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JUDUL: **TRANSMISSION MODE ULTRASONIC TOMOGRAPHY TO IDENTIFY LIQUID/SOLID FLOW REGIME**

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TOMOGRAPHY TO IDENTIFY LIQUID OR SOLID FLOW REGIME

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Electronics)

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Dengan Nama Allah yang Maha Pemurah lagi Maha Mengasihani

To my beloved and supported family

Muhamad bin Lambak

Siti Rohin binti Jusoh

And all my siblings

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ABSTRACT

This project is to develop a suitable ultrasonic tomography system that can identify water and solid flow regime. This project presents the application of the ultrasonic tomography in the process and chemical industries. The transmission mode with fan shaped beam projection had been implemented. The system is designing non-invasively that mean the composition in the system can be monitored without disturbing the nature of process in the pipe. The transmission mode for sensing purpose was implemented by using 4 sensors for transmitters and 4 sensors for receivers where 4x4 projections were produced. This project is divided into two parts which are hardware and software. The hardware part for electronic measurement circuit and fabrication of ultrasonic sensor. For software part is coding to micrcontroller and circuit design. The experiments had been conducted show that the suitable ultrasonic tomography system can identify water and solid flow regime.

ABSTRAK

Projek ini adalah untuk membuat sistem tomografi ultrasonik yang boleh mengenalpasti aliran cecair dan pepejal. Projek ini menbentangkan applikasi ultrasonik tomografi di dalam industri kimia dan proses. Kaedah pancaran dalam bentuk sinaran kipas secara balikan telah dilaksanakan dalam projek ini. Sistem ini direka tidak melibatkan sentuhan atau dengan erti kata lain maklumat mengenai komposisi di dalam sistem boleh didapati tanpa menggangu proses semula jadi ketika ujian sedang dijalankan. 4 biji pemancar dan 4 biji penerima yang bertujuan untuk menghasilkan 4 x 4 pancaran juga telah digunakan. Projek ini terbahagi kepada dua bahagian iaitu perkakasan dan perisian. Bahagian perkakasan bagi litar pengukuran elektronik dan fabrikasi pengesan ultrasonik. Bagi bahagian perisian adalah kod untuk kawalan mikrokontroller dan reka bentuk litar. Eksperimen telah dijalankan menunjukkan bahawa sistem tomografi ultrasonik yang sesuai boleh digunakan untuk mengenal pasti aliran pepejal dan cecair.

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LIST OF SYMBOLS

f	-	frequency
λ	-	wavelength
t	-	period
c	-	velocity
z	-	acoustic impedance
p	-	product of density
c	-	speed of sound
R	-	reflection coefficient
Pr	-	reflected wave sound pressure
Pe	-	Incident wave sound pressure
Pt	-	Transmitted wave sound pressure

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The purpose of this project is to develop a suitable ultrasonic tomography system that can identify water and solid flow regime. In the process and chemical industries, process to flow product in the pipe consists of multiphase flow likes liquid and solid. Sometimes, there has an error in the process because of impurities and other things was no need flow in the pipe, then flow process is not smooth. To solve the problem, process must be shutdown to maintenance it and it is take a long time and high cost. Tomography is the most beneficial technology to solve this problem because installation of ultrasonic tomography system will not disturb the process being examined or it called non invasive technique.

The transmission mode for sensing purpose was implemented by using four ultrasonic sensors as a transmitter and four ultrasonic sensors as a receiver where 4x4 projections was produced. This project is divided into two parts which are hardware and sofware. The data from hardware was transfer to osciloscope to be analyzed.

1.2 Objective of Project

The objective of this project is

1) To develope a suitable ultrasonic tomography system that can identify water and solid flow regime.

1.3 Scopes of Project

The scopes of this project are :

i. To develop a simple ultrasonic tomography system.
ii. To implement an electronic measurement system for ultrasonic tomography system.
iii. To implement microcontroller unit for controlling ultrasonic projection and sample and hold.

1.4 Organizing of thesis

The thesis consist of six chapters. In chapter 1, the discussion was more on the problem statement, objective of the project and scope of the project.

Chapter 2 present the literature review of tomgraphy. This chapter discuss about basic concept of tomography, types of tomography, and recent work related to ultrasonic tomography.

Chapter 3 present about ultrasonic tomography which is discuss about introduction of ultrasonic, principle of ultrasound, propagation of ultrasound,wavelength and frequency of ultrasound, acoustic impedance, sensing mode of ultrasonic and advantage of ultrasonic wave.

Chapter 4 is describing about methodology of this project. Explanation about hadware and software part this project were presented.

Chapter 5 present the results obtained from the test profile and experiment. The discussion based on the result obtained were explained detail.

For last chapter, chapter 7 was discussing the conclusion and recommendation for the future work that can be done for the future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic concept of tomography

Process Tomography is a process of obtaining the plane-section images of a Three dimensional object. Process Tomography techniques produce cross-section images of the distribution of flow components in a pipeline and it offers great potential for the development and verification of flow models and also for process diagnostic (Brown et al., 1996).

Tomography is a radiographic technique that select a level in the body and blur out structures below and above plane leaving a clear image of this selected anatomy. The simple concept is tomography record cross sectional image of selected layer.

2.2 Types of Tomography

There are several types process tomography such as electrical capacitance tomography (ECT), electrical impedance tomography (EIT) and Ultrasonic Tomography.

2.2.1 Electrical Capacitance Tomography (ECT)

Capacitance sensors are now widely used for industrial two-component flow measurement. The basic technique of ECT can be described by considering a parallel plate capacitor. Electrical capacitance tomography (ECT) is a method for determination of the dielectric permittivity distribution in the interior of an object from external capacitance measurements. It is a close relative of electrical impedance tomography and it is proposed as a method for industrial process monitoring, although it has yet to see widespread use. The capacitance between these plates is dependent upon the dielectric permittivity, the area of the plates and the distance between those plates (Xie et al., 1992).

2.2.2 Electrical Impedance Tomography (EIT)

EIT is the most sophisticated impedance sensing system used on electrically conducting materials. Electrical impedance tomography (EIT) is a medical imaging technique in which an image of the conductivity or permittivity of part of the body is inferred from surface electrical measurements. EIT were originally developed for clinical application (Davidson et. al., 2004). Electrodes are placed equidistantly into the vessel wall at fixed location. In such way, they make electrical contact with the fluid inside the vessel but do not affect the normal mass transfer within the process. Based on the obtained measurement, the image reconstruction that changes with time can be performed. This technique is being applied to industrial process environment where the process uses conducting fluid to carry immiscible fluids and solids, which contain different bulk conductivity.

2.2.3 Ultrasonic Tomography

Ultrasonic sensors have been successfully applied in flow measurement nondestructive testing and it is widely used in medical imaging (Hoyle and Xu, 1995). The method involves in using ultrasonic is through transmitting and receiving sensors that are axially spaced along the flow stream. Ultrasonic sensor propagates acoustic waves within range of 18 kHz to 20 MHz. There are two types of ultrasonic signals that are usually used. They are the continuous signal and the pulsed signal (Hoyle, 1996). The pulsed system will be used to avoid the standing wave patterns that can exist within the pipes. The potential benefits are, it is possible to gain an insight into the actual, secondly since ultrasonic tomography is capable on-line monitoring, it is opportunity to develop closed loop control systems and finally it can be non-invasive and possibly non-intrusive system.

2.3 Recent Work Related to Ultrasonic Tomography

Nowadays, research about ultrasonic tomography is increasing time by time. There are recent work related to the ultrasonic tomography had been published.

Zhong Xi Fu, Wu Xi Xiang, Li et.al (2005), presents about specification, measurement principle and application of Ultrasonic Tomography Tool (UTT). UUT is a device that widely used in the oil industry and can be used to inspect corrosion, casing wall damage, casing break off, and casing distortion in the well borehole with the maximum environment temperature being 125 °C and the pressure being 60 Mpa. UUT can be used to solve that problem. There are application of UUT are for calibration test, to check damage and caving in the casing wall, to check break off in the casing wall, to check bend distortion of the casing and inspection the quantity of perforation.

Mohd Hafiz, Ruzairi, et.al (2006) present about the development of non-invasive ultrasonic tomography for imaging liquid and gas flow. The transmission-mode approach has been used for sensing the liquid or gas two phase flow. 16-pair of ultrasonic sensors have been used which are 16 transmitter and 16 transceiver. By using low excitation voltage 20 V, fan shape beam transmitter will emit ultrasonic pulse to receiver. The algorithm used to reconstruct the concentration profile for two phase flow using a fan shaped beam scanning geometry. Hybrid-binary reconstruction algorithm was used to develop a real time ultrasonic transmission mode tomography. They also shows the comparison between hybrid-binary reconstruction (HBR) algorithm and linear back projection (LBP) algorithm. The advantage using HBR algorithm is HBR algorithm improving stability and repeatability of reconstruction image, eliminate unused sensitivity and create a binary picture.

Ruzairi, Ng Wei Nyap And Mohd Hafiz (2007) present about the hardware development of ultrasonic tomography system used for monitoring the composition of water and oil flow. The ultrasonic tomography system consist of the sensor fixture design, signal conditional circuit and image reconstruction software. The design of the transmitter circuit is to transmit the ultrasonic waves while the design of the receiver circuits are to measure the delay propagation time of receiver circuits. Measurements from the receiver circuit are captured into the computer by using the DAS card. The image reconstruction algorithm got by using linear back projection algorithm.

Nor Muzakir, Mohd Hafiz et.al (2010) present a developement of an ultrasonic transmission mode tomography system for the detection small gas bubble using higher frequency ultrasonic sensor. Developement of ultrasonic tomography system use 16 pair of ultrasonic sensor and fixed inside a sensor jig which is designed to hold all the sensors. From their result, the higher frequency of the ultrasonic transducer, the better sensitivity but lower penetration depth. By using ultrasonic sensors with center frequency of 333 kHz, it can detect small test tube and able to succesfully reconstruction the image for small gas detection.

CHAPTER 3

ULTRASONIC TOMOGRAPHY

3.1 Introduction of Ultrasonic

Ultrasonic waves are high ("ultra") frequency sound ("sonic") waves: they vibrate at a frequency above 20 kHz which are too fast to be audible to humans (shull, 2002). Ultrasonic devices are used in many fields of measurement, particularly for measuring fluid flow rates, liquid levels and translational displacements. Ultrasonic is the name given to the study and application of ultrasound, which is sound of pitch too high to be detected by the human ear, especially of frequencies greater than 20 kHz. Naturally, ultrasound occurs in the surroundings where animals such as bats, dolphins and whales are the best-known practitioners of ultrasound.

3.2 Principle of Ultrasound

There are four basic principle that are used in this project which are propagation, wavelength and frequency of ultrasound, acoustic impedance and attenuation of the ultrasound.

3.3 Propagation of Ultrasound

Ultrasonic testing is based on vibrations in materials, which is generally referred to as acoustics. All material substances are comprised of atoms, which may be forced into vibrational motion about their equilibrium positions. Acoustics is focused on particles that contain many atoms that move in unison to produce a mechanical wave. In solids, sound waves can propagate in four principle modes that are based on how the particles oscillate. Sound can propagate as longitudinal waves, shear waves, surface waves, and in thin materials as a plate waves. Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. The particle movement responsible for the propagation of longitudinal and shear waves is illustrated in figure 3.1. In longitudinal waves, the oscillations occur in the longitudinal direction or the direction of wave propagation. In the transverse or shear wave, the particles oscillate at a right angle or transverse to the direction of propagation.

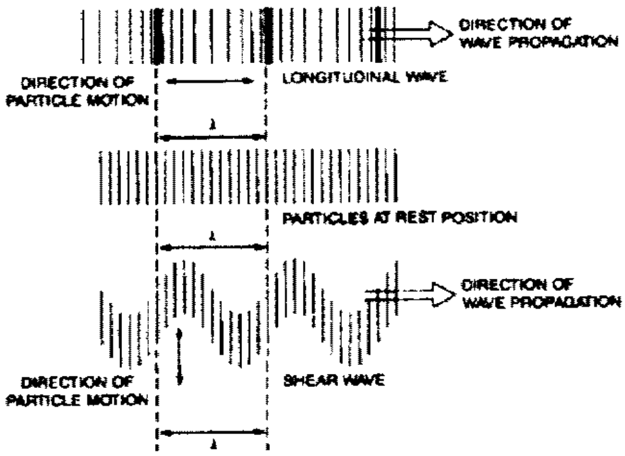

Figure 3.1 : Direction of wave propagation for Longitudinal wave and Transerve wave.

3.4 Wavelength and Frequency of Ultrasound

Ultrasound travels in the form of a wave, similar to the way light travels. However, unlike light waves, which can travel in vacuum, ultrasound requires elastic medium such as solid and liquid to travel. The wavelength, λ is the length of a complete cycle for the ultrasound while the period, *T* is the time taken to complete a full cycle of the ultrasound and measured in seconds (Blitz, 1971). The number of cycles completed in one second is called frequency, *f* and is measured in Hertz (Hz). The relationship between period, T and frequency,f of a continuous wave of ultrasound as shown as follow:

$$f = \frac{1}{T} \qquad \text{(equation 3.1)}$$

The wavelength is directly proportional to the velocity,c of the wave and inversly proportional to the frequency of the wave. The relationship is shown as follow:

$$c = f\lambda \qquad \text{(equation 3.2)}$$

3.5 Acoustic Impedence

Acoustic impedence is a term that used to described the interaction of Ultrasound with material (Ruzairi 2007). The equation for acoustic impedance,z is equal to product of density, *p* and speed of sound,c. The equation given as follow:

$$z = \rho c \qquad \text{(equation 3.3)}$$

The importance to know the acoustic impedance is as follows:

(i) The determination value of acoustic transmission and reflection at the boundary of two materials that have different acoustic impedance.

(ii) The design of ultrasonic transducers.

(iii) The absorption assessment of sound in a medium

If the difference in impedance at the interface is greater, the amount of energy reflected will also be greater. The reflection and transmission coefficient (Ruzairi, 2008) as given as follows:

Reflection coefficient, $R = \frac{Pr}{Pe} = \left[\frac{Z_2 - Z_1}{Z_2 + Z_1}\right]$ (equation 3.4)

Transmission coefficient, $T = R = \frac{Pt}{Pe} = \left[\frac{2Z_2}{Z_2 - Z_1}\right]$ (equation 3.5)

In this project, a related impedance of materials had been chosen. Table 3.1 shows the acoustic impedance of materials.

