ULTRASOUND AIR BUBBLE DETECTOR FOR MOVING BLOOD

(ARTIFICIAL KIDNEY APPLICATION)

By

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FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

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June 2008

This Great gratitude goes to GOD the Almighty.

To my beloved father and mother,
Abdul Malek Hussin
Noridah Ab Talib

Also to my beloved siblings,
Mohd Aizuddin Abdul Malek
Nor Hazwani Abdul Malek
Aizat Abdul Malek
Ajwad Shamin Abdul Malek
Nor Aainaa Abdul Malek

To all my friends, and then last but not least to my precious, Azman.

All your supports will be kept in my soul.

Thank you!

CERTIFICATION OF ORIGINALITY

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

Nor Hafizah Abdul Malek

ABSTRACT

Detection of air bubble using detector is important to reduce the presence of bubbles that may affect the entire body of human. For a hemodialysis machine, if it is operated without a blood pump then the blood circuit would be under positive pressure and allow air entry into the circuit. Multiorgan dysfunction can occur as a consequence of air entering into the blood circulation and giving rise to the appearance of micro emboli. Early sensors were photo-optical, but their sensitivities were limited and the ambient light subjected them to give false alarm. Nowadays, most detectors use ultrasound and its principle of operation is based on the measurements of attenuation, waveform and velocity. But, it could not detect size of air bubbles below 850μm. To improve the sensitivity of the device, a simulation study using Multsim is conducted. Basically, this study is more about the principle of the air sensor and its mechanism. The study consists of theoretical background, simulation and its implementation. It starts with reading and also collecting the information from the journals, articles and books. The simulation is done then a prototype is constructed. In simulation, it is able to detect air bubbles with size less than 850μm, which is 680μm. This report consists of five chapters. Chapter 1 consists of background of study, problem statement and the objectives. Chapter 2 consists of a literature review and overview of the project while methodology part is stated in Chapter 3.The results and discussions are in Chapter 4. The study is ended up with conclusion and recommendation in Chapter 5.

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Hemodialysis is the common method used to treat advanced and permanent kidney failure. It is also a machine that removes waste products and urine from the patient's body. Blood is circulated in a machine which contains a dialyzer (artificial kidney). It has three main functions which are to pump blood and watch flow for safety, clean waste from blood and also to watch blood pressure and the rate of fluid removal from the body. In blood monitor, it has the minor function of job to detect the air bubbles from entering in the blood. The hemodialysis machine performs the function of pumping the patient's blood and the dialysate through the dialyzer. The artificial kidney uses the principle of dialysis to purify the blood of patients whose own kidneys have failed [1, 2, and 3]. The kidney removes waste material from the body, and when this is not achieved properly, the patients develop a kidney failure. Small molecules like urea are removed from the blood because they are free to diffuse between the blood and the bath fluid. The bath fluid contains essential salts added to it to prevent the dangerous loss of these ions from the blood. The blood and the bath fluid flow in the opposite directions across the dialysis membrane. An anticoagulant is added to the blood so it will not clot while passing through the machine. The anticoagulant is neutralized as the blood is returned to the patient.

Artificial kidney is facing many problems such as a leaking blood inside the dialyzer, failure of detection of air bubbles that re-enters in the patient's body and also and the alarm cannot be triggered when certain size of air bubbles passes the security system. Leaking blood usually happens to new dialyzer. When this case is occurs, the machine stops and it will trigger the alarm. The best solution to solve this problem is by replacing it with the new dialyzer. Failure of detection of air bubbles that re-enters the patient's body may produce emboli that may be life threatened [4, 5]. Detection of air bubbles sets the alarm that will stop the dialysis while the technician has to solve the problem. Those occurred problems could be fatal. The effects of that may lead to the patient's difficulty to breathe. They can also experience heart attack. Also, those events can go to irreversible cellular image and may lead to massive brain ischemia and stroke. Nowadays, the hemodialysis devices are equipped with ultrasonic detectors of air larger than 850μm. It triggers the alarm with the extremely larger size of air bubbles. The smaller size however could not be detected.

1.2 Problem Statement

The hemodialysis machine is equipped with ultrasound detector which can only detect air bubbles with size more than 850 μm. However, the small sizes of air bubble which is less than 850 μm in the blood that re-enters the patient's body cannot be detected; passed the security system of the dialysis device without triggering the alarm and produced air emboli that may be life-threaten. The device is not sensitive enough to deal with micro bubbles. Therefore, an improvement detector for detecting a small size micro bubble which is less than 850 μm is required.

1.3 Objectives and Scope of Study

1. To study the behaviour of air bubbles in moving blood.
2. To simulate using MultiSim software to determine the smallest size of air bubble that can be detected.
3. To design ultrasound detector that can detect a size of air bubbles less than 850μm.

Basically, the whole project started with data gathering and theoretical studies. The circuit has to be designed in order to determine the smallest size of air bubbles. Mean while, the further research is continue to determine the relation of radius of air bubbles and the frequency.

CHAPTER 2

LITERATURE REVIEW

2.1 Air Embolism

Air embolism is a medical condition caused by gas bubbles in the bloodstream. In medical context, it refers to any large moving mass or defects in the blood stream. Small amounts of air often get into the blood circulation accidentally during surgery and other medical procedures. Most of air bubbles in veins stop at the lungs and indications of such cases are very rare [6].The symptoms of an air embolism will depend on where the blockage occurs. Usually, the air bubble comes from the leakage due to the improper connection between the tubes into the machine. Between the patient and the blood pump, the negative pressure may develop and air may be sucked into the circuit. In this segment, there are heparin infusion pump and infusion set. The line connection of it will have a large crack, thus it is one of the causes of the air bubbles appearance [7]. Besides, air in the solution of the dialysis fluid diffuses across the membrane into the blood and may form the air bubbles in venous air trap. The above description is on how the air bubbles appear in hemodialysis. For the term of the other medical part itself, it (air embolism) can occur whenever a blood vessel is open and a pressure gradient exists favoring entry of gas. Because the pressure in most arteries and veins is greater than atmospheric pressure, an air embolus does not always happen when a blood vessel is injured. In the veins above the heart, such as in the head and neck, the pressure is less than atmospheric and an injury may let air in. This is one reason why surgeons must be particularly careful when operating on the brain, and why the head of the bed is tilted down when inserting or removing a central venous catheter from the jugular or subclavian veins.

The immediate effects of the air bubbles depend on the speed, quantity and site of introduction of air into the circulation. There are studies at the animal shown that the rapid infusion of a large volume or air may be fatal [8]. The same goes to the human being. A large air embolism affecting the brain arteries will cause immediate loss of consciousness and often convulsions (fits). It can cause a stroke or attack. Also, the micro bubble obstructs blood flow in the capillary causing tissue ischemia. Death may occur if a large bubble of gas becomes lodged in the heart, stopping blood from flowing from the right ventricle to the lungs. Air enters the right atrium and ventricle where it forms foam and passes to the pulmonary artery, causing pulmonary blockade and hypertension. This basically explained the effect on the heart and lungs. The effects on systematic circulation basically come from air crosses to the left side of the hearts through the capillaries and arteriovenous communication of the lungs. Difference in temperature can also can be one of the causes for bubble generate in lines since warming initiates bubble formation. Apart from that, the compositions of air also affect the system of the body. Other symptoms of an air embolism include:

- low blood pressure,
- irregular heartbeat,
- extreme fatigue or lack of strength,
- visual disturbances,
- disorientation,
- cyanosis (a faint blue tone to the skin caused by a lack of oxygen in the blood),
- apnoea (irregular breathing), and
- hypoxia (a lack of oxygen flowing to the body).

As far back, the early method that has been used to detect the air bubbles was photoelectric but their sensitivity was limited and the ambient light subjected them to false alarms [9]. It is also the most unreliable method which it is plagued by allowing detection threshold level between, clear saline and air and requires adjustments for fluids of different opacities [10].

Today, the hemodialysis device is equipped with ultrasound detectors of air larger than 850μm. It is hard to detect the size of air bubbles larger than 850μm. The patient in final stage of renal failure undergoes many treatment and sessions of hemodialysis per week, 150 yearly. Each second, the patient is exposed to the micro air bubbles that might pose greater problems. What is most feared of this is when the patient does a hemodialysis at home which they do not have any technical knowledge or nursing to watch and take care of the device [11].

Ultrasound air detector is one of the safety devices to monitor whether there is any bubble going into the return line (Venous Line) to the patient. The mode of operation is by ultrasonic through transmission, and the detector is preferably employed to prevent air embolism. Transmission of sound from the transmitter, via the sensor head, to the receiver of the detector is dependent upon the existence of a fluid within the tubing [10]. Technically, besides ultrasound Transmitter-receiver, there is also a 1 Red sensor which only checks whether the flow inside the tubing is water (normal saline) or blood. The ultrasound has a protection system which is automatic cyclical checks during entire operating phase. The flow of its operation is sent to trigger the alarm when the size of the bubble is detected within the limit value.

Ultrasound has two stages which are transmitter stage and the receiver stage. When air bubble is detected, the signal will transmit to the receiver and the alarm will trigger at the screen monitor of the hemodialysis machine. The flow of the system is as follow:

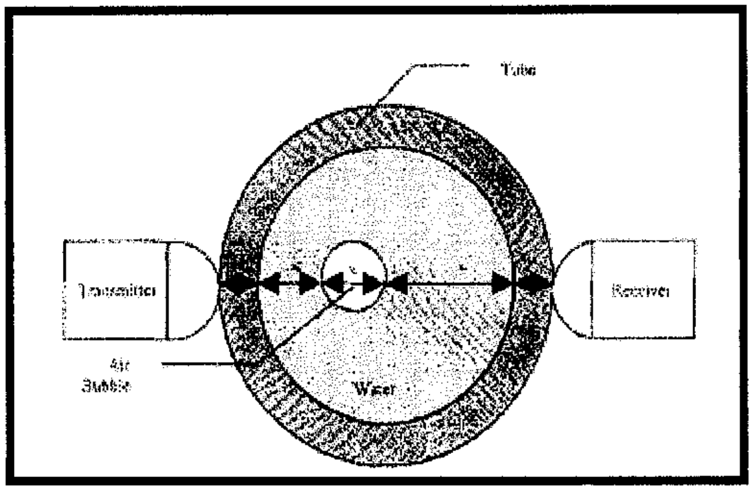


Figure 1 : Tube water air bubble system

2.2 Ultrasound Wave Characteristic

The ultrasound velocity is 380 meter per second (m/s). The echo is the reflection of the sound from the transmitter. The mean frequency for the ultrasound is 20 khertz (kHz). It also involves refraction and interference characteristics. The sound direction of motion is in longitudinal or transverse modes.

