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Clinical evaluation and refinement of an ultrasonic bladder volume determination system

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CLINICAL EVALUATION AND REFINEMENT OF AN ULTRASONIC BLADDER VOLUME DETERMINATION SYSTEM

by

Phillip Joachim Charles Kruczkowski

A Thesis Submitted to the Faculty of the

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

In Partial Fulfillment of the Requirements
For the Degree of

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In the Graduate College

THE UNIVERSITY OF ARIZONA

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TABLE OF CONTENTS

TABLE OF CONTENTS--CONTINUED

Page

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS CONTINUED

LIST OF TABLES

ABSTRACT

An ultrasonic method to determine bladder volumes could help eliminate some of the risk and discomfort resulting from catheterizations. A system using "A" mode ultrasound correctly estimates bladder volumes to within 50 cc's. Near and far walls of bladder sections found at various positions define the bladder, and volumes calculated from these sections are added together for a bladder volume estimate. Accurate volume estimates (mean error of -1.9 cc.'s with standard deviation of 28 cc.'s) were obtained when bladder section characteristics such as: depth of the near wall of the bladder, thickness the far wall echo, distance between near and far bladder walls, and amplitude of the far bladder wall echo, were considered. Most bladders were completely scanned with the transducer placed at the bodies midline, approximately 5 to 7.5 cm. above the pubic bone.

CHAPTER 1

INTRODUCTION

Ultrasound has become an integral part of medical technology, and is used in a wide variety of medical applications ranging from imaging of fetuses to pulverizing of kidney stones. Ultrasound is particularly suited to aid in the study of the pathology of the urinary tract, because the signals received from a urine filled bladder are easily recognized. Ultrasound has been used to measure residual bladder volumes (urine left in the bladder after urination) by Gockel and Ermet and by Holmes (1967,1978). Management and diagnosis of disorders of the prostate and seminal glands are more easily accomplished by ultrasonic techniques than by conventional techniques (Resnick and Boyce). Studies of the bladder contour and urodynamics have also been done using ultrasound (Holmes 1971, Resnick and Boyce). Holmes (1978) mentions that a real-time, bedside ultrasonic system could probably be used in additional diagnostic situations such as renal clearance studies.

Currently, catheterizing patients is a standard procedure in the study of the pathology of the urinary tract, and consequently these patients run an increased risk of urinary tract infections. Patients who suffer from anuria (no urine output), oliguria (low urine output), tubular necrosis, outlet obstruction and emptying failure are susceptible to infections because decreased urinary flow increases the risk due to infection; catheterization only compounds the problems (Holmes 1978). Catheterization of patients receiving immunosuppressive drugs also increases their risk of contracting an infection (Holmes 1978). When ultrasound can be used in lieu of an invasive procedure, such as catheterization, the risks of infection are reduced. An ultrasonic system that determines bladder volumes could be used to decide when catheterizations are necessary to drain excessive residual urinary volumes.

Modes of Ultrasound for Bladder Volume Determination

There are several ways in which ultrasound can be employed in diagnostic instruments. The simplest method is known as "A" mode scan. The result is a one dimensional display of signals emanating from structures in the path of the ultrasonic wave. The transducer that emits the ultrasonic wave also receives the returning signals (echoes). The distance between two structures can be determined by relating the distance between their respective echoes. "A" mode scanning is most useful when echoes of different structures are easily recognizable from each other.

When echoes are not easily distinguishable "B" mode scanning is more useful. "B" mode scanning is two dimensional and can be used to create a picture of the structures being scanned. As a transducer position is changed the image of a surface can be reconstructed by noting the location of returning echoes and the position of the transducer when these echoes were recorded. When all the recorded echoes are shown side by side an image of the structure forms.

Other ultrasonic imaging techniques such as rapid "B" scan, time motion scan, stop-action scan and ultrasonic Doppler scan exist and are used in diagnostic equipment (McDicken,). However, "A" and "B" mode scanning are the primary ultrasonic techniques used for bladder volume determinations. Holmes (1967) and Gockel and Ermet(1977) used "B" mode scanningto approximate bladder volumes by assuming a spherical shape and calculating a volume. Holmes (1967) reported an accuracy of 18.7% for healthy subjects and 24.5% for patients, while Gockel and Ermet (1977) reported 10% accuracy.

Holmes (1978) also investigated a "B" scan "slice" method which used "B" mode imaging to divide the bladder into a set of planes or slices. Each image was traced with a planimeter, and a cross sectional area found and used in the volume calculation. A planimeter is an instrument that measures the area of a plane figure as a mechanically coupled pointer traverses the figure's perimeter.

"A" mode scanning can also be used to determine bladder volumes. An "A" scan directed through the bladder returns an echo from the near and far bladder walls. Knowing the distance between bladder walls and assuming a beam width for the "A" scan, allows calculation of the volume encompassed by the scan. Summing the volumes calculated for multiple "A" scans of bladder sections produces a total bladder volume. The "A" scan method for determining volumes requires little equipment and could easily be integrated into a portable system. Holmes (1978 pg. 353) noted that a portable ultrasonic bladder volume determining device would be of interest.

Results of Previous Studies

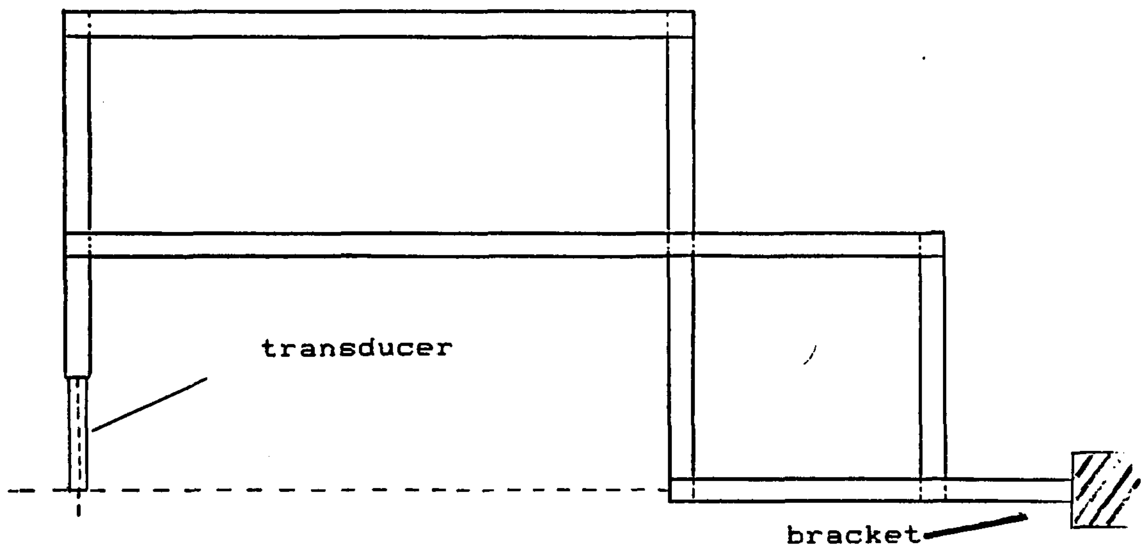
This thesis is a continuation of work on the development of a portable bladder volume determining system. This system uses "A" mode scanning to determine the near and far wall depths of multiple sections of the bladder. A volume is calculated for each near and far wall pair found. Total bladder volume is estimated by summing these individual volumes. The transducer is positioned by a pantograph; a Unirad Sono II ultrasonic examination bed is used to emit and receive the ultrasonic signals; these signals are digitized by an analog to digital converter and stored on a diskette; an Apple II plus personal computer controls the interactions of the equipment and stores the digitized data.

This project involved three previous investigators (McIntosh, 1982; Scott, 1983; and Wu, 1985). McIntosh answered questions concerning how bladder wall locations could be estimated from "A" scan echoes and how accurate the locations must be to obtain a reasonably accurate volume calculation.

Measurements accuracy was tested on a variety of materials including beef muscle and excised cow bladder. Target distances were estimated by threshold scanning. Threshold scanning is a technique that compares the received echo amplitude to a predetermined value. Accuracy of the distance measurements is degraded by the width of the ultrasonic beam and the length of the ultrasonic pulse. These errors increase systematically as the beam/target incident angle increases.

