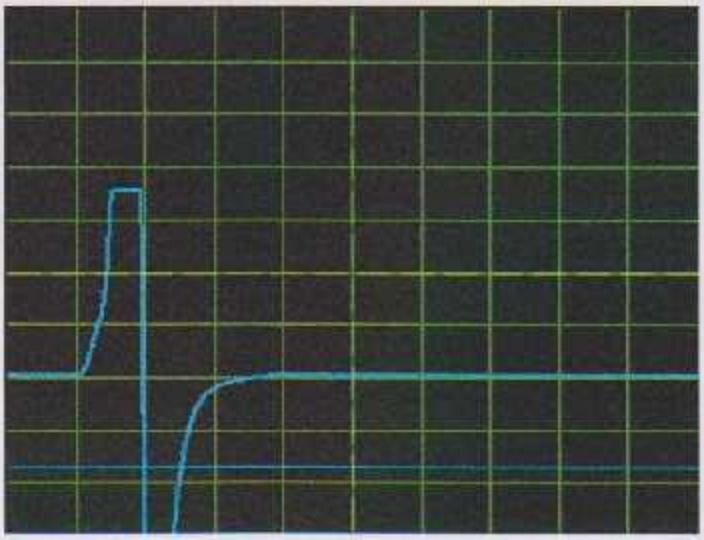

Figure 5.2: Effect of sample and hold circuit after a large motion artifact

5- The final filtering stage of the circuit was tested by measuring the signal before and after the filter. As shown in **Figure 5.3**.