The frequency, f, in Hertz can be defined as the number of oscillation per second and it is illustrated using a simple continues wave shown in Figure 2 [12].

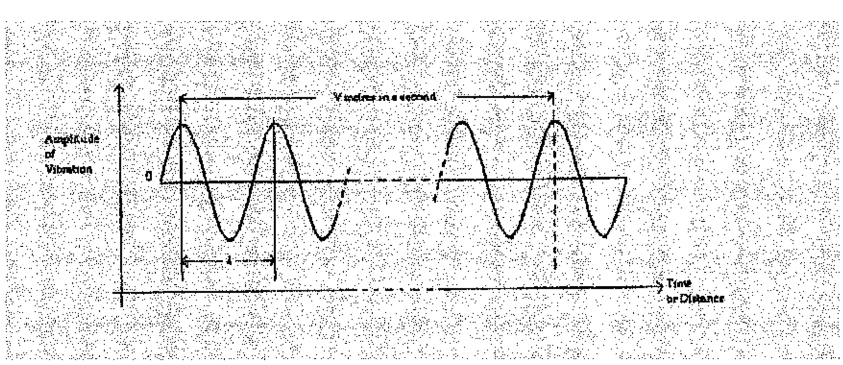


Figure 2: A simple continues wave

The relationship between the wavelength, λ, velocity, v and frequency, f, of a signal is shown in equation 1

$$\lambda = \frac{v}{f} \tag{1}$$

2.3 Operation of Ultrasound Sensor

An ultrasound sensor generates ultrasounds waves from another form of energy is a transmitter whereas a receiver converts ultrasound into another form of energy. Compressional ultrasound can be produced and detected using many techniques. Some of the detectors' technique can be very simple and some of them are quite complex. Therefore, depending on these techniques; it could be used for various types of applications especially for level and flow measurement. The techniques are *monostatic* and *bistatic* mode. These two techniques will be discussed later in the next section.

2.3.1 The Transmitter and Receiver

The term of *monostatic* and *bistatic* are sometimes used in relation to transducers. If the transducer is being used only as a transmitter or only receiver it is known as *monostatic.* The term *bistatic* is used for a transducer that is used for both actions which are transmitter and receiver. However, *monostatic* transducer is used in order to meet the requirement of this project. Figure below shows a *monostatic* transducer and *bistatic* transducer.

Other ultrasonic sensor has separate transducers. This might be very costly cost but it has several advantages; for example it becomes easier to test and characterize the transducer before installation and for maintenance purpose or replacement during the services. However, it depends on the application that is requested by the users. Commonly, the monostatic mode is used in order to measure the flow in a pipeline. This is due to the fact that the flow is measured by measuring the voltage difference from the transmitter

2.3.2 The Basic Features of the Beam Light

The beam profile generated by an ultrasonic transducer is determined by interference (diffraction) phenomena between the Huygens' wavelets. The generation of a beam of compressional ultrasound by a circular plane pistons radiator excited by signal constant amplitude. This situation is particularly relevant to many piezoelectric transducers and also good for many others [13]. The basic features of the beam profile are illustrated in Figure 3.

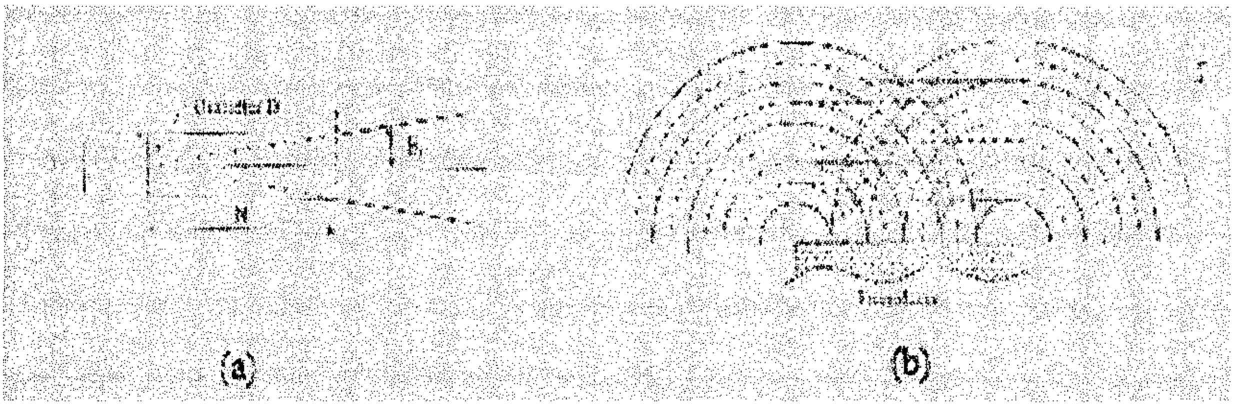


Figure 3: Interference effects

(a) The basic feature of the beam profile

(b) Interference effect in the near field

The simple model shows that near the field changes into far filed at the distance N from the transducers face given by

$$N = \frac{D^2 - \lambda^2}{4\lambda} = \frac{D^2 f}{4 \mathrm{v}} \qquad (2)$$

where; N is distance of field from the face, D is diameter (meter) of the face, f is frequency (Hz), V is velocity (m/s) and λ is the wavelength (meter) [12] .

2.3.3 Ultrasound Sensor's Insertion Loss

The insertion loss is a relative measure of a transducer's energy conversion efficiency. The insertion loss [13] is the decrease in dB, of the amplitude of the received signal compared with amplitude of the input signal and it is given by

$$\text{Insertion Loss} = 20 \log \frac{E_i}{E_r} \text{ Db} \qquad (3)$$

where; E_i is the input voltage of the transducer and E_r the voltage of the received pulse.

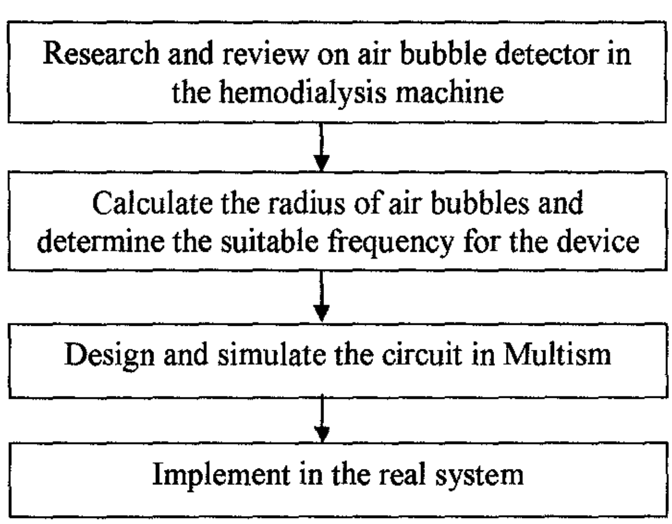
CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

The research for this project basically depends on the electrical circuit, which will detect the air bubbles enter to the patient's body. A simulation will be done using the Multism software to determine the smallest size of air bubbles. The current sensor will be improved to ensure the size of air bubbles detected is beyond than the current size which is more than 850μm. The prototype of the device will be done after all the simulation is succeeded.

The flow of the project as below:-



3.2 Research and review on air bubble detector

Ultrasound in blood operation has transducers which emits a burst of ultrasound, propagates in the medium and hits the reflector in the far field region of the transducers. Then, part of energy is scattered by the blood cells, propagates through tissue and is received by the transducers. Air bubbles oscillate in extreme manner and its resonance frequency is inversely proportional to its radius. Basically, the mechanism of ultrasound is based on waves. In waves, there are two components that play important rules which are velocity and the frequency.

However, the frequency in the same level of medium is the same. In ultrasonic detector, supposedly the flow of the blood is smooth and velocity is constant without presences of air bubbles. However, when the air bubbles is presence, the different medium between the air and the blood can occur the different velocity. This difference actually triggers the alarm of the machine. The blood is the reference of the medium.

It is well established that the natural frequency of oscillation affects the way in which bubbles absorb energy from the ultrasonic field. When a bubble is sonicated at its resonance frequency it intercepts and reradiates more acoustic energy than one would expect from its cross sectional area [14]. The resonance frequency of bubbles is strongly affected by the surrounding boundaries. The natural frequency is lower than the corresponding frequency in unbounded liquids and that it decreases as the bubbles gets closer to the centre of the blood vessel. Furthermore, the width of the energy resonance is dependent on the bubble size and the smallest bubbles have the sharpest resonance [14].

