# ULTRASOUND FOCUSING SYSTEM FOR HYPERTHERMIA

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submitted in partial fulfillment of the
requirements for the degree of
**Master of Technology**

by
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## DISSERTATION APPROVAL SHEET

Dissertation entitled " ULTRASOUND FOCUSING SYSTEM FOR HYPERTHERMIA" by Mr. Uday Pandit Kulavmode is approved for the degree of MASTER OF TECHNOLOGY.

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## ABSTRACT

Ultrasonic focusing technique will be having good potential in therapeutic applications like hyperthermia and lithotripsy. In these applications, ultrasound should cause minimum damage and destruction of normal tissues, at the same time produce high intensity pressure at the lesion. For this purpose, focusing of ultrasound is necessary. In this report, a system for continuous heating of the target (using microcontroller) is proposed and discussed. Here, a large number of transducers are excited sequentially such that at the target ultrasound is absorbed continuously but at other places it occurs for a brief period of time. Thus making the heating more in tissue at the target than at other places. In the latter part of the report, the tests results of different blocks of the system built are discussed. Test results using limited number of transmitters are also described.

# ACKNOWLEDGMENTS

I pay sincere thanks to my guide Prof. T. Anjaneyulu for his invaluable guidance. I also thank Profs. P. C. Pandey, T.S. Rathore and C.P. Gadgil for their co-operation and invaluable guidance.

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# 1. Introduction

## 1.1 Hyperthermia

The number of persons succumbing to cancer is increasing day-by-day and, despite the tremendous efforts being devoted to its cure, a large percentage of patients succumb to various diseases categorized as cancer. It has also been known that elevating the temperature of a malignant tissue or tumor can be an effective treatment for cancer. Cancerous cells are more susceptible to heat than normal cells. Hence the treatment of heating the malignant tissue is one of the methods to kill such tissues. The elevation of temperature for the cancer treatment is known as *hyperthermia.* Thus, hyperthermia can be defined as the heating of an area of a tissue to a temperature below the threshold of thermal pain or damage to normal tissue (in the range of 42 - $45^0$ c or higher but not exceeding). Ideally, the surrounding tissue would be maintained at a lower temperature, to minimize the tissue damage.

Therefore, designing, developing and testing of a hyperthermia system are today's critical problems. In order to meet the requirements of controlled heating of tumor in a non - invasive and flexible manner, the hyperthermia induction equipment must satisfy the following requirements :

1) it should be non - invasive,
2) it should provide a focusing or beam convergence,
3) it should localize the heating on the target volume and prevent excessive heating of tissues outside the target volume.

Following are some of the techniques for heating in hyperthermia. 1) Capacitive heating, 2) Inductive heating, 3) Microwave heating and 4) Ultrasonic heating.

In the capacitive heating, the electrodes called pads are positioned on the body over the region to be treated. The pads are placed so that the portion of the body to be treated is sandwiched between them.

When the radio frequency output is applied to the pads, the dielectric losses of the capacitor manifest themselves as heat in the intervening tissues.

In the inductive heating, a flexible cable is coiled around the portion of the patient's body where plate electrodes are inconvenient to use. When RF current is passed through such a cable, an electrostatic field is set up between its ends and a magnetic field around its center. Deep heating in the tissue results from electrostatic action whereas the heating of the superficial tissues is obtained by eddy currents set up by magnetic effect. The limitation of these methods is that they direct continuous high frequency radio waves, and if a high enough output of energy is sustained for even a brief time they can cause burns.

Microwave heating consists in irradiating the tissues of the patient's body with very short wireless waves having frequency in the microwave region. Typically, the frequency used is 2450 MHz. Heating effect is produced by the absorption of the microwaves in the region of the body under treatment. Here, the microwaves are transmitted from an emitter, and are directed towards the portion of the body to be treated. These waves pass through the intervening air space and are absorbed by the surface of the body producing heating effect. Microwaves are produced by high frequency currents and have the same frequency as the currents which produce them. A Magnetron is used for the production of high frequency currents of high power.

In ultrasonic heating, the heating effect is produced because of the ultrasonic energy absorption property of the tissues.

**1.2 Ultrasound for hyperthermia**

The major consideration in hyperthermia system is to provide an adequate control of the energy deposition in the target volume and for maintaining a therapeutic temperature. Ultrasound in 0.3 to 3 MHz frequency range has the following properties which are favourable in clinical hyperthermia:

1) short wavelength,
2) favourable absorption characteristic,
3) energy can be focused into a small region and at a greater depth. Because of these characteristics, ultrasound is being popular and, therefore used for therapeutical applications.

### 1.3 Ultrasound focusing techniques

Some of the important ultrasonic focusing techniques are given below.

1) Direct ultrasonic beam focusing [1]

In this focusing method, the ultrasonic beam is focused with the help of either a) a mirror or b) an acoustic lens or c) geometrical structure of the transducer as shown in Fig.1.1 [1]. Low resolution and image aberretions are their main disadvantages. Moreover, for use in short ranges a short wavelength is needed, which results in a aperature limitation. Geometric design of this technique is simple, but difficult to manufacture.

2) Time reversal mirror ( TRM ) technique [2]

Time reversal of ultrasonic fields represents a way to focus ultrasound in an inhomogeneous medium. This can be achieved by a time reversal mirror (TRM) [2] made from an array of transmit - receive transducers that respond linearly and allow incident acoustic pressure to be sampled at the target. This time reversal process is divided into three steps.

(i) Transmitting the wavefront through medium as shown in Fig.1.2(a). The target generates scattered pressure field that propogates through inhomogeneous media.
(ii) The scattered pressure field is then detected by a set of transducers as shown in Fig. 1.2(b).

(iii) The pressure field is then retransmitted by the same set of transducers in reversed order i.e. the transducer which detect the scattered pressure field lastly will retransmit the pressure field first as shown in Fig. 1.2(c). Such a process allows to convert divergent waves issued from an acoustic source into a convergent wave focusing on the source. The basic principle of the technique is to receive the sound waves from different transducers at the same instant of time even when they are travelling with different velocities and through different distances. Thus increasing the intensity of pressure wave at the object and decreasing the intensity at other places.

3) Lele [3] had proposed a scheme for ultrasonic focusing where a transducer is rotated around the target as shown in Fig.1.3. Here, the sound beam reaches the target from all the positions and hence a continuous pressure field is applied to the target, whereas, at all other places sound pressure exists only for a very small period of time. Thus heating the target more intensely and reducing the heat at other places. This method was used on patients at M.I.T. lab by Lele [ 3 ].

The same aim as above can be achieved by putting a number of transducers surrounding the target and exciting them in a sequence depending upon the transit time between the transducer and the target.

### 1.4 Focusing method

Various focusing methods of ultrasound are described in the earlier section. The direct focusing with the help of a lens or mirror maynot be useful in many applications, because of variable distance of the target from the source. With change in distance of the target from the lens the focusing will be disturbed. Also some aberrating medium in between could disturbed the focusing. The TRM technique could be useful in lithotripsy, where high intensity ultrasound for short periods are required, as lithotripsy involves destruction of kidney stone through focusing of ultrasonic wave at the site. As this method generates high intensity field at the target, it is not suitable in hyperthermia. Hence it was decided to use Lele's scheme with some modifications.

## 1.5 Project objectives

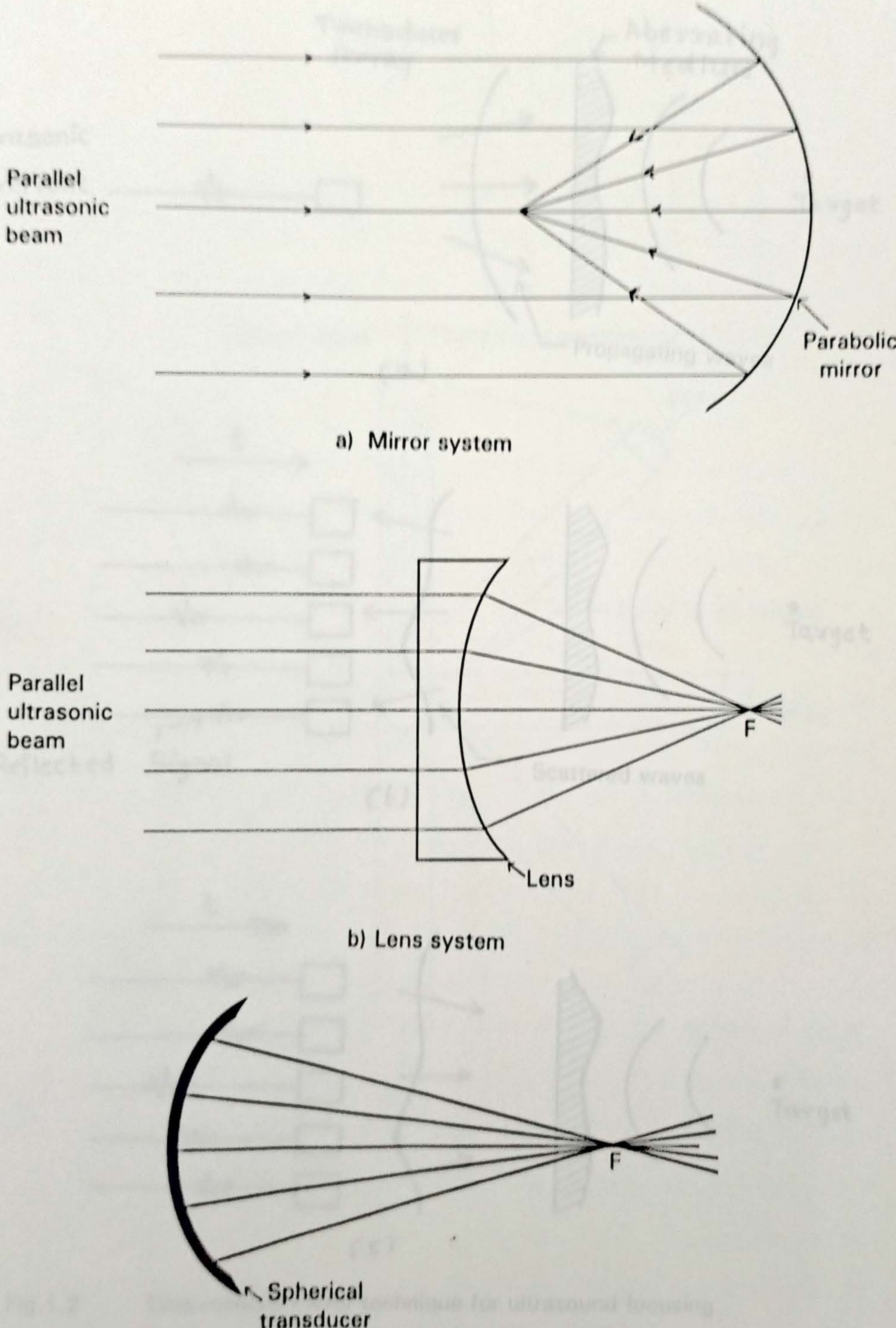
The ultrasonic focusing technique for continuous heating at the target (modification of the scheme proposed by Lele) will be implemented in this project. The main objectives of the project are, 1) to maximize the energy at the target, i.e. to confirm that the acoustic waves transmitted would be focused exactly at the target by arriving there continuously, 2) to take care that the normal tissues do not get damaged.

As in most cases of testing of biomedical equipment, the equipment is first tested in vitro.

In this particular case, the objective of the project is limited to heating of a target in a water bath without heating the intervening media. For simulating different media, some foreign objects in the path of the ultrasound could be used.

## 1.6 Report outline

Second chapter of the report describes the implementation aspects in ultrasonic focusing. It describes the selection of focusing procedure, the selection of transducers and delay elements for the system. Chapter 3 explains the block diagram of the focusing system. The mechanical assembly that was used for positioning the transducers is also explained. Chapter 4 gives the details of the electronic hardware that has been designed, built and tested for the system. Chapter 5 gives the details about experiments that were carried out to prove the focusing technique and the results obtained. Chapter 6 describes some limitations of the scheme.




a) Mirror system

b) Lens system

c) Spherical transducer system

Fig. 1.1 Direct method of ultrasound focusing

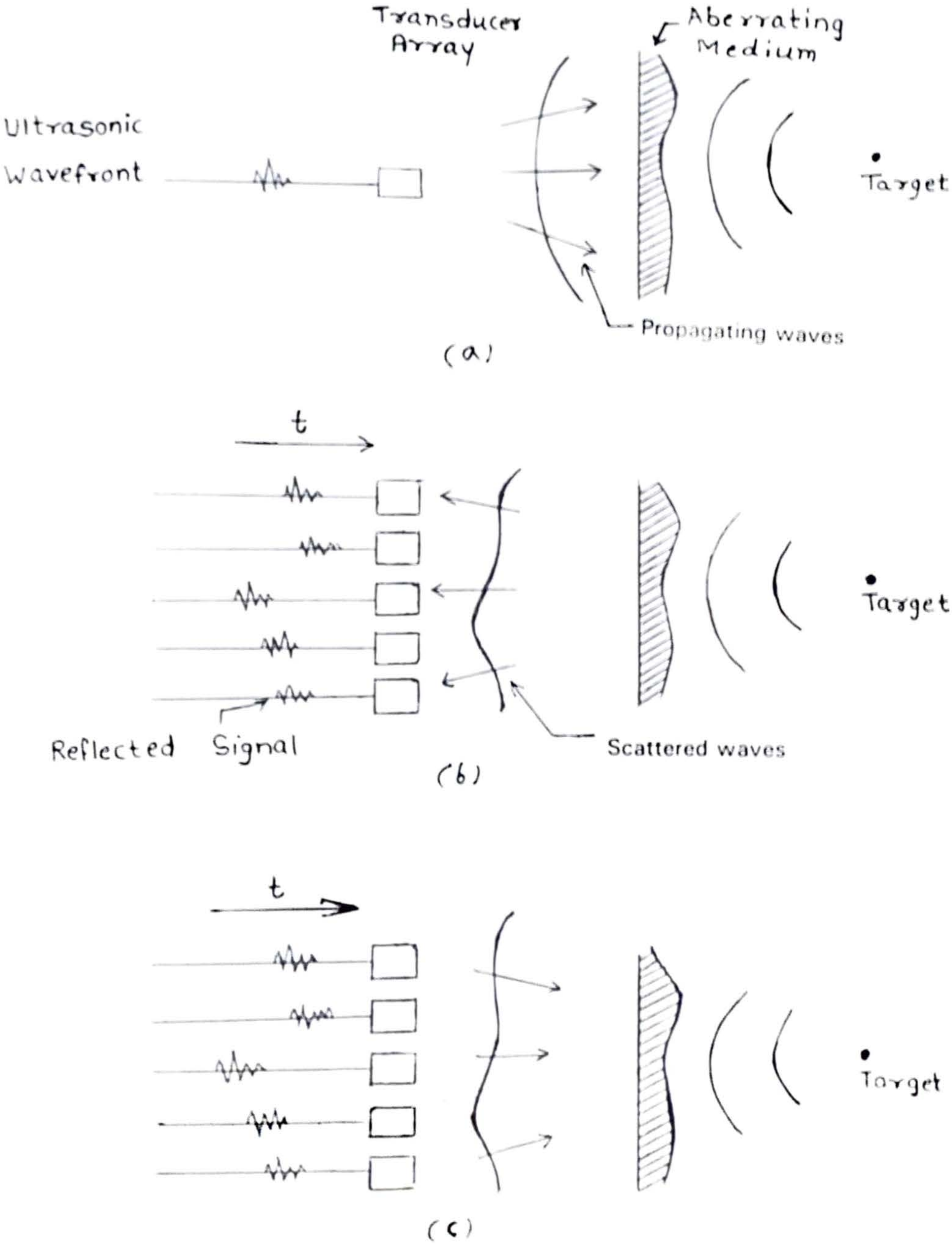



Fig.1.2 Time reversal mirror technique for ultrasound focusing.

a) Transmitting wavefront through the inhomogeneous media.

b) Recording step.

c) Transmitting a time reversed field.

