بسم الله الرحمن الرحيم

# Palestine Polytechnic University

## College of Engineering & Technology

## Electrical and Computer Systems Engineering Department

**Graduation Project**

**Design & Implementation of an Air Bubble Detector for a Hemodialysis Machine**

**Student Name**

**RAJA'I RAJA MOSA**

**Project Supervisor**

**ENG. ABDALLAH ARMAN**

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**جامعة بولتيكنك فلسطين**

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**كلية الهندسة والتكنولوجيا**

**دائرة الهندسة الكهربائية والحاسوب**

**اسم المشروع**

**Design & Implementation of an Air Bubble Detector for a Hemodialysis Machine**

**اسم الطالب**

**رجائي رجا موسى**

بناءً على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية والحاسوب، وذلك للوفاء بمتطلبات درجة البكالوريوس في الهندسة تخصص هندسة أجهزة طبية.

**توقيع المشرف**

**...........................**

**توقيع اللجنة الممتحنة**

**...........................      ...........................      ...........................**

**توقيع رئيس الدائرة**

**.....................................................**

# ملخص المشروع

تم تقديم فكرة تطبيق مشروع لتصميم وبناء وحدة لكشف فقاعات الهواء قبل دخولها إلى جسم المريض باستخدام تقنية جديدة عن طريق المواسع الكهربائي.

الحافز لعمل هذا المشروع كان مستندا على الرغبة في تعميق فهم مبدأ عمل أنظمة المراقبة والكشف عن فقاعات الهواء في العديد من الأجهزة الطبية، وقد تم اختيار جهاز غسيل الكلى بشكل خاص لأهميته وانتشاره الواسع في مجتمعاتنا.

يحتوي هذا التقرير على التصميم وتفاصيل بناء المشروع والاستنتاجات التي تم التوصل إليها خلال عمل هذا المشروع.

تقوم الفكرة بداية على مبدأ عمل المواسع الكهربائي، الذي يعمل على تخزين كمية من الشحنات الكهربائية على صفائح موصلة بينهما مادة عازلة، حيث تمت الاستفادة من قانون المواسعة الكهربائية الذي يربط سماحية تمرير المجال الكهربائي للمادة العازلة بالمواسعة الكهربائية بعلاقة خطية. مر المشروع بعدة مراحل أهمها:-

المرحلة الأولى: بناء المواسع الكهربائي فقد تم تحديد المجس الذي من خلاله سيتم كشف فقاعات الهواء، فمن خلال التجارب تبين أن المواسع قادر على إعطاء فرق في المواسعة بمقدار "10pF" في حال عبور الهواء بين عينة الفحص.

المرحلة الثانية: بناء قنطرة قادرة على تحسس الفرق الناتج في المواسعة وتحويله إلى فرق جهد عن طريق تزويدها بمصدر فولت متردد، فقد تم تسجيل فرق جهد بمقدار 0.1 فولت في حال عبور الهواء.

المرحلة الثالثة: تم تكبير فرق الجهد الناتج من دخول فقاعة الهواء بواسطة مكبر العمليات بمعامل تكبير مقداره 1000، حيث أصبح التغير في الجهد في حالة مرور فقاعة الهواء بمقدار ا فولت.

المرحلة الرابعة: فقد تم مقارنة قيمة التغير في فرق الجهد نتيجة مرور الهواء بقيمة فرق جهد مرجعية لتوليد إشارة فرق جهد تعمل على تفعيل دائرة المنبه.

# ABSTRACT

**The idea of the project is suggested to design and build an air bubbles detection unit by using new technique by electric capacitor.**

**The motivation for making the project is based on the desire to deepen the understand of the principles for monitored detection units, the hemodialysis machine is chosen because it is widely spread and important in our country.**

**The project includes complete information, schematic design circuit and conclusion for applying the capacitance detection method.**

**The idea depends on the property of capacitance that relates directly with relative permittivity of the dielectric material. The project passes by several stages arranged as follows:**

**First stage:** **building the capacitor manually to sense the changes of voltage, during the experiments we indicated that the capacitor detect "10pF" during pass air bubble.**

**Second stage:** **building a bridge circuit which sensed about 0.1v during air bubble passes between the plates.**

**Third stage:** **building the differential amplifier circuit that amplify the voltage difference by voltage gain 1000, and become 1v when air bubble passes.**

**Fourth stage:** **building the comparator amplifier circuit that compares the voltage difference with reference voltage to operate the alarm circuit.**

# الإهداء

إلى السنبلة الذهبيّة في بِلادي و بيّارات البرتقال
إلى كرومِ العِنَب و غصن الزيتون و دَم الشهداء و دَمعة الأطفال

إلى غزّة و مآسيها

إلى رغيف الطابون و ريح الزَعتر

إلى فِلسطين تِلك التي صَنعتني كَي أكونَ هُنا

إلى مَن علّمني كَيف الصعود و حَمل لي شُعلةً

تلذذ بحروقاتِها في يَديهِ لينيرَ لي دَربي

إلى ذاك الرَجل الذي عَلّمني العِزّة و كحّل عينيّ بالكِبرياء

إلى ذاكَ الذي ما زالَت عينيه تَصنعني طِفلة حَتّى اللحظة!.

"إليكَ والدي"

و إليها..

و إلى الحضن المعبَق بأريج الوَطن

و اليَد التي اندّست في خِصال شِعري و صوتها الشجيّ يَروي لي حَكايا الجِدّ و النجاح
قَبل النوم كَي أحلُم بِها

مَن علّمتي كَيف أقِف أمامَكم في لَحظةٍ تَتسابق فيها الدموع لمقلتيّ

"إليكِ أمّي"

و لكلّ مَن صَعنوني مَعكما و حفّتني و إياهم ذِكريات بيتٍ واحِد

إلى مَن اجتمعوا مَعي على دِفء مَوقِد الشِتاء و تَقاسموا مَعي ظلمَة ليلٍ واحِدة

# THANKS & ACKNOWLEDGMENT

**Firstly, I thank my god for blessing me to complete my project, and I a great many thanks to a great many people who helped and supported me during writing the project.**

**My deepest thanks to Lecturer, Eng. Abdulla Arman, the Guide of the project for guiding and correcting various documents of mine with attention and care.**

**I would have not finished this project without the support of my family who has always been there for me whenever I need them, the encouragement they give to keep me going and their love to empower me that never fails all the time.**

**To my friend Engineer "Wajdi Al_Wahsh" whose support has always been my source of strength and inspiration.**

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# Chapter One

## INTRODUCTION

### 1. Introduction:

**1.1 Project Overview**

**1.2 Project Objectives**

**1.3 Time Scheduling**

**1.4 Aim of Project**

**1.5 Actual Cost**

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## 1.1 Project Overview

Medical safety routines are considered nowadays as top priorities and most important parts of medical devices, and they are still the most focused point in designing and implementing any successful medical system.

Not only the electrical safety of the designed device is taken into consideration in medical devices as most people think, but it also goes beyond that to include all the services, connecting parts and therapies which are supplied by the medical devise to the patient body.

Starting from the above mentioned point, I decide on the project idea, the Air Bubble Detection Unit which is based simply on checking and testing the passing and occurring of an air bubbles and embolisms in a full running blood line that must return only blood to the patient body.

The designed system must keep working as long as the blood cycle in tubes are running, if a fault of air bubble exists in blood line, an alarm system will start and the blood cycle must stop immediately, waiting for the clinician to be awaked and remove the foam of the air. A general block diagram of the system is shown in Figure 1-1.

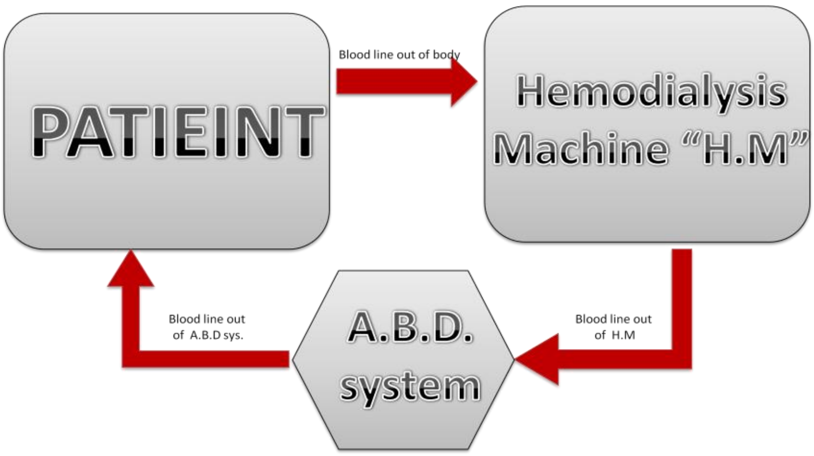



**Figure 1-1: Project General Block Diagram**

Air bubbles detection unit is necessary in any medical procedures that deal with human blood, and it makes a serious problem if it enters the blood stream, so the implemented system in general should be compatible with different medical devices that deal with cycling the blood out of the patient body and returns it back to the patient body, such as the Heart Lung machines, open heart surgery devices and the Hemodialysis machines.

In this project I've chosen the Hemodialysis machine for many different reasons, first this machine is widely spread in many markets and environments. Second, many hemodialysis centers have specialists whose experience is not enough, which causes risk and threatens the patient's life through dealing with air bubbles detection unit.

So the unit requires from us to understand its work in all cases. Third; the machine is available in our local markets and hospitals widely, helping me conduct my search by making contact with engineers and those who have experience in this field. Figure 1-2 shows a typical form of Hemodialysis machine.

**Figure 1-2: Hemodialysis Machine**

The returning blood line to the patient’s body "after ending the therapy process" must have some standards and considerations before it goes directly to the patient's vessels, because any tiny unusual errors and unwanted effects may cause a seriously damage to the patient and may be fatalist in some cases.

One of these dangerous cases happens when there is an air bubble or embolism in the blood line allowing these bubbles to enter the patient body.

Air bubbles detection units are grown field nowadays for companies and researchers from many points of view, that may include the best detection method for bubbles through blood line stream, and the sensitivity for air bubble size plays an important role in choosing them, simplicity, working life of that system, efficiency of the hole system and the total cost of the implemented system.

These are also taken into account to get perfect systems and attract different customers and hospital managers to supply their hospitals with this product.

The project highlights the most important characteristics and properties of a transducer that enables to build and design a system that works efficiently and sufficiently to detect serious and danger air bubbles before entering the patient body. Thus, I focus on the ability to build the transducer manually, and to be less affected for surrounding environment. The total building cost, simplicity and efficiency for the system are also important here to get the required specifications, see Figure 1-3.

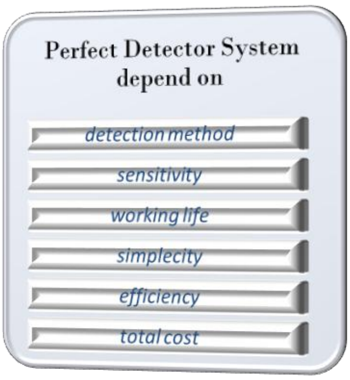



**Figure 1-3: Perfect Detector System**

Figure 1-4, shows a simplified flow chart of the working cycle of the system, at first the blood cycle comes out of the patient body entering the Hemodialysis machine for dialyzing process.

Then the circulating blood comes out of Hemodialysis machine and it must pass by air bubbles detection unit.

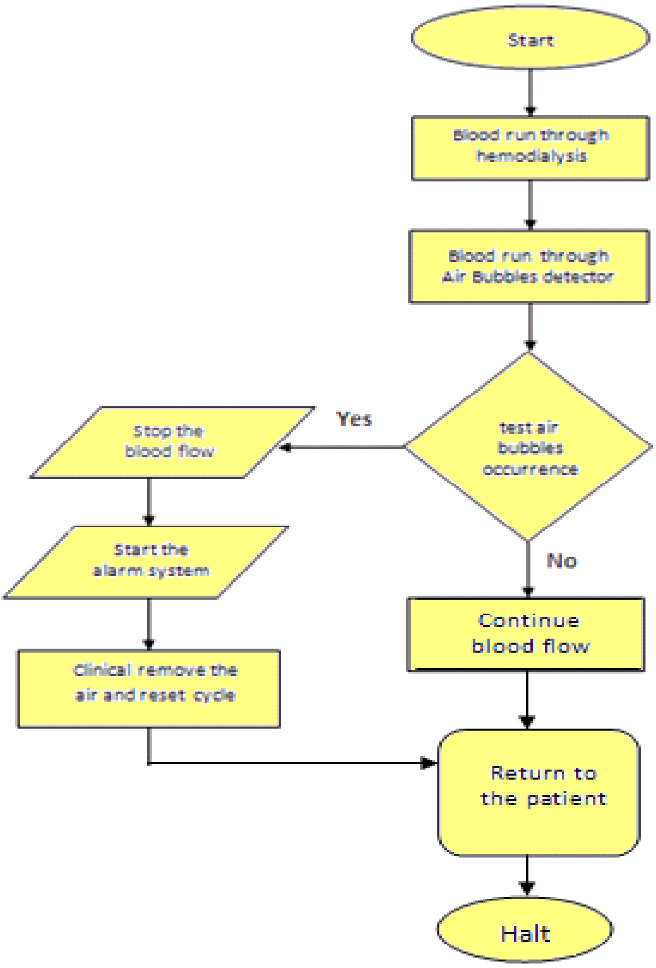



**Figure 1-4: Flow Chart System**

The transducer will begin to work after the blood starts flowing through blood tube and start sensing the occurrence for any air bubbles. If there are no embolisms detected, the blood will continue flowing and return to the patient body safely.

On the other hand, if any faults happen of air embolisms occurrence inside blood line, the blood will stop flowing immediately to prevent the air bubbles passing to the patient and alarm system will operate.

The clinician must remove the dangerous air bubbles and reset the blood cycle to work normally waiting for the next detection alarm. Finally the blood will return safely without any dangerous on the patient.

## 1.2 Project Objectives:

- Design and build manually parallel plate's capacitor that can detect the change of capacitances when air bubble passes in test tube.
- Design and construct deriving circuit of alternating (ac) bridge consists of resistors and capacitors.
- Test the condition of the bridge circuit and make sure that there is a difference voltage when air bubble moves between the plates.
- Design and built differential amplifier circuit that can amplify the difference between bridge arms.
- Design and built comparator amplifier circuit that can compare the output voltage from the differential amplifier circuit with reference voltage.
- Build an alarm system that contains light and audible alarm to aware.
- Ensure that the whole system unit is working probably.

## 1.3 Time Scheduling

The time scheduling shows the stages of developing work and the progress of project growth, the time schedule includes a lot of events during one year studying.

The first semester includes the project introduction clarified in six events. The second semester covers all of requirements that guarantee to complete the entire project in twelve weeks, the project actions summarized in ten events shown below.

**T1:** *Project Preparation*: the first stage of project is basically important, it includes work plan, determining contents, discussing initial information, and evaluation the project levels and priorities of work.

**T2**: *Data Collection*: data collection includes researching for references, books, and papers from internet and library as well as studying all the possible options of the project.

**T3**: *Analysis project and Transducers*: project analysis includes a wide studying and analysis of the available transducers in hemodialysis machine. After all, the capacitive transducer is chosen in my project.

**T4**: *Conceptual Design*: conceptual design includes determining project objectives, designing the expected block diagram, putting schematic diagram for each block and discussing the principles of operation.

**T5**: *Studying Project Component and Schematic Analysis*: it is necessary to review the data sheet for amplifiers and other components, and to investigate that they are available.

**T6**: *Documentation*: the documentations of the project include weekly writing down the information, modification the notes, editing and ordering the project pages and the documentation process start and finish within the progress of the project work.

**T7**: *Review and Modify the Project*: the stage includes viewing the design, analyzing the circuits that represent the system and subsystem of the project.

**T8**: *Design each Circuits of Project theoretically*: includes assumptions and determining the values of components, calculations and wanted equations.

**T9**: *Build and Implement the Project Circuits*: includes repairing the components and measuring the variables, it was started by building the parallel capacitor plates.

**T10**: *Testing the Circuits of Each Block Diagram*: during the testing stage, I made the experiments in the projects lab, recording the output values and comparing the values with theoretical design.

**T11**: *Overall System Testing*: I made tests and connect stages with each other like bridge output with amplification to get real and correct output.

**T12**: *Final Documentation*: final documentation includes collecting each chapter of the project and reviewing precisely the information and equations as well as printing out the final sheets.

**Table 1-1: Time Schedule in First Semester**

| Task /week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | | | | | | | | | | | | | | | | |
| T2 | | | | | | | | | | | | | | | | |
| T3 | | | | | | | | | | | | | | | | |
| T4 | | | | | | | | | | | | | | | | |
| T5 | | | | | | | | | | | | | | | | |
| T6 | | | | | | | | | | | | | | | | |

**Table 1-2: Time Schedule in Second Semester**

| Task /week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T7 | | | ■ | ■ | | | | | | | | | | | | |
| T8 | | | | | ■ | ■ | ■ | | | | | | | | | |
| T9 | | | | | | | ■ | ■ | ■ | ■ | ■ | | | | | |
| T10 | | | | | | ■ | | ■ | ■ | | ■ | ■ | | ■ | | |
| T11 | | | | | | | | | | | ■ | ■ | ■ | ■ | | |
| T12 | | | ■ | ■ | | ■ | | ■ | ■ | ■ | | | ■ | | | |

## 1.4 The Aim of the Project

- What's the importance of the air bubbles detection unit?
- What are the most important parts that should be kept safe in a hemodialysis machine?
- What are the common errors that appear in an hemodialysis machine? And how are these errors detected?
- What are the methods of detection air bubbles? And what is the advantage of each one?
- What are the risks of air bubbles in human body if they enter with blood?
- How could the air bubbles detection unit be improved?

This project presents answers of all the above questions and much more; it demonstrates designing hardware of an "external unit" to hemodialysis machine.

The designed external unit will be able to detect errors in the in blood line before these errors cause any risks; it will have alarm to the unit to switch it off when necessary.

## 1.5 Actual Cost

This section lists the overall cost of the implemented project, Table 1-2 shows all the equipment units and components that are used in the project and the price on each item.

**Table 1-3: Project Components Cost**

| **Items** | **Price "$"** |
|---|---|
| Capacitor Components | 10 |
| Resistors & Capacitors | 10 |
| Power Supply Unit | 20 |
| IC's & Bread Boards | 40 |
| Housing & Alarm | 20 |
| Voltmeter & Electronics | 60 |
| Total | 160 |

The approximated total cost for the project is 160$.

## 1.6 Project Challenges

The project challenges summarized in three important points:

- During the project implementation, I have faced difficulties to bring the capacitor sensor as I wanted to detect air bubbles, and I have faced challenges of designing the capacitor and obtained the correct data from the bridge because the quantity of capacitance is very small in pF, and the available measurement tools measure minimum 2-nF.
- Another difficulty is the high sensitivity of the bridge. The errors continuously appear; they are represented by the alternating signals that need processing in each step of the project, and they also need accurate devices to deal with small change of parameters.
- Another major problem during the project is that the experiments and tests can only be done when the lab is available, which delays completion each stage on time.

## 1.7 Human Development Resources

The project owner is an undergraduate student at Biomedical Engineering Department in Palestine Polytechnic University.

Prepared by: Raja'i Raja Mosa

Supervised by: Eng. Abdullah Arman

## 1.8 Project Scope

This project document consists of six chapters arranged as follows:

**Chapter One:** Introduction

This chapter presents: overview for the total project, objectives, time schedule, actual cost, the main challenges and human development resources.

**Chapter Two:** Background

This chapter discussed the; physiology and anatomy of human kidney, blood overview, dialysis procedure, hemodialysis machine, major risks during hemodialysis, how does air bubbles get into the blood, danger of air bubbles on the patient life.

**Chapter Three:** Air Bubbles Detection Methods

This chapter explains the basic information of photoelectric, ultrasonic, and capacitive transducers, and the relevant considerations to adopt the suitable transducer.

**Chapter Four:** Technical Details of Project Design

This chapter contains: introduction, overall block diagram, capacitor design bridge design, differential amplifier circuit, comparator amplifier circuit.

**Chapter Five:** System Implementation and Testing

This chapter describes the experiments results to design desired capacitor, schematic circuit for stages of projects, and entire project schematic.

**Chapter Six:** Conclusion and Future Work

This chapter includes the conclusion, results and future work.

# Chapter Two

## BACKGROUND

## 2. Background:

**2.1 Physiology of Human Kidney and Blood**

**2.2 Blood Overview**

**2.3 Dialysis Procedure**

**2.4 Hemodialysis Machine**

**2.5 Major Risks during Hemodialysis**

**2.6 How Air Bubbles get into the Blood?**

**2.7 Danger of Air Bubbles on the Patient Life**

## 2.1 Physiology of Human Kidney and Blood

This section provides an overview of human kidney and blood to recognize the constructions and illustrate the major functions for them and their characteristics.