The natural frequency of oscillation in an infinite volume of liquid is given by the Minnaert's formula [15].

$$f_o = \frac{1}{2\pi}\sqrt{\frac{1}{\rho \alpha_o^2}\left(3\gamma P_o - \frac{2\sigma}{\alpha_o}\right)} \qquad (4)$$

where,

ρ = liquid density dextrin (1.06x1000 kg/m^3)

α_o = bubble ambient radius (radius of air bubble that need to find)

P_o = ambient pressure (0.1x10^8 MPa)

γ = effective polytropic exponent (assumed to be 1)

σ = surface tension of the gas liquid interface (0.056 kg/s^2)

3.3 Design and simulation

The block diagram of the circuit as below:

Tubing

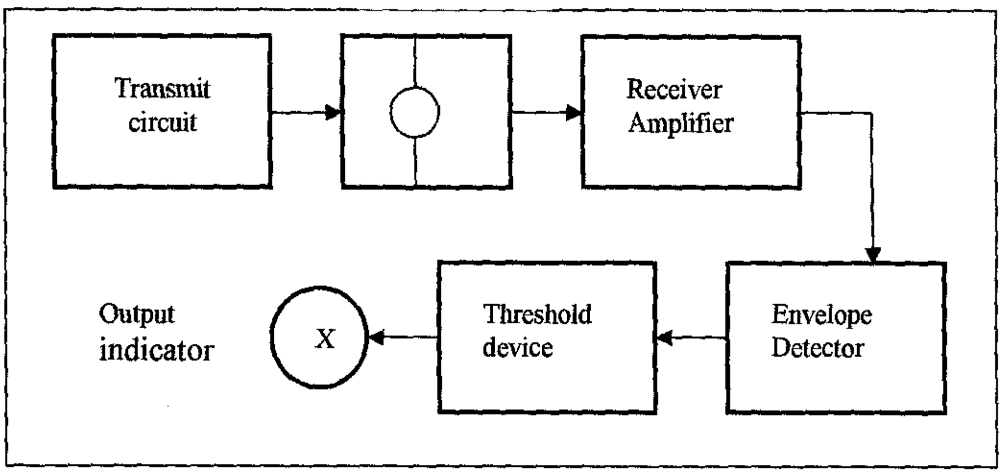


Figure 4: Block diagram

Figure 4 shows a block diagram of the device including transmitter, a sensor head, a receiver amplifier, an envelope detector, a threshold detector and an output indicator. The transmitter may include a sinusoidal oscillator that drives a transmitter transducer which forms a part of the sensor head in the disclosed embodiment. The sensor head is represented by sound absorbent cubes. Receiver transducer is disposed for receiving the sound wave generated from the transmitting transducer. The receiver transducer is excited by the local vibrations, and generates a sinusoidal electrical signal, which is amplified by amplifier, passed to envelope detector and from there to a threshold detector or comparator circuit for detecting a reduction in the sensed signal. When this occurs the output indicator is activated causing a visual or audible alarm and preferably an interruption of the feeding of fluid in the tube.

To get the desired frequency which is high, the wavelength is small, requiring small transducers, small transmitter amplifier power, and a short path length for the orifice. The actual device described used 2 inches thick, 2 inches diameter transducers as transmitter and receiver, a stable frequency oscillator and a power amplifier to drive the transmit transducer, and at the receiver a low frequency tuned amplifier, detector, and post amplifier. The dimension of tube is typically around 5mm.

3.3.1 Transmitter Circuit

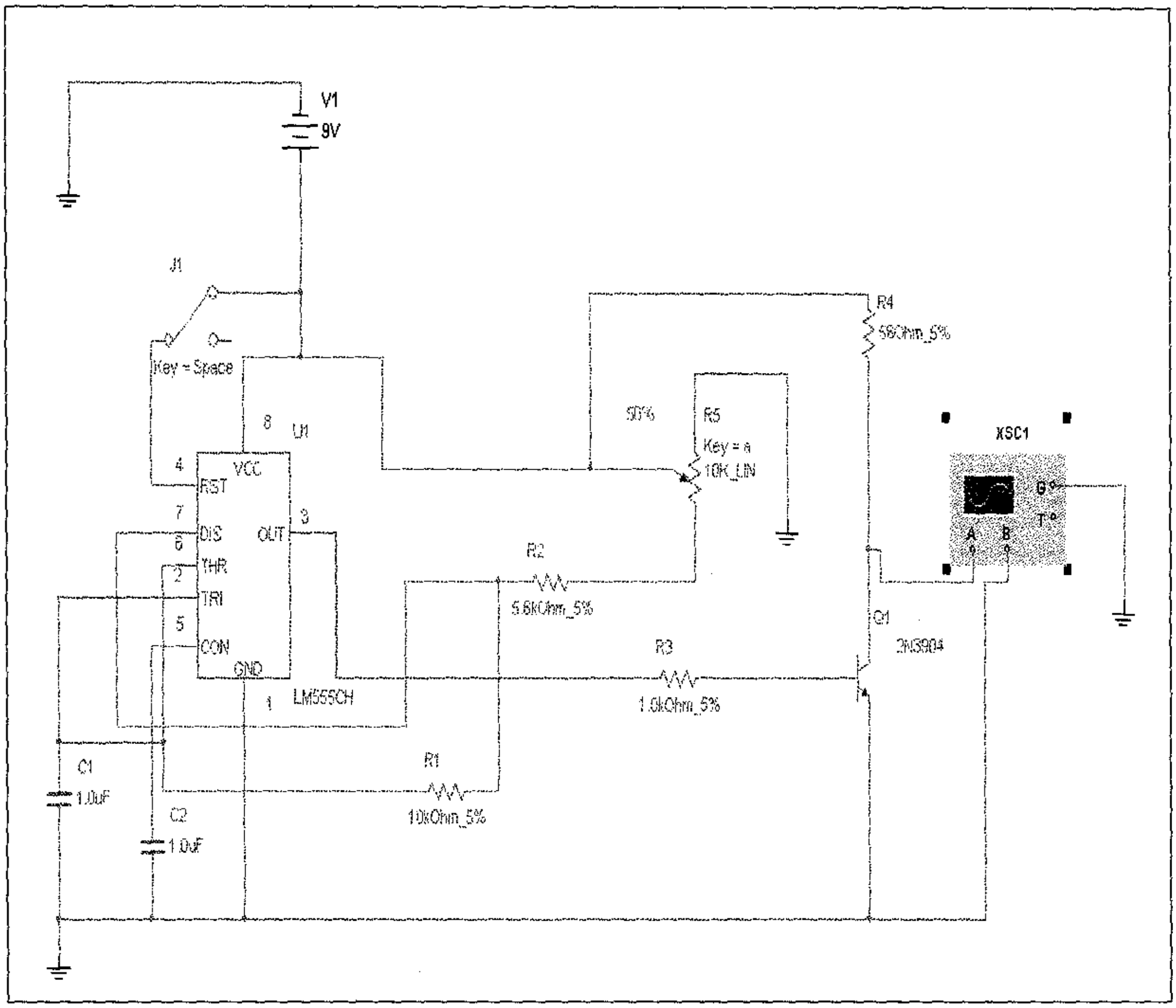


Figure 5: Transmitter circuit

The transmitter circuit contains a 555 timer integrated circuit (IC) that can generate 50 kHz square – wave signal. This signal is used to latch the transistor which receives +9V supply to drive the ultrasonic transducer that is able to work on 50 kHz frequency. The signal is then amplified using a 2N3904 transistor. The amplified signal will be transmitted into the container through the ultrasonic transducer.

The frequency is calculated based on the equation for ultrasound below:

$$c = f\lambda \qquad (5)$$

where c = 3.00×10^8

$\lambda = 850\ \mu m$

Thus, $f = 3.529 \times 10^{11}$Hz

In this circuit, the adjusted resistor is used so that the frequency can varied at certain level. The 10K ohm resistor is chosen to adjust the range of that particular frequency.

