PPU College of Engineering and Technology
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Electrical and Computer Engineering Department

Biomedical Engineering Program

Bachelor Thesis

Graduation Project

Design & Implementation of an Automatic Air Bubble Removal for a Hemodialysis Machine

Project Team

ENG. MOHAND M. KATBEH

Project Supervisor

Dr. ABDALLAH ARMAN

Hebron – Palestine

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ملخص المشروع

تم تقديم فكرة تطبيق مشروع لتصميم وبناء وحدة لكشف فقاعات الهواء قبل دخولها الى 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 دائرة كهربائية تقوم على كشف الفقاعات الهوائية التي قد تظهر في خط الدم النقي الخارج من جهاز غسيل الكلى، والذي قد يكون عرضة لدخول الفقاعة نظرا لعدة عوامل محيطة في بيئة العلاج، هذه الدائرة تقوم بارسال اشارة الى دائرة لاحقة تقوم بتحليلها واعطاء انذار في حال ظهورها ليتمكن الفني المختص من التنبه الى وجودها "للتزود أكثر بخصوص هذا المشروع يمكن الرجوع للكتيب السابق من هذا المشروع"

المرحلة الثانية: بناء دائرة تابعة للدائرة الاولى، وتكمن مهمة هذه الدائرة في محاكاة عمل الممرض المختص في متابعة عمل الجهاز وازالة الفقاعة بشكل آلي ومعاودة رجوع الدارة الدموية للعمل مرة اخرى بعد التأكد من خلوها من الفقاعات.

ABSTRACT

The idea of the project is suggested to design and build an air bubbles detection unit by using unutilized 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 spread widely and important in our country.

First stage: The first stage of 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 that passes through.

Second stage: is to build a system and model that simulates the clinician task of removing the air bubble manually after detecting that Air bubble. And to insure that implemented model is achieving all the objectives of the project.

Design & Implementation of an Air Bubble removal system for a Hemodialysis Machine

Chapter one

Introduction

1. Introduction:

1.1 Project Overview.

1.2 Project Objectives.

1.3 Time Scheduling.

1.4 The Idea of the Project and where it comes from.

1.5 Aim of Project.

1.6 Cost of the Project.

1.7 Project Risks.

1.8 Human Development Resources.

1.9 Scope of Project.

1.1 Project Overview

After finishing the first part of the project, and implementing all its parts on real ground and building the desired design, we get the goals and objectives done as needed, it was extremely necessary now to accomplish the second goal of the project and present the project as complete operating unit.

This part of the project presents and provides a reasonable and simple way to save some human effort, this effort which is applied in the hemodialysis machine to complete the therapy process for dialysis patients and guarantee the save operation of the machine. A suitable designed mechanism will simulate the clinician job, this mechanism what we presents in this part of the project.

Figure 1-1: Clinician Observation

Before start presenting the designed mechanism of this project, we must explain in brief way what are clinicians work accompanying the hemodialysis machine for connected patients. After visiting the department of dialysis at random hospitals "that include the Palestinian and the Kingdom of Saudi Arabia areas" and making a field questionnaire for random clinician who works in those departments and due to some specialized references we can categorize the clinician supervision and jobs into three successive processes:

- Pre- Dialysis Process.
- During Dialysis Process.
- Post Dialysis Process.

1.1.1 Pre- Dialysis Process and Post -Dialysis Process:

These two processes are specialized in all the procedure that concern in preparing the patient to start the dialysis process and finishing it in the correct way "this processes are not our field research and we will skip explaining them.

1.1.2 During Dialysis Process:

This process includes the jobs that the clinician must provide while the dialysis process is running and continued. Start from observing the whole operation, ending with safety insurance jobs that he must supply for the system. One of those responsibilities is the <u>Manual</u> <u>Air</u> <u>Bubble</u> <u>Removal</u> for any air emboli that may interfere the operation "this job will be explained later in a brief way". From this info we realize that, clinician must be aware and awake during the whole time for the therapy, since as we explain before a single dialysis process may take up to four hours. Focusing on this issue, we build our search and information gathering to find a way that facilitate the therapy process and solve the waste of energy and time.

1.1.3 Manual Air Bubble Removing

In this process, the clinician has to remove the air emboli and dangers bubbles that are formed in the final blood tube that supplying the patient body with dialyzed blood. Those bubbles have formed in the blood stream because of some outside factors and random errors as we explained in previous chapters. Clinician job's in this stage realized in, knocking repeatedly in a gentle way and shaking the blood tube to separate the air emboli from blood and make sure to deliver it back "where it has to be" in the air/blood container. See Figure 1-2 that shows a clinician whose trying to separate between air bubbles and some solution.

Figure 1-2: Clinician Knocking Tube to separate blood and bubbles.

The processes of knocking and shacking take place when the blood cycle is off and the air bubbles are detected. So it has some disadvantages, which affects in general, the whole therapy process in a negative way. Those negative points can be summarized in:

- It is subject to human error and mistake, since the clinician is responsible for it.
- It delays the dialysis time. Since the blood cycle is off.
- This process need from the clinician to be alarmed for the whole therapy time and ready to take action, which is can't be achieved in real ground.
- It endangers the lives of the patient.

To avoid the previous mistakes, we need to provide a large number of technician and train them well, which is could be hard in some cases.

Based on the previous data and information, we can state the idea for the project. This idea is to find a way that we can by it simulate the clinician job and convert the manual way to self automatic way that based on the feedback from our sensor.

The flow chart for this part of the project is similar to the previous one in the first chapter except some changes for some additional function that added to the system. Figure 1-3 shows the flowing of this project.

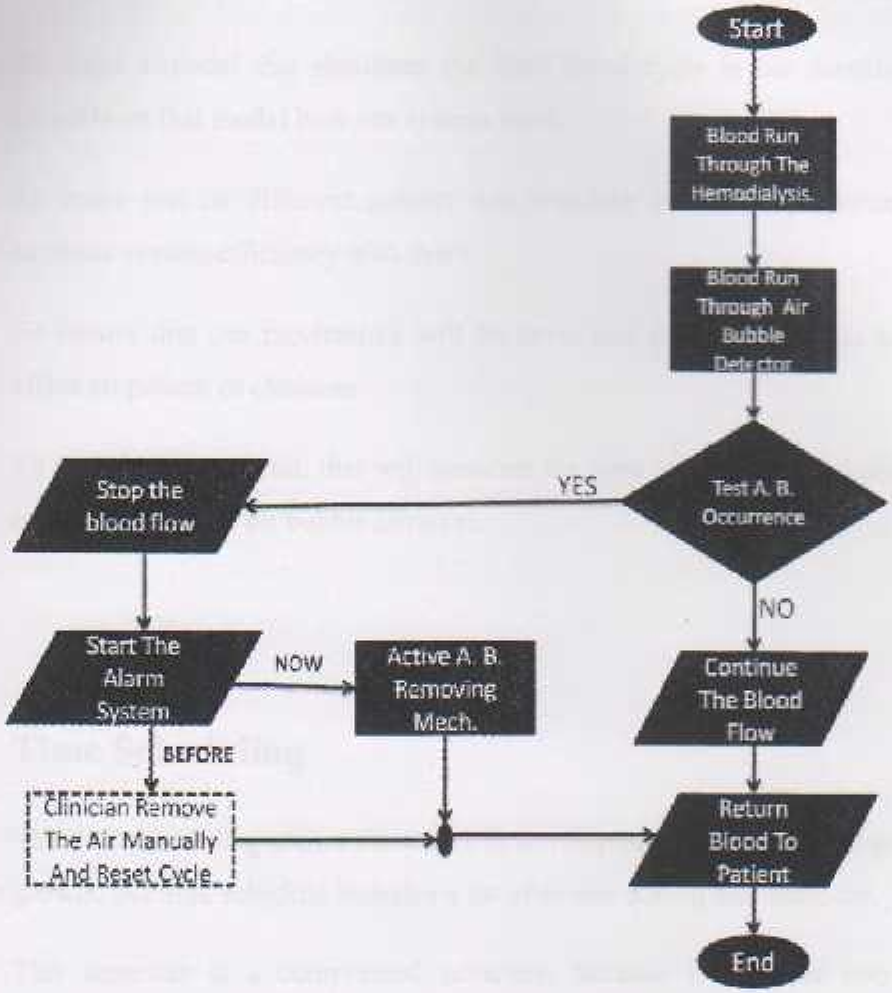


Figure 1-3: Flow of This Project.

The obvious change in the project is by adding a mechanism that simulates the clinician task. This manual task will be converted into simple automated mechanism that will be presented in the next chapter. We should let you know that the cycle in the system is assumed to be stopped.

1.2 Project Objectives:

- Design and build a mechanism that simulate the clinician task automatically, that task is to remove the air bubble from the final blood hose of air bubble.
- To build a model that simulates the final blood cycle in the machine and presents on that model how our system work.
- To make test on different subject that simulate the blood properties and examine system efficiency with them.
- To ensure that our mechanism will be save, and the vibration has no side affect on patient or clinician.
- To build a delay circuit, that will simulate the time needed to accomplish the task of completely air bubble removal.

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 this semester.

This semester is a compressed semester, because it includes two parts theoretical part and practical part. Based on that we must divide the time carefully to cover all objectives and finishing all the tasks. The semester must cover all of requirements that guarantee to complete the entire project in sixteen weeks. The project actions are summarized in ten events.

T1: *Project Preparation and Data Collection*: the first stage of project includes work plan, determining tasks, discussing initial information, and evaluation the project levels and priorities of work. And to start data collection that are required for the project.

T2: *Analysis project and fabricate project idea*: project analysis includes a wide studying and analysis of the available mechanism and to find the best mechanism to complete the task.

T3: *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.

T4: *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.

T5: *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.

T6: *Design each Circuits of Project theoretically*: includes assumptions and determining the values of components, calculations and wanted equations.

T7: *Build and Implement the Project Circuits*: includes repairing the components and measuring the variables.

T8: *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.

T9: *Overall System Testing*: I made tests and connect stages with each other like delay circuit and power supply.

T10: *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 1-2: **Time Schedule in This Semester.**

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1																
T2																
T3																
T4																
T5																
T6																
T7																
T8																
T9																
T10																

1.4 The Idea of the Project

When I took officially this part of the project to solve it and presenting a mechanism to simulate the clinician task, I start seeking around in all neighbored engineering majors" **mechanical, civil, communication…", and if** there is any idea that can be helpful in my case. And by studying and analyzing the project major objective, I conclude that, if I apply a controlled mechanical vibration on the area which could be endanger of forming air bubble, and with help of natural factor that based on differences between Air Emboli and Blood density, where air emboli are less density than blood, that makes them ascend to the top. Unless there are some barriers in their ways. Which are the blood and its component in our study. These barriers will be removed by the mechanical mechanism that we will present in the next chapter.

1.5 Aim of Project

The major aim of this project is to speed up the therapy process of dialysis cycle by saving the wasted time when the cycle is off waiting for the clinician to take the action, and by developing the project idea we save human efforts and awareness while the cycle is running and this project may be useful in case of wars, where the human hand may be unavailable.