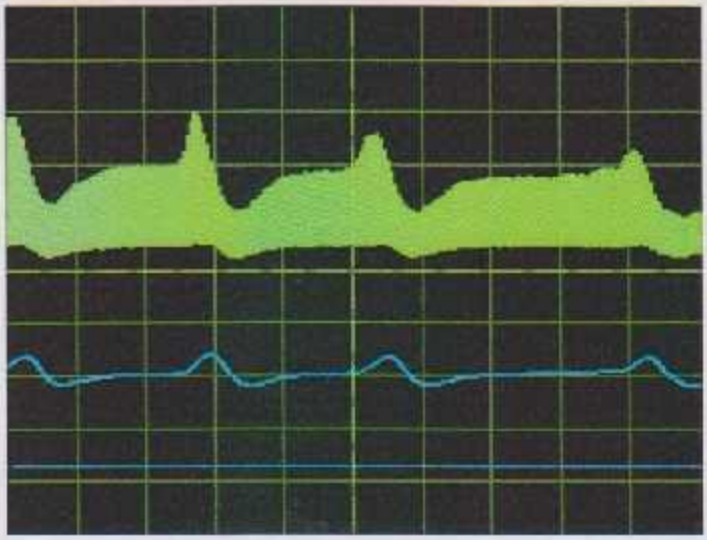

Figure 5.3: The signal before and after filtering stage

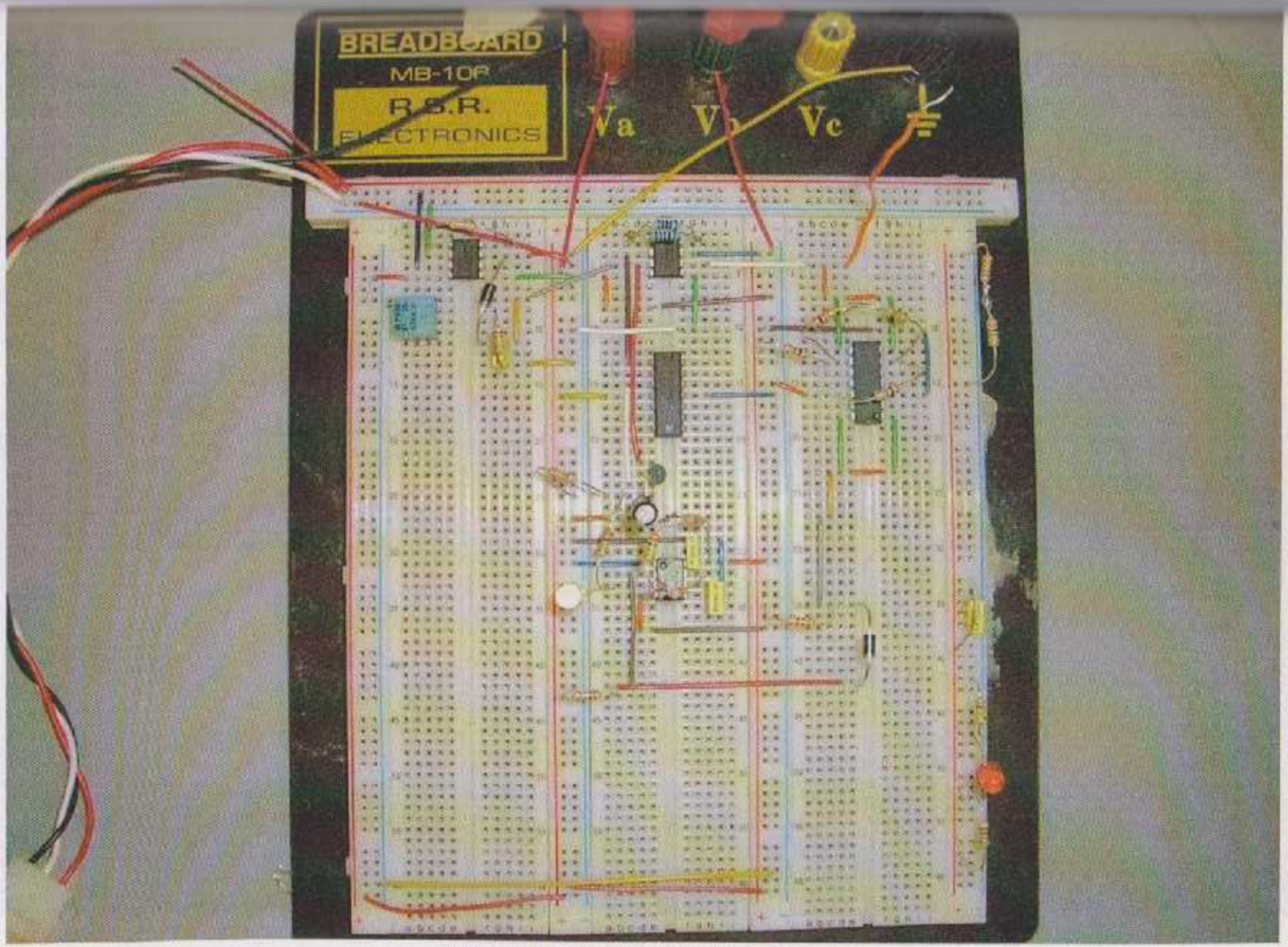

Figure 5.4: Implemented final circuit

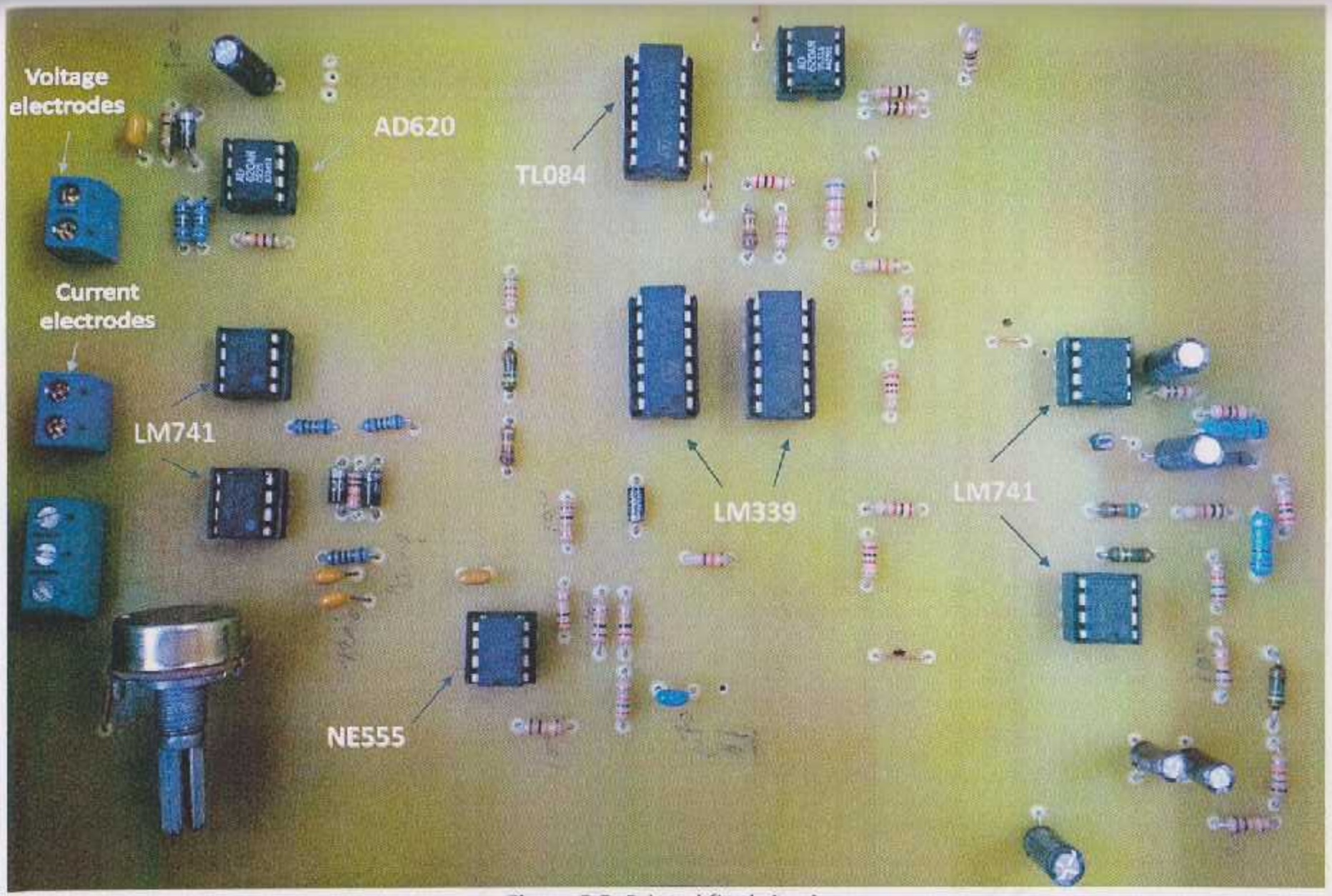

Figure 5.5: Printed final circuit

5.2 Recommendations

Several areas of improvement are required on the prototype to make it an effective testing tool as a plethysmograph for blood resistivity.

1- Once optimized, the device can begin clinical trials to determine whether a correlation between glucose levels and blood resistivity exists. To verify the science behind this device, phantom testing units could be constructed and tested in the plethysmograph device

2- To turn this design into a functional device, signal processing must be used to identify the pulsatile signal of interest.

3- As previously stated, the pulsatile waveform from blood flow in the arteries will be very small with respect to the total impedance value of the finger. Further data analysis will be required therefore, to isolate the signal of interest.

4- To further test this device, and the theories behind it, a phantom could be constructed which pulses blood (or an electrically similar substitute) through an electrically conductive capillary tubing.

5- Furthermore this could also be used to test whether increased glucose levels affect how blood cells align statically or when streaming, and if this affects electrical impedance.

5.3 Conclusions

Our project conclusions that contained in our study and design:

1- Impedance plethysmography test can be used to measure blood resistivity, which may correlate to blood glucose levels and other physiological metrics.

2- We designed a body impedance measurement system in order to use it to build a diabetes detection system.

3- We used a constant current with values ranging from [1-10mA] at 50 – 100 KHz, this values provide a save currant will not harm the test subject.

4- We used preamp Instrumentation Amplifier because the voltage signals from a cross the finger are expected to be very small and could be buried within a substantial amount of noise.

5- Because of we used a high gain; any movement of the finger or any heartbeat would saturate the amplifier. This sensitivity of the measurements requires the need for automatic reset and sample and hold circuit.

6- Our project is a practical implementation of studies indicating that there is a relationship between the value of sugar in the blood and the value of the blood resistivity.

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[9] Analysis of Blood Glucose using Impedance Technique Ingrid Anne P. Nazareth, Sulaxana R.Vernekar, Rajendra S. Gad, Gourish M. Naik.

[10] John G. Webster & Thomas Yen, Finger Plethysmograph to Measure Blood Resistivity, December 10, 2008

[11] Shanker R and Webster J.G. 1984 Design of an Automatically Balancing Electrical Impedance Plethysmograph . Journal of Clinical Engineering, 9(2), 129-134

Website:

[3] http://www.ehow.com/about_4672310_what-low-blood-sugar.html

[5] [6] Diabetes World Health Organization. http://www.who.int/dietphysicalactivity/publications/facts/diabetes/en/.

[7] http://www.diabetes.org/diabetes-statistics.jsp.

[8] www.meters-bloodglucose.com/articles/blood_glucose_monitors_work.html.