3.3.2 Receiver Detector Circuit

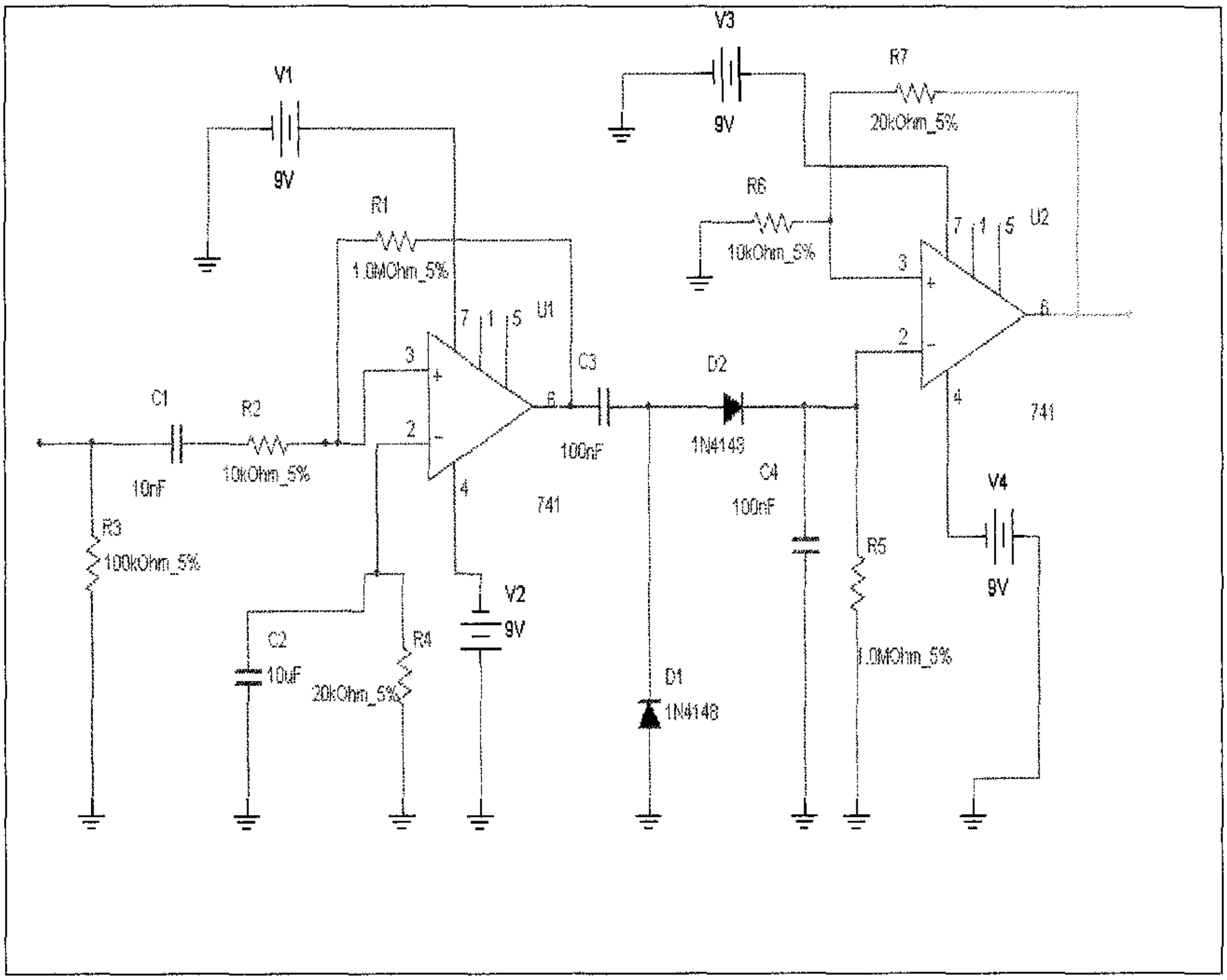


Figure 6: Receiver detector circuit

In receiver circuit, it has two stage amplifiers, a rectifier stage an operational amplifier in inverting mode. It receives the signal from the receiver. This signal will be re-amplified using an LM741 Op-Amp. Besides that, this part also acts a filter to make sure that only a 50 kHz signal wave is received. The amplified signal is converted to DC voltage by a half wave rectifier circuit. The DC signal is amplified by using LM741 Op-Amp. The non inverting pin in amplifier is connected at the DC voltage via preset adjusted resistor can determines the threshold value of ultrasonic receiver.

3.4 Implement in real system

3.4.1 The Transmitter Circuit Construction

After the circuit is constructed at Multism Software, it needs to test to ensure it is working as required. The comparison is between the simulation waveform using Multism and the waveform obtained from the oscilloscope.

3.4.2 The Receiver Circuit Construction

A receiver circuit is very important part of the whole project. This is because, since it is exposed to the environment, it needs to identify the signal that it will receive. The circuit is constructed part by part. The results obtained from the simulation are compared with the waveform obtained from the oscilloscope. The first part of the circuit is a filter [16]. The filter is needed in order to identify the frequency that it should receive in this work is 50kHz signal. The frequency of the filter is determined by the equation 3.3

$$f = \frac{1}{2\Pi C_1 R} \qquad (6)$$

The circuit configuration for the filter is shown in Figure 7.

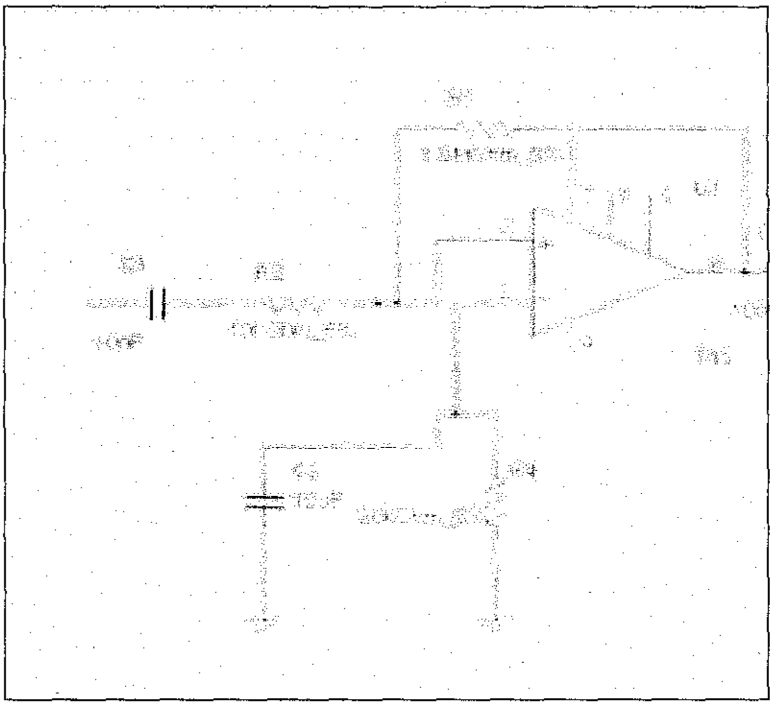


Figure 7: A filter of the receiver circuit

The next part is the rectifier circuit. The rectification is required to convert an AC voltage to DC voltage. Therefore for this small scale model, a simple wave rectifier is used. The circuit is shown in Figure 8.

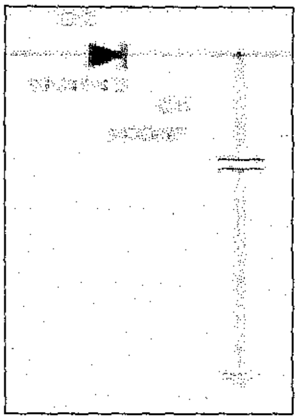


Figure 8: A half wave rectifier circuit with a capacitance effect

Then, the signal from Figure 8 will enter third part of the circuit which is an amplifier. The amplification is carried out using LM741 Op-Amp. The circuit configuration is to non inverting input. This is because; the signal just needs to be amplified and not to be inverted. The circuit configuration for this amplifier is as shown in figure 9.

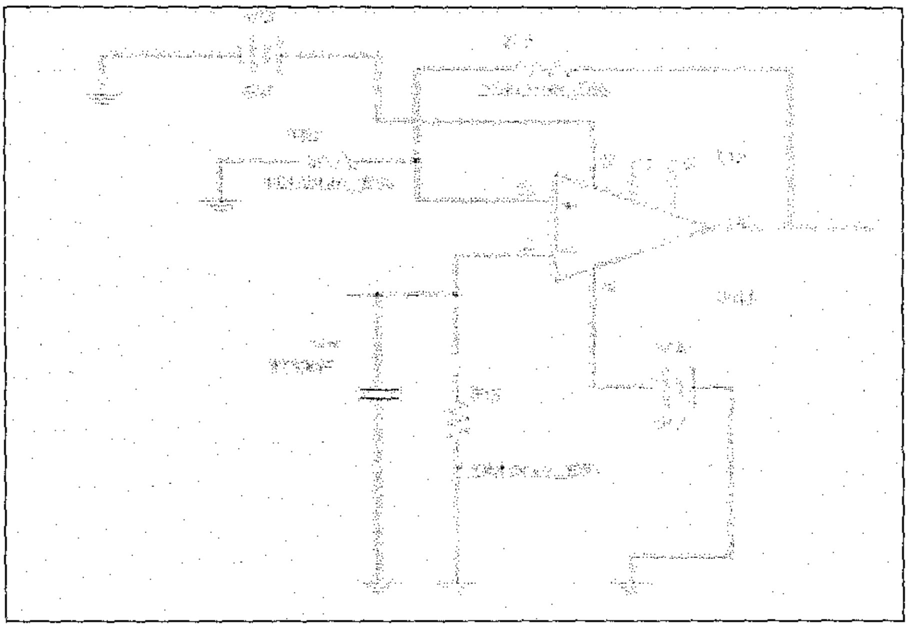


Figure 9: The amplifier configuration circuit

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

From the Minnaert's equation (4), rearrange the equation to get α_o. The value of frequency is set to different values. The values of frequencies are as follow: 500 kHz, 1000 kHz, 1500 kHz, 2000 kHz, 2500 kHz and 3000 kHz. The liquid use is supposedly blood; however, it has been replaced with another liquid, dextrin which has the same density with the blood.

$$f_o = \frac{1}{2\pi}\sqrt{\frac{1}{\rho \alpha_o^2}\left(3\gamma P_o - \frac{2\sigma}{\alpha_o}\right)} \quad (7)$$

$$(2\pi f_o)^2 \rho \alpha_o^3 - 3\gamma P_o \alpha_o + 2\sigma = 0$$

Refer the value for each constant at equation (4).

Table 1 The radius of bubble with different frequency

f_0 (kHz)	500	1000	1500	2000	2500	3000
α_o (μm)	53.5479	26.7730	17.8407	13.3856	10.7081	8.9231

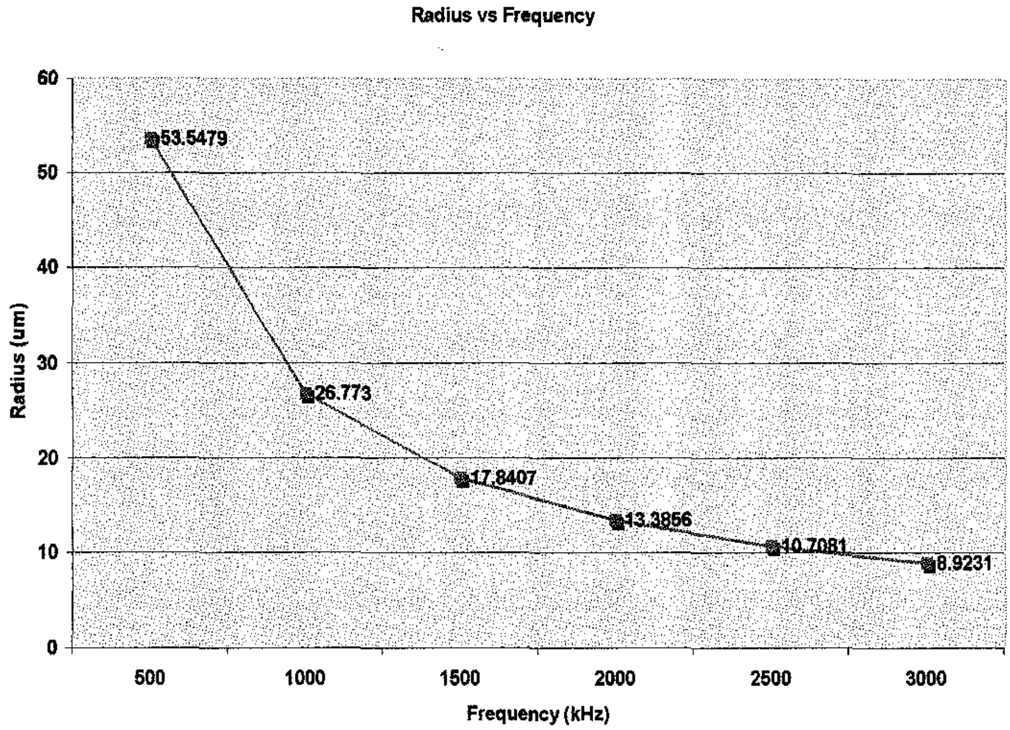


Figure 10: Graph of radius vs. frequency

The graph shows that when the higher frequency is being used, the smaller radius of air bubble can be detected. The reading of radius is decreased by increasing the frequency. This results are obtained after manipulate the equation from the equation (4).