1.6 Cost of the Project

In this section we will present the project cost that spent on this part of the project, table 1-2 shows all units, components and mechanical parts that are used and the price for each item.

Table 1-2: Table of Costs.

Items	Number of used parts	Price "$"
Blood tubes set	1	10
El. Wires	10	5
Bread Boards	1	5
Resistors / Capacitors	20/ 10	10
220-9V AC Transformer	1	10
IC's / Bridges / Diodes	3 / 1 / 4	30
DC Motor	2	30
Mechanical parts	5	10
Basement and Housing	1/1	20
test Solutions	5	10
Total	-	140

1.7 Project Risks

Risks of this part of the project summarized in:

- To find a mechanism that simulates the clinician task in short time and to have the ability to build that mechanism on real ground before the semester end.
- Another risk that I need post mechanical learning base such as information and references and due to my specialist of electrical major, I spent some effort to arrange that.
- The working alone was another risk, since there is no supporting partners that can cover you in case of any fault happen.

1.8 Project Scope

This part of the project document consists of five chapters "1, 2, 3 ,4 and 5" arranged as follow to cover all documentation and information that conclude from this project, those chapters arranged as engineering department demand to agree for the gradation permeation. Chapters' titles and what they cover are:

Chapter one: Introduction:

This chapter presents an overview for project idea and how we develop it, aim of the project, objectives, time schedule, implemented project cost and the main risks that we faced.

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: Project Design

This chapter presents the principle of operation for the project. And presents project overall block diagram, the design for each block as single unit and how it works. For some blocks there is some theories have presented to let you understand the basic ideas.

Chapter four: Implementation for the Project and Tests

In this chapter we transfer our blocks, circuit designs and ideas into implemented model that simulate the last stage of the hemodialysis machine and operate it, then we run some experiments and test to examine our project performance.

Chapter five: Conclusion and Future Work

This chapter includes the conclusion and future work that we get from this part of the project.

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

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.

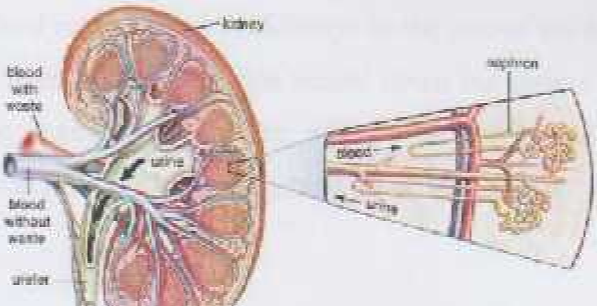


Figure 2-1: Human Kidney and Nephron

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.

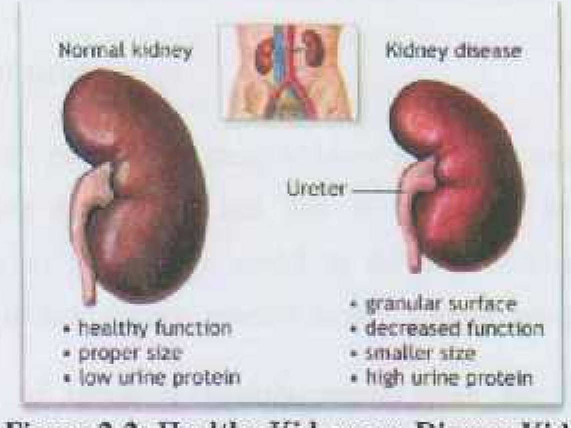


Figure 2-2: Healthy Kidney vs. Disease Kidney

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.

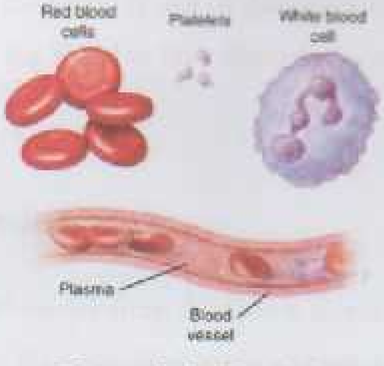


Figure 2-3: Blood Cells

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.

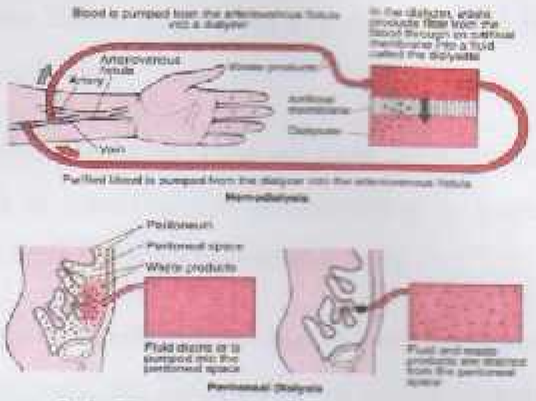


Figure 2-4: Hemodialysis and Peritoneal Dialysis

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".

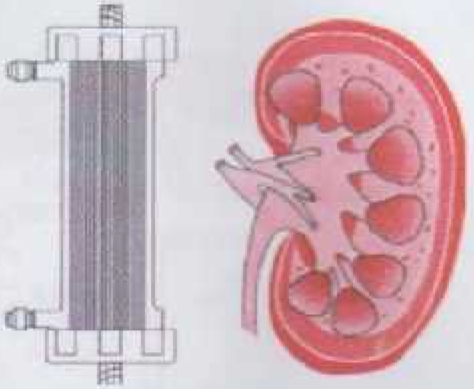


Figure 2-5: Dialyzer

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.

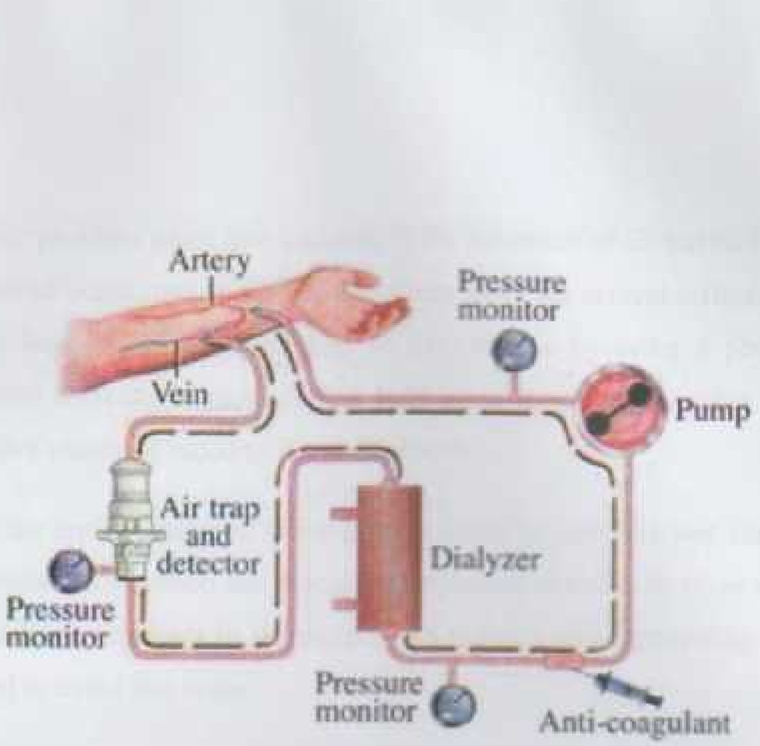


Figure 2-6: Blood Circulation

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.

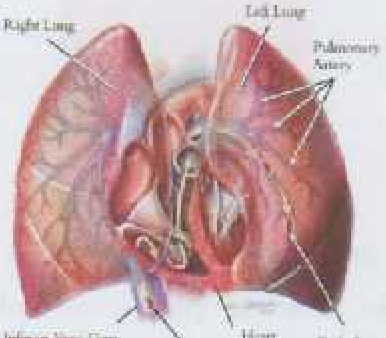


Figure 2-7: Pulmonary Embolism

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

Design and implementation

3. Project Design and implementation

3.1 Block Diagram of the Project.

3.2 Power Supply.

3.3 Circuit of Delay Timer.

3.4 DC Vibration Motors.

3.5 Motor Speed Control and Protection.

3.6 Implementation of the Project.

In this chapter, we will present the project's general block diagram as one single unit, then we will divide the overall block diagram into sub blocks, and explain the circuit design for each block as individual unit and the mechanical design "even theories" in case of some blocks. After that we will assemble the project again as single unit and illustrate it by tracing the signal of the blocks.

3.1 Block Diagram of the Project

Figure 3-1: General Block Diagram

Figure 3-1, shows general design block diagram for the project, which consists of four sub stages. Begin with DC power supply circuit that feed all other circuits with energy. After that there is a timing circuit to operate the next stage for desired time. Then comes the final two blocks of DC motor and its speed controlling circuit.

3.2 Power Supply

This block diagram referred to the electrical **circuit's** design that feed the system with the desired DC input voltage. The designed system need to be operated with 5 Volt DC input. This voltage is supplied from the circuit shown in figure 3-2.

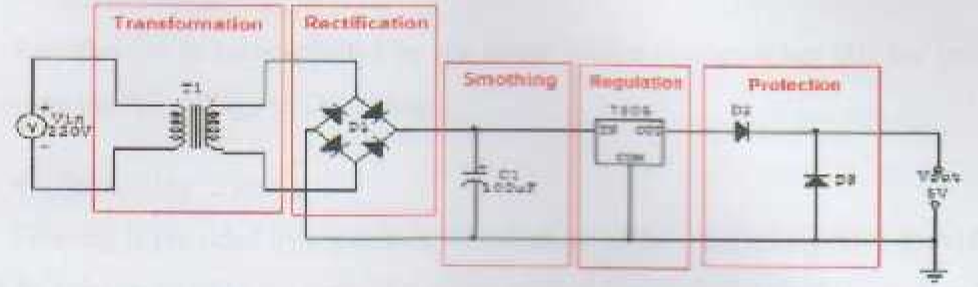


Figure 3-2: power Supply Design.

Before start designing and implementing this part, I tried in the first to use the previous power supply circuit existed in previous project, that my partner implemented in the past semester, but the output voltage for that circuit doesn't match this part of the project requirements, thus come the need to implement this circuit and specify it with this part requirements.

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

- Transformation.

Transformation is accomplished by the transformer (T1) steps down the 220 volts to 9 volt AC, the rms value of the output transformer is 9.1v that means we used the step down transformer with ratio 24:1.

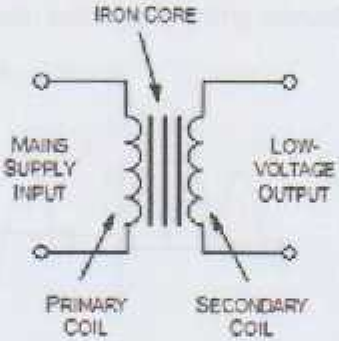


Figure 3-3: The Compensation of the Transformer

- Rectification.

Rectification is accomplished by the diode bridge configuration D1, the bridge converts the AC voltage to DC voltage.

- Smoothing "Filter".

