Personal computer based instrumentation for ultrasonic tissue characterization

by

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CHAPTER 1. INTRODUCTION

Ultrasound has found many applications in both medicine and agriculture. In medicine, ultrasound is used to provide a picture of the fetus, image the circulatory system in motion and provide complementary information to x-rays and CAT-scans. In agriculture, ultrasound has been used to measure many different parameters of foods such as: fat in cattle, pigs and sheep, sugar in fruit juices, alcohol in wine, thickness of egg shells, age of potatoes, cracks in tomato skin, lipid content in fish, plus many more (Javanaud, 1988).

Ultrasound is attractive because it is non-invasive, harmless, portable and cheap. Ultrasound scans are obtained by high frequency sound waves traveling through tissue or some type of medium and reflecting at interfaces. The sound waves do no harm to the tissue and can be applied from outside the body. The equipment needed to perform the scans is small, lightweight and inexpensive as compared to other imaging systems (i.e. x-rays, CAT-scans, NMR, MRI).

Ultrasound traveling through tissues can give information about that tissue by measuring several different parameters. The parameters used most in ultrasound applications include:

- Estimation of attenuation and velocity

- Backscattering techniques
- Spectrum analysis
- Diffraction techniques
- Absorption techniques
- Pattern recognition
- Impedance profile techniques.

This study will set up an ultrasound system that eventually might be used to find an objective way to quality grade beef by using the parameter backscatter. Currently, a meat inspector from the United States Department of Agriculture (USDA) determines the quality grade of meat, in part, by the amount of fat marbling present in the rib eye muscle (*longissmus dorsi*). The amount of marbling is determined by looking at the rib eye muscle and comparing it to pictures or by using past experience, making it a subjective measurement (see Figure 1.1). One meat inspector may classify the marbling as very abundant while another may classify it as abundant. Since ultrasound is reflected at fat to muscle interfaces, the more fat marbling present, the more reflections there should be, making ultrasound an ideal candidate for objective determination of fat marbling. The word "objective" should be stressed because ultrasound scans are not necessarily objective, many times the information obtained from the scans depends upon the person who is reading them.

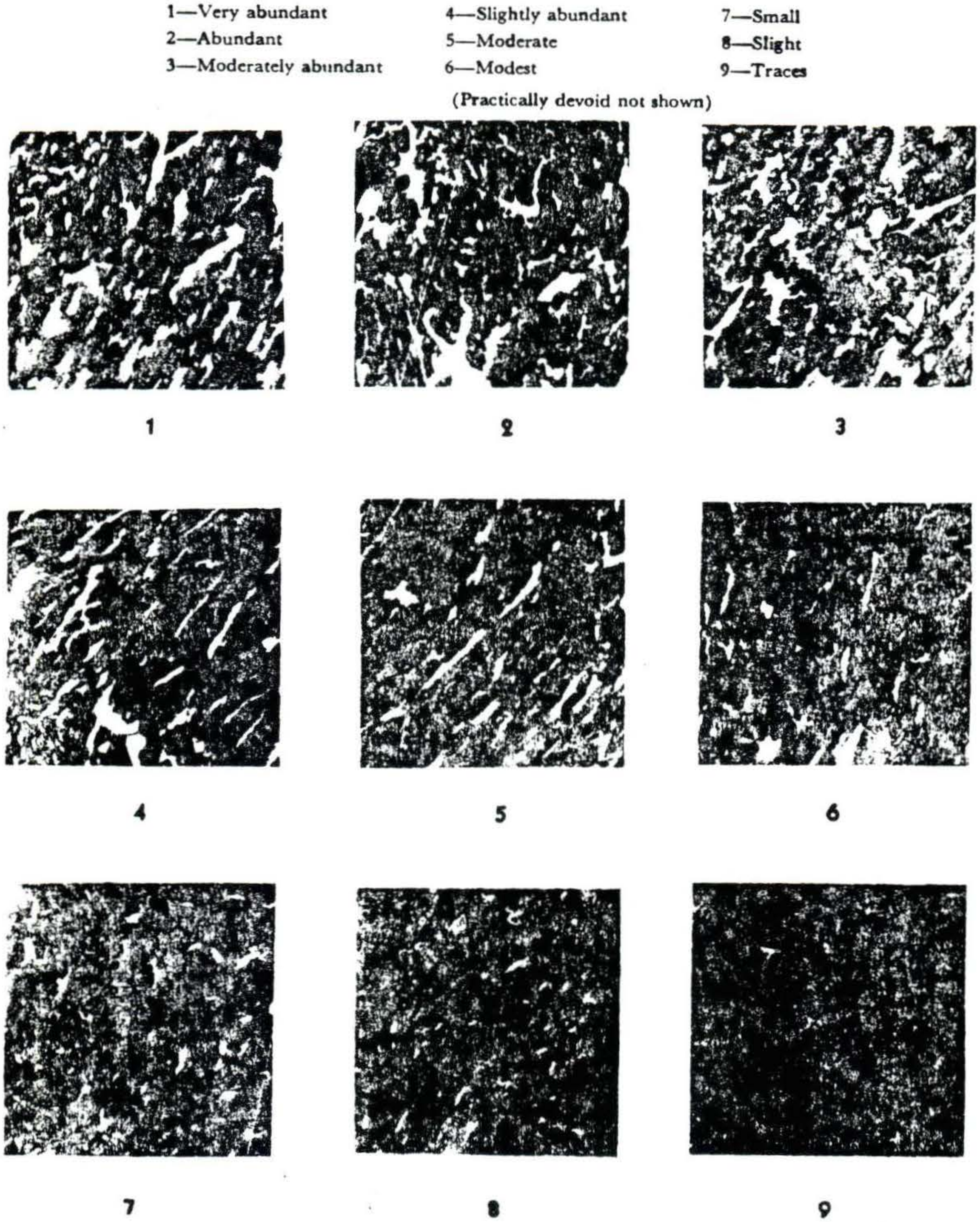


Figure 1.1: Illustrations of the lower limits of certain degrees of typical marbling referred to in the official United States standards for grades of carcass beef

Objectives of Study

The purpose of this study is to develop an "ultrasound tool" by which different digital signal processing schemes can be evaluated.. Examples as to the types of things the ultrasound tool could be used to test are: axial and lateral resolution of transducers, effects of near and far field, effects of attenuatuion in tissues and effects from scatter in tissues. The development will be achieved using the following 3 objectives:

1. Setup a relatively inexpensive hardware system that can take several A-scans of an object and store them in a computer
2. Develop software that can analyze the data, display it in B-mode and give a numerical value for the number of objects encountered
3. Determine if what is displayed on the computer screen is an adequate representation of what was scanned

In addition, a comparison of 3 different transducers will be made with the ultrasound tool to determine which transducer gives the best two-dimensional resolution and therefore might be the best one to use for grading meat. Three types of unfocused ultrasound transducers will be used, a 2.2 MHz 16 mm diameter transducer, a 10 MHz 11 mm diameter transducer and a broadband 13 mm diameter transducer.

This study is a first step towards a long range goal. If this study shows promise the second step might be to scan several cuts of meat which have different quality grades to determine if a correlation exists between the number given by the computer program and the quality grade. The third step might be to use ultrasound to detemine the amount of fat marbling in a carcass without having to cut a piece out. The eventual goal is to determine the amount of fat marbling in a live steer or heifer.

CHAPTER 2. BACKGROUND INFORMATION

Properties of Ultrasound

Definition of ultrasound

Ultrasound is above the threshold of hearing. Humans can hear sounds in the range of 20 Hz to 20 kHz, so ultrasound is considered to be above the frequency 20 kHz. However, the range of ultrasound that is used in most applications with live animals is 1 MHz to 20 MHz.

What actually is a sound wave? Sound waves must be produced by vibrating sources and must have some type of medium to travel in, such as air, water, tissue or steel. Sound will not travel in a vacuum. The vibrating source causes the adjacent molecules in the medium (for example, air) to be compressed together and drawn apart, depending on the movement of the source. These air molecules next to the vibrating source have the same effect on the molecules next to them, causing compression and extension to their neighbors. In this way, the sound wave is propagated in the air (see Figure 2.1). How fast the source is vibrating (moving back and forth) determines the frequecny of the sound wave, which is measured in reciprocal seconds (Hertz). To produce a frequency of 100 Hz, the source would have to vibrate 100 times per second.

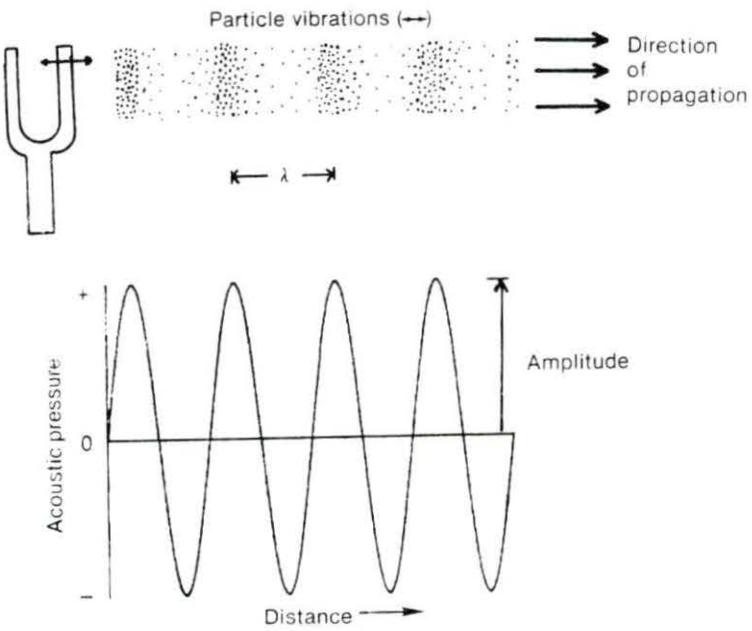


Figure 2.1: Propagation of sound in air and its resulting acoustic pressure versus distance waveform (Hagen-Ansert, 1983, p. 1)

Table 2.1: Speed of sound in biological mediums (Hagen-Ansert, 1983, p. 2)

Biological Mediums	Speed ($\frac{m}{sec}$)
Lung	600
Fat	1460
Water	1480
Aqueous humor	1510
Liver	1555
Blood	1560
Kidney	1565
Muscle	1600
Lens	1620
Skull Bone	4080

Speed of sound

How fast the sound travels in the medium is a property of the medium itself. Since the molecules of solids are much closer together, sound travels fastest in solids, and slowest in gasses. Table 2.1 indicates some biological mediums and their respective speed of sound.

Acoustic impedance

As sound travels through a medium, it will encounter resistance. This resistance is termed acoustic impedance and is also a property of the medium itself. It is equal to the product of the density of the medium and the speed of sound in the medium. Some impedances of biological mediums are indicated in Table 2.2. Acoustic impedance plays an important role in determining the amplitude of the reflected and transmitted sound waves at a tissue interface.

Table 2.2: Impedances of some biological mediums (Hagen-Ansert, 1983, p. 4)

Biological Medium	Impedance (kg/m^2/sec) x 10^6
Air	0.0004
Lung	0.1800
Fat	1.3400
Water	1.4800
Liver	1.6500
Blood	1.6500
Kidney	1.6300
Muscle	1.7100
Skull Bone	7.8000

Specular reflection

When sound is traveling through a medium with acoustic impedance equal to Z_1, and encounters another medium with acoustic impedance equal to Z_2, some of the sound energy will be reflected at the interface of the two mediums and some of the sound energy will be transmitted (see Figure 2.2). If the sound wave is perpendicular to the interface and if the interface is smooth and large with dimensions that are much greater than that of the sound wavelength (termed a specular interface), then the amount of sound wave that will be reflected at the interface is given by equation 2.1.

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{P_r}{P_i} \tag{2.1}$$

where

R = amount of sound wave reflected
Z_2= acoustic impedance of second medium
Z_1= acoustic impedance of first medium
P_r= reflected pressure amplitude
P_i= incident pressure amplitude

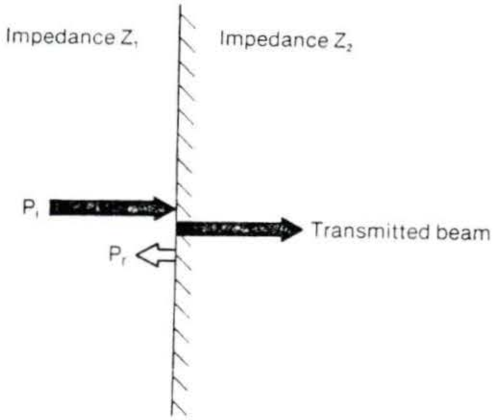


Figure 2.2: When sound encounters a specular interface, part of the incident pressure (P_i) is reflected (P_r), and part of it is transmitted (P_t) (Hagen-Ansert, 1983, p.5)

An important point to remember is that if the reflected sound wave energy is to return to the source, the sound wave must be almost perpendicualr to the interface because the angle of incidence is equal to the angle of reflection (see Figure 2.3). If the same transducer is used as both the transmitter and receiver, and if the angle of incidence is more than 2 degrees away from being perpendicular, then the transducer will not detect the reflection (Rose and Goldberg, 1979). Of course, a separate receiver could be used and then the reflection could be detected.

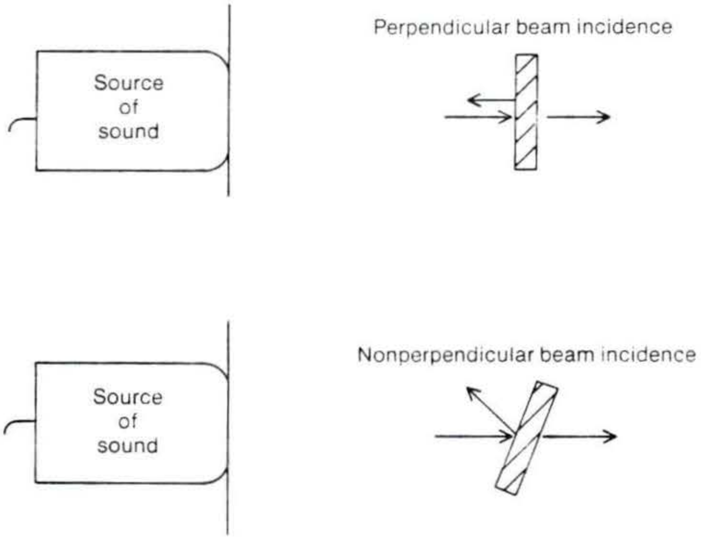


Figure 2.3: If the interface is perpendicular to the sound beam, the reflected beam will go directly back to source because the angle of incidence is equal to the angle of reflection (Hagen-Ansert, 1983, p. 5)

Ultrasound Transducers

Piezoelectric ceramics

Now that the properties of sound have been reviewed, how is the sound produced? Piezoelectric ceramics are the most commonly used materials for ultrasound sources. Piezoelectric ceramics can be made to convert electrical energy into acoustic energy and acoustic energy into electrical energy, which gives them the ablilty to act as both transmitters and detectors of ultrasound. This allows the same transducer to send out a pulse and detect the reflection; however, more than one transducer may be used.

Pulsed sound waves

Ultrasonic transducers can produce sound continuously or in short pulses. For the application used in this study, the pulsed mode is needed because the parameter backscatter is being measured. Different forms of pulses can be sent through a medium, depending on the pulse duration. If the pulse duration is long, the frequency spectrum will be narrow and the transducer is called a narrow-band transducer with the center of the resonation frequency (how fast the source vibrates back and forth) given (see Figure 2.4). The most common narrow-band transducer used for in vivo applications is near the frequency of 2.5 MHz. If the pulse duration is short, the transducer is called a broad-band transducer due to all the different frequencies present in the signal (see Figure 2.4). Most ultrasound scanners have adjustable damping to allow the user to change the length of the pulse.

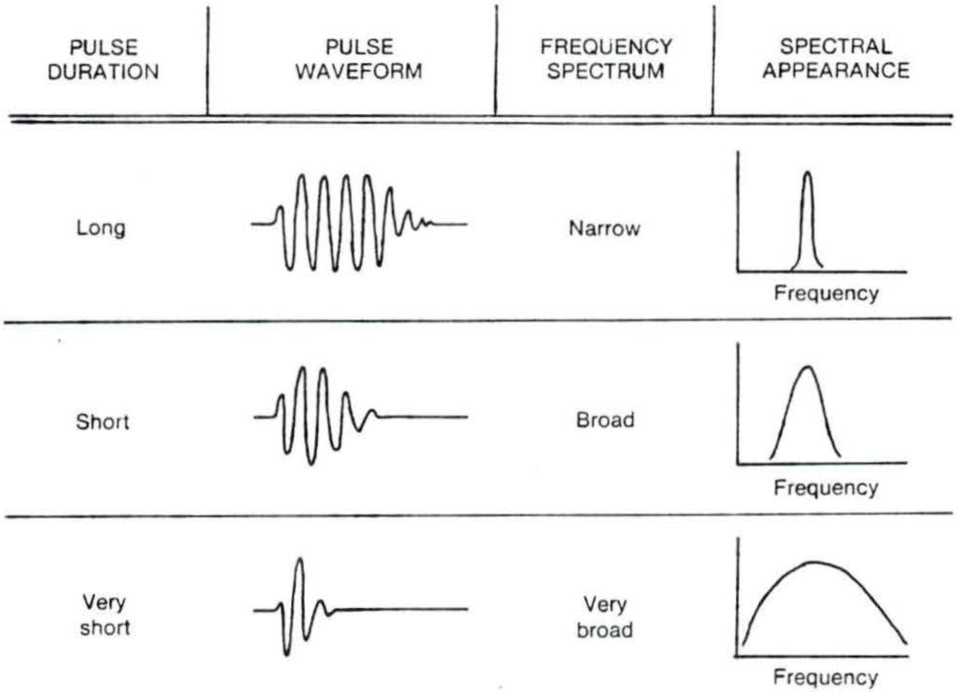


Figure 2.4: Comparison of different pulse durations and their resulting characteristics (Hagen-Ansert, 1983, p. 17)

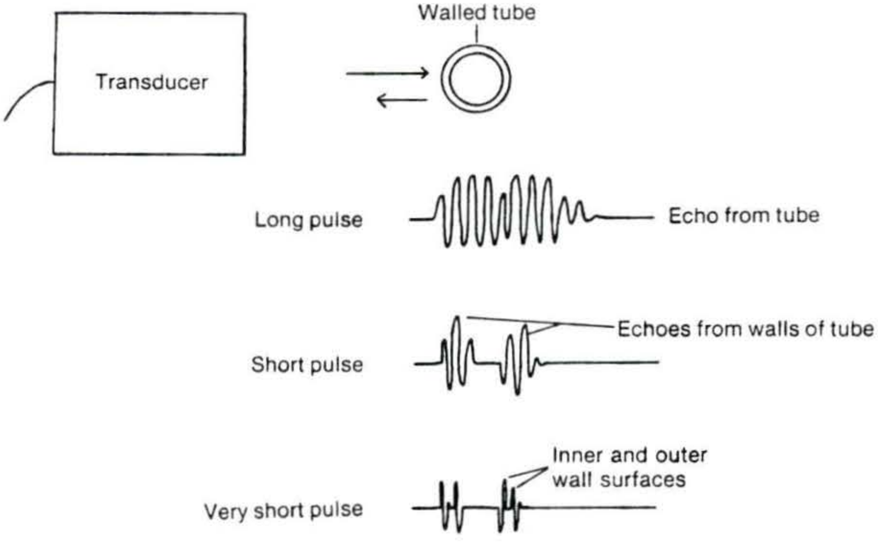


Figure 2.5: The axial resolution of different pulse durations (Hagen-Ansert, 1983, p. 17)

Axial resolution and penetration

The shorter the pulse duration, the closer two objects can be located to each other for an ultrasound scan to still be able to distinguish two objects, which is called axial or depth resolution. Figure 2.5 gives an example. The long pulse causes just one big reflection from the tube, the short pulse causes two reflections, one for each wall, while the very short pulse causes four reflections, one for each inner and outer wall surface. The reason for this is that the axial resolution can be no better than one-half the pulse length, with the pulse length being the product of the speed of sound and the pulse duration. In addition, axial resolution can also not be any better than the wavelength of the sound wave. Some commonly used frequencies and their

Table 2.3: Wavelengths of commonly used ultrasonic frequencies (Haumschild, 1981, p. 16)

Frequency (MHz)	Wavelength (mm)
1.00	1.50
1.60	0.96
2.25	0.68
3.50	0.44
5.00	0.31
10.00	0.15

respective wavelengths are given in Table 2.3.