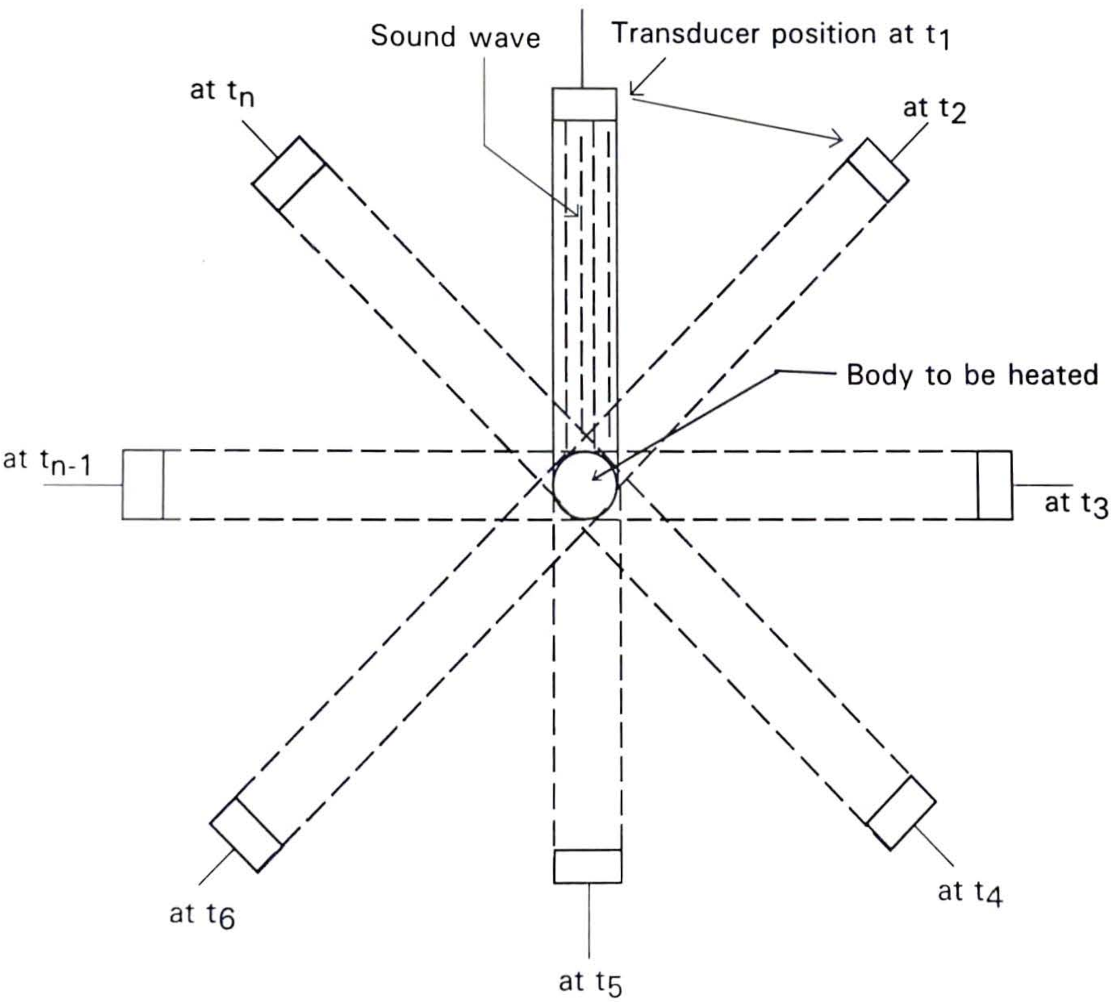



Fig. 1.3 Scheme for continuous heating at the target using single rotating transducer.

# 2. Ultrasound focusing
## Implementation aspects

### 2.1 Introduction

In first chapter, various ultrasound focusing techniques were described. This chapter describes the various aspects towards actual implementation of ultrasound focusing, the focusing procedure, transducers selection, delay elements for measurement and generation of delays.

### 2.2 Focusing procedure

The focusing procedure adopted earlier by Sahasrabuddhe [ 7 ] is discussed briefly here. The focusing of ultrasound wave on the target is carried out in a water tank. The focusing procedure is shown in Fig.2.1. The target region on which ultrasound from transducers is to be focused is first insonified by transmitting transducer. The target scatters the ultrasound waves in different directions and the scattered waves are sensed by the receiving transducers ($Tp_1$ to $Tp_4$). The output of all the receiver transducers after amplification in receiver amplifiers ($R_1$ to $R_4$) are given to timing logic. The timing logic will measure the delay from the time transmitted wave is sent to the time it is received by the receiver. This delay is proportional to distance from target to receiver. Based on this delay the timing logic decides the sequence in which the transducers are supposed to retransmit.

Let Ts be the transmitting transducer which insonifies the region of interest and let the receiving transducers $Tp_1$ to $Tp_4$ receives the reflected signals after a time delay of $T_1$, $T_2$, $T_3$ and $T_4$ where $T_1 > T_2 > T_3 > T_4$. Then while retransmitting, the transducer $Tp_1$ will be excited first and then $Tp_2$, $Tp_3$ and $Tp_4$ after a delay of ($T_1$- $T_2$), ($T_2$- $T_3$) and ($T_3$- $T_4$) respectively, after the excitation of previous transducer is completed. The sound waves delayed in such fashion would reach the target in succession. Since the hardware involved is large, it was felt that a microcontroller could be used in place of timing logic and a signal generator could be used to give continuous output. This scheme is described in the next chapter.

## 2.3 Ultrasound transducers

For the generation of ultrasound waves, the piezoelectric transducers are very commonly used. They work on piezoelectric effect. The material exhibiting this property are certain natural crystals, such as, quartz and tourmaline, ferroelectrics like barium titanate and lead zirconate titanate (PZT).

In selecting the operating frequency for the ultrasound system [4], it is desirable to keep a frequency that will keep the absorbed power in tissues near the skin surface less than the absorbed power at the depth.

The intensity at depth Z cm is given by,

$$I(Z) = I_0 \, e^{-2AZ \vec{Z}} \quad \text{------------- (1)}$$

Where, $\vec{Z}$ = unit vector in Z axis direction,

$I_0$ = acoustic intensity at the surface ($W/cm^2$),

$Z$ = distance into the tissue (cm) and

$A$ = attenuation coefficient of the tissue ($cm^{-1}$)

The rate at which the energy is dissipated as the wave travels through the tissue is equal to the absorbed power per unit volume, $P_a$ that may be derived from the general expression.

$$P_a = -\nabla I$$

i.e. $$P_a = 2 A I_0 \, e^{-2AZ} \quad \text{---------------- (2)}$$

'A' is assumed to be a function of frequency, and is approximately given by,

$$A = A_0 f \quad \text{----------------- (3)}$$

where, $A_0$ = the attenuation coefficient in tissue at 1 MHz.

($A_0$ = 1.0 d B/ cm/ MHz = 0.12 nepers /cm/ MHz) f = frequency in MHz

Therefore, eq. (2) becomes,

$$P_a = 2A_0 f I_0 e^{-2A_0 fZ} \quad \text{------------------ (4)}$$

Also, it is necessary to keep the acoustic intensity $I_0$ below certain level. The relative power deposition rate in the tissue ($P_a$ / $I_0$) is thus a function of frequency (f).

$$\text{i.e. } P_a / I_0 = 2A_0 f e^{-2A_0 fZ} \quad \text{------------------ (5)}$$

Hence, the optimal frequency, f = 1/(2$A_0$ Z) where $P_a$ / $I_0$ will be maximum. Assuming $A_0$ = 0.12 nepers /cm/ MHz, f for heating the plane waves in the 2 cm to 5 cm range is between approximately 0.4 and 2 MHz.

**2.4 Delay generation**

A delay line is an element or component into which an electrical signal can be put and can be taken at its output at some later time, which depends upon the delay set into it, thus causing the signal to get delayed. Thus the time delay circuits are most important elements in the entire set up. The focusing ability of the system would entirely be dependent upon how precisely the delays in the retransmission can be controlled. Firing of transducers with accurate delays would result in the ultrasound waves reaching at the target successively, which ultimately is the aim.

Some of the delay elements are: lumped parameter delay lines [5], switched capacitor delay lines [6], monoshots, digital counters etc. Lumped parameters and switched capacitors delay lines are shown in Fig.2.2. All these delay elements can generate the desired delays if the latter are known already. But to make a closed loop system, a delay element is required that will be able to measure as well as generate the desired delays. Digital counters, microcontrollers can be used for this purpose. The use of microcontroller as a delay measuring and generating device is described later in detail.

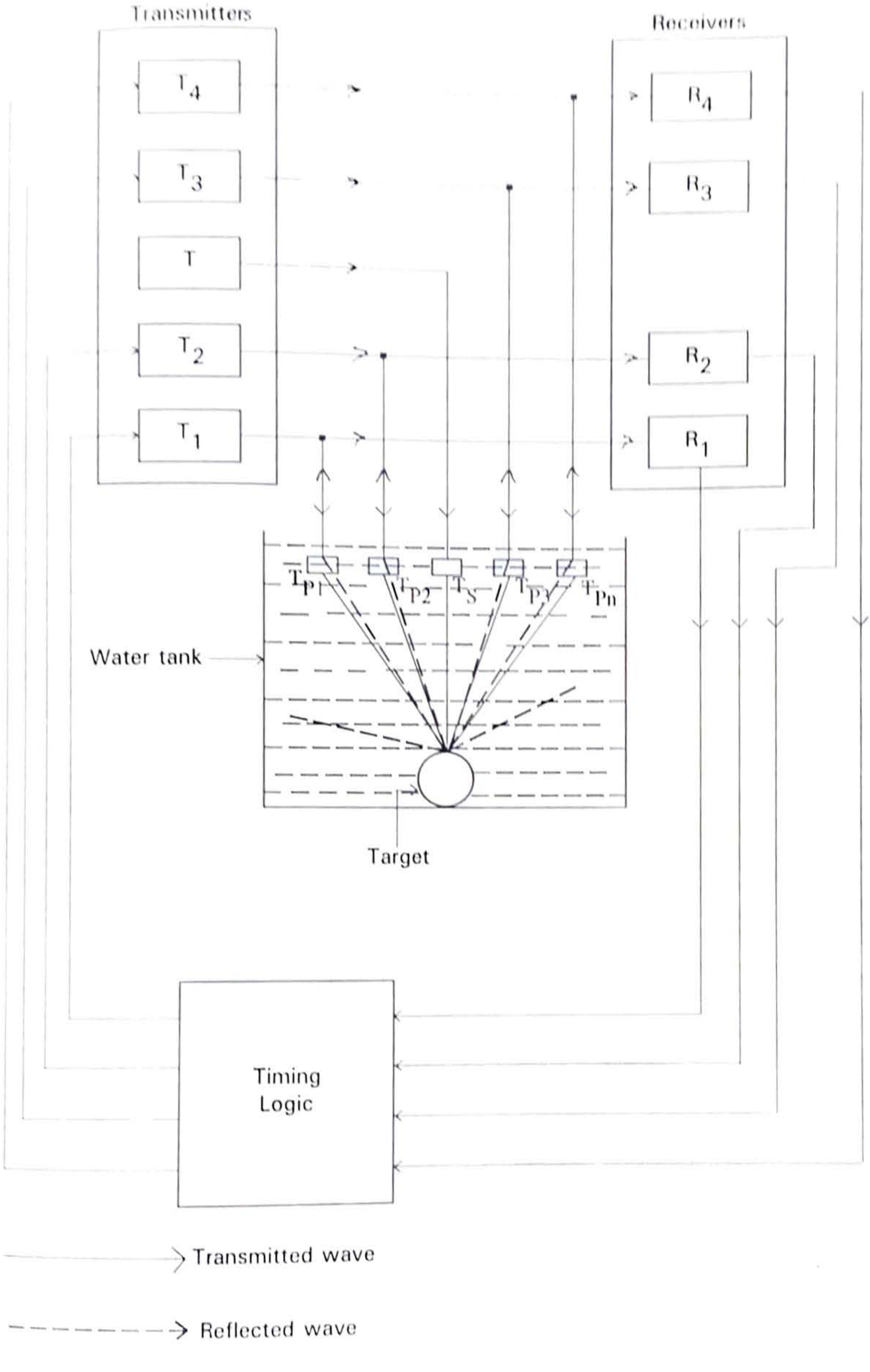



Fig. 2.1 Focusing procedure

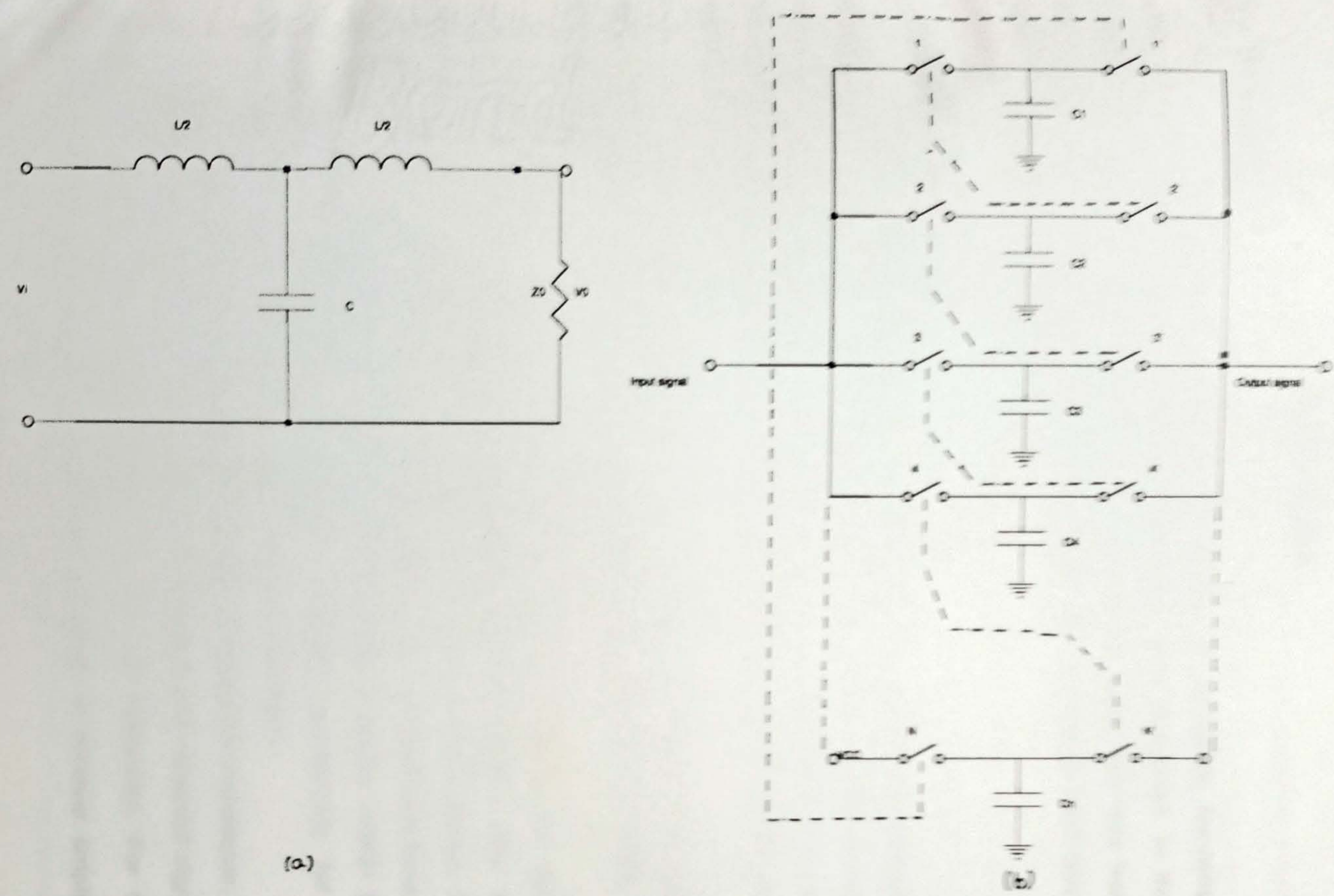



Fig.2.2 (a) Lumped parameter (b) Switched capacitor delay lines.

# 3. Focusing system

## 3.1 Introduction

In the second chapter various aspects of ultrasonic focusing, such as the method, selection of system elements were discussed. In this chapter, the scheme to get continuous heating at the target and less heat around the target is discussed. The block diagram and function of each block of the scheme are also described.

## 3.2 System block diagram

The scheme carried out in the laboratory consists of ultrasound transducers, transmitter circuit, switching network, receiver amplifier circuit, microcontroller and oscillator. It is shown in Fig.3.1. It describes a method for continuous heating of the target while the tissues around the target gets heated to a lesser extent.