Tabel 3.1 : Acoustic Impedance of materials

Medium	**Material**	**Acoustic Impedance, $Z(kg/m^2s)$**
Experimental column	PVC pipe	3.27×10^6
Liquid	Water	1.5×10^6
Solid	Steel	45.8×10^6
Solid	Ceramics/porcelain	13.4×10^6

It is very important to know the ultrasonic propagation in all material. Instead, the reflection and transmission of the ultrasonic propagation between two materials can been known. By presumptuous the ultrasonic energy losses between transducer coupling/ PVC pipes are zero, the investigations of ultrasonic wave propagation for such array are described as follow :

i. Ultrasonic wave propagation from pvc pipe into liquid media

Given that the acoustic impedance of PVC pipe is $Z_1 = 3.27 \times 10^6\ \mathrm{kg/m^2}$ and for water is $Z_2 = 1.5 \times 10^6\ \mathrm{kg/m^2}$. By using equation 3.4 and 3.5 the calculation of R and T shown as below :

$$R_{(PVC/water)} = \left[\frac{1.5 \times 10^6 - 3.27 \times 10^6}{1.5 \times 10^6 + 3.27 \times 10^6}\right] = -0.3711 \Rightarrow -37.11\%$$

$$T_{(PVC/water)} = \left[\frac{2 \times 1.5 \times 10^6}{1.5 \times 10^6 + 3.27 \times 10^6}\right] = 0.6289 \Rightarrow 62.89\%$$

The negative sign indicates the reversal of the phase relative to the indicate wave.

ii. Ultrasonic wave propagation from liquid into solid media

a) Acoustic impedance of water is $Z_1 = 1.5 \times 10^6\ \mathrm{kg/m^2}$ and steel is $Z_2 = 45.8 \times 10^6\ \mathrm{kg/m^2}$. Thus the value of R and T are :

$$R_{(water/copper)} = \left[\frac{45.8 \times 10^6 - 1.5 \times 10^6}{45.8 \times 10^6 + 1.5 \times 10^6}\right] = 0.9365 \Rightarrow 93.65\%$$

$$T_{(water/copper)} = 100\% - 93.65\% = 6.35\%$$

It shows that almost more than 90% ultrasonic wave will be reflected when it propogate from liquid to solid media.

b) Acoustic impedance of water is $Z_1 = 1.5 \times 10^6\ \mathrm{kg/m^2}$ and ceramics is $Z_2 = 13.4 \times 10^6\ \mathrm{kg/m^2}$. Thus the value of R and T are :

$$R_{(water\ /cerami\ cs)} = \left[\frac{13.4 \times 10^6 - 1.5 \times 10^6}{13.4 \times 10^6 + 1.5 \times 10^6}\right] = 0.7987 \Longrightarrow 79.87\%$$

$$T_{(water\ /copper\ )} = 100\% - 79.87\% = 20.13\%$$

It shows that almost more than 70% ultrasonic wave will be reflected when it propogate from liquid to solid media.

3.6 Sensing mode of Ultrasonic

In ultrasonic tomography, it is require an ultrasonic generator, transducers to transmit and receive ultrasonic waves and a computerized imaging processing system. They are three sensing modes of ultrasonic :

1. Transmission mode.
2. Reflection mode.
3. Diffraction sensing mode.

In the transmission mode, this approach is assumes straight ray propagation. The projections are collected using separate sending and receiving transducers. There are several interaction are possible. Each projection may comprise the amplitude, phase or time of flight of the signal received.

For reflection sensing mode, it is also assumes straight line projection like the first mode. The ultrasound waves are transmitted into the object and reflected due to inhomogeneity of the acoustic properties in the medium. The reflected wave can measure and used for image reconstruction. In this mode, each projection contains spatial position information as well as amplitude information, so the reconstruction algorithm may be slightly different than that of the transmission mode.

In diffraction mode, small perturbation approximations are usually employed to solve the wave equation for weakly inhomogeneous objects, where the scattered signal within the scattered field can be neglected.

3.7 Advantage of Ultrasonic Wave

Ultrasonic waves obey the same basic laws of wave motion as lower frequency sound waves. However, they have the following advantages:

i. Non intrusive discrete distances to moving objects can be detected and measured.
ii. Less affected by target materials and surfaces and not aflected at all by colour.
iii. Solid-state units virtually unlimited, maintenance free life.
iv. Can detect small objects over long operating distances.
v. High frequency waves have shorter wavelengths. This means that diffraction around an obstacle of given dimension is correspondingly reduced.
vi. Resistance to external disturbances such as vibration, infrared adiation, ambient noise and EM1 radiation.

CHAPTER 4

METHODOLOGY

4.1 Introduction of Ultrasonic Tomography system

This project is consist of hardware system and software system and designed like a figure 4.1. The hardware system consist of ultrasonic sensor setup and electronic measurement setup. The programming for microcontroller unit was implemented in the software system.

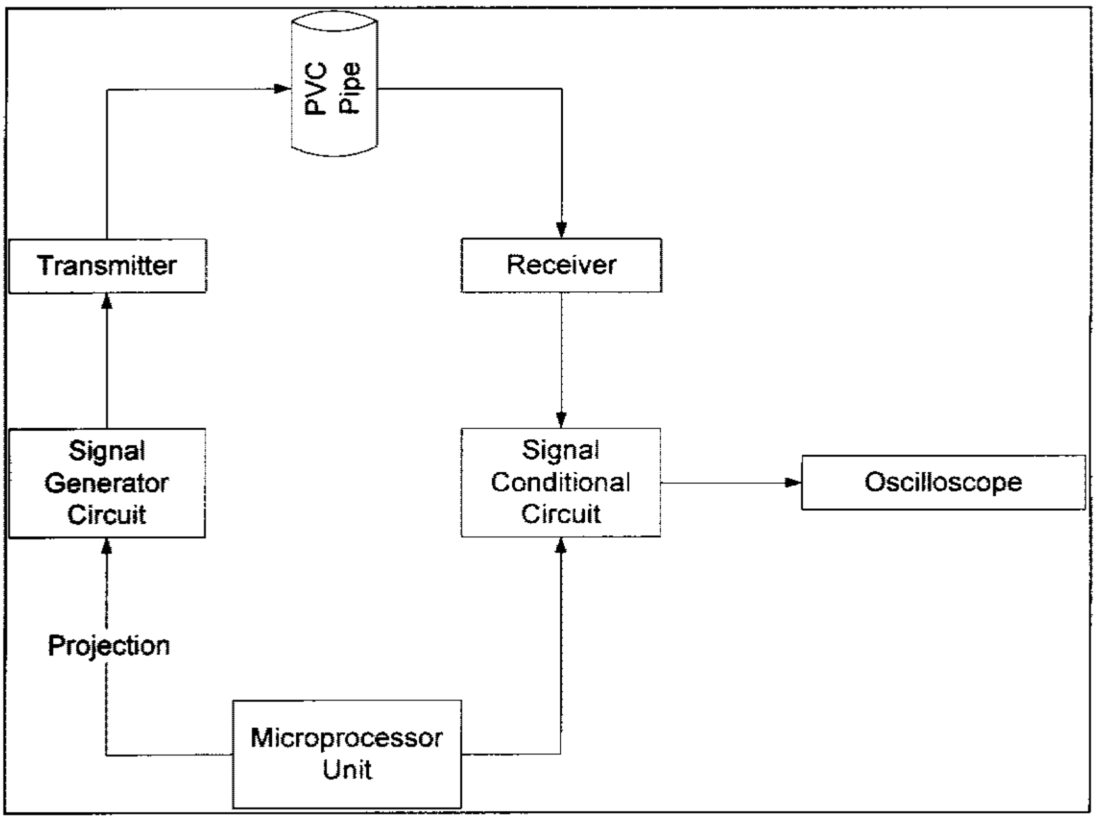

Figure 4.1 : Ultrasonic Tomography System

The hardware system includes signal generator circuit, signal conditional circuit and microcontroller unit. Microcontroller was used to transmit and control the projection of 40 kHz pulses to the signal generator circuit. Signal generator function as a comparator. Then, the signal generator circuit will transmit the signal to the transmitter. After transmitter transmit the ultrasonic wave through the pipe, then the signal will received by receiver. The received signals will then amplify to an appropriate voltage level.

4.2 Hardware System

In this part, the ultrasonic sensor setup and electronics measurement circuit were be pay attention.

4.2.1 Ultrasonic Sensor Setup

By using transmission mode and fan shape beam projection technique, the 8 sensors consist of 4 transmitters and 4 receivers were put side by side non-invasively along the periphery of the outer of pipe wall. The fan shape beam geometry firstly introduced by Xu et. al. in 1997. The fan shape beam is chosen because of the cover area will be bigger for receiver to receive a signal that transmit by transmitter. The figure for 4 transmitter and 4 receivers sensor arrangement shows in figure 4.2.

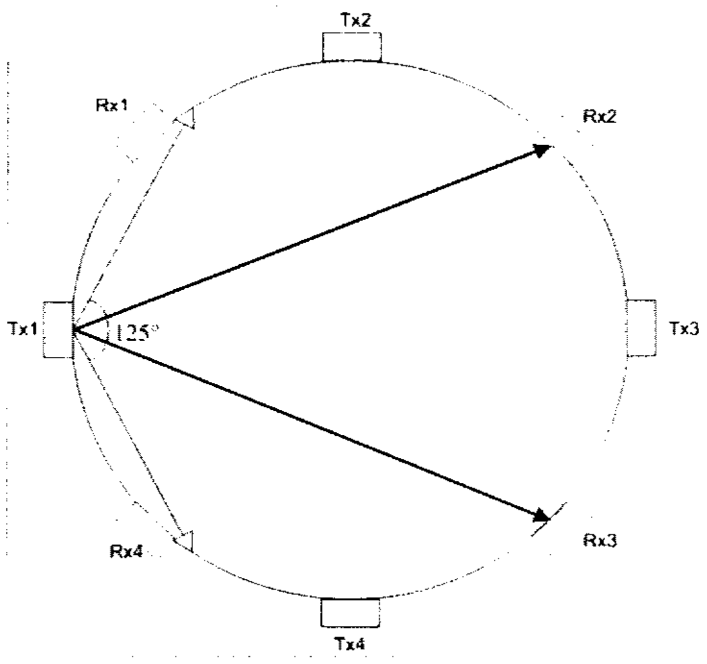

Figure 4.2 : Sensor arrangement and diverging area.

4.2.2 Ultrasonic Transducer

In this project, a choosen of ultrasonic transducer must have a several criterias such as total beam angle, center frequency, maximum driving voltage and easy to mounting and coupling work. For this project, air ultrasonic ceramic transducer, model 400ET/R080 from Prowave Electronic Corporation was choose because of its characteristic. Firstly, it is closed face construction that useful for ease the mounting and coupling work. Secondly, it is durable, sealed construction protects against water, heat, humidity and other elements and lastly is environmental rugged. Then it capable of driving up 15V rms with diverging angle of 125 degree. Figure 4.2 above show direction of diverging area.

4.2.3 Fabrication of Ultrasonic Transducer

The idea of this project, the ultrasonic transducers are implemented non-invasively. A several technique had been planed before preserve with the real hardware. The final design had been chosen with position of pipe was in vertical as shown in figure 4.3.

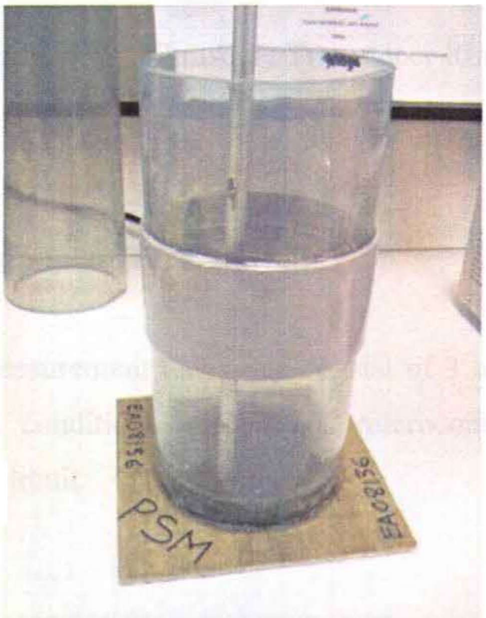

Figure 4.3 : Fabrication of Ultrasonic Transducer

The tranducer ring as shown as figure 4.4 was made by soft rubber with inner diameter of ring is 11.5 cm. Acrylic pipe is used for this experiment to get clear condition of material in the pipe. Size for acrylic pipe used as shown as figure has outer diameter of 11.5 cm and inner diameter is 10 cm. To avoid effect of air gap between acrylic pipe and sensor, greese oil was used. Because of the mediums are liquid and solid, silicon glue was used to make sure there is no leaking at the bottom of pipe.

Figure 4.4 : Ultrasonic Transducer Ring

4.2.4 Electronic Measurement Technique

The electronic measurement technique consist of 3 circuits which are signal generator circuit, signal conditional circuit and microcontroller unit. Figure 4.5 shows the measurement circuit.

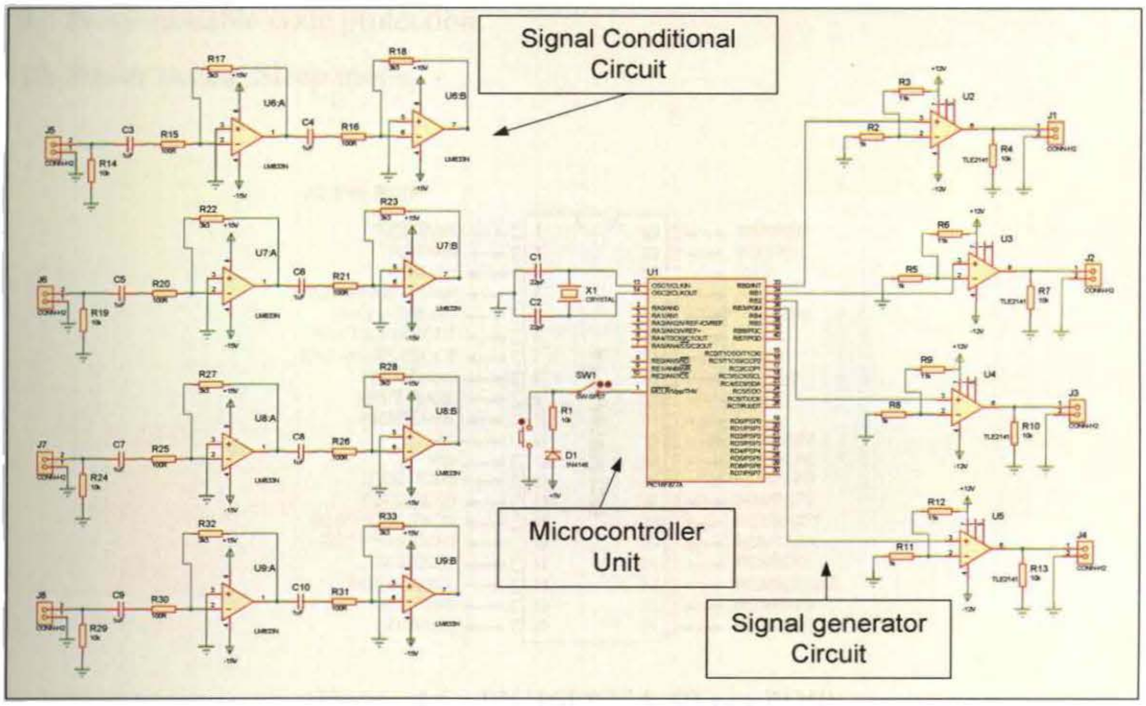

Figure 4.5 : Schematic for Electronic measurement circuit

4.2.4.1 Microcontroller Unit

Microcontroller act as a master controller for the hardware system. The function of microcontroller is to control signal holding circuit, and as a switching circuit for transmitter channel selection for signal generator circuit. In this project, the PIC 16F877A from Microchip Technology will chosen as shown as figure 4.6. There are some reason for choosing this microchip which are :

1. Only 35 single-word instructions to learn.
2. Operating speed: DC – 20 MHz clock input DC – 200 ns instruction cycle.
3. Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory.
4. Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers.
5. 100,000 erase/write cycle Enhanced Flash program memory typical.
6. 1,000,000 erase/write cycle Data EEPROM memory typical.
7. Self-reprogrammable under software control In-Circuit Serial Programming (ICSP) via two pins.
8. Single-supply 5V In-Circuit Serial Programming.
9. Programmable code protection.
10. Power saving Sleep mode.