How far the sound wave penetrates into the medium is dependent upon the pulse duration. The longer the pulse, the more energy the sound wave will have, allowing it to penetrate deeper than would a shorter pulse.

Ultrasound transducers also have a certain beam width, depending upon the diameter of the transducer. Figure 2.6 shows the beam width for two transducers. Note that the smaller transducer's beam diverges more rapidly.

Display of Signal

A-mode

Several methods are available for displaying echoes received from pulsed ultrasound. The simplest mode, A-mode, displays the reflections as spikes (see Figure 2.7). The first spike is always the initial pulse. A-mode scans can be displayed on an oscilloscope or digitized and displayed on a computer. If the speed of sound in the

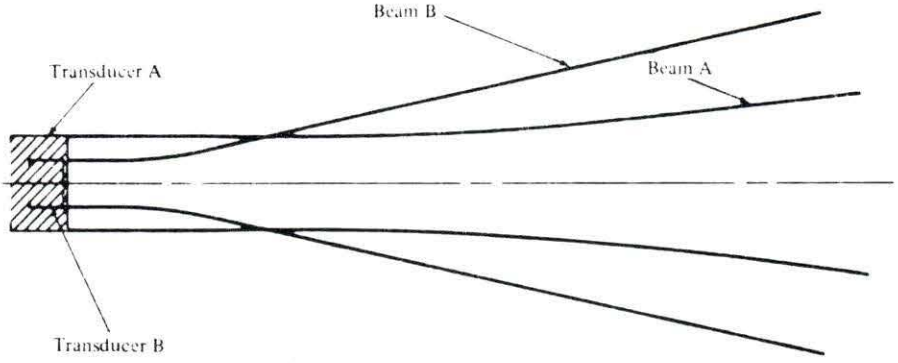


Figure 2.6: The beam profiles for two different size transducers, A and B (Christensen, 1988, p. 103)

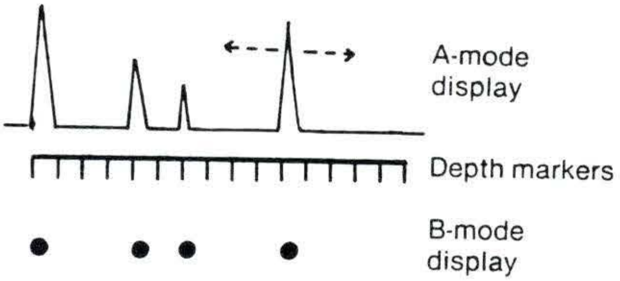


Figure 2.7: Comparison of A and B-mode displays (Hagen-Ansert, 1983, p. 28)

medium is known, the distance can be calculated by equation 2.2.

$$axial\ distance = \frac{1}{2}(v)(t) \tag{2.2}$$

where

v = speed of sound in the medium
t = time between pulse transmission and echo detection

B-mode

B-mode also represents reflections from different reflectors at different distances, except bright spots are used instead of spikes to display the reflections and the position of the transducer is known (see Figure 2.7). The bright spots can also be gray scale modulated, which means larger reflections will give brighter spots while smaller ones will give weaker spots. If the position of the transducer in space is known, then the B-mode can be used to obtain a cross-sectional scan by super-imposing scans taken from different angles. The cross-sectional B-mode scan is used by physicians to scan fetuses, and is typically just called a B-mode scan (see Figure 2.8). B-mode scans can be displayed on a television screen or digitized and displayed on a computer.

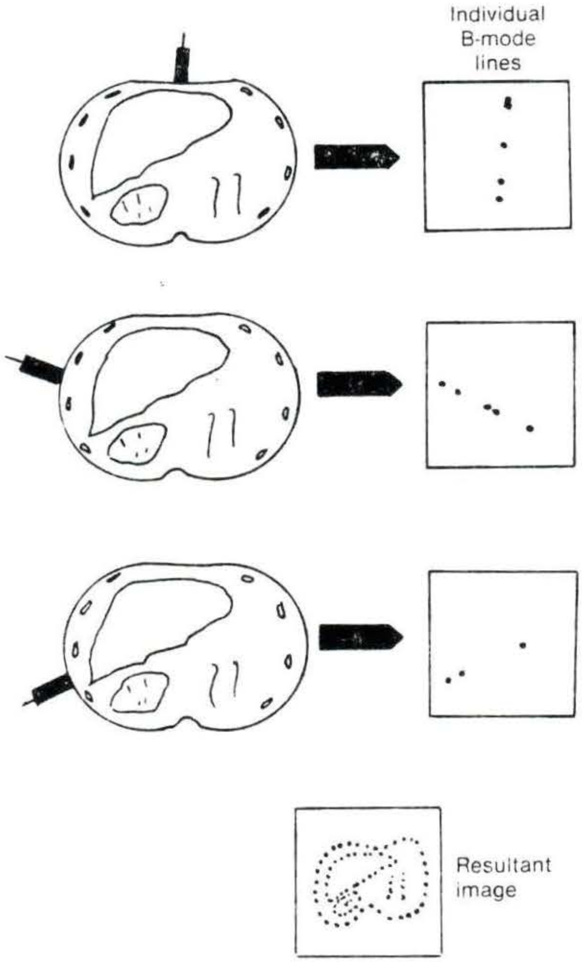


Figure 2.8: Different B-mode scans superimposed on each other to form a cross-sectional scan (Hagen-Ansert, 1983, p. 29)

CHAPTER 3. LITERATURE REVIEW

In Vivo Tissue Characterization

The study of human livers is analogous to the quality grading of beef because abnormal livers have a different tissue composition than normal livers, just as prime cuts have a different composition than good cuts. In 1985, Botros et al. did a study that investigated in vivo tissue differentiation of the human liver by measuring the attenuation coefficient of ultrasound. The attenuation coefficients of twenty-four normal livers were compared to four abnormal livers, and the abnormal attenuation coefficients were indeed different from the normal ones. The attenuation coefficient was obtained from the backscattered signal, which had been digitized, stored in a microcomputer and processed. The processing of the signal included computing the Fast Fourier Transform and using a software bandpass filter.

In 1986, the same group (Botros et al.) compared the average differential backscattering coefficient (which was obtained from the digitized backscattered signal) of twenty-four normal livers to ten abnormal livers. They found a difference between the differential backscattering coefficient for normal and abnormal livers. They used the same equipment setup for both studies (see Figure 3.1).

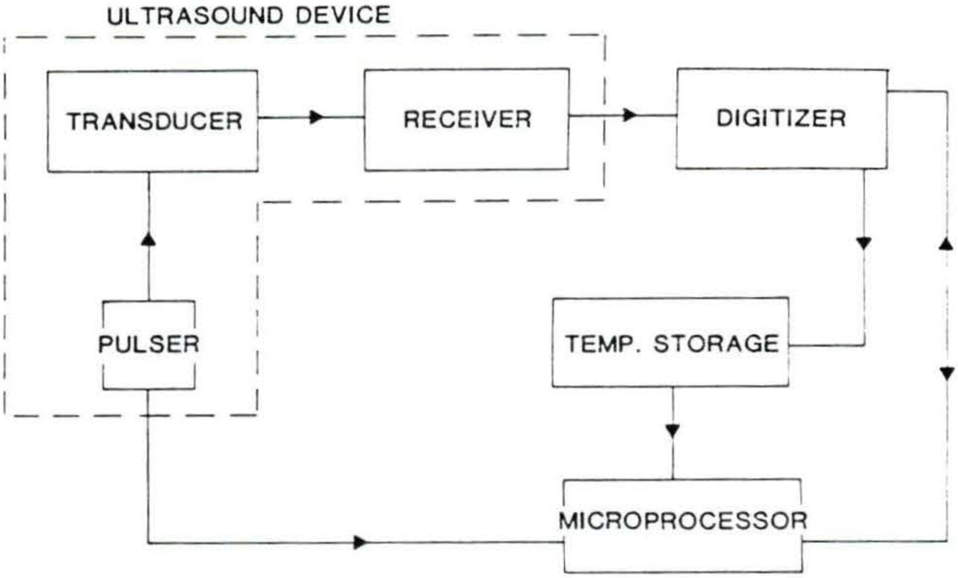
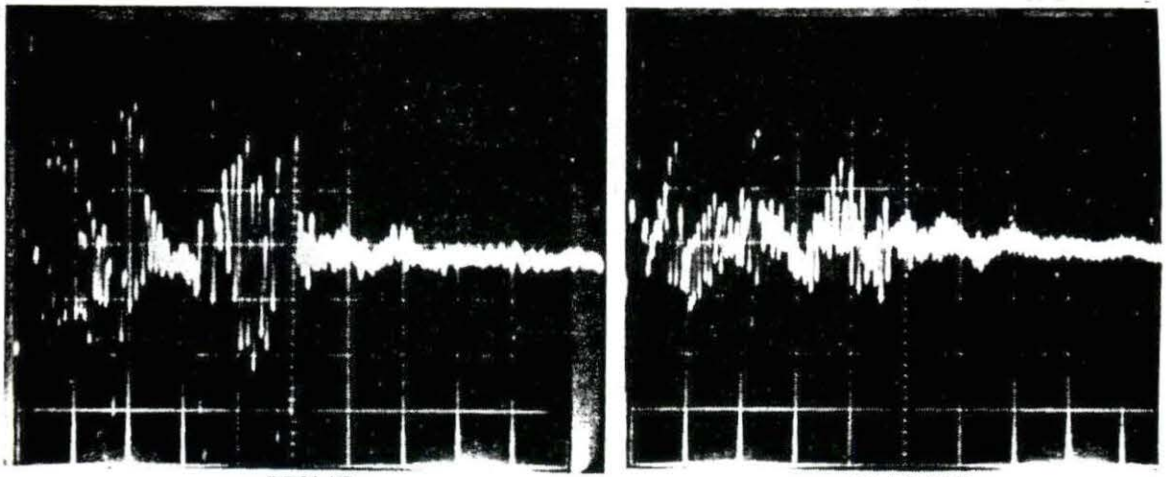


Figure 3.1: Equipment setup used by Botros et al., 1985 for measurement of the attenuation coefficient and differential backscattering coefficient

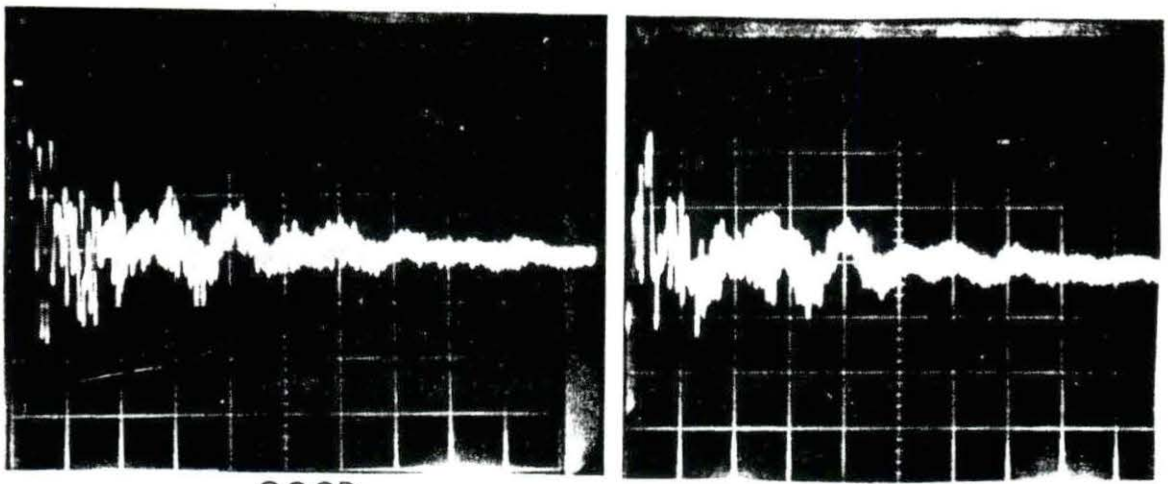
In Vitro Studies to Determine Quality Grade

A preliminary study was done by Anselmo et al. in 1987 to determine if ultrasound could be used to quality grade beef. They decided to use A-mode measurements rather than the B-mode for better objectivity. No attempt was made to optimize all the possible system parameters such as frequency, angle between muscle fibers and sound beam, gain, the detection and display scheme, etc. Their objective was to see if the A-scans of different grades of meat were different subjectively in hopes that in the future these differences could be quantified by suitable instrumentation. They did find subjective differences between the quality grades of meat (see Figure 3.2) and recommended further studies to optimize the system parameters. They also concluded that grading of live animals seemed feasible.

A study was done by Haumschild in 1981 at Iowa State University where the



PRIME CHOICE



GOOD STANDARD

Figure 3.2: Subjective differences of ultrasound signatures in the top four quality grades of beef (Anselmo et al., 1987)

top four grades of beef were ultrasonically examined in vitro. The purpose of the study was to determine if the ultrasonic signatures (A-scan signals) showed different spatial distributions for varying amounts of marbling by using a Bragg scattering technique. He used both a single transducer system and a double transducer system and concluded that:

1. A double transducer system is better able to predict intramuscular fat distribution than a single one
2. A single transducer system is sufficient and may be easier to use, although some accuracy is lost
3. There is an orientation aspect with respect to intramuscular fat deposits
4. Ultrasonic grading cannot be accomplished in a cold locker due to the increased attenuation of ultrasound in cold tissue
5. Out of the four grades, the spatial distribution of the good grade was predicted the best.

CHAPTER 4. DESIGN AND TESTING OF SYSTEM

Hardware System

The equipment used consisted of a Zenith 80286 personal computer[1], a Keithley 570 data aquisition system (12 bit A/D converter)[2], a Heath model IC-4802 computer oscilloscope (8 bit A/D converter)[3], a Panametrics pulser/receiver model 5052PR[4], a specially built tank and three unfocused ultrasound transducers. The total hardware system can be seen in Figure 4.1.

Keithley data acquisition system

The Keithley 570 system has 32 single ended or 16 differential analog inputs, 2 analog outputs, 16 digital inputs, 16 digital outputs and a relay control, all of which interface easily to a personal computer.

One analog input was used to obtain the transducer location signal from the potentiometer, ranging from 0 to 5 V. The Keithley digitized the signal with 4096 steps (12 bits), making the resolution 1.22 mV. Its relay control was used to activate the stepper motor.