### 2.1.1 Kidney Structure and Functions

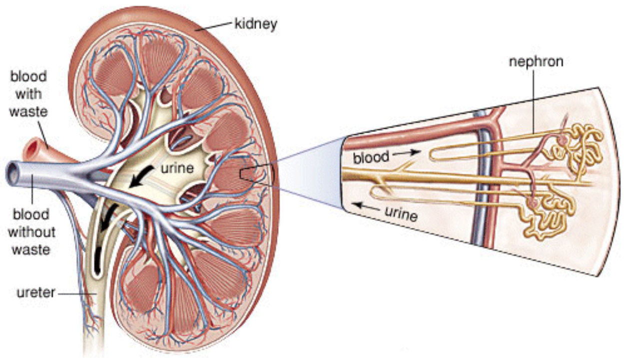



**Figure 2-1: Human Kidney and Nephron**

The kidneys are the main excretion organs in the body; they are two organs, each about the size of the fist, approximately 11 centimeters in length and 6 centimeters wide. They are located in the back, above the waist, one on each side just beneath the lower ribs. They are protected from injury by the ribs and by several muscles at the back, which overlie them. Two healthy kidneys excrete between 1.5 and 2.5 liters of urine daily.

Each kidney is surrounded by membrane known as the renal capsule, each kidney is made up of approximately a million nephrons, each nephron consists of a filtering component called the glomerulus and a tubule which reabsorbs essential water and chemicals into the blood stream and transports urine from the glomerulus to the ureter.

The kidneys perform a number of important functions. They are:

1. Remove waste products from the body.
2. Control the amount of fluid in the body.
3. Control the chemical composition of the body.
4. Produce certain important hormones and chemicals.

Each day approximately 180 liter of filtrate is formed by the glomeruli; it contains fluid and some chemicals, which the body needs, as well as waste and toxins. This filtrate then passes down tiny tubules. As the filtrate travels down the tubules, all the essential chemicals and fluid that we need are reabsorbed into the circulation, leaving behind the waste products and excess fluid that we don't need (urine). This remaining fluid is the urine.

The purified blood returns from the kidneys to the rest of the body through blood vessels called the renal veins. The urine passes down the ureters (usually one from each kidney) to be stored in the bladder, where it is stored until such time as it is ready for elimination from the body via a tube called the urethra.

### 2.1.2 Kidney Failure

As mentioned in previous section the kidneys perform a number of important functions, Kidney failure occurs when the kidneys no longer function adequately to remove waste products and excess fluids from the body. Frequently, kidney failure is also associated with a lack of erythropoietin (which stimulates red blood cell production). Other terms commonly used interchangeably to describe kidney failure include Chronic Renal Failure, Uremia and End-Stage Renal Failure.

Strictly speaking, Chronic Renal Failure is any reduction in kidney function below normal levels, and this term describes a broad spectrum of disease from mild to severe kidney disease. Uremia is said to be present when kidney function has deteriorated to such an extent as to be causing medical side effects.

End-stage renal failure describes the point at which artificial renal replacement therapy needs to be started in order to avoid the serious consequences of Uremia. End-stage renal failure is said to be present when the kidneys are working at less than 10% of normal.

Medical intervention can slow the rate of progression of kidney failure and prevent the development of many of the symptoms that can result from renal failure. It can also delay or even perhaps prevent the need to start artificial kidney replacement therapy (dialysis).

When kidney failure progresses to the point where the kidneys do not function well enough to keep a person healthy, replacement of kidney function with dialysis or a kidney transplant is necessary to maintain good health.

Dialysis is used to replace some of the functions of the kidneys, particularly removal of waste products, substances toxic to the body and excess fluids. Dialysis can be performed using an artificial kidney Hemodialysis Machine, usually for five hours three times per week. Figure 2-2 shows a healthy kidney on the left and disease one on the right.

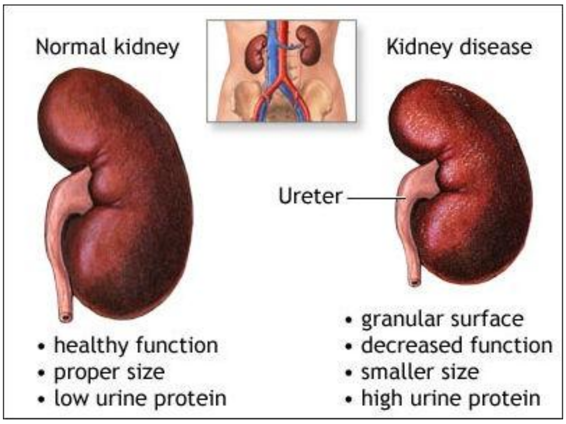



**Figure 2-2: Healthy Kidney vs. Disease Kidney**

## 2.2 Blood Overview

Blood consists of 40 to 45 percent formed elements. See Figure 2-3 below. Those formed elements include red blood cells, white blood cells and platelets. Red blood cells are those cells involved primarily in the transport of oxygen and carbon dioxide. White blood cells are cells involved primarily in phagocytosis and immune responses. Platelets are involved in blood clotting.

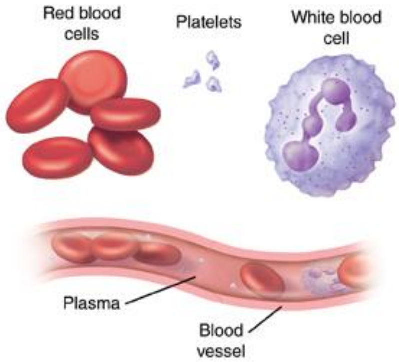



**Figure 2-3: Blood Cells**

In addition to the formed elements in blood, 55 to 60 percent of blood by volume consists of plasma. Plasma is the transparent, amber-colored liquid in which the cellular components of blood are suspended. Blood accounts for 6 to 8 percent of body weight in normal, healthy humans.

### 2.2.1 Blood Properties

Subsection 2.2.1 presents the study of blood properties, especially the properties associated with the deformation and flow of blood. To study the behavior of materials that act as fluids, it is useful to define a number of important fluid properties, which include density, specific weight, specific gravity, and viscosity.

The density of blood is slightly greater than the density of water at approximately 1060 kg/m3. The increased density comes from the increased density of a red blood cell compared with the density of water or plasma. The density of water is 1000 kg/m3. Most people have between 4.5 and 6.0 L of blood.

Specific weight is defined as the weight per unit volume of a substance. Specific gravity is the ratio of the weight of a liquid at a standard reference temperature to the weight of water.

Viscosity is defined by the slope of the curve on a shear stress versus shearing rate diagram. Viscosity of the blood is one of the characteristics of blood that affects the work required to cause the blood to flow through the arteries.

## 2.3 Dialysis Procedure

The word “dialysis” comes from the Greek words, “dia” that means through, and “lysis” which means to dissolve. Dialysis is a physical process whereby particles in a solution are transported through a membrane.

The process is facilitated by different concentrations on both sides of the membrane, aiming to achieve equilibrium by diffusion.

When chronic renal failure progresses to the point where the kidneys do not function well enough to keep a person healthy, replacement of kidney function with dialysis (renal replacement therapy) or a kidney transplant is necessary to maintain good health. Dialysis replaces some of the functions of the kidneys, particularly the removal of waste products and excess fluids.

The two major forms of dialysis are hemodialysis and peritoneal dialysis. Hemodialysis, see Figure 2-4, uses a special filter called a dialyzer that functions as an artificial kidney to clean a person’s blood.

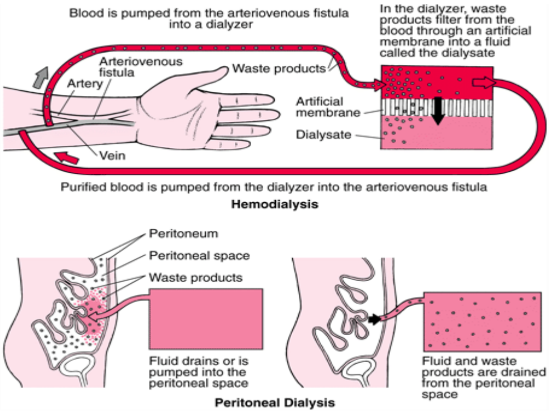



**Figure 2-4: Hemodialysis and Peritoneal Dialysis**

The dialyzer is a canister connected to the hemodialysis machine. During treatment, the blood travels through tubes into the dialyzer, which filters out wastes, extra salt, and extra water. Then the cleaned blood flows through another set of tubes back into the body. The hemodialysis machine monitors blood flow and removes wastes from the dialyzer. Hemodialysis is usually performed at a dialysis center three times per week for 3 to 4 hours.

In peritoneal dialysis a fluid called dialysis solution is put into the abdomen. This fluid captures the waste products from a person's blood. After a few hours when the fluid is nearly saturated with wastes, the fluid is drained through a catheter. Then, a fresh bag of fluid is dripped into the abdomen to continue the cleaning process. Patients can perform peritoneal dialysis themselves.

## 2.4 Hemodialysis Machine

Hemodialysis machine is one of the most important medical devices that perform renal replacement therapy when someone has end-stage renal failure; the machine removes waste products and metabolism from the blood.

This task is normally performed by the natural kidneys. In the safety side, any medical device must be classified according to the protection system, The hemodialysis machine classified as class (1), that contains two lines connections; neutral, phase plus earth line.

The hemodialysis machine could not replace the natural kidney that our God give it to us, and it is classified just as supporting or helping machine, while it performs of 60-70% from filtration of natural kidney.

In hemodialysis machine, there are two basic parts that simulate the natural organs in the human body, the blood pump or peristaltic pump simulate the heart pump, it is used to pull the blood from the artery. The second part is the dialyzer that performs filtering operation which simulates the nephrons in natural kidney.

Hemodialysis machine regulates the amount of water in human body, where as the percent of water in the human body estimated 45%-75% from the body weight, and the water is important for transferring the oxygen and food from blood to tissues, transfer the carbon oxide and metabolism from body tissues to blood and other metabolic reactions, so the amount of water must be equilibrium in human body.

If we make comparison between natural kidney and the artificial kidney, we find the following differences in Table 2-1:

**Table 2-1: Natural Kidney vs. Artificial Kidney**

| ________ | **Natural Kidney** | **Artificial Kidney** |
|---|---|---|
| Pumps | Heart | Blood pump |
| Filter | Nephrons | Dialyzer |
| Weights | 30 grams | 110 kilograms |
| Number of filters | One millions nephrons per kidney | 12000-17000 fiber |
| Number of dialysis | 36 per day | 3 per week |

### 2.4.1 Molecular Transport Mechanisms

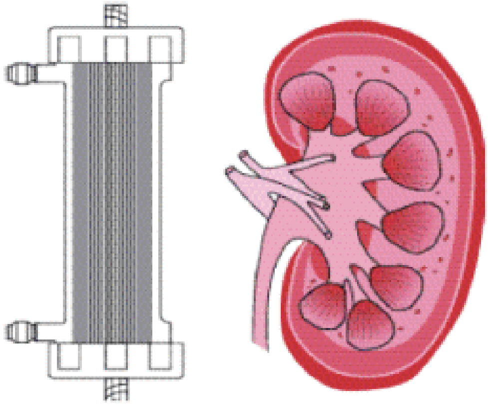
- **Diffusion**: The movement of solutes from a higher to a lower solute concentration "Very efficient for removing small molecules".
- **Osmosis**: The movement of water through a membrane from a higher to a lower concentration area.
- **Ultra-filtration**: The movement of fluid across a membrane caused by a pressure gradient.
- **Convection**: The movement of solutes with a water flow, "solvent drag", e.g. movement of membrane permeable solutes with ultra-filtered water.

### 2.4.2 Dialyzer

The dialyzer is a disposable component in which solute exchange, or clearance, takes place. There are three basic design configurations: coil, parallel plate, and hollow fiber. In all three, electrolytes, waste products, and water pass across a semi permeable membrane into a flowing stream of dialysate solution.

By diffusion, osmosis, and Ultra-filtration (UF), water and metabolites are exchanged between the blood and the dialysate. Concentration gradients cause waste products, such as urea and creatinine, to diffuse across the membrane from the blood to the dialysate. Electrolytes move in both directions to maintain equilibrium.

Red and white blood cells and proteins are too large to pass through the pores in the membrane. Figure 2-5 shows a comparison between natural kidney and artificial one “Dialyzer”.



The dialyzer performs some of the functions of a normal kidney.

**Figure 2-5: Dialyzer**

### 2.4.3 Blood Circulation in the Hemodialysis Machine

The external blood-delivery system (extracorporeal blood circuit) circulates a portion of the patient's blood through the dialyzer and returns it to the patient. Usually, an artery and a vein in the patient's arm are surgically joined for circulatory access; this junction is called an arterio-venous (AV) fistula.

In Figure 2-6, blood pump moves blood through the external tubing and dialyzer. As the pump draws blood into the extracorporeal circuit, it creates a partial vacuum that will draw air into the tubing if connections are not absolutely tight.

As a safety feature, air/foam detectors are employed to detect air in the blood line and prevent it from being pumped into the patient. External blood pressures are monitored on both venous and arterial lines; high- and low-pressure alarms turn off the blood pump if necessary.

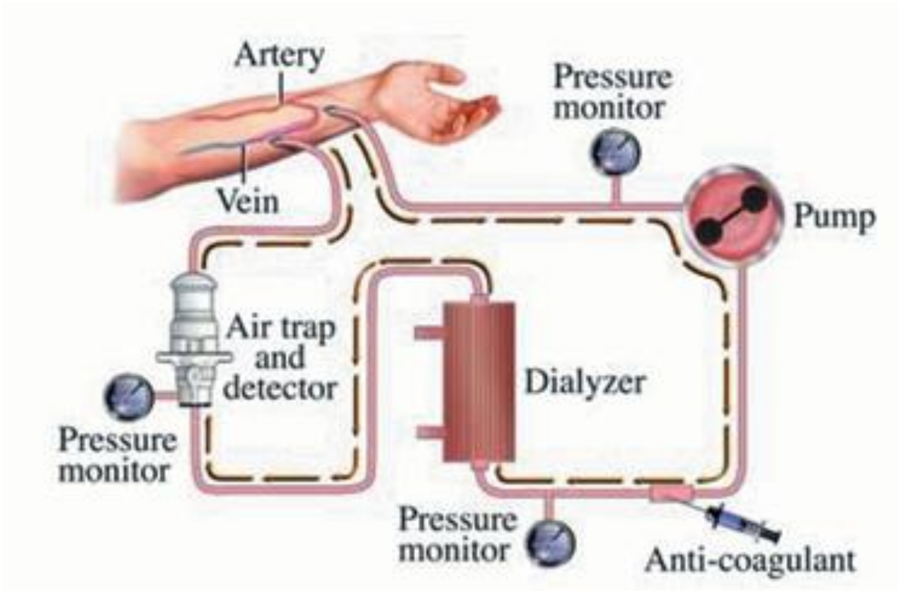


**Figure 2-6: Blood Circulation**

Because blood tends to clot when it comes into contact with foreign surfaces such as those in the tubing and dialyzer, heparin, an anticoagulant, is infused through a syringe pump aseptically connected to an infusion line in the arterial side of the blood circuit. The infusion pump can be set to deliver heparin at a predetermined rate. A drip chamber on the venous side of the blood circuit contains a clot-trapping filter to help prevent upstream clots and other debris from reaching the patient.

## 2.5 Major Risks during Hemodialysis

Even though the safety of the Hemodialysis procedure has improved greatly over the years, the dialyzing procedure is not without risks.

There are many risks that maybe occur during the dialysis, we mention here the major serious problems and how companies and developers were able deal with it and solve it, since there is a recirculation for blood through different parts of the machine using different tubes, a blood leaks have a big probability to occur, it is discovered by blood leak detecting unit. This unit uses photoelectric technique that sends and receives specific wave length 'λ' of infrared light.

Another problem taken into account, is the existence of air bubbles and foam inside transported blood lines to the patient, where there are several different ways to detect the air bubbles, an older method of detection is by using a photoelectric method, another detection method for air bubbles is by detection using ultrasonic technique before returning blood to the patient body.

Since the entire system of hemodialysis machine involves wet components, direct blood stream connection and electrically operated devices. So there is a risk to leakage some deadly currents to the patient and nurse, a good grounding technique should be used to avoid this issue.

## 2.6 How Air Bubbles get into the Blood?

Air bubbles have been detected in human circulation of end-stage renal disease patients who are treated by hemodialysis machine. In hemodialysis machine, the blood circulation line is exposed to entrance of air bubbles at any time from different parts of the machine.

This interference may result in serious morbidity and death; many studies have shown that rapid infusion of air bubbles may be fatal.

The safety condition requires being aware from reaching this critical stage to keep us on the safe side. This fault can happen in many parts that have a serious risk to produce foam in the blood stream line. The causes of air entry to the artificial blood stream through Figure 2-6 include:

- Falling out of the needle and the outflow needle.
- Leaks around any joint between the outflow needle and the blood pump.

- Air entry from an empty intravenous glass fluid container infusion system before the blood pump.
- Formation of gas bubbles as the result of pressure gradients and turbulent flow in the tubes and access.
- Air entry from damage syringes and tubes.
- Air entry from the heparin infusion system placed before the blood pump.
- During the dialysis operation by dialysate solution in the dialyzer "artificial kidney".

## 2.7 Danger of Air Bubbles on the Patient Life

First let us define the following terms.

**Embolism**: is defined as the transfer of abnormal material by the blood stream and its subsequent impaction in the vascular system. Usually it could be solid or insoluble material.

In studying them, the gravity of embolism depends on the position of it in the human body, the diameter of the embolus and the diameter of blood vessels in the stream.

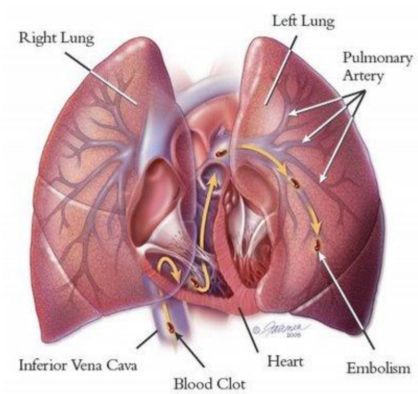



**Figure 2-7: Pulmonary Embolism**

**Air embolism**: a large bubble of air admitted into a vessel does not dissolve quickly and may cause obstruction.

Gas which enters the bloodstream acts as solid physical mass unless it is small enough such that it can dissolve quickly. If the volume of air is large enough (>100 ml of gas), the pumping action of the heart causes severe foaming or frothiness, impeding the circulation leading to loss of cardiac output and possible death. Smaller bubbles of air are dissolved and eliminated through the lungs. The risks are even greater with open heart surgery or if bubbles of air enter the pulmonary veins (e.g. with dialysis machine).

Air bubble be fatal and serious because if it enter with blood, it will maintain inside the vessels until enter to the capillaries, at that time the bubble will suspense in the channel and prevent the blood to enter from or to tissues of organs, by means, the tissues of organs cannot exchange the oxygen, carbon oxide and food because there is a block in the capillaries, then this bubble will make up a clot in the path lead to death of tissues, and the organ become cannot perform of its job.

The most dangerous clotting occurs when air bubble reach to the crucial organs like the heart or lungs or brain. So it's essential to supply the hemodialysis machines with air bubbles detector to avoid any clotting in human body, see Figure 2-8.

**Figure 2-8: Blood Clotting**

Prevention of air bubbles to entry the blood line depends partly on better design of equipment and partly on the incorporation in the hemodialysis circuit of devices which detect air and prevent it to reaching the patient.

# Chapter Three

# AIR BUBBLES DETECTION METHODS

## 3. Air Bubble Detection Methods

### 3.1 Introduction

### 3.2 Photoelectric Detection Method

### 3.3 Ultrasonic Detection Method

### 3.4 Capacitive Detection Method

## 3.1 Introduction

The researchers of medical devices field’s and companies developers are continuously search and seek to improve their air bubble detection units in the hemodialysis machines, for better performance and higher patient safety.

In the liquid detection applications, There are different transducers that are usually used, that might be depends on the principle of the transmitted light waves through that liquid, each have different quality of detection the abnormity events in that liquid.

The purpose of this chapter is to help us to understand the most used detection methods and its principle of operation, and to clarify each method advantages and disadvantages to compare it with our transducer.

## 3.2 Photoelectric Detection Method

This method considered as first technique that has been used to detect air bubble in the hemodialysis machine, it was used in the ancient generation of hemodialysis machine like (Gambro-AK200).

The method based on convert the electrical signal to the light and convert the light back to electrical signal, while the light pass through the blood line with specific wave length”$\lambda 0$”, it pass through the blood line with losing amount of energy that proportionally fixed with full blood line, this amount is measured by sensing element and keep the system in the safe work, the amount of energy varies when air bubble passes through the blood line, At that time the alarm system begin work and stop the blood stream. See Figure 3-1.

**Figure 3-1: Optical Sensor**

For the full blood line detection, there are many semiconductors elements that are used, like light diodes and light transistors, the kind of light spectrum that uses for detection air bubbles in the blood line are infrared(IR) rays.