4.1.1 Result of simulation

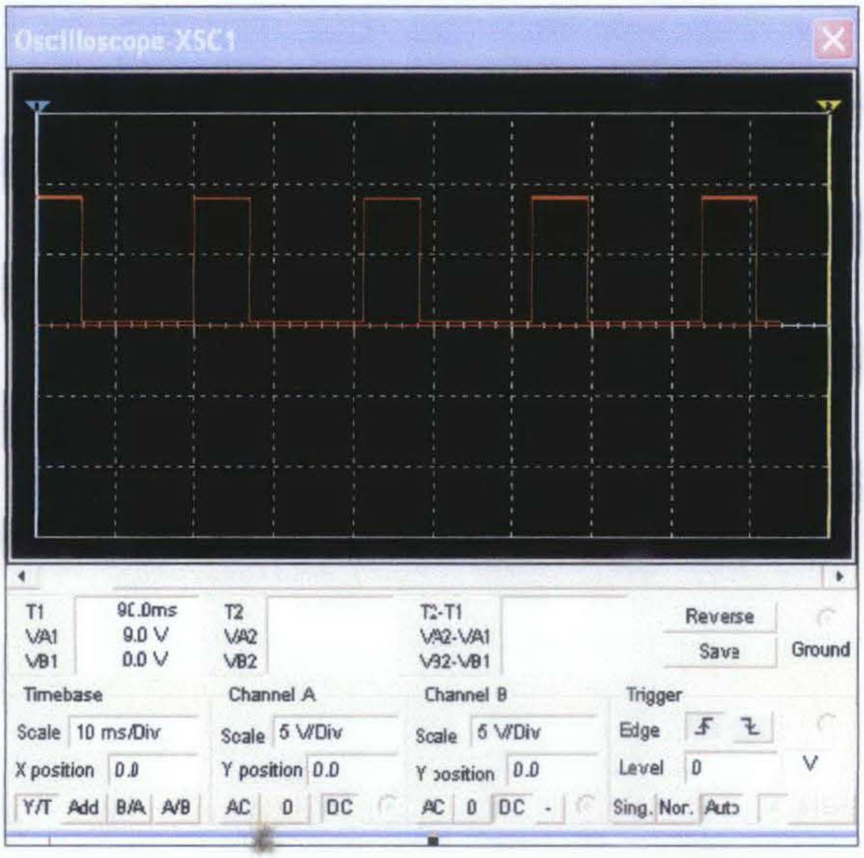


Figure 11: Output from transmitter circuit

Figure 11 shows the output from the transmitter circuit. The waveform is square waveform because the timer 555 has been used for this circuit. The signal is used to transmit the data before the ultrasound can detect the attendance of air bubbles.

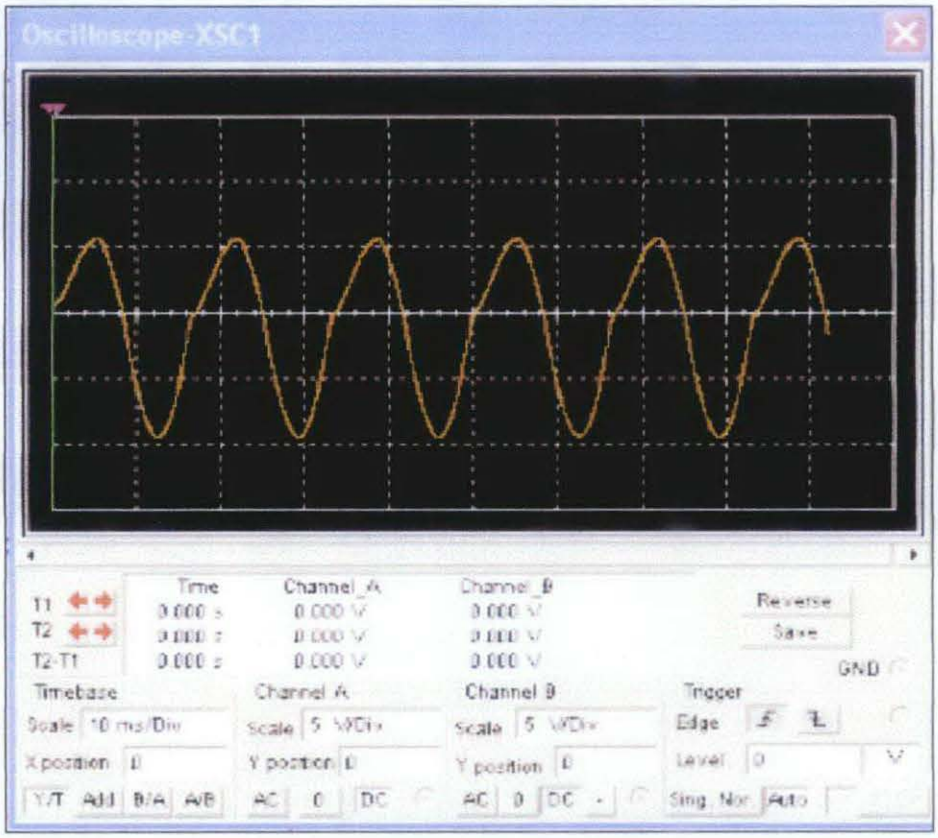


Figure 12: Output from filter

Figure 12 shows the output from the filter which is needed to identify the frequency that should receive the same from the signal. From the simulation, the output shows that the input frequency is maintained and the sinusoidal waveform is act as the stable frequency received.

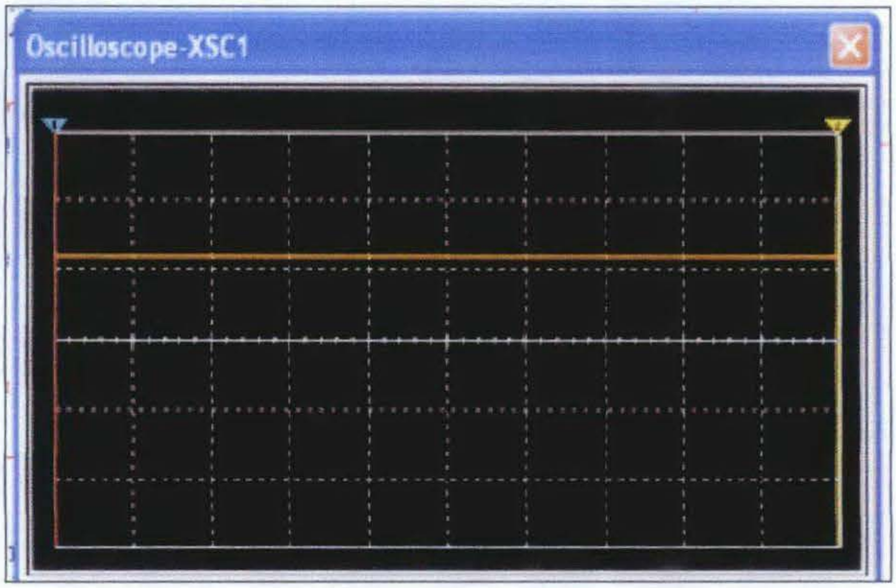


Figure 13: Output from completed receiver circuit

This waveform shows the output from the receiver circuit. The straight line indicates the signal without the attendance of air bubbles.