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[1] Zenith Data Systems Corporation, St. Joseph, MI

[2] Keithley Data Acquisition and Control, Cleveland, OH

[3] Heath Company, Benton Harbor, MI

[4] Panametrics, Inc., Waltham, MA

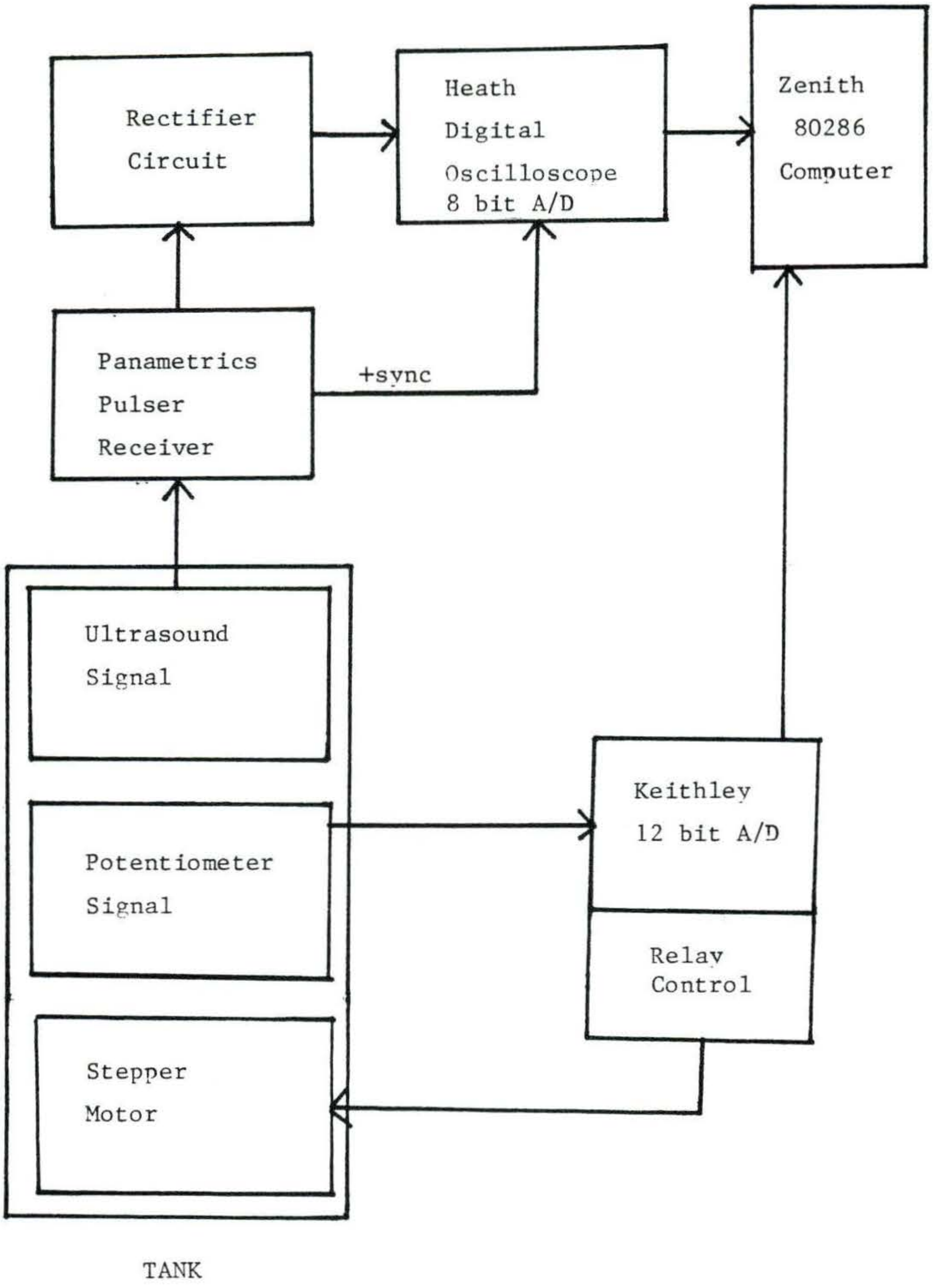


Figure 4.1: The schematic of the hardware setup used to take A-scans of a model

Computer oscilloscope

A computer oscilloscope was needed to sample and store the data because a relatively high sampling rate was needed (512 data points at 5.12 MHz). Computers normally cannot sample at such high rates, and so the computer oscilloscope samples the data and transmits it to the computer at a slower rate.

In order to sample at such high frequencies, the computer oscilloscope used what is called equivalent-time sampling. Equivalent-time sampling can only be used on repetitive signals, and the signals obtained in this study were repetitive. This technique takes only one sample each time the oscilloscope is triggered, which means the input signal must repeat itself 512 times since 512 data points made up one A-scan signal. On each successive trigger, the delay is increased, thus sampling a little farther along in the signal each time. The data points are stored until all 512 samples are taken, and then are transmitted to the computer. Equivalent-time sampling is thus not real time sampling because there is a delay before the data can be transmitted.

The computer oscilloscope software was supplied by the manufacturer which allowed the user to vary such things as the sampling rate, offset, triggering, etc. This software will be explained in section 4.2.

Pulser/receiver

The Panametric pulser/receiver was used to stimulate the transducer and receive the reflected signal. The Panametric unit allowed the following parameters to be varied: repetition rate of pulse (200-5000 Hz), energy of pulse (14-94 ujoules), damping of pulse (0 to 250 ohms), gain of receiver (0 to 68 dB) and cut off frequency

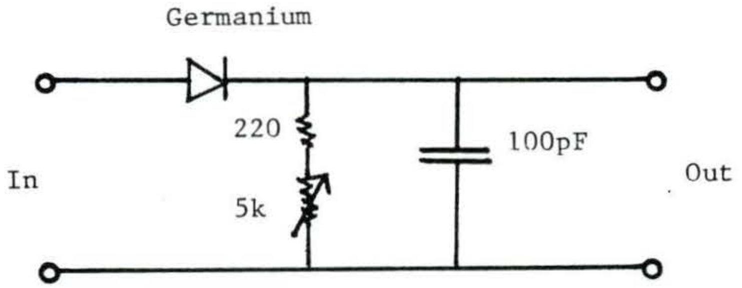


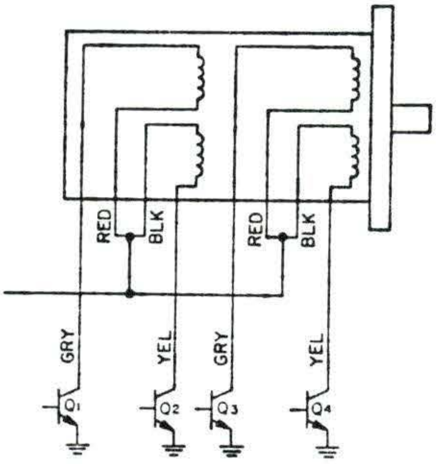
Figure 4.2: The rectifier circuit used

of high pass filter (1 kHz to 35 MHz). Its output was rectified by the circuit shown in Figure 4.2. went on to the Heath computer oscilloscope and then to the computer for storage and display. A positive sync signal from the Panametric pulser was used to trigger the digital oscilloscope.

Stepper motor

A stepper motor was used to rotate the transducer around the model to be scanned. The motor rotates in discrete steps in response to electrical pulses. The amount of rotation is determined by the construction of the motor and the scheme used to pulse the motor.

In this study, a unipolar stepper motor was used. The schematic of the motor as well as the pulsing pattern needed to produce full steps or half steps can be seen in Figure 4.3. The pulsing of the motor was achieved using the Keithley relay control.



UNIPOLAR

CW ROTATION

CCW ROTATION

1	ON	OFF	ON	OFF
2	ON	OFF	OFF	OFF
3	ON	OFF	OFF	ON
4	OFF	OFF	OFF	ON
5	OFF	ON	OFF	ON
6	OFF	ON	OFF	OFF
7	OFF	ON	ON	OFF
8	OFF	OFF	ON	OFF
1	ON	OFF	ON	OFF

½ Step
8 Step Sequence

CW ROTATION

CCW ROTATION

Step	Q_1	Q_2	Q_3	Q_4
1	ON	OFF	ON	OFF
2	ON	OFF	OFF	ON
3	OFF	ON	OFF	ON
4	OFF	ON	ON	OFF
1	ON	OFF	ON	OFF

Normal
4 Step Sequence

Figure 4.3: Schematic of unipolar stepper motor and pulsing patterns needed to produce full steps or half steps (Christ, 1988, p. 11)

Tank

The tank was 45 cm x 30 cm x 30 cm and was made out of Plexiglas. Mounted on top of the tank were two protractors, with their flat sides touching each other (see Figure 4.4). The protractors had a combined diameter of 20 cm and were marked with 1/2 degree increments. Mounted in the center of the protractors was a brass pipe, and connected to this pipe were clamps which could hold two transducers. The transducers were free to move separately.

The brass pipe had a gear attached to the top of it, and that gear turned another gear which was connected to a potentiometer whose output signal was between 0 and 5 V. Only one of the transducer clamps caused the potentiometer to vary its voltage out. The electrical signal was sent to the Keithley A/D converter which was connected to the Zenith computer. The electrical signal was used to find the position of the transducer.

The stepper motor was mounted next to the potentiometer, and turned the gear attached to the brass pipe which moved one of the transducers. The stepper motor was controlled by the Keithley relay control.

Ultrasound transducers

Three unfocused transducers were compared in this study. One was a 2.2 MHz, 16 mm diameter transducer from Renco Corporation, the second was a 10 MHz, 11 mm diameter transducer from Hoffrel/Metrix and the third was a 13 mm diameter broadband transducer (#P9) developed by Lewis Brown at Iowa State University (Brown, 1988). These transducers were chosen to observe the effects of frequency

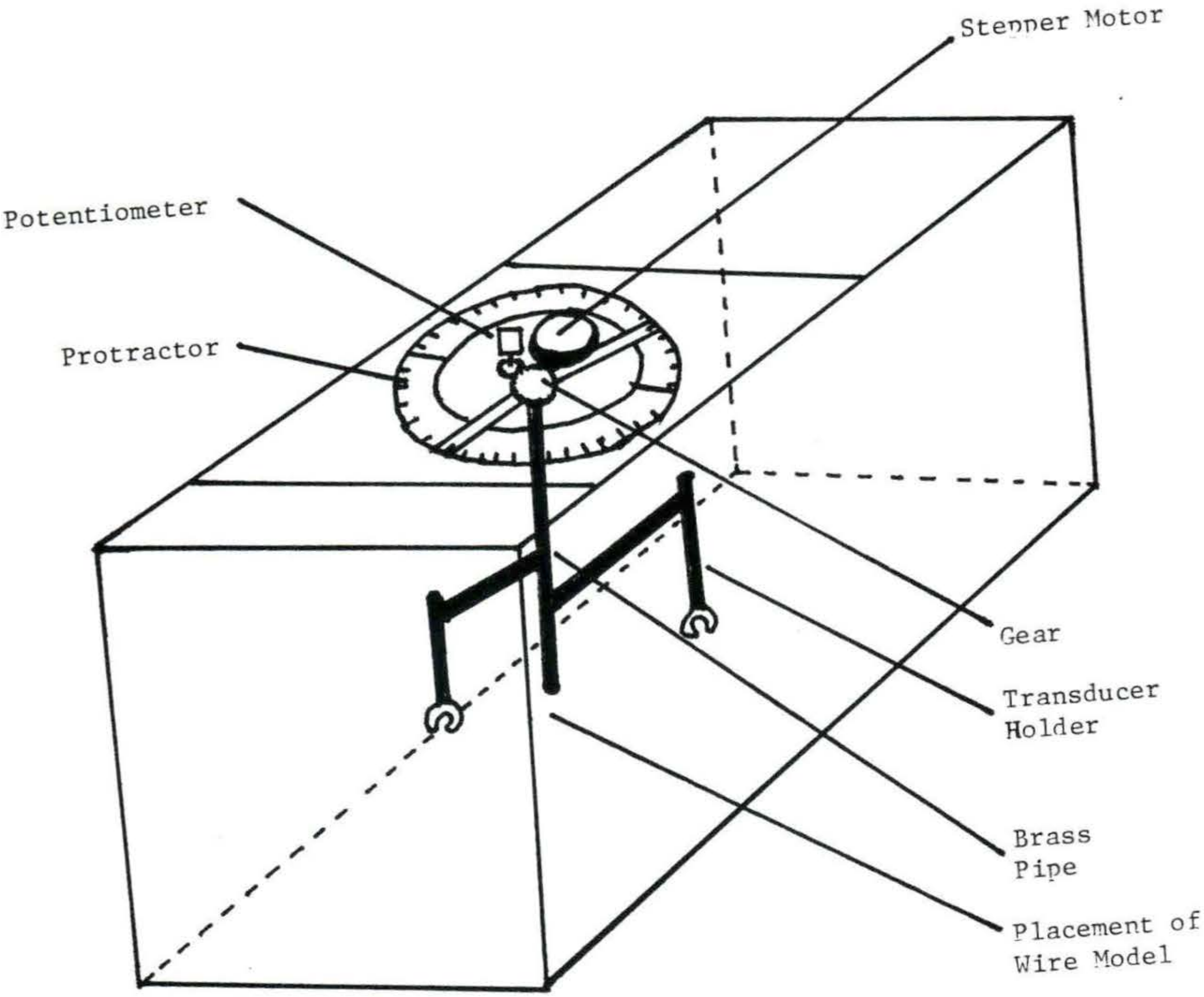


Figure 4.4: Drawing of tank used to take scans

(2.2 MHz vs 10 MHz) and length of pulse (2.2 MHz and 10 MHz vs broadband).

Knowing that the axial resolution can be no better than 1/2 the pulse length or no better than the wavelength of the sound wave, predictions can be made as to which transducer will give the best axial resolution. The limiting factor for all the transducers is their pulse lengths, with the best that the 2.2 MHz transducer can resolve axially being 1.1 mm and the best that the 10 MHz transducer can do is 1.85 mm, while the broadband theoretically could resolve as close as .296 mm.

Software System

Three computer programs were developed in this study. The first program, called CALIBRAT, calibrated the transducer location and was written in QuickBASIC. The transducer was moved to wherever the scan was to begin and the location on the protractor was noted. Then the transducer was moved to where the scan was to end and the position was noted again. The computer program would input the beginning and ending scan numbers from the potentiometer through the Keithley, the user would input the degrees between them (read from the protractor) and the computer would store these numbers in a temporary file. This file would then be incorporated into a permanent file when actual scans were being stored. The listing of the program is in Appendix A.

The second program, called TRIAL and written in BASIC, was used to store several scans as well as the position of each scan. This program was a modified version of the manufacturer's software used to operate the computer oscilloscope. The program was modified by allowing the transducer location (from the Keithley) to be stored along with the signal, as well as the calibration data which was stored in a temporary file. After a transducer location and scan were saved, the program moved the stepper motor 1/2 step by pulsing the motor via the Keithley system. The SCOPE program controlled several parameters: amplitudes of both channels (5 mV/div - 5 V/div), timebase (10 nsec/div - 20 sec/div), trigger source (either channel 1 or 2), trigger slope, trigger level and trigger mode.

Storage of data

The calibration data and all the scans taken of a model were stored in one file on a floppy disk. The four calibration numbers were stored at the beginning of the file, beginning with the number where the scan started (corresponding to 0 degrees), the number where the scan ended, degrees between the two, and finally the conversion number that converts the raw potentiometer numbers to degrees. After these four numbers came five numbers which gave the setup information from the digital scope when the scans were stored. These numbers were the sensitivity, timebase, inversion, vertical offset and horizontal offset in that order. These numbers were not used in any of the programs, but provided information as to what the settings were on the digital oscilloscope when the scans were stored in case future programs might need these parameters. The remainder of the file was the raw transducer location (number from the potentiometer), the 512 data points of a scan, the raw transducer location of the next scan, the 512 data points, etc., until all transducer locations and scans had been stored (maximum of 229 scans). This file was then read by the third program.

Display of A-scans

The third program, called COMBINED, was used to display the stored signals in B-mode, and was written in QuickBASIC. At the beginning of the program, the user entered five variables; the name of the file to be read, the threshold to be used, the width of the horizontal window, the width of the vertical window and the number of points to be skipped at the beginning. The last four will be explained later in this section. The program initially drew a blank sector that would display the signals as shown in Figure 4.5. The part circle on the arc is the location of the transducer where the first A-scan was taken. This part circle continues to move down the arc, representing where the transducer was located for each A-scan taken. The location of the transducer is found by reading the conversion number obtained from the calibration data (which was stored when the signals were taken) and the stored transducer location of that particular A-scan. The actual arc on the computer screen does not change from scan to scan, but the ending degree number will, meaning that a 90 degree scan will be compressed more on the computer screen than a 50 degree scan.

The computer then inputed the individual A-scans one by one. The 512 data points corresponded to 512 pixels along the line from the transducer to the center of the circle being scanned. All pixels in the signal above the threshold were colored white and all pixels below it were colored black and displayed on the sector that was drawn previously by the program on the computer screen. The reason the user could specify the number of points he or she wanted skipped at the beginning of the signal was to eliminate threshold crossings from the intial pulse of the transducer.

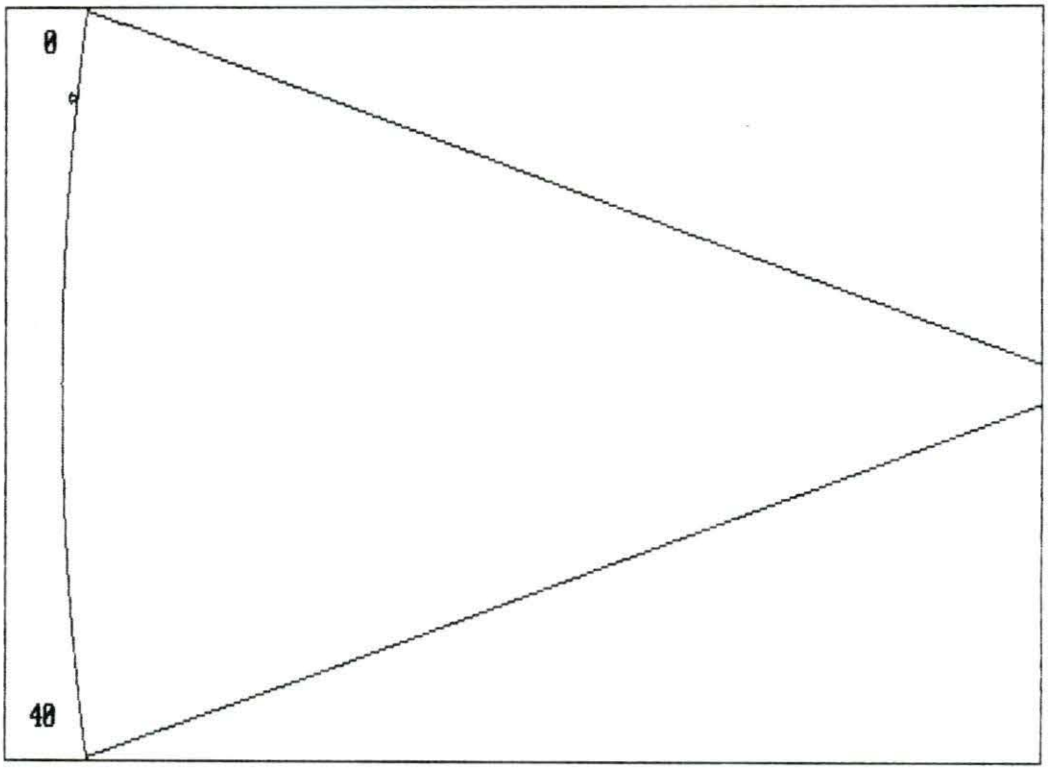


Figure 4.5: Sector displayed on the computer screen. 0 is always beginning angle. and the final angle depends upon the calibration