### 3.2.1 Definition of Infrared Light Technique

Figure 3-2 shows the electromagnetic spectrum which is divided into a number of wavelength regions called bands. Light at frequencies less than red, which is at the low frequency edge of the visible portion of the spectrum, are called infrared (IR).

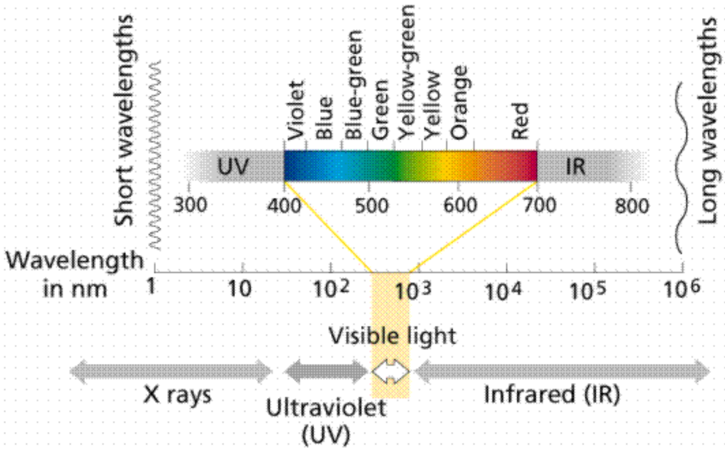



**Figure 3-2: Waves Spectrums**

It is not visible to the human eye, the IR band of the spectrum covers wavelengths between 724 to 1000 nm, and the energy of infrared light travels like light in all directions, radiations striking a surface are reflected, absorbed and/or transmitted through that surface.

### 3.2.2 Infrared Transducer

Infrared transducers play an important role in the development of highly sensitive and selective methods for detection faults. The fundamental principle employed is based on the change in optical properties of a biological or physical medium; the change produced can be the result of intrinsic changes in absorbance, reflectance, scattering or refractive index of the biological medium.

Infrared transducers have very rapid response times (milliseconds) and they do not require contact with an object or surface (avoid contamination) and their principle is simple to be used.[1]

### 3.2.3 Basic Components

**1) Light Source:**

Most photoelectric sensors use a light emitting diode (LED) as the light source. The LED is a solid-state semiconductor that emits light when current is applied; LEDs are made to emit specific wavelengths or colors, of light. Infrared, visible red, green, and blue LEDs are used as the light source in most photoelectric sensors; the Infrared LEDs are the most efficient, generating the most light and the least heat of any LED color.

**2) Light Detector:**

The light detector is the component that is used to detect the light from the light source after passing through the tested material; usually light detector is composed of a photodiode or phototransistor. It is a solid-state component that provides a change in conducted current depending on the amount of light detected. The spectral response of a light detector determines its sensitivity. See Figure 3-3.

[1] Allen Bradley, Fundamental of Sensing, 1999.

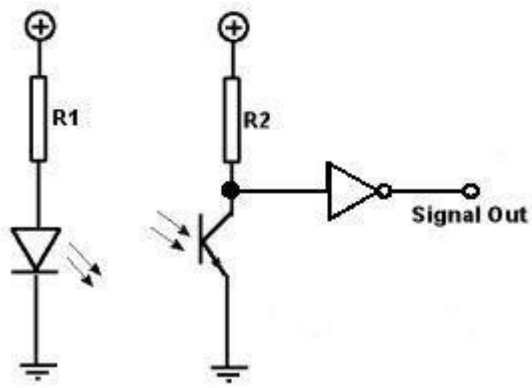



**Figure 3-3: Opt-Coupler**

**3) Conditioning Circuit:**

The sensor logic circuit provides the necessary electronics to amplify the signal from the detector, and determine whether the output should be activated or not.

**4) Air Detector Alarm:**

In normal state without air bubbles detected the circuit of alarm are not active, in the alarm circuit, the LM555 timer are usually suitable to give flashing and audible sound as trigger pulse and make reset to alarm.

### 3.2.4 Block Diagram for Optical Bubble Detector

A simple block diagram is illustrated in Figure 3-4, which shows the basic components of photoelectric detection unit.

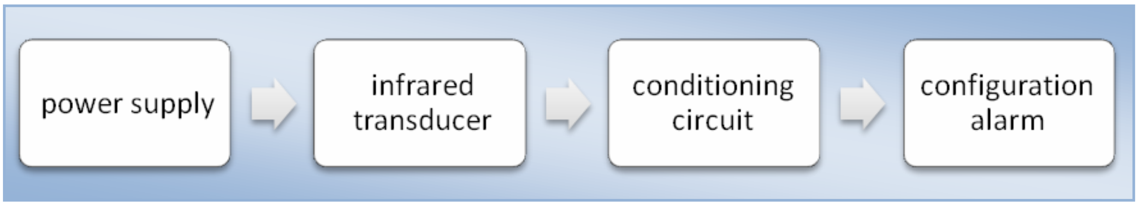



**Figure 3-4: Optical Block Diagram**

A transducer combines LED and photodiode, when the current passes through the LED, it will emits light and hits the photodiode, the energy of light produce electron hole fairs to form a current, the output voltage on receiver differentiate and compare with reference voltage.

When the air bubbles passes in tube the amount of light will change, leads to change the current and change voltage produced, the conditioning circuit amplify the signal and activate the alarm.

### 3.2.5 Advantage/Disadvantage of Optical Method

**Advantage:**

- Easy to use and Can respond simultaneously to different reactants.
- Can be very accurate, especially when more wavelengths are used.
- Can use optical fibers for efficient "photon transport".

**Disadvantage:**

- Depend on availability of reactant that changes optical properties.
- Response time may be slow "analytic diffusion ".
- Insensitive and could not react if the light path was obstructed by fibrin deposits on the inner wall of the bubble trap.
- Difficult to miniaturize.
- Ambient light could reach the photocell and cause false alarm.

## 3.3 Ultrasonic Detection Method

A modern technique of detection method for the air bubbles became available in markets nowadays which use ultrasound property, most of hospitals and healing centers in our country start using (Gambro or Fresenius products), those companies use the ultrasonic transducer. This method showed the ability to detect smaller air bubbles, it's principle similar to that one used in photoelectric method disperse exist transmitter and receiver.

### 3.3.1 Definition of Ultrasonic Waves

The ultrasonic waves generated by transmitter piezoelectric crystal converts the electrical energy to mechanical energy. While the receiver piezoelectric crystal converts back the ultrasonic energy that is transmitted across the tube into electrical energy.

Ultrasonic sound waves are mechanical vibrations that exhibit all of the same characteristics as audible sound waves, only they operate at higher frequencies. Audible sound wave frequencies range anywhere from 20 Hz to 20 kHz, whereas ultrasonic waves are sound waves with frequencies from 20 kHz to 20 MHz, The velocity of ultrasound in blood (1560-1590 m/sec).[2]

### 3.3.2 Ultrasonic Transducer

Ultrasonic sensors emit a sound pulse that reflected off of any objects entering the wave field. The reflected sound, or "echo" is then received by the sensor. Ultrasonic sensing technology is based on the principle that sound has a relatively constant velocity.

Allen Bradley, Fundamental of Sensing, 1999 [2]

The time for an ultrasonic sensor's beam to strike the target and return is directly proportional to the distance to the object, a typical unit of Ultrasonic Transducer shown in Figure 3-5.

Doppler ultrasonic made it possible to detect air bubbles, but the main disadvantage of the ultrasonic method is the fact that bubbles are seen in the circulation without the capability of preventing the event and ultrasonic sending and receiving transducers are positioned on same sides of blood tube that need a reflection angel constant which is hard to build.

**Figure 3-5: Typical Unit of Ultrasonic Transducer**

### 3.3.3 Basic Components

**1) Transmitter / Receiver**

The ultrasonic transmitter sends sound waves outward from the crystal and the receiver crystal receives echoes of those waves as reflected off an object.

**2) Conditioning Circuit**

This block usually contains differential amplifier that check the difference of the output voltage and its output goes to next stage where it runs alarming.

### 3.3.4 Advantage / Disadvantage of Ultrasonic Method

**Advantage:**

- Ultrasonic sensor's response is not dependent upon the surface color or optical reflectivity of the object.
- Ultrasonic sensors outputs have excellent repeat sensing accuracy.
- Higher sensitivity to the small air bubbles.

**Disadvantage:**

- Ultrasonic sensors must view a surface to receive ample sound echo or the wave will not reflect.
- Although ultrasonic sensors have immunity to noise, but are still to falsely respond to some loud noises.
- Sensor response times are typically slower than other technologies at about 0.1 second.
- Ultrasonic method cannot prevent occurrence air bubbles in line.
- In building the transducer we must fix our transmitter and receiver at constant-angel which is hard to build and affected rabidly by surrounding accidents.
- Any moving for the machine could affect the transducer.

## 3.4 Capacitive Detection Method

In the air bubble detection units, the capacitive method is rarely used in the hemodialysis machine. The principle of varying the capacitive of the sensor based on changing different factors affect the building and operation the capacitor, here I am going to take the advantage of one of these factors to build the detector unit, the capacitive transducer consists of two metallic parallel plates separated by a variable dielectric material.

### 3.4.1 Parallel Plate Capacitance Theory

A parallel plate capacitor consists of two parallel plates with area A and separated by a small distance d. Those two plates are filled with dielectric or insulating material as shown in Figure 3-6.

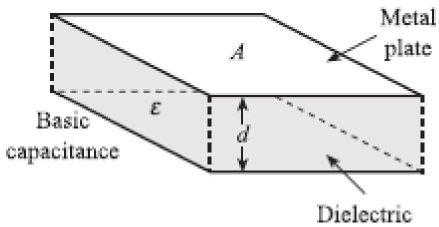



**Figure 3-6: Regular Capacitor**

If the separated space is vacuumed and σ is the magnitude of the surface charge density on other plate, there is an electric field magnitude (E) between the plates the two plates:

$$E = \frac{\sigma}{\varepsilon_\circ} = \frac{Q}{\varepsilon_\circ} \quad \text{Eq. (3-1)}$$

Where:

$\varepsilon_o$: permittivity of free space.

Q: is the total charge on each plate.

If we consider the electric field between the plates to be uniform, the potential difference between the plates is:

$$V = Ed = \frac{Qd}{\varepsilon_\circ} \quad \text{Eq. (3-2)}$$

Therefore, the capacitance of a parallel plate capacitor in vacuum can be written as:

$$C_{\circ} = \frac{Q}{V} = \frac{\varepsilon_{\circ} A}{d} \qquad \text{Eq. (3-3)}$$

Putting a dielectric material between the plates causes an increase in capacitance, proportional to the dielectric constant (also known as the relative permittivity). The relative permittivity is basically a measurement of how good a material is at the production of electric flux. It can be written as the ratio of the absolute permittivity of a material $\varepsilon$ to the absolute permittivity of a vacuum $\varepsilon_o$.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o} \qquad \text{Eq. (3-4)}$$

The relative permittivity of a vacuum is 1, it is taken as reference. For any other material, the constant is greater than 1 depending on how much electric flux would be produced if the material were used as a path between the plates instead of a free space.

The final equation becomes:

$$C = \frac{\varepsilon_r \varepsilon_{\circ} A}{d} \qquad \text{Eq. (3-5)}$$

Where:

A: The area of the plates.

d: The distance between the plates.

$\varepsilon_r$: The relative permittivity of the material between the plates.

$\varepsilon_{\circ} = 8.854188 \times 10^{-12}$ F/m

The plate's area and plate's separation distance can be considered in the design as fixed value, and the variation in the capacitance is based only on changing the permittivity of the dielectric material (in our case a solution sample).

The capacitance between parallel plates will change according to the difference between the dielectric permittivity of solution sample and the dielectric permittivity of the air bubbles, and change in capacitance lead to change output voltage.

### 3.4.2 Frequency Effect of Capacitance Circuit

Electrical reactance can be defined as the opposition to AC current flow due to capacitive reactance. Capacitive reactance ($X_C$) is the ratio of the of capacitor voltage to current, the capacitive reactance is inversely proportional to both the frequency and the capacitance.

Figure 3-7a represents capacitance circuit. Note how in Figure 3-7b the magnitude of $X_C$ vary with frequency.

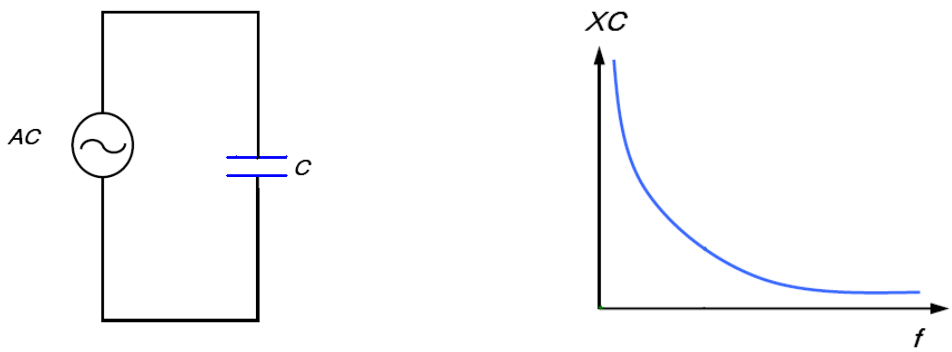



**Figure 3-7: (a) Capacitance Circuit Diagram, (b) Reactance vs. Frequency Plot**

Where the equation used to calculate capacitive reactance XC is given by:

$$X_C = \frac{1}{j\omega C} = \frac{1}{j(2\pi f)C} \qquad \text{Eq. (3-6)}$$

Where:

$X_C$: Capacitance Reactance.

ω: angular velocity.

f: frequency (Hz).

C: Capacitance (F)

### 3.4.3 Approximation of Capacitances:

In the capacitive sensor design, it is needed to make some approximations that help to calculate the total capacitances in the normal condition and in the faults condition, and helping the reader to figure what's happened when enter air bubbles the capacitor.

Since we are dealing with isotonic water mixed with little ink to simulate the real blood and to facilitate seeing air bubbles, the dielectric material will be approximated to isotonic water only, this solution have specific relative permittivity ≈ 80 and will be taken as a reference point to make the capacitance between two plates fixed at full blood line which leads no output voltage.

After obtain the fixed capacitance between the two plates, we inject the air bubbles in the test tube which cause different relative permittivity, the result of outcomes capacitance differ from the original capacitance, this air bubble divides the original capacitance into two capacitances in series as in Figure 3-8.

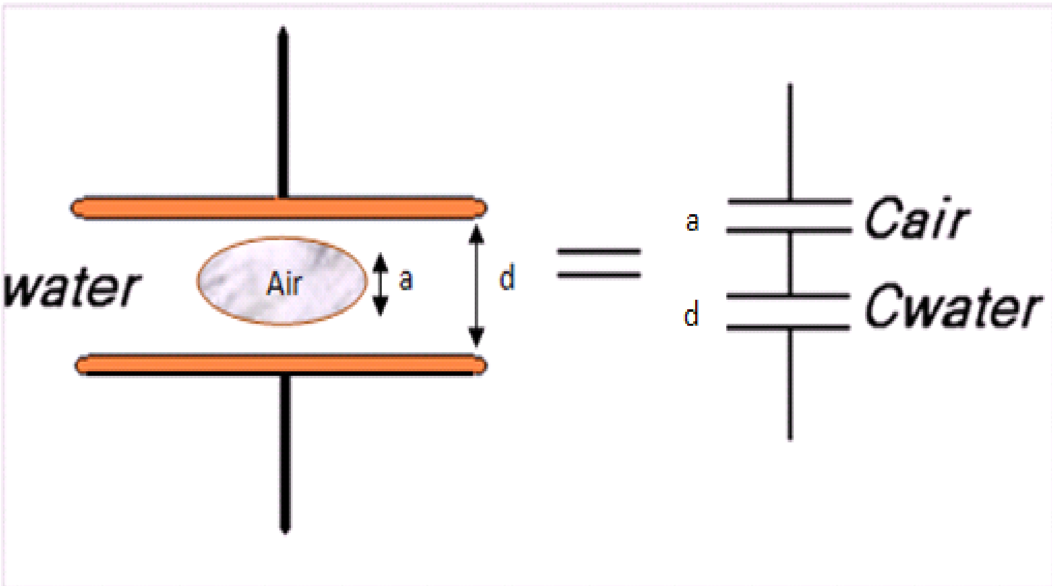



**Figure 3-8: Approximated Capacitance**

Where in general;

$$C = \frac{\varepsilon_r \varepsilon_\circ A}{d}$$

$$C_w = \frac{\varepsilon_{r,w} \varepsilon_\circ A}{d}$$

$$C_a = \frac{\varepsilon_{r,a} \varepsilon_\circ A}{d}$$

Where;

$C_w$ and $C_a$: Capacitance of water and air respectively.

$\varepsilon_{r,a}$: Relative permittivity of air nearly equal 1.

$\varepsilon_{r,w}$: Relative permittivity of water and approximately 80.

Assuming the diameter of air bubbles equal the distance between plates, therefore:

$$C_{net} = \frac{C_w \times C_a}{C_w + C_a}$$

## 3.5 Transducers Analysis

According to the study of properties for each detection method, A simple comparison made between the detection methods to evaluate which one of detection methods will adopt.

**Table 3-1: Transducer Analysis**

| ________ | Infrared sensor | Ultrasonic Sensor | Capacitive Sensor |
|---|---|---|---|
| **Cost** | Low | High | Low |
| **Background Noise** | High | Medium | Medium |
| **Availability** | Yes | Hard to Get | Yes |
| **Life Time** | Low | Medium | Medium |
| **Sensitivity** | Low | High | Medium |
| **Response Time** | High | Medium | Medium |
| **Complexity** | Low | High | Low |

Based on those comparison in Table 3-1, I am relies that the capacitive transducer is a good component to design and build air bubbles detection unit.

# Chapter Four

# TECHNICAL DETAILS OF PROJECT DESIGN

4. **Technical Details of Project Design**

   **4.1 Overall Block Diagram of the Project**

   **4.2 Power Supply Circuit**

   **4.3Capacitor Design**

   **4.4 Capacitive Bridge Design**

   **4.5 Differential Amplifier Circuit**

   **4.6 Comparator Amplifier Circuit**

This chapter explains the design details of the overall system, and its major parts that used in the air bubbles detection unit. Also it clarify the main characteristics that makes this project operate as planted after viewing the theoretical background and flow charts that explain how the system works in previous chapter.

## 4.1 Overall Block Diagram of the Project

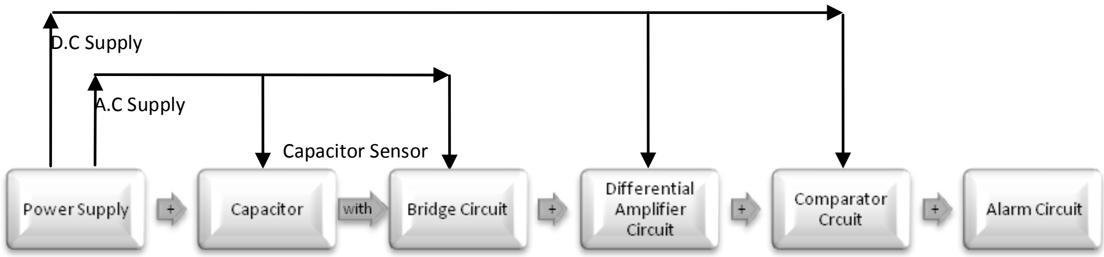



**Figure 4-1: Overall Block Diagram**

Figure 4-1 shows the block diagram of the air bubbles detection unit; first block of diagram is power supply that feeds the project components with fixed or alternating power, followed by the capacitive sensor and its bridge.

The voltage signal output of ac bridge needs to amplify the difference voltage between bridge arms by differential amplifier, and then a comparator uses to compare the voltages on the capacitor sensor with reference voltage, and it is need ($+V_{CC}$) for bubble occurring and ($-V_{CC}$) for safe operation, this $+V_{CC}$ voltage will operate the final stage of the unit that include light alarm.

## 4.2 Power Supply Circuit

To make Air Bubbles Detection Unit self sufficient, AC (alternating current) supply and DC (direct current) positive and negative supply voltage is necessary from power-supply for the electronic components.

The AC supply is needed to operate the capacitive sensor and its bridge in the transducer circuit and it take from function generator with specific frequency, where the dc power is needed to operate comparator circuit.

This section shows and explain the schematics, characteristics, features, and the specifications of each component.

The circuit in Figure 4-2 converts the input of 220V AC / 50Hz to ± 15V DC to supply the amplifier circuits.