The scheme is proposed initially for heating a target in a water bath. The amount of heat energy necessory to be imparted on the target is not discussed.

The scheme involves two steps. The first step is for delay measurement. Delay measurement step determines the delays that are required to be stored in the microcontroller. At the end of these delays, the transducers are connected to the power oscillator to get a continuous heat at the target. The second step involves a firing process during which the transducers are connected to the power oscillator sequentially for a predetermined period to get a continuous output at the target.

In Fig.3.1, the transmitter, T is used to excite the transducer, Ts with a large spike. The transit times of the transmitted and reflected signals received at the primary transducers $Tp_1$ to Tpn are measured. For this purpose, the received signals at $Tp_1$ to Tpn are given to receiver amplifier circuit, R through a switching network, $S'_N$. The receiver amplifier amplifies the signal which is then fed to the microcontroller, μc. The microcontroller will measure the delays and store them. During delay measurement, the switching circuit selects one transducer at a time. The switches $S'_1$ ------ $S'_N$ are controlled by the microcontroller and connect the transducers to the receiver amplifier.

After delay measurement, the transducers are excited with a sine burst which can be generated with the help of oscillator, O, power amplifier, P and switching network $S_N$. Details of the scheme are described below.

### 3.3 Delay measurement

The delay measurement set up is shown in Fig.3.2. Here, a transducer, $T_{p1}$ is selected with the help of switching network, $S'_N$ which is controlled by the microcontroller. The transducer, Ts is excited with a large spike generated by the transmitter and Ts generates a mechanical sound pressure. The transit time taken by the ultrasound to reach $T_{p1}$ is measured and stored in the microcontroller. Let the transit time taken by the ultrasound to reach $T_{p1}$ is $T_1$. Similarly, the transit times $T_2$ to Tn (the transit times from other transducers $T_{p2}$ to Tpn) are measured and stored in the microcontroller.

### 3.4 Firing step

The firing process is shown in Fig.3.3. During the firing process, the transducers are excited with sine burst which is generated with the help of oscillator, O and switching network, $S_N$. The switching network, $S_N$ is controlled by the microcontroller, μc so as to excite the transducers one after other sequentially depending upon the delays measured and stored earlier. If

$T_1 > T_2$ ----- $> T_n$, then, the transucer $T_{p1}$ is excited first with a sine burst of width Tx as shown in Fig.3.4(a). The transducer $T_{p2}$ is excited with a sine bust after a time delay of $(T_1\text{-}T_2+Tx)$ as shown in Fig.3.4(b). The transducer $T_{p3}$ is excited with a sine burst after a further time delay of $(T_2\text{-}T_3+Tx)$ as shown in Fig.3.4(c) and so on. Such a type of excitation will give a continuous heating of the target as shown in Fig.3.4(e). Here, the transducers are excited with a sine burst instead of pulse so as to transmit more energy to the target. Thus the target receives the energy continuously while at all other places it is in bursts and hence heating is limited.

### 3.5 Mechanical arrangement

The primary (receiving) and the secondary (transmitting) transducers are to be positioned in such a way that the reflections from the target surface can be detected by the primary transducers. This in other words is the geometrical focusing of the ultrasonic waves because we are directing the transducers towards the target. As the attenuation of ultrasonic waves through water is very small, it is required to dip the crystals in water. For this purpose a platform as shown in Fig.3.5 is designed. The piezo crystals are fixed at the bottom surface of the plastic tube. These tubes are placed on a thin metal sheet. The metal sheet is bent such that the transducers it holds directs the waves towards the target. With such an arrangement, the crystals can be dipped inside the water and the waves directed towards the target.

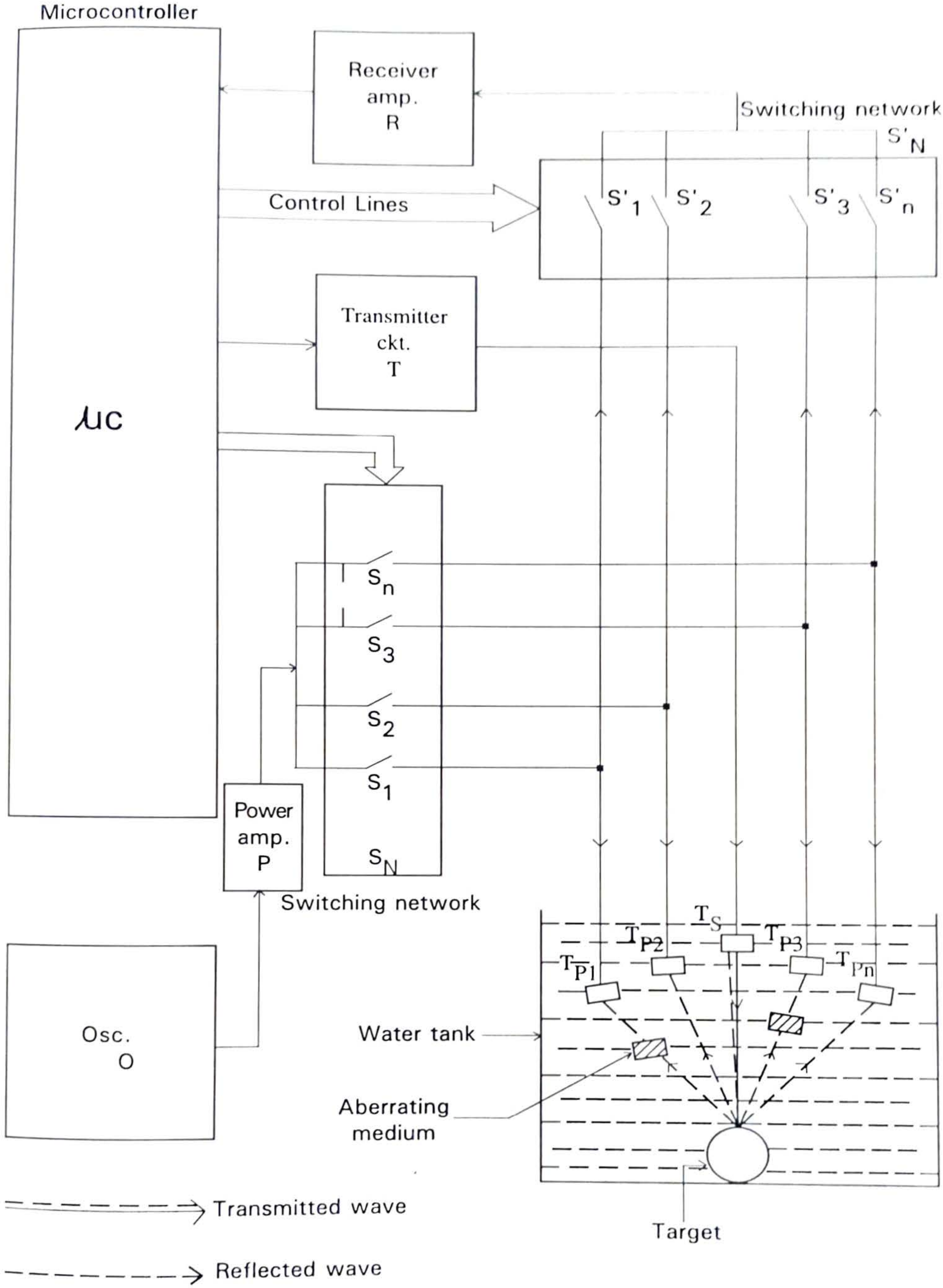



Fig. 3.1 System block diagram for continuous heating at the target.

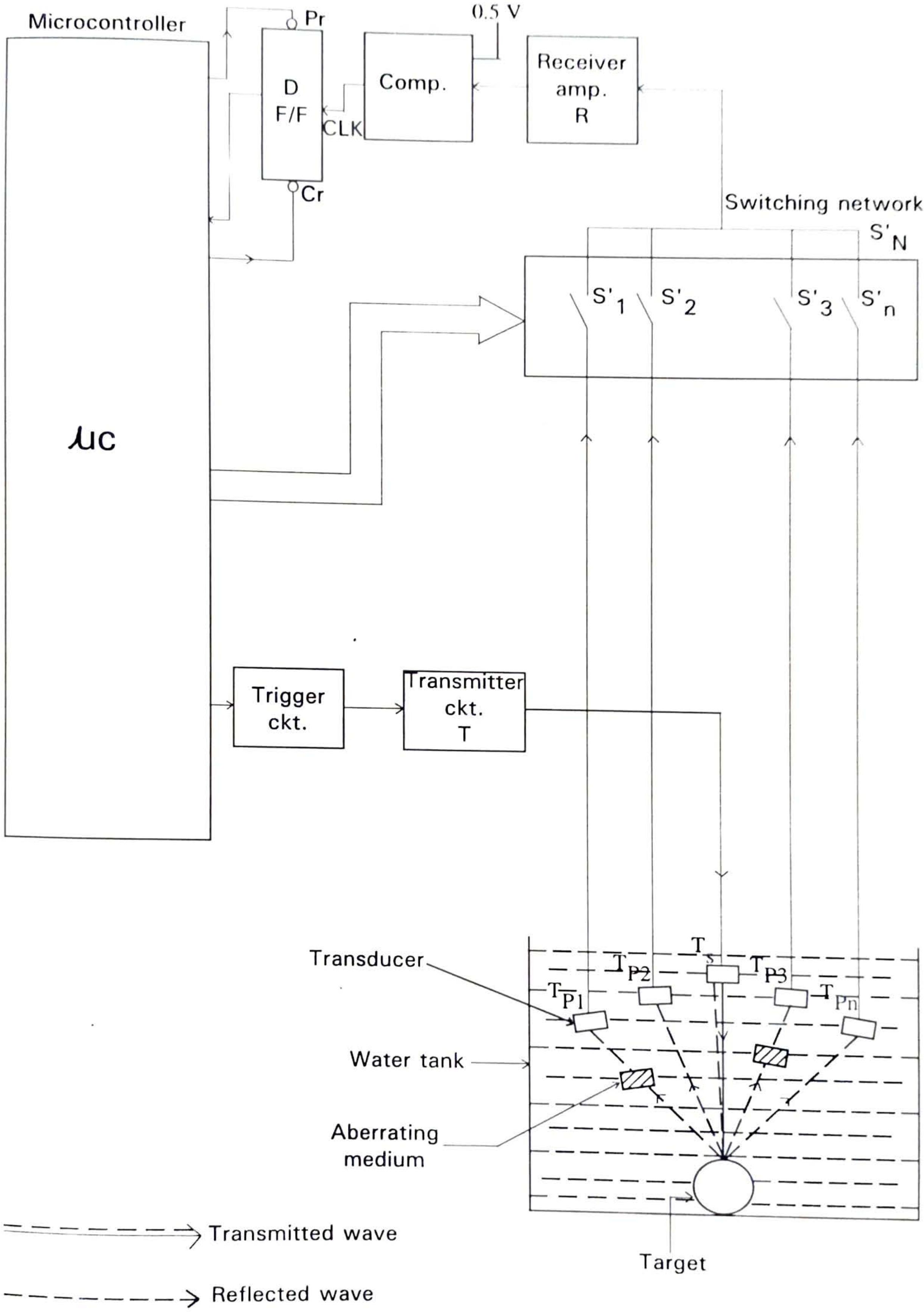



Fig. 3.2 Delay measurement.

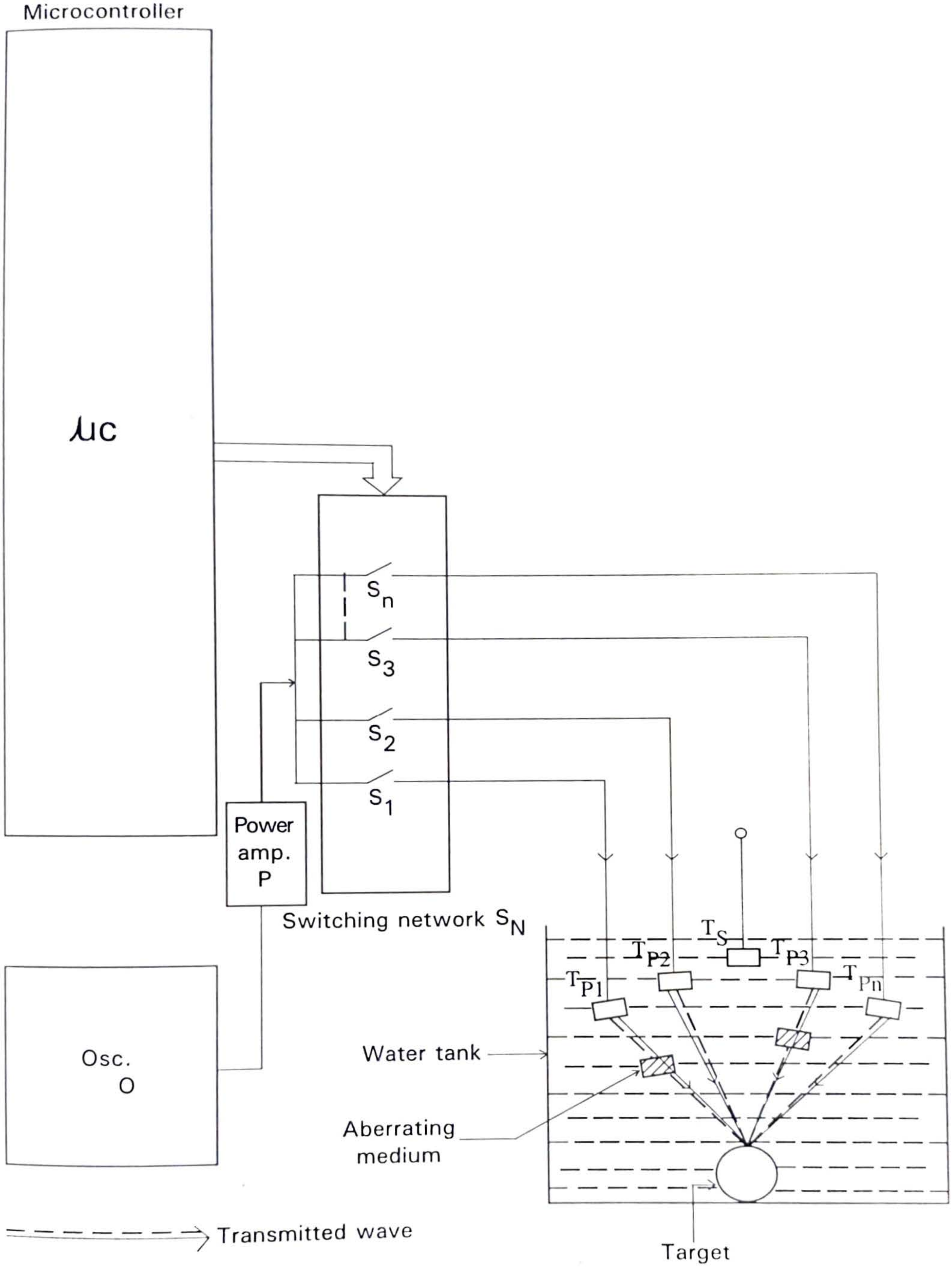



Fig. 3.3 Firing process.