[12] http://bio.felk.cvut.cz/biocmsms/index.php?page=body-impedance

Datasheet

A

LM741 Operational amplifier

May 1998

National Semiconductor

LM741
Operational Amplifier

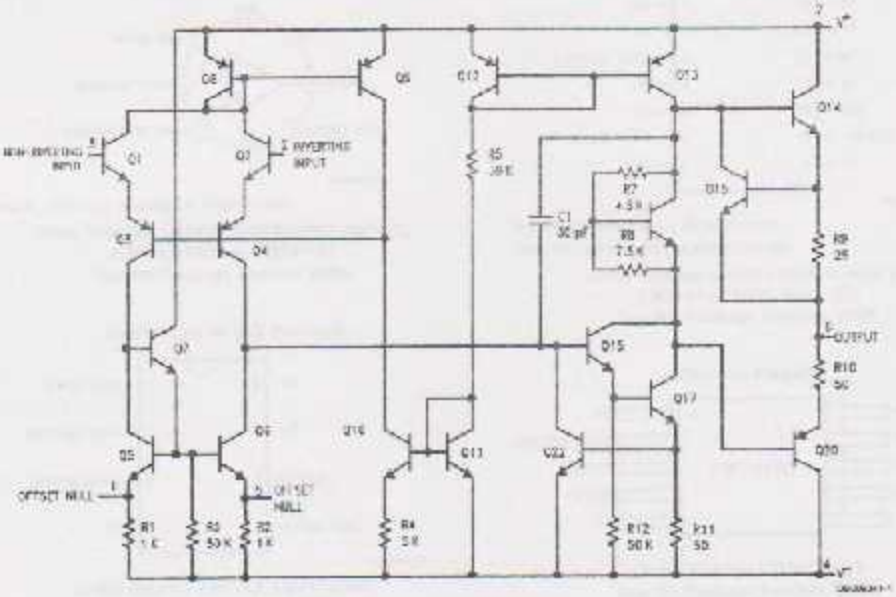
General Description

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

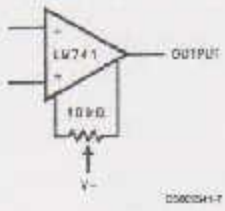
The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C/LM741E are identical to the LM741/LM741A except that the LM741C/LM741E have their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Schematic Diagram



Offset Nulling Circuit



Electrical Characteristics (Note 4) (Continued)

Note 2: For operation at elevated temperature, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	H08 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 3: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

Note 4: Unless otherwise specified, these specifications apply for V_S = ±15V, −55°C ≤ T_A ≤ +125°C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0°C ≤ T_A ≤ +70°C.

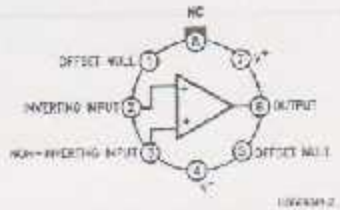
Note 5: Calculated value from: BW (MHz) = 0.35/Rise Time(μs).

Note 6: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 7: Human body model, 1.5 kΩ in series with 100 pF.

Connection Diagram

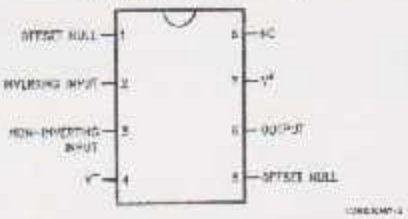
Metal Can Package



Note 8: LM741H is available per JM38510/10101.

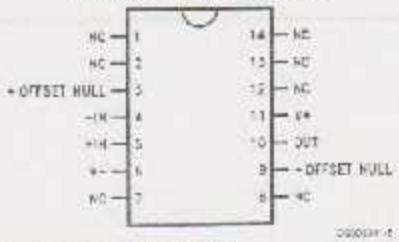
Order Number LM741H, LM741H/883 (Note 8), LM741AH/883 or LM741CH
See NS Package Number H08C

Dual-In-Line or S.O. Package



Order Number LM741J, LM741J/883, LM741CM, LM741CN or LM741EN
See NS Package Number J08A, M08A or N08E

Ceramic Dual-In-Line Package



Note 9: also available per JM38510/10101

Note 10: also available per JM38510/10102

Order Number LM741J-14/883 (Note 9), LM741AJ-14/883 (Note 10)
See NS Package Number J14A

Ceramic Flatpak

Order Number LM741W/883
See NS Package Number W10A

B

AD620 Instrumentation Amplifier

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)

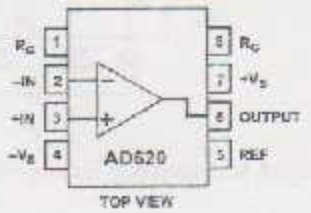
LOW NOISE
9 nV/√Hz, @ 1 kHz, Input Voltage Noise
0.28 μV p-p Noise (0.1 Hz to 10 Hz)

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



TOP VIEW

PRODUCT DESCRIPTION

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

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

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

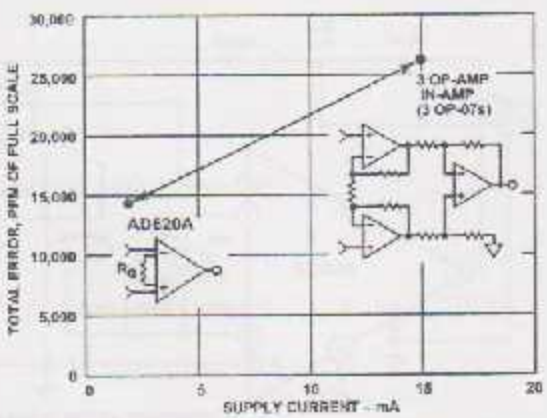


Figure 1. Three Op Amp IA Designs vs. AD620

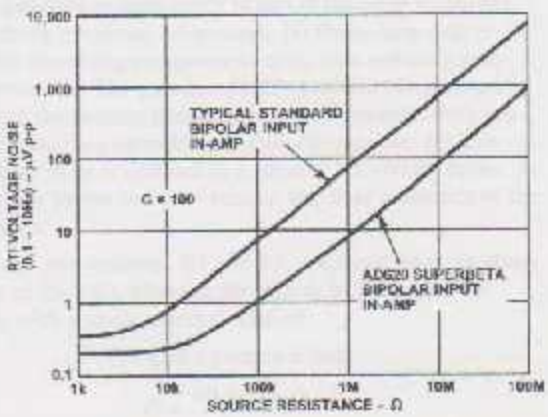


Figure 2. Total Voltage Noise vs. Source Resistance

REV. E

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

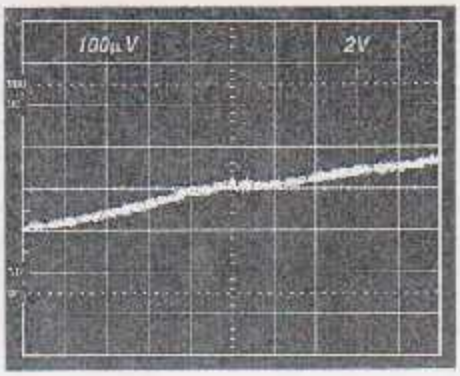


Figure 31b. Gain Nonlinearity, G = 100, R_L = 10 kΩ (100 µV = 10 ppm)