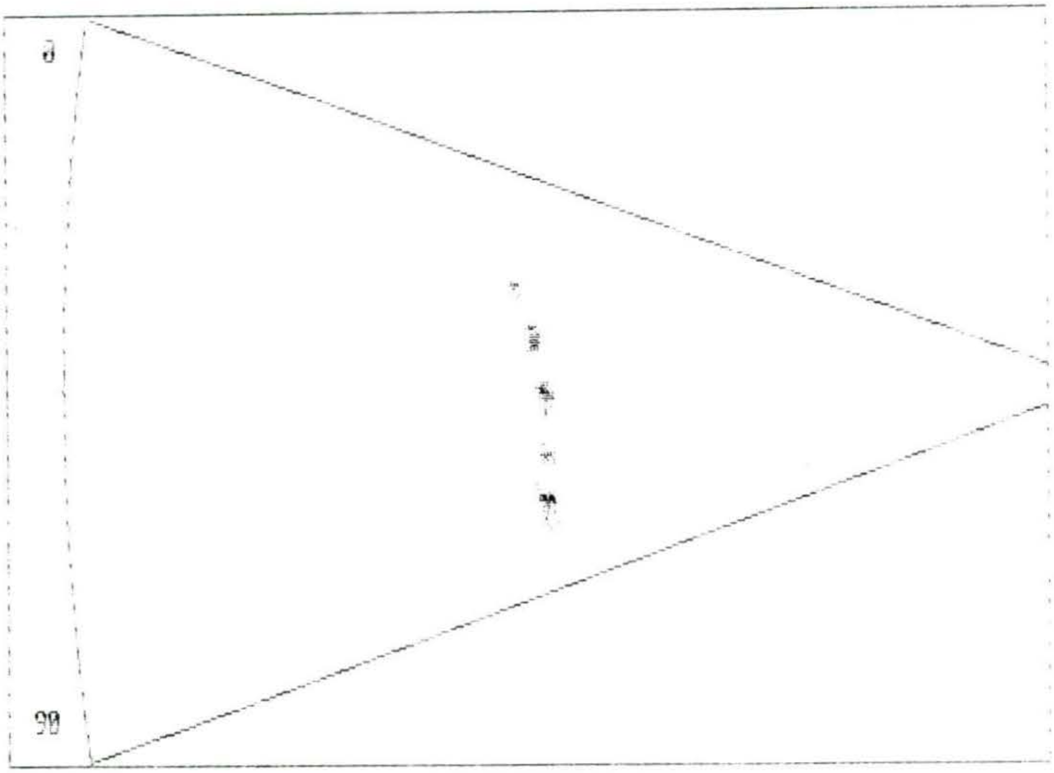


Figure 4.6: Several points represent five thin wires

The problem with this display was that several white points may represent small reflectors, such as thin wires (see Figure 4.6). It would be much better to represent these wires as a single pixel rather than several. To eliminate this problem, the program contains two subroutines, a horizontal window subroutine and a vertical window subroutine. The horizontal window subroutine condenses the points horizontally by taking the average of the first threshold crossing and the last (see Figure 4.7). The user specifies how many points ahead the computer should look for a threshold crossing (called the horizontal window width). If no threshold crossing occurs within the

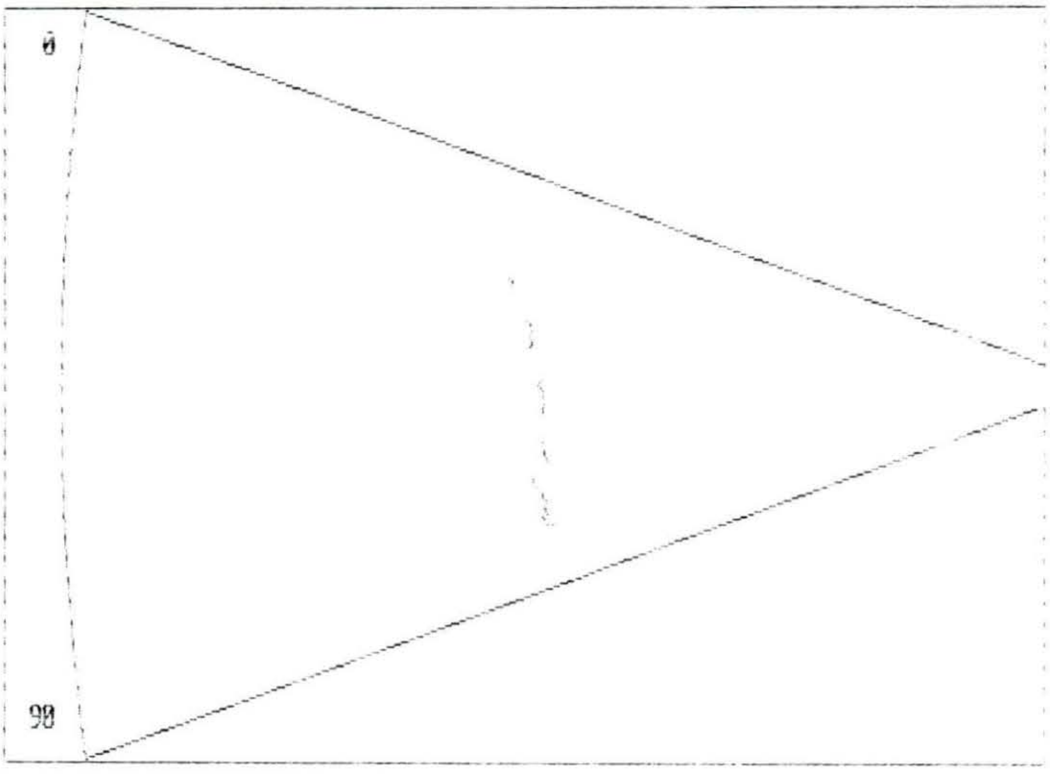


Figure 4.7: Horizontal reduction of data points

specified points, the computer takes the average of the first threshold found and the last threshold found and places one white pixel there. The horizontal location of all the white pixels are stored in a two-dimensional array, the first dimension being the A-scan number and the second dimension being the number of times the threshold had been crossed in one individual scan. The program plots the A-scans one by one on the sector that was drawn on the computer screen previously. After all A-scans have been horizontally reduced and plotted, the user presses any key and the sector is cleared and redrawn and the program goes on to the vertical window subroutine.

The vertical window subroutine works on the same principle as the horizontal one, except it reduces the number of points vertically (see Figure 4.8). The vertical subroutine involves more calculations and subroutines than the horizontal subroutine, and it uses the two-dimensional array that was created by the horizontal subroutine which stored the location of the threshold crossings. First, the computer must find the very first A-scan where the threshold crossing occurred, which is done in a subroutine. After this is found, the computer stores the A-scan number and location and looks at the next A-scan for a threshold crossing within plus or minus the horizontal window width of the threshold crossing in the A-scan before it. If no threshold crossing is found, the computer will keep looking at successive A-scans, with the number it looks ahead being specified by the user and called the vertical window width. The computer takes the average of the first A-scan found with the threshold crossing and the last A-scan found with the threshold crossing and plots one white pixel at that point on the computer screen. This continues until all of the points in the two-dimensional array are analyzed.

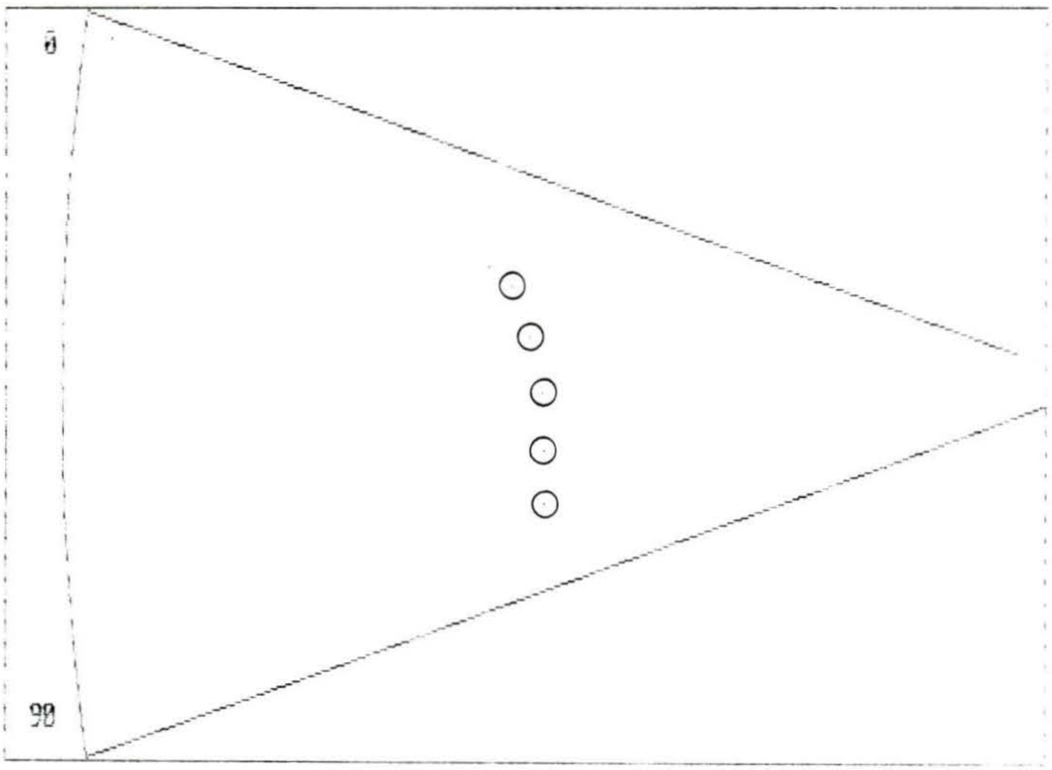


Figure 4.8: Vertical reduction of data points (actual points are circled)

The user can set the length of the vertical window independent from the length of the horizontal window (both were specified at the beginning of the program). After both the horizontal and vertical subroutines have run, the computer displays the number of reflectors it found present (corresponding to the number of points plotted after the vertical subroutine had run) in the scan at the top of the screen. Sometimes this number does not correspond to the number of white pixels present in the sector because two of the A-scans which contained white pixels were close enough together that the second A-scan erased the first white pixel. The user must watch carefully when the computer is plotting the pixels to see if one is eliminated.

Due to the memory limitation of the computer, this program can only handle 229 scans (the two dimensional array created in the horizontal window subroutine being the limiting factor), and the scans must be input one by one. Also, attenuation of the ultrasound signal was not taken into account since only scans in a tank of water were taken, and sound can travel a few meters in water with no noticable power loss (Christensen, 1988, p. 59). The listing of the display program is in Appendix B.

Wire Model

The model that was scanned in all the tests was simple. It consisted of two circuit boards mounted in a Plexiglas frame 8.5 cm apart. The holes in the circuit board were 2.85 mm apart from center to center. One millimeter in diameter stainless steel wires were placed in the circuit boards to act as reflectors. The drawing of the model can be seen in Figure 4.9.

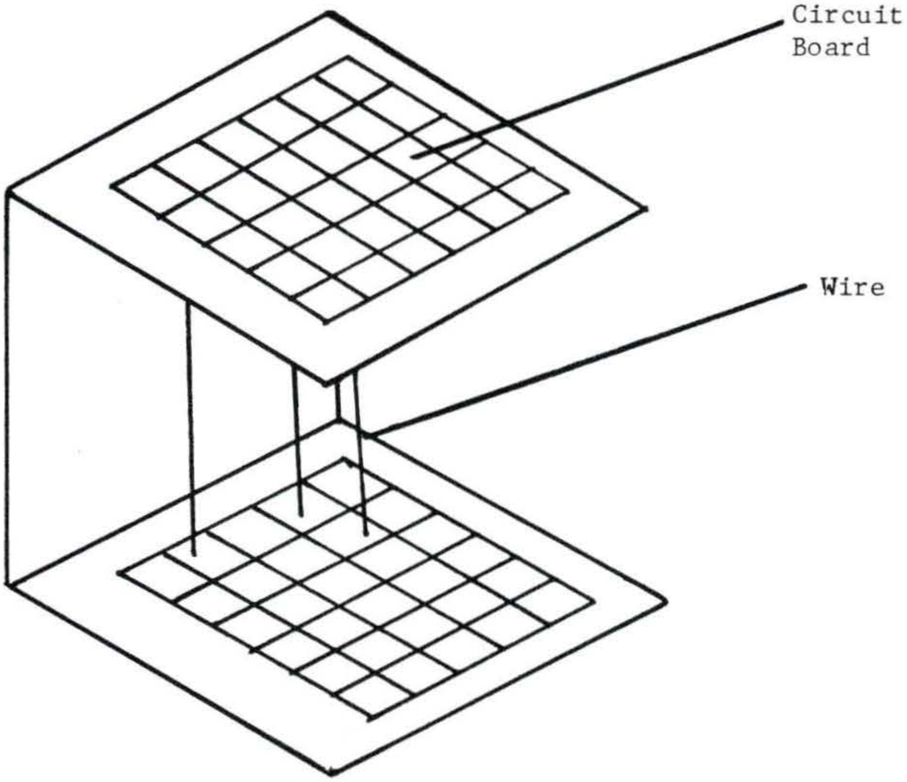


Figure 4.9: Drawing of wire model that was scanned in all the tests

Initial Tests

Several initial tests were made to determine if the system worked and to optimize the variable parameters on the pulser/receiver, the computer oscilloscope and the display software. The first test done was to determine the linearity of the potentiometer. The transducer was calibrated (using the calibration program) and moved in two degree increments, with the position of the transducer determined by the potentiometer stored as well as the position determined by the protractor. The position of the transducer from the potentiometer was converted to degrees using the calibration data. Figure 4.10 displays the graph of converted degrees to measured degrees over the full range of the potentiometer. Note that the potentiometer is not linear at either extreme. Since all the scans taken in this study will be less than 90 degrees, the graph should be linear in this range as Figure 4.11 shows. The accuracy of the position of the transducer is not a big concern since only the general area is needed to determine the number of reflectors.

It was also determined that the optimal settings on the Panametrics unit for both the 2.2 MHz and 10 MHz transducers were:

- Repetition rate: maximum (5000 Hz)
- Energy: 3
- Attenuation: 14 dB
- High pass filter: 1.0 MHz
- Damping: 4

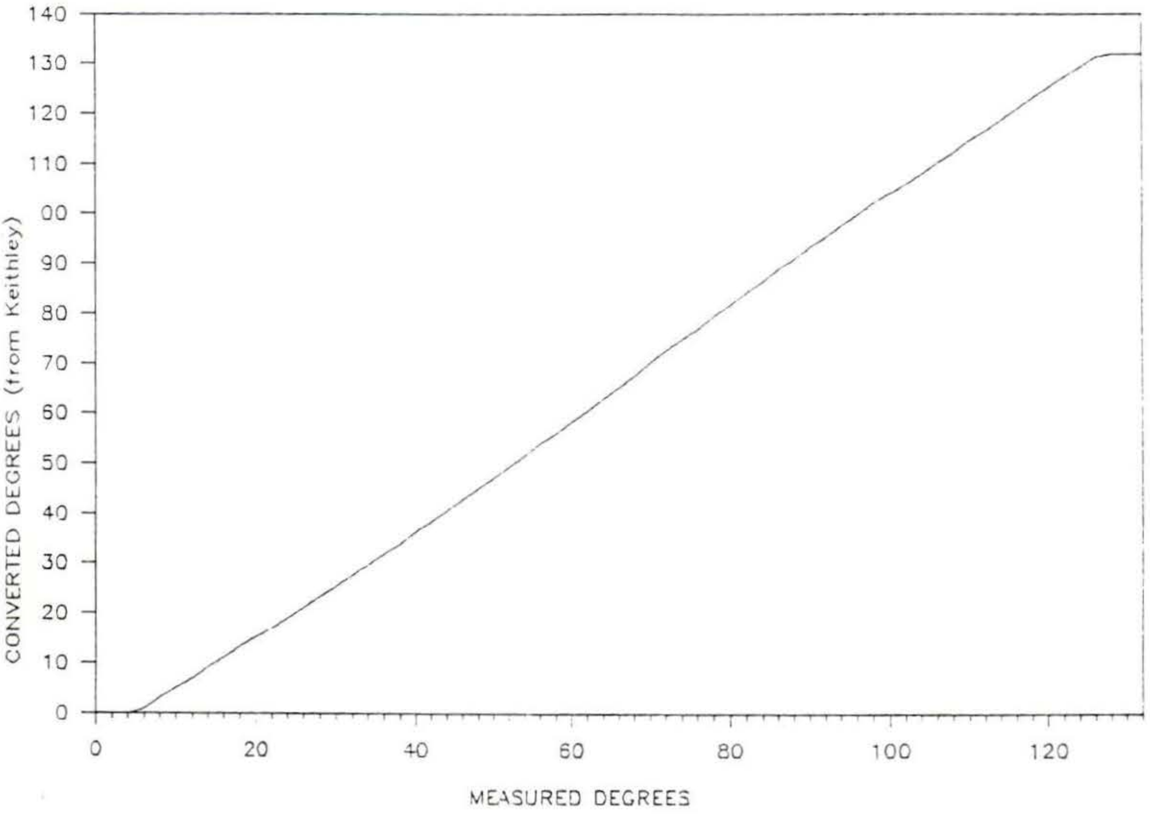


Figure 4.10: Converted degrees vs measured degrees for the full range of the potentiometer

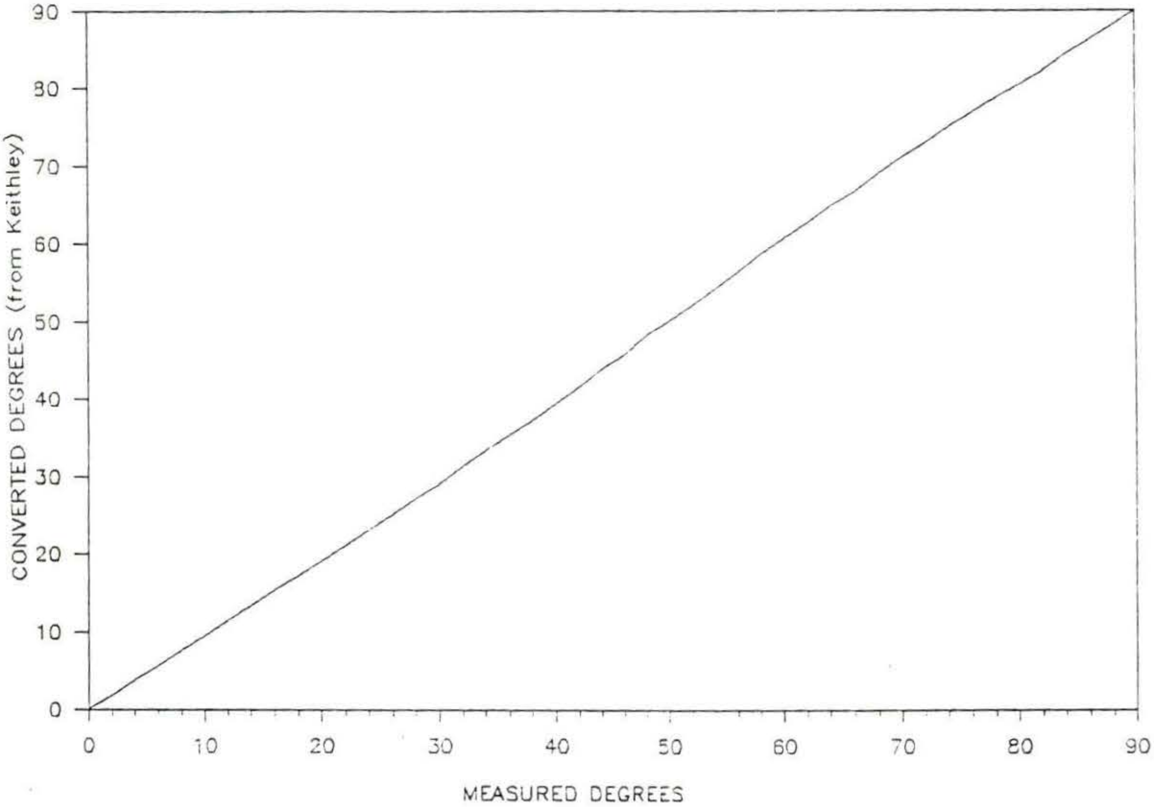


Figure 4.11: Converted degrees vs measured degrees for middle range of the potentiometer

- Gain: 20 dB

These settings were determined subjectively by observing the signal of an A-scan of four wires on the oscilloscope. These settings gave the sharpest peaks with the fewest oscillations. The amplitude of the computer oscilloscope was optimal at 20 mV/div for these two transducers.