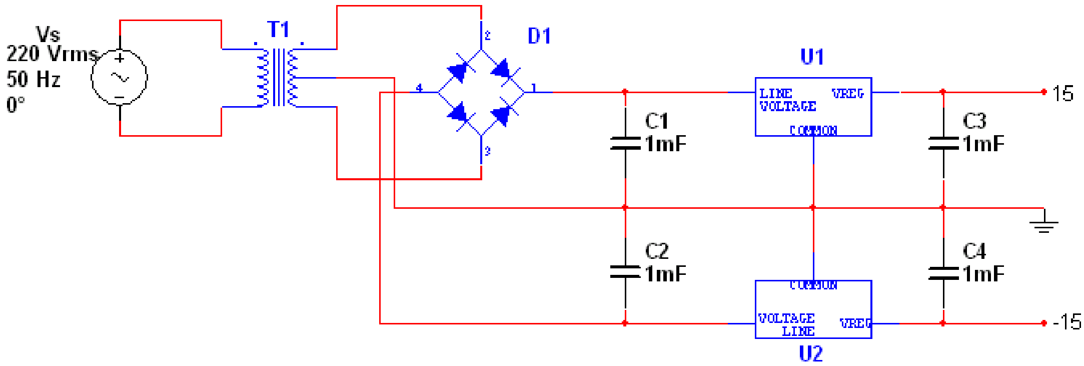



**Figure 4-2: DC Power Supply Circuit**

The power supply circuit can be divided into four stages: transformation, rectification, filtering, and regulation.

1. Transformation is accomplished by the transformer (T1) steps down the voltage source 220V to desired ac output voltage 24V.

2. Rectification is accomplished by the diode bridge configuration B1; the type of full wave bridge LM.BR31, the bridge converts the AC voltage to pulsating DC voltage.

3. Filtering is provided by capacitors C1, C2, C3 and C4 which level the rectified signal to provide smoothing dc voltage.

4. Regulation is provided by U1 and U2 to get a constant output voltage. type number of regulator 7815 and 7915 to give ±15 Volt.

Figure 4-3 shows the output waveform from each stage of the designed power supply, where the first wave represents the 220V/50Hz source line and the second wave stated for the output of the center taped transformer.

The third wave represent the pulsated DC that out from the full wave bridge, the fourth wave represent the filtered DC signal after applying it on the smoothing capacitor and on the final wave we get the desired constant output voltage from the regulator.

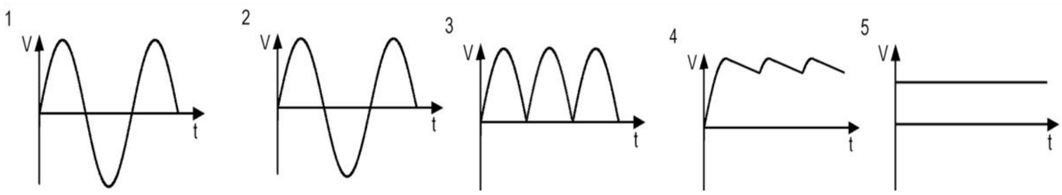



**Figure 4-3: Power Supply Waveform Stages**

According to the ratio between primary and secondary:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} \qquad \text{Eq. (4-1)}$$

$$\frac{V_P}{V_S} = \frac{220}{24} = 9.1$$

Turn ratio between primary and secondary is about 9:1.

$$V_{S(P)} = 220 \times \sqrt{2} = 311.1V$$

$$V_{S(P)} = 24 \times \sqrt{2} = 33.9\,V$$

$$V_{rect.} = V_S - 1.4 = 33.9 - 1.4 = 32.5\,V$$

$$V_{dc} = 1 - \frac{1}{2f\,R_L C} \qquad \text{Eq. (4-2)}$$

$$V_{r(p-p)} = \frac{1}{f\,R_L C} V_{rect.} \qquad \text{Eq. (4-3)}$$

$$\text{Ripple Factor} = \frac{V_{r(p-p)}}{V_{dc}} \times 100\% \qquad \text{Eq. (4-4)}$$

The value of capacitor that used is "1000µF, 35V" by assuming, and the frequency after full wave bridge rectifier is 100Hz and $R_L$ will be nearly 1005**Ω**.

$V_{dc}$ = 32.33V.

$V_{ripple}$ = 0.32 V.

## 4.3 Capacitor Design

Generally, the capacitor design establish the road that determine the success rate of the design, the capacitor consider the back bone of the project because all of the following stages depend on its response when air bubbles enter with sample test, so a lot of considerations were taken to obtain acceptable results.

The parallel plates made from copper material that distinguished by good conductivity to electrical current and can be formed easily. The cupper plates must be parallel to obtain uniform electric field, start up from this point the tube that contain sample test must be rectangular or square shape with small thickness to be able fixe the plates on it easily, the tube is made from plastic, and the sample consist of water mixed with sodium chloride (saline), this capacitor is manually made to obtain the best result.

Assuming the capacitor have:

$$A = (8 \times 2.5) \times 10^{-4} m^2 = 20 \times 10^{-4} m^2$$

$$d = 0.5 \times 10^{-2} m$$

The values of relative permittivity of the water, air and plastic is known, arranged as follows to calculate the capacitance for each of them.

$$\varepsilon_{r,w} = 80$$

$$\varepsilon_{r,a} = 1$$

$$\varepsilon_{r,p} = 4$$

$$\varepsilon_o = 8.85 \times 10^{-12} F/m$$

Where $\varepsilon_{r,w}$ , $\varepsilon_{r,a}$ and $\varepsilon_{r,p}$ is the relative permittivity of water, air and plastic respectively.

$$C_w = \frac{\varepsilon_{r,w} \varepsilon_\circ A}{d} = \frac{80 \times 8.85 \times 10^{-12} \times 20 \times 10^{-4}}{0.5 \times 10^{-2}} = 283.2 \times 10^{-12} F = 283.2 pF$$

$$C_a = \frac{\varepsilon_{r,a} \varepsilon_\circ A}{d} = \frac{1 \times 8.85 \times 10^{-12} \times 20 \times 10^{-4}}{0.5 \times 10^{-2}} = 3.54 \times 10^{-12} F = 3.54 pF$$

$$C_p = \frac{\varepsilon_{r,p} \varepsilon_\circ A}{d} = \frac{4 \times 8.85 \times 10^{-12} \times 20 \times 10^{-4}}{0.5 \times 10^{-2}} = 14.16 \times 10^{-12} F = 14.16 pF$$

In the case of no existence of air bubbles in the tube, the net capacitance approximately like two capacitors in series such that:

$$C_{net1} = \frac{C_w \times C_p}{C_w + C_p} = \frac{(283.2\times10^{-12})\times(14.16\times10^{-12})}{(283.2+14.16)\times10^{-12}} = 13.5\times10^{-12}\,F = 13.5\,pF$$

In the case of existence the air bubbles in the tube, the net capacitance approximately equal:

$$C_{net2} = \frac{C_{net1} \times C_a}{C_{net1} + C_a} = \frac{(13.5\times10^{-12})\times(3.54\times10^{-12})}{(13.5+3.54)\times10^{-12}} = 2.9\times10^{-12}\,F = 2.9\,pF$$

$$\therefore \Delta C = C_{net1} - C_{net2} = 10.6\,pF$$

Figure 4-4 shows the design of manually made capacitor that has rectangular shape with specific dimensions, all of the dimensions taken in millimeter.

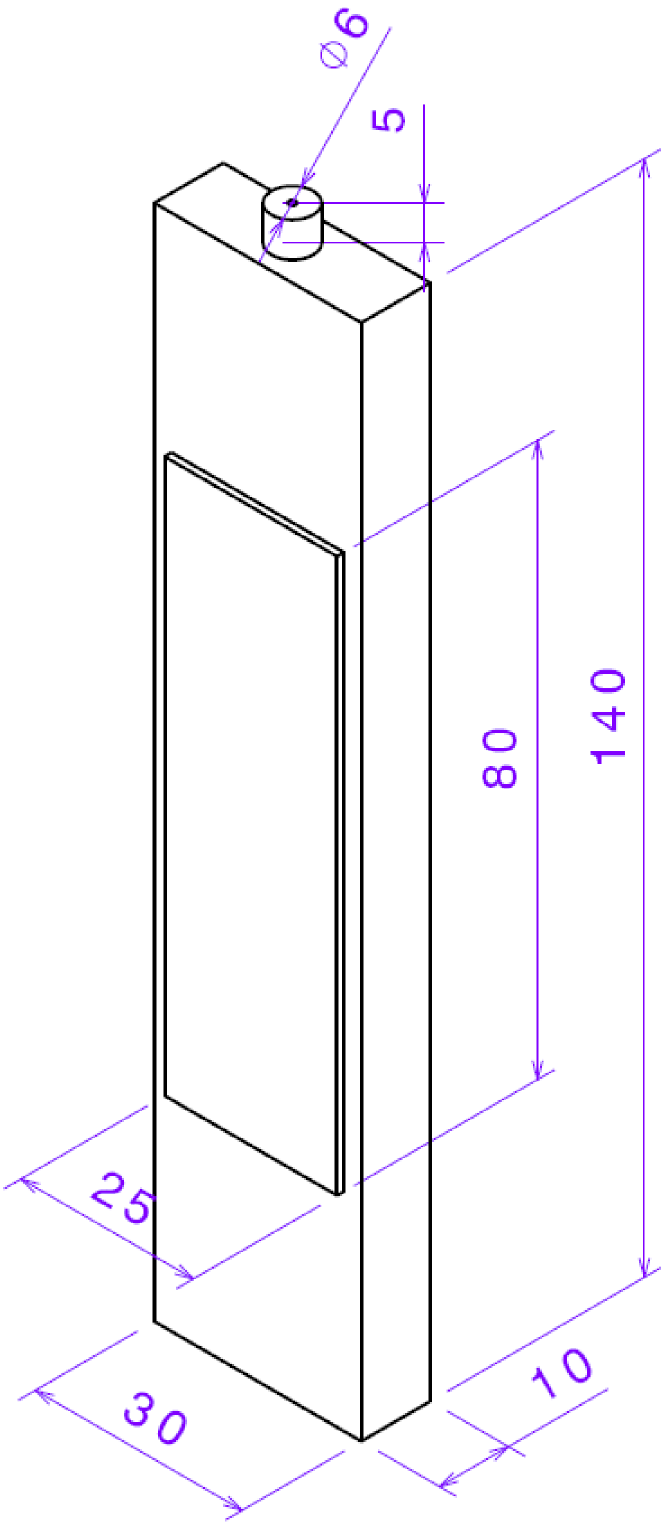



**Figure 4-4: Design of Manually Made Capacitor**

## 4.4 Capacitive Bridge Design

This section illustrate the final design of bridge circuit that consists of both resistors and capacitors and supplied with alternating sinusoidal voltage source to get two outputs from A and B, since the output A depend on the frequency, and output B depend on the value of potentiometer, these outputs has peak voltage monitored by oscilloscope, see Figure 4-5.

The goal of this bridge is to make suitable calibration in each output, by assume a fixed voltage on the output B, let us take for example 4 voltage peak, at specific frequency the output A in case of no bubbles nearly 3.9 voltage peak, if we push the air bubble in the capacitor the voltage will increased to reach above 4 voltage peak, this change can be more signifies if we measure the voltage as DC not as AC voltage.

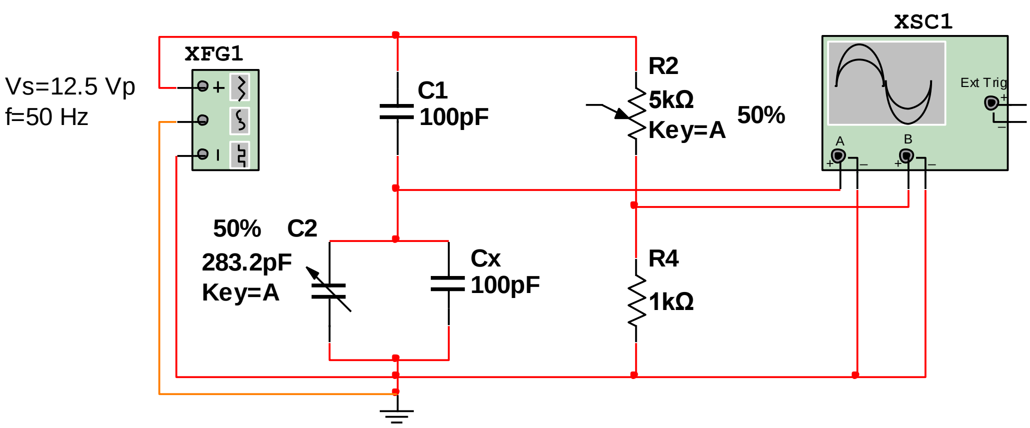



**Figure 4-5: Bridge Circuit**

The capacitors in the bridge circuit have impedances at specific frequency, but in case of DC the impedance will be very large and approach to infinity lead to infinity voltage at a capacitor, by means the capacitor become open circuit, hence the rule that capacitors pass AC but block DC.

To make a calculation for the voltages in the bridge circuit let us uniform the reactance for resistances and capacitors.

Assume that:

$$C_1 = C_X = 100\text{pF}$$

$$R_4 = 1\text{k}\Omega$$

By take a proper frequency according to experiments in the following chapter:

$$f = 50\text{Hz}$$

$C_w$ = 283.2pF by calculation.

Converting the values of capacitors and resistors to the reactance, we obtain:

$$C_3 = (C_w \parallel C_x) = C_w + C_x = 383.2\,\text{pF}$$

$$X_{C1} = X_x = \frac{1}{j(2\pi f)C_1} = \frac{1}{j(2\pi \times 50)\times 100 \times 10^{-12}} = -j31800\,\text{K}\Omega$$

$$X_{C3} = \frac{1}{j(2\pi f)C_3} = \frac{1}{j(2\pi \times 50)\times 383.2 \times 10^{-12}} = -j8300\text{K}\Omega$$

$X_{R4} = R_4$ = 1kΩ.

$X_{R2} = R_2$ = Variable resistor to adjust the voltage on $V_{R4}$.

Convert the reactance of the capacitors and resistors to the impedances in the polar coordinate to analyze the circuit:

$$Z_1 = 0 - J31800 = 31800\measuredangle -90^\circ$$

$Z_2$ is variable.

$$Z_3 = 0 - J8300 = 8300\measuredangle -90^\circ$$

$$Z_4 = 1 + j0 = 1\measuredangle 0^\circ$$

Redraw the bridge circuit with impedance quantity as in Figure 4-6.

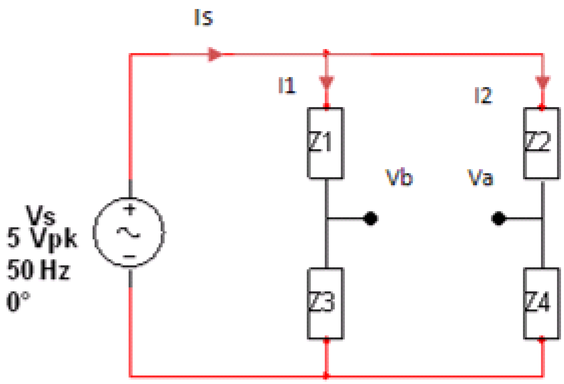



**Figure 4-6: Impedances Bridge Circuit**

The balanced bridge is important and easy to build in case of DC bridge, even if there is a small changes of sensing quantity, the AC bridge make the calibration more complicated specially there is a phase shift between the current and voltage in bridge element "capacitor and resistor".

## 4.5 Differential Amplifier Circuit

A differential amplifier featured by have two input, it is amplify the difference between the terminal input, the design of differential circuit measures the small voltage differences that exists between the two arms of the bridge circuit. The differential amplifier circuit shown in Figure 4-7 is used for that purpose.

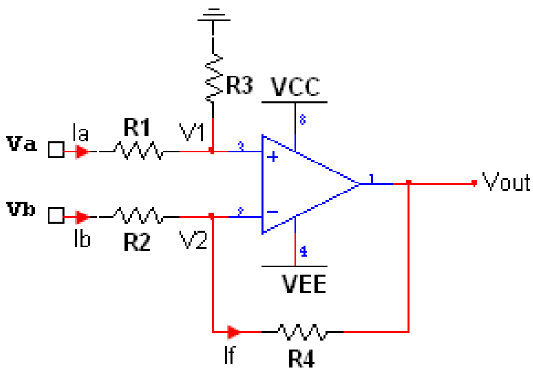



**Figure 4-7: Differential Amplifier**

To find the $V_{out\,(a)}$ we can use the super position technique where we eliminate one source as short and calculate the output for the other, then eliminate the first one and calculate $V_{out\,(b)}$, total $V_{out}$ output will be the summation of them.

$$I_a = \frac{V_a - V_1}{R_1},\ I_b = \frac{V_b - V_2}{R_2},\ I_f = \frac{V_1 - (-V_{out})}{R_3}$$

Summing point $V_1 = V_2$

If $V_b = 0$, then:

$$V_{out(a)} = -V_a\left[\frac{R_3}{R_3 + R_1}\right] = -V_a\left[\frac{R_3}{R_1}\right]$$

If $V_a = 0$, then:

$$V_{out(b)} = V_b\left[\frac{R_4}{R_4 + R_2}\right]\times\left[1 + \frac{R_3}{R_1}\right]$$

$$V_{out} = V_{out(a)} + V_{out(b)}$$

$$\therefore V_{out} = -V_a\left[\frac{R_3}{R_1}\right] + V_b\left[\frac{R_4}{R_4 + R_2}\right]\times\left[1 + \frac{R_3}{R_1}\right]$$

When resistors $R_1 = R_2$ and $R_3 = R_4$ the output voltage for the differential amplifier can be simplified to the following expression:

$$V_{out} = \left(\frac{R_3}{R_1}\right)\times(V_a - V_b) \qquad \text{Eq. (\textbf{4}-5)}$$

Where: $\frac{R_3}{R_1} = A_v$ is the knowing by differential gain of amplifier.

Common Mode Rejection Ratio (CMMR):

The CMRR is a measure of how well the device rejects a common-mode signal; it's simply the ratio of the differential gain $A_v$ over the common-mode gain $A_{cm}$

$CMRR = \frac{A_v}{A_{cm}}$, measured by decibels.

$$CMRR = \frac{V_{out}}{(V_a - V_b)} \cdot \frac{V_{out\ (cm)}}{V_{cm}}$$

Since $V_{cm} = V_a = V_b$

$$CMRR = \log_{10}\left(\frac{A_v}{|A_{cm}|}\right) \qquad \text{Eq. (4-6)}$$

## 4.6 Comparator Amplifier Circuit

A comparator is a circuit that compares the input voltage with some reference voltage, See Figure 4-8 it is a simply schematic for comparator.

Usually one of the terminals uses for input signal voltage and the other is used to set the reference voltage, when the non-inverting input voltage $V_C$ is higher than the inverting input $V_{ref}$, the high gain of the op-amp causes the output saturates at the highest positive voltage.

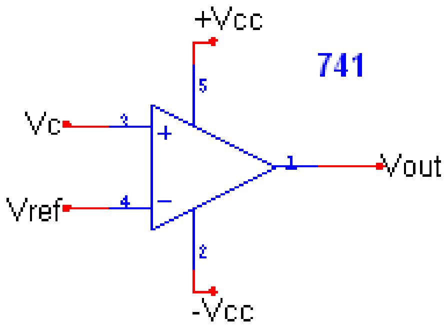



**Figure 4-8: Comparator Amplifier Symbol**

When the inverting input voltage $V_{ref}$ is higher than the non-inverting input, the output saturates at the most negative voltage, the op-amp's output voltage is limited by the supply voltage, and it is the principle of operation for the comparator.

The output waveform after stage of comparison must looks like steady voltage signal an in Figure 4-9, this signal of +15-Volt feed the alarm such that led and buzzer to operate continuously if detect air bubble, and the alarm not active if there is no bubble in the capacitor sensor while the output of comparator negative (open circuit).

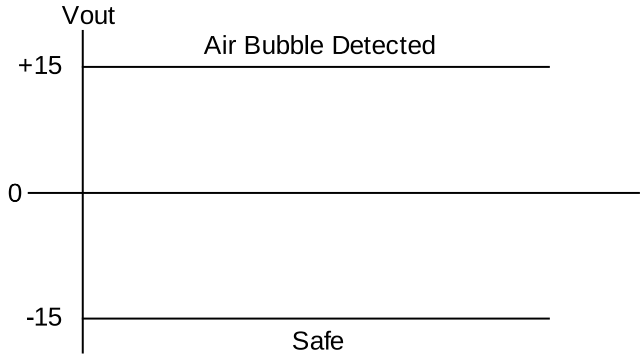



**Figure 4-9: Comparator Output Signal**

# Chapter Five

# <u>SYSTEM IMPLEMENTATION AND TESTING</u>

**5. System Implementation and Testing**

**5.1 Capacitor Building**

**5.2 Bridge Implementation**

**5.3 Differential Amplifier Circuit**

**5.4 Comparator and Alarm Circuit**

**5.5 Schematic Circuit for Entire Project**

**Introduction**

This chapter concern on the application of the theoretical concepts that studied in last chapters, the implementation depend basically on the practical experiments and tests that will describes many of ambiguity between the designed circuits.