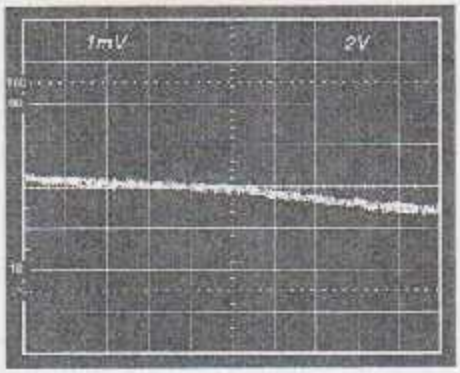


Figure 31c. Gain Nonlinearity, G = 1000, R_L = 10 kΩ (1 mV = 100 ppm)

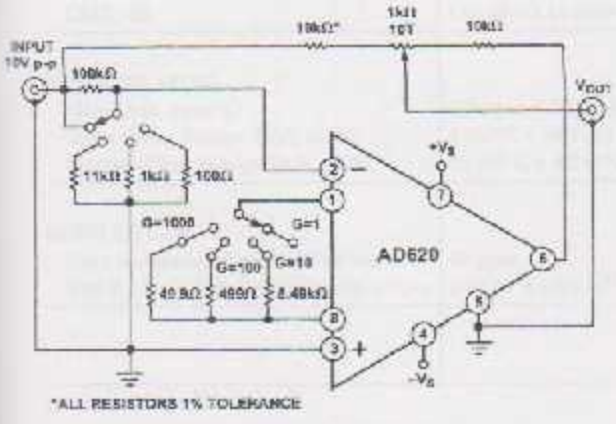


Figure 32. Settling Time Test Circuit

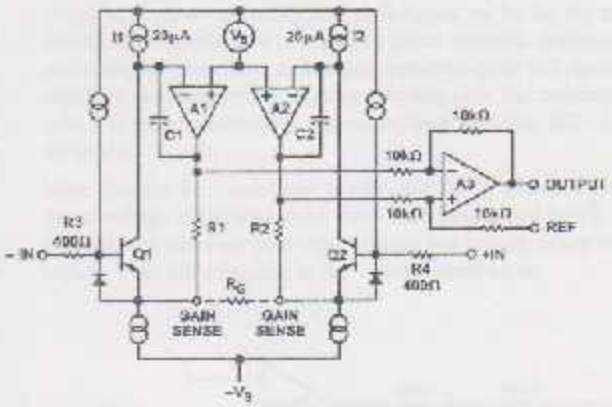


Figure 33. Simplified Schematic of AD620

THEORY OF OPERATION

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

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

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

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

The gain equation is then

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

so that

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

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

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

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

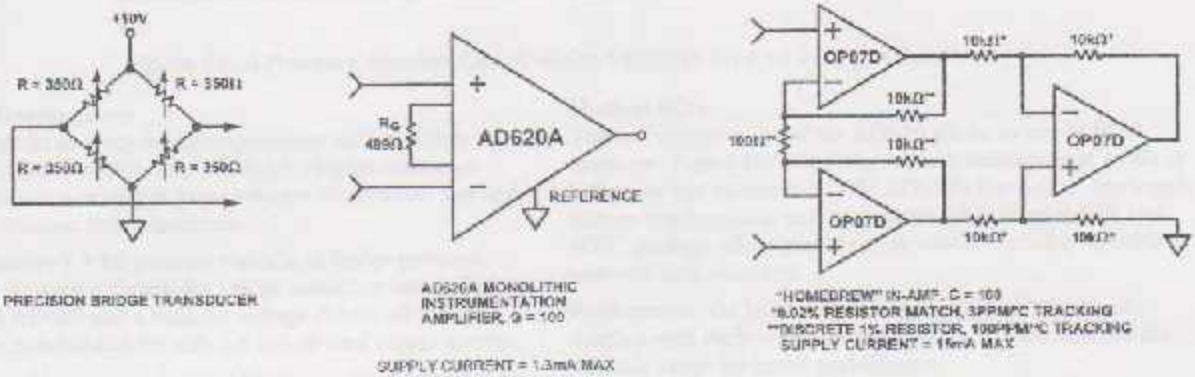


Figure 34. Make vs. Buy

Table I. Make vs. Buy Error Budget

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

G = 100, V_S = ±15 V.