The settings on the Panametrics box using the broadband transducer were optimal at:

- Repetition rate: maximum (5000 Hz)
- Energy: 4
- Attenuation: 0 dB
- High pass filter: 1 MHz
- Damping: 0
- Gain: 40 dB

The amplitude of the computer oscilloscope was optimal at 5 mV/div. Note that the broadband transducer requires more power and higher gain to generate a readable signal.

A comparison of the A-mode scan of 4 wires from each of the transducers can be seen in Figure 4.12. Note that the 10 MHz and broadband transducers gave the sharpest peaks. The major drawback to the broadband transducer is the low signal to noise ratio, due to the amplification of the signal.

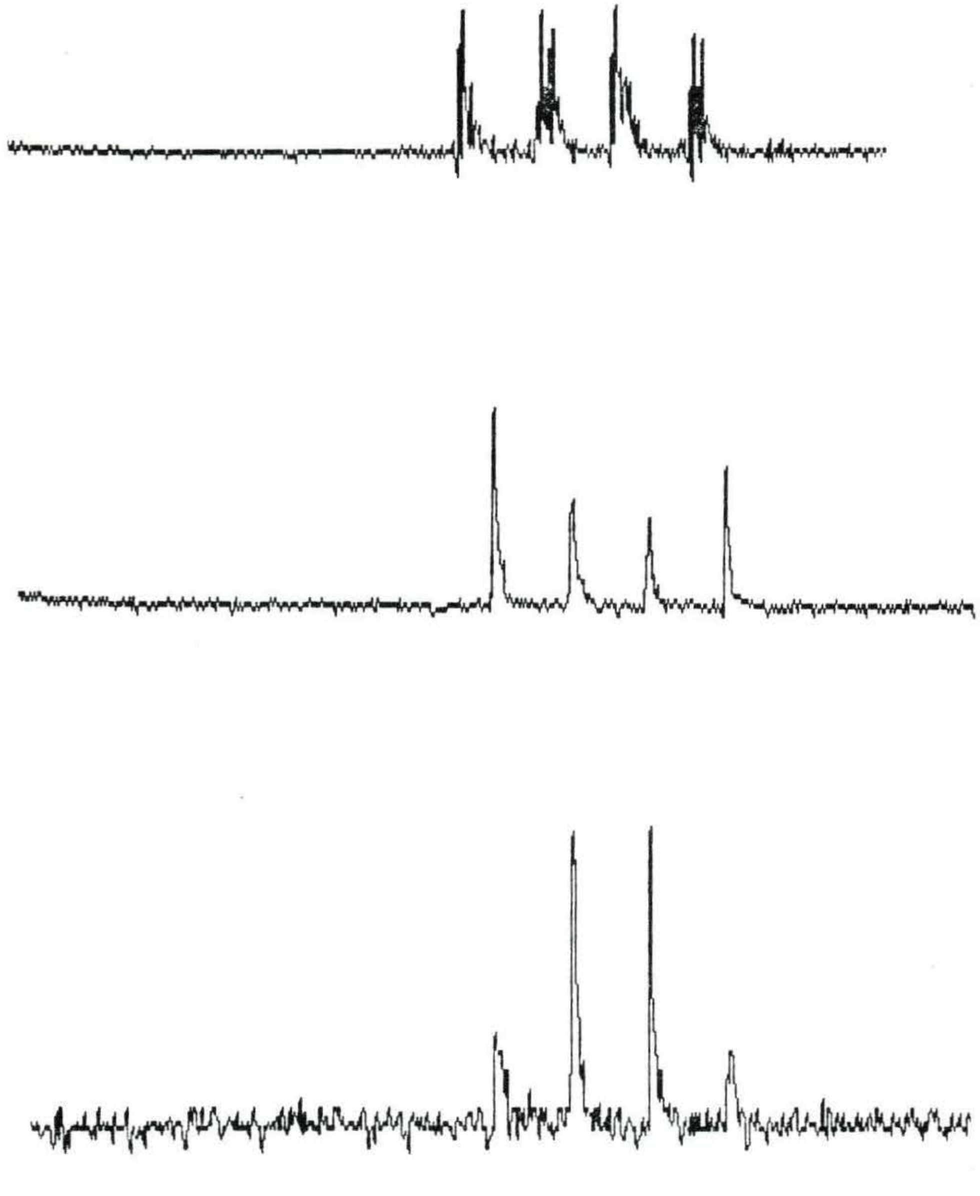


Figure 4.12: A comparison of 3 different transducer's A-mode signals scanning the same 4 wires (Top: 2.2 MHz transducer Middle: 10 MHz transducer Bottom: Broadband transducer)

It was also determined that the smallest step size in scanning was optimal to make the display of the B-mode scan on the computer screen look continuous, which for this sytem was 1/4 of a degree because the protractors mounted on top of the tank were in 1/2 degree increments. Unfortunately, the stepper moter could only step in 3 degree increments, so all the scans were done by hand.

Whatever was being scanned was placed no closer than 3.5 cm to the transducer. The maximum amount of area that could be scanned was just over 2.54 cm^2, the limiting factor being that only 229 scans could be taken.

The threshold level was set as high as possible, that is, the highest value such that the smallest reflection could just be detected which assured that all objects encountered by the ultrasound scan would appear on the computer screen. The optimal threshold level for each scan was found by running the program a few times with different threshold levels.

The widths of the horizontal and vertical windows were usually given a value of eight for both, although higher values could be given if the reflectors were spaced far apart. Values much smaller than eight did not work because data points from the same reflector would cross the threshold sometimes seven points away from the last threshold crossing, although this seemed to be more of a problem with the horizontal window than the vertical window.

Experimental Procedure and Results

Prior to the observation of any scan, a screwdriver was placed in the transducer clamp and rotated where the scan would be taken. The clamp was adjusted so that the screwdriver would not move at the center of the protractors. This assured that the transducer was aimed properly.

The tank was then filled with enough tap water to cover the transducer completely. The model was then placed in the tank such that the closest wire to the transducer was 3.5 cm away and then the calibration program was run. A few degrees were usually added on either end of the scan to be sure that the scan would be within the sector on the computer screen.

Several scans were then taken by moving the transducer 1/4 of a degree with the settings listed above, depending on the transducer used.

Simple tests

A few simple tests were performed to determine if the pixels displayed in B-mode on the computer screen were in the approximate arrangement as the wires were in the model. Five wires were placed in the model 5.45 mm apart and scanned according to Figure 4.13, using the 2.2 MHz transducer. Figures 4.6, 4.7 and 4.8 show the three steps of the display program, before any point reduction (found by setting the horizontal and vertical windows equal to one), after horizontal reduction and after vertical reduction respectively. The alignment of the wires appears distorted on the computer screen because a circular scan of the wires was taken and therefore the end wires appear to be a little closer than the center wires, as long as the wires are placed in the center of the area being scanned.

Two more tests were done using simple geometric figures that could be easily recognized; five wires placed like the five on a die and five wires representing the

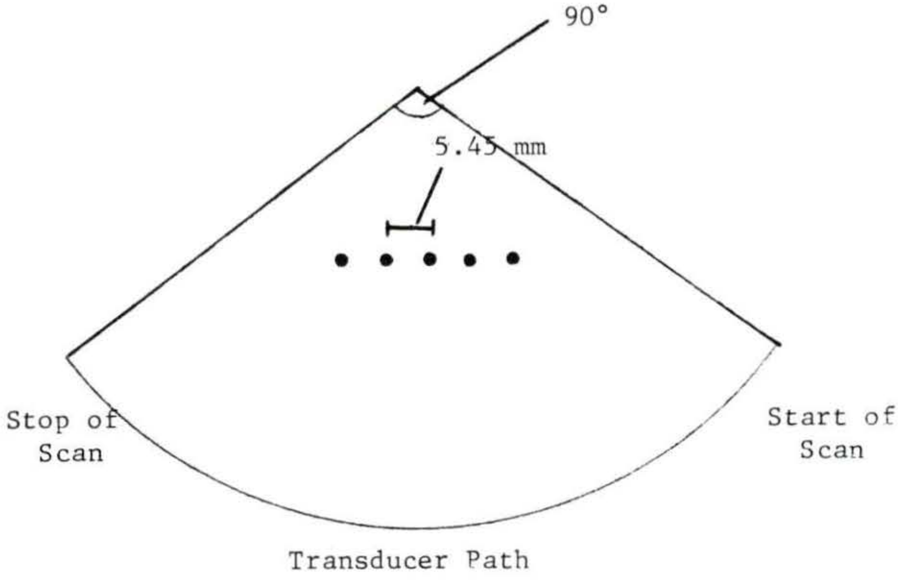


Figure 4.13: Placement of wires for initial test

sharp edges of the letter W. Both of these tests gave the correct computer displays as Figures 4.14 and 4.15 show.

Two-dimensional resolution

The next tests performed were to determine the two-dimensional resolution of the system using the different transducers. A two-dimensional scan was considered successful if the program could give the correct number of wires present and their approximate placement. The 2.2 MHz transducer was tested first.

A 3x3 matrix was formed with the wires, with the distance between the wires varied for each test. The first test had the wires 8.55 mm apart. The system was able to distinguish the nine wires as can be seen by Figure 4.16.

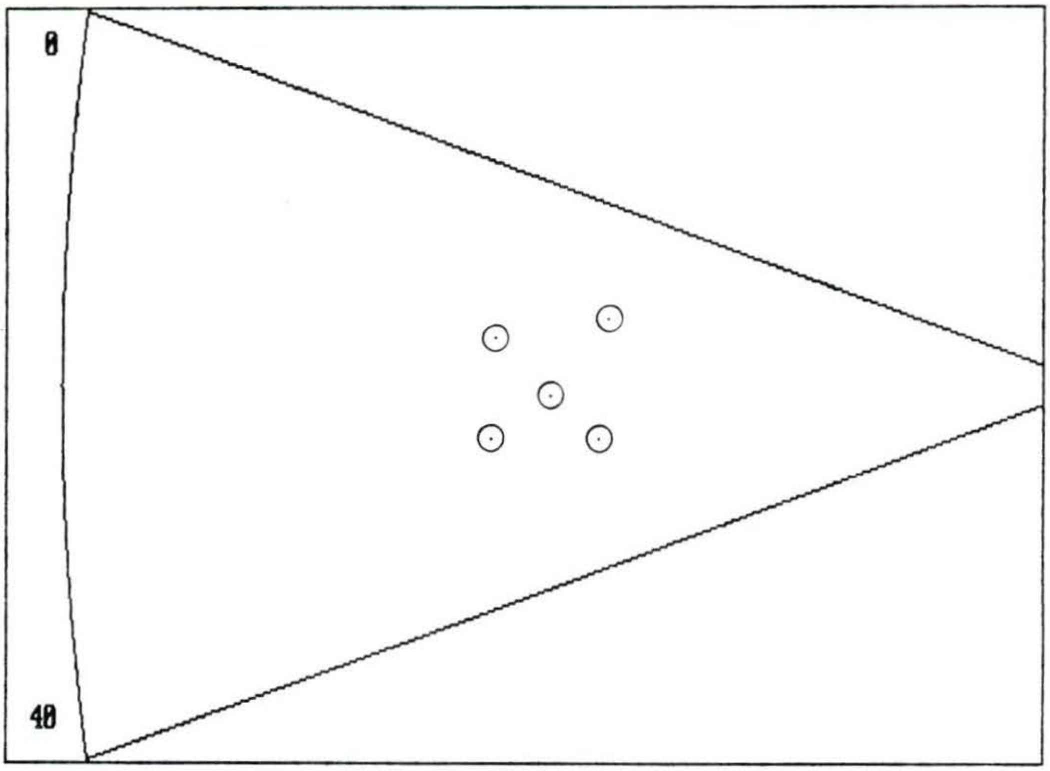


Figure 4.14: Scan of five wires spaced like the five on a die

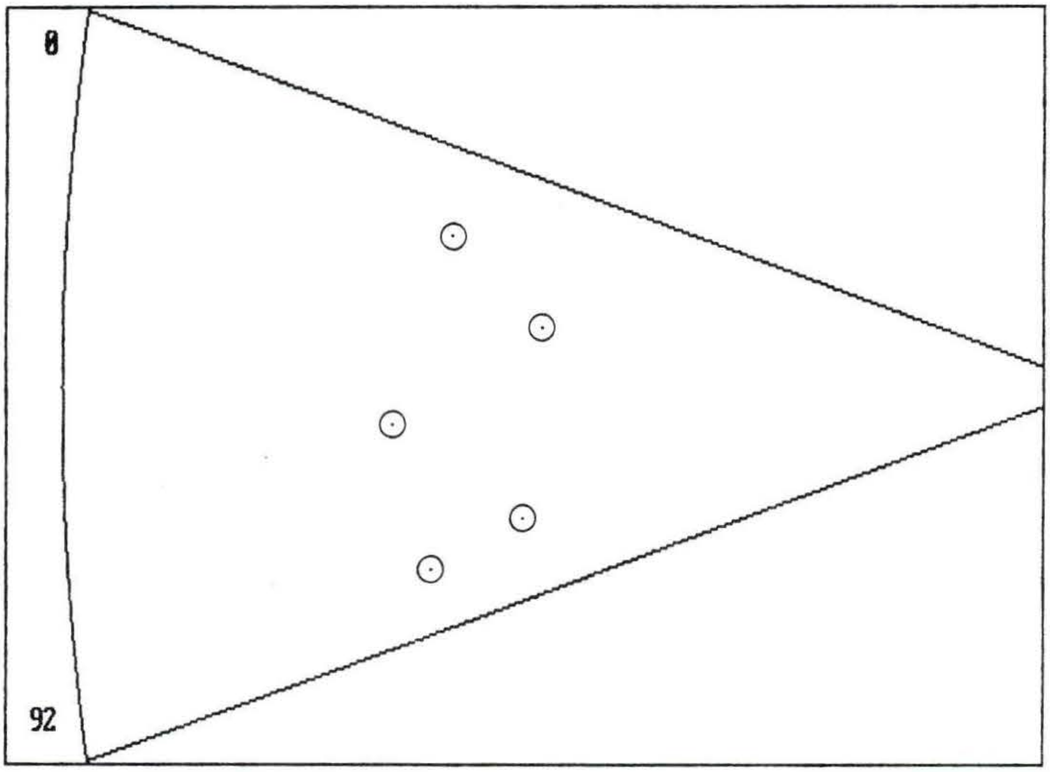


Figure 4.15: Scan of five wires spaced like the sharp points on the letter W

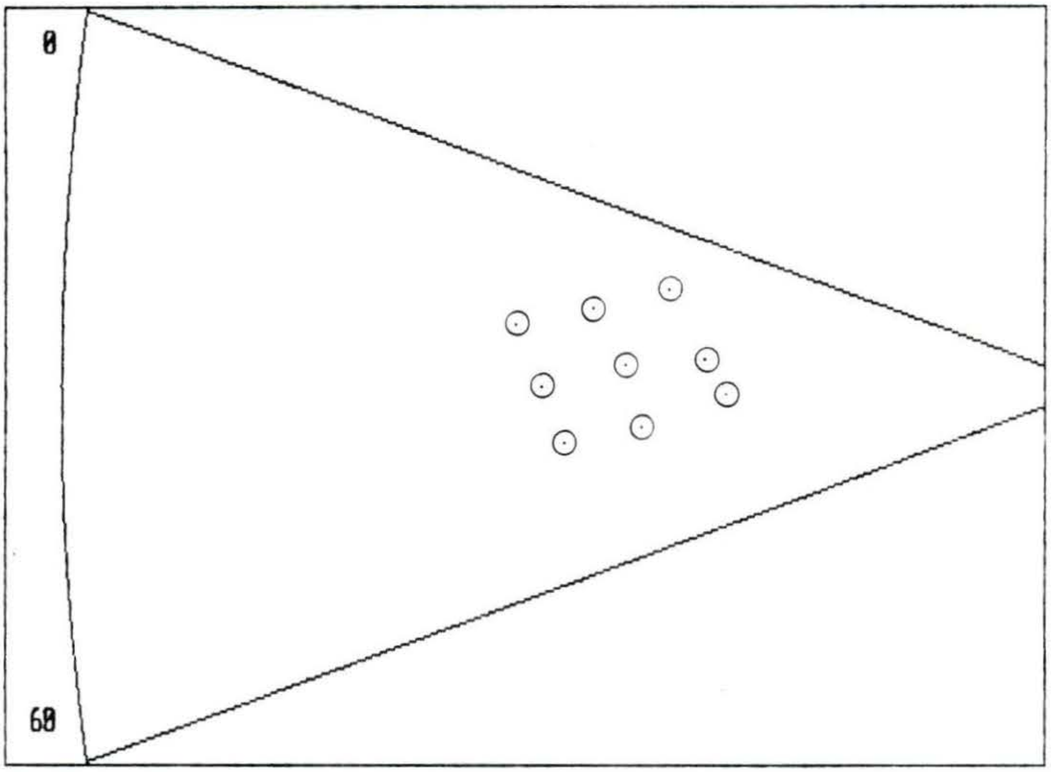


Figure 4.16: Scan of 3x3 matrix of wires spaced 8.55 mm apart using the 2.2 MHz transducer