McIntosh studied several ways in which to perform ultrasonic bladder scans to ensure that all of the bladder would be covered, he determined that because of the location of the pubic bone either cylindrical or spheroidal geometry should be employed. With cylindrical geometry the transducer is positioned at one of the ends of an imaginary cylinder and a set of "A" scans is collected by rotating the transducer at right angles to the cylinder. The transducer is then moved toward the other end of the cylinder, and a set of "A" scans is collected at predetermined locations along the cylinder's length. Moving the transducer along the length of the cylinder takes time and creates coupling problems. With spheroidal scanning the transducer crystal is not moved from it's starting position, but the transducer is oriented at different angles to the surface of the object. McIntosh noted that spheroidal scanning is most susceptible to systematic errors such as noise and the assumed speed of ultrasonic transmission through tissue.

Scott investigated the problem of multiple reflections in ultrasonic "A" scans, and expanded McIntosh's work on a distance correction factor for varying incident angles. Multiple reflections occur, for example, when a returning echo is reflected off the transducer and travels back to the target creating another echo. This second echo occurs later in time and is most probably of smaller amplitude. He determined that with gain attenuation and low pass filtering, multiple reflections could be eliminated. Scott developed a correction factor which compensated for distance estimation errors arising from the ultrasonic beam width and pulse length noted by McIntosh. He also found that with incident angles greater than 50°, returning echoes were too attenuated to be detected by threshold techniques. Scott also developed a pantograph (Figure 1.1) to obtain scans using a spherical scanning geometry. The pantograph



PANTOGRAPH

FIGURE 1.1

positions the transducer crystal and allows the transducer crystal to remain in the same position as the pantograph rotates the transducer through the scanning angles.

Wu (1985) developed software to determine total bladder volumes. The software was based on a spherical coordinate scanning method. "A" scans were collected at 5° increments for a grid of 100° by 80°. Each "A" scan was tested for near and far bladder wall, and the distance between them was determined. This distance was used to calculate a volume for that particular "A" scan. Volumes of the individual "A" scans were summed to yield an estimate of total volume.

Goals of This Thesis

The main objectives of this thesis are to evaluate and refine the system previously studied and determine if it could be made simple and accurate enough to be used in a clinical setting. The following constraints were imposed on the system for use in the clinical setting:

1.) Instrumentation settings are preset so that operator/equipment interactions are minimal, that is a scan could be performed by turning the system on and running the controlling computer program.

2.) An easily located initial position of the transducer was used. This position was determined from pre-clinical data to be approximately 2 to 3 inches superior to the pubic bone, on the midline of the body.

These constraints were imposed to facilitate use by a non-technical operator in a quick and efficient manner. Without these constraints, a technically trained operator would be needed to correctly operate the electronics of the Unirad Sono II, the oscilloscope used to view the "A" scans and the computer used to control equipment interactions.

Data were collected in two phases, (non-clinical and clinical). Non-clinical subjects were healthy, with no known bladder problems. Data collected were used to establish parameters and guidelines to be used in the clinical setting. Clinical participants included symptomatic patients and asymptomatic subjects. Clinical patients were all diagnosed as having some form of bladder dysfunction. The data was collected in a clinical environment, as part of an urological examination for residual bladder volume. The patients were catheterized immediately following the scanning.

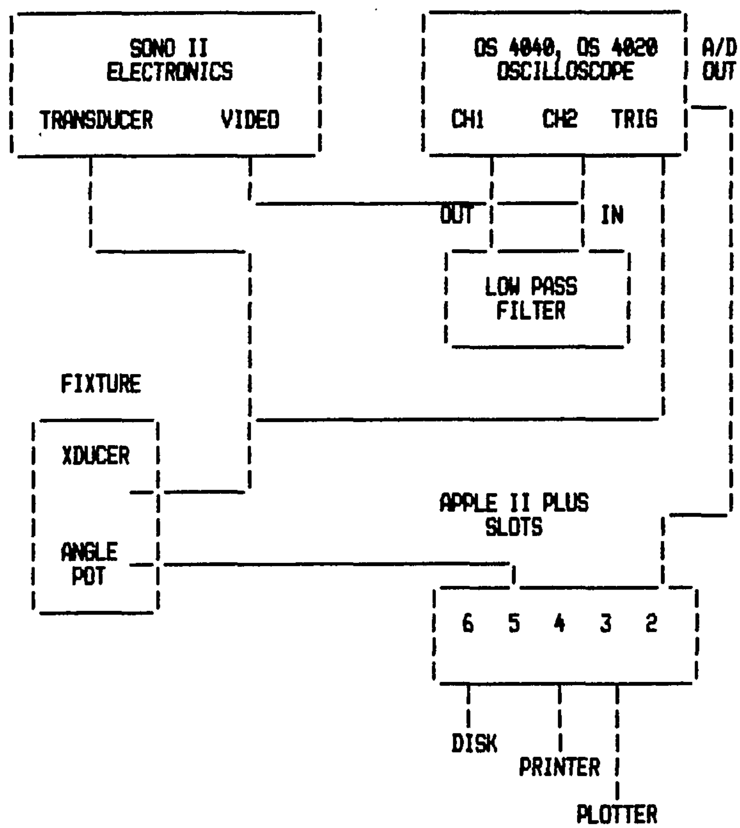
CHAPTER 2

SYSTEM DESCRIPTION

System Hardware

A block diagram of the system hardware is given in Figure 2.1. The basic system is composed of an Apple II plus personal computer, a Gould OS 4040 digital storage oscilloscope with a Model 4020 A/D converter, an Unirad Sono II ultrasonic scanning system, a pantograph with a position sensing potentiometer for tracking the incident angle, and a two pole low pass filter with a cutoff frequency of 200 Khz.

The Unirad Sono II provides a bed for the subject to lie on and the electronics necessary to pulse the transducer and receive and process the signal. The processing includes rectifying, filtering and amplifying the returning signals so that the echoes from the bladder walls may be distinguished from the rest of the signal. Amplifier gain can be djusted in steps of 10 db. or 1db., and is set to provide enough gain to allow deep echoes to be seen with some near echoes over amplified. The Unirad Sono II uses time gain control circuitry (TGC) to control the over amplification the nearer echoes.



SYSTEM BLOCK DIAGRAM

FIGURE 2.1

TGC is made up of three dirrerent gain controls known as: initial, delay, and slope. The initial control setting determines the amount of initial gain the amplifiers have immediately after the transducer is pulsed. The slope setting allows the rate of gain change with time to be adjusted to compensate for the attenuation. The delay control adjusts the amount of time that the initial gain is maintained. An additional control, named reject, aids in eliminating spurious signals (noise) combined with the signal of interest. This is accomplished by attenuating smaller echoes to a much greater degree than larger echoes. Appendix B contains all the control settings used in the study.

The electrical impulses used to create the ultrasonic pulses emitted from the transducer originate in the Unirad Sono II and can be generated from 385 to 1538 times per second. The electrical stimulus is a 90 volt pulse that is approximately 1.5 µs in duration. For our experiments the highest frequency rate was used.

The transducer is a piezoelectric crystal made of lead zerconate titanate, it is 13 mm in diameter and has a frequency of 2.25 Mhz. Each ultrasonic pulse contains approximately 17.5 mw/cm^2 of acoustic power.

A returning echo is converted to an electrical signal which is amplified, rectified, filtered, digitally sampled and stored. The rectified signal is referred to as the video signal and is low pass filtered at 200 Khz. The output of the filter is fed to the Gould OS 4040 digital oscilloscope where the model OS 4020 A/D converter samples the "A" scan and records 5120 samples. The bladder echoes are encompassed within the first 128 samples, which are transferred to the computer memory. Each sample requires one byte of storage (128 bytes per "A" scan), and 20 "A" scans are sampled and stored in the computer before the controlling program transfers the data on to diskette.