Filtering is provided by capacitors C1 which level the rectified signal to provide a flat dc voltage equal to the peak of the un-rectified signal. Some ripple occurs on the signal and this is a function of the load and the size of the capacitor.

- Regulation.

The function of the regulator 7805 is to provide a constant output voltage. The input voltage required to maintain desired output of the regulator must be greater than line regulation of the regulator, regulator output equal to 5Volt pure DC.

- Protection.

This part consists of D2 and D3 diodes. D2 function is to protect from reversed back currents, while D3 function is to insure the output will be +5 volt in the output node.

Figure 3-4 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 step-down transformer, the third wave is the output of the full wave rectifier, the forth come after using smoothing capacitor and the final stage comes after the regulators.

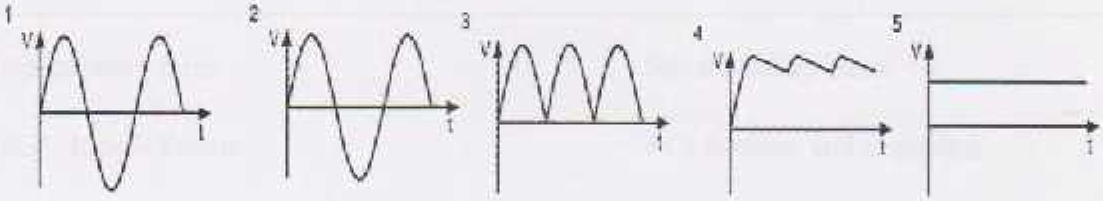


Figure 0-4: Output waveform for each stage.

The ratio between primary and secondary is:

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} \qquad \text{Eq. 3-1}$$

$$\frac{V_P}{V_S} = \frac{220}{9} = 24$$

Turn ratio between primary and secondary is about 24:1.

$$V_S = \frac{220}{24} = 9.1\ V_{rms}$$

$$V_{s,peak} = V_S\sqrt{2} = 9.1 \times \sqrt{2} = 12.8\ V$$

$$V_{rec} = V_{s,peak} - 1.4 = 12.8 - 1.4 = 11.4\ V$$

But we need the DC Voltage 5V

$$RF = \frac{1}{\sqrt{2}(4fRC-1)} \qquad \text{Eq. 3-2}$$

$$V_{DC} = V_{s,peak} - \frac{V_{s,peak}}{4fRC} \qquad \text{Eq. 3-3}$$

$$RC = \frac{V_{s,peak}}{4f\,(V_{s,peak} - V_{DC})} = \frac{12.8}{4\times 50(12.8-5)} = .0082$$

$$\therefore\ RF = \frac{1}{\sqrt{2}(4\times 50\times .0082-1)} = .011\ \%$$

Np: primary turns

Ns: secondary turns

R.F.: Ripple Factor

RC: Resistor and Capacitor

f: Frequency

3.3 Delay Timer Circuit

This block contain the circuit used to get the system DC motors operate for the desired time, but first what is the desired time and why we use this circuit?

When air bubbles formed in the blood line, the system stopped by blood flow cutting circuit, the clinician must chick the machine cycle and removes the air bubble by hand shaking and knocking manual method. Since this process what we need to simulate in this project, so we need a timing circuit that operate the motors for desired calculated time. This time after field research and clinician observation found to be about 10-15 seconds. Figure 3-5 show timing circuit that will satisfy our need.

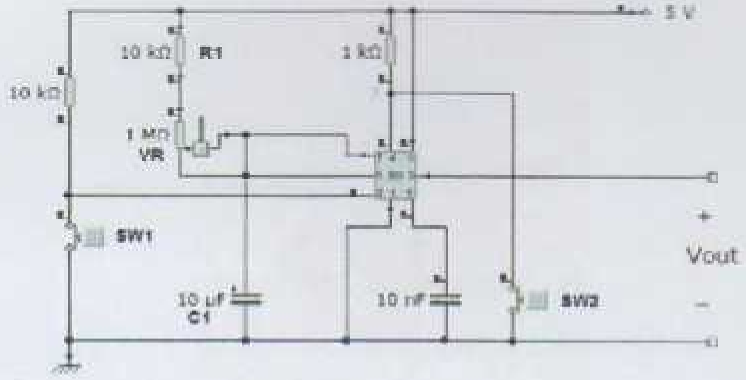


Figure 3-5 Timing Circuit

We use LM555 IC timer in monostable operation mode to get the output 5 Volt DC for 10 second time delay as shown in figure 8-6.

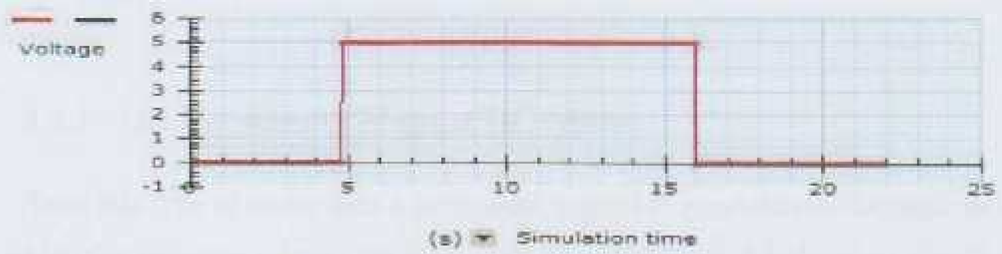


Figure 3-6: Output from Timer.

The time delay T in seconds is:

$$T = 1.1 \times C1 \times (R1 + VR) \qquad \text{Eq. 3-4}$$

$$T = 1.1 \times 10\mu F \times (10\,K + VR) \cong 12s$$

Switch SW1 for simulating the triggering signal that comes from the sensor, since I couldn't get a signal from the first air bubble detector part of the project.SW2 stated for rest the signal in case of any fault.

3.4 DC Vibration Motor

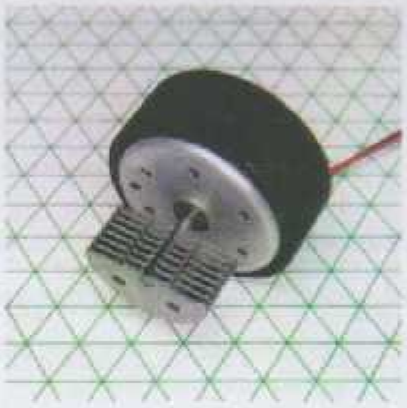


Figure 3-7 DC Motor with Unbalanced Load.

Figure 3-7; represents a permanent magnetic field DC motor. We need to review some theoretical basics about the used DC motor and the analysis for the mechanism used in a brief way. Then we will move illustrate how this mechanism will be useful in our case.

3.4.1 The Permanent Magnet DC Motor

Since this type of motor uses a permanent magnet to generate the magnetic field in which the armature rotates, the motor can be modeled by the electrical circuit in the armature alone. If we further simplify the circuit by ignoring the inductance of the armature coil, draw the following circuit diagram for a simple motor. See figure 3-8.

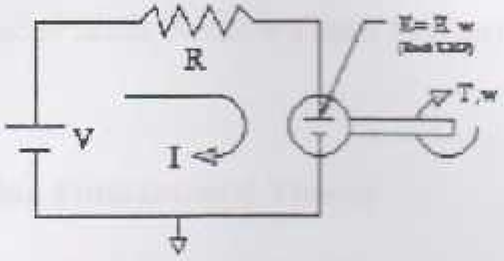


Figure 3-8 Equivalent Electrical Circuit

V is the voltage supplied by the power source (usually a battery), and R is the resistance of the motor's armature coil. This resistance cannot be measured at rest, since it changes as speed increases towards the steady state speed. Kirchoff's voltage law leads to the following equation:

$v = IR + E$ Eq. 3-5

By examining the effect of the magnetic field in the motor, and realizing that magnetic flux is constant, we can arrive at the following two equations relating the torque and speed output of the motor to the supplied current and voltage:

$E = K_v \times w$ Eq. 3-6

$T = K_m \times I$ Eq. 3-7

These are often known as the transducer equations for a motor, since a motor is really an electro-mechanical transducer. The constants Kv and Km are dependent on the particular motor, but if they are expressed in SI UNITS, their values are always equal, thus

$w = \left(\frac{V}{K}\right) - \left(\frac{R}{K^2}\right) T$ Eq. 3-8

It is important to remember that, in this equation, T is the total torque acting on the motor, and is generally non-zero even with no applied load, due to the internal loss in the motor. This equation implies that the speed of the motor is equal to some constant, which is a function of the applied voltage and the motor constant, minus another constant times the applied torque. This is an important relation, since it reveals that for this motor model, Torque is a linear function of speed.

3.4.2 Vibration Fundamental Theory

This section covers fundamental theory and useful equations.

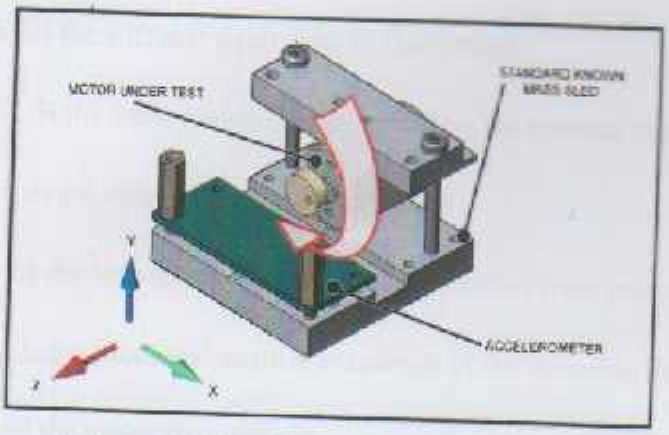
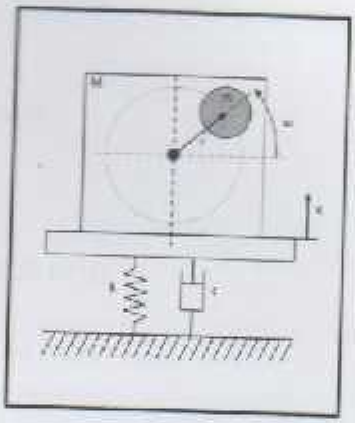


Figure 3-10 3d illustration



3-11 2d illustration

In illustration above figure 3-10, 3-11the motor is orientated to vibrate in the X and Y planes. As the eccentric mass rotates, it experiences a centripetal force, which in turn exerts a centrifugal force on the sled. The diagram to the right shows the simplified 1-dimensional (DOF) rotating unbalance spring-damper model which approximates an object excited by a vibration motor. The formulas below describe the motion and generated force based on this model:

$$M\ddot{x} + C\dot{x} + Kx = (mrw^2).\sin wt$$ Eq.3-9

$$F_{0=mrw^2}$$ Eq. 3-10

Where:

$\ddot{x}$:Is the sled acceleration.

$\dot{x}$:Is the sled velocity.

x :Is the sled displacement from equilibrium

M :Is the non-eccentric mass including the sled and motor.

C :Is the linear damping constant.

K :Is the stiffness equivalent of the system.