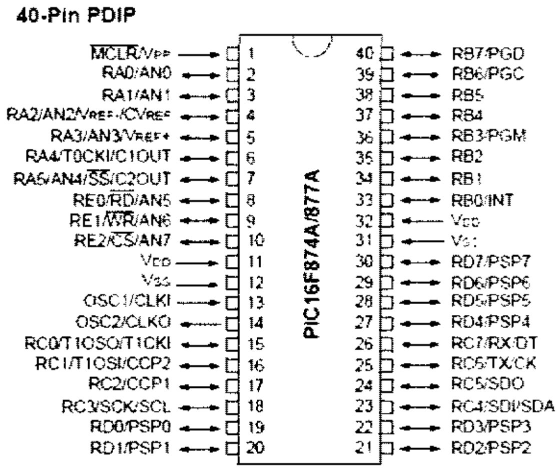

Figure 4.6 : PIC16F877A 40-pin PDIP

The comparison between PIC16F877A with other PIC16F87XA device family shown at table 4.1 :

Table 4.1 : PIC16F87X device family

Device	Program Memory		Data SRAM (Bytes)	EEPROM (Bytes)	I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8/16-bit	Comparators
	Bytes	# Single Word Instructions						SPI	Master I^2C			
PIC16F873A	7.2K	4096	192	128	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F874A	7.2K	4096	192	128	33	8	2	Yes	Yes	Yes	2/1	2
PIC16F876A	14.3K	8192	368	256	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F877A	14.3K	8192	368	256	33	8	2	Yes	Yes	Yes	2/1	2

The schematic diagram and real circuit of microcontroller unit was shown in figure 4.7 and figure 4.8. The output of microcontroller unit that produce +5V voltage and 40 kHz frequency that has been programmed using PIC C Complier as shown as figure 4.9.

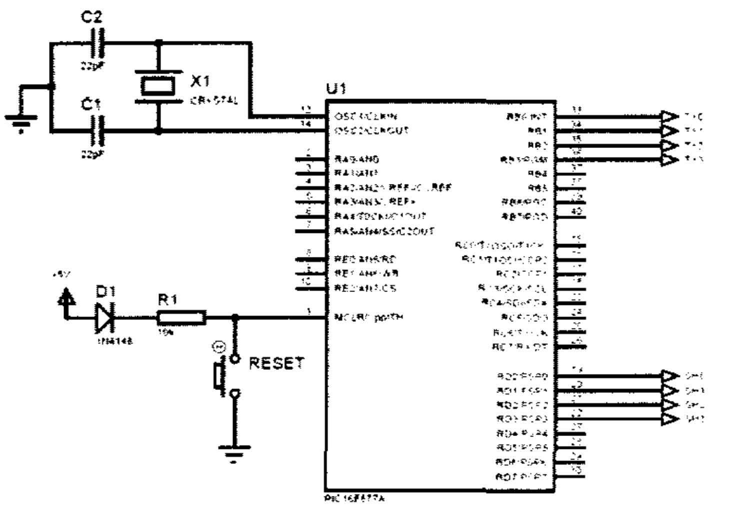

Figure 4.7 : Schematic Diagram of Microcontroller Unit

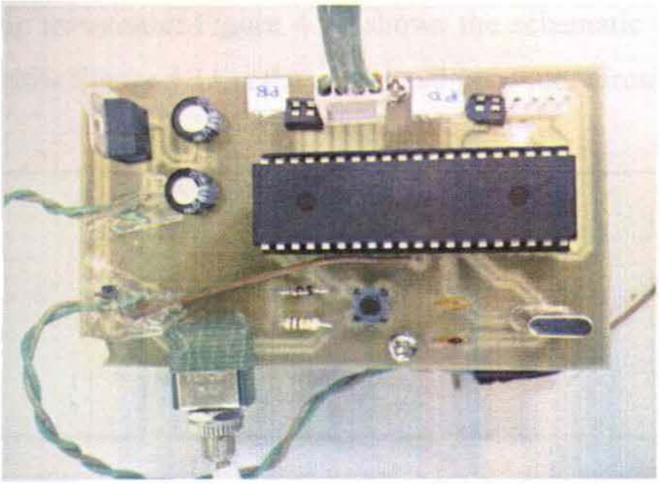

Figure 4.8 : Real Circuit of Microcontroller Unit

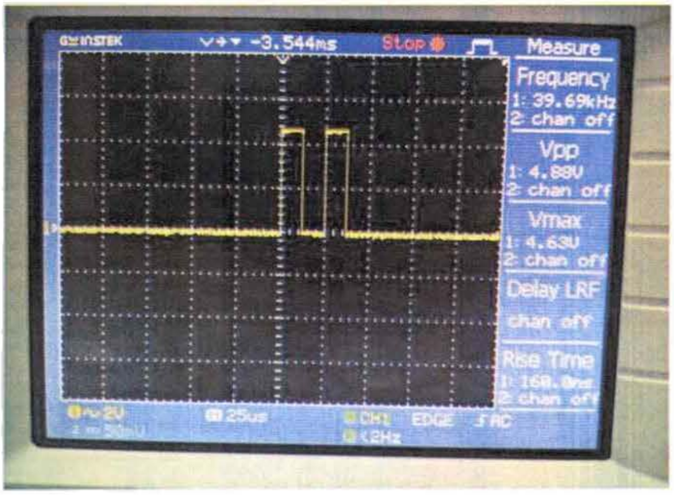

Figure 4.9 : Output of Microcontroller Unit

4.2.4.2 Signal Generator Circuit

For signal generator circuit, the excalibur low noise high speed precision amplifiers or low noise speed op-amp, IC TLE2141CP from Texas Instrument was selected to be implementing as a comparator in the signal generator circuit. The purpose of signal generator circuit is to generate a frequency 40 kHz at every 100 Hz or 10ms delay. Figure 4.10 show the signal generated by transmitter. Without this delay time, the reverberation effects will totally finish before new excitation is activated and can avoid the overlapping echoes at receiver. Figure 4.10 show the signal generated by transmitter.Figure 4.11 shows the schematic diagram of signal generator circuit while Figure 4.11 is the real signal generator circuit.

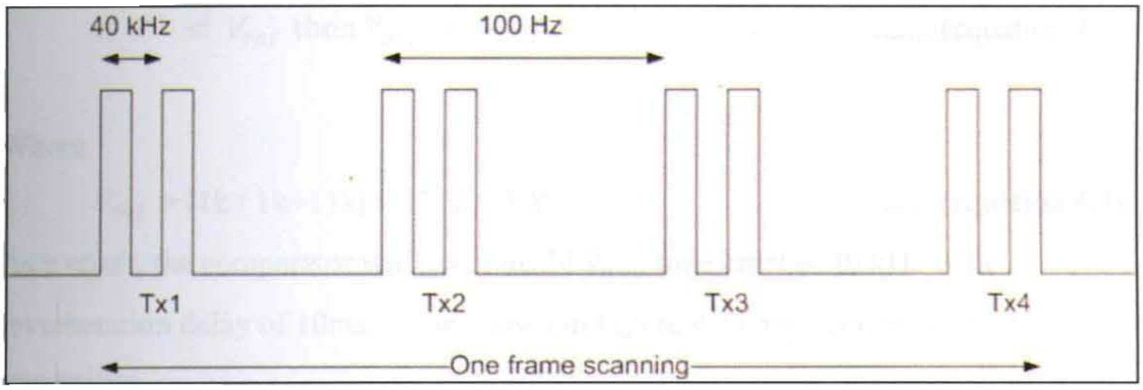

Figure 4.10 : Generated signal by transmitter.

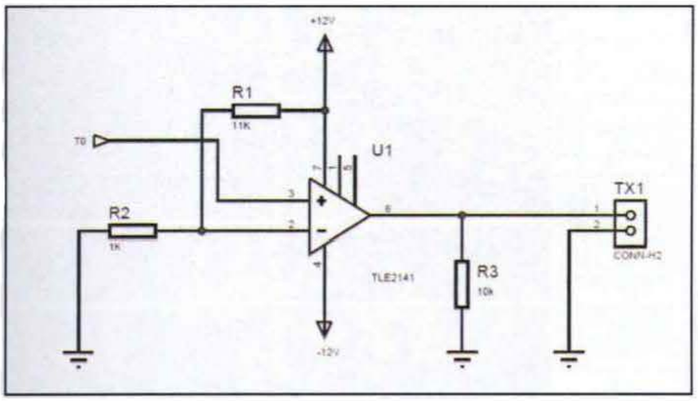

Figure 4.11 : Schematic diagram of Signal Generator Circuit

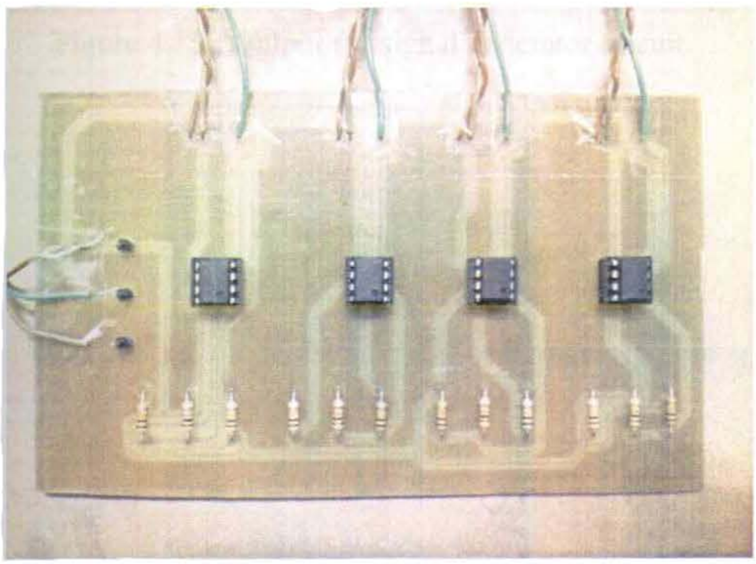

Figure 4.12 : Real Signal Generator Circuit

The comparator was designed such that :

If $V^{+} > V_{ref}$ then $V_{out} = +V_{cc}$ (equation 4.1)

If $V^{+} < V_{ref}$ then $V_{out} = -V_{cc}$ ....(equation 4.2)

Where

V_{ref} = (1k / 1k+11k) x 12 V = 1 V ....(equation 4.3)

As a result, the comparator will generate 24 V_{p-p} tone burst at 40 kHz with reverberation delay of 10ms. It can shown in Figure 4.13 after connected with transmitter.

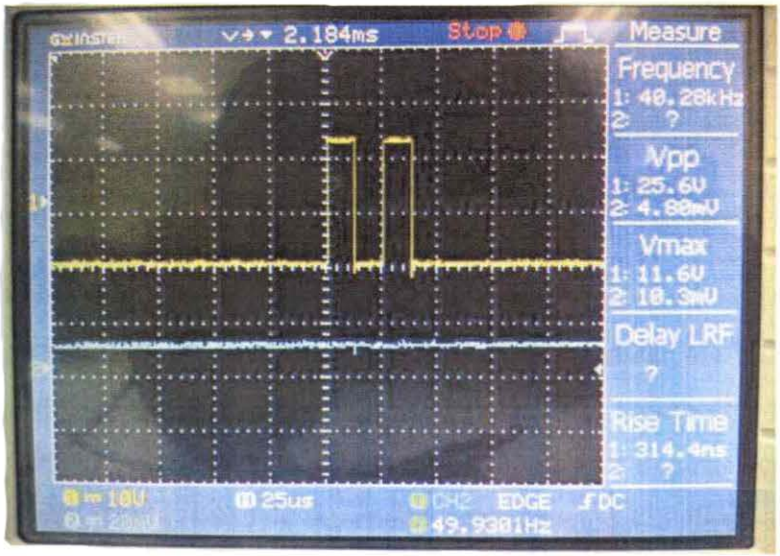

Figure 4.13 : Output for signal generator circuit.

4.2.4.3 Signal Conditioning Circuit

Signal conditonal circuit consist of two part which are the amplifier part and sample and hold part as shown in Figure 4.10.

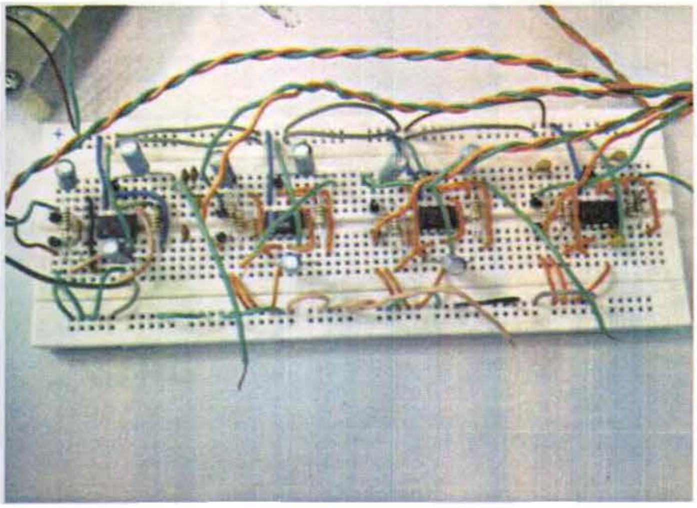

Figure 4.14 : Real Signal Conditional Circuit

For amplifier part, dual audio operational amplifier, LM833 from Motorola was use because of the high speed op-amp with excellent phase margin and stability. This dual amplifier IC utilizes new circuit and processing techniques to deliver low noise, high speed and wide bandwidth without increasing external components or decreasing stability. The LM833 is internally compensated for all closed loop gains and is optimizing for all preamp and high level stages in HiFi systems. The LM833 is pin-for-pin compatible with industry standard dual operational amplifiers.

Function of amplifier part is to get voltage gain. It was designed in two stage inverting amplifier with gain for every stage is -33. Thus, it produces a gain with 1089. The value of gain voltage is important in order to keep the signal always in the safety mode. If not, it will influence the signal to clip at positive and negative saturation level. This schematic diagram of amplifier circuit is shown in figure 4.15 and example output of signal from signal conditional circuit that represent in blue color is shows in figure 4.16.