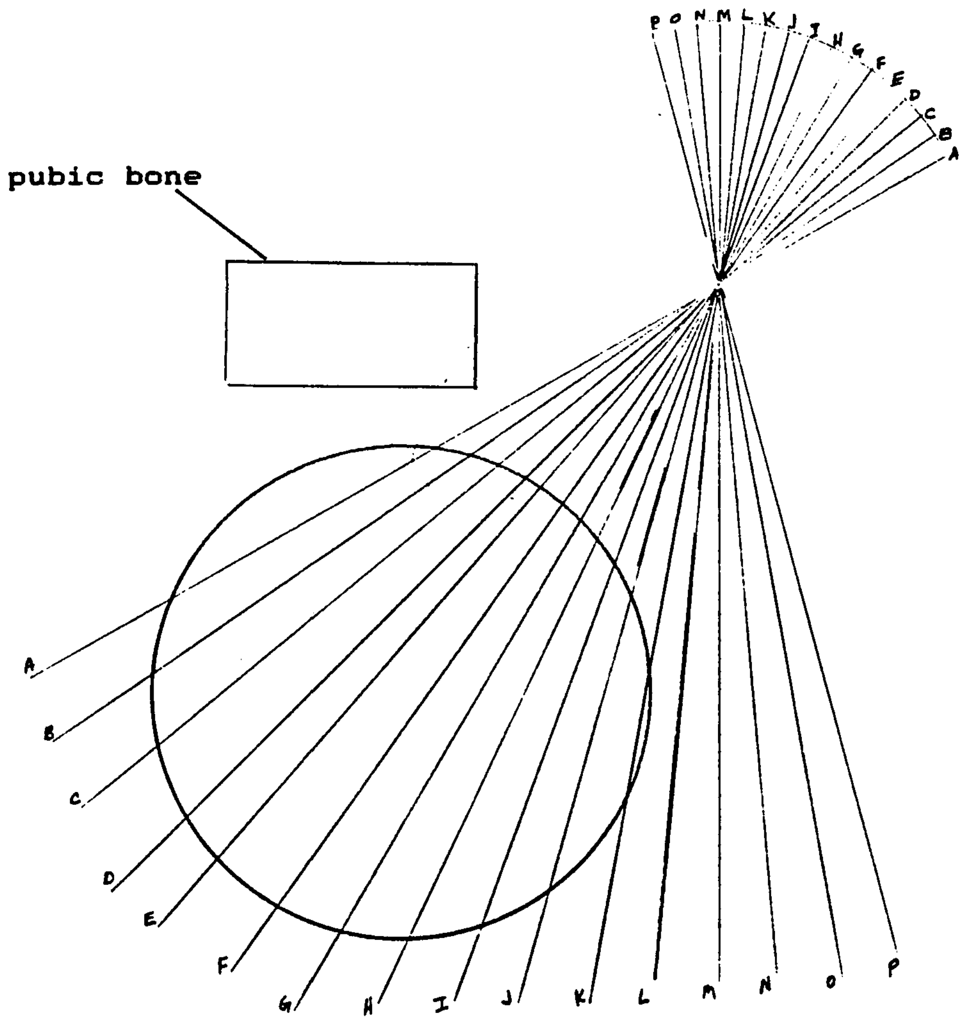
The pantograph is used to position the transducer at the origin of a spherical coordinate system. The pantograph allows the center of the transducer's face to remain in the same position through out the duration of the scan; only the orientation of the transducer's face changes. Figure 2.2 is an illustration of the orientations of the transducer in the longitudinal plane. At each position the pantograph and transducer are moved laterally through a 100° angle producing what will be referred to as a "slice". Figure 2.3 illustrates the positions in which the 20 "A" scans are collected. An "A" scan is recorded every 5°. After the 20 "A" scans are recorded and stored on the diskette, the transducer is moved to the next vertical orientation position; this is also a 5° change in position. Sixteen different vertical positions are used (16 x 5° =

80°) as illustrated by Figure 2.2. Note that this procedure covers the grid of 100° by 80°.

In addition to digitizing and acting as a temporary storage location, the Gould OS 4040 oscilloscope allows each scan to be viewed. This allows the operator to locate the bladder and ensure that the scan will completely encompass it.

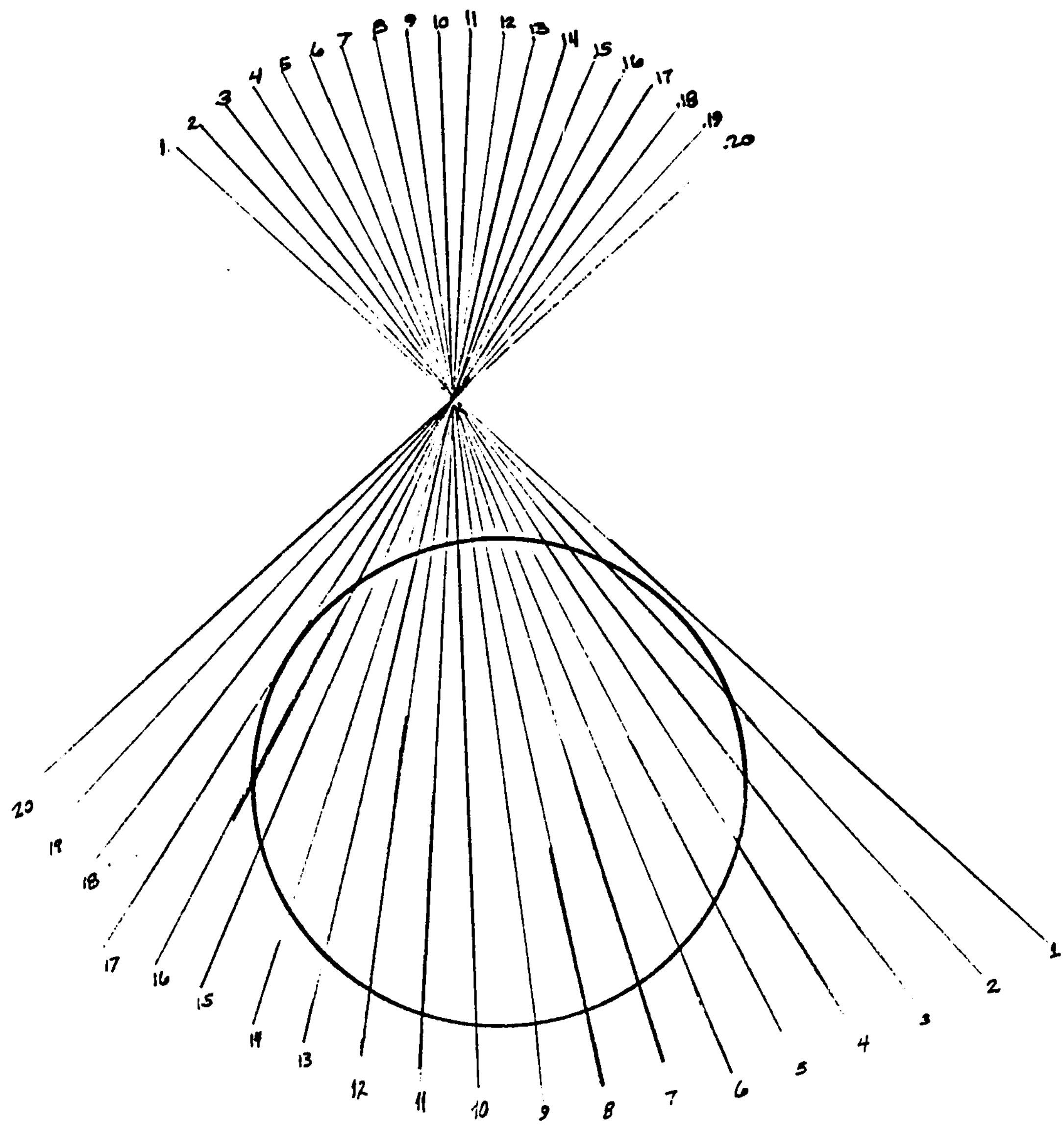
The Apple II plus personal computer is used to control the procedure and store the data. It is equipped with a California Systems parallel interface board, an A/D board, a parallel interface board for the printer, a diskette controller board, and 64K bytes of memory. The computer also determines when a new "A" scan should be collected by monitoring the output of a potentiometer mounted on the pantograph. When the output has increased by a set amount the computer recognizes this as a 5° change of transducer alignment.

The pantograph is manipulated by two different sets of gears. One set raises and lowers the pantograph above the abdomen, the other system of gears moves the pantograph through its longitudinal angles. During a scanning procedure the pantograph is moved in 5° increments to reorient the transducer. This is accomplished by rotating a crank 360° (see Figure 2.4).