F_0 :Is the force magnitude generated by the rotating unbalance

m :Is the mass of the eccentric weight

r :Is the eccentricity (centre of gravity offset from motor shaft axis)

w :Is the rotational angular frequency of the eccentric mass in rad/s

And the motor frequency is:

$$f = \frac{w}{2\pi} \qquad \text{Eq. 8-8}$$

The vibration response of an object being driven by an oscillating force using this general vibration model is significantly affected by the mass, damping and spring rate characteristic for every application. For a steady-state condition; after the system vibration has settled to a constant vibration, the displacement amplitude of the vibrating body can be approximated with the following formula:

$$X_{max} = \frac{F_0}{k} \cdot \frac{1}{\sqrt{\left[1-\left(\frac{w}{w_n}\right)^2\right]^2+\left[2\zeta\left(\frac{w}{w_n}\right)\right]^2}}$$

Where:

w_N is the angular frequency at resonance of the system

ζ is the damping ratio of the system (<1 for underdamped, >1 for overdamped).

The figure 3-11 below shows graph for the relation between motor parameters.

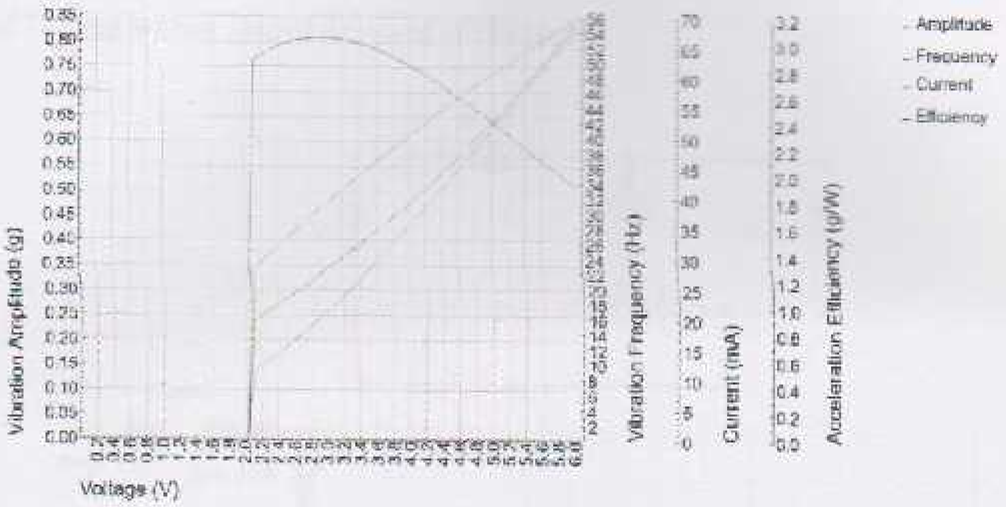


Figure 3-11 The Relation Between Motor Parameters

Based on the previous information and some approximation from previous two sections, we found our objective could be accomplished, if use this vibrated DC motor with its unbalanced mechanism to generate desired vibration.

3.5 Motor Speed control and protection

After deciding to use this motor, it's necessary now to build a driving circuit for this motor to control it and avoid burning this motor, or burning previous circuit if the motor consume maximum current than allowed.

Since we choose permanent magnetic DC motor, which is have fixed magnetized field and the flux is **fixed, therefore, it's not possible to control the speed** by varying the field current or flux. The only methods of speed control available for motor are **armature voltage control "this method will not be used"** or **armature** resistance control. The second method will be used. This method is achieved by adding a variable resistance that has a good value in series with motor armature resistance, so we can control the armature current by adding variable resistance, which control the speed of motor, see figure 3-12. That shows if we change the value of 1K ohm we can control the speed of this motor.

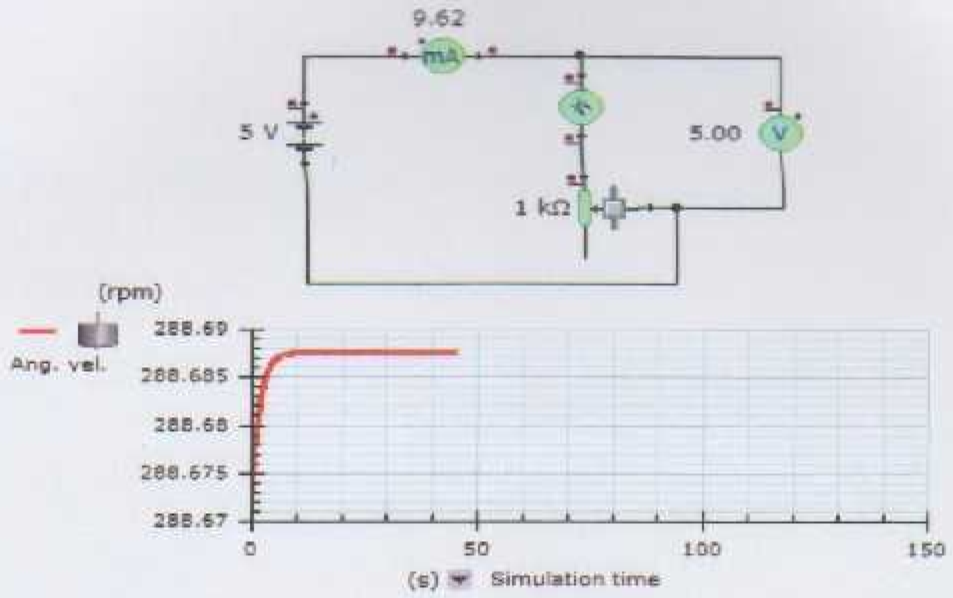


Figure 3-12. Speed control circuit

This variable resistance also used to prevent the motor form sucking more un allowed current from the source that may be danger on other part of the project, so it's considered as protection circuit too.

After finishing each block function and design, now we need to assemble the project again and briefly trace the flowing of the it.

First, a signal is generated from the sensor to indicate the occurrence of air emboli, this signal we but instead for it a bush button triggering switch that will simulate the on trigger from sensor when we need, this signal activate a delay timer circuit that simulate the necessary time to remove the air bubble as tested, the output of the timer circuit is active high DC pulse, that will run DC vibration motor for about 15s, the speed of the motor can be controlled by a potentiometer as it requires.

Chapter four

Implementation for the Project and Tests

4. System Implementation and Testing

4.1 Power Supply Build.

4.2 Delay Timer circuit build.

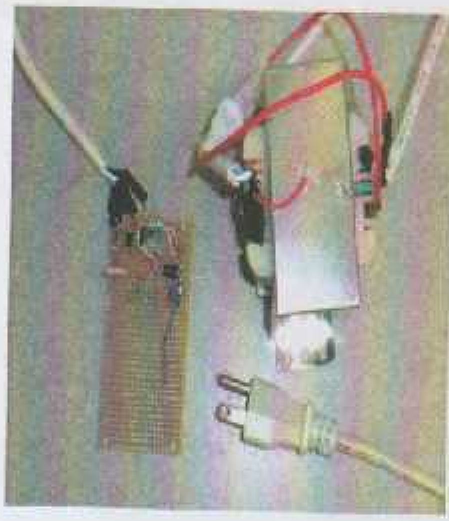
4.3 Assemble the Project.

4.4 Experiments on Project.

In this chapter we are going to transfer all designed circuits and models on real ground. The implementing for each unit will be separated, and after testing that block and insure it get its function as needed, it will assembled with other parts to build the model as one unit. After gathering the project parts, some tests and experiments will be done to increase the project efficiency and getting the final conclusion and recommendations of the project.

4.1 Power Supply Build

Based on the previous calculation we start building this circuit, I used a transformer with the transforming ratio 24:1, so the AC voltage stepped down to 9 volt AC, the maximum current for this transformer is 500mA, so it supplies our motors with the desired input, after transformer choosing, other parts are simple and doesn't affect the flow of the project. Figure 4-1 and figure 4-2 shows the power supply and its output voltage.



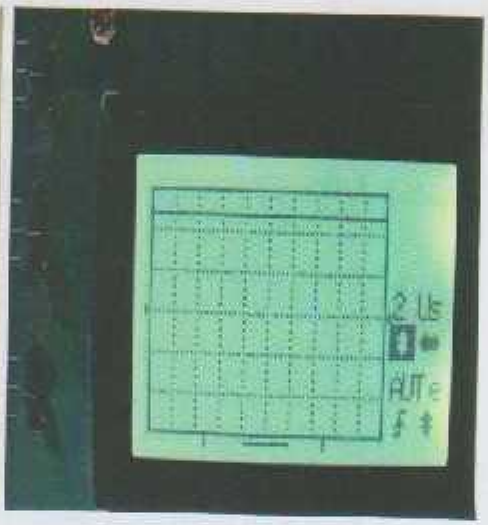


Figure 4-1 power supply **figure 4-2 pure 5 Volt output**

4.2 Delay Timer circuit build

By gathering all final stage requirements, which include the working delay time for the motor circuit and by calculating the flowed maximum currents for the motor, which doesn't exceed 160mA and the easy build for this circuit, we conclude that the IC LM555 precision timer, "see figure 4-3 for leg configuration" is suitable for our design.

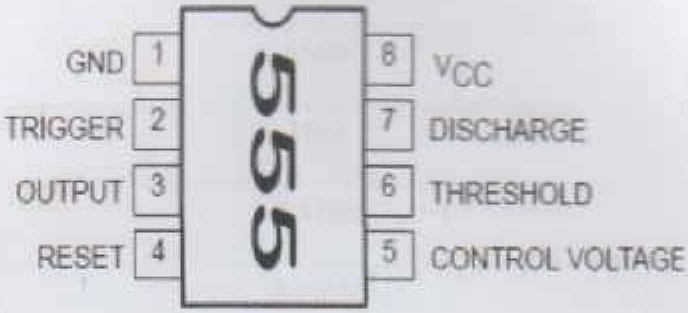


Figure 4-3: LM555

The delay time for this circuit can be driven easily by the potentiometer. See figure 3-5 form previous chapter. Figure 4-4 below shows the circuit on real ground.

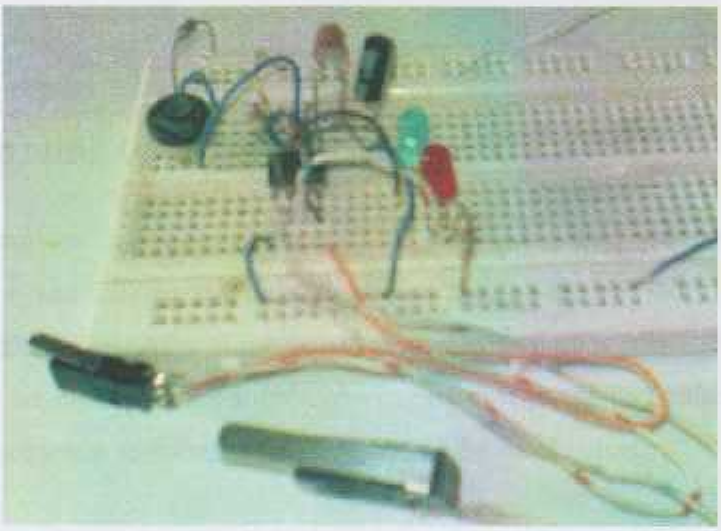


Figure 4-4: Delay Circuit

PARTS LIST USED IN THIS CIRCUIT	
R1	1KΩ
R2	10KΩ
R3	1KΩ
R4	1KΩ
VR1	1MΩ
C3	10µF
C2	0.01µF
IC1	LM555
SW1	PUSH TO ON SWITCH (FOR START)
SW2	PUSH TO ON SWITCH (FOR RESET)

4.3 Assembling the Project

In this part we assemble all parts of the project together as a single unit to start operating it and making testing with it. See figure 4-5 that shows the overall system schematic design. After finishing this part, the project is ready now to work, but before that we need to make some experiments to it to see its performance, and to add some mechanism to increase performance of the mechanism.