First and foremost we must know the application on the ground take many efforts and time during construct and comparing the results, the chapter contains the reality quantity of variables that will be close from the theoretical calculations, and contains figures that show the relationships between variables and parameters.

## 5.1 Capacitor Building

The section show the experiments that needed to get the desired results that able to meet what we need in the following bridge circuit, in fact the most important thing lies in the ability of the bridge to sense two different quantities during two cases.

First case the voltage is constant without air bubble, and second case the voltage change clearly with longer period of time to guarantee the following stage operate correctly.

### 5.1.1Experiment No. One: Capacitance Dependency on Dielectric Material

Choose five samples to test the change of capacitance for each sample with fixed area, distance and the test tube, look at picture in Figure 5-1.


**Figure 5-1: Capacitance Readings**

The resulting reading during use different dielectric materials by capacitancemeter appears as seen in the Table 5-1.

**Table 5-1: Capacitance vs. Dielectric Material**

| **Sample Number** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
|---|---|---|---|---|---|---|---|
| **Sample** | air | water | juice | perfume | saline | Ink with water | Inked water with juice |
| **Capacitance (pF)** | 4 | 95 | 107 | 93 | 100 | 101 | 101 |
| **Relative Permittivity($\varepsilon_r$)** | 1.1 | 26.8 | 30.2 | 26.2 | 28.2 | 28.5 | 28.5 |

According to general capacitance law we calculate the relative permittivity for the samples as the following:

Known data:

$A = 20\times10^{-4}\,\mathrm{m}^2$ , $d = 0.5\times10^{-2}\,m$ ,

$\varepsilon_\circ = 8.85\times10^{-12}\,F/m$

Where: $\varepsilon_r = \dfrac{C.d}{\varepsilon_\circ A}$

$$\varepsilon_{r1} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(4\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.011\times10^{2} = 1.1$$

$$\varepsilon_{r2} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(95\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.268\times10^{2} = 26.8$$

$$\varepsilon_{r3} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(107\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.302\times10^{2} = 30.2$$

$$\varepsilon_{r4} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(93\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.282\times10^{2} = 26.2$$

$$\varepsilon_{r5} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(100\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.282\times10^{2} = 28.2$$

$$\varepsilon_{r6} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(101\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.285\times10^{2} = 28.5$$

$$\varepsilon_{r7} = \frac{Cd}{\varepsilon_{\circ} A} = \frac{\left(0.5\times10^{-2}\right)\times\left(101\times10^{-12}\right)}{(8.85\times10^{-12})\times(20\times10^{-4})} = 0.285\times10^{2} = 28.5$$

We conclude that the highest value of capacitance $\varepsilon_{r3}$ for the juice liquid, the selected sample that I will use the saline sample for many reasons summarized by:

1. Easy moving the water and air bubble inside the tube.
2. Non-clotting liquid inside the tube with the passage of time.
3. The saline don't affect with environment.
4. Can be notice the bubble through the test tube.

So $(\varepsilon_{rs} = \varepsilon_{r7} = 28.5)$

Where $\varepsilon_{r,s}$ the reference relative permittivity for sample, that will use for testing air bubble in the tube.

The volume of sample is 25mL and the mass of sample is 0.030 kg.

$D = \frac{m}{V} = \frac{0.030}{25} = 1.2\left(gm/cm^3\right)$, Where “D” is the density of the sample.

### 5.1.2Experiment No. Two: Capacitor Sensitivity to the Diameter of Air Bubble.

In this experiment air bubbles injected by syringe pump in the test tube to change the radius of air bubble inside the tube and measure the diameter.

The resulting reading in the Table 5-2 shows the minimum diameter that can the capacitor notice the change when air bubbles pass, the diameter measures by caliper meter.

The capacitor sensitivity of air bubble must have radius at least 0.85cm, minimum this radius “0.85cm” the sensor could not sense.

**Table 5-2: Capacitor Sensitivity vs. Air Bubble Diameter**

| **Diameter (cm)** | 2.8 | 2.4 | 2.1 | 1.7 |
|---|---|---|---|---|
| **Capacitance Difference (pF)** | 0.017 | 0.008 | 0.004 | 0.001 |

We conclude that the relationship between the sensitivity and diameter of air bubble is nearly linear as you see in Figure 5-2.

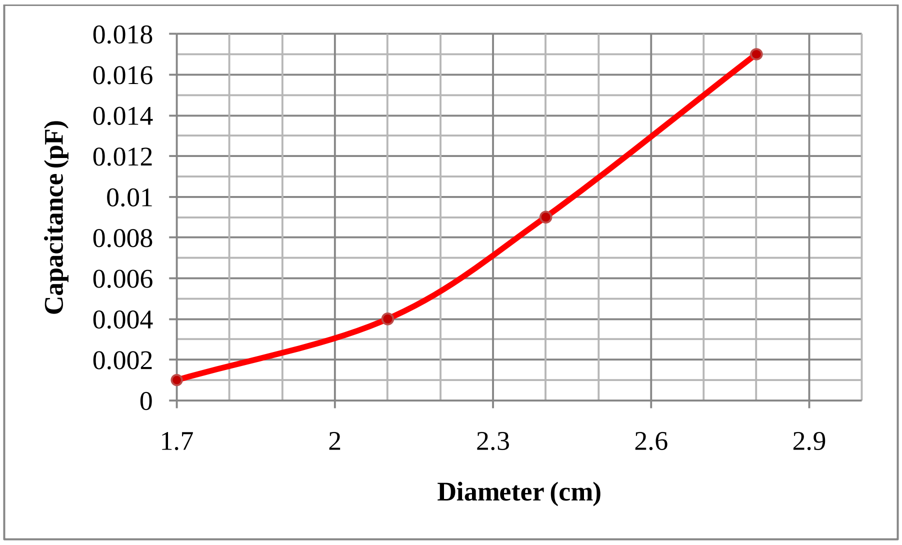



**Figure 5-2: Relationship between Capacitance and Air Bubble Diameter**

**Relationship between the Capacitance and Distance between the Plates**

By assuming the parameters A and $\varepsilon_{r,s}$ are constant to the test sample and the distance between the plates is variable, we obtain by calculation of capacitance the following readings as in Table 5-3.

$\varepsilon_o = 8.85\times10^{-12}\,F/m$

**Table 5-3: Capacitance vs. Distance**

| Area ($m^2$) | Distance ($m$) | Relative permittivity ($\varepsilon_{rs}$) | Capacitance ($pF$) |
|---|---|---|---|
| $(8\times2.5).10^{-4}$ | $0.5\times10^{-2}$ | 28.2 | 99.83 |
| $(8\times2.5).10^{-4}$ | $1\times10^{-2}$ | 28.2 | 49.91 |
| $(8\times2.5).10^{-4}$ | $2\times10^{-2}$ | 28.2 | 24.96 |

$$C_1 = \frac{\varepsilon_r\,\varepsilon_o\,A}{d_1} = \frac{28.2\times\left(8.85\times10^{-12}\right)\times\left(8\times2.5\right)\times10^{-4}}{0.5\times10^{-2}} = 99.83\,pF$$

$$C_2 = \frac{\varepsilon_r \varepsilon_\circ A}{d_2} = \frac{28.2\times\left(8.85\times10^{-12}\right)\times\left(8\times2.5\right)\times10^{-4}}{1\times10^{-2}} = 49.91\,pF$$

$$C_3 = \frac{\varepsilon_r \varepsilon_\circ A}{d_3} = \frac{28.2\times\left(8.85\times10^{-12}\right)\times\left(8\times2.5\right)\times10^{-4}}{2\times10^{-2}} = 24.96\,pF$$

It is worth noting that the sensitivity of a parallel plate capacitance sensor is a function of the distance between the conducting plates. The sensitivity of air bubble can be considered as the change in capacitance with the change in plate distance:

$$C \propto \frac{1}{d}$$

$$\text{Sensitivity } \Delta S = \frac{\Delta C}{\Delta d} = \frac{\left(99.83-49.91\right)\times10^{-12}}{\left(1-0.5\right)} = 9.984\left(nF/cm\right)$$

Figure 5-3 illustrates that a smaller separation distance leads to an increase in the sensitivity of the capacitive sensor (that is a small value of *d* leads to a larger slope on the curve).

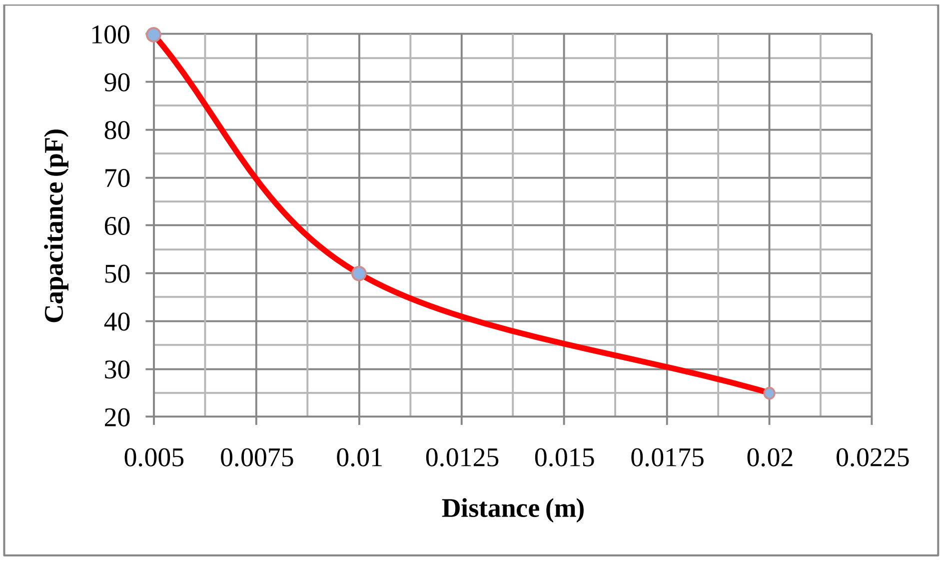



**Figure 5-3: Capacitance vs. Distance**

### 5.1.3Experiment No. Three: Frequency Effect on Output Voltage

The voltage on a capacitor depends on the amount of frequency, the following experiment shows what is the relationship between the frequency and the output voltage, by assuming that the test sample that used is saline with fixed value of capacitance $C_s$ = 100pF, the circuit of resistor and capacitor in series shown in Figure 5-4.

Let take by assuming $R_1 = 2k\Omega$, $V_S = 12.5V_P$.

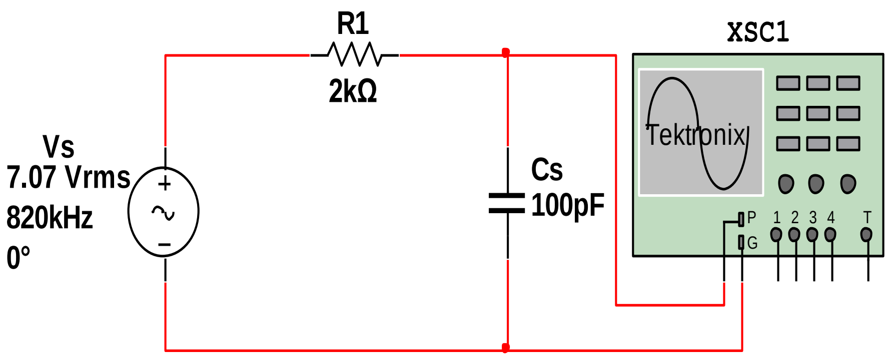



**Figure 5-4: Resistor Capacitor Circuit**

At $X_S = 2k\Omega$ $\Rightarrow$ $$f = \frac{1}{2\pi X_S C_S} = \frac{1}{2\pi \times (2\times10^3)\times(97\times10^{-12})} = 820\,KHz$$

With take more different values of reading of frequency, we obtain the output voltage from oscilloscope as in Figure 5-5.

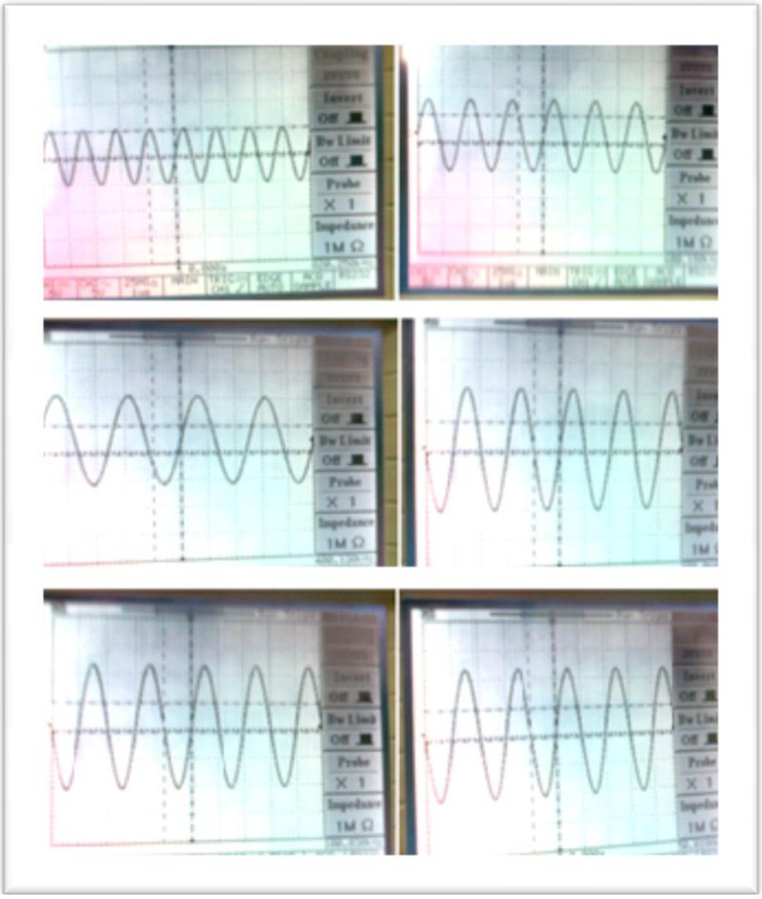


**Figure 5-5: Voltage vs. Frequency**

Capacitive Reactance calculations at different frequencies:

$$X_S = \frac{1}{2\pi \, f \, C_S}$$

$$X_{S2} = \frac{1}{2\pi \times \left(600 \times 10^3\right) \times \left(97 \times 10^{-12}\right)} = 2.7\,k\Omega$$

$$X_{S2} = \frac{1}{2\pi \times \left(400 \times 10^3\right) \times \left(97 \times 10^{-12}\right)} = 4.2\,k\Omega$$

$$X_{S3} = \frac{1}{2\pi \times \left(200 \times 10^3\right) \times \left(97 \times 10^{-12}\right)} = 8.3\,k\Omega$$

$$X_{S4} = \frac{1}{2\pi \times \left(100 \times 10^3\right) \times \left(97 \times 10^{-12}\right)} = 16.4\,k\Omega$$

$$X_{S5} = \frac{1}{2\pi \times (50 \times 10^3) \times (97 \times 10^{-12})} = 32.9\,k\Omega$$

Table 5-4 shows the relation between frequency, reactance, and voltage and Figure 5-6 shows an approximated inversely relation between voltage and frequency.

**Table 5-4: Frequency vs. Reactance and Voltage**

| Frequency (KHz) | 820 | 600 | 400 | 200 | 100 | 50 |
|---|---|---|---|---|---|---|
| Capacitor Reactance (KΩ) | 2 | 2.7 | 4.2 | 8.3 | 16.4 | 32.9 |
| Voltage ($V_P$) | 5 | 6.25 | 7.5 | 10 | 10.75 | 10.75 |

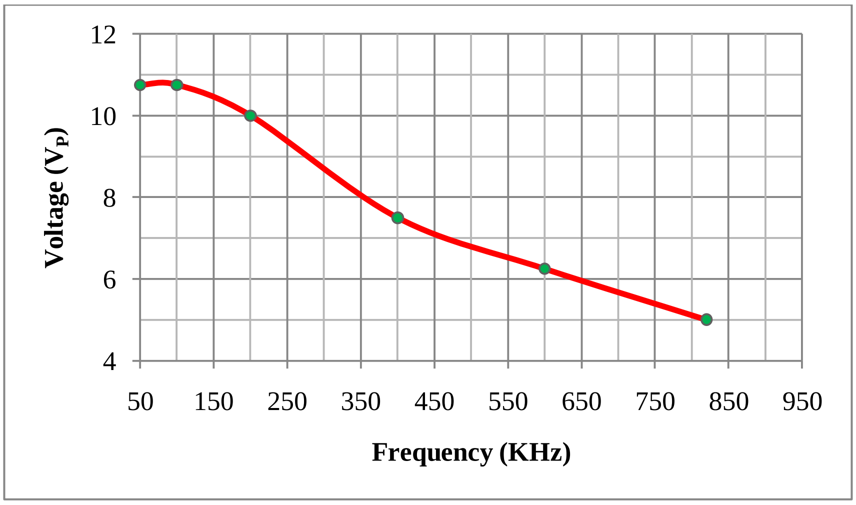



**Figure 5-6: Voltage vs. Frequency**

## 5.2 Capacitive Bridge Driven Circuit

The capacitive bridge as mentioned in the last chapter must detect the change in potential difference on the capacitor, the final practical design shown in Figure 5-7.

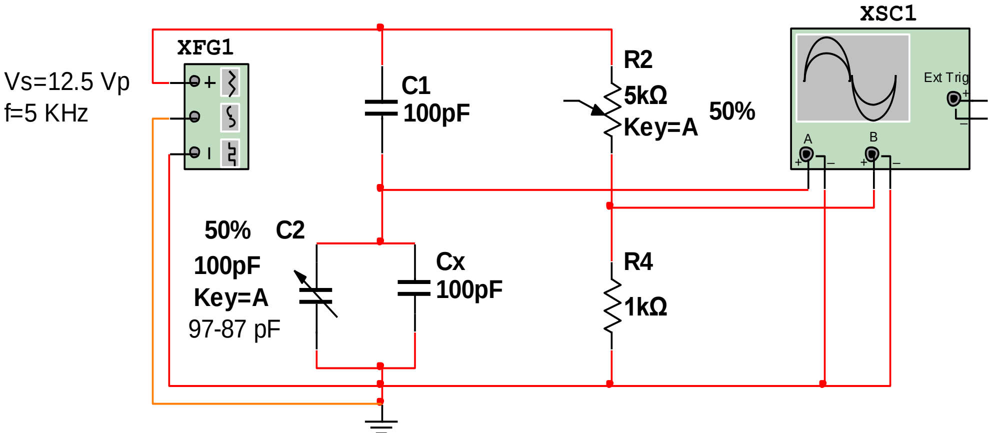



**Figure 5-7: Capacitive Bridge Circuit**

The simulation for this circuit appear in Figure 5-8 & 5-9, where signal (A) show the output voltage signal when there is no bubble in test tube, the DC value on the capacitor sensor as shown in figure at time 17.341µs equal 2.180 volt.

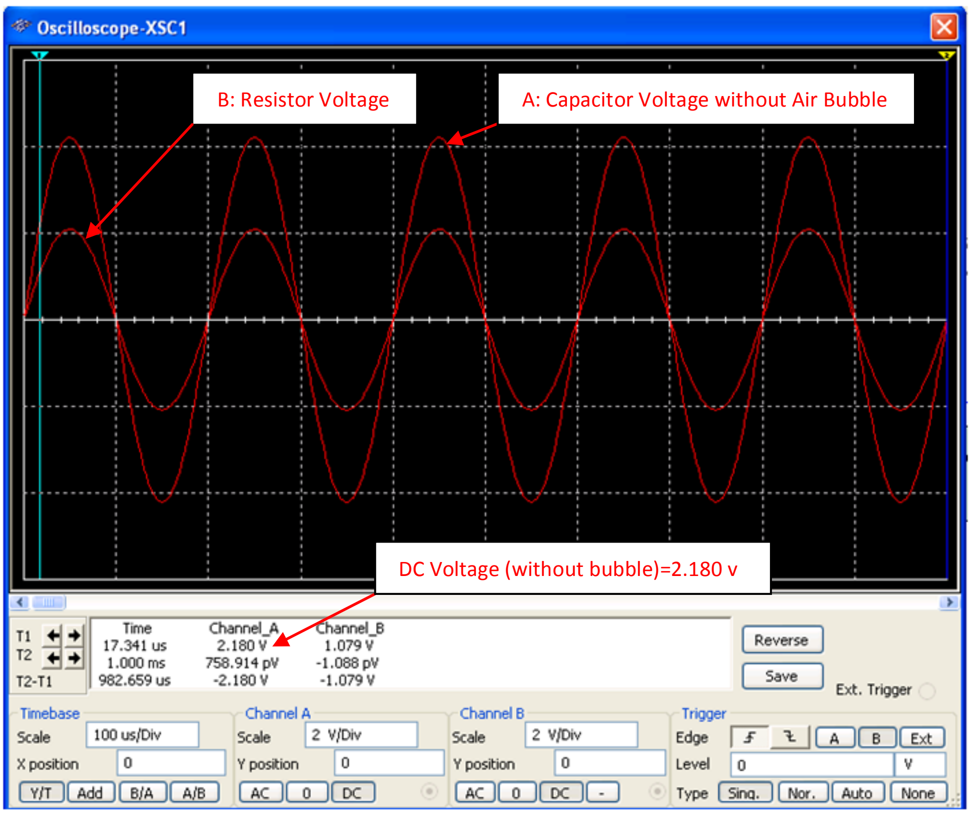



**Figure 5-8: Output Voltage Signal without Air Bubble**

In Figure 5-9, the output voltage signal at time 17.341μs signal increases to reach 2.256 volt.