IDEALIZATION OF THE TRANSDUCER
FACE ORIENTATION ANGLES

FIGURE 2.2



IDEALIZATION OF THE "A" SCAN COLLECTION
LOCATIONS, SPACED EVERY 5°

FIGURE 2.3

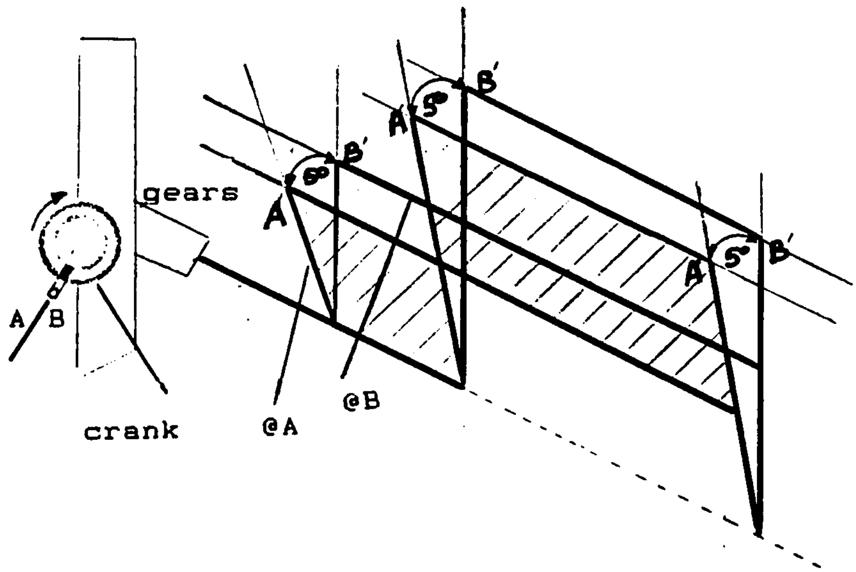
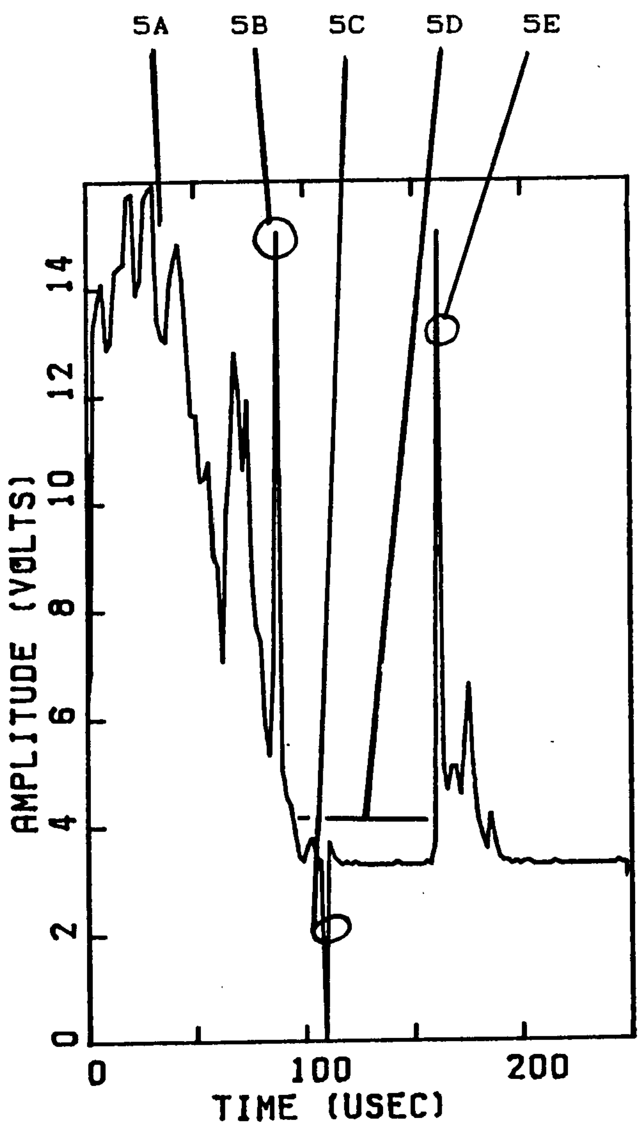


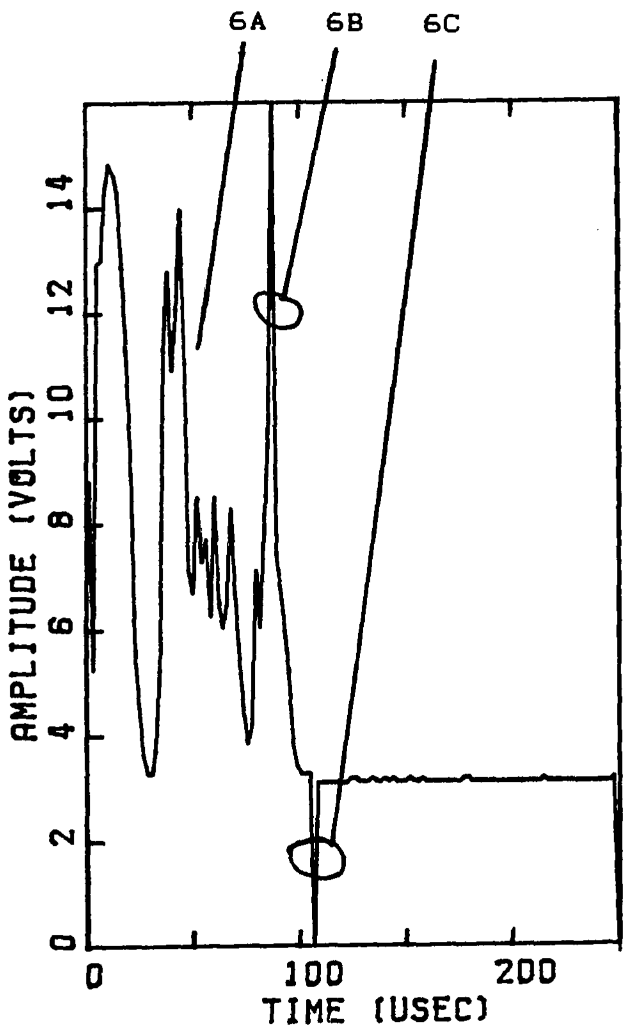
ILLUSTRATION OF THE PANTOGRAPH
POSITIONING CONTROL

FIGURE 2.4



TYPICAL "A" SCAN OF A
BLADDER SECTION

FIGURE 2.5



TYPICAL "A" SCAN OF AN
ABDOMINAL REGION

FIGURE 2.6

"A" Scan Profiles"

Figure 2.5 is an example of an "A" scan containing ultrasonic echoes from a bladder section. The portion of Figure 2.5 labeled 5A are the echoes from the skin and outer tissue layers of the abdomen. Note that the echo amplitude decreases along the time axis. The peak labeled 5B and the steep valley labeled 5C are inserted by a computer program to indicate certain characteristics of the received echos. 5D corresponds to the urine filled region of the bladder where no echoes are returned. 5E indicates the ultrasonic echoes from the far wall of the bladder.

Figure 2.6 is a typical "A" scan without a bladder section. The labels 6A, 6B, and 6C are analogous to labels 5A, 5B, and 5C of Figure 2.5.

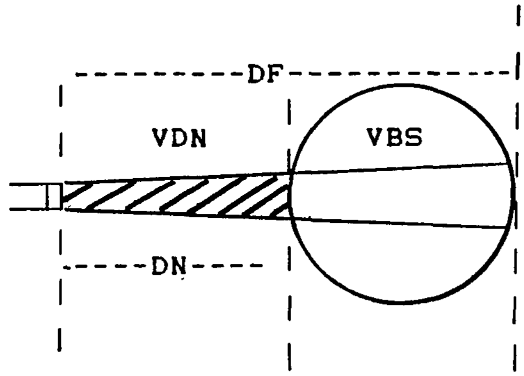
The peaks and valleys, referred to above, are created by the computer program that inspects each "A" scan for a bladder section. The flags labeled 5B and 6B mark positions chosen by the program to represent the near wall of the bladder. The computer has selected positions 5C and 6C to represent the end of the smallest allowable urine filled bladder. The computer marked the position labeled 5E to indicate the peak of a far wall. No bladder was found in Figure 2.6.