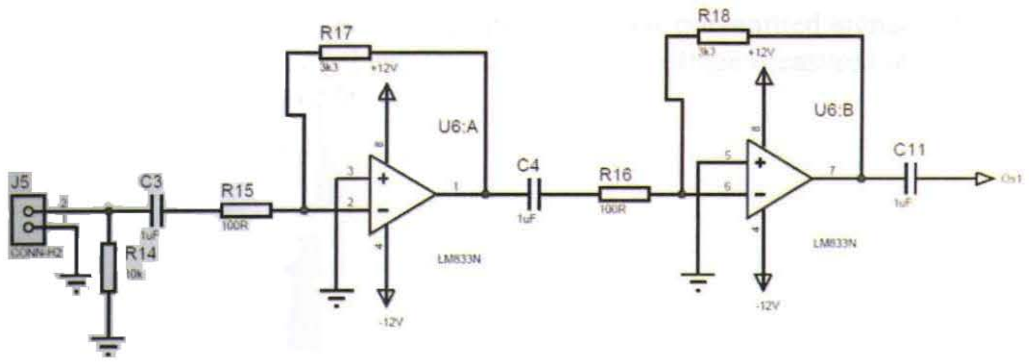

Figure 4.15 : Schematic diagram of two stage of inverting amplifier

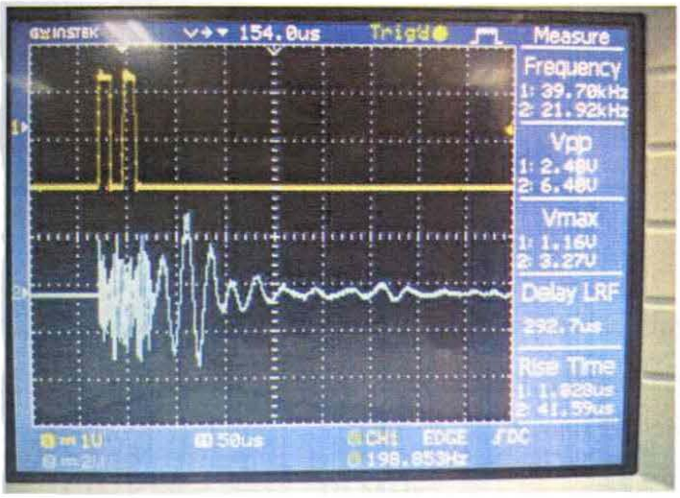

Figure 4.16 : Example output signal conditioning circuit

In this part, the value of time of flight and the first highest peak of signal was measured. Figure 4.17 shows the measurement technique to get value of time of flight and first highest peak voltage from the received signal.

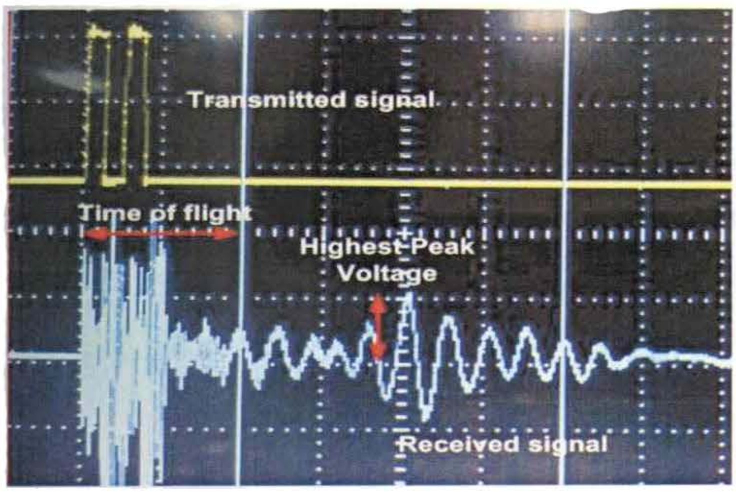

Figure 4.17 : Measurement technique of receiver signal

The time of flight measured starting from first transmitted signal pulse to the first signal received at the receiver. The first highest voltage measured at first highest peak voltage at the received signal.

4.3 Software Systems

The softwares will use for this project are Proteus Professional 7.8 for designing and simulating circuit and PIC C Compiler for programming the microcontroller.

4.3.1 Timing in Programming.

Time for one time execute is important to get precise time fram for each controlled instruction to microcontroller. For this project, 10Mhz crystal oscillator is used.

Clock Frequency : 10 MHz

$$\text{Instruction Time} : \frac{4}{\text{Clock Frequency}} = \frac{4}{10\ \text{MHz}} = 0.4\ \text{us}$$

4.3.2 Signal Projection

The purpose of signal projection is to produce dual pulse 40 kHz waveform at every 100 Hz. Programming to produce this pupose was apply by using PIC C complier programmer. Example of program for channel one transmitter is shown in figure 4.17.

```
output_b 0x01
delay_us 9

output_b 0x00
delay_us 9

output_b 0x01
delay_us 9

output_b 0x00
delay_us 9
```

Figure 4.18 : Program for channel 1 Transmitter

Port B was used as a transmitter port with :

PortB0=Channel 0
PortB1=Channel 1
PortB2=Channel 2
PortB3=Channel 3

4.3.3 Signal Conditioning

After receiver receive the signal from transmitter, the signal was sent to signal conditional circuit. This process is important to get the value of apropriate time of flight (TOF) and the first highest peak of signal. TOF were considered just after the signal is projected by transmitter.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

Some experiments have been conducted in this project. The purpose of the experiments is conducted to find out whether there are any changes in the graph in the oscilloscope in term of different materials used. The signals from one transmitter's channel in the corresponding receiver's channel are taken using a digital oscilloscope and being captured to provide a better view during the analysis session. Material used for liquid and solid medium as shown in Table 5.1. The acoustic impedance of PVC pipe that used for this purpose was neglected so that the ultrasonic can penetrate through PVC pipes.

Table 5.1 : Material used for the project.

Medium	Material	Size (mm)
Liquid	Water	
Solid	Ceramics/porcelain	21 x 14
Solid	Steel	19 x 12

5.2 Result for full liquid with solid

Based on the table 5.1, the material is used are water as a liquid medium and ceramics and steel as a solid medium.

5.2.1 Water

From the data take from experiments in the table 5.2 and 5.3, graph for first highest peak value of receivers and time of flight for water was plotted as shown as Figure 5.1 and 5.2.

Table 5.2 : First highest peak value at receivers (water) (mV)

	Tx1	Tx2	Tx3	Tx4
Rx1			520	500
Rx2	760			540
Rx3	720	500		
Rx4		520	520	

Table 5.3 : Time of flight (water) (μs)

	Tx1	Tx2	Tx3	Tx4
Rx1			108	109
Rx2	99			110
Rx3	100	105		
Rx4		101	108	

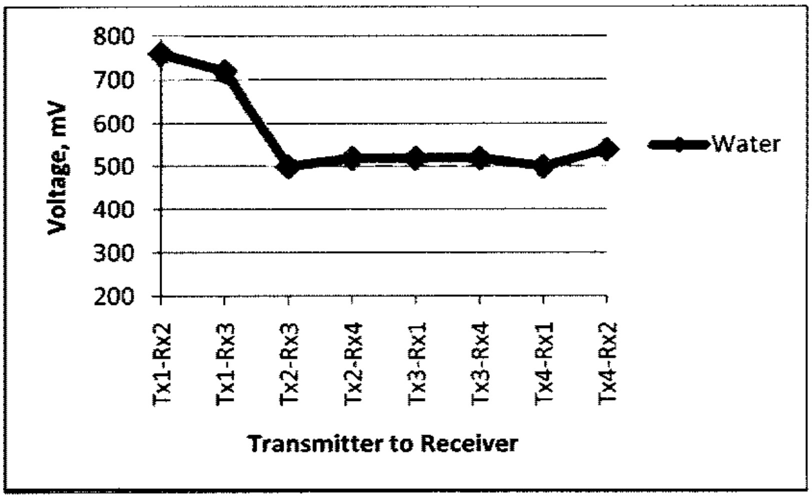

Figure 5.1 : First highest peak value at receivers (water) (mV)

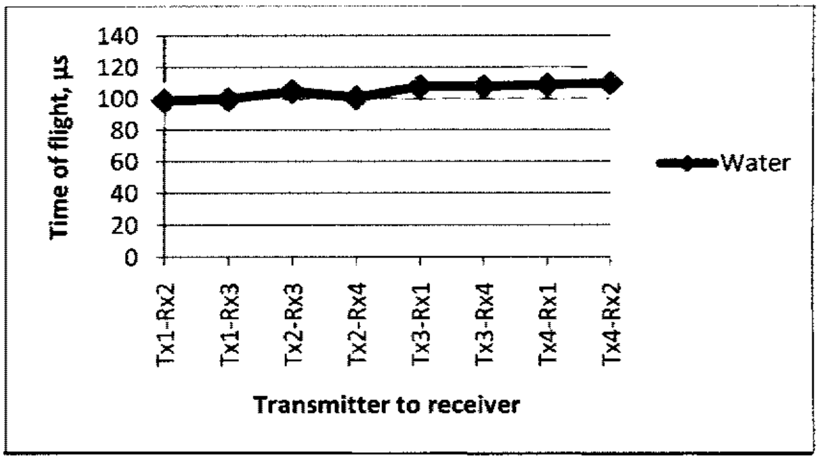

Figure 5.2 : Time of flight (water) (µs)

From the graph in figure 5.1 and 5.2, it it shows that there is a difference between sensors first highest peak voltage and time of flight although no object exists in the pipe. Most probably, the difference is due to imperfection acoustic coupling that's been attached between the sensor and the outer pipe wall. The most different value is at transmitter Tx1 for first highest peak voltage. Besides, the sensor surface has to keep perpendicular to the pipe wall, so that the transmitted acoustic energy will beam perfectly through the pipe.

5.2.2 Water and Ceramics

Figure 5.3 shows the position of ceramics/porcelain in the PVC pipe. From the data take from experiments in the table 5.4 and 5.5, graph for first highest peak value of receivers and time of flight for water and ceramics was plotted as shown as Figure 5.4 and 5.5.

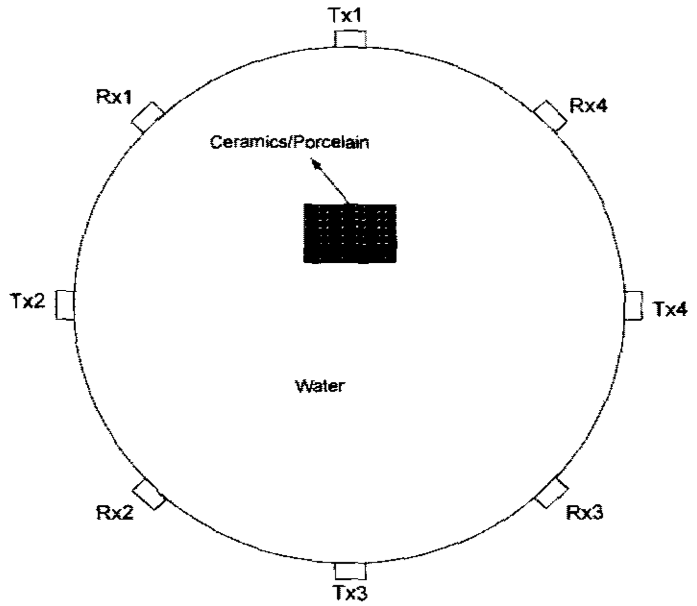

Figure 5.3 : Position of ceramic in the PVC pipe

Table 5.4 : First highest peak value at receivers (water and ceramics) (mV)

	Tx1	Tx2	Tx3	Tx4
Rx1			440	300
Rx2	600			520
Rx3	680	520		
Rx4		380	480	

Table 5.5 : Time of flight (water and ceramics) ((μs)

	Tx1	Tx2	Tx3	Tx4
Rx1			110	111
Rx2	99			114
Rx3	101	105		
Rx4		125	110	

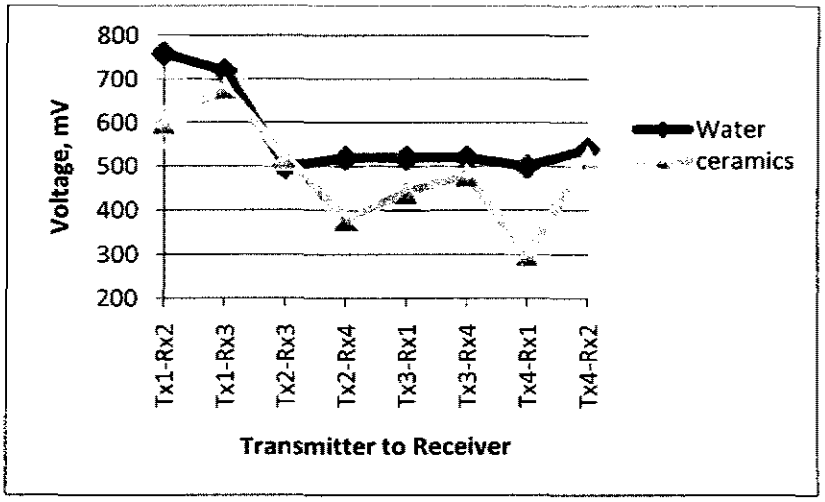

Figure 5.4 : First highest peak value at receivers (water and ceramics) ((mV)

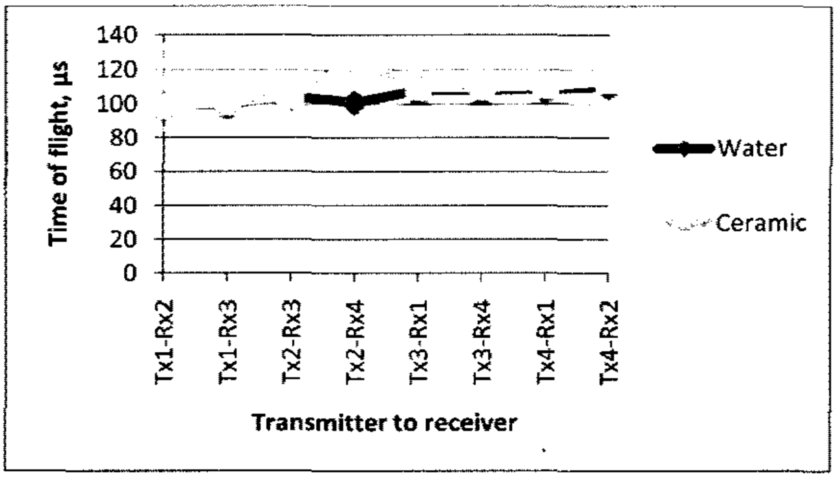

Figure 5.5 : Time of flight (water and ceramics) (µs)

From the graph in figure 5.4 and 5.5, the value of voltage and time that received by the receiver is depending on the location of the sensor and medium. Figure 5.4 shows that at Tx2-Rx4 and Tx4-Rx1, there has a different value which is the peak voltage for ceramics lower than water. This means the ceramics is blocking the transmitted signal from being projected to the receiver, so the voltage will reduce. The lowest value of voltage is at Tx4-Rx1 because the ceramics block all transmitted signal Tx4 and reflect it before reach at receiver. In figure 5.5, at Tx2-Rx4, time of flight for ceramics higher than water because ceramics block all the transmitted signal and being reflected by the ceramics and pipe wall before reach at the receiver. The other value is same with water, although ceramics have blocked the transmitted signal but not fully blocked and the rest can move directly to the receiver.