We conclude that the change in voltage signal when the capacitance change from 97pF (no air bubble) to 87pF (passing air bubble) is very small and difficult to notice that, but it is clear when we measure by DC quantity.

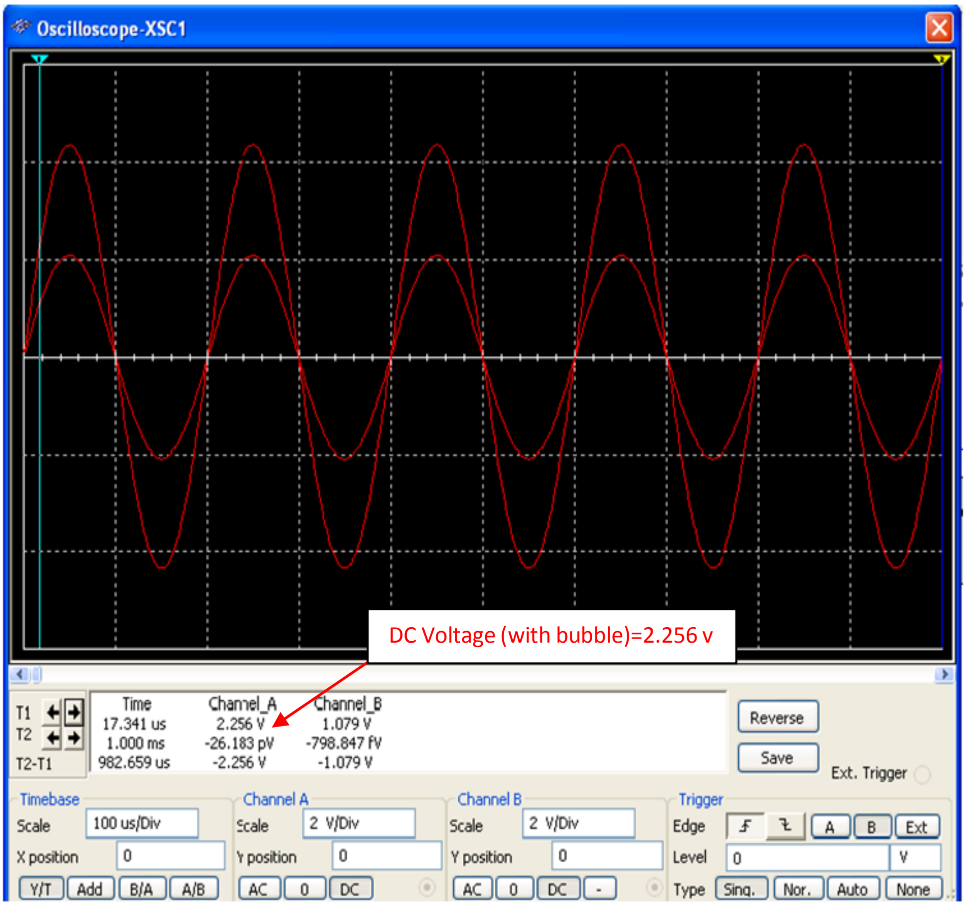



**Figure 5-9: Output Voltage Signal with Air Bubble**

$$\Delta V = 2.256 - 2.180 = 0.076\,V$$

In the practical work we can notice the change in DC voltage even 0.13 volt, this small change need to amplification by differential amplifier circuit with specific voltage gain to obtain and notice the difference clearly.

## 5.3 Differential Amplifier Circuit

Figure 5-10 show the circuit of differential amplifier that built to amplify the voltage signal from the bridge circuit.

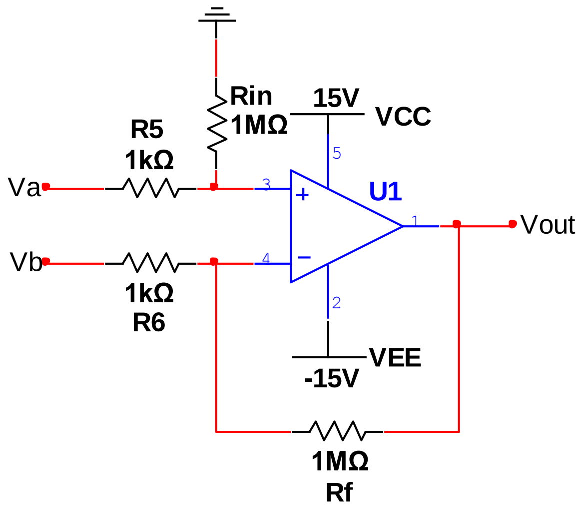



**Figure 5-10: Differential Amplifier Circuit**

Let voltage gain "Av" = 1000, by take $R_5 = R_6 = 1k\Omega$ and $R_f = R_{in} = 1M\Omega$.

$$V_{out} = \frac{R_3}{R_1}(V_a - V_b)$$

$$V_{out} = \frac{1M\Omega}{1k\Omega} \times 0.1 = 100V$$

The output voltage relates with Vcc that feed the amplifier circuit and don't exceed this value. Figure 5-11 show the waveform voltage signal before and after the amplification when take the output voltage directly between the bridge arms when there is no air bubble in the test tube.

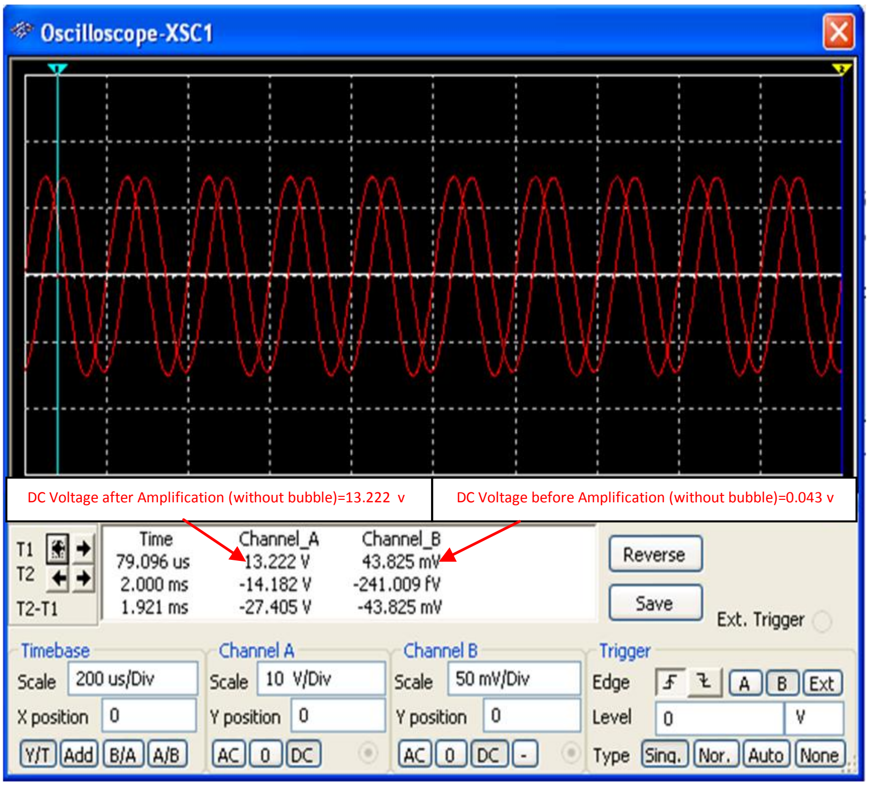



**Figure 5-11: Signal Waveform with/without Amplification (without bubble).**

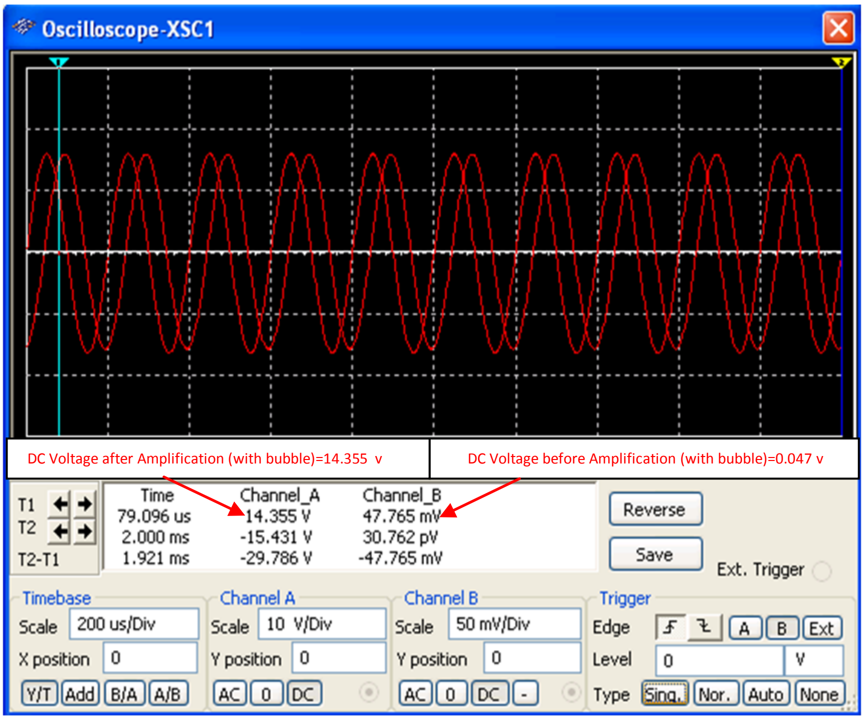



**Figure 5-12: Signal Waveform with/without Amplification (with bubble)**

## 5.4 Comparator and Alarm Circuit

The circuit in the Figure 5-13 represent an comparator circuit and alarming led, the led must be on if $V_1$ larger than $V_{ref}$, by mean when there is a bubble in test sample, and led be off when there is no bubble in the test sample.

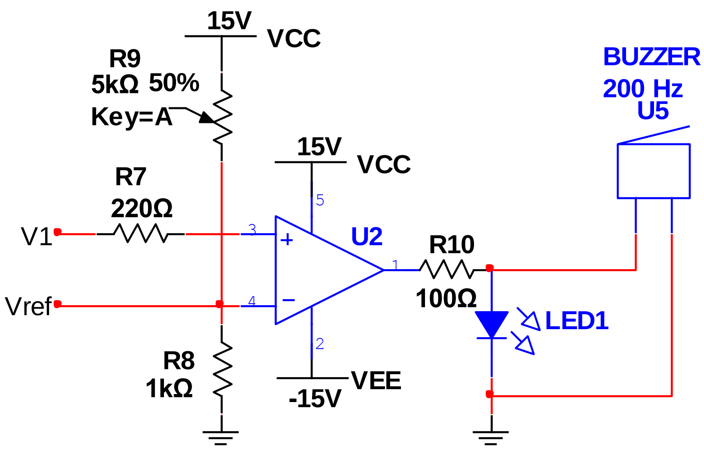



**Figure 5-13: Comparator with Alarm Circuit**

Using voltage divider rule to compute R9; Take Vref. (13.2V-14.3V) = 13.7V

$$\text{assume} V_{in} = Vcc = 15V,\ R_8 = 1K\Omega$$

$$V_{ref} = V_{in} . \frac{R_8}{R_8 + R_9} \Rightarrow 13.7 = 15.\frac{1000}{1000 + R_9} \Rightarrow 13.7 = 15.\frac{1000}{1000 + R_9} \Rightarrow R_9 = 94.9\Omega$$

The LED work as forward (short circuit) bias if there is a positive voltage signal on output amplifier (Vcc), and work reverse bias when there is negative voltage signal outs from the comparator circuit (open circuit).

## 5.5 Schematic Circuit for Entire Project

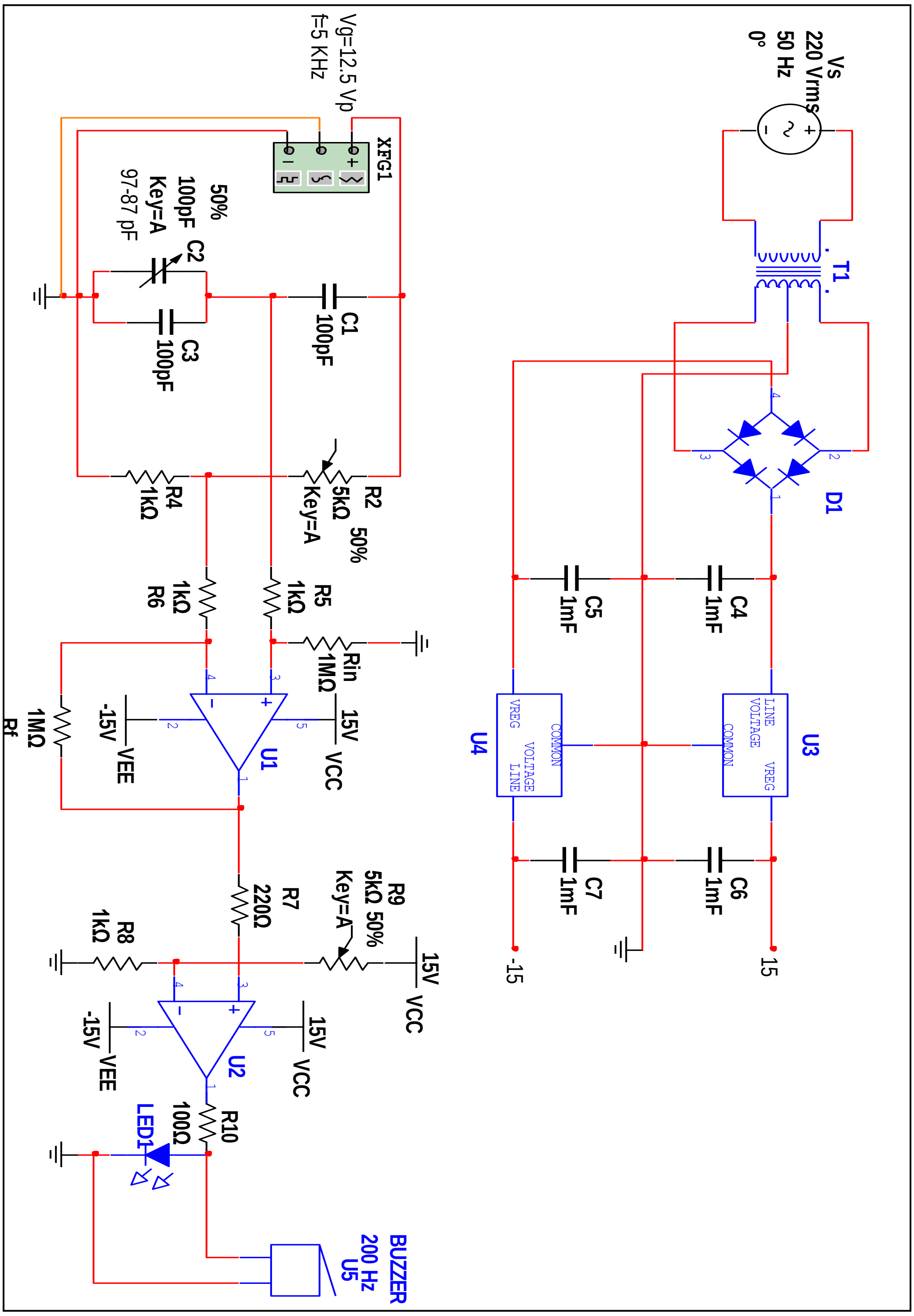



Figure 5-14: Entire Project Schematic Circuit

**Table 5-5: Part List**

| Description | Quantity | Reference ID |
|---|---|---|
| Power Line | 1 | Vs |
| Step Down Transformer | 2 | T1 |
| Full Wave Rectifier | 3 | D1 |
| Capacitor | 4 | C1,C3,C5,C6 |
| Regulator | 2 | U3,U4 |
| Function Generator | 1 | Vg |
| Capacitor | 2 | Cx1,C2 |
| Variable Capacitor (Sensor) | 1 | Cs |
| Variable Resistor | 1 | R3 |
| Resistor | 8 | R1,Rin1,Rin2,Rf1,Rf2,R4,R5,R6 |
| Amplifiers | 2 | LM 741 |
| LED | 1 | LED1 |
| Common Ground | 1 | GND |

# Chapter Six

# <u>CONCLUSION AND FUTURE WORK</u>

## 6.1 Conclusion

According to my study and work design through this project, there are many important conclusion become clear and significant and must be mentioned, it is focused mainly about the capacitor deign to get perfect operate of air bubbles detection unit.

1) The capacitor device has the ability to change the potential difference when air bubbles get into the test sample.

2) The main advantages of this capacitor device are its reliability, and it is very cheap when compared with the other devices.

3) The main disadvantage of the ac driven bridge circuit is affect by external artifacts and signals, this is prevent to make a balance condition to the bridge.

4) The unit can be applying to detect anything else air bubble like gas bubbles or oil bubbles in specific solution.

## 6.2 Results

1. The capacitor sensitivity depend on the distance between the plates, with decrease of distance the sensitivity will be increase, by mean the inversely relationship between distance and sensitivity.

2. The relationship between the capacitance relative permittivity is linear through Appling capacitance law on different sample of dielectric material.

3. The relationship between the capacitance and reactance, voltage is inverse relationship.

## Recommendations and Future Work

a) My project was for saline sample instead of blood; in the future projects the students can develop it to a sample that simulates the standard specification of blood.

b) The air bubble detection unit can improve by make some modification on the capacitive sensor represented by make inlet and outlet to the test tube.

c) The air bubble detection unit becomes more powerful if it sophisticates by makes removal system that can eliminate the air bubbles.