Digital Sampling of "A" Scans

When an "A" scan is received by the system it is sent to the oscilloscope to be displayed and also to be digitally sampled at a rate of 500Khz (1 sample every 2 µs.). 128 samples are sufficient to encompass an "A" scan of the bladder, and with an assumed ultrasonic transmission speed of 1545 m/s the 128th sample represents a distance of 39.55 cm. Since this represents the distance to and from the reflecting target the actual distance to the farthest target is about 19.8 cm. For the purposes of this research only the distance to the target is of interest; which is one-half the assumed speed of ultrasonic transmission (.1545 cm/µs) multiplied by the time required for the ultrasonic wave to travel to and return from the reflecting surface.

Volume Calculations

A volume for the "A" scan may be calculated if a far bladder wall is found. The volume is considered to be the difference between two imaginary pyramids formed when a divergent ultrasonic wave encounters a volume. The larger of the pyramids will have a height equal to the depth of the far wall of the bladder; the smaller has a height equal to the depth of the near wall of the bladder. Figure 2.7 is an illustration of this simplification.



VBS = VDF - VDN

DF: Distance to the Far wall
DN: Distance to the Near wall
VBS: Volume of the Bladder Section between the Far and Near walls.
VDF: Volume of larger pyramid.
VDN: Volume of small pyramid.

Figure 2.7

The depth of a reflecting surface can be calculated for any sample by:

$$D = Vs * T/2 \tag{2.3}$$

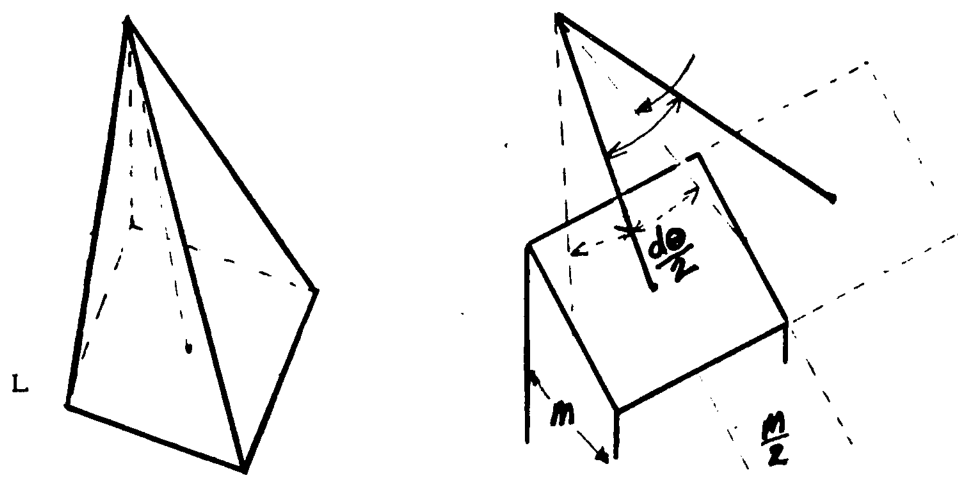
D: depth of the sample in question
T: value along the time axis corresponding to the sample in question.
Vs: the estimated velocity of ultrasound through the tissue (approximately 1545 m/s)

The volume formula for a pyramid is (Figure. 2.8):

$$Vp = 1/3*H*A \tag{2.5}$$

H: height or the pyramid in Figure 2.8a
A: surface area in Figure 2.8b

$$A = [2*L* SIN\ (\theta/2)]^2 \tag{2.6}$$



A = surface area

$SIN(d\theta/2) = opp/adj$
$= (m/2)*(1/L)$
$= (m/2L)$

$m = 2L \sin (d\theta/2)^2$

$A = m^2$
$= (2L \sin (d\theta/2)^2)^2$

Figure 2.8

A bladder section volume is calculated to be:

$$VBS = (1/3)*DF*A_{fw} - (1/3)*DN*A_{nw} \tag{2.7}$$

DF: distance to the far wall
DN: distance to the near wall
A_{fw}: area of the base of the larger pyramid
A_{nw}: area of the base of the smaller pyramid

Combining equations 2.6 and 2.7 yields:

$$= (1/3)*DF*[2 * DF * SIN(d\theta/2)]^2 -$$

$$(1/3)*DN*[2 * DN * SIN(d\theta/2)] \qquad (2.8)$$

DF: distance to the far wall
DN: distance to the near wall
dθ: the angle increment between transducer scanning positions

By collecting the 320 "A" scans, (total "A" scans over the 100° by 80° grid), calculating and summing the volumes for bladder sections, a total volume is found.

The total volume is given by:

$$V_t = \Sigma\Sigma\ (DF^3 - DN^3) * (((4/3) * SIN\ \ (d\theta/2))^2 \qquad (2.9)$$

DF: distance to the far wall
DN: distance to the near wall
dθ: the angle increment between transducer scanning positions

<u>Software Overview</u>

The system is controlled by a computer program named PSCAN. PSCAN keeps track of the horizontal angle of the pantograph, collects and stores sampled "A" scans at every 5° increment of a slice, and tells the operator when all 16 slices have been collected. PSCAN is written in Basic and calls three subroutines (written in 6502 Assembly language), PACKSCAN, PEAKDET, and NEWVOLUME. Figure 2.9 is a flow chart of PSCAN.

PACKSCAN monitors the angle of incidence and communicates with the Gould OS 4040 oscilloscope. It directs the scope to sample a scan and record the first 128 samples. It then moves the data to computer memory (starting at address 5000H).

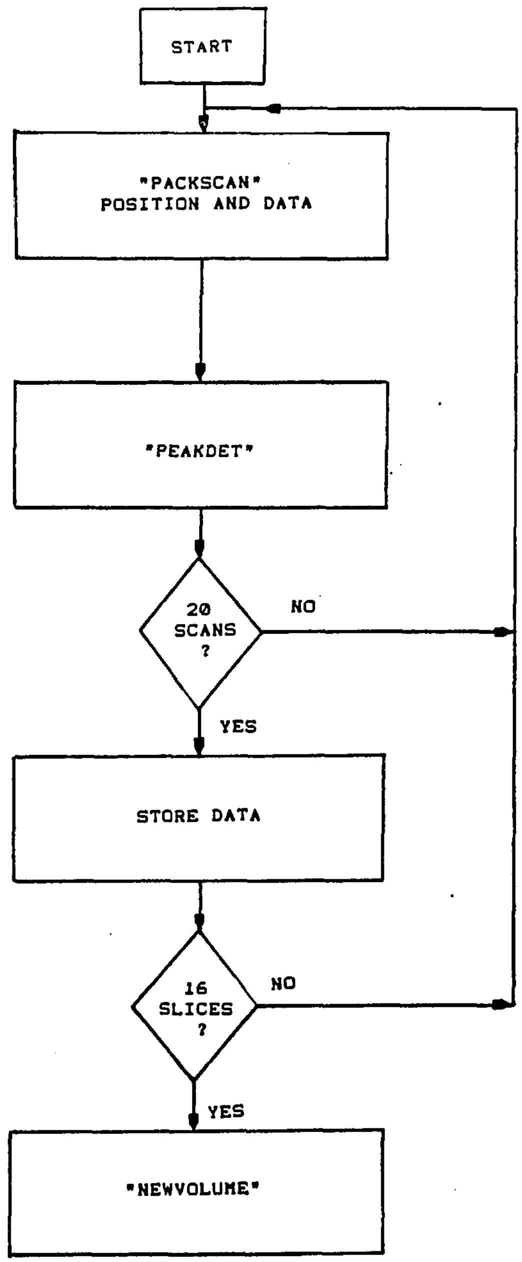
PEAKDET determines if an "A" scan includes a bladder section, and if so, determines and stores the near and far wall locations (these locations are also stored into memory starting at address 8000H). PSCAN then repeats PACKSCAN and PEAKDET until a slice has been collected. After all 320 "A" scans are collected, NEWVOLUME calculates a total volume from the stored front and far wall locations. This volume is then displayed on the screen.