5.2.3 Water and steel

Figure 5.6 shows the position of ceramics/porcelain in the PVC pipe. From the data take from experiments in the table 5.6 and 5.7, graph for first highest peak value of receivers and time of flight was plotted as shown as Figure 5.7 and 5.8.

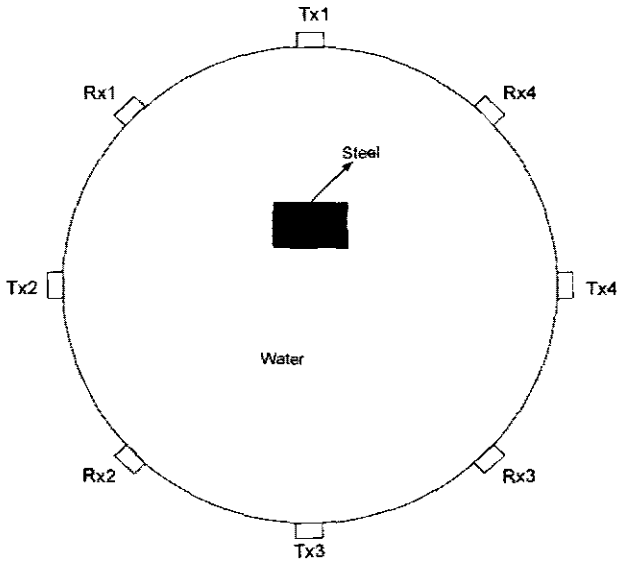

Figure 5.6 : Position of steel in the PVC pipe

Table 5.6 : First highest peak value at receivers (water and steel) (mV)

	Tx1	Tx2	Tx3	Tx4
Rx1			520	300
Rx2	520			520
Rx3	500	440		
Rx4		300	400	

Table 5.7 : Time of flight (water and steel) (μs)

	Tx1	Tx2	Tx3	Tx4
Rx1			112	110
Rx2	100			115
Rx3	100	106		
Rx4		126	109	

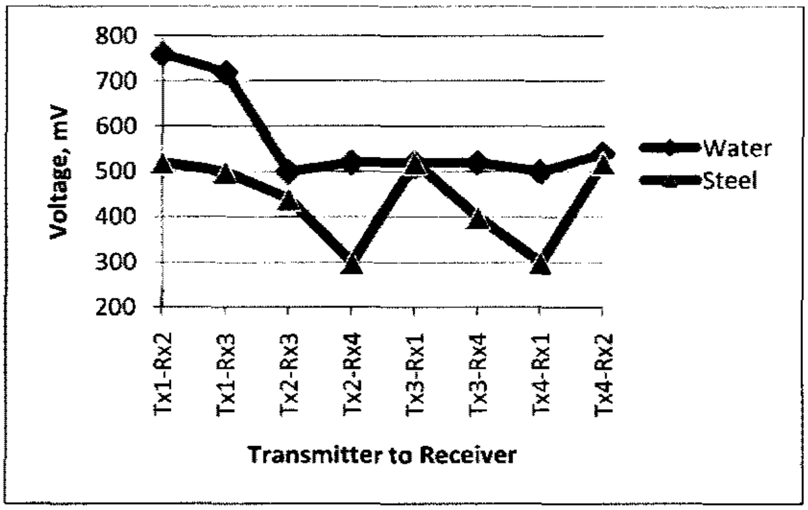

Figure 5.7 : First highest peak value at receivers (water and steel) (mV)

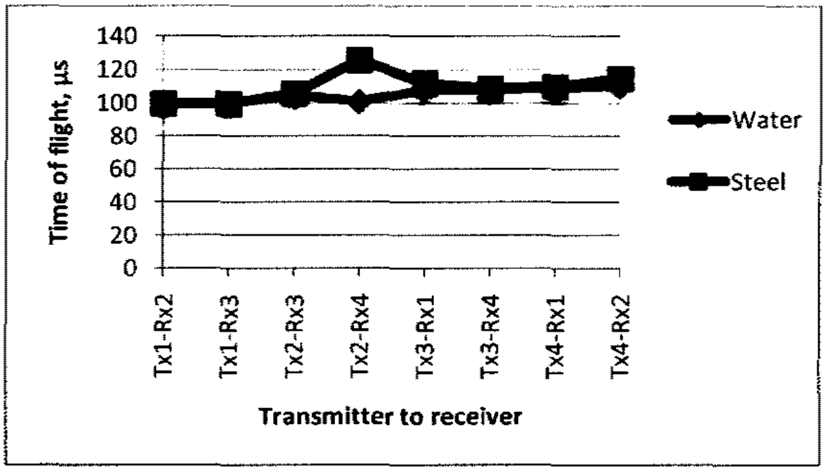

Figure 5.8 : Time of flight (water and steel) (µs)

From the graph in figure 5.7 and 5.8, the value of voltage and time that received by the receiver is depending on the location of the sensor and medium. Figure 5.7 shows that at Tx2-Rx4 and Tx4-Rx1, there has a different value which is the peak voltage for ceramics lower than water. This means the ceramics is blocking the transmitted signal from being projected to the receiver, so the voltage will reduce. The lowest value of voltage is at Tx4-Rx1 because the ceramics block all transmitted signal Tx4 and reflect it before reach at receiver. In figure 5.8, at Tx2-Rx4, time of flight for ceramics higher than water because ceramics block all the transmitted signal and being reflected by the ceramics and pipe wall before reach at the receiver. The other value is same with water, although ceramics have blocked the transmitted signal but not fully blocked and the rest can move directly to the receiver.

5.2.4 Water, ceramics and steel

Figure 5.9 shows the position of ceramics/porcelain in the PVC pipe. From the data take from experiments in the table 5.8 and 5.9, graph for first highest peak value of receivers and time of flight was plotted as shown as Figure 5.10 and 5.11.

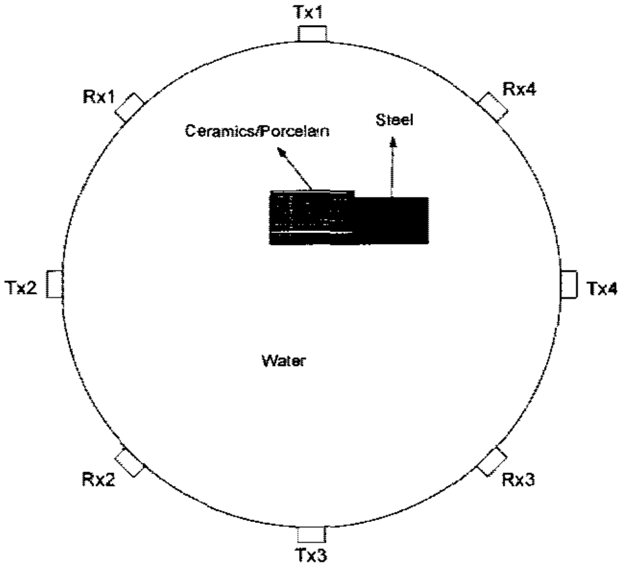

Figure 5.9 : Position of ceramic and steel in the PVC pipe

Table 5.8 : First highest peak value at receivers (water, steel and ceramics) (mV)

	Tx1	Tx2	Tx3	Tx4
Rx1			460	260
Rx2	650			480
Rx3	460	432		
Rx4		360	380	

Table 5.9 : Time of flight (μs)

	Tx1	Tx2	Tx3	Tx4
Rx1			110	155
Rx2	100			111
Rx3	163	110		
Rx4		125	111	

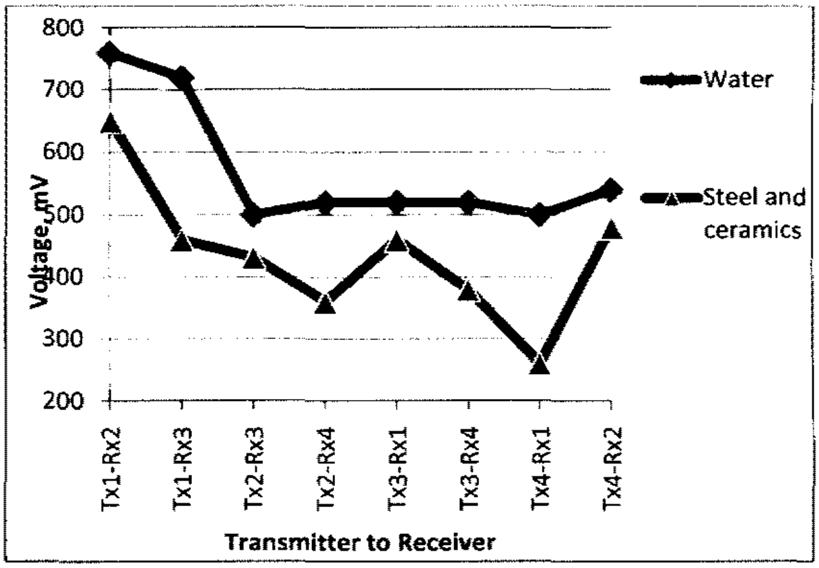

Figure 5.10 : First highest peak value at receivers (water, steel and ceramics) (mV)

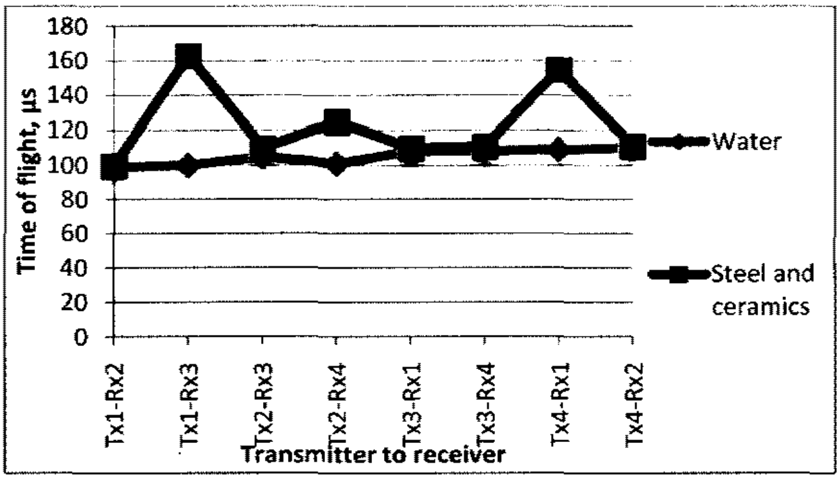

Figure 5.11 : Time of flight (water, steel and ceramics) (µs)

For this experiment, steel and ceramics arranged in series. This purpose is to examine the factor of size of materials. From graph 5.10, more sensors show that the voltage will reduce compare to graph in figure 5.1, 5.4 and 5.7. It proves that more size of materials, more transmitted signal will be blocked. Tx2-Rx3 and Tx4-Rx1 have big different voltages between water and steel and ceramics because the steel and ceramics block all transmitted signals Tx2 and Tx4 and reflected by materials and pipe wall before the reach at receiver. Figure 5.11 shows there have three different times between water and steel and ceramics. It proves that more size of materials, more transmitted signal will be blocked. The highest value is at Tx1-Rx3 followed by Tx4-Rx2. This is because the materials were full blocked the transmitted signal and reflect it by materials and pipe wall more than Tx2-Rx4. This means the increasing of time of flight was affected by increasing length of transmitting signal travel to the receiver.

5.3 Discussion

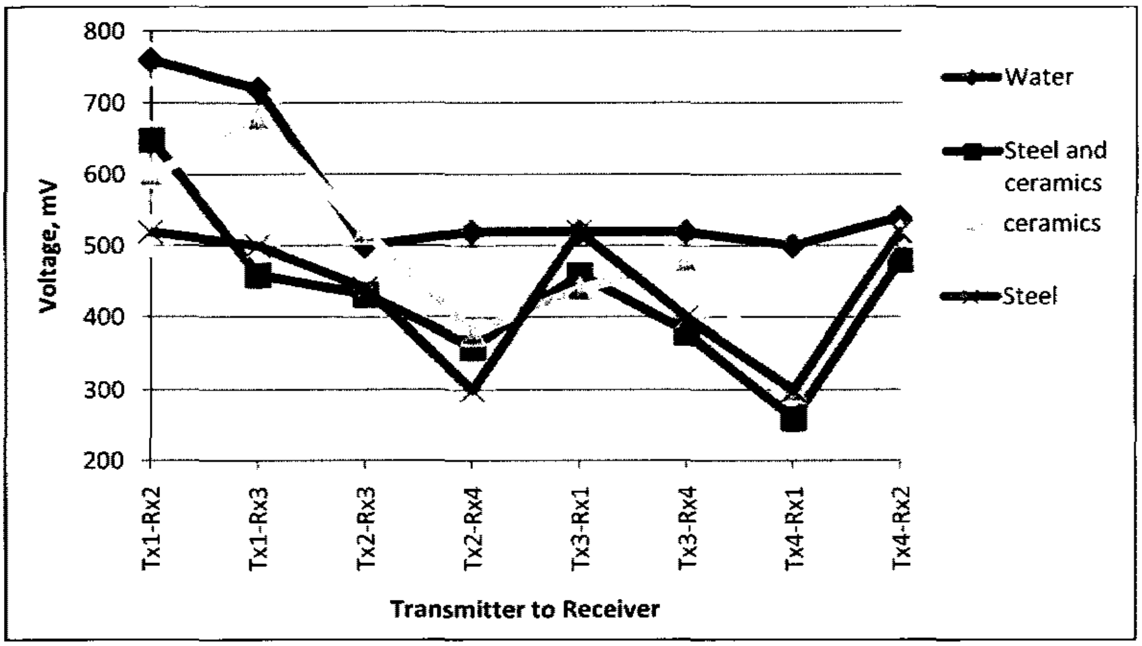

Figure 5.12 : Graph first highest peak voltage comparison between water with different kinds of materials.

The lowest voltage at Tx4-Rx1 in the graph in figure 5.12 shows that the signal was blocked by steel and ceramics. The near same voltage with water at Tx2-Rx3 and Tx4-Rx2 shows that no object was blocking the signal to transmit. Graph for steel lower than ceramics because from calculation at chapter 3.5, steel has a reflection coefficient higher than ceramics which is steel is 93.65% and ceramics is 79.87%. Decreasing the voltage shows that the power of the signal was blocked by the material. The factor changes of voltage depend on reflection coefficients and size of materials.