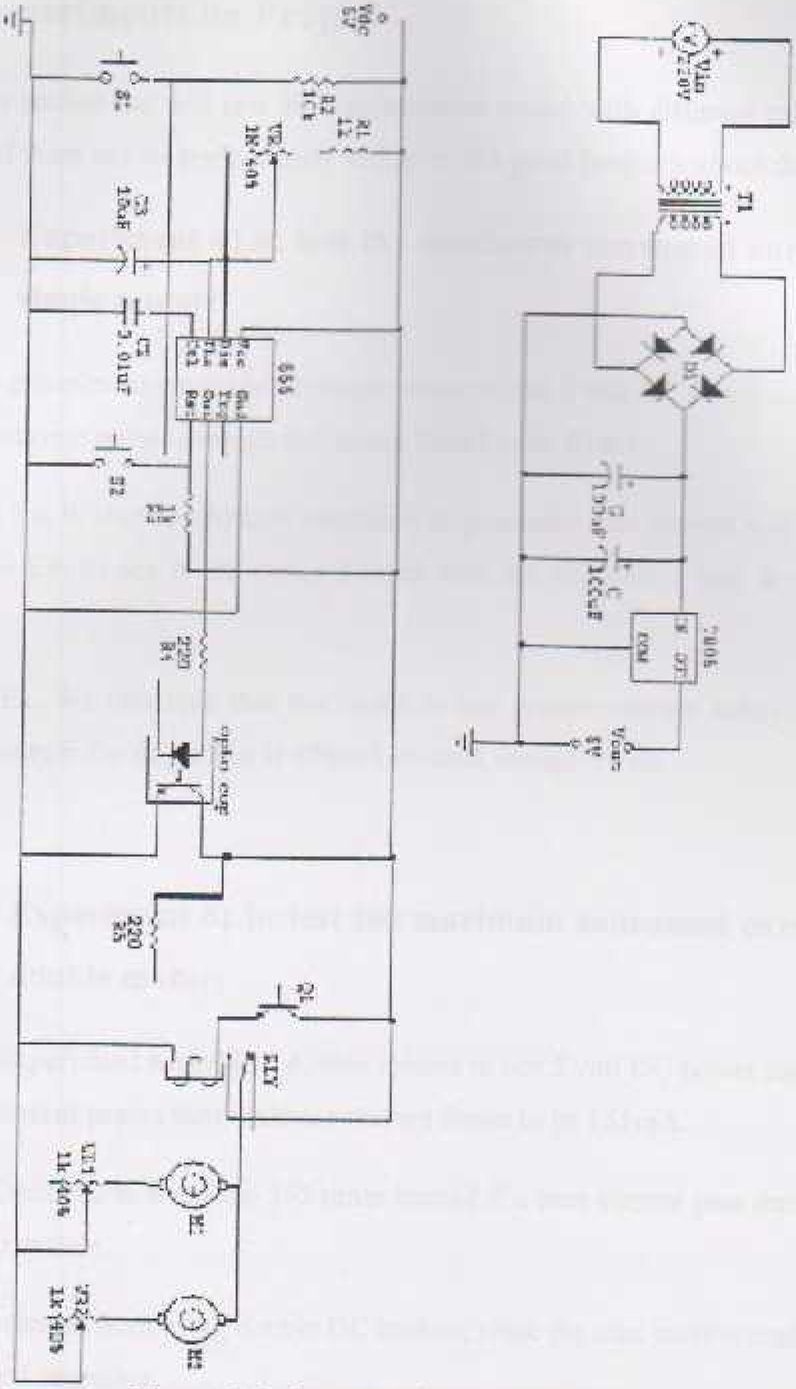


Figure 4-5: System schematic diagram

4.4 Experiments on Project

In this section we will test the implemented model with different experiments, each one of them has its goals, which will give us a good feedback about the system.

4.4.1 Experiment #1.a: test the maximum consumed current for single motor:

In this experiment we subject a single motor to our 5 volt DC power supply. The maximum current passes through this motor found to be **82mA.**

We do this Ex. Without protection resistance to guarantee max current will pass. The goal of this Ex. to see if the motor burned with the supplied 5 volt at maximum current.

From this Ex. We conclude that the motor in our system operate safely, since the max. start current for this motor is **170mA** at rated voltage **5Volt.**

4.4.2 Experiment #1.b: test the maximum consumed current for double motor:

In this experiment we subject double motors to our 5 volt DC power supply. The maximum current passes through those motors found to be **161mA.**

The goal of this Ex. to see if the 555 timer burned if a max current pass through it to feed the two motors.

There is no danger from using double DC motors, since the max current could be **200 mA** at normal operating.

4.4.3 Experiment #2: speed control of the motor at fixed load:

In this Ex. we use the controlling circuit that consists of 1K ohm variable resistance.

The goal of this Ex. is to see the relation between current, resistances and when motors start to rotate. After making the Ex. we generate the following table:

Resistance / ohm	Current / mA	rotating
1 000	0	No
500	10	No
60	33	Begin rotating
55	39	Slow rotating
0	83	Full speed rotating

We found that the motor start to rotate at 33 mA.

4.4.4 Experiment #3: load increase affects:

In this Ex. we increase the load here to test what the best stretching point for the motors that will help removing the bubbles in best smoothest way.

From this Ex. we find that if the motor and the load were stretched to each other Rigidity, we will have the best ability to remove the air bubbles.

4.4.5 Experiment #4: testing a foaming material:

In this Ex. we make a test on soaping material **"washing soap" to chick of the** vibrated mechanism will have disadvantage of foaming bubbles.

After finishing this Ex. we found that no side bubbles have formed.

4.4.6 Experiment #5: testing the bubble size and the position for that bubble:

In this Ex. we subject our model to different bubbles size for different material, and we will test the bubble position and how it will affected by the distance between it and the center of the motor vibration for.

The resulted table from this Ex. is shown below:

Diameter of the tube = 5mm							
	Bubble size mm			Bubble distance cm			Bubble forming
substance	0.5<X	0.5<X<2	2<X<5	X centered	1<X<2	X>2	
Pure water	Y	Y	S. TIME	Y	Y	N	N
Salt water	N	Y	N	Y	Y	N	Y
Sugar water	Y	Y	Y	Y	Y	Y	N
Inked water	Y	Y	Y	Y	Y	Y	N
Mango juice	Y	Y	Y	Y	Y	N	N
Apple juice	Y	Y	Y	Y	Y	Y	N
yogurt	Y	Y	N	Y	N	N	N
oil	N	N	Y	Y	N	N	YES

We conclude that our system passes for most liquid material with different density.

We are not able to test blood because the sample is not available.

Chapter Five

Conclusion and Future Work

5. Conclusion and Future Work

   5.1 Conclusion.

   5.2 Recommendations and Future Work.

5.1 Conclusion

According to my study and work design through this project, there are many important conclusion become clear and significant and must be mentioned, those conclusion are:

- We build a model which has a mechanism that simulates the human job performed with this part of the machine.
- After making Experiments and test on this model part of the machine, we can say that our project is achieve its objective and goal by a good percent.
- This project and any other simulating project can't ever replace the clinician observation for the operated machine and patient, and the presence of specialist is highly recommended even if his job only observation.
- To increase the model performance we can design it with manufacturing ability that give us a design for this purpose.
- We can increase the air bubble removing by adding a third motor, but this step consume extra power which could be danger on other circuit.

5.2 Recommendations and Future Work

After finishing this part of the project and studying the previous part conclusion, we recommend the follow:

- This project can be much better and have more powerful side and logic if it's designed with programmable integrated computer "PIC", which I couldn't do because of shortage of time.
- The Hemodialysis Machine is a device with a wide range of development, since a lot of its process based on human effort to complete the therapies.
- If any group need to work with this filed, I recommend them to work in cooperation with hospital, where they can run their machine in real ground

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20. http://www.lh-electric.4t.com/vtpsupply.htm, Saturday – 21/5/2011 – 6:25 PM.

21. http://nptel.iitm.ac.in/courses/Webcoursecontents/IIT%20Kharagpur/Industrial%20Automation%20control/pdf/L09(SS)(IA&C)%20((EE)NPTEL).pdf, Thursday – 24/5/2011 – 12:30 AM.

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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.
Nephrons	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, 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.
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.
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.

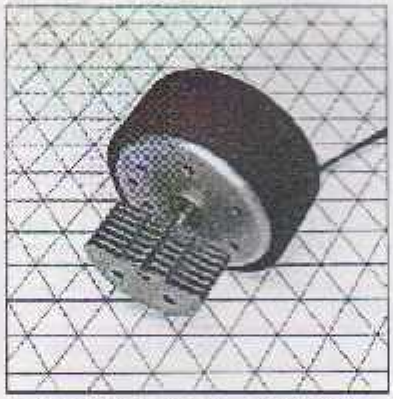
Appendix: B

Programs

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

Appendix: c

Datasheet



24mm Vibration Motor - 12mm Type
Shown on 6mm Isometric Grid

PRECISION MICRODRIVES™

Product Data Sheet
Uni Vibe™
24mm Vibration Motor
12mm Type
Model: 324-102

Ordering Information

The model number 324-102 fully defines the model, variant and additional features of the product. Please quote this number when ordering.
For stocked types, testing and evaluation samples can be ordered directly through our online store.