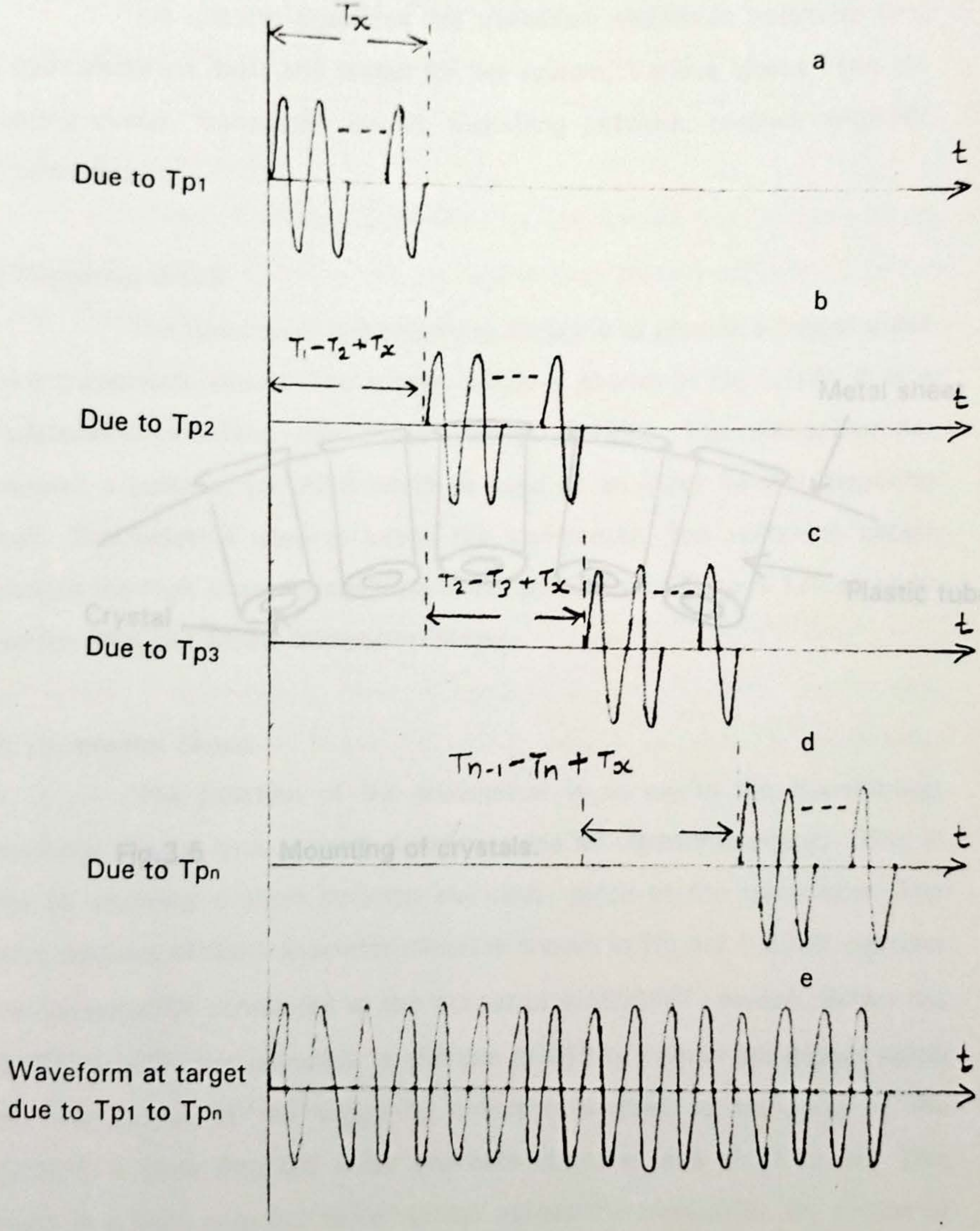



Fig.3.4 The waveforms at the target due to excitation of various transducers.

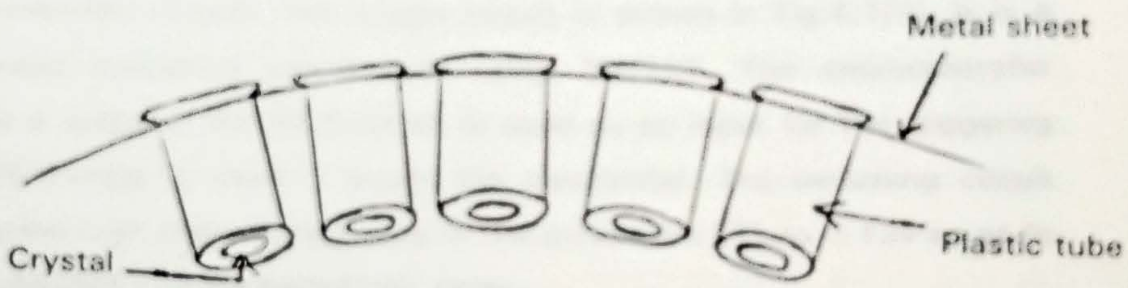



Fig.3.5 Mounting of crystals.

# 4. System hardware

## 4.1 Introduction

This chapter describes the necessary electronic hardware that has been designed, built and tested for the system. Various blocks used are triggering circuit, transmitter circuit, switching network, receiver amplifier and delay circuit.

## 4.2 Triggering circuit

The function of the triggering circuit is to provide a trigger pulse to the transmitter circuit. The trigger circuit is shown in Fig.4.1[7]. It is a transistorized switching circuit built using 2N2222. The microcontroller generates a pulse at pin P2.3 which is used as an input for the triggering circuit. This pulse is used to excite the transmitter. The switching circuit increases the high state voltage level of the pulse from TTL to +12v so as to drive the MOSFET of the transmitter stage.

## 4.3 Transmitter circuit

The function of the transmitter is to excite the transmitting transducer, Ts to emit a short duration pulse of ultrasonic energy. This is done by applying a short duration electrical pulse to the transducer. The circuit diagram of the transmitter circuit is shown in Fig.4.2 [ 7 ]. It consists of a capacitor $C_1$ connected at the output of a MOSFET switch. When the MOSFET is OFF, the capacitor is charged to +120V. When the trigger signal from the output of the triggering circuit is applied to the gate of the MOSFET, it goes into ON state and acts virtually as a short circuit. This results in a large negative spike voltage across the transducer. By means of this electric pulse, the transmitting transducer is excited to produce mechanical pulse which is transmitted into water.

The amplitude and shape of the transmitter pulse have a great effect on the transmitted ultrasonic pulse. The width of the pulse and hence the energy transferred to the transmitting transducer can be increased by choosing higher value capacitance $C_1$ [ 8 ].

### 4.4 Switching network

When the spike generated by the transmitter is given to the transmitting transducer, Ts, the transducer generates mechanical pressure wave. During delay measurement, the transit times for ultrasound to reach the transducer $T_{p1}$ to Tpn are measured successively. The selection of $T_{p1}$ to Tpn is done with the help of switching network, $S'_N$ (Fig.3.2) which is controlled by the microcontroller. A switching cell of the switching network is shown in Fig.4.3. Here DG 201A (Quad monolithic SPST CMOS analog switches) [ 9 ] is used. A DG 201A is bi-directional, latch proof switch which can block signals upto 30 $V_{PP}$ in OFF state. The switch is TTL and CMOS compatible. The switching network will play an important role during delay measurement. When a single DG 201A switch is used, a considerable leakage voltage was observed even when the switch is OFF. When the input was 60m$V_{PP}$ and the switch is OFF, the output observed was 8m$V_{PP}$. This is not an acceptable value and hence the switching network shown in Fig.4.3a was tried out. When $S_1$ and $S_3$ are OFF, and $S_2$ is ON, the leakage was reduced to 2mV. Thus the switching network reduces the leakage and the crosstalk between two received signals will also be reduced. But, when $S_1$ and $S_3$ are ON, their ON resistance causes loading effect on the received signal during delay measurement and on excitation signal during the firing process. Hence the switching cell of switching network, $S'_N$ shown in Fig.4.3b during delay measurement and the switching cell of switching network, $S_N$ shown in Fig.4.3c during firing process are preffered. In the switching network shown in Fig.4.3b, a CD 4066 (Quad bilateral switch) [9] is used. As its ON resistance is very very less, it reduces the loading effect on received signal. Also it produces less leakage during OFF state. The switches are controlled by microcontroller pins ( P3.0 to P3.7). In the circuit shown in Fig.4.3c, reed relays are used which has very low ON resistance ( 0.7 ohm) causing less loading on the excitation signal during firing process. A transistorized switch is use to make the reed relay ON and OFF which in turn controlled by the microcontroller pins ( P1.0 to P1.7).

### 4.5 Receiver amplifier circuit

The signal available at the output of the receiver ultrasonic transducers are of very small amplitude of the order of few millivolts. They need to be amplified before feeding them to other circuit for further processing. The receiver amplifier circuit is shown in Fig.4.4. The amplifier has a bandwidth of 45 MHz [ 7,10 ]. It consists of a preamplifier followed by another amplifier with diode clipping circuits at the outputs of the both the stages. The gain of the preamplifier can be adjusted in such a fashion that the noise and echoes in the received signal are not amplified beyond the cut-in signal of the diode. Thus the output of the center dipping circuit will be free of noise and echo signals. The second amplifier boosts the signal from clipping circuit. The amplifier is built using NE592, a differential input, differential output wide band amplifier [11].

### 4.6 Delay circuit

The delay generation and the delay measurement is done with the help of microcontroller 89C55 [12]. It is a 16 bit microcontroller having 2 internal counters which can be used as timer or counter depending upon the application. The output of the receiver amplifier is given to the high speed comparator NE521 which compares the received signal with the reference signal (≅0.5 V) and gives out a square waveform. This waveform is then given as a clock pulse to a D- type flip - flop 7474. The input of D - type flip-flop is held at zero. The output of D-type flip - flop is given to microcontroller pin (P2.6) [Fig.3.2]

The microcontroller pin (P2.6) is held to logic 1 level first. When a pulse generated by microcontroller is given to the transmitter circuit, a counter of microcontroller is started. When the microcontroller receives a logic 0 level on its pin P2.6, it stops the counter. The reading of the counter is corresponding to the delay required for the ultrasonic wave to travel from the transmitting transducer, Ts and to reach at one of the receiving transducers $T_{p1}$ - $T_{pn}$. These delays are then stored in the microcontroller. During firing process, the delays are obtained with the help of same counters. The complete circuit diagram of the scheme is shown in Fig.4.5.

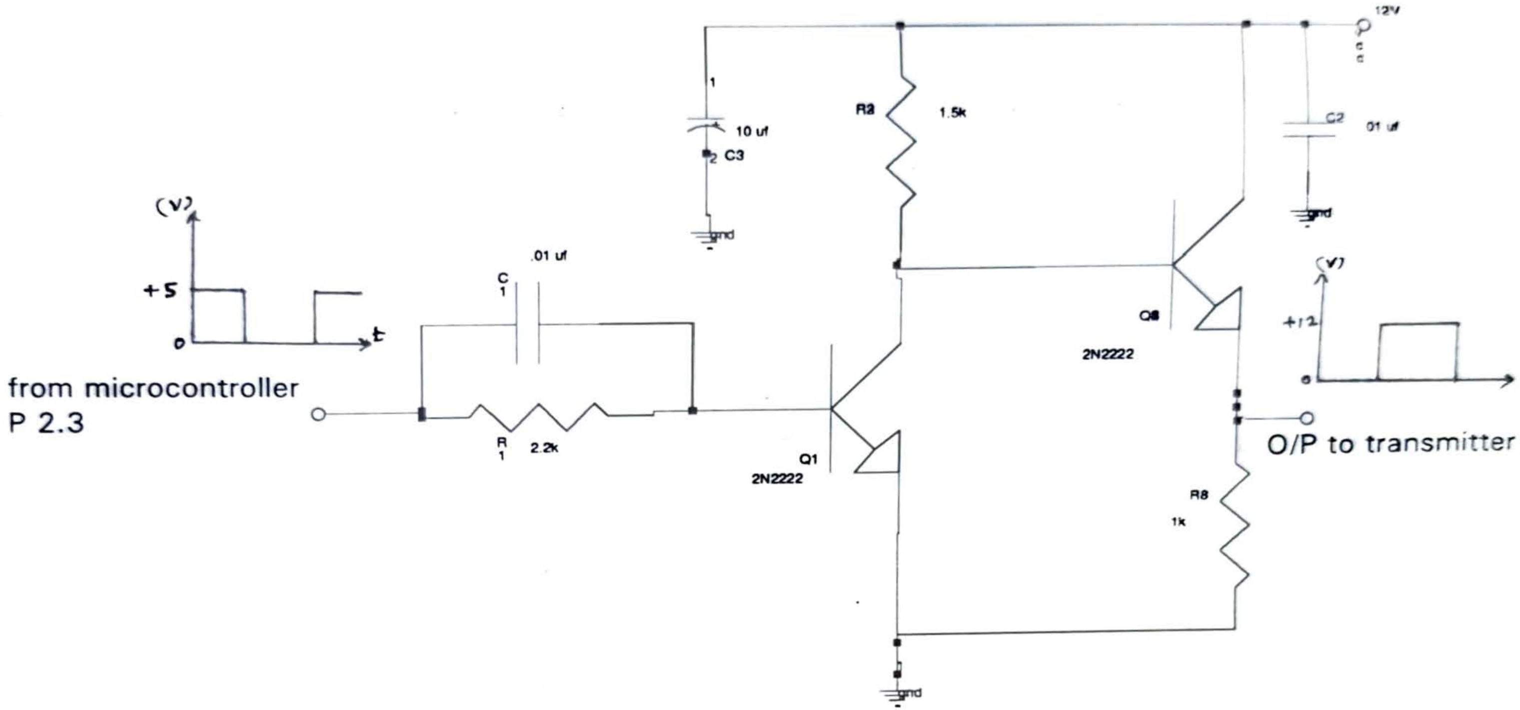
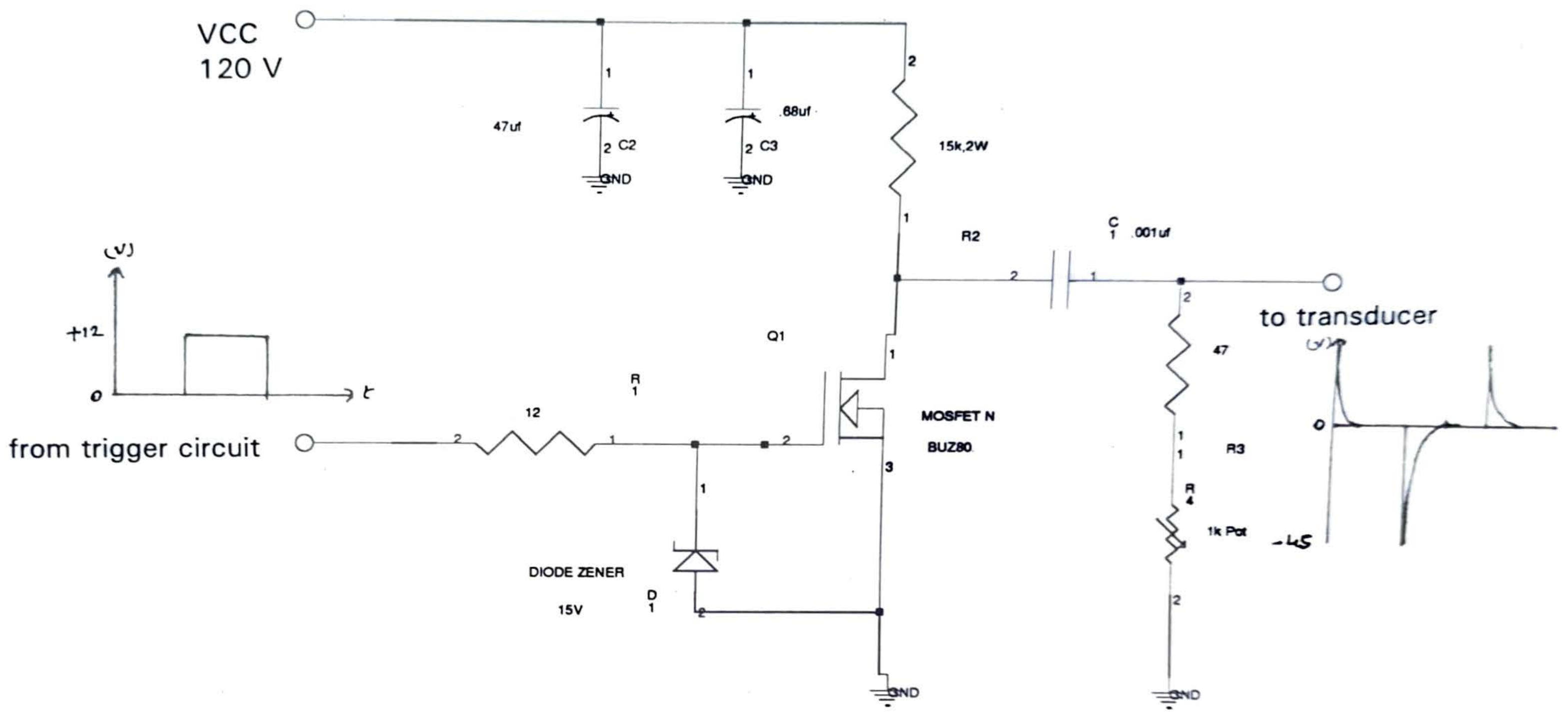



Fig.4.1 Trigger circuit.