Data Storage

Due to the memory limitations of the Apple II plus and the fact that the diskettes for the system are single sided a data compacting algorithm was implemented. This enables three complete sets of data to be stored on a diskette with each set filling 10 of 34 available tracks.

Technical Description of PEAKDET

PEAKDET chooses the near and far bladder wall locations and selects the urine filled region (flat region) by comparing data signal amplitude to various threshold values. Figure 2.10 is the flow chart of PEAKDET.



FLOW CHART OF PSCAN

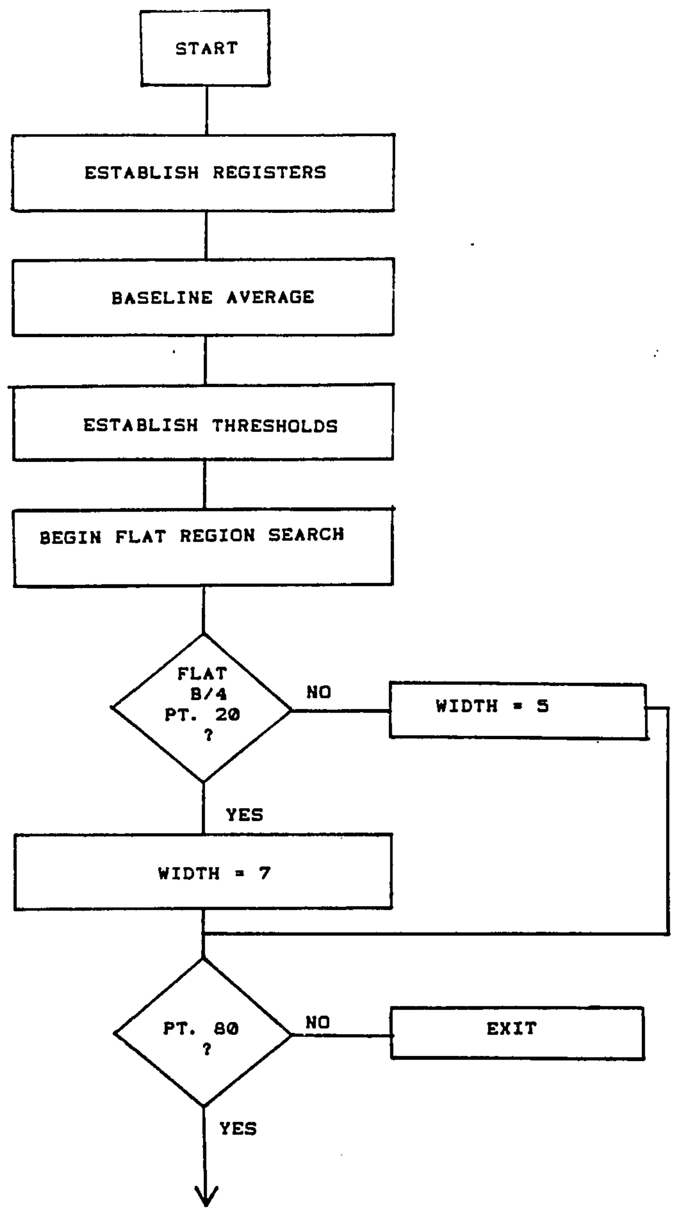
FIGURE 2.9

PEAKDET determines, for each "A" scan, a reference value which aids in finding the wall locations and the urine filled region. The reference value is calculated for each "A" scan so that offset voltages between "A" scans will have no effect. The reference value is the average of the last 8 bytes of data rounded off to the nearest integer (ie. 10.4 = 10; 10.6 = 11).

The reference is increased to establish thresholds. The threshold used to determine the flat region and the far bladder wall is the reference value plus seven; the threshold of the near bladder wall is the reference value plus 21 (15 Hex).

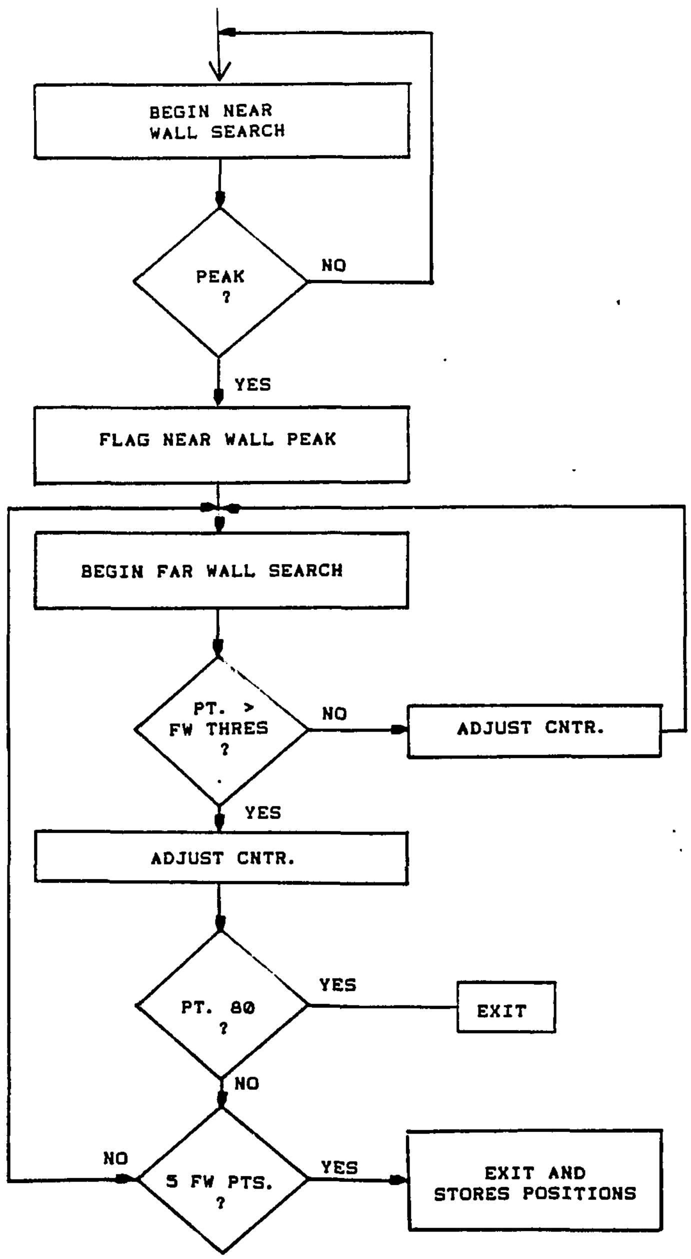
The flat region is the first bladder characteristic to be searched for. The search for the flat region begins at sample 16; there are two reasons for this. First, a false bladder (characteristic gap) occurs directly after the initial pulse on some of the subjects. This appears as a valid near wall, flat region, far wall, see Figure 2.11. Any flat region found prior to location 16 indicates the bladder is within 2.5 cm. of the surface. This is not reasonable except on very thin persons with full bladders.

Noise signals are combined with the signals of interest and for this reason the computer uses the following logic to determine when a valid flat region has been located. Any sample below the flat threshold (flat sample)