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

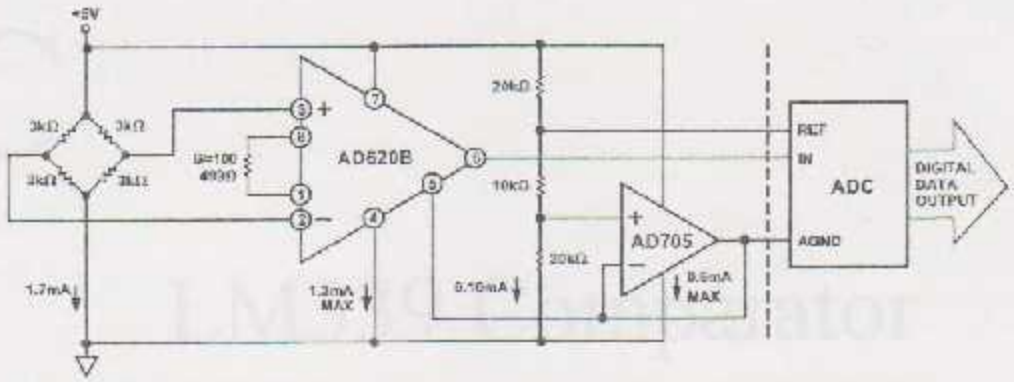


Figure 35. A Pressure Monitor Circuit which Operates on a +5 V Single Supply

Pressure Measurement

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

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

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

Medical ECG

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

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

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

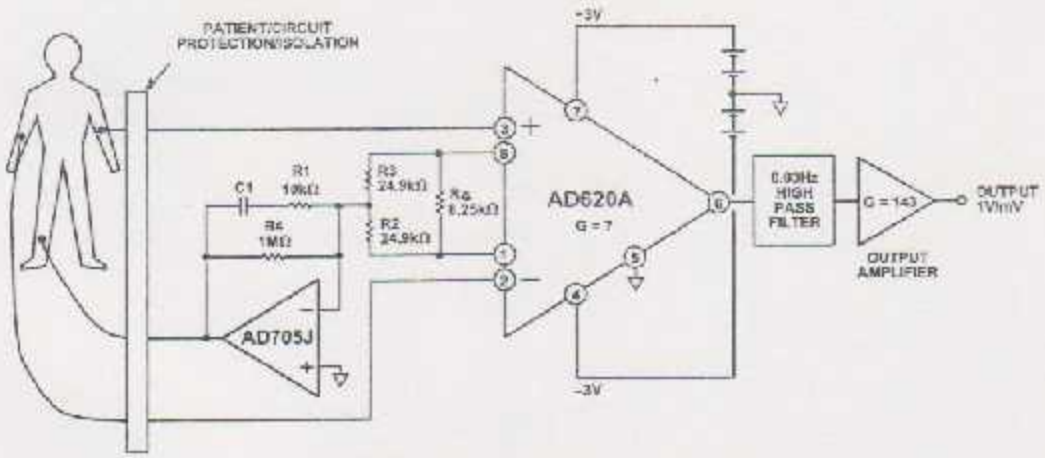


Figure 36. A Medical ECG Monitor Circuit

C

LM339 Comparator

FAIRCHILD
SEMICONDUCTOR®

www.fairchildsemi.com

LM339/LM339A, LM239A, LM2901

Quad Comparator

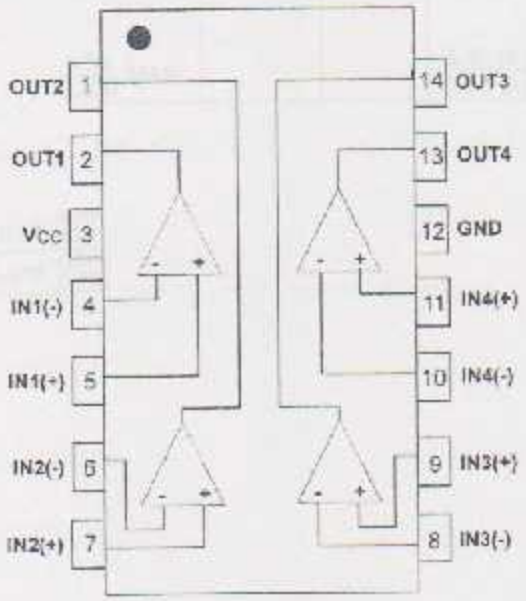
Features

- Single or Dual Supply Operation
- Wide Range of Supply Voltage LM2901, LM339/LM339A, LM239A: 2 ~ 36V (or ±1 ~ ±18V)
- Low Supply Current Drain 800μA Typ.
- Open Collector Outputs for Wired and Connectors
- Low Input Bias Current 25nA Typ.
- Low Input Offset Current ±2.3nA Typ.
- Low Input Offset Voltage ±1.4mV Typ.
- Input Common Mode Voltage Range Includes Ground.
- Low Output Saturation Voltage
- Output Compatible With TTL, DTL and MOS Logic System

Description

The LM339/LM339A ,LM239A, LM2901 consist of four independent voltage comparators designed to operate from single power supply over a wide voltage range.