Note : All resistances are in ohms.

All capacitors are in microfarads.

Fig.4.2 Transmitter circuit.

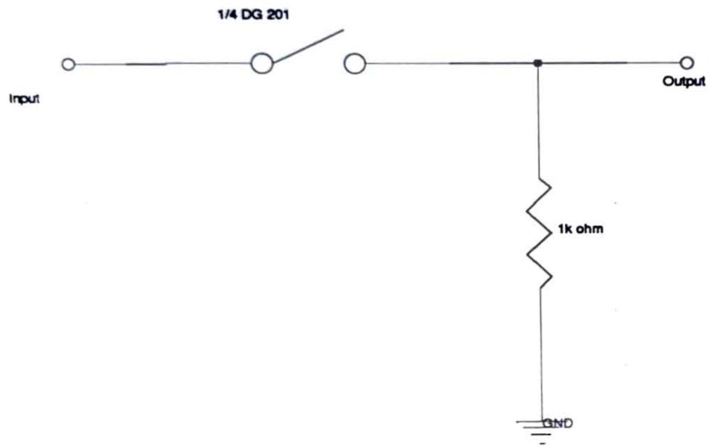



Fig.4.3 Switching cell.

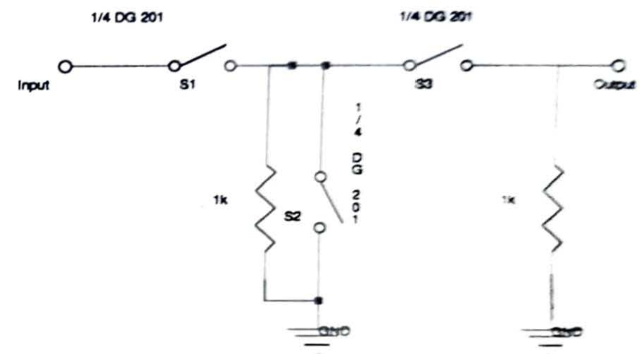



Fig.4.3a Switching network.

Note : All resistances are in ohms.

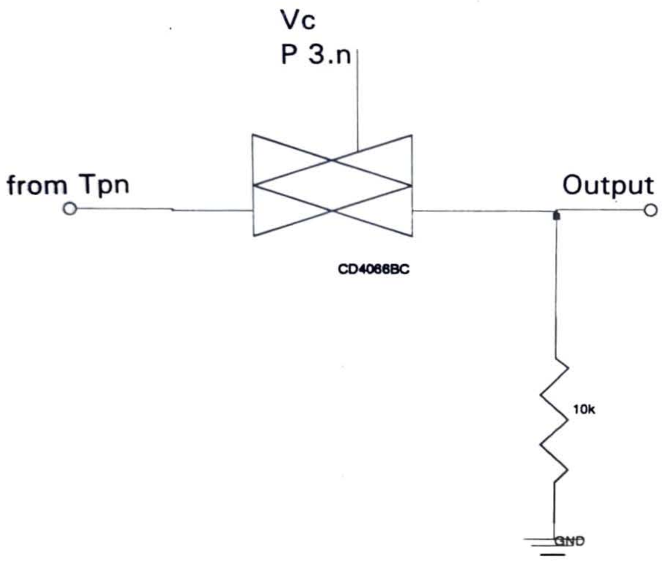



Fig.4.3b Switching cell of S′N.

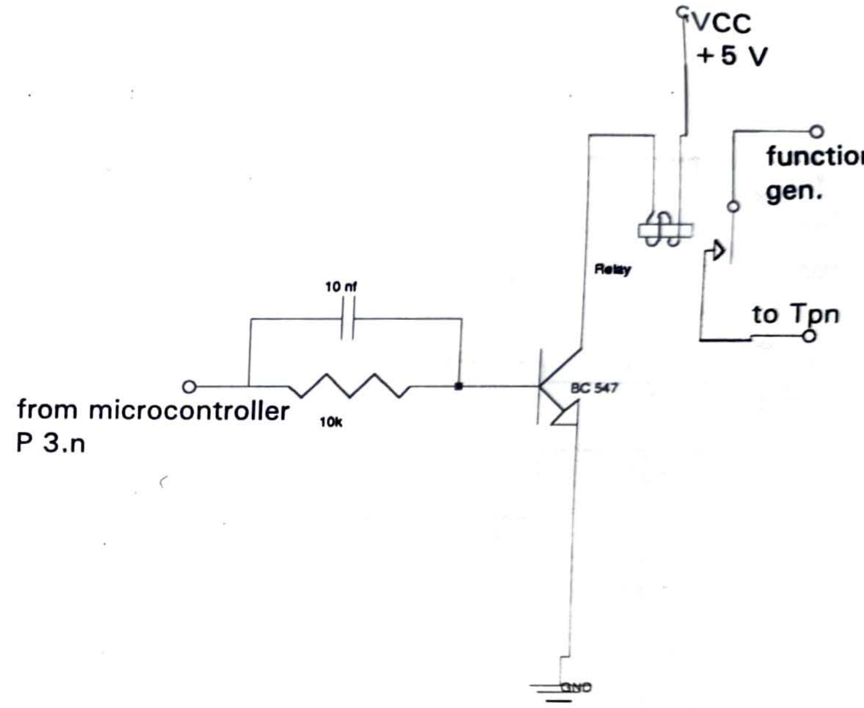



Fig.4.3c Switching cell of SN.

Note : All resistances are in ohms.

All capacitors are in microfarads.

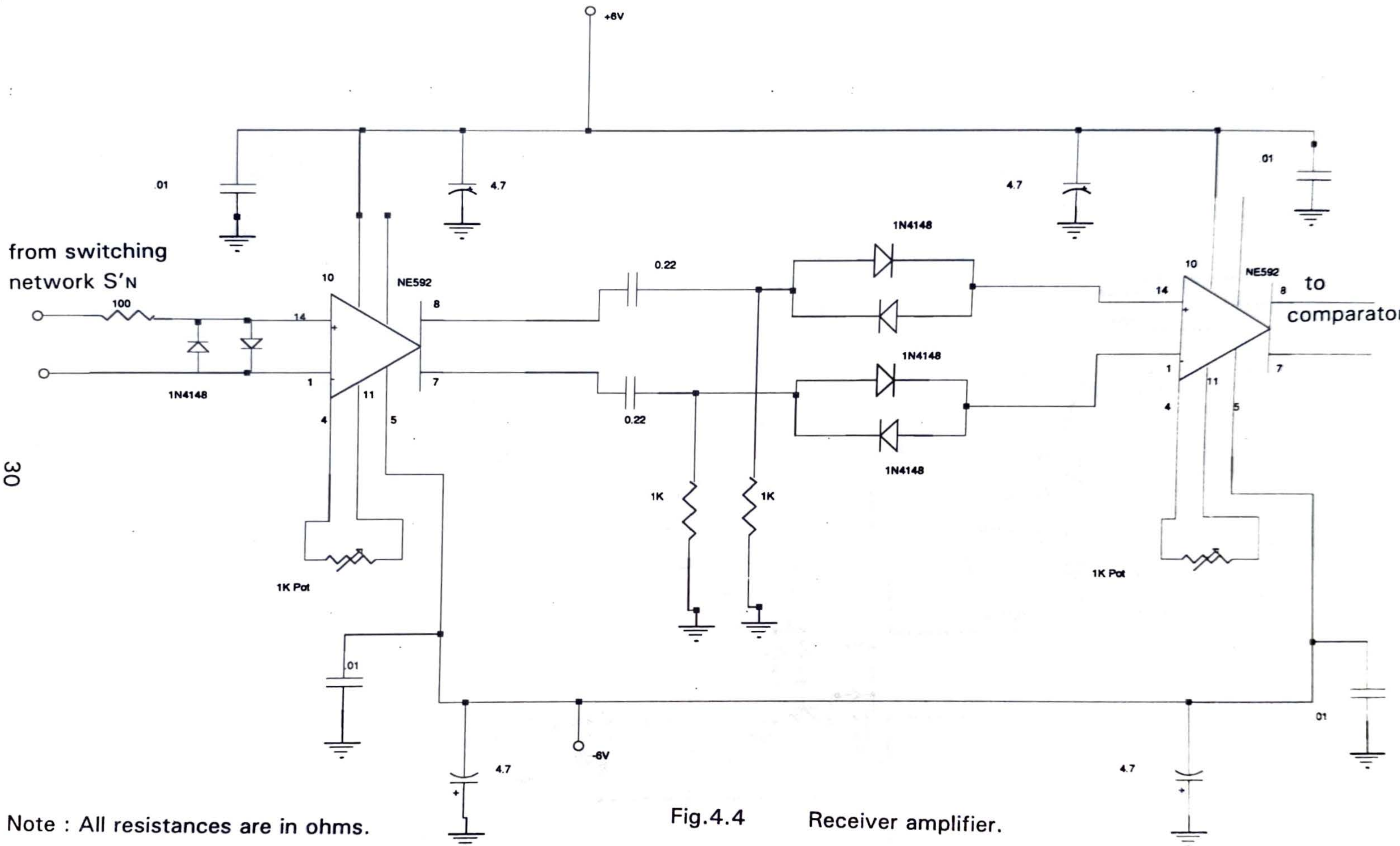



Fig.4.4 Receiver amplifier.

Note : All resistances are in ohms.

All capacitors are in microfarads.

All diodes are 1N4148.

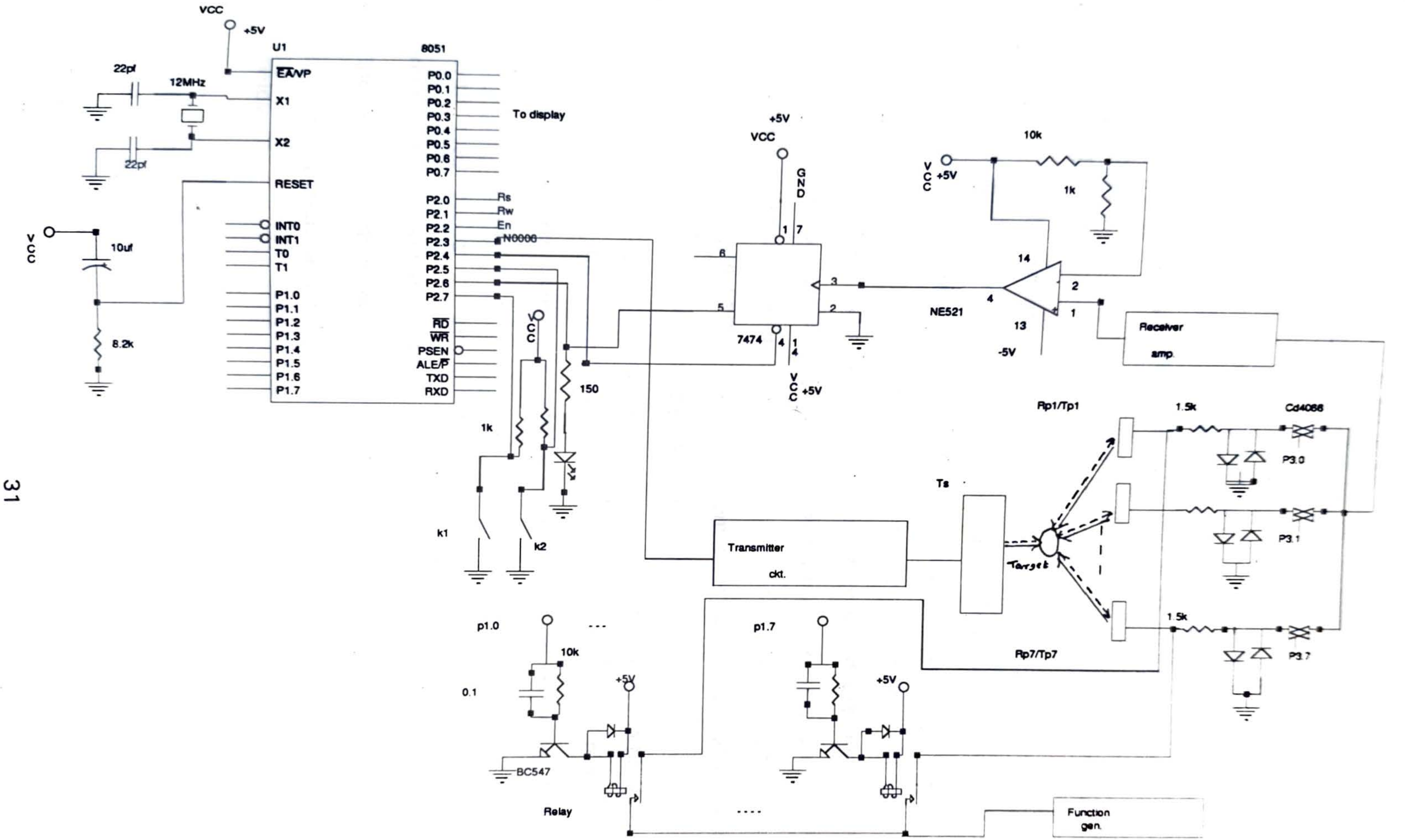



Fig.4.5 Circuit diagram of the scheme.

# 5. Experiments and results

## 5.1 Introduction

This chapter describes the experiments carried out in order to test the focusing ability of the system and gives the results obtained thereof.

## 5.2 Results

The scheme shown in Fig.3.1 was built using the blocks discussed in chapter 4. Initially the testing was carried out using a single transmitting and receiving transducer. During delay measurement the receiving transducer was connected to receiving amplifier manually. The receiving transducer was kept at different heights and the delay measured and these delays were stored in the microcontroller. The microcontroller then decides the order in which the delays are to be rearranged. The firing process was observed on 8 LEDs. These LEDs simulated the firing transducers. The system was found to be working satisfactorily.

Because of the problems of the mechanical assembly for holding the transducers that caused the misalignment and due to the reduced power of oscillator, the transducers placed at larger angles could not receive the reflected signals and hence the scheme was carried out for two transducers with two types of switching network (using CD 4066 during delay measurement and using reed relays during firing process). The strength of the received signal reduces approximately to 20% for $2^0$ deviation from the line of alignment and 50% at $3^0$ deviation. The results obtained are described below.

Fig.5.1a shows the pulse generated by the microcontroller (CH- A) to trigger the triggering circuit which in turn gives a large negative spike (CH- B) at the output of transmitter circuit. Fig.5.1b shows the expanded version of the output of the transmitting network. Fig.5.2 shows the waveform when transducer, Ts is connected to the output of the transmitting circuit. This shows some loading effect of the transducer. When the resistance $R_4$ of the transmitting circuitry shown Fig.4.2 is changed, the resulting transmitting waveform is shown in Fig.5.3. Fig.5.4 shows the pulse transmitted to the transmitting transducer, Ts (CH- A) and the pulse received at receiving transducer $Tp_1$ (CH- B). Fig.5.5 shows the pulse transmitted to Ts (CH- A) and the pulse received at $Tp_2$ (CH- B). The delays between the transmitted pulses and the received pulses are measured.

Following delays were observed.

1. Time delay between the transmitted pulse and the received pulse at $Tp_1$ was 101 $\mu$sec.
2. Time delay between the transmitted pulse and the received pulse at $Tp_2$ was 84 $\mu$sec.
3. Thus the difference between the two received pulses is 17 $\mu$sec.

After the delay measurement, the microconttroller will trigger the transducer, $Tp_1$ corresponding to the maximum delay first (CH- A) and then triggers the remaining transducer ($Tp_2$) as shown in Fig.5.6 (CH- B). Fig.5.7 shows the excitation of the transducer, $Tp_1$ with a sine burst (CH- A) the continuous wave of amplitude 268 mVpp and frequency 2.5 MHz seen at the target spot (CH- B).This was measured using immersible transducer.

The same procedure is carried out at other heights of transducer $Tp_1$ and $Tp_2$. The results obtained are shown in Fig.5.8, Fig.5.9 and Fig.5.10.

Efforts were made to extend the scheme using 8 transducers. But again due to reduced power output of the oscillator and mechanical misalignment at greater angles it could not be carried out successfully. It is required to calculate the power deposited at the target before designing the power amplifier. This requires a matching scheme and the transducer parameters have to be found out.

Following tests were performed to measure the transducer parameters.