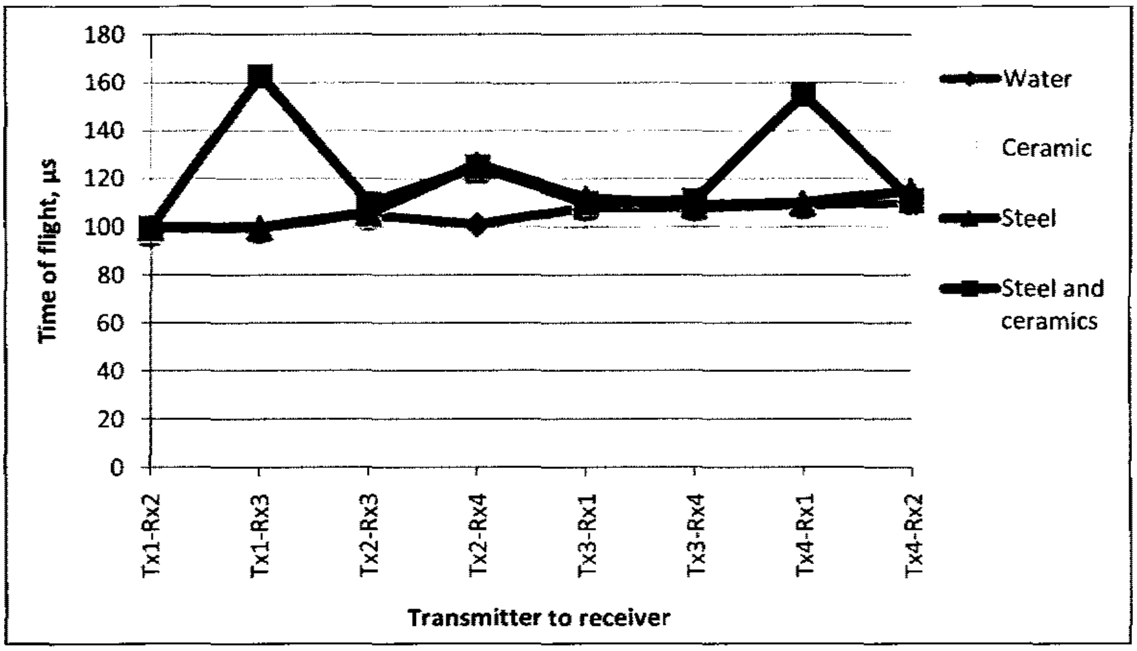

Figure 5.13 : Graph comparison time of flight between between water with different kinds of materials

In figure 5.13, the nearest same value at Tx1-Rx2, Tx2-Rx3, Tx3-Rx1, Tx3-Rx4 and Tx4-Rx2 shows that the receiver receives the signal in the straight line from the transmitter although there has obstacle. At Tx2-Rx4, the time is increased because the materials block the signal to transmit in the straight line. So, the signal reflected by the material before reach to receiver. Steel and ceramics for red line graph get the highest time of flight at Tx1-Rx3 and Tx4-Rx1. This is because the size of steel and ceramics is bigger than single steel and ceramics. It shows that the size of material makes the transmission signal reflect many times by pipe wall and materials before reaching to the receiver. The increasing time of flight shows that the transmission signal cannot flow straight to the receiver but it reflects by the material or pipe wall before reach to the receiver.

In conclusion, the result shows that ultrasonic tomography can be used to identify solid and liquid based on different transmission and reflection characteristic was analyzed in the graph.

From the graphs above, it shows that all receivers receive signal from transmitter in various amplitudes and time. The changing amplitude and time depend on location sensor and medium and size of medium. Shape of solid medium also has given effect to the graph because the degree of reflection signal from solid depend on the shape of the solid. The highest value first highest peak voltage shows that there are no obstacle block receiver receive the signal and the lowest value shows that there has obstacle block receiver receive the signal.

Based on the acoustic impedance and calculation of transmission coefficient and reflection coefficient in subtopic 3.5, steel has a higher reflection coefficient compare to ceramics. Then, from the experiment, the different first highest peak voltage and time of flight for steel is higher than ceramics when blocked the transmitted signal. It is because the steel will reflect the transmitted signal is higher than ceramics.

The differential value of water, ceramics and steel shows that ultrasonic tomography system can use to identify water and solid flow regime.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The objective of this project generally had been achieved. The ultrasonic tomography system used to identify solid and liquid flow is developed successfully. The hardware fabrication of ultrasonic transducer also effectively implemented. Although the circuit has bit problem, it doesn't affect the objective at all.

Other than the acoustic impedance of materials, the size of material also affects the value of voltage and time of flight.

The conclusion from this project is that the ultrasonic tomography system is reliable and can be applied in the industries for monitoring the solid and liquid flow.

6.2 Problem Faced

There has some problem that occurred during the project. The delay or time programming for pulse projection to initially do in the Proteus software simulation not same in the real reading at the oscilloscope. To get exact value, various value had been tried and the best value was chosen.

The output got also not very good which contain a high frequency. A capacitor was used as a coupling between Vcc and Vdd in other thought out the high frequency and the better output obtained.

The printed circuit board must be designed carefully. Although at the simulation show there is no error, circuit must be troubleshoote to make sure there no has error. Failed to troubleshoote circuit will make components broken and circuit not function well.

The position of the material used must be decided earlier whether to put 90 degrees straight without hold by hand. The position of material used will influence experiment and the results obtained.

6.3 Recommendation for Future Work

The recommendations for improving and expanding the ultrasonic tomography system for this project for future works are listed below:

i. Use ultrasonic sensor with wider beam angle for more coverage of the projected signal. The current ultrasonic sensor angle is 125°.
ii. Use high projection for example 8x8 projection in order to get clearer results.
iii. Other coupling materials such as silicone gel that last longer and not easily dry up should be investigated. The coupling efficiency is the main criteria that must be considered. The coupling material used in the project is grease.
iv. High power ultrasonic sensors should be investigated as they can penetrate deeper through the pipe with wider diameter. The signal generator which can generate pulses to trigger the high power ultrasonic transmitter should be investigated and designed. This is important as the pipes used in the industries are usually very wide in diameter.

v. To get the value of higher peak voltage and time of flight from signal conditioning circuit is hard because of the analog graph hard to read. So, make sample and hold circuit to get the appropriate value for first highest voltage and time of flight.

vi. Use the bigger size of a medium to more clearly results.

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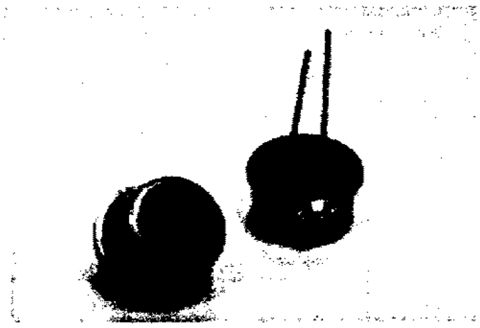
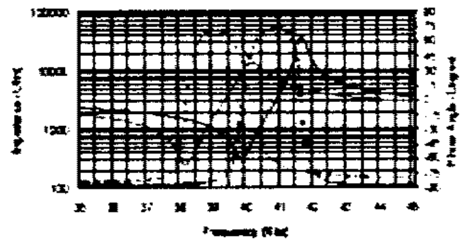
APPENDIX A

Air Ultrasonic Ceramic Transducers 400ET/R080



Impedance/Phase Angle vs. Frequency
Tested under 1Vrms Oscillation Level
400ER080 Impedance
400ER080 Phase
400ET080 Impedance
400ET080 Phase

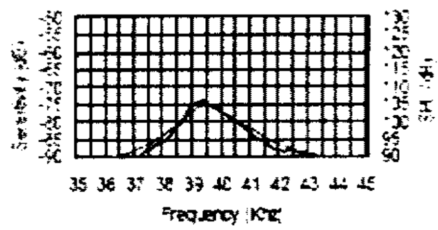


Specification

400ET080		Transmitter
400ER080		Receiver
Center Frequency		40.0±3.0KHz
Bandwidth (-6dB)	400ET080	1.5KHz
	400ER080	2.0KHz
Transmitting Sound Pressure Level		100dB min.
Receiving Sensitivity		-80dB min.
Capacitance at 1KHz ±20%		1700 pF
Max. Driving Voltage (cont.)		15Vrms
Total Beam Angle	-6dB	125° typical
Operation Temperature		-30 to 70°C
Storage Temperature		-40 to 80°C

All specification taken typical at 25°C
Closer frequency tolerance can be supplied upon request

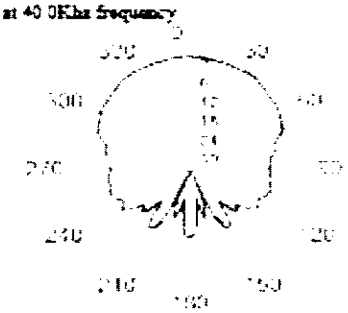
Sensitivity/Sound Pressure Level
Tested under 10Vrms @30cm



Model available:

1	400ET/R080	Nickel Plated Steel Housing

Beam Angle
Tested at 40.0Khz frequency

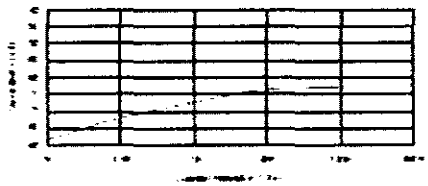


Dimensions: dimensions are in mm

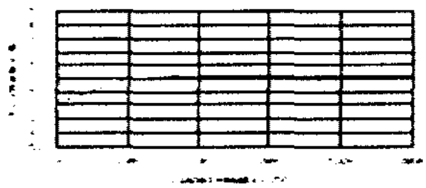
S. Square Enterprise Company Limited
Pro-Wave Electronics Corporation
Http://www.pro-wave.com.tw, E-mail: sales@pro-wave.com.tw, Tel: 886-2-22465101, Fax: 886-2-22465105

400ER080 Receiver

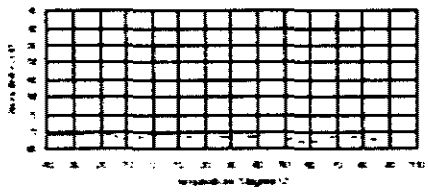
Sensitivity Variation vs. Loaded Resistor



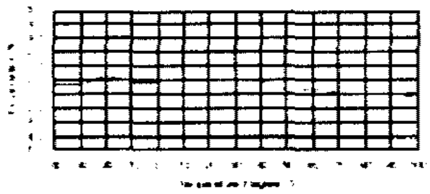
Center Frequency Shift vs. Loaded Resistor



Sensitivity Variation vs. Temperature

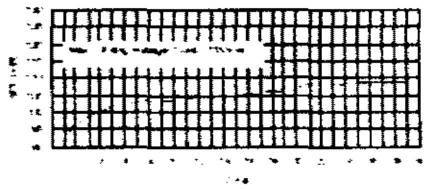


Center Frequency Shift vs. Temperature

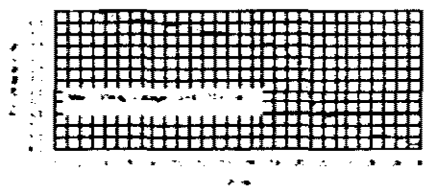


400ET080 Transmitter

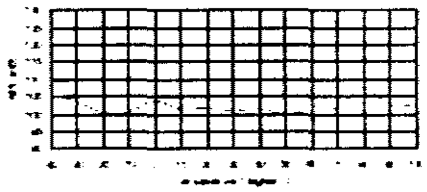
SPL Variation vs. Driving Voltage



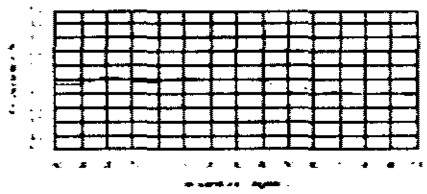
Center Frequency Shift vs. Driving Voltage



SPL Variation vs. Temperature



Center Frequency Shift vs. Temperature



S. Square Enterprise Company Limited
Pro-Wave Electronics Corporation
Http://www.pro-wave.com.tw, E-mail: sales@pro-wave.com.tw, Tel: 886-2-22465101 ; Fax: 886-2-22465105

APPENDIX B

MICROCHIP

PIC16F87XA

28/40/44-Pin Enhanced Flash Microcontrollers

Devices Included in this Data Sheet:

- PIC16F873A
- PIC16F874A
- PIC16F876A
- PIC16F877A

High-Performance RISC CPU:

- Only 35 single-word instructions to learn
- All single-cycle instructions except for program branches, which are two-cycle
- Operating speed: DC – 20 MHz clock input
  DC – 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pinout compatible to other 28-pin or 40/44-pin PIC16CXXX and PIC16FXXX microcontrollers

Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during Sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. resolution is 10-bit
- Synchronous Serial Port (SSP) with SPI™ (Master mode) and I²C™ (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) – 8 bits wide with external $\overline{RD}$, $\overline{WR}$ and $\overline{CS}$ controls (40/44-pin only)
- Brown-out detection circuitry for Brown-out Reset (BOR)

Analog Features:

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)
- Brown-out Reset (BOR)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference (V_{REF}) module
  - Programmable input multiplexing from device inputs and internal voltage reference
  - Comparator outputs are externally accessible

Special Microcontroller Features:

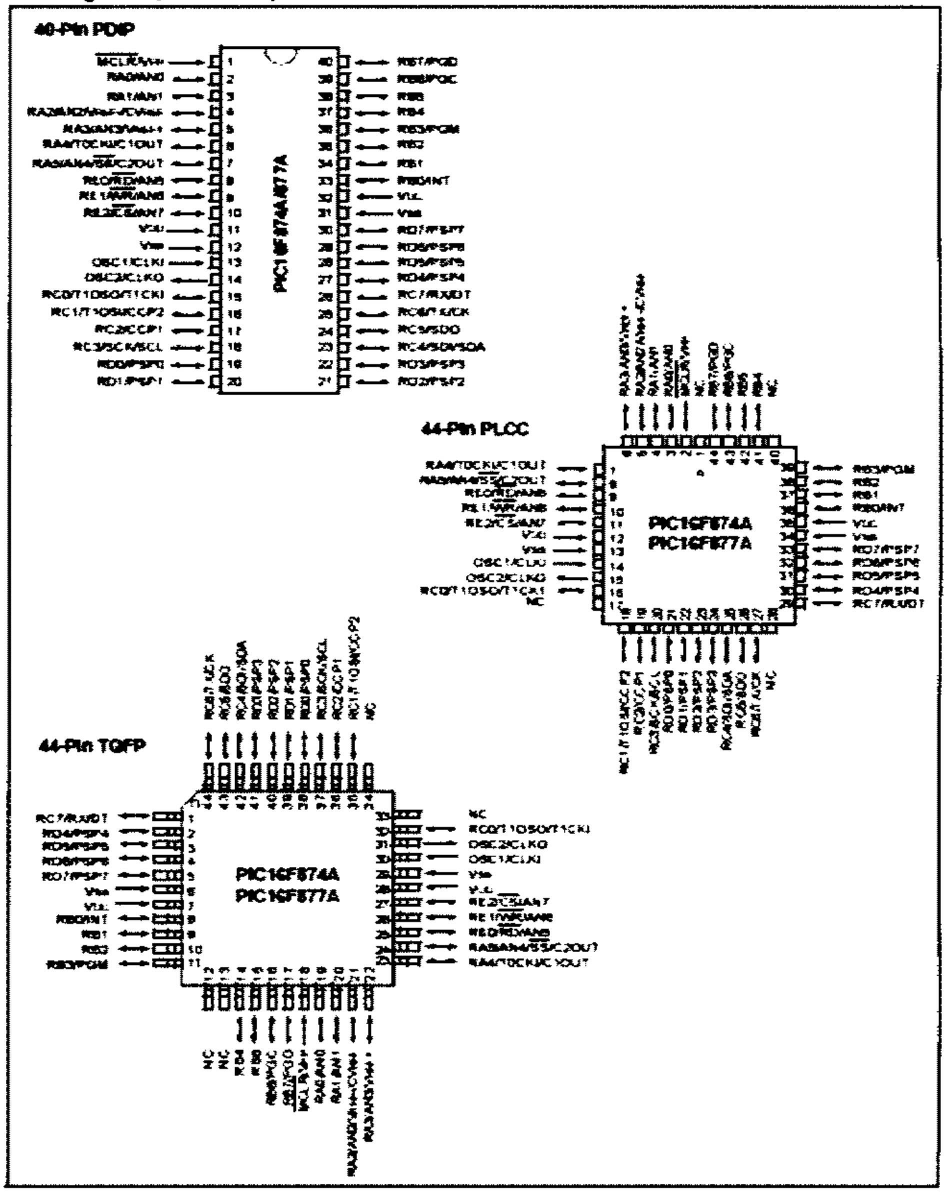
- 100,000 erase/write cycle Enhanced Flash program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Data EEPROM Retention > 40 years
- Self-reprogrammable under software control
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Single-supply 5V In-Circuit Serial Programming
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving Sleep mode
- Selectable oscillator options
- In-Circuit Debug (ICD) via two pins