Datasheet Versions

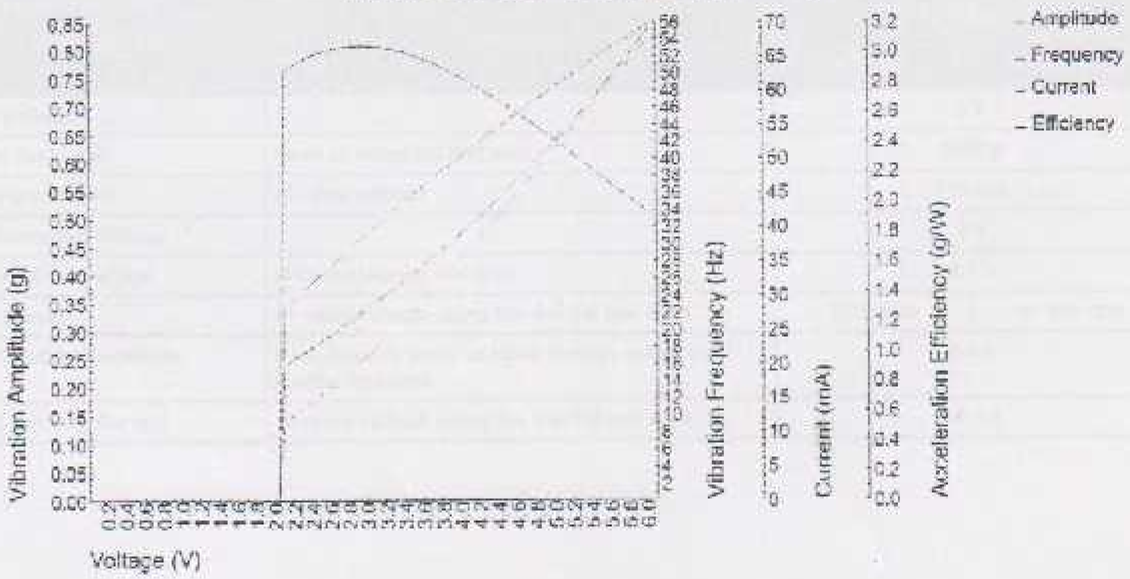
It is our intention to provide our customers with the best information available to ensure the successful integration between our products and your application. Therefore, our publications will be updated and enhanced as improvements to the data and product updates are introduced.
To obtain the most up-to-date version of this datasheet, please visit our website at:
www.precisionmicrodrives.com
The version number of this datasheet can be found on the bottom left hand corner of any page of the datasheet and is referenced with an ascending R-number (e.g. R0002 is newer than R0001). Please contact us if you require a copy of the engineering change notice between revisions.

If you have any questions, suggestions or comments regarding this publication or need technical assistance, please contact us via email at:
enquiries@precisionmicrodrives.com or call us on +44 (0) 1932 252 482

Key Features

Body Diameter:	24.4 mm
Body Length:	12.4 mm
Typical Operating Current:	56 mA
Typical Power Consumption:	280 mW
Typical Vibration Amplitude:	0.6 G
Typical Normalised Amplitude:	5 G
Rated Voltage:	5 V
Rated Speed:	2800 rpm
Lead Length:	80 mm
Lead Wire Gauge:	30 AWG
Lead Configuration:	Straight

Typical Vibration Motor Performance Characteristics



Physical Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Body Diameter	Max body diameter or max face dimension where non-circular	24.4 mm	+/- 0.2 mm
Body Length	Excl. shafts, leads and terminals	12.4 mm	+/- 0.2 mm
Unit Weight		28.9 g	
Counterweight Radius	Radius from shaft for non-cylindrical weights	9 mm	+/- 0.2 mm
Counterweight Length		8.5 mm	+/- 0.2 mm

Construction Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Motor Construction		Iron Core	
Commutation		Precious Metal Brush	
No. of Poles		3	
Bearing Type		Sintered Bronze	
No. of Output Shafts		1	
Shaft Orientation		Inline	

Leads & Connectors Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Lead Length	Lead lengths defined as total length or between motor and connector	80 mm	+/- 2 mm
Lead Strip Length		2.5 mm	+/- 0.5 mm
Lead Wire Gauge		30 AWG	
Lead Configuration		Straight	

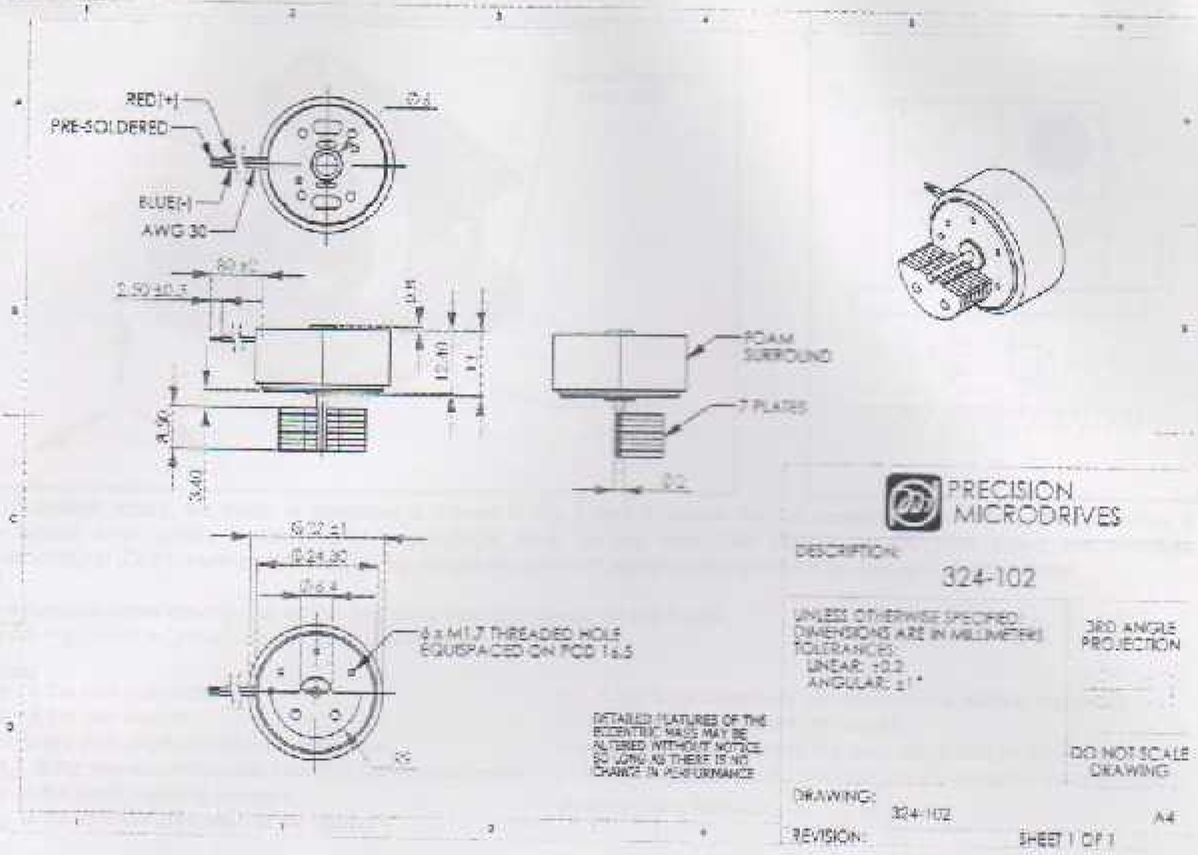
Conformity Limits Specification

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Rated Voltage		5 V	
Inertial Test Load	Mass of standard test sled	1000 g	
Max. Start Current	At rated voltage	170 mA	
Max. Operating Voltage		6 V	
Certified Start Voltage	With the inertial test load	2.7 V	
Rated Speed	At rated voltage using the inertial test load	2800 rpm	+/- 560 rpm
Min. Vibration Amplitude	Peak-to-peak value at rated voltage using the inertial test load	0.4 G	
Max. Operating Current	At rated voltage using the inertial test load	68 mA	

Typical Packing Conditions

PARAMETER	CONDITIONS	SPECIFICATION	
		VALUE	TOLERANCE
Carton Type		Boxed Trays	

Product Dimensional Specification



Life Support Policy

PRECISION MICRODRIVES PRODUCTS ARE NOT AUTHORISED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF PRECISION MICRODRIVES LIMITED
As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.

2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

Precision Microdrives Limited

Canterbury Court, 1-3 Brixton Road
London
SW9 6DE
United Kingdom

Tel: +44 (0) 1932 252482
Fax: +44 (0) 1932 325353
Email: enquiries@precisionmicrodrives.com
Web: www.precisionmicrodrives.com

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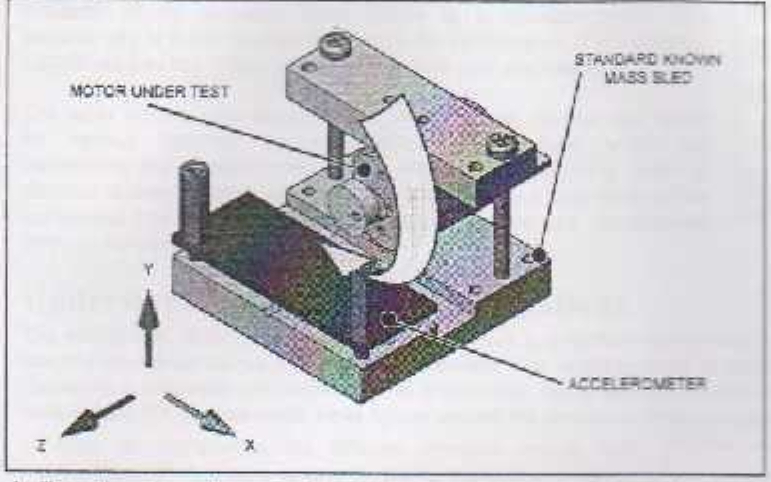
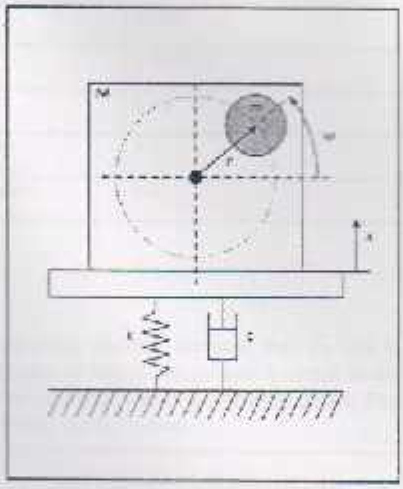
VAT registration. GB 900 1238 84

Vibration Fundamental Theory

A more in-depth guidance can be found on our website www.precisionmicrodrives.com. This section covers fundamental theory and useful equations.





In illustration above, the motor is orientated to vibrate in the X and Y planes. As the eccentric mass rotates, it experiences a centripetal force, which in turn exerts a centrifugal force on the sled. The diagram to the right shows the simplified 1-dimensional (DOF) rotating unbalance spring-damper model which approximates an object excited by a vibration motor.