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# Appendices

- **Appendix A: Definitions**
- **Appendix B: Programs**
- **Appendix C: Datasheets of Project Components**

# Appendix :A

# Definitions

| | |
|---|---|
| Hemodialysis | A medical procedure that uses to filter waste products from the blood and to restore normal constituents to it. |
| Kidney | One of a pair of organs located in the right and left side of the abdomen which clear poisons from the blood, regulate acid concentration and maintain water balance in the body by excreting urine. |
| Nephron | A tiny structure in the kidney responsible on filter the blood in kidney |
| Blood | A fluid in the body that contains red and white cells as well as platelets, proteins, plasma and other elements, It is transported throughout the body by the circulatory system. |
| Blood Viscosity | It is the friction force of the blood on the veins and arteries, are mainly based on proteins found in plasma. |
| Frequency (f) | Number of cycles per second, the cycle include positive and negative side, measured in Hz. |
| Amplitude(A) | The maximum value of voltage, measured by volt. |
| Peak-peak voltage (Vpp) | The voltage from peak to peak in the alternating signals. |
| rms Value | Root Mean Square, it is a statistical measure of the magnitude of varying quantity |
| Dc Current | The current that pass in the same direction without increasing or decreasing in its magnitude. |
| Ac Current | An electric current in which the flow reverses periodically. |
| Impedance (Z) | Is a measure of the overall opposition of a circuit to current, it show how much the circuit impedes the flow of current, It is like resistance, but it also effects of capacitance and inductance. |
| Reactance (X) | Is a measure of the opposition of capacitance and inductance to current, reactance varies with the frequency of the electrical signal. |

| | |
|---|---|
| Voltage Gain(Av) | The amount of increase in signal power or voltage or current expressed as the ratio of output to input . |
| Impedance | Is a comprehensive expression of opposition to electron flow, including both resistance and reactance, impedance is the general name that give to the ratio of voltage to current. |
| Amplification | The amount of increase in signal power, voltage or current expressed as the ratio of output to input . |
| Capacitor | An electric circuit element used to store charge temporarily, consisting in general of two metallic plates separated and insulated from each other by a dielectric, also called condenser. |
| Phase Shift | Means that the current and voltage are out of phase, in charging a capacitor when the voltage across the capacitor is zero, the current is at a maximum, when the capacitor has charged and the voltage is at a maximum, the current is at a minimum. |

# Appendix: B

Programs

- Microsoft Office Word 2007
- Adobe Reader 8.0
- Multism 10.1
- Paint
- Catia V5
- Google Chrome
- Microsoft Office PowerPoint 2007
- Circuit Maker 2000

# Appendix: C

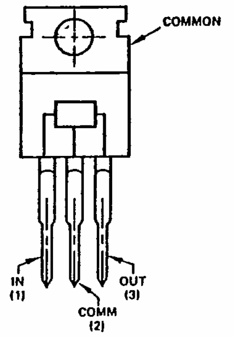
Datasheets

# CODI Semiconductor, Inc.

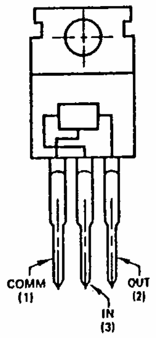
## LINEAR

### LOGIC SYMBOLS AND CONNECTION DIAGRAMS

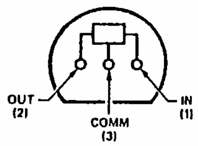
**L-CD1**




**L-CD2**

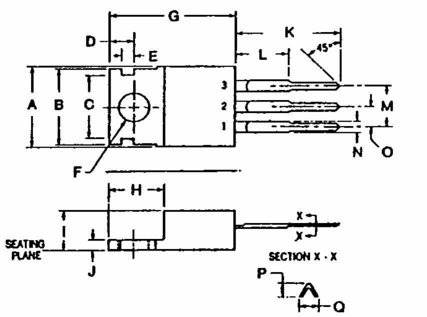



**L-CD3**




### PACKAGE OUTLINES

**JEDEC TO-220 Outline**
**Plastic Power Package**

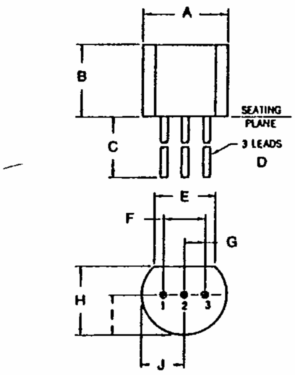



| DIM. | INCHES MIN. | INCHES TYP. | INCHES MAX. | MILLIMETERS MIN. | MILLIMETERS TYP. | MILLIMETERS MAX. |
|---|---|---|---|---|---|---|
| A | .395 | | .410 | 10.03 | | 10.41 |
| B | .365 | | .385 | 9.27 | | 9.77 |
| C | .300 | | .320 | 7.62 | | 8.13 |
| D | .100 | | .120 | 2.54 | | 3.05 |
| E | .040 | | .060 | 1.02 | | 1.52 |
| F | .141 | | .145 | 3.58 | | 3.68 |
| G | .575 | | .600 | 14.6 | | 15.24 |
| H | .235 | | .265 | 5.97 | | 6.73 |
| I | .160 | | .190 | 4.06 | | 4.83 |
| J | .020 | | .055 | .508 | | 1.40 |
| K | .500 | | | 12.70 | | |
| L | | | .250 | | | 6.35 |
| M | .190 | | .210 | 4.83 | | 5.33 |
| N | .045 | | .055 | 1.05 | | 1.40 |
| O | .095 | | .105 | 2.41 | | 2.66 |
| P | .015 | | .030 | .381 | | .762 |
| Q | .020 | | .045 | .508 | | 1.43 |

NOTES: See table for dimensions in inches and millimeters
Center lead is electrical contact with the mounting tab

Package weight is 2.1 grams

**JEDEC TO-92 Outline**
**Plastic Package**




| DIM. | INCHES MIN. | INCHES TYP. | INCHES MAX. | MILLIMETERS MIN. | MILLIMETERS TYP. | MILLIMETERS MAX. |
|---|---|---|---|---|---|---|
| A | .175 | | .205 | 4.45 | | 5.20 |
| B | .170 | | .210 | 4.32 | | 5.33 |
| C | .500 | | | 12.70 | | |
| D | .016 | | .019 | 0.406 | | 0.483 |
| E | .135 | | | .343 | | |
| F | | .100 | | | 2.54 | |
| G | | .050 | | | 1.27 | |
| H | .125 | | .165 | 3.18 | | 4.19 |
| I | .080 | | .105 | 2.03 | | 2.67 |
| J | .080 | | .105 | 2.03 | | 2.67 |

NOTES: See table for dimensions in inches and millimeters
Package material is transfer molded thermosetting plastic
Package weight is 0.25 grams

**144 Market St., Kenilworth, NJ, USA 07033 • (201) 298-0400**

TOLL-FREE: 1-800-232-CODI TELEX: 844-796 FAX NUMBER: 201-298-0477

# CODI Semiconductor, Inc.

## LINEAR INTEGRATED CIRCUITS
## 3 - TERMINAL VOLTAGE REGULATORS

| | 1 AMP Pos. 7805-7824 | 1 AMP Neg. 7905-7924 | .5A Pos. 78M05-78M24 | .1A Pos. 78L05-78L24 |
|---|---|---|---|---|
| **Thermal resistance** Rj-c / Rj-a | 5°c/w / 70°c/w | | | 7°c/w / 100°c/w |
| **Power** Dissipation | 20W | | 10W | 500MW |
| **Temperature range** Operating Ambient / Operating Junction / Storage | -20 to + 80°C / -20 to + 125°C / -55 to + 125°C | | | -20 to + 75°C / -20 to + 125°C / -40 to + 125°C |
| **Line Regulation (MV)** Vo/Vi (%) | 2.0 | | 1.0 | 2.0 |
| **Load Regulation (MV)** Vo/Io (%) | 2.0 | | 1.0 | |
| **Logic/Connection diagram** | L-CD 1 | L-CD 2 | L-CD 1 | L-CD 3 |
| **Package** | TO-220 | | | TO-92 |

| TYPE No. | Nominal OUTPUT Voltage Range (V) | OUTPUT Voltage Range (V) | INPUT Voltage Range (V) | Quiescent Current (MA) | Ripple Rejection (dB) MIN | OUTPUT Noise Voltage (uV) | OUTPUT Voltage Drift (TYP) MV/°C |
|---|---|---|---|---|---|---|---|
| **1 AMP POSITIVE** | | | | | | | |
| 7805 | 5.0 | 4.8-5.2 | 7.0-35.0 | 5.3 | 62 | 40 | 0.4 |
| 7806 | 6.0 | 5.75-6.25 | 8.0-35.0 | 4.7 | 59 | 45 | 0.4 |
| 7808 | 8.0 | 7.7-8.3 | 10.5-35.0 | 4.7 | 56 | 50 | 0.4 |
| 7812 | 12.0 | 11.5-12.5 | 14.5-35.0 | 4.7 | 55 | 70 | 0.8 |
| 7815 | 15.0 | 14.4-15.6 | 17.5-35.0 | 4.7 | 54 | 85 | 1.0 |
| 7818 | 18.0 | 17.3-18.7 | 21.0-35.0 | 5.0 | 53 | 95 | 1.2 |
| 7824 | 24.0 | 23.0-25.0 | 27.0-40.0 | 5.0 | 50 | 120 | 1.4 |
| **1 AMP NEGATIVE** | | | | | | | |
| 7905 | -5.0 | -4.8-5.2 | -7.0-35.0 | 1.0 | 54 | 100 | -0.4 |
| 7906 | -6.0 | -5.75-6.25 | -8.0-35.0 | 1.0 | 54 | 150 | -0.5 |
| 7908 | -8.0 | -7.7-8.3 | -10.5-35.0 | 1.0 | 54 | 200 | -0.6 |
| 7912 | -12.0 | -11.5-12.5 | -14.5-35.0 | 1.5 | 54 | 300 | -0.8 |
| 7915 | -15.0 | -14.4-15.6 | -17.5-35.0 | 1.5 | 54 | 375 | -1.0 |
| 7918 | -18.0 | -17.3-18.7 | -21.0-35.0 | 1.5 | 54 | 450 | -1.0 |
| 7924 | -24.0 | -23.0-25.0 | -27.0-40.0 | 1.5 | 51 | 600 | -1.0 |
| **.5A (500ma) POSITIVE** | | | | | | | |
| 78M05 | 5.0 | 4.8-5.2 | 7.0-35.0 | 4.5 | 62 | 40 | -1.0 |
| 78M06 | 6.0 | 5.75-6.25 | 8.0-35.0 | 4.6 | 59 | 45 | -1.0 |
| 78M08 | 8.0 | 7.7-8.3 | 10.5-35.0 | 4.6 | 56 | 52 | -1.0 |
| 78M12 | 12.0 | 11.5-12.5 | 14.5-35.0 | 4.8 | 55 | 75 | -1.0 |
| 78M15 | 15.0 | 14.4-15.6 | 17.5-35.0 | 4.8 | 54 | 90 | -1.0 |
| 78M18 | 18.0 | 17.3-18.7 | 21.0-35.0 | 4.8 | 53 | 100 | -1.0 |
| 78M24 | 24.0 | 23.0-25.0 | 27.0-40.0 | 5.0 | 50 | 170 | -1.0 |
| **.1A (100ma) POSITIVE** | | | | | | | |
| 78L05 | 5.0 | 4.75-5.25 | 7.0-30.0 | 6.0* | 40 | 40 | -1.0 |
| 78L06 | 6.0 | 5.95-6.45 | 8.0-30.0 | 6.0* | 39 | 50 | -1.0 |
| 78L08 | 8.0 | 7.6-8.4 | 10.5-30.0 | 6.0* | 39 | 60 | -1.0 |
| 78L12 | 12.0 | 11.4-12.6 | 14.5-35.0 | 6.5* | 37 | 80 | -1.5 |
| 78L15 | 15.0 | 14.3-15.7 | 17.5-35.0 | 6.5* | 34 | 90 | -1.5 |
| 78L18 | 18.0 | 17.1-18.9 | 21.0-40.0 | 6.5* | 33 | 120 | -2.0 |
| 78L24 | 24.0 | 22.8-25.2 | 27.0-40.0 | 7.0* | 32 | 200 | -2.0 |

*max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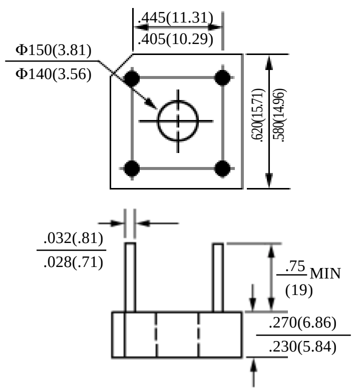
# BR305 – BR310
# KBPC1005 – KBPC110

## 3.0A 桥式整流器

## 3.0A BRIDGE RECTIFIERS

最大额定值、电性 MAXIMUM RATINGS AND ELECTRICAL CHARACTERISTICS
Ratings at 25°C ambient temperature unless otherwise specified. Single phase,half wave, 60Hz,resistive or inductive load. For capacitive load,derate current by 20%.

| 型 号 TYPE | | 最大反向峰值电压 Maximum Peak Reverse Voltage | 最大平均正向电流 Maximum Average Forward Output Current @$T_A$=40°C | 最大正向浪涌电流 Maximum Forward Peak Surge Current @ 8.3ms Superimposed | 最大正向峰值电压 Maximum DC Forward Voltage drop per element at $I_F$=3.0ADC | 最大反向电 流 Maximum DC Reverse Current at rated DC Blocking Voltage per element | | 结 温 Operating Junction Temperature | 外型尺寸 Package Dimensions |
|---|---|---|---|---|---|---|---|---|---|
| | | PRV | $I_O$ | $I_{FM}$(Surge) | $V_F$ | $I_R$ | | $T_J$ | |
| | | $V_{PK}$ | $A_{AV}$ | $A_{PK}$ | $V_{PK}$ | 25°CTA µADC | 125°CTA µADC | °C | |
| BR305 | KBPC1005 | 50 | 3.0 | 50 | 1.1 | 10 | 500 | 125 | BR – 3 |
| BR31 | KBPC101 | 100 | | | | | | | |
| BR32 | KBPC102 | 200 | | | | | | | |
| BR34 | KBPC104 | 400 | | | | | | | |
| BR36 | KBPC106 | 600 | | | | | | | |
| BR38 | KBPC108 | 800 | | | | | | | |
| BR310 | KBPC110 | 1000 | | | | | | | |




BR – 3

# BR305-BR310 KBPC1005-KBPC110
# 桥式整流器额定值与特性曲线
# BRIDGE RECTIFIERS RATING & CHARACTERISTIC CURVES

FIG. 1 - TYPICAL FORWARD CURRENT DERATING CURVE

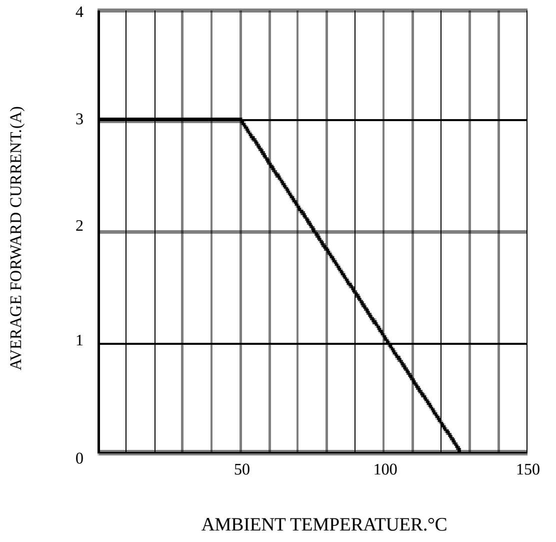



FIG. 2 - PEAK FORWARD CURRENT

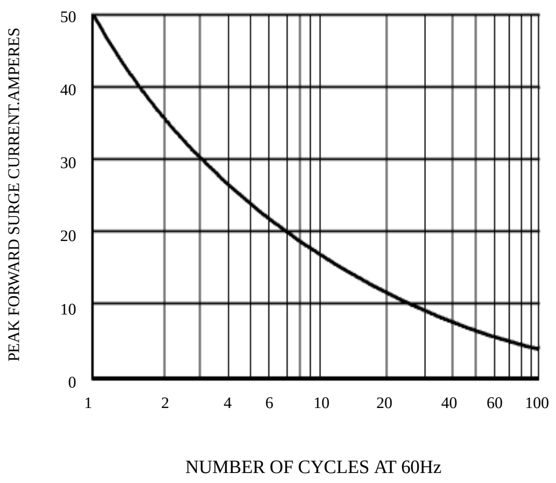



FIG. 3 - TYPICAL REVERSE CHARACTERISTICS

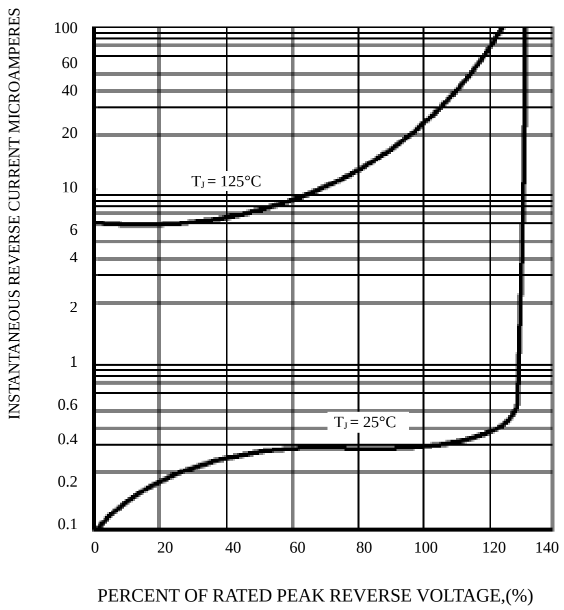
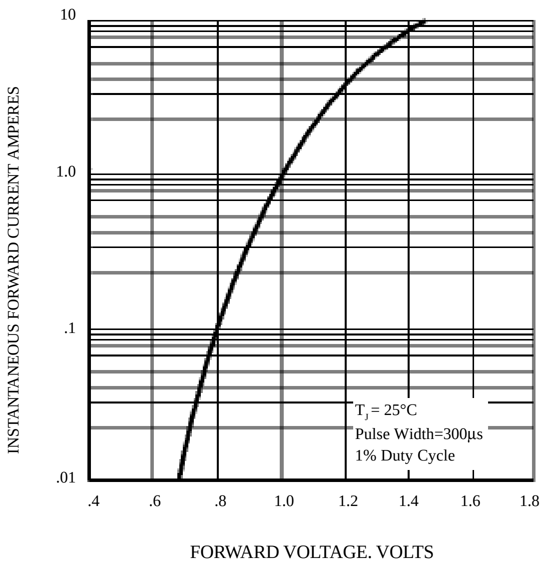



FIG. 4 - TYPICAL FORWARD CHARACTERISTICS



www.fairchildsemi.com

# LM741

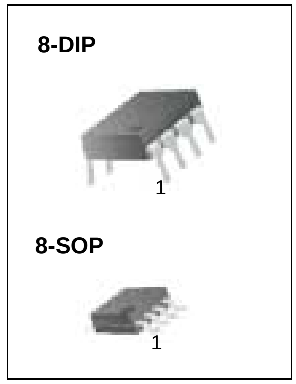
## Single Operational Amplifier

### Features

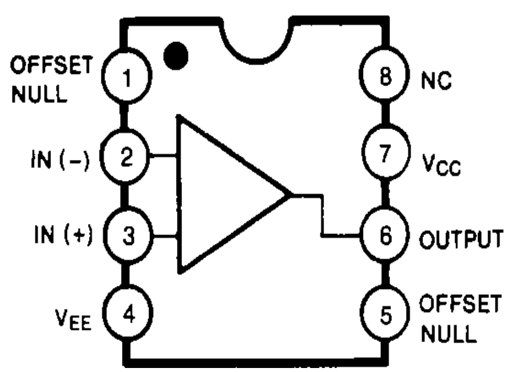
- Short circuit protection
- Excellent temperature stability
- Internal frequency compensation
- High Input voltage range
- Null of offset

### Description

The LM741 series are general purpose operational amplifiers. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in intergrator, summing amplifier, and general feedback applications.

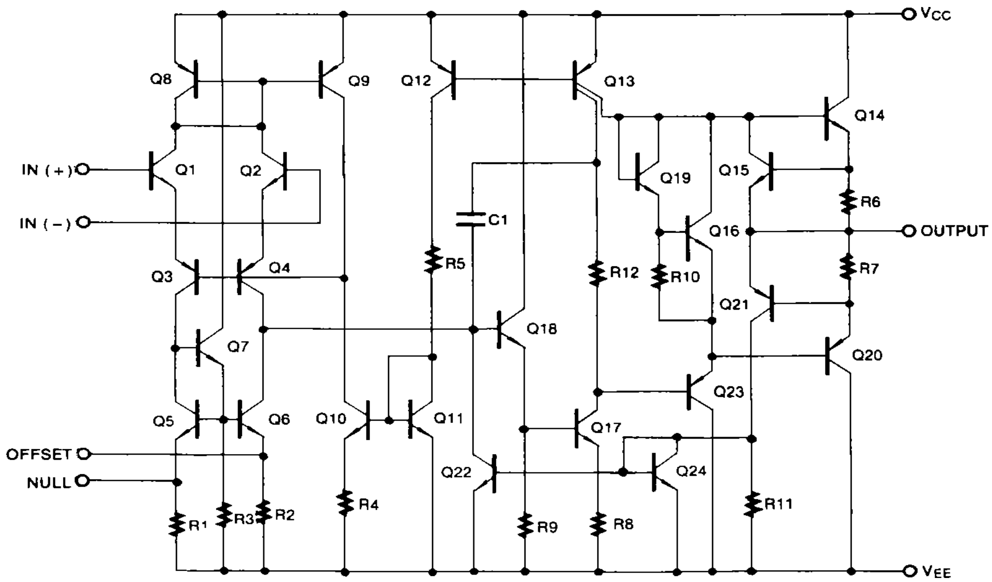



### Internal Block Diagram




Rev. 1.0.1

## Schematic Diagram




## Absolute Maximum Ratings ($T_A$ = 25°C)

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Supply Voltage | $V_{CC}$ | ±18 | V |
| Differential Input Voltage | $V_{I(DIFF)}$ | 30 | V |
| Input Voltage | $V_I$ | ±15 | V |
| Output Short Circuit Duration | - | Indefinite | - |
| Power Dissipation | $P_D$ | 500 | mW |
| Operating Temperature Range<br>LM741C<br>LM741I | $T_{OPR}$ | 0 ~ + 70<br>-40 ~ +85 | °C |
| Storage Temperature Range | $T_{STG}$ | -65 ~ + 150 | °C |

## Electrical Characteristics

($V_{CC}$ = 15V, $V_{EE}$ = - 15V. $T_A$ = 25 °C, unless otherwise specified)

| Parameter | | Symbol | Conditions | | LM741C/LM741I | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | | | | Min. | Typ. | Max. | |
| Input Offset Voltage | | $V_{IO}$ | $R_S$≤10KΩ | | - | 2.0 | 6.0 | mV |
| | | | $R_S$≤50Ω | | - | - | - | |
| Input Offset Voltage Adjustment Range | | $V_{IO(R)}$ | $V_{CC}$ = ±20V | | - | ±15 | - | mV |
| Input Offset Current | | $I_{IO}$ | - | | - | 20 | 200 | nA |
| Input Bias Current | | $I_{BIAS}$ | - | | - | 80 | 500 | nA |
| Input Resistance (Note1) | | $R_I$ | $V_{CC}$ =±20V | | 0.3 | 2.0 | - | MΩ |
| Input Voltage Range | | $V_{I(R)}$ | - | | ±12 | ±13 | - | V |
| Large Signal Voltage Gain | | $G_V$ | $R_L$≥2KΩ | $V_{CC}$ =±20V, $V_{O(P-P)}$ =±15V | - | - | - | V/mV |
| | | | | $V_{CC}$ =±15V, $V_{O(P-P)}$ =±10V | 20 | 200 | - | |
| Output Short Circuit Current | | $I_{SC}$ | - | | - | 25 | - | mA |
| Output Voltage Swing | | $V_{O(P-P)}$ | $V_{CC}$ = ±20V | $R_L$≥10KΩ | - | - | - | V |
| | | | | $R_L$≥2KΩ | - | - | - | |
| | | | $V_{CC}$ = ±15V | $R_L$≥10KΩ | ±12 | ±14 | - | |
| | | | | $R_L$≥2KΩ | ±10 | ±13 | - | |
| Common Mode Rejection Ratio | | CMRR | $R_S$≤10KΩ, $V_{CM}$ = ±12V | | 70 | 90 | - | dB |
| | | | $R_S$≤50Ω, $V_{CM}$ = ±12V | | - | - | - | |
| Power Supply Rejection Ratio | | PSRR | $V_{CC}$ = ±15V to $V_{CC}$ = ±15V $R_S$≤50Ω | | - | - | - | dB |
| | | | $V_{CC}$ = ±15V to $V_{CC}$ = ±15V $R_S$≤10KΩ | | 77 | 96 | - | |
| Transient Response | Rise Time | $T_R$ | Unity Gain | | - | 0.3 | - | μs |
| | Overshoot | OS | | | - | 10 | - | % |
| Bandwidth | | BW | - | | - | - | - | MHz |
| Slew Rate | | SR | Unity Gain | | - | 0.5 | - | V/μs |
| Supply Current | | $I_{CC}$ | $R_L$= ∞Ω | | - | 1.5 | 2.8 | mA |
| Power Consumption | | $P_C$ | $V_{CC}$ = ±20V | | - | - | - | mW |
| | | | $V_{CC}$ = ±15V | | - | 50 | 85 | |

Note:
1. Guaranteed by design.