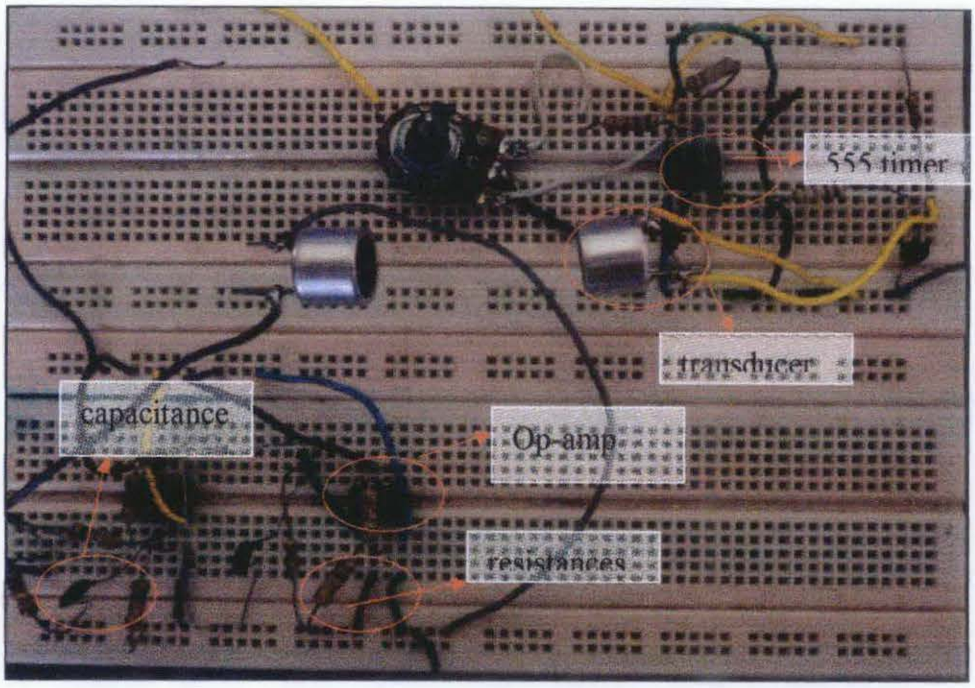


Figure 14: The complete circuit

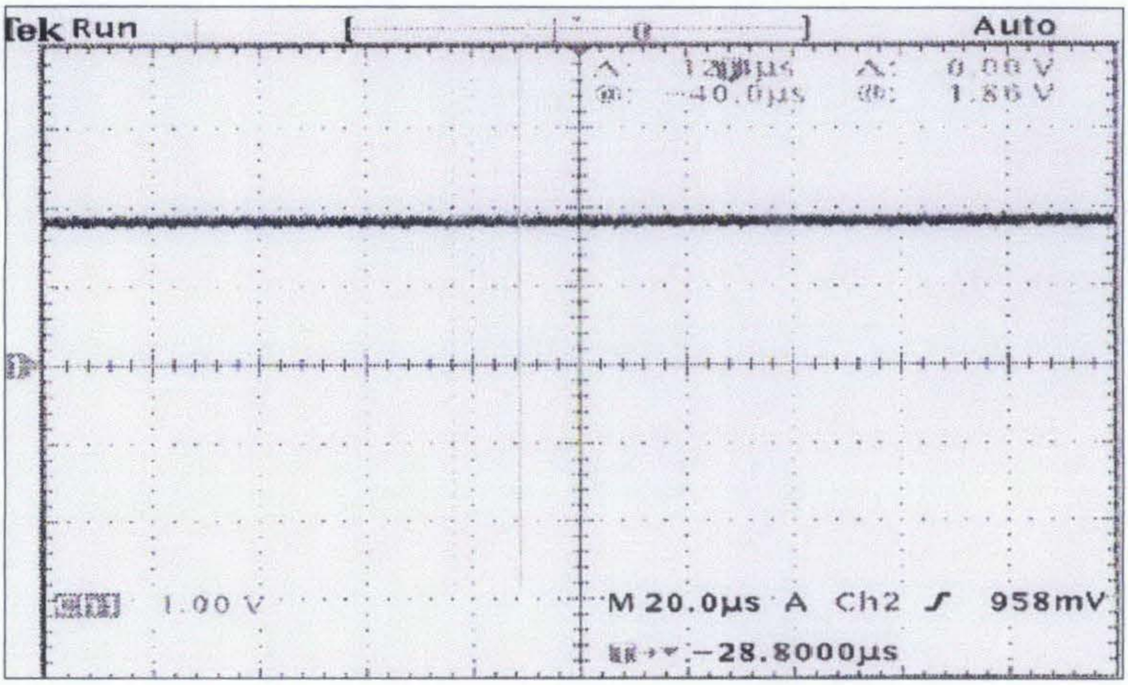


Figure 15: Output obtained from transmitter on the oscilloscope

The output shows the straight line signal from the transmitter monitored at the oscilloscope. Supposed, the signal is expected to be the square waveform. However the signal appeared in straight line form due to certain circumstances which is the connection wire in the circuit is not proper. The circuit construction is not in a good condition.

4.2 Discussions

From the calculation, different values of frequencies have been used. Frequency versus radius graph is shown in Figure 10. It claims that when the higher frequency is used the smallest size of radius of air bubble is detected.

Simulation result shows that the 555 timer circuit is able to generate 50 kHz square-wave signal accurately. However, there is potentiometer to control the frequency of the signal that depends on the type of sensor and materials that are dealing with. In receiver circuit, the output DC voltage from the amplifier is proportional to the input voltage.

By simulation, the circuit is working but it could not be proven during the experiment and construction of the circuit. Unfortunately, during the experiment, the output voltage could not be detected.

It may due to several problems. One of them is could be the type of sensor that has being used. The reason of that is because there are many sensors in typically market. Each sensor has it owns specification; the different range of frequency. The chosen one might be not suitable to reach objectives of this project.

Besides, another reason of this project was unsuccessful is because of the constraints of each of the component itself. During the experiment, there is a noise everywhere from the output of the circuit. Other problem is the signal lost during the connection.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The theoretical, survey and research of the artificial kidney also the hemodialysis device are collected. The Multism software is selected for simulation and it has being used in designing the size of the micro bubbles. The study of behaviour of air bubbles in moving blood is done. Simulation using Multism software to determine the smallest size of air bubble is done which it detected radius up to 680μm.

The preliminary goal of this project is to design the device that could detect the small air bubbles. Only the simulation part of the transmitter and receiver are achieved. The construction of the ultrasound detector is done however the circuit is not working due to the several of circumstances occurred. The output of the circuit could not be determined.

However, from the calculation of radius of bubble, the results can be concluded that the higher frequency that is being used, the smaller size of radius of bubble can be determined. It shows when the frequency is set to several different values.

5.2 Recommendation

As a recommendation, the transmitter circuit that is used is commonly used to generate a signal by using a 555 timer. However, this project still needs a lot of improvement from other skill innovators for better features. The connection of the component is constructed on the breadboard. Instead using the breadboard, it can also use the PCB board that will give more accurately and better results of the output circuit. One method to overcome the signal lost during the connection, it should be centralized and is taken from one point. The device cannot use a different power supply. So, it makes the electrical system becomes simpler.

Supposed, after all the results are obtained, the next step that should be considered of is the diameter of the tube. This is because the diameter of the tube is highly infected the detection of air bubbles for this application. As the smaller diameter, it could reduce the attendance of air bubbles. Thus, it depends of the next inventor to continue this project and improve it for the better features in future.

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APPENDICES

APPENDIX A

RS

Data Sheet

Ultrasonic transducers

RS stock numbers 307-351, 307-367

A range of two transducers operating at 40kHz approximately and designed for ultrasonic transmission and reception. The ultrasonic transmitter, 307-351 is capable of emitting 106dB (0dB = 2 × 10⁻⁴μbar) and the receiver 307-367 has a sensitivity of -65dB (0dB = 1μbar/V/metre).

These units can be used for the transmission of continuous wave ultrasonic sound or for pulsed sound applications.

Characteristics

Item		Unit	307-351	307-367
Transmitting sensitivity	Sv	dB*1	106	-
Receiving sensitivity	Mv	dB*2	-	-65
Resonant frequency (transmitting)	Fsv	kHz*3	40±1	-
Resonant frequency (receiving)	Fsmv	kHz*4	-	40±1
Directional angle	θ½	°	±30	
Maximum input voltage		Vrms	20	-
Impedance		Ω	Approx. 500	Approx. 25k
Capacitance		pF	1800±20%	
Pulse rise time		msec.	2.0	0.5
Maximum input voltage for pulse operation		Vp-p	20	-
Temperature range		°C	-20 to +60	
Transmitting selectivity	Qsv		Approx. 10	
Receiving selectivity	Qmv			Approx. 20

[illegible]

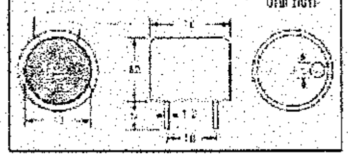
[illegible]

[illegible]

[illegible]

Shape and dimensions

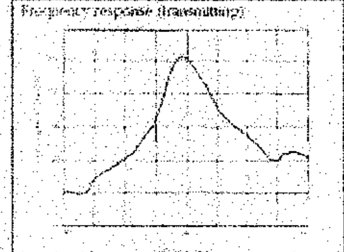
Unit: mm



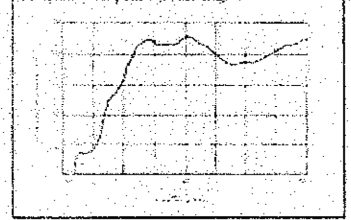
Applications

- Burglar alarm systems
- Proximity switches
- Liquid level meters
- Anti-collision devices
- Counters for moving objects
- TV remote control systems.

Frequency response (transmitting)



Frequency response (receiving)



APPENDIX B

National Semiconductor

July 2006

LM555
Timer

General Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200mA or drive TTL circuits.

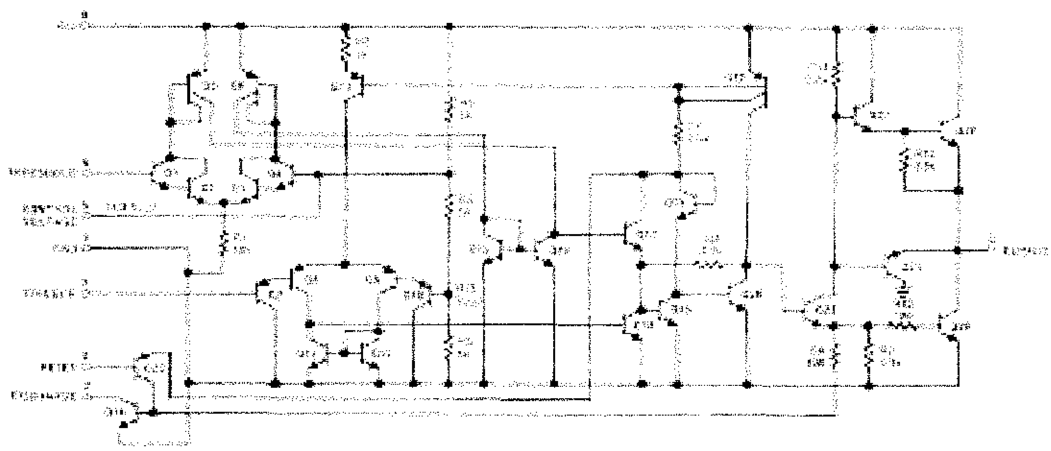
Features

- Direct replacement for SE555/NE555
- Timing from microseconds through hours
- Operates in both astable and monostable modes
- Adjustable duty cycle
- Output can source or sink 200 mA
- Output and supply TTL compatible
- Temperature stability better than 0.005% per °C
- Normally on and normally off output
- Available in 8-pin MSOP package

Applications

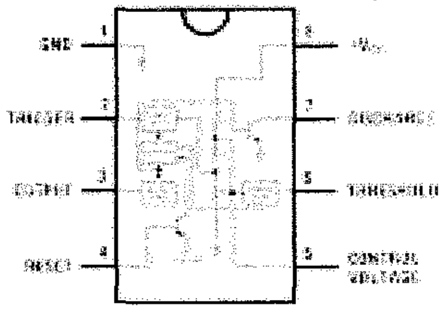
- Precision timing
- Pulse generation
- Sequential timing
- Time delay generation
- Pulse width modulation
- Pulse position modulation
- Linear ramp generator

Schematic Diagram



Connection Diagram

Dual-In-Line, Small Outline and Molded Mini Small Outline Packages



Top View

Ordering Information

Package	Part Number	Package Marking	Media Transport	NSC Drawing
8-Pin SOIC	LM555CM	LM555CM	Rails	M08A
	LM555CMX	LM555CM	2.5k Units Tape and Reel	
8-Pin MSOP	LM555CMM	Z55	1k Units Tape and Reel	MUA08A
	LM555CMMX	Z55	3.5k Units Tape and Reel	
8-Pin MDIP	LM555CN	LM555CN	Rails	N08E

Applications Information

MONOSTABLE OPERATION

In this mode of operation, the timer functions as a one-shot (Figure 1). The external capacitor is initially held discharged by a transistor inside the timer. Upon application of a negative trigger pulse of less than 1/3 V_{CC} to pin 2, the flip-flop is set which both releases the short circuit across the capacitor and drives the output high.