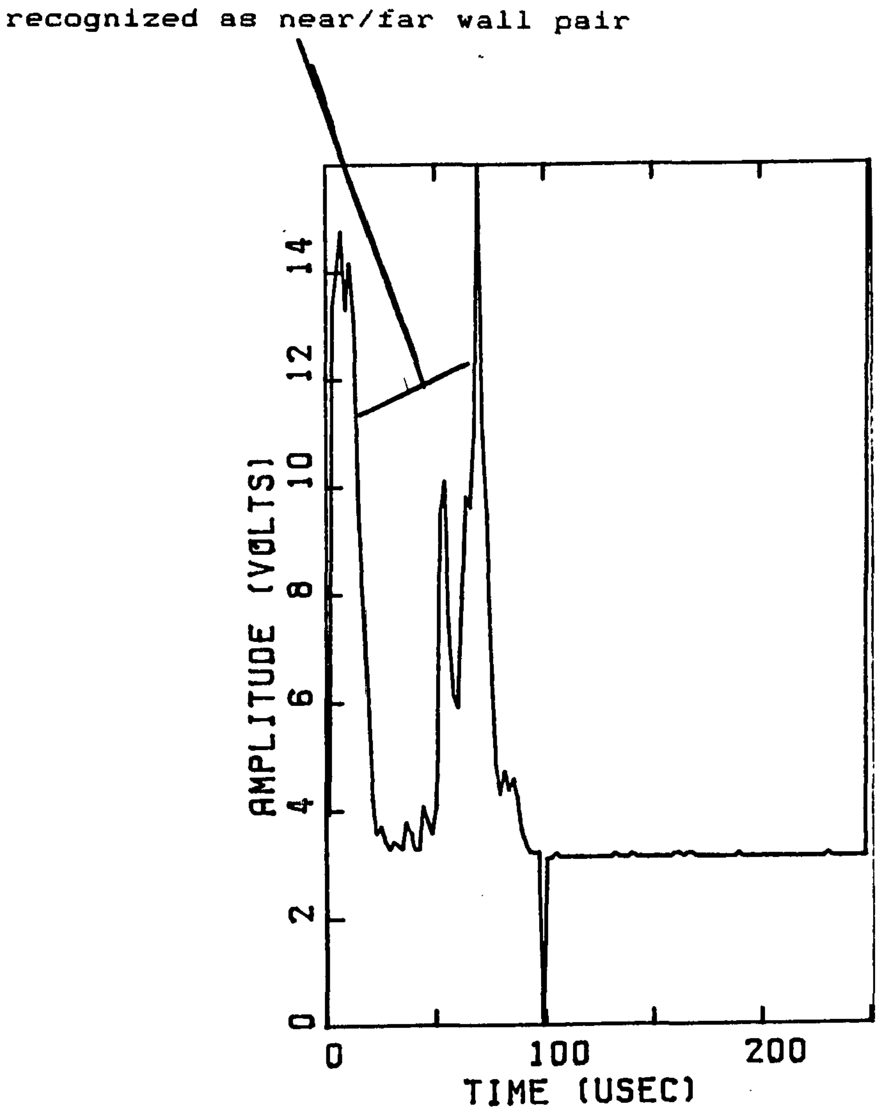
FLOW CHART OF PEAKDET

FIGURE 2.10



FLOW CHART OF PEAKDET
CONTINUED

FIGURE 2.10



"A" SCAN SHOWING THE
CHARACTERISTIC GAP

FIGURE 2.11

is considered the start of the flat region. A flat region consists of 5 samples below the flat threshold with the following considerations. If a sequential sample is above the flat threshold (noise) the next flat sample is not counted (Figure 2.12a)

When two sequential noise samples are found the flat sample counter decrements by one (Figure 2.12b). If three noise samples in sequence are found the counter is reset, ie. the search begins again (Figure 2.12c). When five flat samples are found the ending sample location is "flagged" by storing a value equal to zero into it, creating the steep valley shown in Figures 2.5 and 2.6.

The search for the flat region continues to sample 80 which is the sample of a signal approximately 5.85 inches deep. If the flat region is not found, another "A" scan is then checked. The search for the near wall is carried out after the flat region is found. The near wall is chosen as the first peak found immediately before the flat region having at least two samples above the near wall threshold. The near wall algorithm begins its search at the sample immediately before the flat region, and compares the preceding data to the near wall threshold. Figures 2.13 a,b show an invalid and valid near wall respectively.

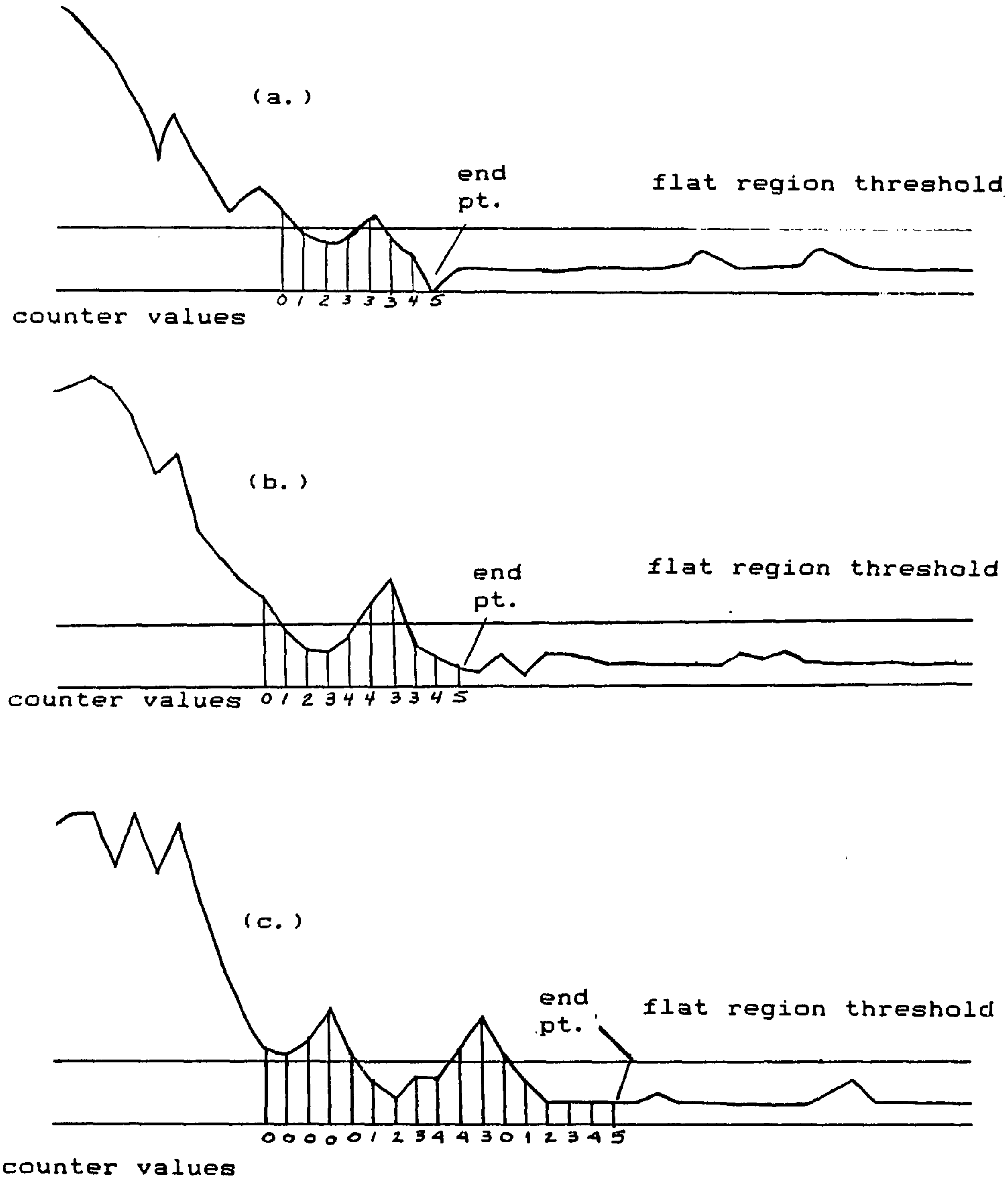


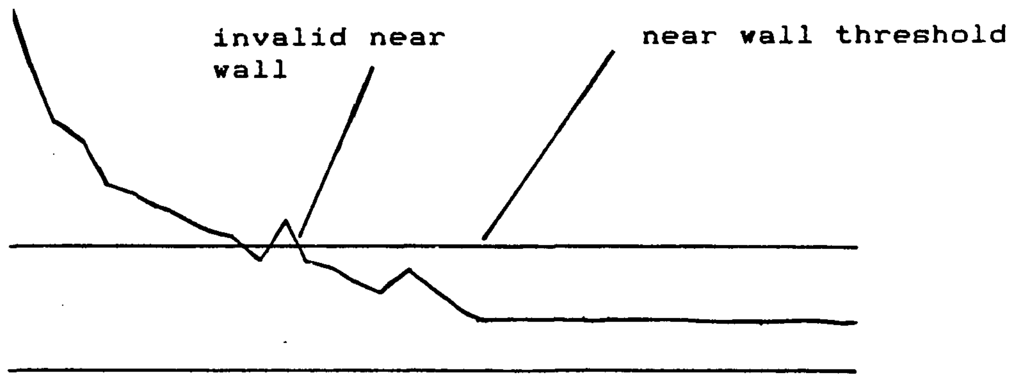
ILLUSTRATION OF THE NOISE SELECTION CRITERIA FOR
a.) 1 NOISE SAMPLE, b.) 2 NOISE SAMPLES, AND 3 NOISE SAMPLES