### 5.3 Crystal parameters

In order to design appropriate matching circuit, the characteristics of the crystal have to be determined. The tests are carried out to find the characteristics of the crystal. The experimental circuit is shown in Fig.5.11. The results obtained are described below.

The crystal is excited with a constant amplitude sine wave. The results obtained for different frequencies are given in Table 5.1. The characteristic Fin Vs Zo is shown in Fig.5.12.

Table 5.1: Impedance measurement of the crystal at different frequencies.

Vin = 7 Vpp

| Fin (MHz) | Vin (V) | $V_R$ (V) | $V_o$ (V) | $I_R$ (mA) | $Z_o$ (ohm) |
|---|---|---|---|---|---|
| 1 | 2.474 | 0.247 | 2.29 | 24.7 | 92.7 |
| 2.0 | 2.474 | 0.459 | 2.899 | 45.9 | 63.1 |
| 2.5 | 2.474 | 1.555 | 1.484 | 155.5 | 9.5 |
| 2.8 | 2.474 | 0.212 | 2.51 | 21.2 | 118.3 |
| 3.0 | 2.474 | 0.353 | 2.79 | 35.3 | 79 |

Thus, the resonant frequency of the crystal has found to be 2.5 MHz. At resonant frequency, the impedance of the crystal $Z_o$ is approximately 10 ohms.

### 5.4 Flow chart

The flow chart for controlling the switching network, $S_N$ and $S'_N$, for the measurement of delays and for firing process is given in the appendix A. The software is given in appendix B.

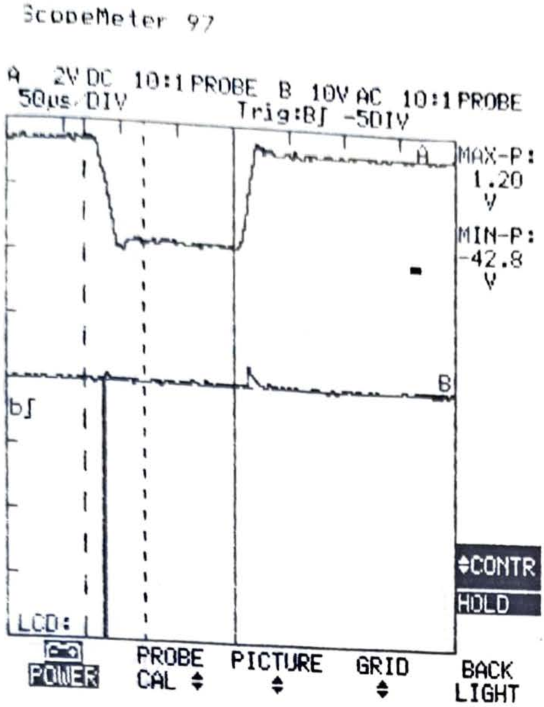



Fig.5.1a I/P pulse to trigger circuit. CH- A

O/P of the transmitter circuit. CH- B

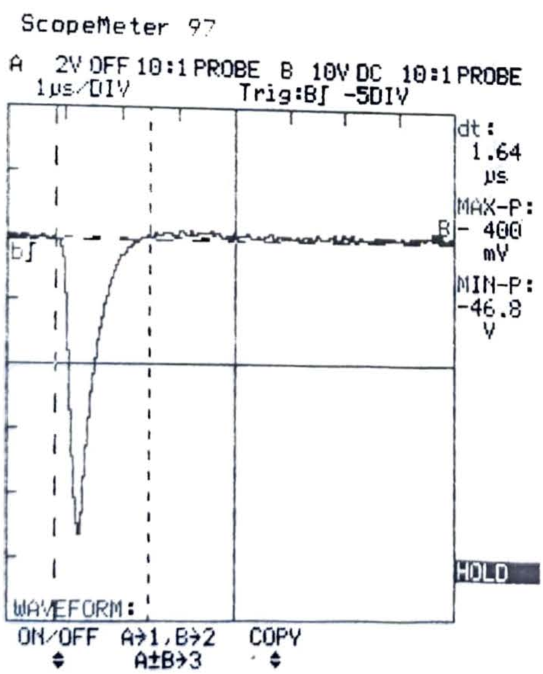



Fig.5.1b Expanded version of the o/p of the transmitter circuit.

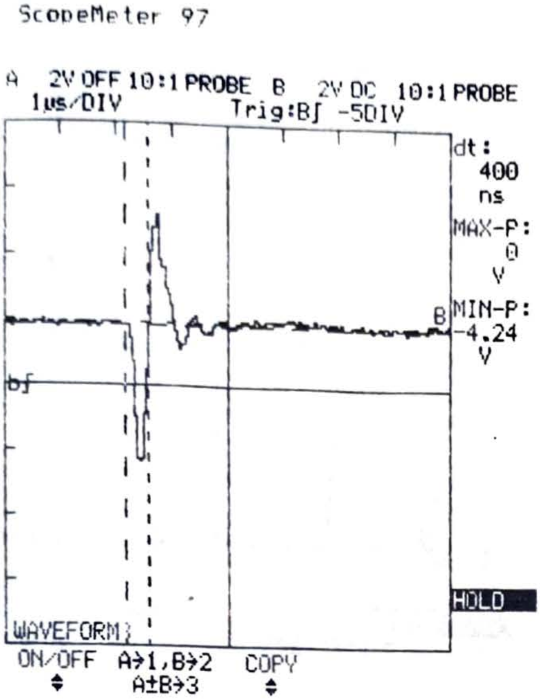



Fig.5.2 O/P of the transmitter circuit after connecting to Ts with $R_4$ = 1k ohm.

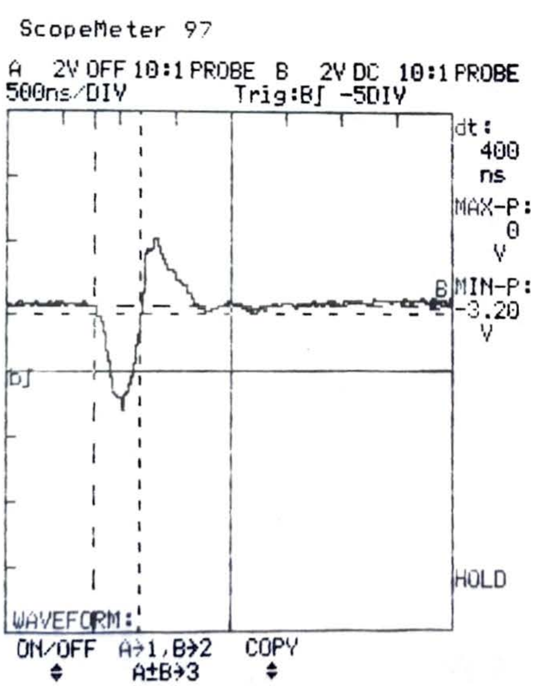



Fig.5.3 O/P of the transmitter circuit after connecting to Ts with $R_4$ = 0 ohm.

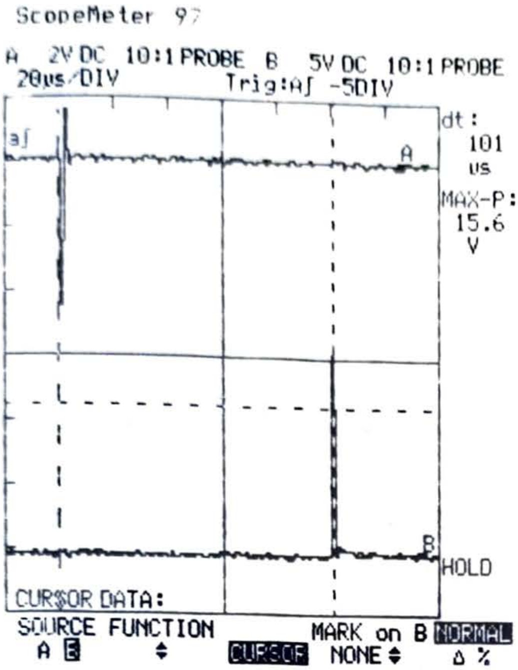



Fig.5.4 Excitation pulse to Ts. CH- A

Received signal at Tp1. CH- B

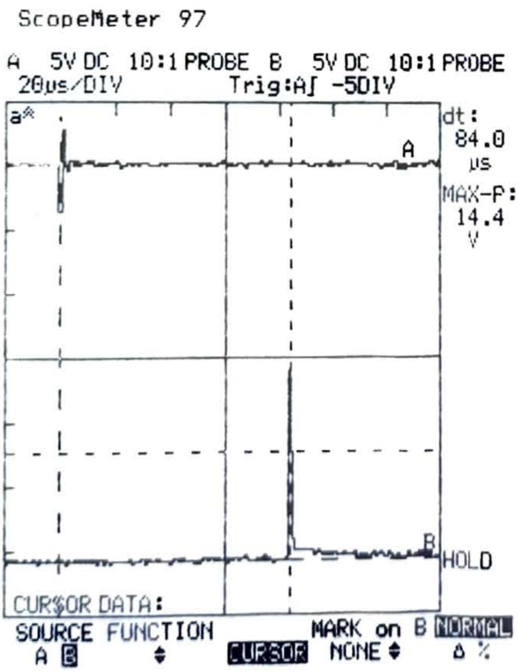



Fig.5.5 Excitation pulse to Ts. CH- A

Received signal at Tp2. CH- B

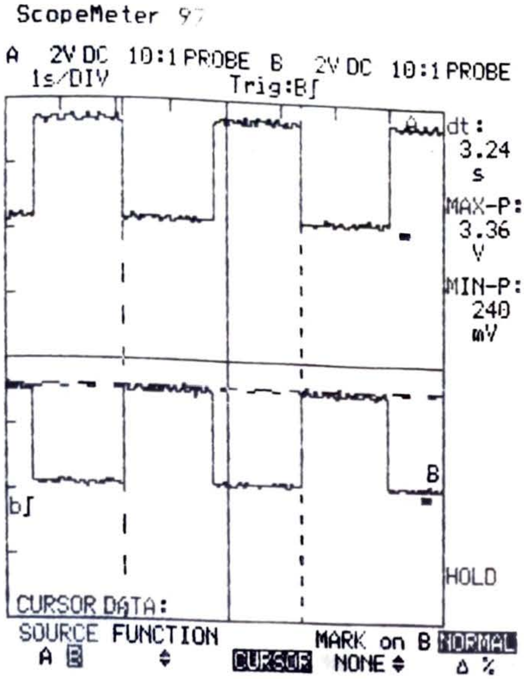



Fig.5.6 O/P at P1.0. CH- A

O/P at P1.1. CH- B

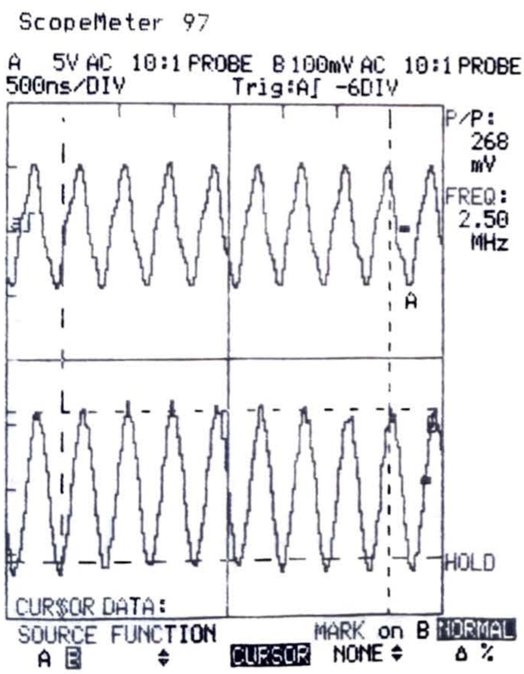



Fig.5.7 Excitation signal for Tp1. CH- A

Received signal at the target. CH- B

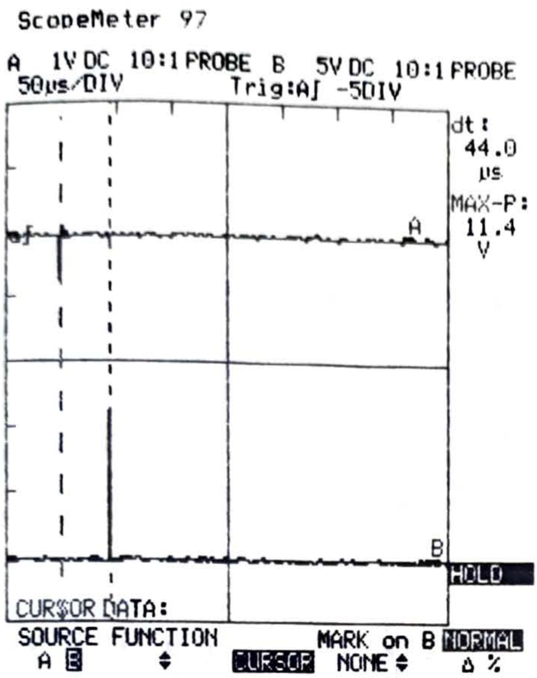



Fig.5.8 Excitation pulse to Ts. CH- A

Received signal at Tp1. CH- B

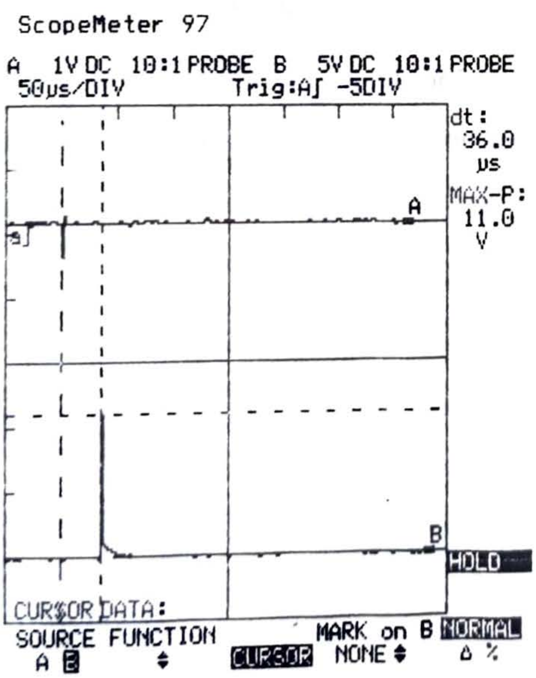



Fig.5.9 Excitation pulse to Ts. CH- A

Received signal at Tp2. CH- B

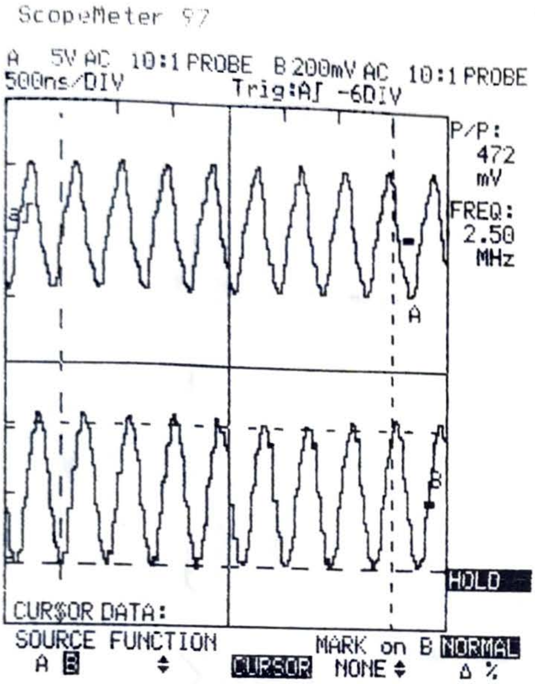



Fig.5.10 Excitation signal for Tp1. CH- A

Received signal at the target. CH- B

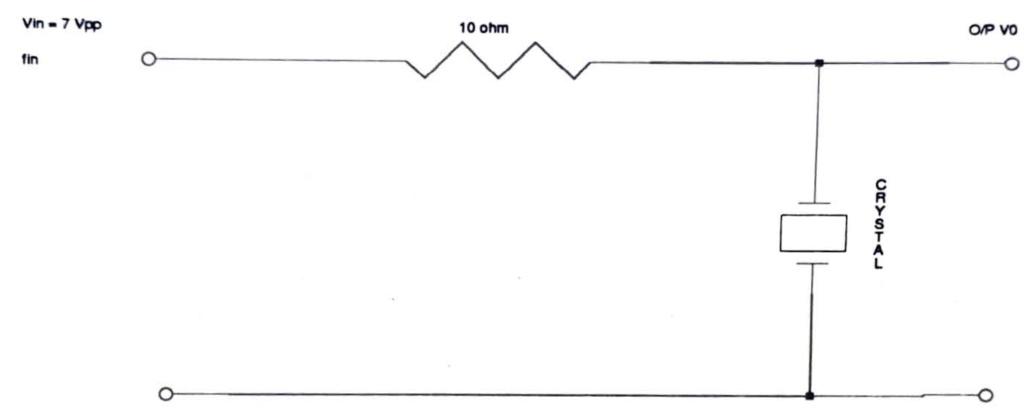



Fig.5.11 Experimental setup to find the parameters of the crystal.