The formulas below describe the motion and generated force based on this model:

$M\ddot{x} + c\dot{x} + kx = (mr\omega^2)\sin\omega t$ and $F_0 = mr\omega^2$

where

- $\ddot{x}$ is the sled acceleration
- $\dot{x}$ is the sled velocity
- x is the sled displacement from equilibrium
- M is the non-eccentric mass including the sled and motor
- c is the linear damping constant
- k is the stiffness equivalent of the system
- F_0 is the force magnitude generated by the rotating unbalance
- m is the mass of the eccentric weight
- r is the eccentricity (centre of gravity offset from motor shaft axis)
- ω is the rotational angular frequency of the eccentric mass in rad/s

and the motor frequency is: $f = \frac{\omega}{2\pi}$

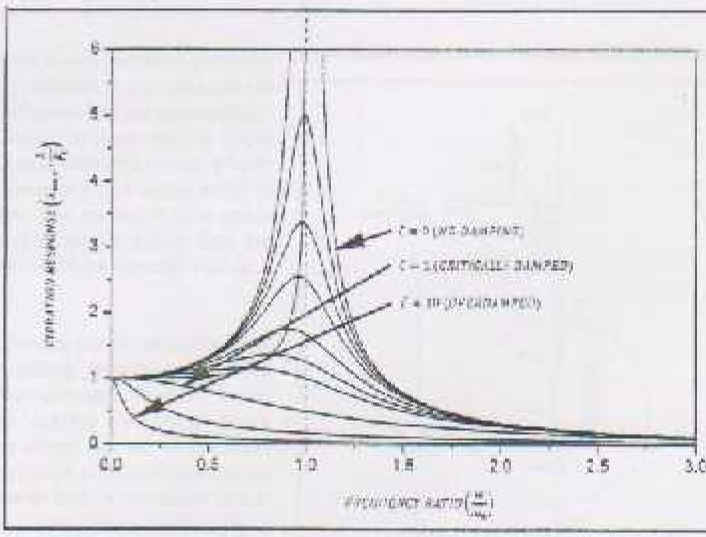
The vibration response of an object being driven by an oscillating force using this general vibration model is significantly affected by the mass, damping and spring rate characteristic for every application. For a steady-state condition; after the system vibration has settled to a constant vibration, the displacement amplitude of the vibrating body can be approximated with the following formula:

$$X_{max} = \frac{F_0}{k} \cdot \frac{1}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta\left(\frac{\omega}{\omega_n}\right)\right]^2}}$$

where

- ω_n is the angular frequency at resonance of the system
- ζ is the damping ratio of the system (<1 for underdamped, >1 for overdamped)

The chart on the right shows the vibration response from the model with different damping ratios and across the frequency range. The response is influenced greatly at resonance where the frequency ratio is 1.



The excitation required to drive the vibration at steady-state is balanced by the energy lost from the system through damping. With damping present, the force-displacement relationship will represent a hysteresis loop proportional to the energy lost per cycle.

Based on an idealised viscous damping model, the energy dissipated per cycle can be simplified to the following formula:

$W_d = \eta\pi k X^2$

where

- η is the equivalent damping loss factor
- W_d is the energy dissipated per cycle

and the power is: $P = W_d \cdot 2\pi\omega$

Typical Approximate Values

The formulas from the previous page is based on a simplified theoretical model of the behaviour of a discreet object under the influence of an oscillating force similar to a vibration motor. The practical use of these forumlas to estimate the performance of our vibration motors requires key unique characteristics from your application.

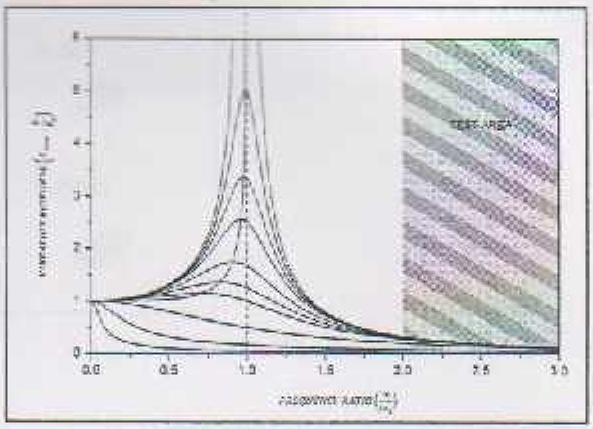
The table on the right shows a few typical values for the loss factor for various materials as a guidance for materials which are transmitting the vibration from the vibrating motor. Damping ratios of vibration isolated systems typically vary from 0.05 to 0.3 depending on the application. The stiffness of the system is the force per unit displacement (N/m) of the vibrating system.

Material	Approximate Loss Factor
Metals	<0.001
ABS	0.01-0.02
PA	0.03
Neoprene	0.1
Butyl Rubber	0.4

Understanding Vibration Specifications

The testing sled shown on the previous page shows a simplified view of one of our calibrated vibration test-sled that we use to produce the typical figures printed in this datasheet. The vibration motor is secured to a sled of known weight and a circuit board containing a calibrated accelerometer and preamplifier, feeds test signals into one of our computer controlled testing suites. Our software and QA process check these figures against the conformity limits, as well as producing typical values.

In order to characterise the different vibration motors with representative performance values, the testing platform is designed with a very low resonance frequency and damping. The low resonance frequency allows the motors to be tested without significant impact from the resonance response of the system.



The area shown on the chart on the right indicates the ideal test area for characterising the motor. The test frequency should be greater than double the system frequency.

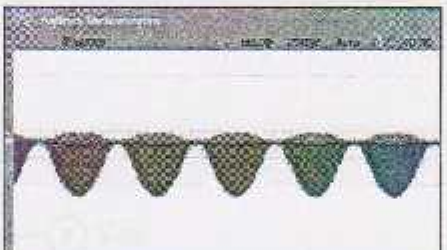
Using this set up, the governing model can be simplified for the test condition as follows:

$$\frac{1}{2} Ma = \frac{E\omega^2}{g_0}$$

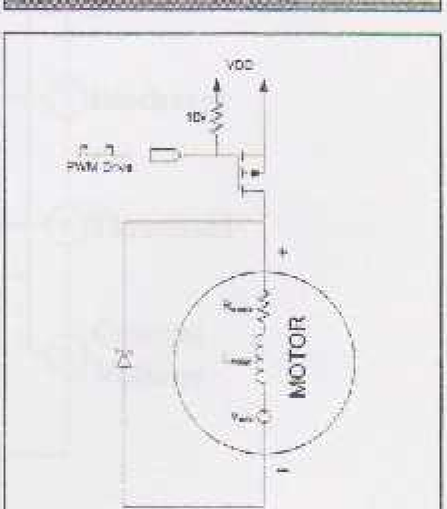
where

M is the total system mass (eccentric mass << total mass)
a is the vibration acceleration (peak-to-peak) in 'G's
E is a motor specific constant (mass of the eccentric weight x eccentricity)
ω is the motor speed in rad/s
g_0 is the standard gravity (9.807)

Products are QA passed if they meet the conformity limits (both electrical and mechanical) shown on page 2 of this datasheet. Typical values, shown on page 3 of this datasheet can vary between manufacturing batches and operating conditions, and should only be used as guidance.



The minimum level of vibration which most healthy humans can perceive on naked skin is 0.04 G . Since the force that the vibration motor generates at a given speed is fixed, increasing the mass of the vibrated object will decrease the net acceleration, and reduce the chance of it being perceived. Ergo, larger devices require larger vibration motors. Additionally, the vibration energy dissipated from the vibrating body is balanced by the excitation energy from the motor. Consider that a motor which is tightly clamped to a hard surface, e.g. a desk, will draw less current than a motor that is held by hand. In the latter, the vibration energy dissipated is higher than the desk and the current draw for the desk-clamped motor would be typically half or a third that of the hand held motor.



The typical values presented include time constants taken for the vibration motor to start and stop. These can be useful to consider, as a pulsing vibration is generally perceived to be more effective at attracting attention than constant vibration. These time constants determine the practical limits of the pulsing frequency. Some applications can also benefit from modulated vibration where one varies the drive signal (e.g. pulse-width-modulation) in such a way to create an amplitude-modulated vibration, as shown right. This oscilloscope plot was taken from a massager which we designed, and the PWM signal was generated from a sine look-up table inside a microcontroller. The drive circuit used by this application is typical and shown right. It consists of a high-side MOSFET driven by a microcontroller and a Schottky diode across the meter to offer protection from the motor's inductive element.

LM555
Single Timer

Features

- High Current Drive Capability (200mA)
- Adjustable Duty Cycle
- Temperature Stability of 0.005%/°C
- Timing From µSec to Hours
- Turn off Time Less Than 2µSec

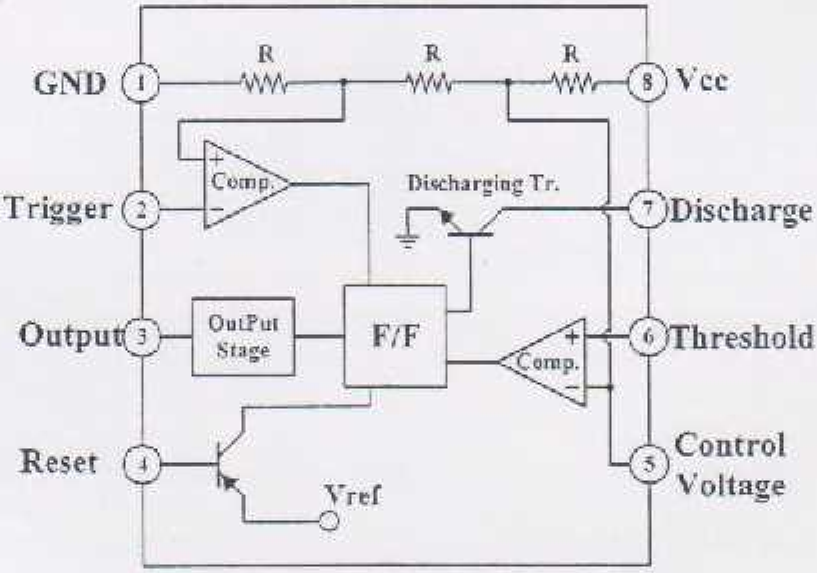
Applications

- Precision Timing
- Pulse Generation
- Time Delay Generation
- Sequential Timing

Description

The LM555 is a highly stable controller capable of producing accurate timing pulses. With a monostable operation, the time delay is controlled by one external resistor and one capacitor. With an astable operation, the frequency and duty cycle are accurately controlled by two external resistors and one capacitor.

Internal Block Diagram



Rev. 1.0.4

Absolute Maximum Ratings (T_A = 25°C)

Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	16	V
Lead Temperature (Soldering 10sec)	T_{LEAD}	300	°C
Power Dissipation	P_D	600	mW
Operating Temperature Range (LM555)	T_{OPR}	0 ~ +70	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

Electrical Characteristics

(TA = 25°C, VCC = 5 ~ 15V, unless otherwise specified)

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply Voltage	VCC	-	4.5	-	16	V
Supply Current (Low Stable) (Note1)	ICC	VCC = 5V, RL = ∞	-	3	6	mA
		VCC = 15V, RL = ∞	-	7.5	15	mA
Timing Error (Monostable) Initial Accuracy (Note2) Drift with Temperature (Note4) Drift with Supply Voltage (Note4)	ACCUR Δt/ΔT Δt/ΔVCC	RA = 1kΩ to100kΩ C = 0.1μF	-	1.0 50 0.1	3.0 0.5	% ppm/°C %/V
Timing Error (Astable) Intial Accuracy (Note2) Drift with Temperature (Note4) Drift with Supply Voltage (Note4)	ACCUR Δt/ΔT Δt/ΔVCC	RA = 1kΩ to 100kΩ C = 0.1μF	-	2.25 150 0.3	-	% ppm/°C %/V
Control Voltage	VC	VCC = 15V	9.0	10.0	11.0	V
		VCC = 5V	2.6	3.33	4.0	V
Threshold Voltage	VTH	VCC = 15V	-	10.0	-	V
		VCC = 5V	-	3.33	-	V
Threshold Current (Note3)	ITH	-	-	0.1	0.25	μA
Trigger Voltage	VTR	VCC = 5V	1.1	1.67	2.2	V
		VCC = 15V	4.5	5	5.6	V
Trigger Current	ITR	VTR = 0V		0.01	2.0	μA
Reset Voltage	VRST	-	0.4	0.7	1.0	V
Reset Current	IRST	-		0.1	0.4	mA
Low Output Voltage	VOL	VCC = 15V ISINK = 10mA ISINK = 50mA	-	0.06 0.3	0.25 0.75	V V
		VCC = 5V ISINK = 5mA	-	0.05	0.35	V
High Output Voltage	VOH	VCC = 15V ISOURCE = 200mA ISOURCE = 100mA	12.75	12.5 13.3	-	V V
		VCC = 5V ISOURCE = 100mA	2.75	3.3	-	V
Rise Time of Output (Note4)	tR	-	-	100	-	ns
Fall Time of Output (Note4)	tF	-	-	100	-	ns
Discharge Leakage Current	ILKG	-	-	20	100	nA

Notes:

1. When the output is high, the supply current is typically 1mA less than at VCC = 5V.
2. Tested at VCC = 5.0V and VCC = 15V.
3. This will determine the maximum value of RA + RB for 15V operation, the max. total R = 20MΩ, and for 5V operation, the max. total R = 6.7MΩ.
4. These parameters, although guaranteed, are not 100% tested in production.