CMOS Technology:

- Low-power, high-speed Flash/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Commercial and Industrial temperature ranges
- Low-power consumption

Device	Program Memory		Data SRAM (Bytes)	EEPROM (Bytes)	I/O	10-bit A/D (ch)	CCP (PWM)	MSSP		USART	Timers 8/16-bit	Comparators
	Bytes	# Single Word Instructions						SPI	Master I²C			
PIC16F873A	7.2K	4096	192	128	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F874A	7.2K	4096	192	128	33	8	2	Yes	Yes	Yes	2/1	2
PIC16F876A	14.3K	8192	368	256	22	5	2	Yes	Yes	Yes	2/1	2
PIC16F877A	14.3K	8192	368	256	33	8	2	Yes	Yes	Yes	2/1	2

Pin Diagrams (Continued)



APPENDIX C

Order this document by LM833/D

MOTOROLA

LM833

Dual Low Noise, Audio Amplifier

The LM833 is a standard low–cost monolithic dual general–purpose operational amplifier employing Bipolar technology with innovative high–performance concepts for audio systems applications. With high frequency PNP transistors, the LM833 offers low voltage noise (4.5 nV/√Hz), 15 MHz gain bandwidth product, 7.0 V/µs slew rate, 0.3 mV input offset voltage with 2.0 µV/°C temperature coefficient of input offset voltage. The LM833 output stage exhibits no deadband crossover distortion, large output voltage swing, excellent phase and gain margins, low open loop high frequency output impedance and symmetrical source/sink AC frequency response.

The LM833 is specified over the automotive temperature range and is available in the plastic DIP and SO–8 packages (P and D suffixes). For an improved performance dual/quad version, see the MC33079 family.

- Low Voltage Noise: 4.5 nV/√Hz
- High Gain Bandwidth Product: 15 MHz
- High Slew Rate: 7.0 V/µs
- Low Input Offset Voltage: 0.3 mV
- Low T.C. of Input Offset Voltage: 2.0 µV/°C
- Low Distortion: 0.002%
- Excellent Frequency Stability
- Dual Supply Operation

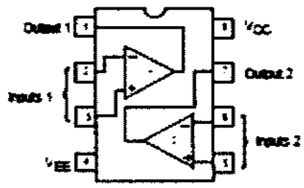
DUAL OPERATIONAL AMPLIFIER

SEMICONDUCTOR TECHNICAL DATA

N SUFFIX
PLASTIC PACKAGE
CASE 626

D SUFFIX
PLASTIC PACKAGE
CASE 751
(SO–8)

PIN CONNECTIONS



(Top View)

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Supply Voltage (V_{CC} to V_{EE})	V_S	+36	V
Input Differential Voltage Range (Note 1)	V_{IDR}	30	V
Input Voltage Range (Note 1)	V_{IR}	±15	V
Output Short Circuit Duration (Note 2)	t_{SC}	Indefinite	
Operating Ambient Temperature Range	T_A	−40 to +85	°C
Operating Junction Temperature	T_J	+150	°C
Storage Temperature	T_{stg}	−60 to +150	°C
Maximum Power Dissipation (Notes 2 and 3)	P_D	500	mW

NOTES: 1. Either or both input voltages must not exceed the magnitude of V_{CC} or V_{EE}.
2. Power dissipation must be considered to ensure maximum junction temperature (T_J) is not exceeded (see power dissipation performance characteristic).
3. Maximum value at $T_A \leq 85°C$.

ORDERING INFORMATION

Device	Operating Temperature Range	Package
LM833N	T_A = − 40° to +85°C	Plastic DIP
LM833D		SO–8

 Rev 0

LM833

ELECTRICAL CHARACTERISTICS (V_{CC} = +15 V, V_{EE} = −15 V, T_A = 25°C, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Input Offset Voltage (R_S = 10 Ω, V_O = 0 V)	V_{IO}	–	0.3	5.0	mV
Average Temperature Coefficient of Input Offset Voltage R_S = 10 Ω, V_O = 0 V, T_A = T_{low} to T_{high}	$\Delta V_{IO}/\Delta T$	–	2.0	–	µV/°C
Input Offset Current (V_{CM} = 0 V, V_O = 0 V)	I_{IO}	–	10	200	nA
Input Bias Current (V_{CM} = 0 V, V_O = 0 V)	I_{IB}	–	300	1000	nA
Common Mode Input Voltage Range	V_{ICR}	– −12	+14 −14	+12 –	V
Large Signal Voltage Gain (R_L = 2.0 kΩ, V_O = ±10 V	A_{VOL}	90	110	–	dB
Output Voltage Swing: R_L = 2.0 kΩ, V_{ID} = 1.0 V R_L = 2.0 kΩ, V_{ID} = 1.0 V R_L = 10 kΩ, V_{ID} = 1.0 V R_L = 10 kΩ, V_{ID} = 1.0 V	 V_{O+} V_{O-} V_{O+} V_{O-}	 10 – 12 –	 13.7 −14.1 13.9 −14.7	 – −10 – −12	V
Common Mode Rejection (V_{in} = ±12 V)	CMR	80	100	–	dB
Power Supply Rejection (V_S = 15 V to 5.0 V, −15 V to −5.0 V)	PSR	80	115	–	dB
Power Supply Current (V_O = 0 V, Both Amplifiers)	I_D	–	4.0	8.0	mA

AC ELECTRICAL CHARACTERISTICS (V_{CC} = +15 V, V_{EE} = −15 V, T_A = 25°C, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Slew Rate (V_{in} = −10 V to +10 V, R_L = 2.0 kΩ, A_V = +1.0)	SR	5.0	7.0	–	V/µs
Gain Bandwidth Product (f = 100 kHz)	GBW	10	15	–	MHz
Unity Gain Frequency (Open Loop)	f_U	–	9.0	–	MHz
Unity Gain Phase Margin (Open Loop)	θ_m	–	60	–	Deg
Equivalent Input Noise Voltage (R_S = 100 Ω, f = 1.0 kHz)	e_n	–	4.5	–	nV/√Hz
Equivalent Input Noise Current (f = 1.0 kHz)	i_n	–	0.5	–	pA/√Hz
Power Bandwidth (V_O = 27 V_{pp}, R_L = 2.0 kΩ, THD ≤ 1.0%)	BW_P	–	120	–	kHz
Distortion (R_L = 2.0 kΩ, f = 20 Hz to 20 kHz, V_O = 3.0 V_{rms}, A_V = +1.0)	THD	–	0.002	–	%
Channel Separation (f = 20 Hz to 20 kHz)	C_S	–	−120	–	dB

Figure 1. Maximum Power Dissipation versus Temperature

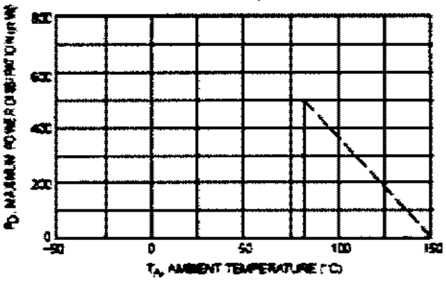
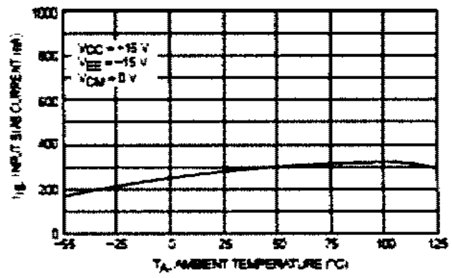


Figure 2. Input Bias Current versus Temperature



APPENDIX D

National Semiconductor

July 2000

LF198/LF298/LF398, LF198A/LF398A Monolithic Sample-and-Hold Circuits

General Description

The LF198/LF298/LF398 are monolithic sample-and-hold circuits which utilize BI-FET technology to obtain ultra-high dc accuracy with fast acquisition of signal and low droop rate. Operating as a unity gain follower, dc gain accuracy is 0.002% typical and acquisition time is as low as 6 µs to 0.01%. A bipolar input stage is used to achieve low offset voltage and wide bandwidth. Input offset adjust is accomplished with a single pin, and does not degrade input offset drift. The wide bandwidth allows the LF198 to be included inside the feedback loop of 1 MHz op amps without having stability problems. Input impedance of $10^{10}\Omega$ allows high source impedances to be used without degrading accuracy.

P-channel junction FET's are combined with bipolar devices in the output amplifier to give droop rates as low as 5 mV/min with a 1 µF hold capacitor. The JFET's have much lower noise than MOS devices used in previous designs and do not exhibit high temperature instabilities. The overall design guarantees no feed-through from input to output in the hold mode, even for input signals equal to the supply voltages.

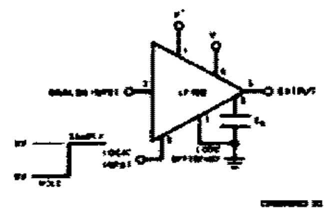
Features

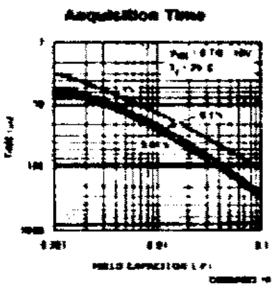
- Operates from ±5V to ±18V supplies
- Less than 10 µs acquisition time
- TTL, PMOS, CMOS compatible logic input
- 0.5 mV typical hold step at C_h = 0.01 µF
- Low input offset
- 0.002% gain accuracy
- Low output noise in hold mode
- Input characteristics do not change during hold mode
- High supply rejection ratio in sample or hold
- Wide bandwidth
- Space qualified, JM38510

Logic inputs on the LF198 are fully differential with low input current, allowing direct connection to TTL, PMOS, and CMOS. Differential threshold is 1.4V. The LF198 will operate from ±5V to ±18V supplies.

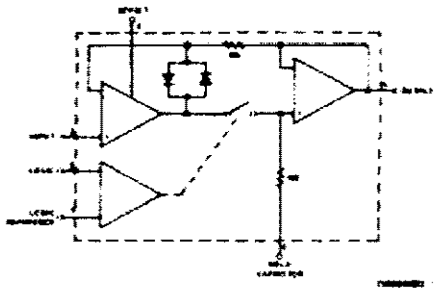
An "A" version is available with tightened electrical specifications.

Typical Connection and Performance Curve





Functional Diagram



Absolute Maximum Ratings (Note 1)

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

Supply Voltage	±18V
Power Dissipation (Package Limitation) (Note 2)	500 mW
Operating Ambient Temperature Range	
LF198/LF198A	−55°C to +125°C
LF298	−25°C to +85°C
LF398/LF398A	0°C to +70°C
Storage Temperature Range	−65°C to +150°C
Input Voltage	Equal to Supply Voltage
Logic To Logic Reference Differential Voltage (Note 3)	+7V, −30V
Output Short Circuit Duration	Indefinite
Hold Capacitor Short Circuit Duration	10 sec
Lead Temperature (Note 4)	
H package (Soldering, 10 sec.)	260°C
N package (Soldering, 10 sec.)	260°C
M package:	
Vapor Phase (60 sec.)	215°C
Infrared (15 sec.)	220°C

Thermal Resistance (θ_{JA}) (typicals)
H package 215°C/W (Board mount in still air)
85°C/W (Board mount in 400LF/min air flow)
N package 115°C/W
M package 106°C/W
θ_{JC} (H package, typical) 20°C/W

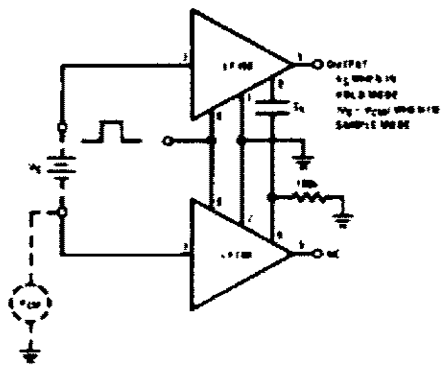
Electrical Characteristics

The following specifications apply for $-V_S + 3.5V \le V_{IN} \le +V_S - 3.5V$, $+V_S = +15V$, $-V_S = -15V$, $T_A = T_j = 25°C$, $C_h = 0.01\ \mu F$, $R_L = 10\ k\Omega$, LOGIC REFERENCE = 0V, LOGIC HIGH = 2.5V, LOGIC LOW = 0V unless otherwise specified.

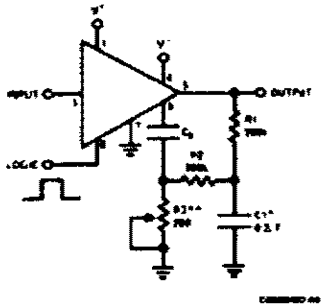
Parameter	Conditions	LF198/LF298			LF398			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage, (Note 5)	$T_j = 25°C$		1	3		2	7	mV
	Full Temperature Range			5			10	mV
Input Bias Current, (Note 5)	$T_j = 25°C$		5	25		10	50	nA
	Full Temperature Range			75			100	nA
Input Impedance	$T_j = 25°C$		10^{10}			10^{10}		Ω
Gain Error	$T_j = 25°C$, $R_L = 10k$		0.002	0.005		0.004	0.01	%
	Full Temperature Range			0.02			0.02	%
Feedthrough Attenuation Ratio at 1 kHz	$T_j = 25°C$, $C_h = 0.01\ \mu F$	86	96		80	90		dB
Output Impedance	$T_j = 25°C$, "HOLD" mode		0.5	2		0.5	4	Ω
	Full Temperature Range			4			6	Ω
"HOLD" Step, (Note 6)	$T_j = 25°C$, $C_h = 0.01\ \mu F$, $V_{OUT} = 0$		0.5	2.0		1.0	2.5	mV
Supply Current, (Note 5)	$T_j \ge 25°C$		4.5	5.5		4.5	6.5	mA
Logic and Logic Reference Input Current	$T_j = 25°C$		2	10		2	10	µA
Leakage Current into Hold Capacitor (Note 5)	$T_j = 25°C$, (Note 7) Hold Mode		30	100		30	200	pA
Acquisition Time to 0.1%	$\Delta V_{OUT} = 10V$, $C_h = 1000$ pF		4			4		µs
	$C_h = 0.01\ \mu F$		20			20		µs
Hold Capacitor Charging Current	$V_{IN} - V_{OUT} = 2V$		5			5		mA
Supply Voltage Rejection Ratio	$V_{OUT} = 0$	80	110		80	110		dB
Differential Logic Threshold	$T_j = 25°C$	0.8	1.4	2.4	0.8	1.4	2.4	V
Input Offset Voltage, (Note 5)	$T_j = 25°C$		1	1		2	2	mV
	Full Temperature Range			2			3	mV
Input Bias Current, (Note 5)	$T_j = 25°C$		5	25		10	25	nA
	Full Temperature Range			75			50	nA

Typical Applications (Continued)

Differential Hold



Capacitor Hysteresis Compensation



*Select for time constant C1 = …

**Adjust for amplitude

Definition of Terms

Hold Step: The voltage step at the output of the sample and hold when switching from sample mode to hold mode with a steady (dc) analog input voltage. Logic swing is 5V.