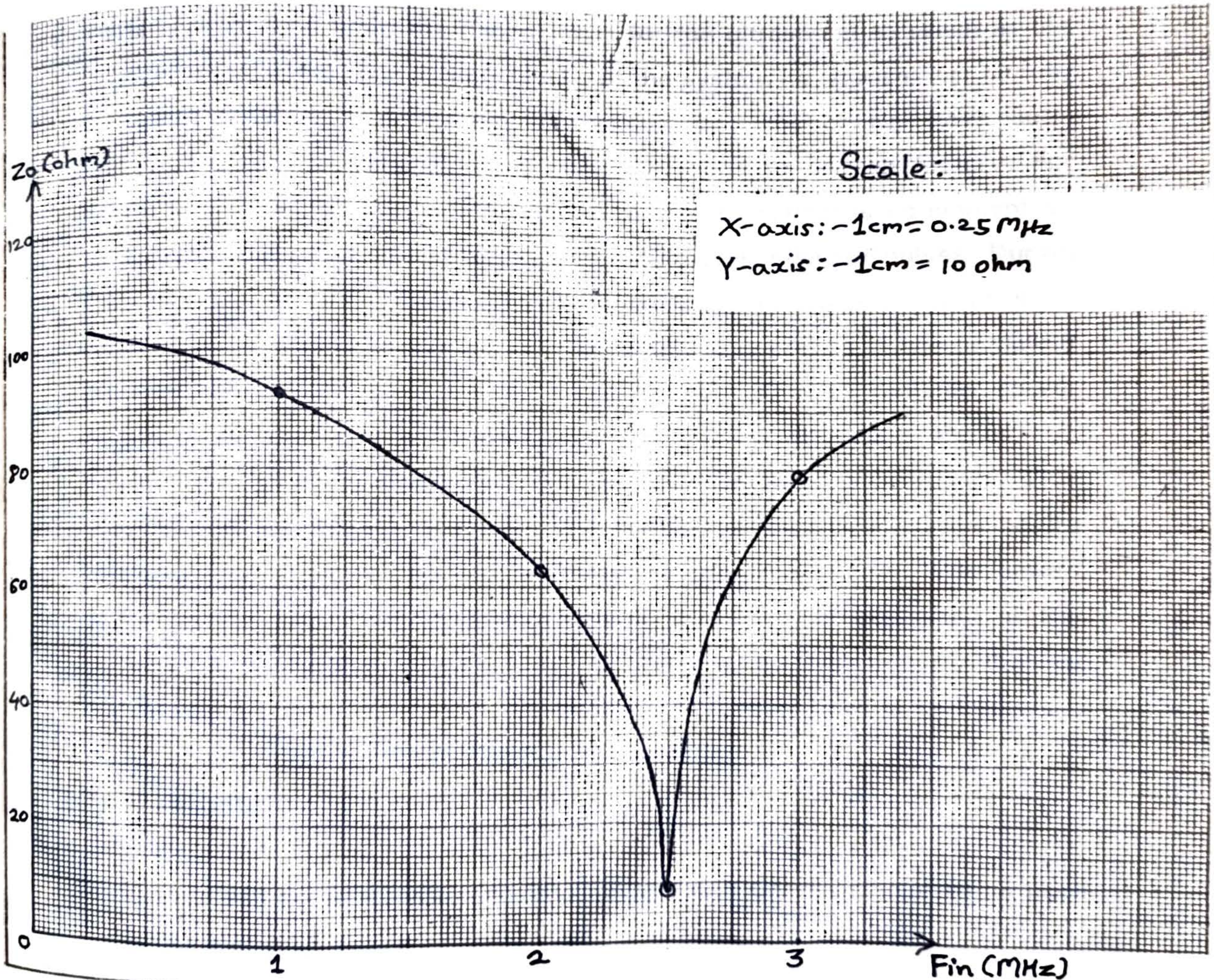



Fig.5.12 Impedance characteristic of the crystal.

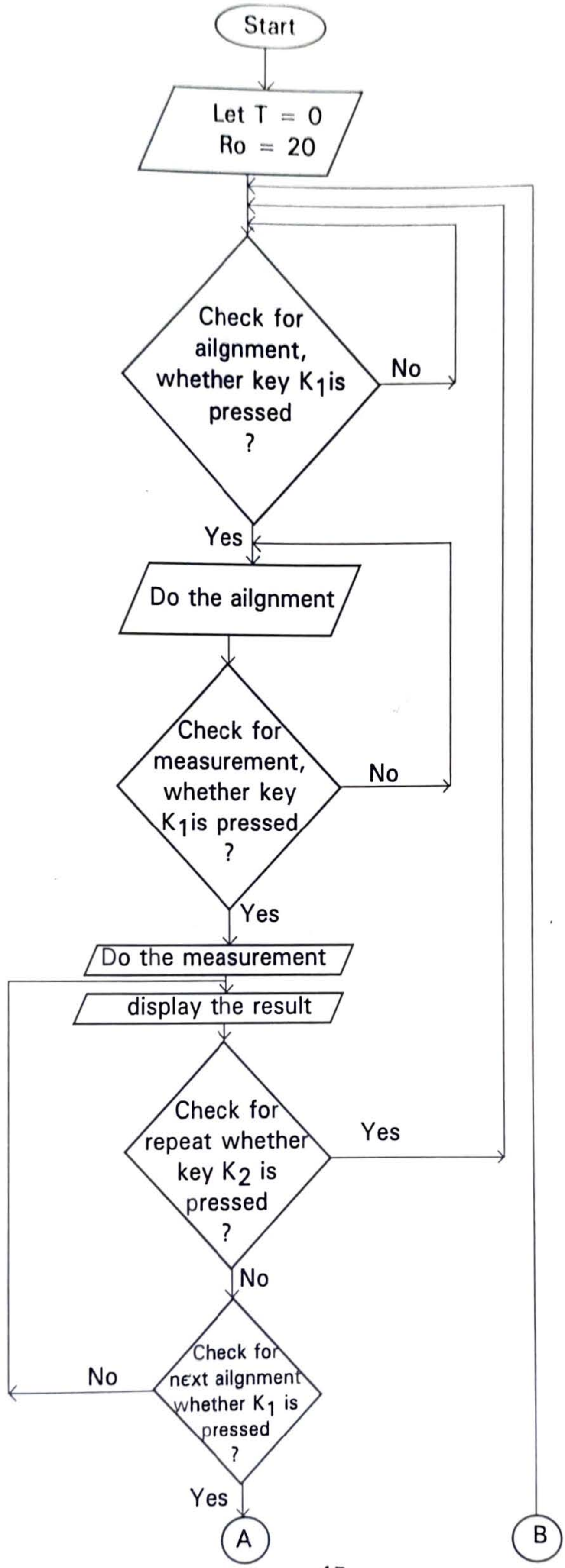
# 6. SUMMARY AND CONCLUSION

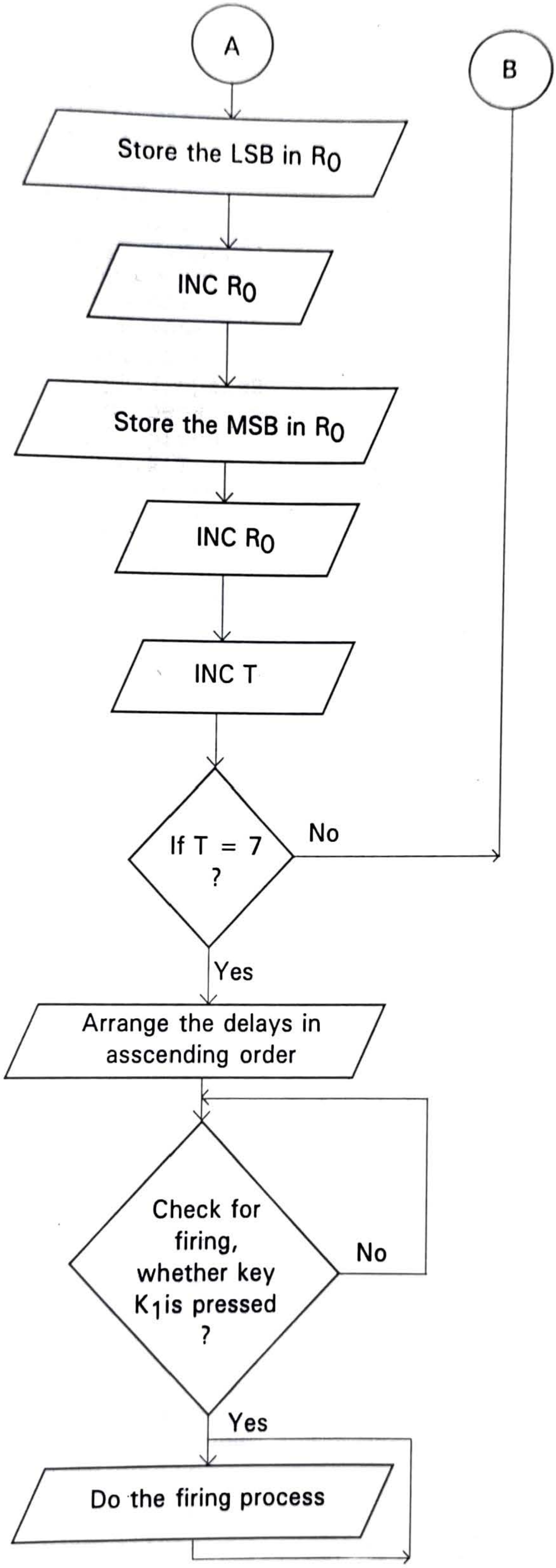
Hyperthermia is a therapeutic procedure where a particular part of human body is exposed to very high energy to destroy the lesion. Focused ultrasound will have potential for this purpose. Continuous heating of the target can be achieved by exciting the transducers successively at the instants depending upon the transit times for the ultrasound to reach at the receiver transducers. The various blocks of the system i.e. transmitter circuit, switching network, receiver amplifier circuit, and the crystal have been tested. The results obtained from them are found to be satisfactory. For delay measurement, the pulse excitation of the transducer is convenient so as to avoid the cross talk between transmitted and reflected pulses. During the firing process, the transducer will be excited with a sine burst so as to transmit more energy to the target. The switching operation in the complete process will be controlled by the microcontroller. Due to reduced power output of the oscillator and mechanical misalignment at greater angles, the scheme could not be carried out successfully for three transducers. This requires the matching scheme and the transducer parameters have to be found out. Also it is required to design a power amplifier. But before designing the power amplifier, the required power to be deposited at the target, the conversion efficiency of the transmitting transducers, thermal conversion factors of the target, attenuator in the media have to be known.

Following are the problems to be looked into.

1) Misalignment of the sound waves.
2) Power amplifier.
3) High speed switches with less leakage and low ON resistance to be used in place of reed relays.
4) Energy estimation to be made.

APPENDIX A


Start
Let T = 0
Ro = 20
Check for ailgnment, whether key K1 is pressed ?
No
Yes
Do the ailgnment
Check for measurement, whether key K1 is pressed ?
No
Yes
Do the measurement
display the result
Check for repeat whether key K2 is pressed ?
Yes
No
Check for next ailgnment whether K1 is pressed ?
No
Yes
A
B