Internal Block Diagram

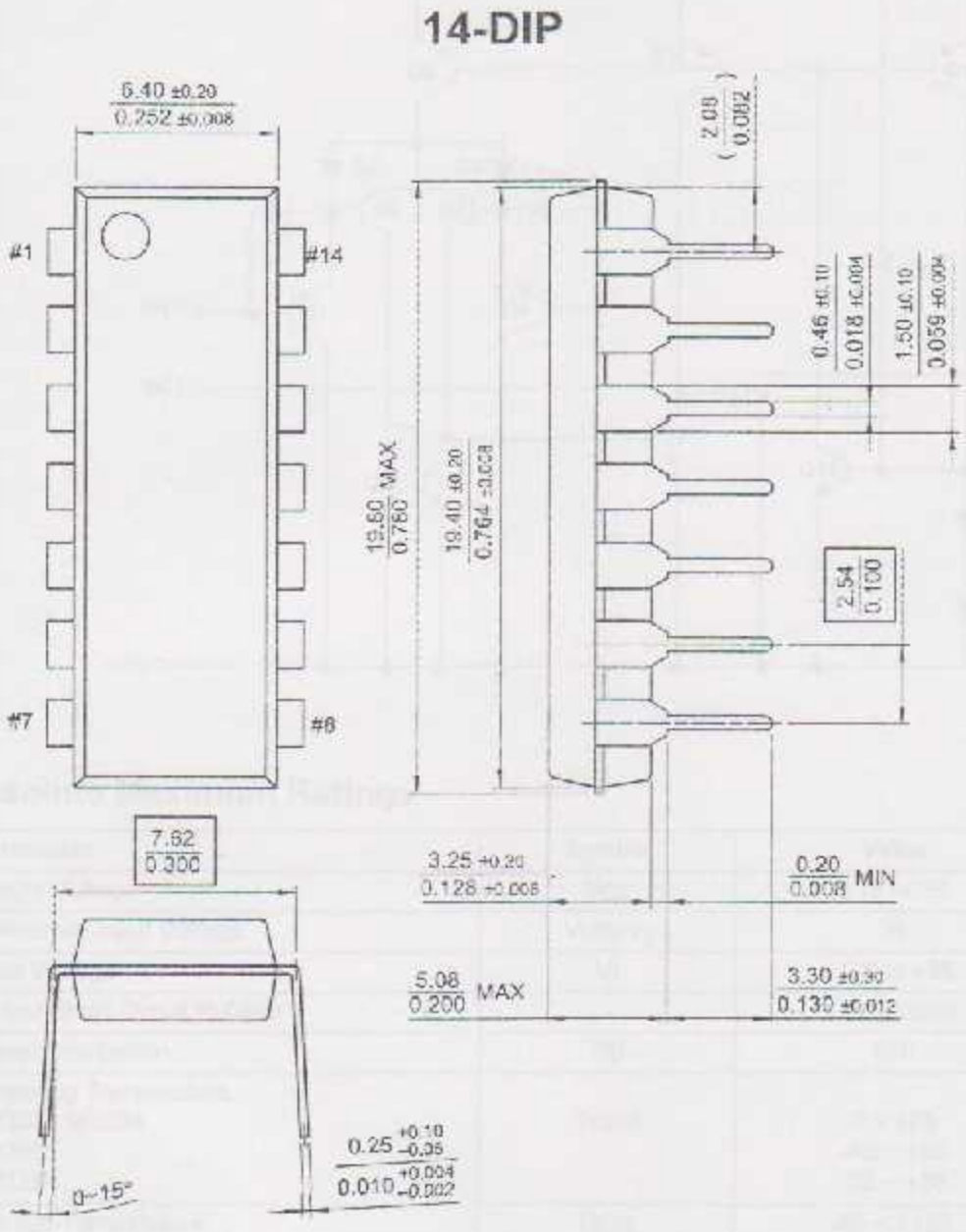


Rev. 1.0.5

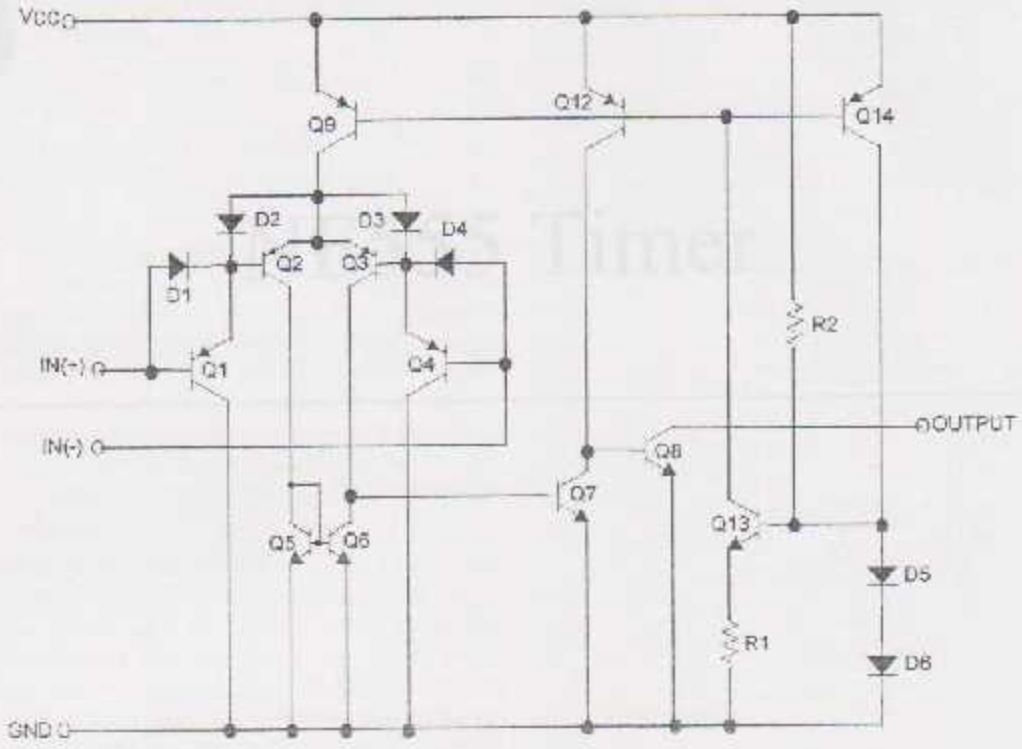
Mechanical Dimensions

Package

Dimensions in millimeters



Schematic Diagram



Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	⊥18 or 36	V
Differential Input Voltage	$V_{I(DIFF)}$	36	V
Input Voltage	V_I	-0.3 to +36	V
Output Short Circuit to GND	-	Continuous	-
Power Dissipation	P_D	570	mW
Operating Temperature LM339/LM339A LM2901 LM239A	T_{OPR}	0 ~ +70 -40 ~ +85 -25 ~ +85	°C
Storage Temperature	T_{STG}	-65 ~ +150	°C

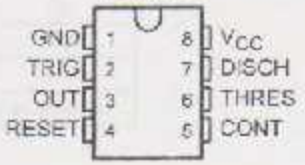
D

NE555 Timer

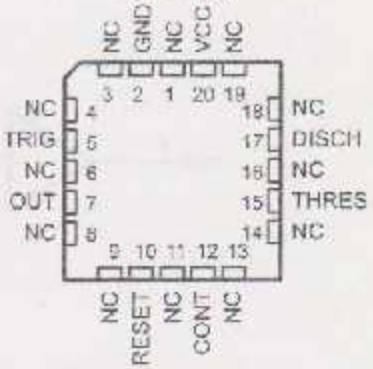
SLFS022C – SEPTEMBER 1973 – REVISED FEBRUARY 2002

- Timing From Microseconds to Hours
- Astable or Monostable Operation
- Adjustable Duty Cycle
- TTL-Compatible Output Can Sink or Source up to 200 mA
- Designed To Be Interchangeable With Signetics NE555, SA555, and SE555

NE555 . . . D, P, PS, OR PW PACKAGE
SA555 . . . D OR P PACKAGE
SE555 . . . D, JG, OR P PACKAGE
(TOP VIEW)



SE555 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

description

These devices are precision timing circuits capable of producing accurate time delays or oscillation. In the time-delay or monostable mode of operation, the timed interval is controlled by a single external resistor and capacitor network. In the astable mode of operation, the frequency and duty cycle can be controlled independently with two external resistors and a single external capacitor.

The threshold and trigger levels normally are two-thirds and one-third, respectively, of V_{CC}. These levels can be altered by use of the control-voltage terminal. When the trigger input falls below the trigger level, the flip-flop is set and the output goes high. If the trigger input is above the trigger level and the threshold input is above the threshold level, the flip-flop is reset and the output is low. The reset (RESET) input can override all other inputs and can be used to initiate a new timing cycle. When RESET goes low, the flip-flop is reset and the output goes low. When the output is low, a low-impedance path is provided between discharge (DISCH) and ground.

The output circuit is capable of sinking or sourcing current up to 200 mA. Operation is specified for supplies of 5 V to 15 V. With a 5-V supply, output levels are compatible with TTL inputs.

The NE555 is characterized for operation from 0°C to 70°C. The SA555 is characterized for operation from –40°C to 85°C. The SE555 is characterized for operation over the full military range of –55°C to 125°C.

AVAILABLE OPTIONS

T_A	PACKAGE					
	V_{THRES} MAX V_{CC} = 15 V	SMALL OUTLINE (D, PS)	CHIP CARRIER (FK)	CERAMIC DIP (JG)	PLASTIC DIP (P)	PLASTIC THIN SHRINK SMALL OUTLINE (PW)
0°C to 70°C	11.2 V	NE555D NE555PS	—	—	NE555P	NE555PW
–40°C to 85°C	11.2 V	SA555D	—	—	SA555P	—
–55°C to 125°C	10.6 V	SE555D	SE555FK	SE555JG	SE555P	—