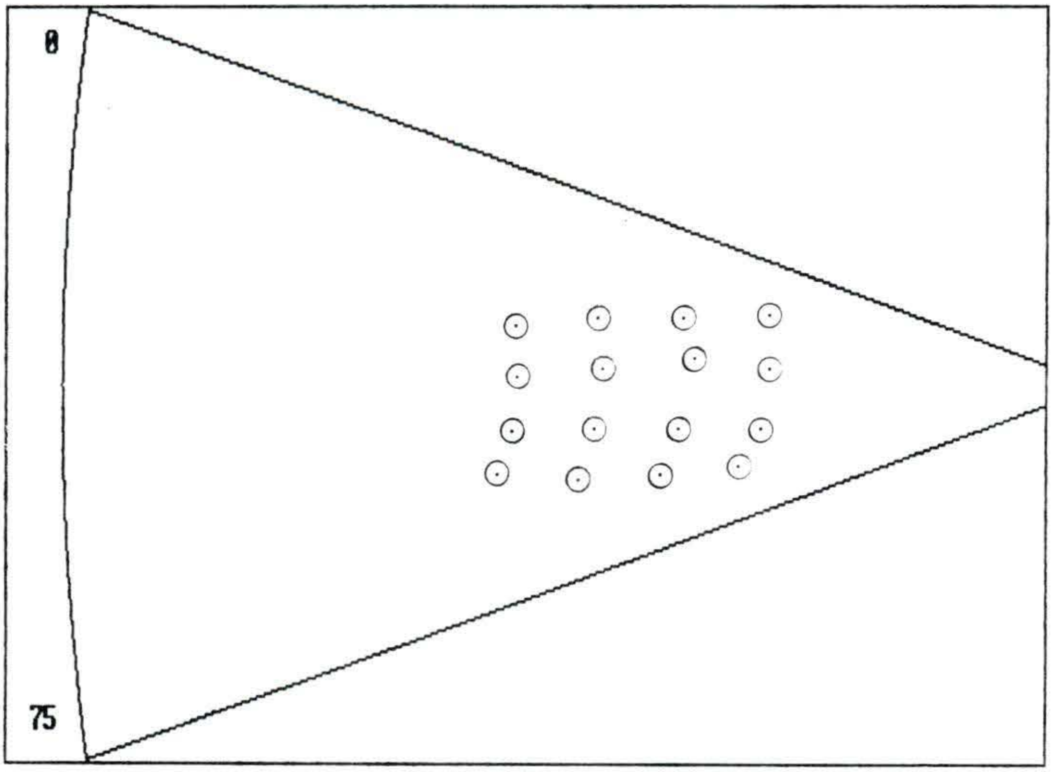


Figure 4.17: Scan of a 4x4 matrix with all wires 8.55 mm apart using the 2.2 MHz transducer

The wires were then moved closer together so that the wires were only 5.7 mm apart. The system could not distinguish the nine wires.

The wires were then moved so that horizontally, the wires were 8.55 mm apart while vertically they were 5.7 mm apart. The system still could not distinguish all nine wires.

Next, a 4x4 matrix was tried so that all the wires were 8.55 mm apart. The system was able to distinguish all 16 wires as can be seen in Figure 4.17.

Bigger matrices could not be tried because more than 229 scans would have to

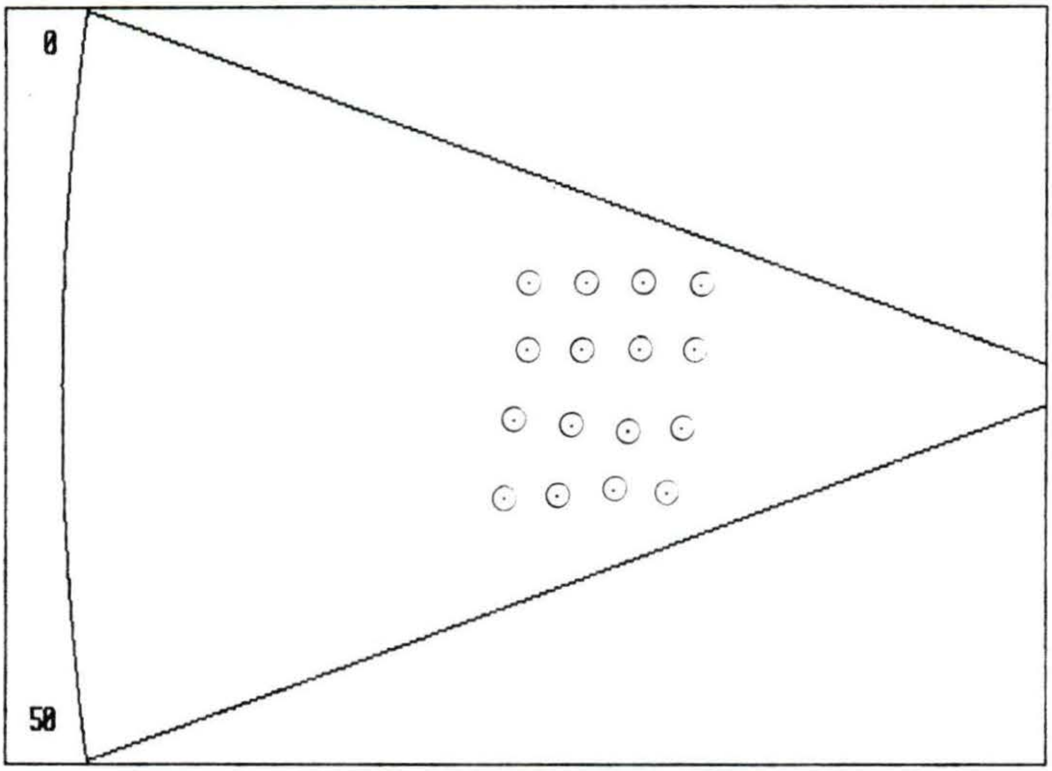


Figure 4.18: Scan of a 4x4 matrix with the wires 5.7 mm apart vertically and 8.55 mm apart horizontally using the 10 MHz transducer

be taken and the display computer program can only handle 229.

The 10 MHz transducer was tested next. A 4x4 matrix with all the wires 5.7 mm apart was tried, and the system could not distinguish the wires.

Next, a 4x4 matrix with the wires 5.7 mm apart vertically and 8.55 mm apart horizontally was tried. As can be seen in Figure 4.18, the sytem was able to distinguish these.

A 4x5 matrix was tried, once again with the vertical spacing 5.7 mm and the horizontal spacing 8.55 mm. The system could not resolve the 20 wires, and Fig-

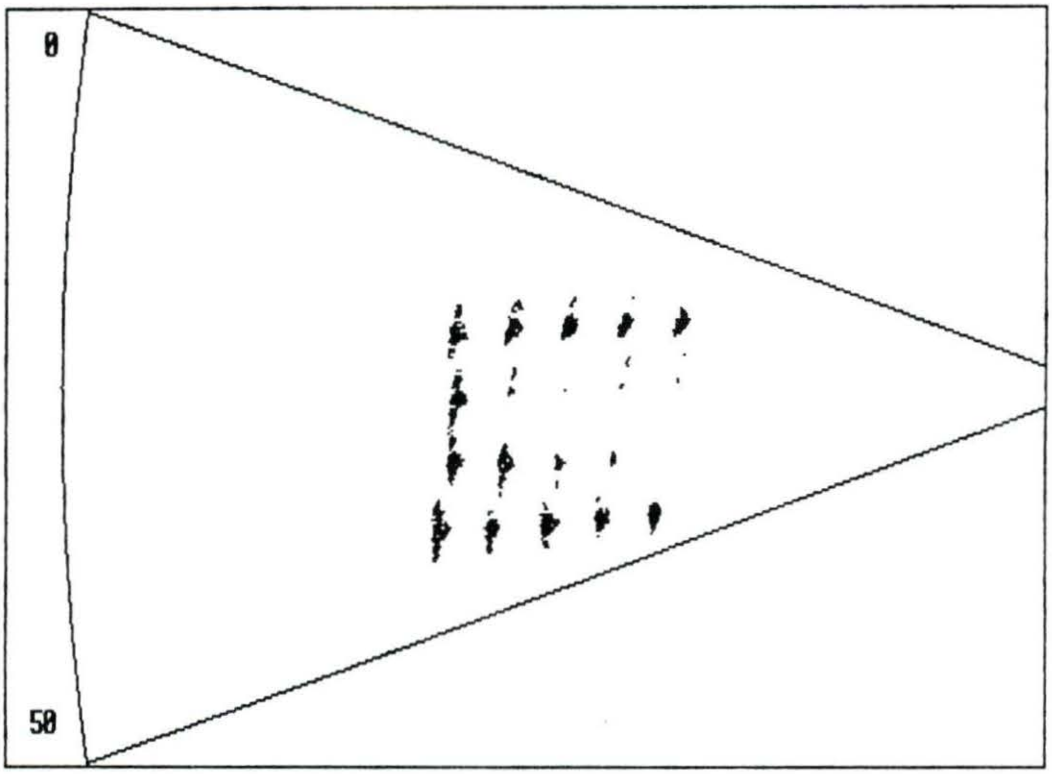


Figure 4.19: Scan of 4x5 matrix with the wires 5.7 mm apart vertically and 8.55 mm apart horizontally before any horizontal or vertical reduction using the 10 MHz transducer

ure 4.19 shows what the scan looked like at its lowest threshold level possible before any horizontal or vertical reduction took place.

The broadband transducer was tested on a 4x4 matrix with horizontal wire spacing of 8.55 mm and vertical wire spacing of 5.7 mm (this same matrix was also tested with the 10 MHz transducer). The broadband transducer was unable to resolve all 16 wires and Figure 4.20 shows the scan without any horizontal or vertical reduction.

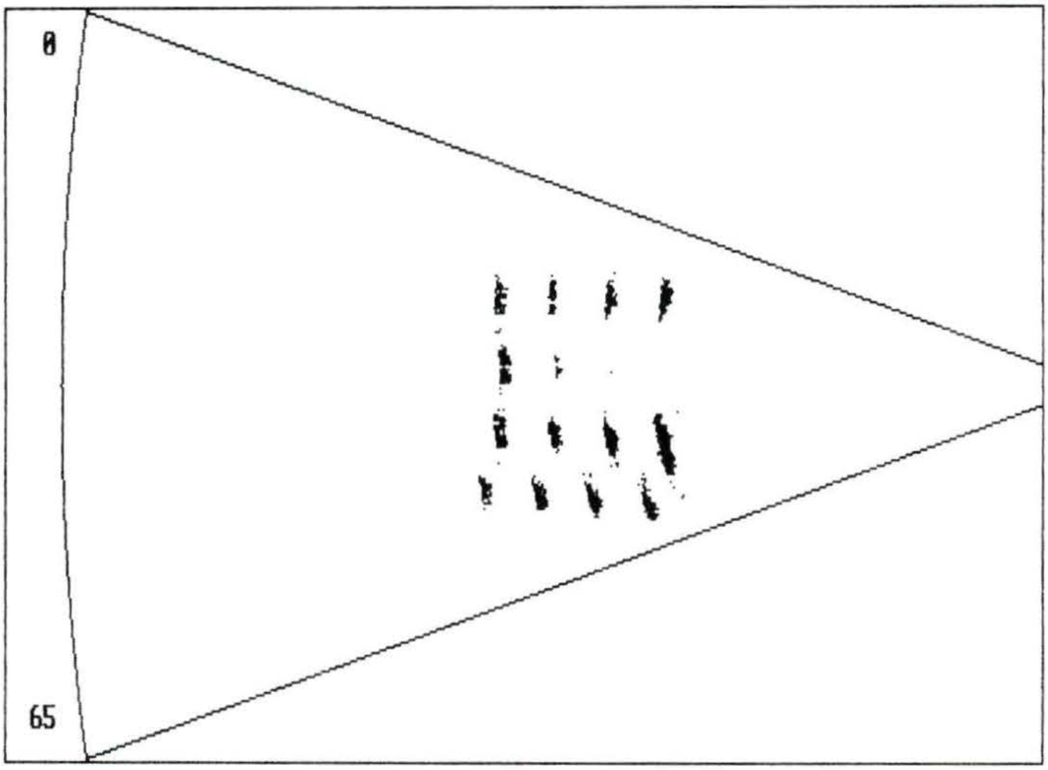


Figure 4.20: Scan of 4x4 matrix with horizontal wire spacing of 8.55 mm and vertical wire wire spacing of 5.7 mm using broadband transducer

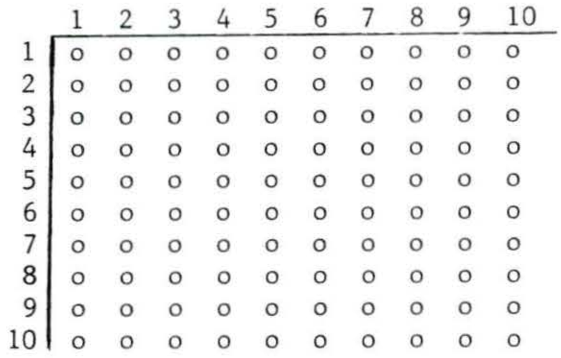


Figure 4.21: Ten hole by ten hole square on wire model used for random placement of wires

Random placement of wires

The next tests performed used random placement of wires. Only the 2.2 MHz and the 10 MHz transducers were used in these tests because the broadband transducer had such a high level of noise that some of the reflections in the A-mode signal were lost. The 2.2 MHz transducer was tested first.

A 10 hole by 10 hole square on the wire model (corresponding to 2.54 cm^2) was used for placement of the wires, as shown in Figure 4.21.

The coordinates for placement of the wires were drawn randomly with the following two rules:

1. The wires could be no closer than 8.55 mm horizontally (two empty holes between the wires)
2. The wires could not be directly behind each other.

A scan of seven wires was done with the 2.2 MHz transducer with the wires

	1	2	3	4	5	6	7	8	9	10
1	○	○	○	○	○	○	○	○	○	○
2	○	○	○	○	○	●	○	○	○	○
3	○	○	○	●	○	○	○	○	○	○
4	○	○	○	○	●	○	○	○	○	○
5	○	○	○	○	○	○	○	○	○	○
6	○	○	○	○	○	○	●	○	○	○
7	○	○	○	○	○	○	○	○	○	○
8	○	○	○	○	●	○	○	○	○	○
9	○	○	○	○	○	●	○	○	○	○
10	○	○	○	○	○	○	○	●	○	○

Figure 4.22: Random placement of seven wires

positioned as in Figure 4.22. The system was unable to resolve the wires.

One more rule was added to the above rules: a wire cannot be directly kitty corner (corresponding to 4.03 mm) to another. Another random drawing was done to obtain the coordinates of seven wires and Figure 4.23 shows the result. This time, the system was able to resolve the seven wires as Figure 4.24 shows.

The next test used ten wires instead of seven. The random drawing came up with the configuration shown in Figure 4.25. The system was just able to resolve the ten wires as Figure 4.26 indicates.

Since the 10 MHz transducer had better resolution in the matrix tests, it was tested using the following rules:

1. The wires could be no closer than 5.7 mm horizontally (one empty hole between the wires)
2. The wires could not be directly behind each other

	1	2	3	4	5	6	7	8	9	10
1	○	○	○	○	○	○	○	○	○	○
2	○	○	○	○	○	○	○	●	○	○
3	○	○	○	○	○	○	○	○	○	○
4	○	○	○	○	○	○	○	○	○	○
5	○	○	○	●	○	○	○	○	○	○
6	○	○	○	○	○	●	○	○	○	○
7	○	○	○	○	○	○	○	○	○	●
8	○	○	●	○	○	○	○	○	○	○
9	○	○	○	○	○	○	○	○	●	○
10	○	○	○	○	●	○	○	○	○	○

Figure 4.23: Random placement of seven wires using additional rule

3. The wires could be directly kitty corner.

Seven wires were positioned as shown in Figure 4.22, and the system was able to resolve the wires as shown in Figure 4.27.

Ten wires were then tried, and a random drawing came up with the configuration shown in Figure 4.28. The system was able to resolve the ten wires as Figure 4.29 indicates.

Thirteen wires were randomly placed as shown in Figure 4.30 and scanned. The system was able to resolve all thirteen wires as Figure 4.31 shows.

The last test performed scanned fifteen randomly placed wires as shown in Figure 4.32. The system could not resolve all fifteen wires and Figure 4.33 gives the scan before any horizontal or vertical point reduction had taken place.