# Electrical Characteristics

( 0°C ≤$T_A$≤70 °C $V_{CC}$ = ±15V, unless otherwise specified)
The following specification apply over the range of 0°C ≤ $T_A$ ≤ +70 °C for the LM741C; and the -40°C ≤ $T_A$ ≤ +85 °C for the LM741I

| Parameter | Symbol | Conditions | | LM741C/LM741I Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|---|
| Input Offset Voltage | $V_{IO}$ | $R_S$≤50Ω | | - | - | - | mV |
| | | $R_S$≤10KΩ | | - | - | 7.5 | |
| Input Offset Voltage Drift | $\Delta V_{IO}/\Delta T$ | - | | - | - | | µV/ °C |
| Input Offset Current | $I_{IO}$ | - | | - | - | 300 | nA |
| Input Offset Current Drift | $\Delta I_{IO}/\Delta T$ | - | | - | - | | nA/ °C |
| Input Bias Current | $I_{BIAS}$ | - | | - | - | 0.8 | µA |
| Input Resistance (Note1) | $R_I$ | $V_{CC}$ = ±20V | | - | - | - | MΩ |
| Input Voltage Range | $V_{I(R)}$ | - | | ±12 | ±13 | - | V |
| Output Voltage Swing | $V_{O(P-P)}$ | $V_{CC}$ =±20V | $R_S$≥10KΩ | - | - | - | V |
| | | | $R_S$≥2KΩ | - | - | - | |
| | | $V_{CC}$ =±15V | $R_S$≥10KΩ | ±12 | ±14 | - | |
| | | | $R_S$≥2KΩ | ±10 | ±13 | - | |
| Output Short Circuit Current | $I_{SC}$ | - | | 10 | - | 40 | mA |
| Common Mode Rejection Ratio | CMRR | $R_S$≤10KΩ, $V_{CM}$ = ±12V | | 70 | 90 | - | dB |
| | | $R_S$≤50Ω, $V_{CM}$ = ±12V | | - | - | - | |
| Power Supply Rejection Ratio | PSRR | $V_{CC}$ = ±20V to ±5V | $R_S$≤50Ω | - | - | - | dB |
| | | | $R_S$≤10KΩ | 77 | 96 | - | |
| Large Signal Voltage Gain | $G_V$ | $R_S$≥2KΩ | $V_{CC}$ = ±20V, $V_{O(P-P)}$ = ±15V | - | - | - | V/mV |
| | | | $V_{CC}$ = ±15V, $V_{O(P.P)}$ = ±10V | 15 | - | - | |
| | | | $V_{CC}$ = ±15V, $V_{O(P-P)}$ = ±2V | - | - | - | |

Note :
1. Guaranteed by design.

# Typical Performance Characteristics

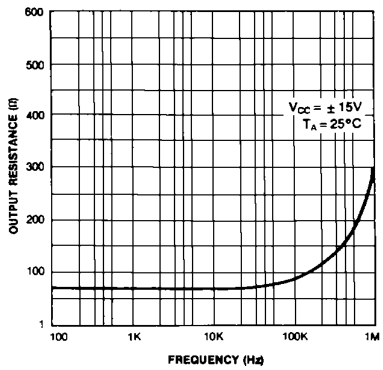



Figure 1. Output Resistance vs Frequency

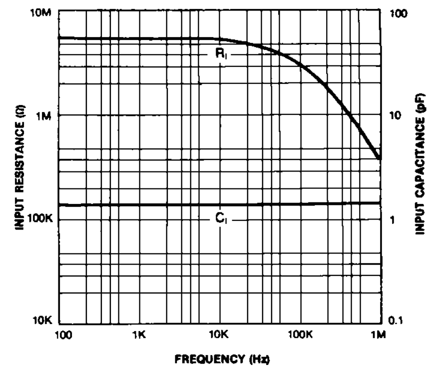



Figure 2. Input Resistance and Input Capacitance vs Frequency

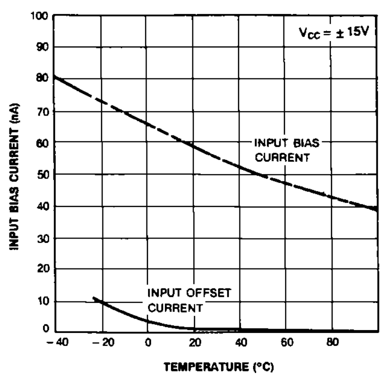



Figure 3. Input Bias Current vs Ambient Temperature

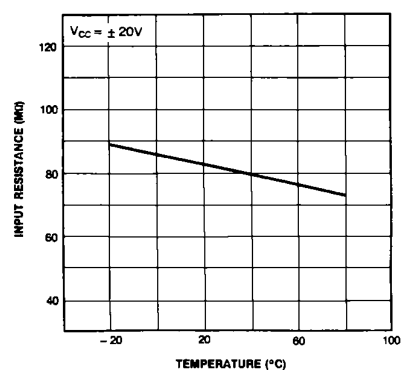



Figure 4. Power Consumption vs Ambient Temperature

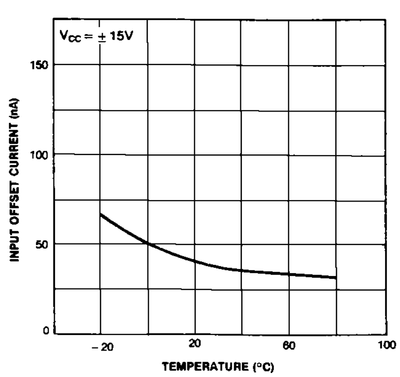



Figure 5. Input Offset Current vs Ambient Temperature

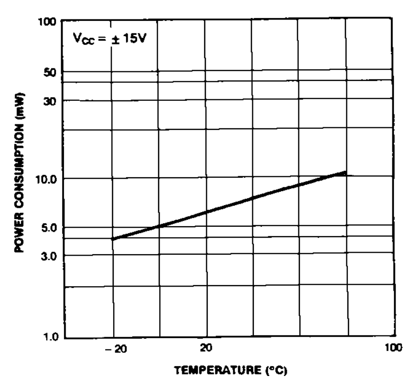



Figure 6. Input Resistance vs Ambient Temperature

# Typical Performance Characteristics (continued)

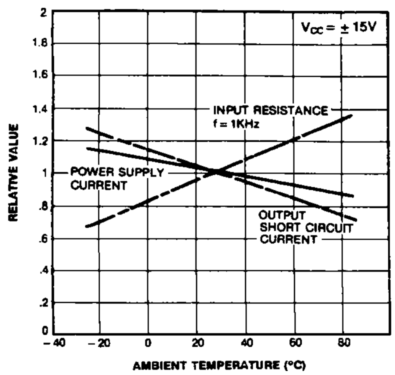



Figure 7. Normalized DC Parameters vs Ambient Temperature

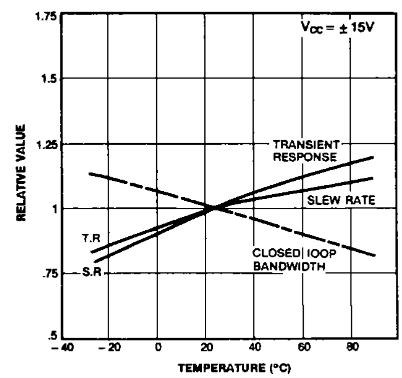



Figure 8. Frequency Characteristics vs Ambient Temperature

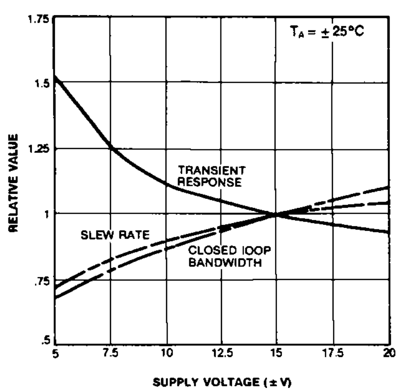



Figure 9. Frequency Characteristics vs Supply Voltage

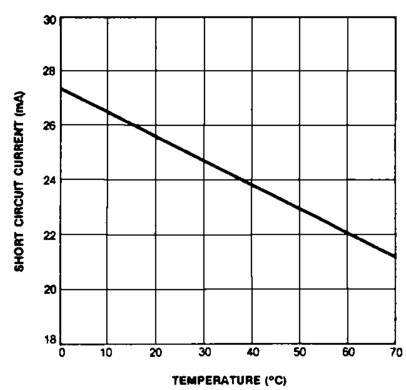



Figure 10. Output Short Circuit Current vs Ambient Temperature

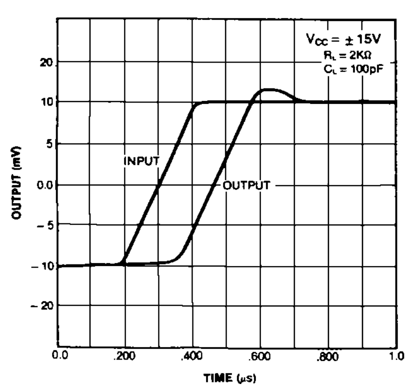



Figure 11. Transient Response

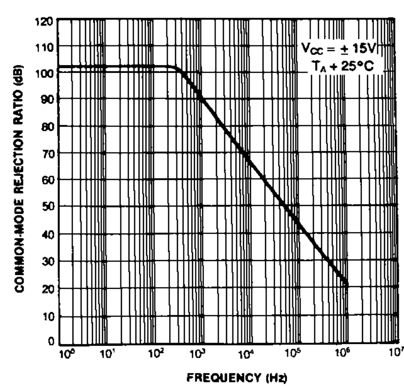



Figure 12. Common-Mode Rejection Ratio vs Frequency

## Typical Performance Characteristics (continued)

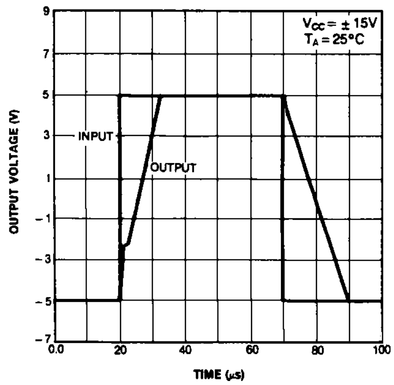



**Figure 13. Voltage Follower Large Signal Pulse Response**

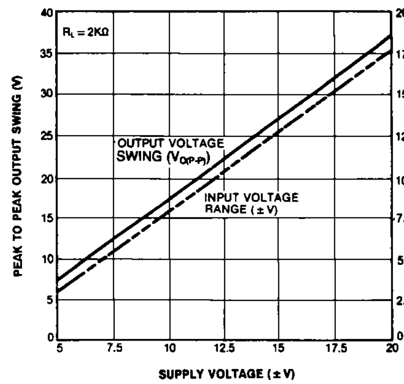
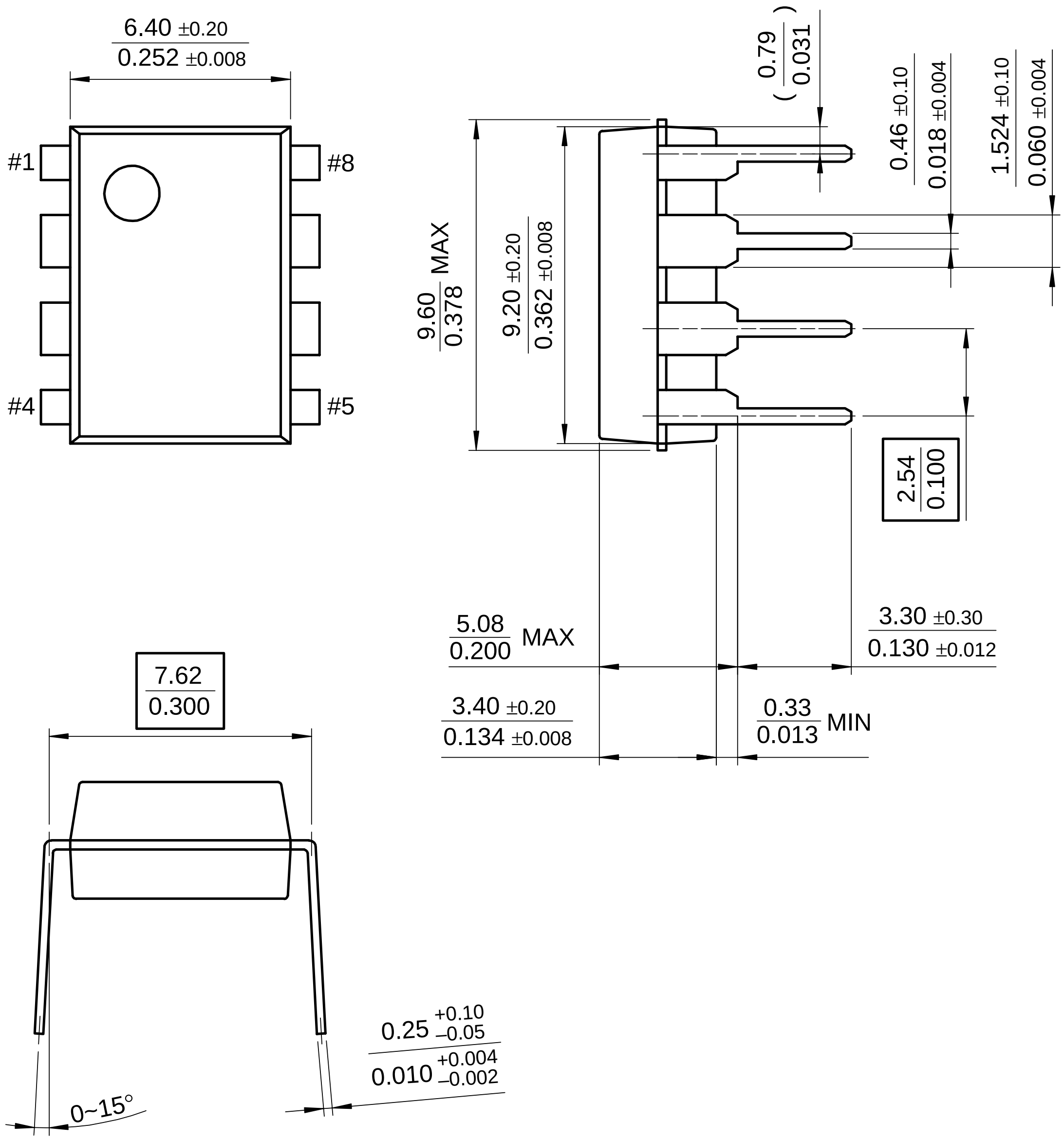



**Figure 14. Output Swing and Input Range vs Supply Voltage**

## Mechanical Dimensions

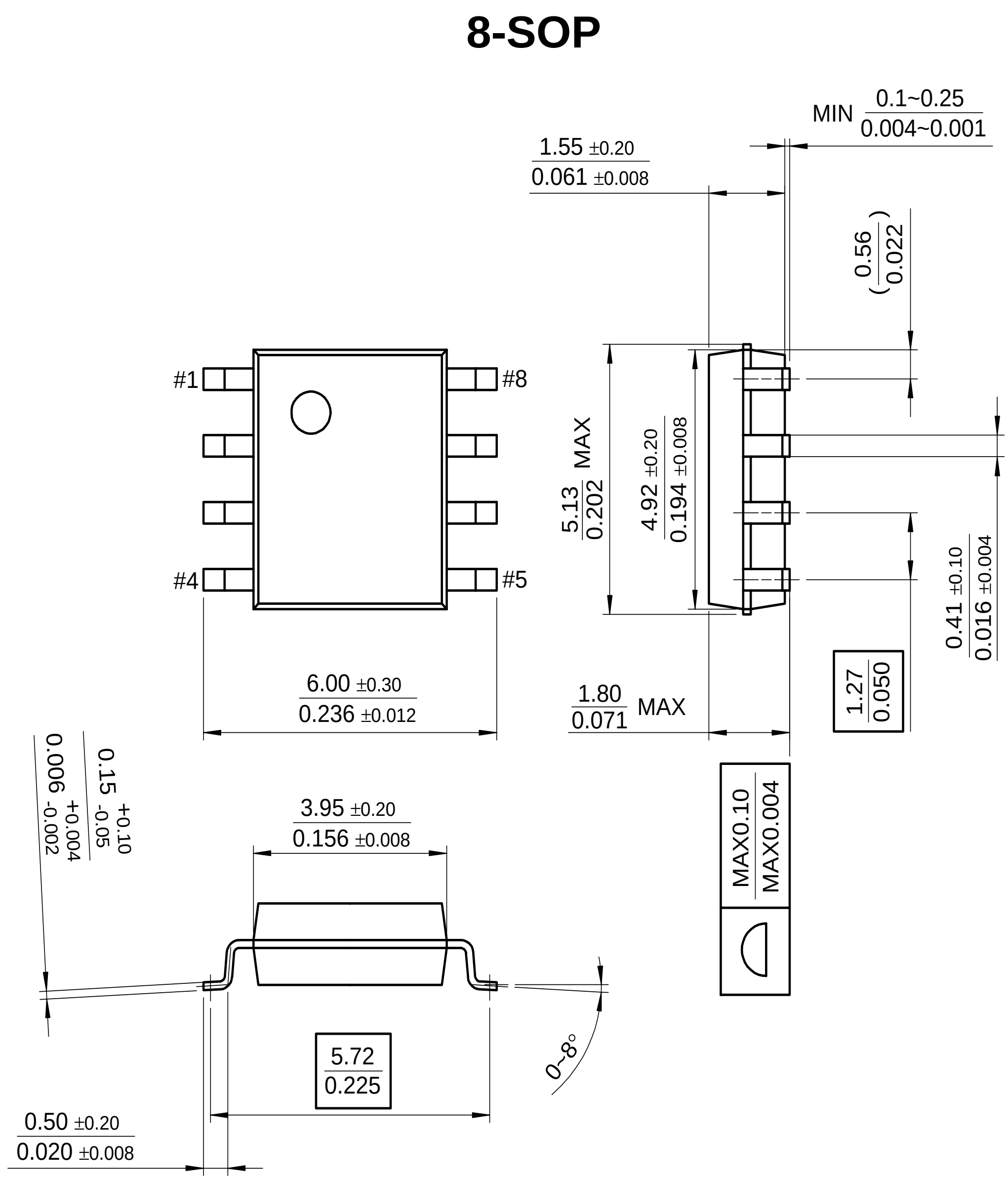
### Package

# 8-DIP



## Mechanical Dimensions (Continued)

### Package



## Ordering Information

| Product Number | Package | Operating Temperature |
|---|---|---|
| LM741CN | 8-DIP | 0 ~ + 70°C |
| LM741CM | 8-SOP | |
| LM741IN | 8-DIP | -40 ~ + 85°C |





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Stock#DSxxxxxxxx