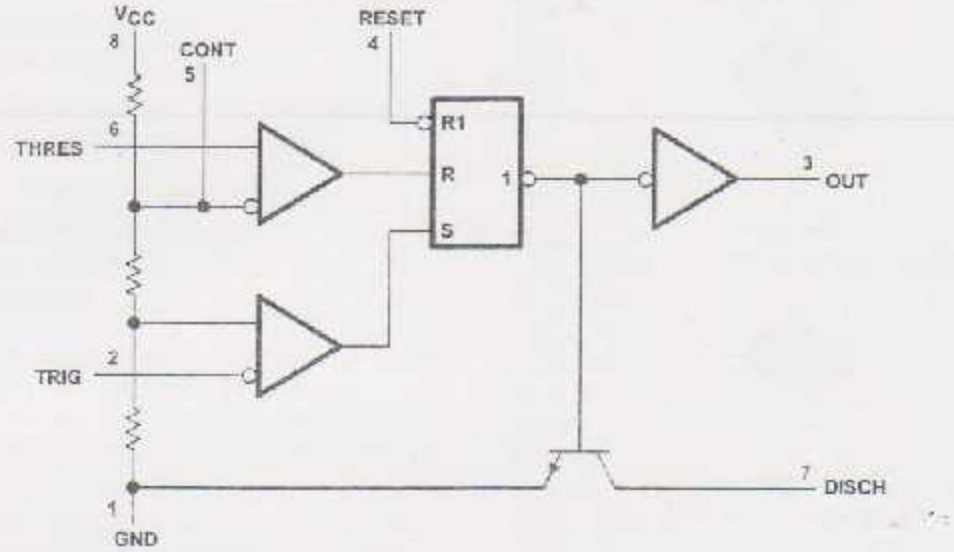
The D package is available taped and reeled. Add the suffix R to the device type (e.g., NE555DR). The PS and PW packages are only available taped and reeled.

FUNCTION TABLE

RESET	TRIGGER VOLTAGE†	THRESHOLD VOLTAGE†	OUTPUT	DISCHARGE SWITCH
Low	Irrelevant	Irrelevant	Low	On
High	<1/3 V_{DD}	Irrelevant	High	Off
High	>1/3 V_{DD}	>2/3 V_{DD}	Low	On
High	>1/3 V_{DD}	<2/3 V_{DD}	As previously established	

† Voltage levels shown are nominal.

functional block diagram



Pin numbers shown are for the D, JG, P, PS, and PW packages.
NOTE A: RESET can override TRIG, which can override THRES.

E

TL084 Amplifier

TL084, TL084A, TL084B

General purpose JFET quad operational amplifiers

Datasheet — production data

Features

- Wide common-mode (up to V_{CC}^+) and differential voltage range
- Low input bias and offset current
- Output short-circuit protection
- High input impedance JFET input stage
- Internal frequency compensation
- Latch up free operation
- High slew rate: 16 V/µs (typical)

Description

The TL084, TL084A, and TL084B are high-speed, JFET input, quad operational amplifiers incorporating well matched, high voltage JFET and bipolar transistors in a monolithic integrated circuit.

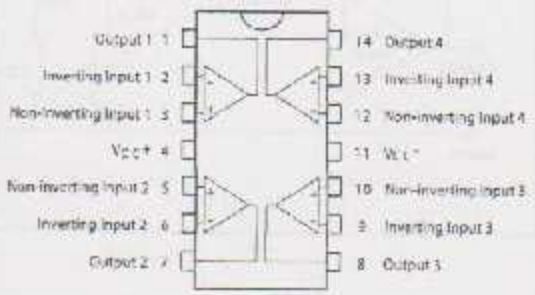
The devices feature high slew rates, low input bias and offset currents, and low offset voltage temperature coefficient.

N
DIP14
(Plastic package)

D
TSSOP14
(Thin shrink small outline package)

D
SO-14
(Plastic micropackage)

Pin connections
(Top view)



5 Typical applications

Figure 21. Audio distribution amplifier

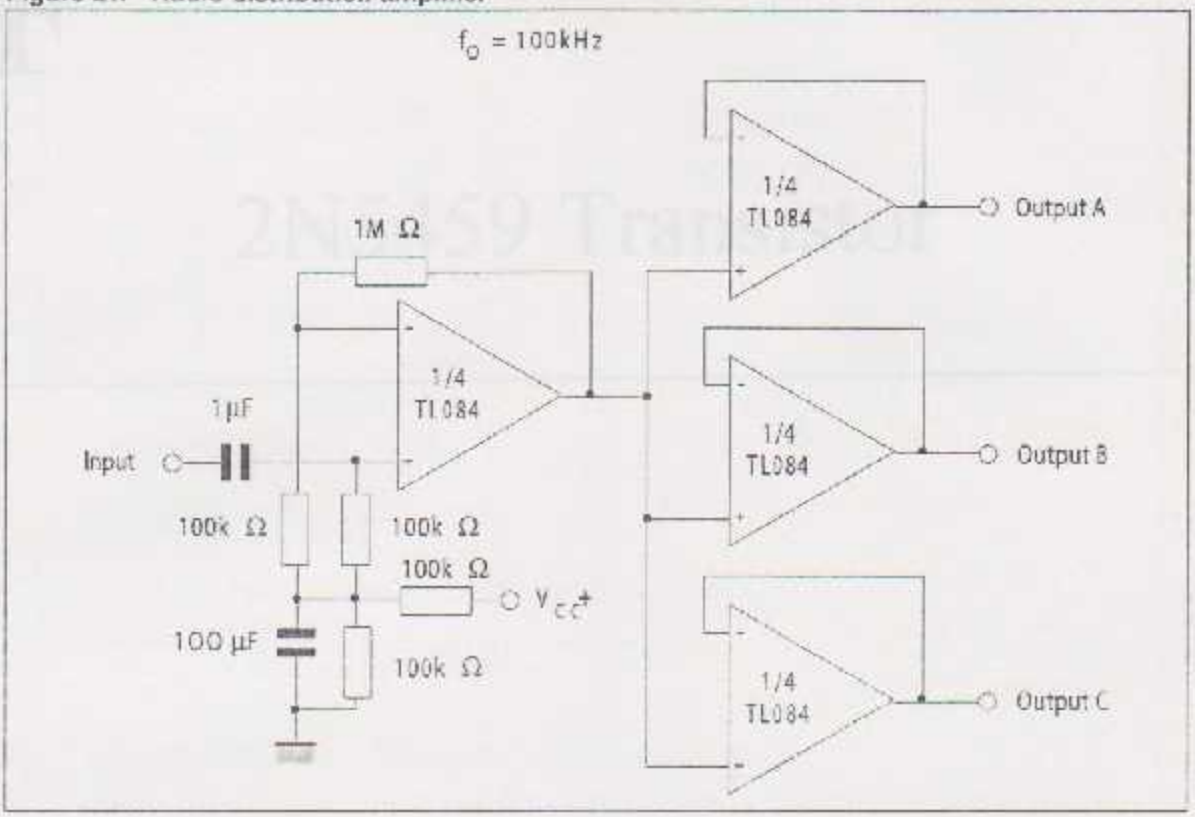
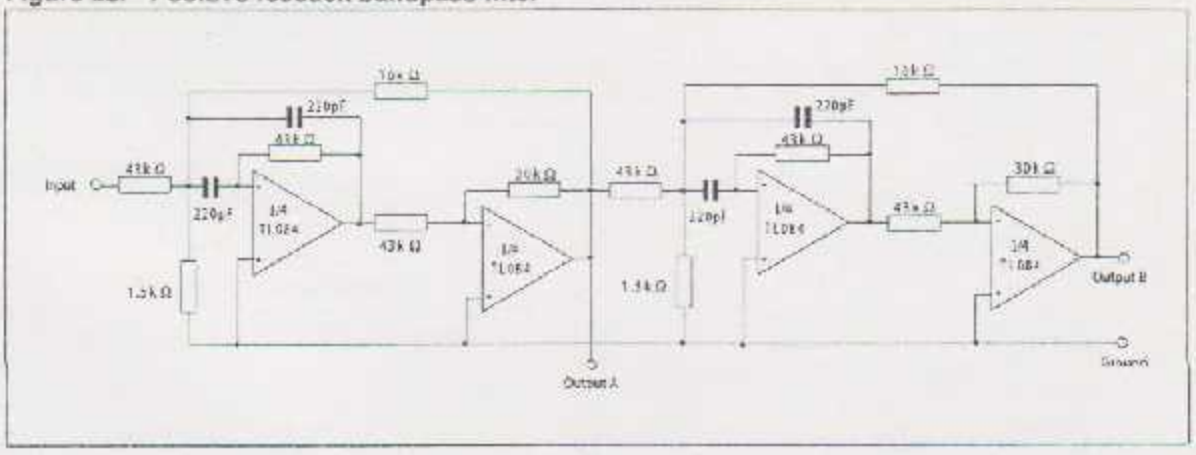