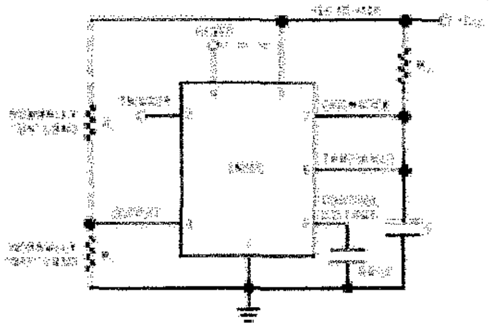


FIGURE 1. Monostable

The voltage across the capacitor then increases exponentially for a period of $t = 1.1\ R_A C$, at the end of which time the voltage equals 2/3 V_{CC}. The comparator then resets the flip-flop which in turn discharges the capacitor and drives the output to its low state. Figure 2 shows the waveforms generated in this mode of operation. Since the charge and the threshold level of the comparator are both directly proportional to supply voltage, the timing interval is independent of supply.

V_{CC} = 5V
TIME = 0.1 ms/DIV.
R_A = 9.1kΩ
C = 0.01µF

Top Trace: Input 5V/Div.
Middle Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 2V/Div.

FIGURE 2. Monostable Waveforms

During the timing cycle when the output is high, the further application of a trigger pulse will not effect the circuit so long as the trigger input is returned high at least 10µs before the end of the timing interval. However the circuit can be reset during this time by the application of a negative pulse to the reset terminal (pin 4). The output will then remain in the low state until a trigger pulse is again applied.

When the reset function is not in use, it is recommended that it be connected to V_{CC} to avoid any possibility of false triggering.

Figure 3 is a nomograph for easy determination of R, C values for various time delays.

NOTE: In monostable operation, the trigger should be driven high before the end of timing cycle.

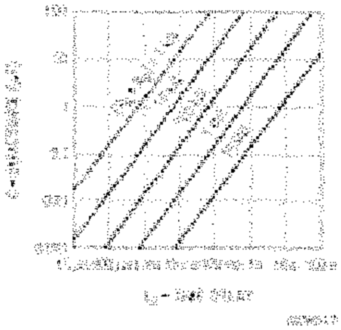


FIGURE 3. Time Delay

ASTABLE OPERATION

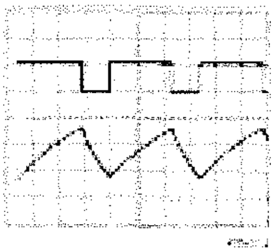
If the circuit is connected as shown in Figure 4 (pins 2 and 6 connected) it will trigger itself and free run as a multivibrator. The external capacitor charges through $R_A + R_B$ and discharges through R_B. Thus the duty cycle may be precisely set by the ratio of these two resistors.

FIGURE 4. Astable

In this mode of operation, the capacitor charges and discharges between 1/3 V_{CC} and 2/3 V_{CC}. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

Applications Information (Continued)

Figure 5 shows the waveforms generated in this mode of operation.



V_{CC} = 5V
TIME = 20μs/DIV.
R_A = 3.9kΩ
R_B = 3kΩ
C = 0.01μF

Top Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 1V/Div.

FIGURE 5. Astable Waveforms

The charge time (output high) is given by:

$$t_1 = 0.693 (R_A + R_B) C$$

And the discharge time (output low) by:

$$t_2 = 0.693 (R_B) C$$

Thus the total period is:

$$T = t_1 + t_2 = 0.693 (R_A + 2R_B) C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B) C}$$

Figure 6 may be used for quick determination of these RC values.

The duty cycle is:

$$D = \frac{R_B}{R_A + 2R_B}$$

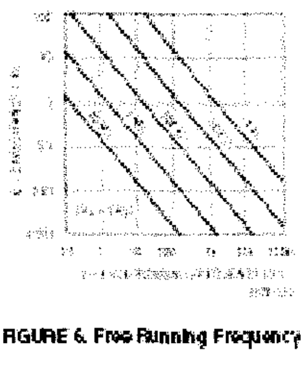
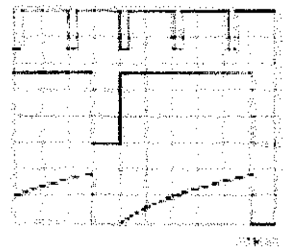


FIGURE 6. Free Running Frequency

FREQUENCY DIVIDER

The monostable circuit of *Figure 1* can be used as a frequency divider by adjusting the length of the timing cycle. *Figure 7* shows the waveforms generated in a divide by three circuit.



V_{CC} = 5V
TIME = 20μs/DIV.
R_A = 9.1kΩ
C = 0.01μF

Top Trace: Input 4V/Div.
Middle Trace: Output 2V/Div.
Bottom Trace: Capacitor 2V/Div.

FIGURE 7. Frequency Divider

PULSE WIDTH MODULATOR

When the timer is connected in the monostable mode and triggered with a continuous pulse train, the output pulse width can be modulated by a signal applied to pin 5. *Figure 8* shows the circuit, and in *Figure 9* are some waveform examples.

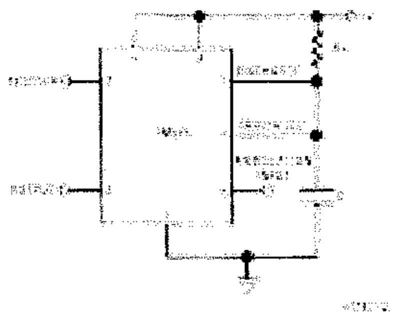
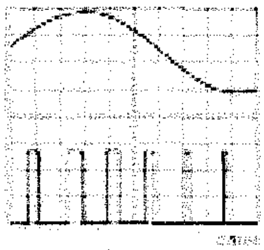


FIGURE 8. Pulse Width Modulator

Applications Information (Continued)



V_{CC} = 5V   Top Trace: Modulation 1V/Div.
TIME = 0.2 ms/DIV.   Bottom Trace: Output Voltage 2V/Div.
R_A = 9.1kΩ
C = 0.01µF

FIGURE 9. Pulse Width Modulator

PULSE POSITION MODULATOR

This application uses the timer connected for astable operation, as in Figure 10, with a modulating signal again applied to the control voltage terminal. The pulse position varies with the modulating signal, since the threshold voltage and hence the time delay is varied. Figure 11 shows the waveforms generated for a triangle wave modulation signal.

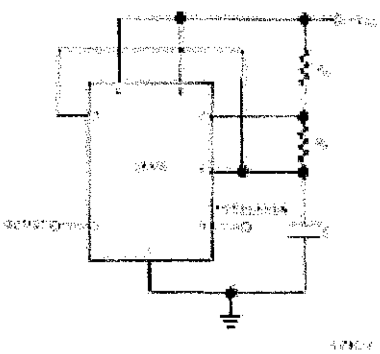
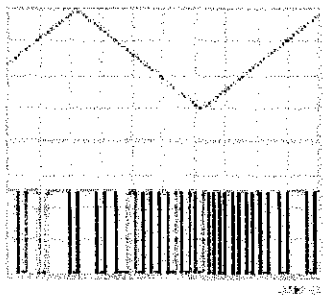


FIGURE 10. Pulse Position Modulator



V_{CC} = 5V   Top Trace: Modulation Input 1V/Div.
TIME = 0.1 ms/DIV.   Bottom Trace: Output 2V/Div.
R_A = 3.9kΩ
R_B = 3kΩ
C = 0.01µF

FIGURE 11. Pulse Position Modulator

LINEAR RAMP

When the pullup resistor, R_A, in the monostable circuit is replaced by a constant current source, a linear ramp is generated. Figure 12 shows a circuit configuration that will perform this function.

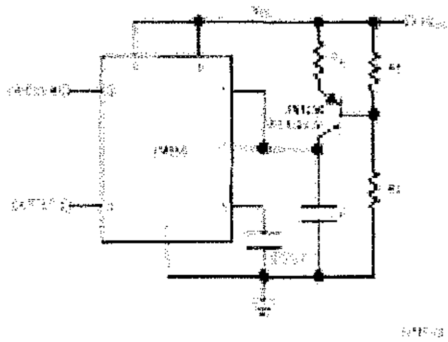


FIGURE 12.

Figure 13 shows waveforms generated by the linear ramp.