A
B
Store the LSB in R0
INC R0
Store the MSB in R0
INC R0
INC T
If T = 7 ?
No
Yes
Arrange the delays in asscending order
Check for firing, whether key K1is pressed ?
No
Yes
Do the firing process

```
.equ rs, p2.0
.equ rw, p2.1
.equ en, p2.2
.equ busy, p0.7

            .org 0000h
            mov sp,#6fh
            lcall disp
start:      mov p1,#00h
opens:      mov p2,#0ffh
            mov p3,#00h
            setb p3.0
            jb p2.7,opens1
            sjmp opens
opens1:     mov a,#32h
            mov b,#00h
            lcall stime
            jb p2.7,opens2
            sjmp opens
opens2:     lcall press
            mov a,#'T'
            lcall strobe
            mov a,#'O'
            lcall strobe
            mov a,#' '
            lcall strobe
            mov a,#'A'
            lcall strobe
            mov a,#00h
            mov b,#08h
            lcall stime
shorts:     jnb p2.7,shorts1
            sjmp opens2
shorts1:    mov a,#14h
            mov b,#00h
            lcall stime
            jnb p2.7,shorts2
            sjmp opens2
shorts2:    mov a,#01h
            lcall stobe
            mov a,#00h
            mov b,#08h
            lcall stime
            mov a,#0c0h
            lcall stobe
            mov a,#'O'
            lcall strobe
            mov a,#'K'
            lcall strobe
            mov a,#00h
            mov b,#08h
            lcall stime
opena:      jb p2.7,opena1
            sjmp shorts2
opena1:     mov a,#32h
            mov b,#00h
            lcall stime
            jb p2.7,ailgna
            sjmp shorts2
ailgna:     lcall ailgn
shorta:     jnb p2.7,shorta1
            sjmp ailgna
shorta1:    mov a,#14h
```

```
            mov b,#00h
            lcall stime
            jnb p2.7,shorta2
            sjmp ailgna
shorta2:    mov a,#01h
            lcall stobe
            mov a,#00h
            mov b,#08h
            lcall stime
            mov a,#0c0h
            lcall stobe
            mov a,#'O'
            lcall strobe
            mov a,#'K'
            lcall strobe
            mov a,#00h
            mov b,#08h
            lcall stime
            jb p2.7,opena2
            sjmp shorta2
opena2:     mov a,#32h
            mov b,#00h
            lcall stime
            jb p2.7,measa
            sjmp shorta2
measa:      setb p2.3
            anl tcon,#0cfh
            anl tmod,#0f0h
            orl tmod,#01h
            mov tl0,#00h
            mov th0,#00h
            clr p2.4
            nop
            nop
            setb p2.4
            clr p2.3
            orl tcon,#10h
waita:      jnb p2.6,stopa
            jnb p2.5,shortsr1
            sjmp waita
stopa:      anl tcon,#0efh
            mov 20h,tl0
            mov 21h,th0
res0:       mov 15h,20h                 ;lsb
            mov 16h,21h                 ;msb
            lcall result1
            mov a,#'0'
            lcall strobe
            lcall result2
            mov a,#00h
            mov b,#08h
            lcall stime
shortsr:    jnb p2.5,shortsr1
            sjmp opent
shortsr1:   mov a,#14h
            mov b,#00h
            lcall stime
            jnb p2.5,shortsr2
            sjmp opent
shortsr2:   mov a,#01h
            lcall stobe
            mov a,#00h
            mov b,#08h
            lcall stime
```

```
            mov a,#0c0h
            lcall stobe
            mov a,#'O'
            lcall strobe
            mov a,#'K'
            lcall strobe
            mov a,#'R'
            lcall strobe
            mov a,#00h
            mov b,#08h
            lcall stime
            jb p2.5,opes
            sjmp shortsr2
opes:       ljmp opens


opent:      mov p3,#00h
            setb p3.1
            jb p2.7,opent1
            sjmp opent
opent1:     mov a,#32h
            mov b,#00h
            lcall stime
            jb p2.7,opent2
            sjmp opent
opent2:     lcall press
            mov a,#'T'
            lcall strobe
            mov a,#'1'
            lcall strobe
            mov a,#' '
            lcall strobe
            mov a,#'A'
            lcall strobe
            mov a,#00h
            mov b,#08h
            lcall stime
shortt:     jnb p2.7,shortt1
            ljmp res0
shortt1:    mov a,#14h
            mov b,#00h
            lcall stime
            jnb p2.7,shortt2
            ljmp res0
shortt2:    mov a,#01h
            lcall stobe
            mov a,#00h
            mov b,#08h
            lcall stime
            mov a,#0c0h
            lcall stobe
            mov a,#'O'
            lcall strobe
            mov a,#'K'
            lcall strobe
            mov a,#00h
            mov b,#08h
            lcall stime
openb:      jb p2.7,openb1
            sjmp shortt2
openb1:     mov a,#32h
            mov b,#00h
            lcall stime
            jb p2.7,ailgnb
```

```
                    sjmp shortt2
ailgnb:             lcall ailgn
shortb:             jnb p2.7,shortb1
                    sjmp ailgnb
shortb1:            mov a,#14h
                    mov b,#00h
                    lcall stime
                    jnb p2.7,shortb2
                    sjmp ailgnb
shortb2:            mov a,#01h
                    lcall stobe
                    mov a,#00h
                    mov b,#08h
                    lcall stime
                    mov a,#0c0h
                    lcall stobe
                    mov a,#'O'
                    lcall strobe
                    mov a,#'K'
                    lcall strobe
                    mov a,#00h
                    mov b,#08h
                    lcall stime
                    jb p2.7,openb2
                    sjmp shortb2
openb2:             mov a,#32h
                    mov b,#00h
                    lcall stime
                    jb p2.7,measb
                    sjmp shortb2
measb:              setb p2.3
                    anl tcon,#0cfh
                    anl tmod,#0f0h
                    orl tmod,#01h
                    mov tl0,#00h
                    mov th0,#00h
                    clr p2.4
                    nop
                    nop
                    setb p2.4
                    clr p2.3
                    orl tcon,#10h
waitb:              jnb p2.6,stopb
                    jnb p2.5,shorttr1
                    sjmp waitb
stopb:              anl tcon,#0efh
                    mov 22h,tl0
                    mov 23h,th0
res1:               mov 15h,22h                  ;lsb
                    mov 16h,23h                  ;msb
                    lcall result1
                    mov a,#'1'
                    lcall strobe
                    lcall result2
                    mov a,#00h
                    mov b,#08h
                    lcall stime
shorttr:            jnb p2.5,shorttr1
                    sjmp fir
shorttr1:           mov a,#14h
                    mov b,#00h
                    lcall stime
                    jnb p2.5,shorttr2
                    sjmp fir
```

```
shorttr2:       mov a,#01h
                lcall stobe
                mov a,#00h
                mov b,#08h
                lcall stime
                mov a,#0c0h
                lcall stobe
                mov a,#'O'
                lcall strobe
                mov a,#'K'
                lcall strobe
                mov a,#'R'
                lcall strobe
                mov a,#00h
                mov b,#08h
                lcall stime
                jb p2.5,opet
                sjmp shorttr2
opet:           ljmp opent



fir:            jb p2.7,fir1
                sjmp fir
fir1:           mov a,#32h
                mov b,#00h
                lcall stime
                jb p2.7,fir2
                sjmp fir
fir2:           lcall press
                mov a,#'F'
                lcall strobe
                mov a,#'I'
                lcall strobe
                mov a,#'R'
                lcall strobe
                mov a,#00h
                mov b,#08h
                lcall stime
fir3:           jnb p2.7,fir4
                ljmp res1
fir4:           mov a,#14h
                mov b,#00h
                lcall stime
                jnb p2.7,focus
                ljmp res1

;**************************************************************************
;Program to arrange 16 bit delays in 20h-23h in descending order in 40h-43h
;**************************************************************************

focus:
                mov p3,#00h
                lcall max
                mov 40h,a
                mov 41h,b
                lcall sense
                mov 58h,@r1

                lcall max
                mov 42h,a
                mov 43h,b
```

```
        lcall sense
        mov 59h,@r1
        ljmp subp


;************************************************************************
;program to find interval between two succesive delays
;************************************************************************
subp:   mov r0,#40h
        mov r1,#60h
        mov r7,#01h
sub:    clr c
        mov a,@r0
        inc r0
        inc r0
        subb a,@r0
        mov @r1,a
        dec r0
        mov a,@r0
        inc r0
        inc r0
        subb a,@r0
        inc r1
        mov @r1,a
        jc sub1
        sjmp sub3
sub1:   clr c
        mov a,@r1
        cpl a
        mov @r1,a
        dec r1
        mov a,@r1
        cpl a
        add a,#01h
        mov @r1,a
        jc sub2
        inc r1
        sjmp sub3
sub2:   inc r1
        mov a,@r1
        add a,#01h
        mov @r1,a
sub3:   inc r1
        dec r0
        djnz r7,sub
        sjmp cplp


;************************************************************************
;Program to find 2's compliment of data in 60 - 61
;************************************************************************
cplp:
        mov r0,#60h
cplx:   mov r7,#01h
         clr c
        inc r0
        mov a,@r0
        cpl a
        mov @r0,a
        dec r0
        mov a,@r0
        cpl a
```

```
            add a,#01h
            mov @r0,a
            jc cpl1
            inc r0
            sjmp cpl2
cpl1:       inc r0
            mov a,@r0
            add a,#01h
            mov @r0,a
cpl2:       inc r0
            djnz r7,cplx
            sjmp firing


;*****************************************************************************
;Program for the firing process
;*****************************************************************************
;
firing:     mov p1,#00h
            mov tl0,#0feh
            mov th0,#0ffh

;            mov a,#00h
;            mov b,#08h
;            lcall stime

            mov a,58h
            lcall timerx

            mov a,#00h
            mov b,#08h
            lcall stime

            mov p1,#00h
;
            mov tl0,60h
            mov th0,61h
            lcall stimer
            mov tl0,#0feh
            mov th0,#0ffh
            lcall stimer
            mov tl0,#0feh
            mov th0,#0ffh

;            mov a,#00h
;            mov b,#08h
;            lcall stime

            mov a,59h
            lcall timerx

            mov a,#00h
            mov b,#08h
            lcall stime

;           mov p1,#00h

            ljmp firing
;*****************************************************************************
;Subroutine to find max. 16 bit data from 20h-23h.Result in b(msb),a(lsb)
;*****************************************************************************
max:
        mov r7,#02h
            mov r0,#20h
```

```
          mov a,@r0
maxx:         jnz maxs
              inc r0
              mov a,@r0
              jnz maxs1
              inc r0
              djnz r7,maxx
              mov b,#00h
              sjmp last
          dec r0
maxs1:    mov a,#00h
maxs:         mov b,#00h
              sjmp max1
          clr c
max4:         mov a,r3
              subb a,r2
              mov r4,a
              clr c
              mov a,r4
              add a,#02h
              mov r5,a
              mov 08h,r2
              mov r0,08h
              mov a,@r0
              mov 08h,r3
              mov r0,08h
          clr c
max1:         subb a,@r0
              mov a,b
              inc r0
              subb a,@r0
              jnc max2
              mov b,@r0
              dec r0
              mov a,@r0
              mov 08h,r0
              mov r2,08h
              clr c
              inc r0
              inc r0
              mov 08h,r0
              mov r3,08h
              djnz r7,max4
              sjmp last
max2:     dec r0
              djnz r4,max2
              mov b,@r0
              dec r0
              mov a,@r0
              mov 08h,r0
              mov r2,08h
              clr c
max3:     inc r0
              djnz r5,max3
              mov 08h,r0
              mov r3,08h
              djnz r7,max4                 ; a= lsb of max.
last:     ret                                    ; b= msb of max.

;*******************************************************************************
;Subroutine to sense fixed data from 50h-53h correspond to desc. order
;*******************************************************************************
sense:        mov 50h,#01h
```

```
                mov 51h,#02h
                mov r0,#20h
                mov r1,#50h
                mov r7,#02h
                mov r6,a
sense1:         mov 08h,@r0
                inc r0
                mov 09h,@r0
                clr c
                cjne a,08h,sense2
                mov a,b
                clr c
                cjne a,09h,sense2
                sjmp sense3
sense2:         mov a,r6
                inc r0
                inc r1
                djnz r7,sense1
sense3:         mov @r0,#00h
                dec r0
                mov @r0,#00h
                ret


;******************************************************************
;Subroutine for stimer
;******************************************************************
stimer:         anl tcon,#0cfh
                anl tmod,#0f0h
                orl tmod,#01h
                orl tcon,#10h
waitx:          jbc tf0,dwnab
                sjmp waitx
dwnab:          anl tcon,#0efh
                ret

;******************************************************************
;Subroutine for timerx
;******************************************************************
timerx:         anl tcon,#0cfh
                anl tmod,#0f0h
                orl tmod,#01h
                mov p1,a
                orl tcon,#10h
waits:          jbc tf0,dwnabs
                sjmp waits
dwnabs:         anl tcon,#0efh
                ret

;******************************************************************
; Subroutine for result1
;******************************************************************
result1:        lcall decimal
                mov a,#01h
                lcall stobe
                mov a,#00h
                mov b,#08h
                lcall stime
        ;        mov a,#80h
        ;        lcall stobe
                mov a,#'T'
                lcall strobe
```

```
          ret

;***********************************************************************
;Subroutine for result2
;***********************************************************************
result2:        mov a,#' '
                lcall strobe
                mov a,#'='
                lcall strobe
                mov a,34h
                jz Ax1
                ljmp Px1
Ax1:            mov a,35h
                jz Bx1
                sjmp Qx1
Bx1:            mov a,36h
                jz Cx1
                sjmp Rx1
Cx1:            mov a,37h
                jz Dx1
                sjmp Sx1
Dx1:            mov a,38h
                sjmp Tx1
Px1:            lcall ncode2
                lcall strobe
                mov a,35h
Qx1:            lcall ncode2
                lcall strobe
                mov a,36h
Rx1:            lcall ncode2
                lcall strobe
                mov a,37h
Sx1:            lcall ncode2
                lcall strobe
                mov a,38h
Tx1:            lcall ncode2
                lcall strobe
                mov a,#' '
                lcall strobe
                mov a,#'u'
                lcall strobe
                mov a,#'S'
                lcall strobe
                ret

;***********************************************************************
;Subroutine for ailgnment
;***********************************************************************
ailgn:          mov p2,#0ffh
                setb p2.3
                mov tl0,#0d4h           ;delay of 300 uS
                mov th0,#0feh
                lcall stimer
                clr p2.3
                mov tl0,#9ch            ;delay of 100 uS
                mov th0,#0ffh
                lcall stimer
                 ret

;***********************************************************************
;Subroutine to display" press K for"
;***********************************************************************
press:          mov a,#01h
                lcall stobe
```

```
                mov a,#00h
                mov b,#08h
                lcall stime
                mov a,#0c0h
                lcall stobe
                mov a,#'P'
                lcall strobe
                mov a,#'R'
                lcall strobe
                mov a,#'E'
                lcall strobe
                mov a,#'S'
                lcall strobe
                mov a,#'S'
                lcall strobe
                mov a,#' '
                lcall strobe
                mov a,#'K'
                lcall strobe
                mov a,#' '
                lcall strobe
                mov a,#'F'
                lcall strobe
                mov a,#'O'
                lcall strobe
                mov a,#'R'
                lcall strobe
                mov a,#' '
                lcall strobe
                ret

;*****************************************************************************
;Subroutine to find decimal of 21h(m),20h(l) & store in 34h(m),35h,36h,37h,38h
;*****************************************************************************
decimal:        mov 34h,#00h
                mov 35h,#00h
                mov 36h,#00h
                mov 37h,#00h
                mov 38h,#00h
                setb psw.4
                clr psw.3
                mov a, 16h
                jz store_b
                mov r2, 16h             ; msb
                mov r1, 15h             ; lsb
                sjmp htd
store_b:        mov r2, #00h
                mov r1, 15h
htd:            nop
xxx1:           mov   a,#00h
                mov   r4,a
                mov   r5,a
                mov   r6,a
                mov   r0,#10h
                nop
mm:             mov   a,#00h
                mov   a,r1
                rlc   a
                mov   r1,a
                mov   a,r2
                rlc   a
                mov   r2,a
                mov   a,#00h
```

```
                addc  a,r4
                da    a
                jc    xx
                add   a,r4
                da    a
                mov   r4,a
nn:             mov   a,#00h
                addc  a,r5
                da    a
                jc    yy
                add   a,r5
                da    a
                mov   r5,a
ll:             mov   a,#00h
                addc  a,r6
                da    a
                add   a,r6
                da    a
                mov   r6,a
                dec   r0
                cjne  r0,#00h,mm
                ajmp split

xx:             add   a,r4
                da    a
                mov   r4,a
                setb  c
                sjmp  nn
yy:             add   a,r5
                da    a
                mov   r5,a
                setb  c
                sjmp  ll
split:          mov 34h, #00h         ;R6-R5-R4 contains decimal value
                mov 35h, #00h         ;of hex value form R1-R2
                mov 36h, #00h
                mov 37h, #00h
                mov 38h, #00h
                mov   a,r4
                anl   a,#0fh
                mov   38h,a
                mov   a,r4
                swap  a
                anl   a,#0fh
                mov   37h,a
                mov   a,r5
                anl   a,#0fh
                mov   36h,a
                mov   a,r5
                swap  a
                anl   a,#0fh
                mov   35h,a
                mov   a,r6
                anl   a,#0fh
                mov   34h,a
                clr psw.4
                clr psw.3               ;[result - 34h to 38h]
                ret
```



```
;*****************************************************************************
```

SOFTWARE DELAY ROUTINE

```
;
;*****************************************************************************
;
; software delay
; load the number ms delay in binary in register a (lsb) and b (msb)
; and call delay
; loading zeros in a and b means immediate return
;
.equ delay, 08ch        ; for timer

stime:          push 07h
                push acc                ;save r7
                orl a,b                 ;checking for a=b=00
                cjne a,#00h,ok          ;will be 00 if both 00
                pop acc                 ;return if all 00
                sjmp done               ;keep stack balanced
ok:             pop acc
timer:          mov r7,#delay           ;not all eroes, proceed
onemil:         nop                     ;initialise r7, 1
                nop                     ;tune the loop for 6 cycles, 1
                nop                     ;this makes 2 cycles total, 1
                djnz r7,onemil          ;3 cycles total, 1
                                        ;count r7 down
                djnz acc,timer          ;total delay 5 cycles(3.75us X delay)
                cjne a, b, bdown1       ;count A and B down as one
                sjmp done               ;A = 00, count B down until = 00
bdown1:         dec b                   ;if so then delay is done
                sjmp timer              ;count B down and time again
done:           pop 07h
ret                                     ;restore r7 to original value


ncode2:         inc a
                movc a, @a+pc
                ret
                .db 30h
                .db 31h
                .db 32h
                .db 33h
                .db 34h
                .db 35h
                .db 36h
                .db 37h
                .db 38h
                .db 39h

;*****************************************************************************
; software initialization for display
;*****************************************************************************
disp:           clr rs          ; function set
                clr rw
                mov p0,#38h     ; function set
; 4.1 ms delay
                mov a,#05h      ; 5 ms delay
                mov b,#00h
                lcall stime
                mov p0,#38h     ; function set
; 1 ms delay
                mov a,#01h
                mov b,#00h
                lcall stime
; 1 line 5x7 dots
                mov a,#38h
                lcall stobe
```

```
; command screen and cursor on, no blink
                mov a,#1eh
                lcall stobe
;display on/off control
                mov a,#0ch
                lcall stobe
; command cursor right as data displayed
                mov a,#06h
                lcall stobe
; clear all and home cursor
                mov a,#01h
                lcall stobe
                ret

;*****************************************************************************
; this is the strobe routine  for display
;*****************************************************************************
strobe:         mov p0,#0ffh
                clr rs
                setb rw         ; for reading busy flag
wait:           clr en          ; read signal
                setb en
                jb busy,wait    ; this generates the enable strobe
                clr en
                clr rw          ; this pulls down EN
                setb rs         ; write signal
                setb en         ; choose data ram
                mov p0,a        ; enable strobe
                clr en          ; write to data ram
                clr rs
                ret

stobe:          mov p0,#0ffh    ; configure p1 as an input port
                clr rs
                setb rw         ; read signal
wat:            clr en
                setb en         ; this generates the enable strobe
                jb busy,wat
                clr en
                clr rw          ; write signal
                clr rs
                setb en         ; enable strobe
                nop
                mov p0,a
                clr en
                nop
                ret


               .end
```

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