Figure 22. Positive feeback bandpass filter



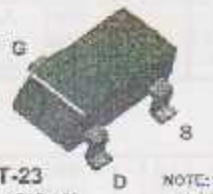
F

2N5459 Transistor

FAIRCHILD
SEMICONDUCTOR

2N5457 / 2N5458 / 2N5459
MMBF5457 / MMBF5458 / MMBF5459

TO-92



SOT-23
Mark: 6D / 61S / 6L

NOTE: Source & Drain are interchangeable

N-Channel General Purpose Amplifier

This device is a low level audio amplifier and switching transistors, and can be used for analog switching applications. Sourced from Process 55.

Absolute Maximum Ratings*

TA = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{DG}	Drain-Gate Voltage	25	V
V_{GS}	Gate-Source Voltage	- 25	V
I_{GF}	Forward Gate Current	10	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics

TA = 25°C unless otherwise noted

Symbol	Characteristic	Max		Units
		2N5457-5459	*MMBF5457-5459	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	125		°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	357	556	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06".

N-Channel General Purpose Amplifier
(continued)

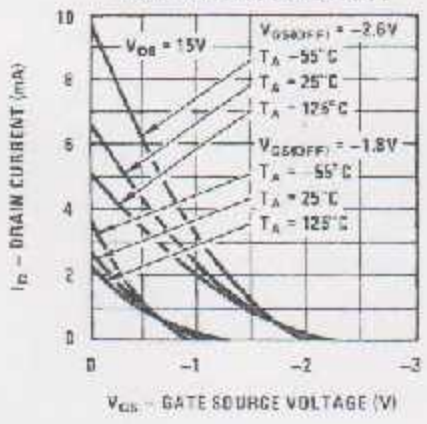
Electrical Characteristics
T_A = 25°C unless otherwise noted

Symbol	Parameter	Test Conditions		Min	Typ	Max	Units
OFF CHARACTERISTICS							
$V_{(BR)GSS}$	Gate-Source Breakdown Voltage	I_G = 10 µA, V_{DS} = 0		-25			V
I_{GSS}	Gate Reverse Current	V_{GS} = -15 V, V_{DS} = 0				-1.0	nA
		V_{GS} = -15 V, V_{DS} = 0, T_A = 100°C				-200	nA
$V_{GS(off)}$	Gate-Source Cutoff Voltage	V_{DS} = 15 V, I_D = 10 nA	5457	-0.5		-6.0	V
			5458	-1.0		-7.0	V
			5459	-2.0		-8.0	V
V_{GS}	Gate-Source Voltage	V_{DS} = 15 V, I_D = 100 µA	5457		-2.5		V
		V_{DS} = 15 V, I_D = 200 µA	5458		-3.5		V
		V_{DS} = 15 V, I_D = 400 µA	5459		-4.5		V
ON CHARACTERISTICS							
I_{DSS}	Zero-Gate Voltage Drain Current*	V_{DS} = 15 V, V_{GS} = 0	5457	1.0	3.0	5.0	mA
			5458	2.0	6.0	9.0	mA
			5459	4.0	9.0	16	mA
SMALL SIGNAL CHARACTERISTICS							
g_{fs}	Forward Transfer Conductance*	V_{DS} = 15 V, V_{GS} = 0, f = 1.0 kHz					
			5457	1000		5000	µmhos
			5458	1500		5500	µmhos
			5459	2000		6000	µmhos
g_{os}	Output Conductance*	V_{DS} = 15 V, V_{GS} = 0, f = 1.0 kHz			10	50	µmhos
C_{iss}	Input Capacitance	V_{DS} = 15 V, V_{GS} = 0, f = 1.0 MHz			4.5	7.0	pF
C_{rss}	Reverse Transfer Capacitance	V_{DS} = 15 V, V_{GS} = 0, f = 1.0 MHz			1.5	3.0	pF
NF	Noise Figure	V_{DS} = 15 V, V_{GS} = 0, f = 1.0 kHz, R_S = 1.0 megohm, BW = 1.0 Hz				3.0	dB

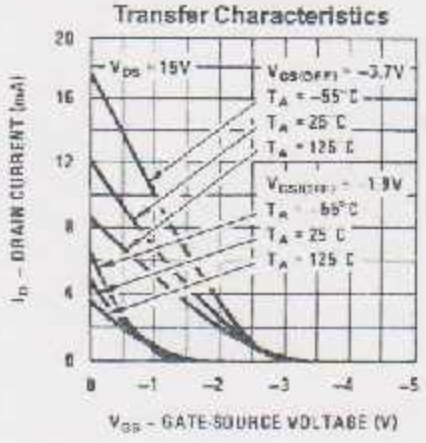
*Pulse Test: Pulse Width ≤ 300 ms, Duty Cycle ≤ 2%

Typical Characteristics

Transfer Characteristics



Transfer Characteristics



G

1N4001 Diode

1N4001 - 1N4007

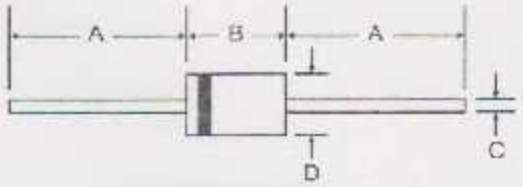
1.0A RECTIFIER

Features

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

Mechanical Data

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



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

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

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

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

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