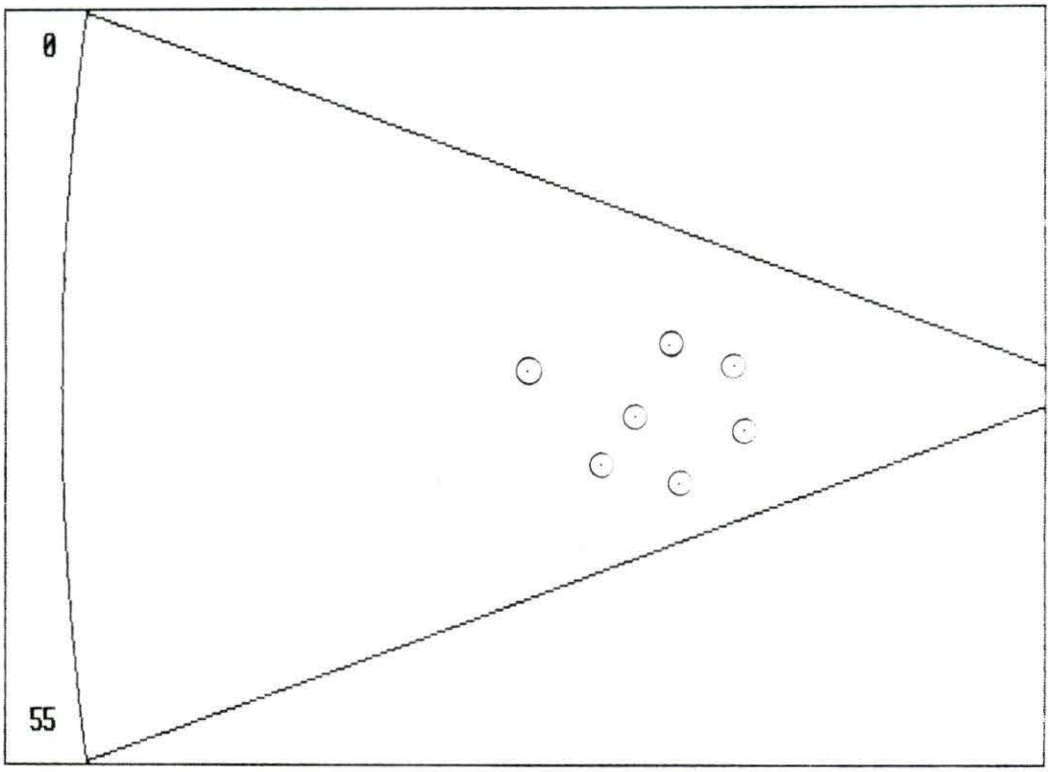


Figure 4.24: Scan of seven random wires placed as in Figure 4.23 using the 2.2 MHz transducer

	1	2	3	4	5	6	7	8	9	10
1	○	○	○	●	○	○	○	○	○	○
2	○	○	○	○	○	○	○	○	○	○
3	○	○	○	○	○	○	●	○	○	●
4	○	●	○	○	○	○	○	○	○	○
5	○	○	○	○	○	○	●	○	○	○
6	○	○	○	○	●	○	○	○	○	○
7	○	●	○	○	○	○	○	○	●	○
8	○	○	○	○	○	○	○	○	○	○
9	○	●	○	○	○	○	○	○	○	○
10	○	○	○	○	●	○	○	○	○	○

Figure 4.25: Random placement of ten wires

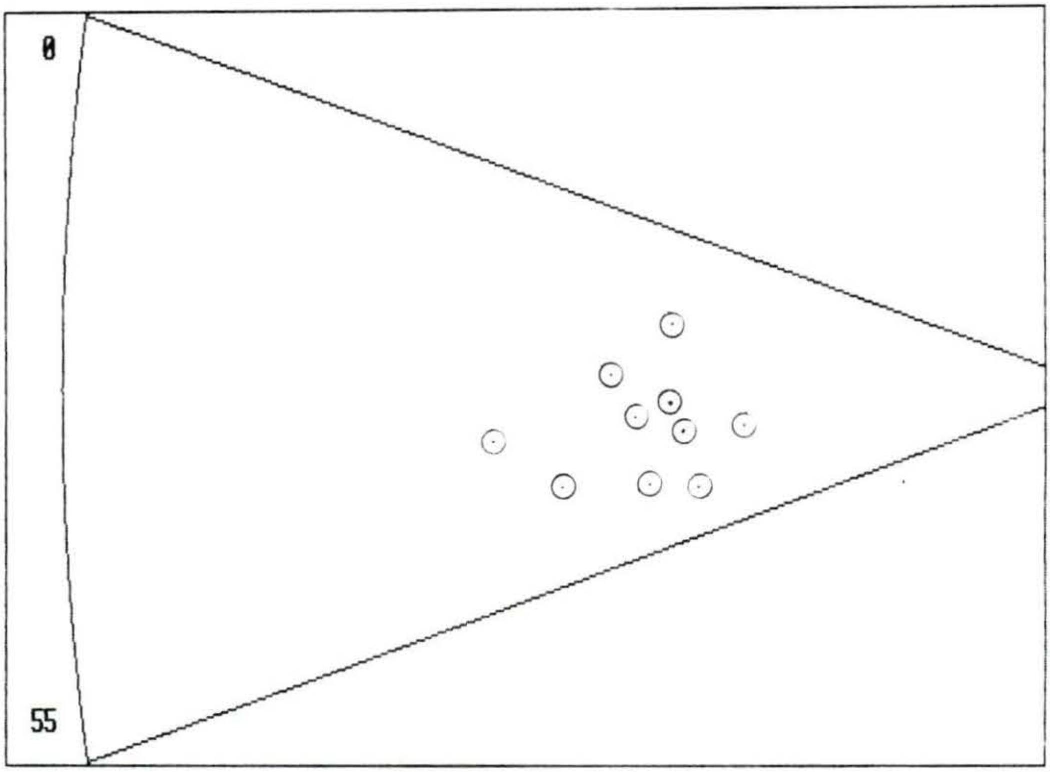


Figure 4.26: Scan of ten random wires placed as in Figure 4.25 using the 2.2 MHz transducer

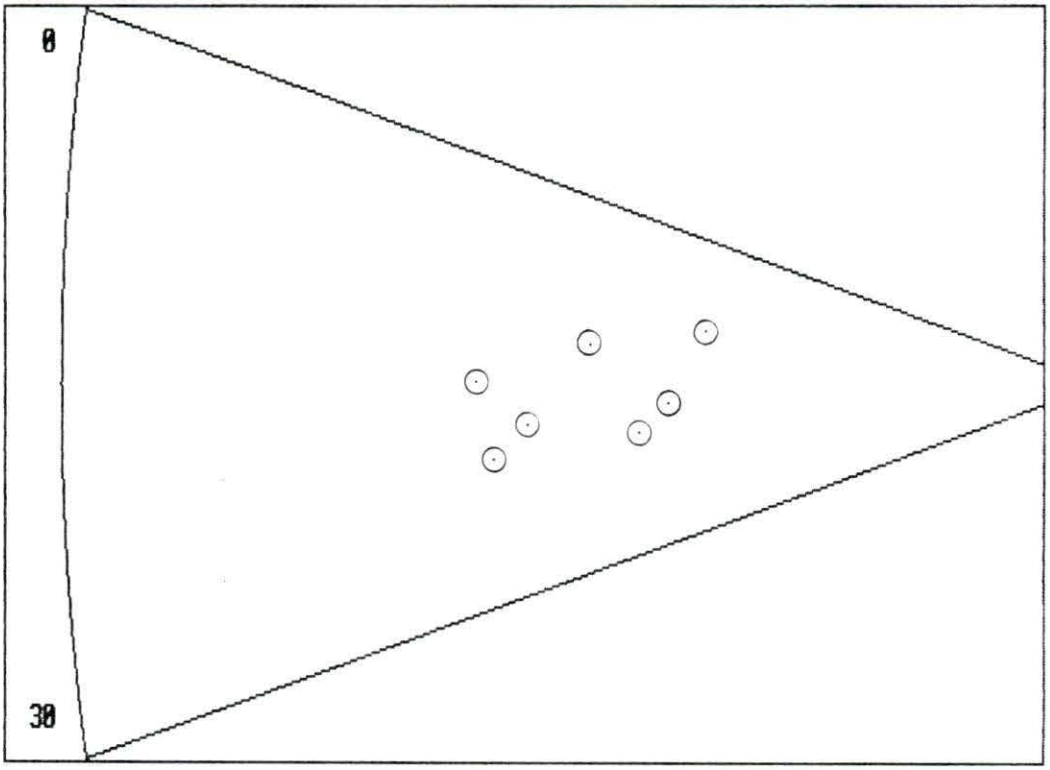


Figure 4.27: Scan of seven wires placed as in Figure 4.22 using the 10 MHz transducer

	1	2	3	4	5	6	7	8	9	10
1	○	○	○	○	●	○	○	○	●	○
2	○	○	○	○	○	●	○	○	○	○
3	○	○	○	○	○	○	○	○	○	○
4	○	○	●	○	○	○	○	○	○	○
5	○	●	○	●	○	○	●	○	○	○
6	○	○	○	○	○	○	○	○	○	○
7	○	○	○	○	○	○	○	○	○	○
8	○	○	○	○	○	○	○	○	○	○
9	○	○	○	●	○	●	○	○	○	○
10	○	○	○	○	○	○	○	●	○	○

Figure 4.28: Random placement of ten wires

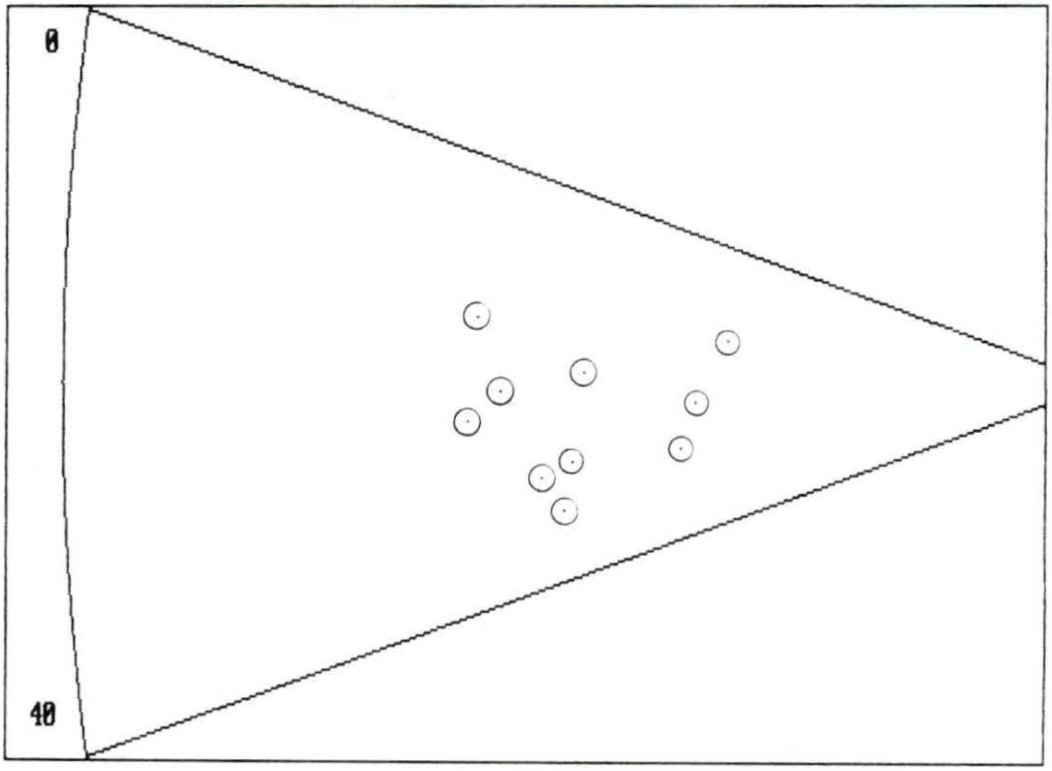


Figure 4.29: Scan of ten wires placed as in Figure 4.28 using the 10 MHz transducer

	1	2	3	4	5	6	7	8	9	10
1	○	○	●	○	○	●	○	○	○	○
2	○	○	○	○	○	○	○	○	○	○
3	●	○	●	○	○	○	○	○	○	○
4	○	○	○	○	○	○	●	○	○	○
5	○	○	○	○	○	○	○	●	○	○
6	○	○	●	○	●	○	○	○	●	○
7	○	○	○	●	○	○	○	○	○	○
8	●	○	●	○	○	○	○	○	○	○
9	○	○	○	○	○	○	○	●	○	○
10	○	○	○	○	○	○	○	○	○	○

Figure 4.30: Random placement of thirteen wires

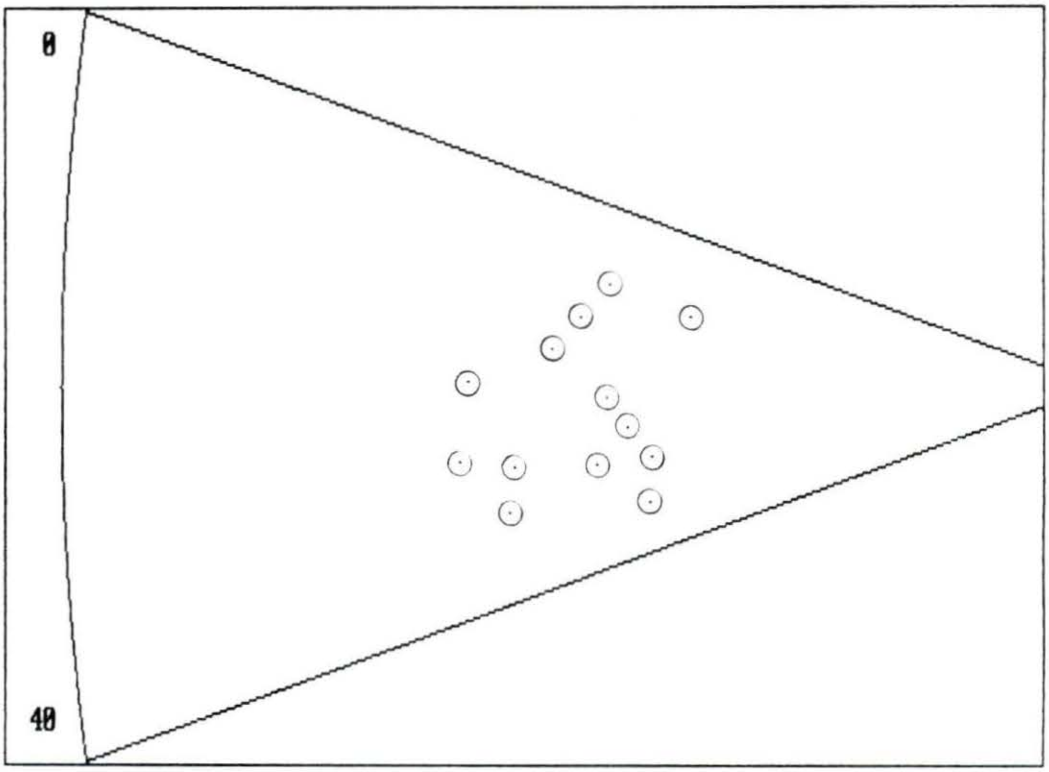


Figure 4.31: Scan of thirteen wires placed as in Figure 4.30 using the 10 MHz transducer

	1	2	3	4	5	6	7	8	9	10
1	○	○	○	○	○	○	○	○	○	○
2	○	○	○	○	○	●	○	○	○	○
3	○	●	○	○	○	○	●	○	●	○
4	○	○	○	○	●	○	○	●	○	○
5	○	○	○	●	○	●	○	○	●	○
6	○	○	○	○	●	○	○	○	○	○
7	○	○	○	○	○	●	○	●	○	○
8	●	○	○	○	○	○	○	○	○	○
9	○	○	○	●	○	●	○	○	○	○
10	○	○	○	○	○	○	○	○	○	○

Figure 4.32: Random placement of fifteen wires

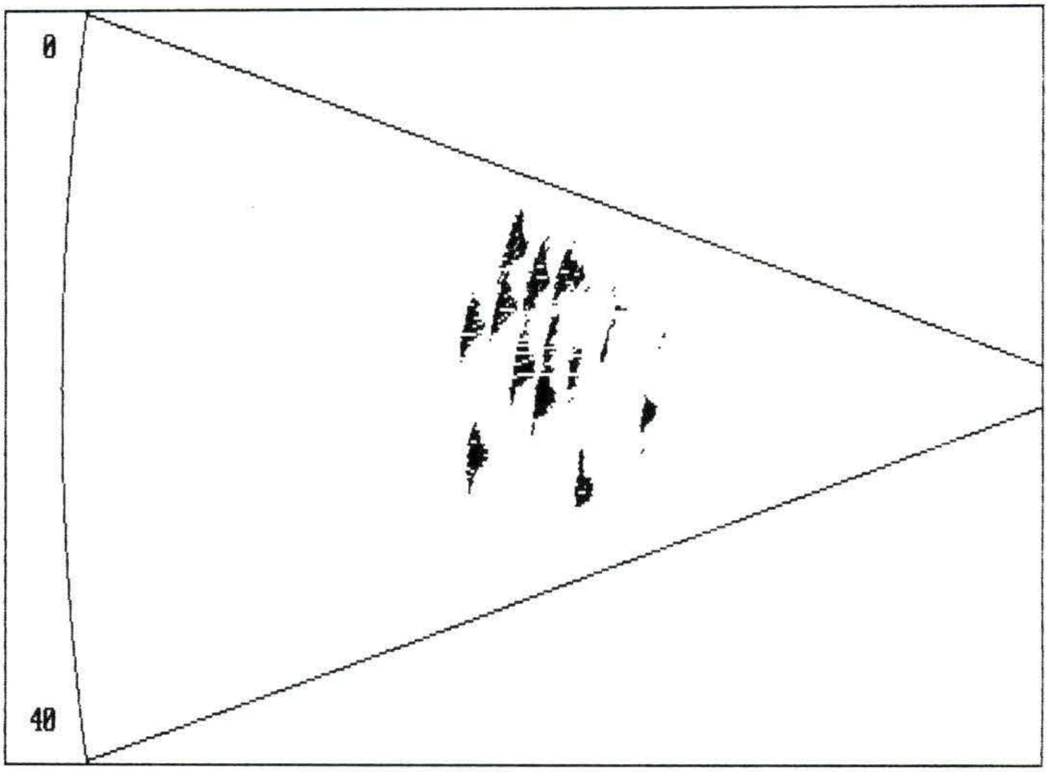


Figure 4.33: Scan of fifteen wires placed as in Figure 4.32 before any horizontal or vertical point reduction had taken place using the 10 MHz transducer

CHAPTER 5. DISCUSSION AND CONCLUSIONS

Discussion

The first simple tests performed showed that the system was working properly and that what was appearing on the computer screen was just a slightly distorted image of what was being scanned in the tank. The distortion was due to the fact that a circular scan was taken, so straight wires appeared to be slightly curved.

Although theoretically the broadband transducer should give the best axial resolution, after viewing the A-mode signal waveform from each transducer (see Figure 4.12), it was predicted that the 10 MHz transducer would be able to give finer axial resolution and have very little noise interference as compared to the 2.2 MHz transducer or the broadband transducer. It was also predicted that the broadband transducer would probably give the same type of resolution as the 10 MHz transducer but would have noise problems.

Indeed, the 10 MHz transducer could image matrices of wires that were closer together depthwise than the 2.2 MHz transducer (see Figures 4.17 and 4.18). Better depth resolution was achieved with the 10 MHz transducer because depth resolution is a function of frequency.

The broadband transducer could not quite image the wires in a matix as close together as the 10 MHz, probably because the reflections from the broadband transducer were not as strong as the ones from the 10 MHz, even with amplification. The broadband transducer also had a noticeable noise level and was very sensitive to outside interference.