The time interval is given by:

$$T = \frac{\frac{2}{3} V_{CC} R_E (R_1 + R_2) C}{R_1 V_{CC} - V_{BE} (R_1 + R_2)}$$

$$V_{BE} \cong 0.6V$$

$$V_{BE} \cong 0.6V$$

APPENDIX C

National Semiconductor

August 2000

LM741

Operational Amplifier

General Description

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

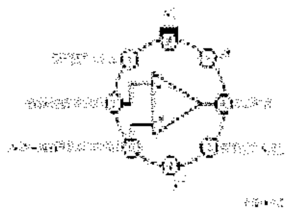
The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

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

Features

Connection Diagrams

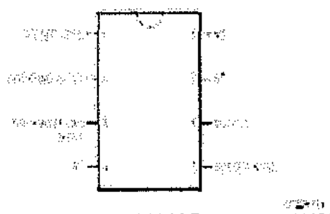
Metal Can Package



Note 1: LM741H is available per JM38510/10101

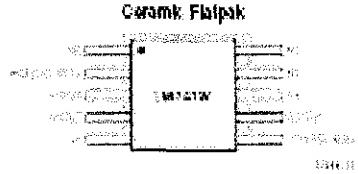
Order Number LM741H, LM741H/883 (Note 1), LM741AH/883 or LM741CH
See NS Package Number H08C

Dual-In-Line or S.O. Package



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

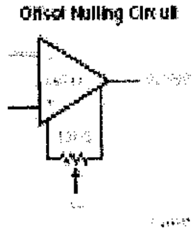
Ceramic Flatpak



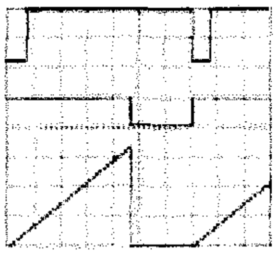
Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



Applications Information (Continued)



V_{CC} = 5V Top Trace: Input 3V/Div.
TIME = 20μs/DIV. Middle Trace: Output 5V/Div.
R_1 = 47kΩ Bottom Trace: Capacitor Voltage 1V/Div.
R_2 = 100kΩ
R_E = 2.7 kΩ
C = 0.01μF

FIGURE 13. Linear Ramp

50% DUTY CYCLE OSCILLATOR

For a 50% duty cycle, the resistors R_A and R_B may be connected as in Figure 14. The time period for the output high is the same as previous, $t_1 = 0.693\ R_A\ C$. For the output low it is t_2 =

$$\left[(R_A R_B)/(R_A + R_B)\right] C \ln\left[\frac{R_B - 2R_A}{2R_B - R_A}\right]$$

Thus the frequency of oscillation is

$$f = \frac{1}{t_1 + t_2}$$

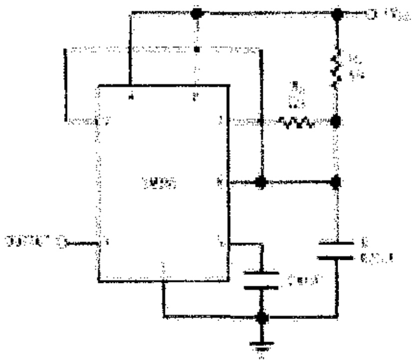


FIGURE 14. 50% Duty Cycle Oscillator

Note that this circuit will not oscillate if R_B is greater than 1/2 R_A because the junction of R_A and R_B cannot bring pin 2 down to 1/3 V_{CC} and trigger the lower comparator.

ADDITIONAL INFORMATION

Adequate power supply bypassing is necessary to protect associated circuitry. Minimum recommended is 0.1μF in parallel with 1μF electrolytic.

Lower comparator storage time can be as long as 10μs when pin 2 is driven fully to ground for triggering. This limits the monostable pulse width to 10μs minimum.

Delay time reset to output is 0.47μs typical. Minimum reset pulse width must be 0.3μs typical.

Pin 7 current switches within 30ns of the output (pin 3) voltage.

Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.
(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
N-Package (10 seconds)	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C

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

ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	$T_A = 25°C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25°C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V

Electrical Characteristics (Note 5) (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

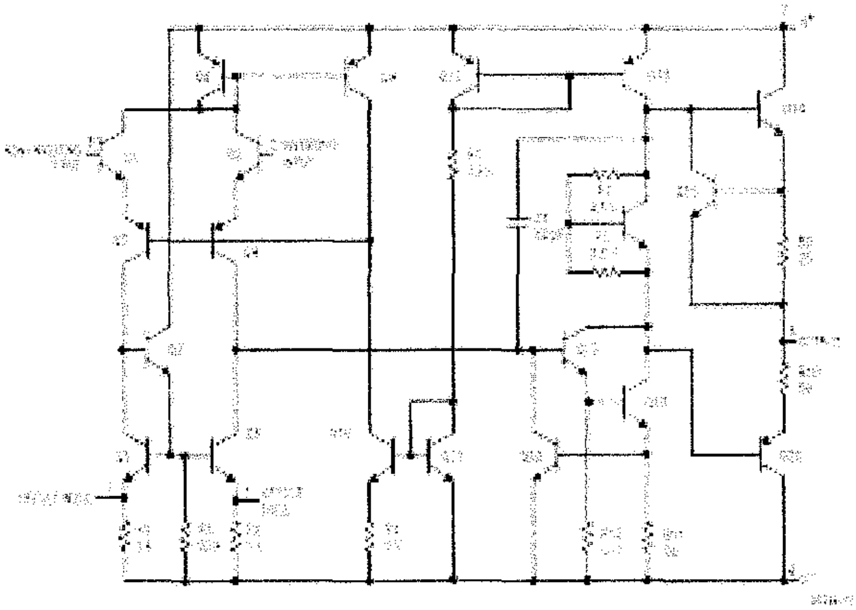
Note 5: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \le T_A \le +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \le T_A \le +70°C$.

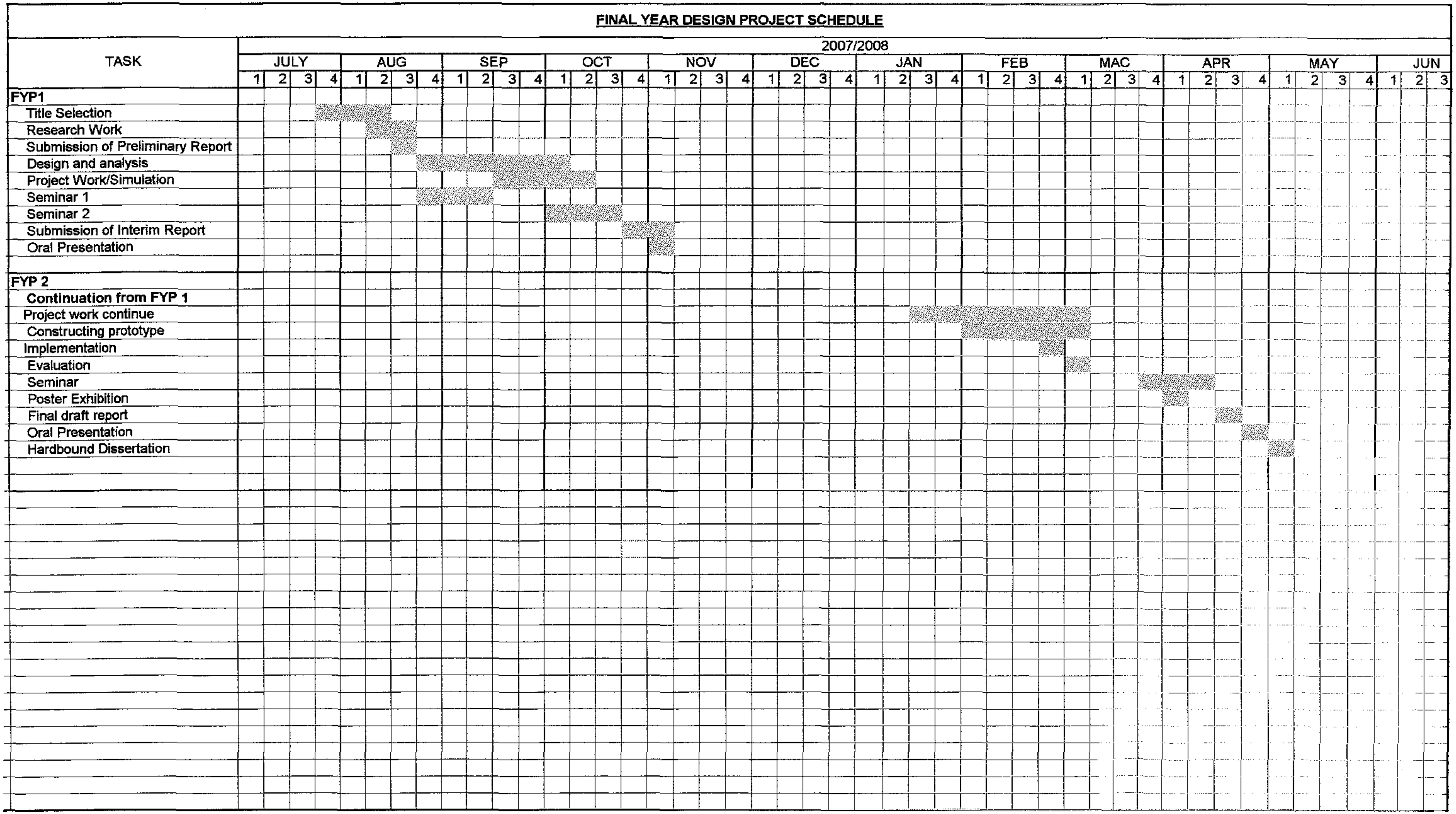
Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram




FINAL YEAR DESIGN PROJECT SCHEDULE
TASK
2007/2008
JULY
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAC
APR
MAY
JUN
1 2 3 4
FYP1
Title Selection
Research Work
Submission of Preliminary Report
Design and analysis
Project Work/Simulation
Seminar 1
Seminar 2
Submission of Interim Report
Oral Presentation
FYP 2
Continuation from FYP 1
Project work continue
Constructing prototype
Implementation
Evaluation
Seminar
Poster Exhibition
Final draft report
Oral Presentation
Hardbound Dissertation