Application Information

Table 1 below is the basic operating table of 555 timer:

Table 1. Basic Operating Table

Threshold Voltage (V_{th})(PIN 6)	Trigger Voltage (V_{tr})(PIN 2)	Reset(PIN 4)	Output(PIN 3)	Discharging Tr. (PIN 7)
Don't care	Don't care	Low	Low	ON
V_{th} > 2Vcc / 3	V_{th} > 2Vcc / 3	High	Low	ON
Vcc / 3 < V_{th} < 2 Vcc / 3	Vcc / 3 < V_{th} < 2 Vcc / 3	High	-	-
V_{th} < Vcc / 3	V_{th} < Vcc / 3	High	High	OFF

When the low signal input is applied to the reset terminal, the timer output remains low regardless of the threshold voltage or the trigger voltage. Only when the high signal is applied to the reset terminal, the timer's output changes according to threshold voltage and trigger voltage.
When the threshold voltage exceeds 2/3 of the supply voltage while the timer output is high, the timer's internal discharge Tr. turns on, lowering the threshold voltage to below 1/3 of the supply voltage. During this time, the timer output is maintained low. Later, if a low signal is applied to the trigger voltage so that it becomes 1/3 of the supply voltage, the timer's internal discharge Tr. turns off, increasing the threshold voltage and driving the timer output again at high.

1. Monostable Operation

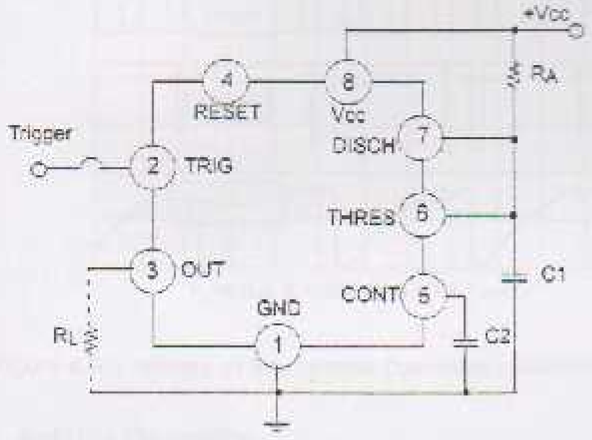


Figure 1. Monoatable Circuit

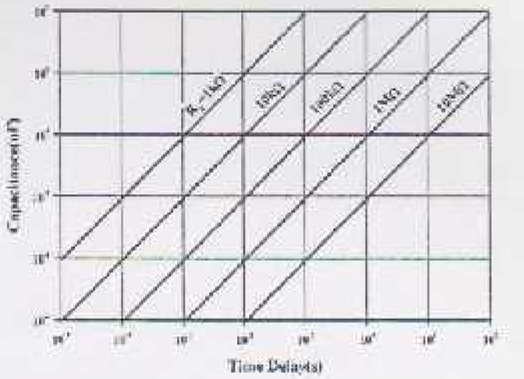


Figure 2. Resistance and Capacitance vs. Time delay(td)

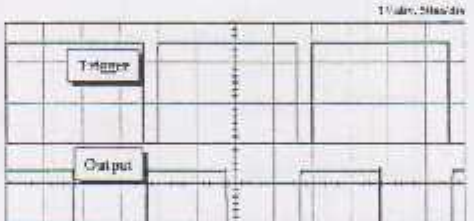


Figure 3. Waveforms of Monostable Operation

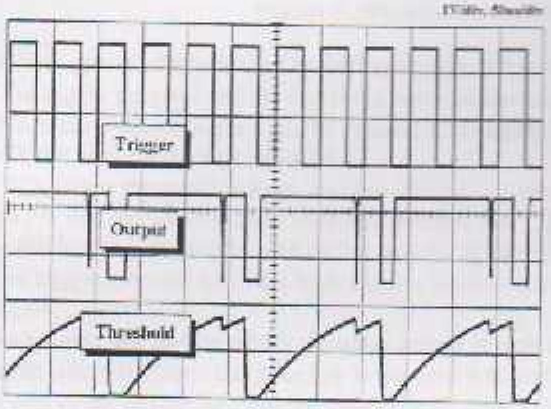
Figure 1 illustrates a monostable circuit. In this mode, the timer generates a fixed pulse whenever the trigger voltage falls below Vcc/3. When the trigger pulse voltage applied to the #2 pin falls below Vcc/3 while the timer output is low, the timer's internal flip-flop turns the discharging Tr. off and causes the timer output to become high by charging the external capacitor C1 and setting the flip-flop output at the same time.

The voltage across the external capacitor C1, V_{C1} increases exponentially with the time constant $t=R_A*C$ and reaches 2Vcc/3 at $td=1.1R_A*C$. Hence, capacitor C1 is charged through resistor R_A. The greater the time constant R_AC, the longer it takes for the V_{C1} to reach 2Vcc/3. In other words, the time constant R_AC controls the output pulse width.

When the applied voltage to the capacitor C1 reaches 2Vcc/3, the comparator on the trigger terminal resets the flip-flop, turning the discharging Tr. on. At this time, C1 begins to discharge and the timer output converts to low.

In this way, the timer operating in the monostable repeats the above process. Figure 2 shows the time constant relationship based on R_A and C. Figure 3 shows the general waveforms during the monostable operation.

It must be noted that, for a normal operation, the trigger pulse voltage needs to maintain a minimum of Vcc/3 before the timer output turns low. That is, although the output remains unaffected even if a different trigger pulse is applied while the output is high, it may be affected and the waveform does not operate properly if the trigger pulse voltage at the end of the output pulse remains at below Vcc/3. Figure 4 shows such a timer output abnormality.



R_A=9.1kΩ, R_L=1kΩ, C1=0.01uF, Vcc=5V

Figure 4. Waveforms of Monostable Operation (abnormal)

2. Astable Operation

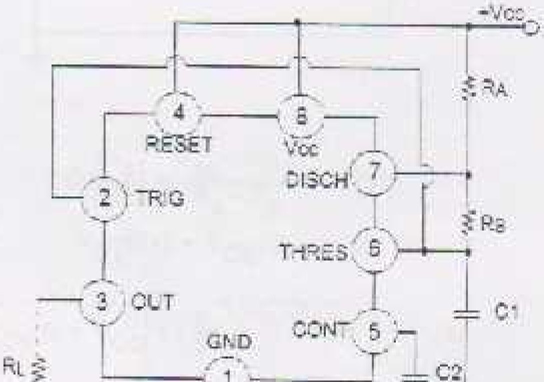
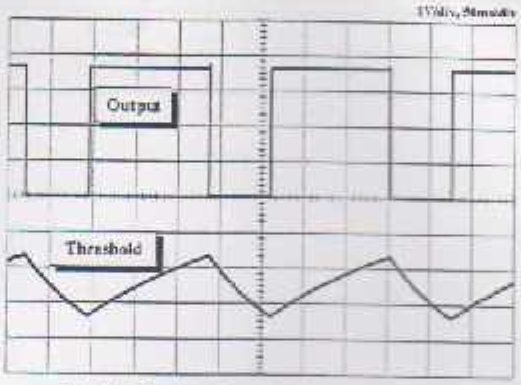


Figure 5. Astable Circuit

Figure 6. Capacitance and Resistance vs. Frequency



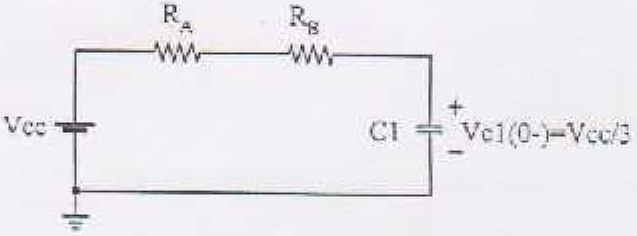
R_A=1kΩ, R_B=1kΩ, R_L=1kW, C1=1uF, Vcc=5V

Figure 7. Waveforms of Astable Operation

An astable timer operation is achieved by adding resistor R_B to Figure 1 and configuring as shown on Figure 5. In the astable operation, the trigger terminal and the threshold terminal are connected so that a self-trigger is formed, operating as a multi vibrator. When the timer output is high, its internal discharging Tr. turns off and the V_{C1} increases by exponential function with the time constant (R_A+R_B)*C.

When the V_{C1}, or the threshold voltage, reaches 2Vcc/3, the comparator output on the trigger terminal becomes high, resetting the F/F and causing the timer output to become low. This in turn turns on the discharging Tr. and the C1 discharges through the discharging channel formed by R_B and the discharging Tr. When the V_{C1} falls below Vcc/3, the comparator output on the trigger terminal becomes high and the timer output becomes high again. The discharging Tr. turns off and the V_{C1} rises again.

In the above process, the section where the timer output is high is the time it takes for the V_{C1} to rise from Vcc/3 to 2Vcc/3, and the section where the timer output is low is the time it takes for the V_{C1} to drop from 2Vcc/3 to Vcc/3. When timer output is high, the equivalent circuit for charging capacitor C1 is as follows:



$$C_1\frac{dv_{c1}}{dt} = \frac{V_{cc}-V(0-)}{R_A+R_B} \qquad (1)$$

$$V_{C1}(0+) = V_{CC}/3 \qquad (2)$$

$$V_{C1}(t) = V_{CC}\left(1-\frac{2}{3}e^{\left(-\frac{t}{(R_A+R_B)C1}\right)}\right) \qquad (3)$$

Since the duration of the timer output high state(t_H) is the amount of time it takes for the $V_{C1}(t)$ to reach 2Vcc/3,

Ordering Information

Product Number	Package	Operating Temperature
LM555CN	8-DIP	0 ~ +70°C
LM555CM	8-SOIC	

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2. A critical component in any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.