Acquisition Time: The time required to acquire a new analog input voltage with an output step of 10V. Note that acquisition time is not just the time required for the output to settle, but also includes the time required for all internal nodes to settle so that the output assumes the proper value when switched to the hold mode.

Gain Error: The ratio of output voltage swing to input voltage swing in the sample mode expressed as a per cent difference.

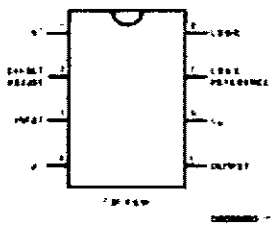
Hold Settling Time: The time required for the output to settle within 1 mV of final value after the "hold" logic command.

Dynamic Sampling Error: The error introduced into the held output due to a changing analog input at the time the hold command is given. Error is expressed in mV with a given hold capacitor value and input slew rate. Note that this error term occurs even for long sample times.

Aperture Time: The delay required between "Hold" command and an input analog transition, so that the transition does not affect the held output.

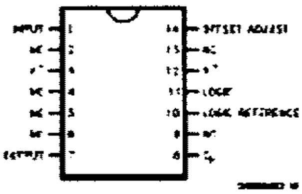
Connection Diagrams

Dual-In-Line Package



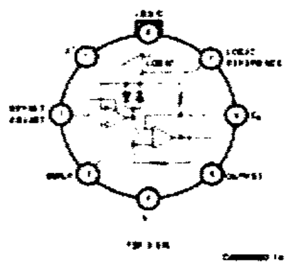
Order Number LF398N or LF398AN
See NS Package Number N08E

Small-Outline Package



Order Number LF298M or LF398M
See NS Package Number M14A

Metal Can Package



Order Number LF198H, LF198H/883, LF298H, LF398H, LF198AH or LF398AH
See NS Package Number H08C
(Note 9)

APPENDIX E

TLE214x, TLE214xA, TLE214xY
EXCALIBUR LOW-NOISE HIGH-SPEED PRECISION OPERATIONAL AMPLIFIERS

[illegible] – FEBRUARY 1997 – REVISED MARCH [illegible]

- Low Noise
  - 10 Hz . . . 15 nV/√Hz
  - 1 kHz . . . 10.5 nV/√Hz
- 10000-pF Load Capability
- 20-mA Min Short-Circuit Output Current
- 27-V/μs Min Slew Rate
- High Gain-Bandwidth Product . . . 5.9 MHz
- Low V_{IO} . . . 500 μV Max at 25°C
- Single or Split Supply . . . 4 V to 44 V
- Fast Settling Time
  - 340 ns to 0.1%
  - 400 ns to 0.01%
- Saturation Recovery . . . 150 ns
- Large Output Swing
  - V_{CC-} + 0.1 V to V_{CC+} − 1 V

description

The TLE214x and TLE214xA devices are high-performance, internally compensated operational amplifiers built using Texas Instruments complementary bipolar Excalibur process. The TLE214xA is a tighter offset voltage grade of the TLE214x. Both are pin-compatible upgrades to standard industry products.

The design incorporates an input stage that simultaneously achieves low audio-band noise of 10.5 nV/√Hz with a 10-Hz 1/f corner and symmetrical 40-V/μs slew rate typically with loads up to 800 pF. The resulting low distortion and high power bandwidth are important in high-fidelity audio applications. A fast settling time of 340 ns to 0.1% of a 10-V step with a 2-kΩ/100-pF load is useful in fast actuator/positioning drivers. Under similar test conditions, settling time to 0.01% is 400 ns.

The devices are stable with capacitive loads up to 10 nF, although the 6-MHz bandwidth decreases to 1.8 MHz at this high loading level. As such, the TLE214x and TLE214xA are useful for low-droop sample-and-holds and direct buffering of long cables, including 4-mA to 20-mA current loops.

The special design also exhibits an improved insensitivity to inherent integrated circuit component mismatches as is evidenced by a 500-μV maximum offset voltage and 1.7-μV/°C typical drift. Minimum common-mode rejection ratio and supply-voltage rejection ratio are 85 dB and 90 dB, respectively.

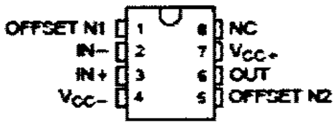
Device performance is relatively independent of supply voltage over the ±2-V to ±22-V range. Inputs can operate between V_{CC-} − 0.3 to V_{CC+} − 1.8 V without inducing phase reversal, although excessive input current may flow out of each input exceeding the lower common-mode input range. The all-npn output stage provides a nearly rail-to-rail output swing of V_{CC-} − 0.1 to V_{CC+} − 1 V under light current-loading conditions. The device can sustain shorts to either supply since output current is internally limited, but care must be taken to ensure that maximum package power dissipation is not exceeded.

Both versions can also be used as comparators. Differential inputs of $V_{CC\pm}$ can be maintained without damage to the device. Open-loop propagation delay with TTL supply levels is typically 200 ns. This gives a good indication as to output stage saturation recovery when the device is driven beyond the limits of recommended output swing.

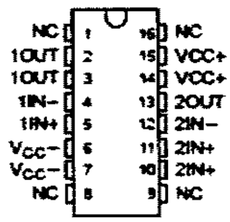
Both the TLE214x and TLE214xA are available in a wide variety of packages, including both the industry-standard 8-pin small-outline version and chip form for high-density system applications. The C-suffix devices are characterized for operation from 0°C to 70°C, I-suffix devices from −40°C to 105°C, and M-suffix devices over the full military temperature range of −55°C to 125°C.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

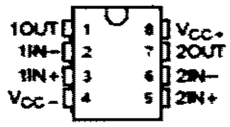
TLE2141
D, JG, OR P PACKAGE
(TOP VIEW)



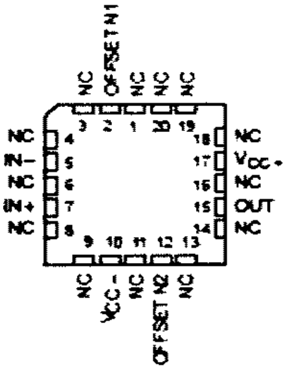
TLE2142
PW PACKAGE
(TOP VIEW)



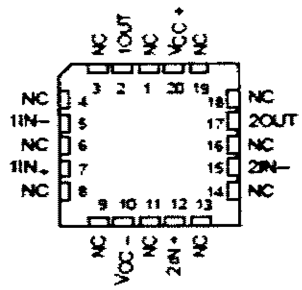
TLE2142
D, JG, OR P PACKAGE
(TOP VIEW)



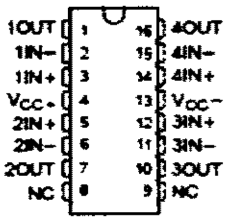
TLE2141
FK PACKAGE
(TOP VIEW)



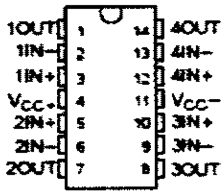
TLE2142
FK PACKAGE
(TOP VIEW)



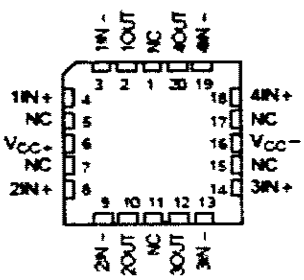
TLE2144
DW PACKAGE
(TOP VIEW)



TLE2144
J OR N PACKAGE
(TOP VIEW)



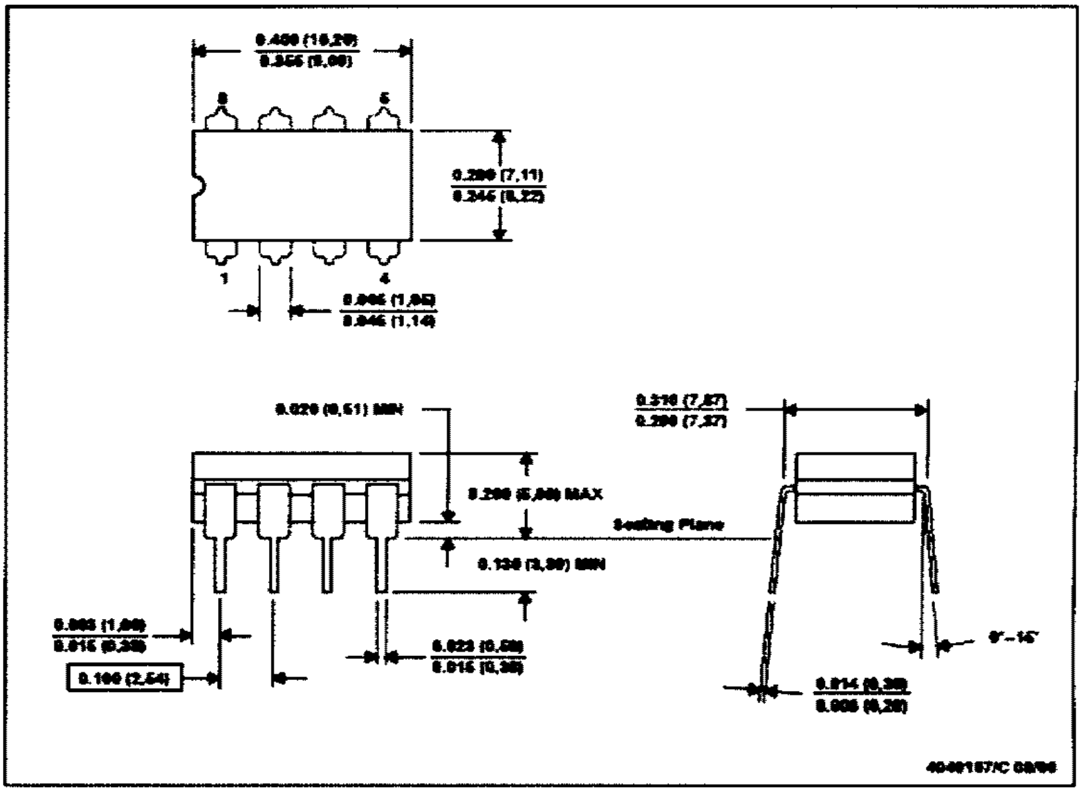
TLE2144
FK PACKAGE
(TOP VIEW)



NC – No internal connection

MECHANICAL INFORMATION

JG (R-GDIP-T8) **CERAMIC DUAL-IN-LINE PACKAGE**



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. This package can be hermetically sealed with a ceramic lid using glass frit.
D. Index point is provided on cap for terminal identification only on press ceramic glass frit seal only.
E. Falls within MIL-STD-1835 GDIP1-T8

APPENDIX F

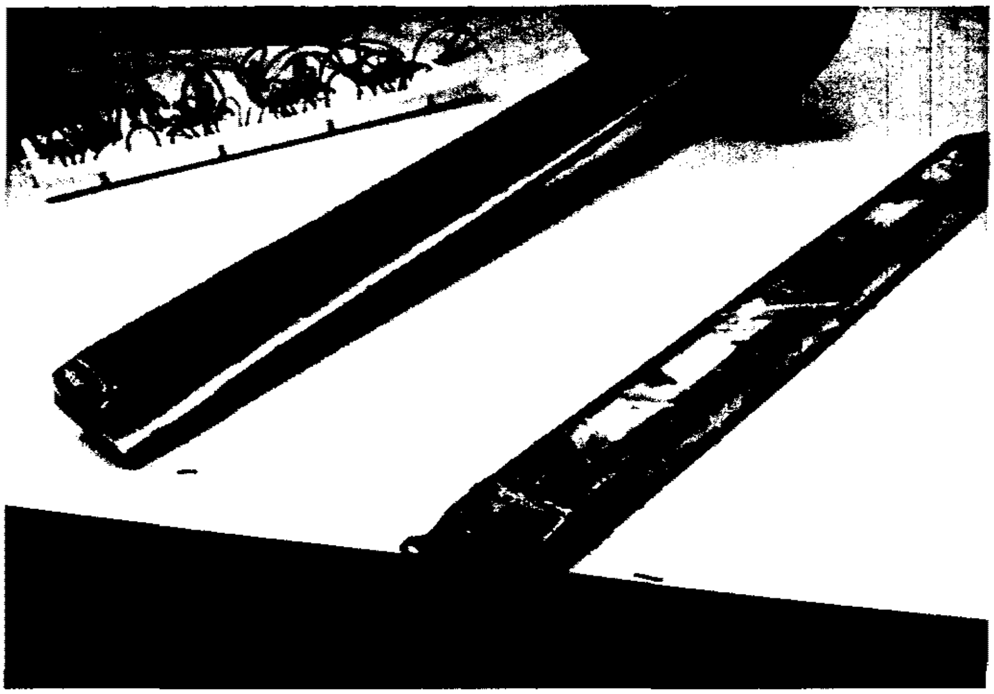
```
#include <16F877A.h>
#fuses
XT,NOWDT,NOLVP,NOPROTECT
#use delay (clock=10M)
///transmitter///
#define Tx1 PIN_B0
#define Tx2 PIN_B1
#define Tx3 PIN_B2
#define Tx4 PIN_B3
void main()
{
///port initialize///
set_tris_b(0x00);
set_tris_d(0x00);
output_b(0x00);
output_d(0x00);
while(TRUE)

//////TX0//////
output_b(0x01);
delay_us(9);
output_b(0x00);
delay_us(9);
output_b(0x01);
delay_us(9);
output_b(0x00);
delay_us(9);
//////TX1//////
output_b(0x02);
delay_us(9);
output_b(0x00);
delay_us(9);
output_b(0x02);
delay_us(9);
output_b(0x00);
delay_us(9);

//////TX2//////
output_b(0x04);
delay_us(9);
output_b(0x00);
delay_us(9);
output_b(0x04);
delay_us(9);
output_b(0x00);
delay_us(9);

//////TX3//////
output_b(0x08);
delay_us(9);
output_b(0x00);
delay_us(9);
output_b(0x08);
delay_us(9);
output_b(0x00);
delay_us(9);
}
}
```

APPENDIX G



Medium	Material	Size (mm)
Liquid	Water	
Solid	Ceramics/porcelain	21 x 14
Solid	Steel	19 x 12