Broadband transducers usually give the best depth resolution because they have the shortest initial pulse. One reason for not getting better results may be that the Panametrics pulser/receiver unit was not well suited to this particular transducer. All the settings were either at its maximum values (repitition rate, energy, gain) or at its minimum values (attenuation, damping). Perhaps if a different pulser/receiver box were used the broadband transducer would give better results. Shielding all the wires and electrical circuits might also improve the performance of the broadband transducer.

The 10 MHz transducer also had better lateral resolution than the 2.2 MHz transducer. This may be due to the fact that the beam diameter of the 10 MHz was smaller than the 2.2 MHz transducer's beam (11 mm vs 16 mm) and the scans were taken close to the trandsducer, which would not allow much time for beam divergence to occur.

The random wire tests were done to act as a better model for marbling in meat (as compared to the matrix formations) and thus draw some conclusions about using this system to scan meat. The wires in the model correspond to fat particles, while the water corresponds to muscle. Figure 5.1 shows where another wire cannot be if the two wires are to be resolved separately using the 2.2 MHz transducer. Figure 5.2 shows the same results for the 10 MHz transducer. These figures were drawn using

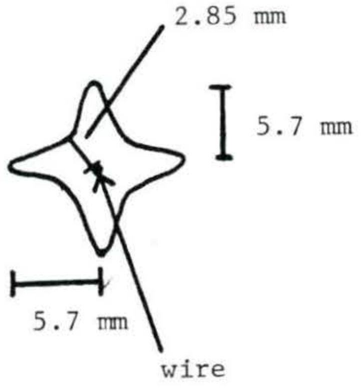


Figure 5.1: Area where another wire cannot be if the wires are to be resolved separately using the 2.2 MHz transducer

the results of the random wire tests.

Also note that the random wire tests had the wires placed closer together than the wires were in the matrix tests, depending on how the coordinates were drawn randomly. The problem with scanning matrices is that the wires are lined up one behind the other, and the wires may be in the "shadow" of the one before it. After the pulse of sound has encounterd the first 3 or 4 wires, it may not have enough energy to "see" the 5th wire in the matrix, as Figure 4.19 shows. Note that the wires on the side of the matrix show up very clearly because the sound has only to travel through water. Also note that because the threshold level has to be dropped so much to see the last row of wires, the first row of wires begins to blend togehter. With random wire placement, there is less chance that a wire will end up in the shadow of another.

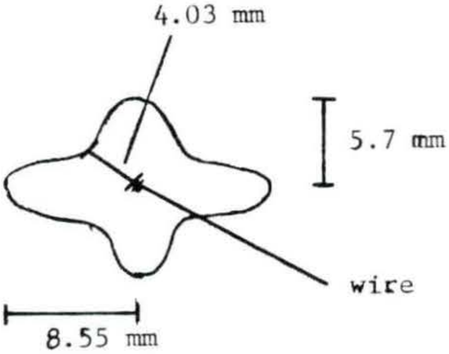


Figure 5.2: Area where another wire cannot be if the wires are to be resolved separately using the 10 MHz transducer

Conclusions

A relatively inexpensive hardware system was setup that could take several A-scans of an object and store them in a computer. The hardware system consisted of a personal computer, a digital oscilloscope, a 12 bit A/D converter, a pulser/receiver, an ultrasound transducer and a specially built tank.

Software was developed that calibrated the transducer location and could display the scans in the B-mode on the computer screen. The software also had the capability to display the objects scanned as a single point rather than a cluster of points, allowing a numerical value for the number of reflectors encountered in a scan to be obtained.

Simple geometric arrangements of wires were scanned and displayed on the computer screen, showing that what was displayed on the computer screen was an adequate representation of what was being scanned. It was adequate in the sense that what was important in this study was the number of reflectors present, not their exact location.

Using this newly developed "ultrasound tool", the two-dimensional resolution of a 2.2 MHz and a 10 MHz transducer was tested by using random placement of wires. Using the 2.2 MHz transducer, no more than 10 wires per 2.54 cm^2 could be resolved with the wires no closer than what was shown in Figure 5.1. Thirteen wires per 2.54 cm^2 with the wires no closer than Figure 5.2 could be resolved using the 10 MHz transducer.

The 10 MHz transducer gave the best resolution and the lowest noise as compared to the 2.2 MHz and the broadband transducers. It could also resolve more wires per unit area than the 2.2 MHz transducer.

Recommendations

Recommended improvements on the system

The lateral resolution of the transducers tested in this study might be improved by focusing the transducers. The same tests done in this study could be tried again using a focused transducer.

A different pulser/receiver unit could be tried also, one that is more suited to the broadband transducer used in this study, perhaps improving the perfomance of the broadband transducer.

If the 2.54 cm^2 proves to be too small of an area to scan, the memory of the computer could be expanded.

It would also be very easy to install a stepper motor that rotated in smaller increments than the one used in this study to move the transducer around the object being scanned. The system would then be totally automated.

Recommendations for further studies

The next step after this study would be to scan pieces of meat that already have been quality graded. The program in Appendix B would have to be modified to account for attenuation since attenuation of ultrasound through tissue is significant. Statistical tests could be done on the number of reflectors present in the meat given by the computer program to see if a correlation exists between that number and the quality grade of meat.

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APPENDIX A

```
3 'Program CALIBRAT

5 CLS

10 'Program to calibrate transducer angle.

20 'Program written by Anne M. Smith for thesis work

30 LOCATE 3,5:PRINT"MAKE SURE INSIDE SETTING ON KIETHLY IS FOR 0 TO
 5 V"

40 LOCATE 5,5:PRINT"MAKE SURE POWER SUPPLY IS PLUGGED IN"

50 DEF SEG=&HCFF8

60 POKE 1,6:POKE 10,0:POKE 26,0 'ANALOG CHANNEL 0, 1x GAIN

70 LOCATE 10,1:INPUT"ARE YOU READY TO BEGIN CALIBRATION? (Y/N)";ANS$

80 IF ANS$<>"Y" AND ANS$<>"N" AND ANS$<>"y" AND ANS$<>"n" THEN GOTO
 70

90 IF ANS$="N" OR ANS$="n" THEN GOTO 70

100 CLS

110 LOCATE 3,1:PRINT"SET TRANSDUCER AT BEGINNING ANGLE.  PRESS ANY
 KEY WHEN DONE."

115 LOCATE 4,1:PRINT"THIS WILL BE ANGLE 0 ON SCREEN."
```

```
120 A$=INKEY$

    AA=PEEK(3):BB=PEEK(2)

125 LOCATE 16,30:B=256*(AA-240)+BB:PRINT B:POKE 24,0

130 IF A$="" THEN GOTO 120

    AA=PEEK(3):BB=PEEK(2)

140 BEG=256*(AA-240)+BB

150 POKE 24,0

160 LOCATE 5,5:PRINT"BEGINNING POSITION ";BEG

170 LOCATE 7,1:PRINT"SET TRANSDUCER AT ENDING ANGLE.  PRESS ANY KEY

 WHEN DONE."

180 A$=INKEY$

    AA=PEEK(3):BB=PEEK(2)

185 LOCATE 16,30:B=256*(AA-240)+BB:PRINT B:POKE 24,0

190 IF A$="" THEN GOTO 180

    AA=PEEK(3):BB=PEEK(2)

200 FIN=256*(AA-240)+BB

210 POKE 24,0

220 LOCATE 9,5:PRINT"ENDING POSITION    ";FIN

230 LOCATE 11,1:INPUT"ENTER NUMBER OF DEGREES BETWEEN BEGINNING AND

 FINAL POSITION: ";DEGREES

240 CONV=ABS((FIN-BEG))/DEGREES

250 LOCATE 14,1:PRINT"1 DEGREE = ";CONV

260 OPEN"B:TEMP.DAT" FOR OUTPUT AS #1
```

```
270 WRITE #1,BEG,FIN,DEGREES,CONV

280 CLOSE #1

290 END
```

APPENDIX B

```
'Program COMBINED
'PROGRAM WRITTEN BY ANNE M. SMITH
'DISPLAYS SCANS IN A TWO-DIMENSIONAL SECTOR ON COMPUTER SCREEN

 DIM X(229):DIM Y(229):DIM DEGREES(229) 'ONLY 229 SCANS CAN BE
 TAKEN!
 DIM HP(229,50):DIM SCAN(229):DIM NUMWHT(229)
 DIM DTA(512)
 DIM TRK(229)
 DIM CLR(517) 'WILL BE COLOR OF 512 POINTS
 DIM USED(229)

 MAX=0 'COUNTS MAXIMUM # OF WHITE POINTS IN SCAN
 FLAG=0 'SET HI WHEN GOING TO VERTICAL WINDOW SUBROUTINE
 TOTAL=0 'COUNTS FINAL NUMBER OF LIT UP PIXELS

  LOCATE 5,1:INPUT"FILENAME (NO EXTENSION): ";FLE$:FILE$=FLE$+".DAT"
```

```
  OPEN FILE$ FOR INPUT AS #1  'BRING DATA FROM CALIBRATION
  INPUT #1,BEG,FIN,DEG,CONV   'BEGINNING #, ENDING #, TOTAL
  DEGEEES, CONVERSION

  LOCATE 7,1:INPUT"THRESHOLD (100-220): ";THSHOLD
1  LOCATE 9,1:INPUT"HORIZONTAL WINDOW LENGTH (USUALLY 5-30): ";WNDOW
  IF WNDOW=0 THEN GOTO 1
  LOCATE 11,1:INPUT"VERTICAL WINDOW LENGTH (USUALLY 5-30): ";VW
  LOCATE 13,1:INPUT"NUMBER OF POINTS SKIPPED AT BEGINNING
  (20-100): ";SKIP

  INPUT#1,SENS,TIMEBASE,INV,VERT,HORIZ 'SET UP INFO FROM
  OSCILLOSCOPE

  SCREEN 9
  VIEW SCREEN (1,50)-(638,330),,3    'SET UP WHERE SCAN WILL BE ON
  SCREEN
  WINDOW SCREEN (-675,-190)-(-36,159) 'MAKE NEW COORDINATE SYSTEM,
  0,0 IS CENTER OF CIRCLE

  GOSUB 8000 'DRAWS ARC

  LOCATE 1,1:PRINT"DEGREES: "
```

```
 LOCATE 1,40:PRINT"THRESHOLD: ";THSHOLD
 LOCATE 2,40:PRINT"WINDOW (H,V): ";WNDOW;",";VW
 LOCATE 3,40:PRINT"# POINTS SKIPPED AT BEG: ";SKIP
 LOCATE 3,1:PRINT"FILENAME: ";FILE$

 CNT=1

20  FOR C=0 TO 512  'INPUT DATA POINTS
     INPUT#1,DTA(C)   'DTA(0) CONTAINS RAW TRANSDUCER LOCATION
   NEXT C   'DTA(1-512) CONTAINS ACTUAL SIGNAL, CNT IS WHICH SIGNAL
   IT IS

   DEGREES(CNT)=ABS((DTA(0)-BEG))/CONV 'DTA(0) IS TRANSDUCER
   POSITION OF Eth SCAN
   Y(CNT)=INT((280*DEGREES(CNT))/DEG - 140)
   X(CNT)=INT(-SQR(640^2-Y(CNT)^2))
   X=X(CNT)
   Y=Y(CNT)

   PSET(X,Y)                    'TURN POSITION ON
   CIRCLE(X,Y),5,,-2.36,-3.71
   LOCATE 1,10:PRINT USING"###.#";DEGREES(CNT)
```

```
   LOCATE 2,1:PRINT"SCAN #: ";CNT


   GOSUB 1000
   CIRCLE(X,Y),5,0,-2.36,-3.71  'TURN POSITION OFF
   PSET(X,Y),14



   IF EOF(1)=0 THEN CNT=CNT+1:GOTO 20
  38 A$=INKEY$:IF A$="" THEN GOTO 38

   FLAG=1:CLS 1:GOSUB 8000

   GOSUB 3000 'VERTICAL WINDOW SUBROUTINE

 ' LOCATE 2,30:PRINT"PRESS ANY KEY TO END PROGRAM"
  40 A$=INKEY$:IF A$="" THEN GOTO 40
  END

1000 '  HORIZONTAL WINDOW SUBROUTINE
     ' DOES ONLY 1 SCAN AT A TIME.  DETERMINES # OF WHITE POINTS, AND
     ' WHERE THEY ARE AT IN SCAN.

 AB=SKIP 'SKIP FIRST SKIP POINTS
```

```
 NUMWHT(CNT)=0


1900 IF DTA(AB)<=THSHOLD THEN AB=AB+1

     IF AB=513 THEN GOSUB 2000:RETURN 'ALL 512 POINTS ARE DONE

     IF DTA(AB)<=THSHOLD THEN GOTO 1900


     TRK(0)=AB 'KEEP TRACK OF FIRST TIME POINT CROSSES THRESHOLD

     N=1

     FOR J= 1 TO WNDOW 'IF POINTS DON'T CROSS THRESHOLD IN WNDOW

     POINTS, STOP

                    'WINDOW

       AB=AB+1

       IF AB=513 THEN GOSUB 2000:RETURN 'ALL 512 POINTS HAVE BEEN

        LOOKED AT

       IF DTA(AB)>THSHOLD THEN TRK(N)=AB:J=1:N=N+1 'IF T'HOLD

       CROSSED, START

     NEXT J                                     'NEW WINDOW




    B=INT((TRK(0)+TRK(N-1))/2)

    NUMWHT(CNT)=NUMWHT(CNT)+1: HP(CNT,NUMWHT(CNT))=B

    IF NUMWHT(CNT)>MAX THEN MAX=NUMWHT(CNT)
```

```
    CLR(B)=15 'ONLY PUT ONE POINT BETWEEN 1st AND LAST T'HOLD

    CROSSING


    GOTO 1900



2000 'SUBROUTINE TO PLOT SCANS

    IF FLAG=1 THEN TOTAL=TOTAL+1

    IF FLAG=1 THEN LOCATE 1,1:PRINT "TOTAL: ";TOTAL;"          "

    IF FLAG=1 THEN LOCATE 2,1:PRINT "SCAN #: ";MIDSCAN

    FOR XX=X+1 TO X+512

       YY=(Y/X)*XX

       PSET (XX,YY),CLR(XX-X)

    NEXT XX


  GOSUB 5000 'MAKE ALL POINTS BLACK AGAIN

  RETURN




3000 GOSUB 5000

 FOR ZZ=1 TO MAX

    FOR CC=1 TO CNT
```

```
      IF NUMWHT(CC)>0 AND HP(CC,ZZ)>0 THEN C=CC:Z=ZZ:GOSUB 7000
     NEXT CC
   NEXT ZZ

RETURN

3010 TRK(1)=HP(C,Z):SCAN(1)=C 'KEEP TRACK OF 1st HORIZ.POINTS AND
      SCAN #
      NN=2:B=Z:NUM=C:DC=C

    FOR JJ=1 TO VW
      DC=DC+1
      IF DC=CNT+1 THEN GOTO 3020 'ALL SCANS TESTED
      FOR A=1 TO NUMWHT(DC)
        IF ((HP(DC,A)<=HP(NUM,B)+WNDOW) AND (HP(DC,A)>=HP(NUM,B)-
        WNDOW)) THEN
        TRK(NN)=HP(DC,A):SCAN(NN)=DC:JJ=1:NN=NN+1:HP(NUM,B)=0:
        B=A:NUM=DC
       :GOTO 3005
      NEXT A
3005 NEXT JJ
3020   HP(NUM,B)=0 'BLANK OUT LAST VERTICAL WHITE POINT
```

```
    SUM=0
    FOR D=1 TO NN-1
      SUM=SUM+TRK(D)
    NEXT D

    BB=INT(SUM/(NN-1)) 'CALCULATES AVERAGE HORIZ. POINT
    CLR(BB)=12 'COLOR PIXEL LIGHT RED

    MIDSCAN=INT((SCAN(1)+SCAN(NN-1))/2) 'CALCULATES MIDDLE SCAN
    X=X(MIDSCAN)
    Y=Y(MIDSCAN)
    USED(MIDSCAN)=USED(MIDSCAN)+1 'KEEP TRACK OF HOW MANY TIMES
    SCAN USED
    IF USED(MIDSCAN)>1 THEN GOSUB 6000 'WILL WIPE OUT 1st WHITE
    PIXEL

    GOSUB 2000 'PRNT OUT SCAN LINE
    RETURN 'GO BACK TO 3000 LOOP


5000 'SUBROUTINE TO CLEAR POINTS TO BLACK
  FOR A=0 TO 517
    CLR(A)=0 'ALL POINTS BLACK INITIALLY
```

```
  NEXT A
 RETURN


6000 'SUBROUTINE TO CALCULATE NEW X AND Y COORDINATES OF SCAN
   Y=Y+(2*USED(MIDSCAN)) 'PUT NEW WHITE POINT 2 POINTS BELOW
   ORIGNAL SCAN
   X=INT(-SQR(640^2-Y^2)) 'CALCULATE X-COORDINATE TO GO WITH Y
   RETURN


7000 'SUBROUTINE TO FIND VERY FIRST SCAN WHERE HP(#,#) OCCURRED
  DDCC=C:NNM=C:BBB=Z
  FOR JJJ=1 TO VW
    DDCC=DDCC-1
    IF DDCC=0 THEN GOSUB 3010:RETURN 'BACK TO 3000
    FOR A=1 TO NUMWHT(DDCC)
      IF ((HP(DDCC,A)<=HP(NNM,BBB)+WNDOW) AND
        (HP(DDCC,A)>=HP(NNM,BBB)-WNDOW)) THEN JJJ=1:NNM=DDCC:
        C=DDCC:Z=A:BBB=A:GOTO 7005
    NEXT A
7005 NEXT JJJ
GOSUB 3010:RETURN 'GO BACK TO 3000 LOOP


8000 'SUBROUTINE TO DRAW ARC
```

```
 LOCATE 5,4:PRINT"O"
 LOCATE 23,2:PRINT DEG
 FOR Y= -140 TO 140   'DRAWS ARC IN PURPLE
   X=INT(-SQR(640^2-Y^2))
   PSET(X,Y),13
   NEXT Y

 LINE (-625,-140)-(0,0),13
 LINE (-625,140)-(0,0),13
 'PAINT (-600,0),8,13    'PAINTS ARC IN GRAY
RETURN
```

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