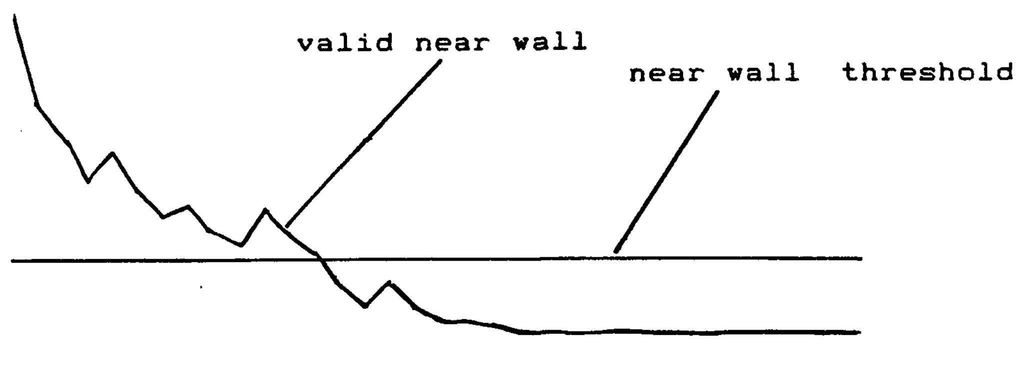
FIGURE 2.12A

After the near wall is found the program sets the location to maximum creating a marker peak and begins the search for the far wall.

The far wall algorithm selects the largest sample of the far wall region to be the far wall location. The far wall region is composed of at least 5 samples above the flat region threshold. The far wall algorithm begins it's search at the sample immediately following the flat region. Each sample is compared to the flat region threshold and when the first valid far wall sample is found it's location is recorded; the search continues for the rest of the far wall region samples. When the far wall region is found the largest of the samples in the region is chosen as the back wall location. A value of FF Hex. is stored in it's location to mark the far wall.

Noise in the far wall region is treated similarly to the flat region noise. One or two samples below the flat region threshold will cause the far wall counter to decrement by one or two respectively, see Figure 2.14. Three samples below the threshold will cause the far wall search to start again from the present location; all counters are reset. If a suitable far wall is not found no volume will





ILLUSTRATIONS OF THE NEAR WALL
SELECTION PROCESS

FIGURE 2.13

be calculated for that "A" scan. The next "A" scan is fetched and the procedure continues until all 20 "A" scans of a slice are checked. Once a slice is collected and PEAKDET searches through each "A" scan, the data is stored on a diskette and the 20 scans of the next slice are collected. This procedure is repeated until all 16 slices are collected, analyzed, and stored. There is storage space enough for three entire bladder scans per diskette. The storage location is specified by the system operator. See Appendix C for a description of how the data is stored onto the diskettes.

Other Subroutines

After all 320 "A" scans (16 slices) have been analyzed, program PSCAN calls subroutine NEWVOLUME. NEWVOLUME uses the near and far wall location pairs (stored from 8000H through 827FH) to calculate and display the total bladder volume. NEWVOLUME is the programmed equivalent of equation 2.11. The volume is then displayed.

A post processing algorithm, POSTPROC, was created to fill in and eliminate data that, judging by their neighboring data, seem to be misrepresented, (see data labeled "E" in Figures 2.15 and 2.16). POSTPROC cannot discern between groups of data as can be seen from the groups of data labeled "D" of Figures # 2.15 and 2.16. Figure 2.15 shows the data before POSTPROC and Figure # 2.16

shows the data after POSTPROC.

POSTPROC searches for empty data locations and fills them with the average of their neighboring data. first each slice (column) is checked for the absence of a bladder section (empty data location) having two data filled neighbors (samples where bladder was found) on one side (in the same slice), and at least one additional neighbor on the other side, (compare Figures # 2.15 and 2.16 position A). If such a location is found it will be given the value of the average of data on either side of it. Next, after each slice is checked, POSTPROC checks empty data samples in every row for at least two non empty neighbors on one side (in the same row), and at least one non-empty neighbor on it's other side, (compare Figures # 2.15 and 2.16 position B). If such a location is found it will be given the values of the average of data on either side of it. POSTPROC now checks each empty data entry for three neighbors on three of it's four sides. If the data entry is on the boundary of the grid only the three neighboring sides are checked, (compare Figures # 2.15 and 2.16, with positions labeled C). If such a position is found it will be given the values of the average of data on the two opposite sides of it. A new bladder volume is calculated with the post processed values.

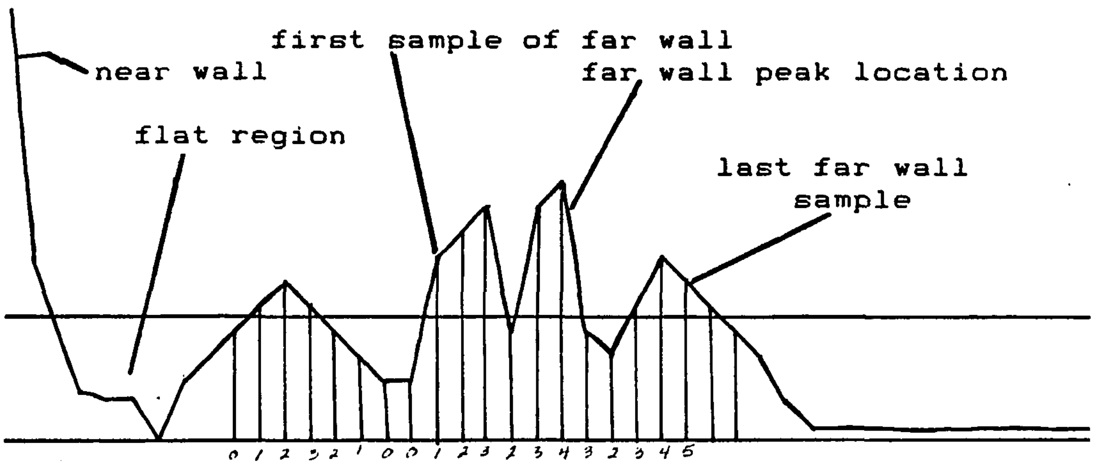
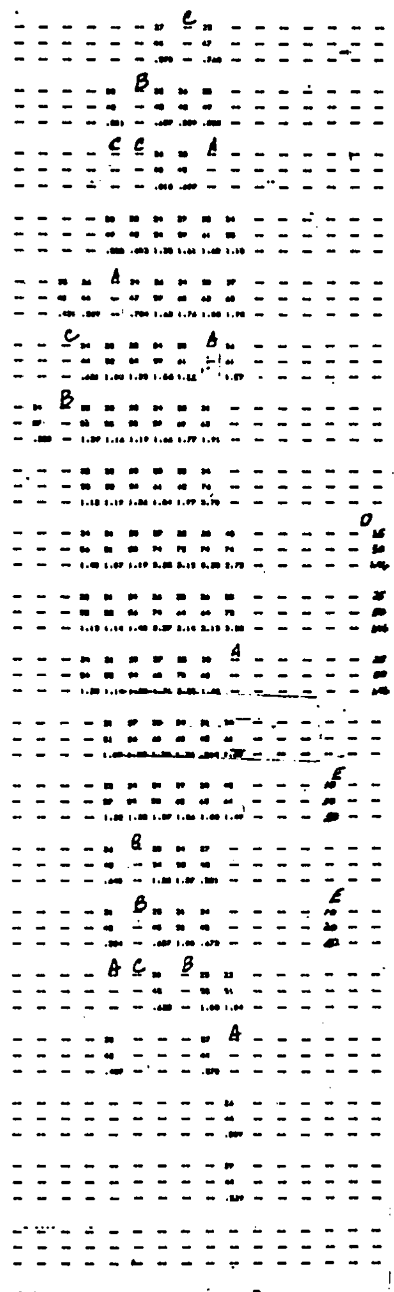


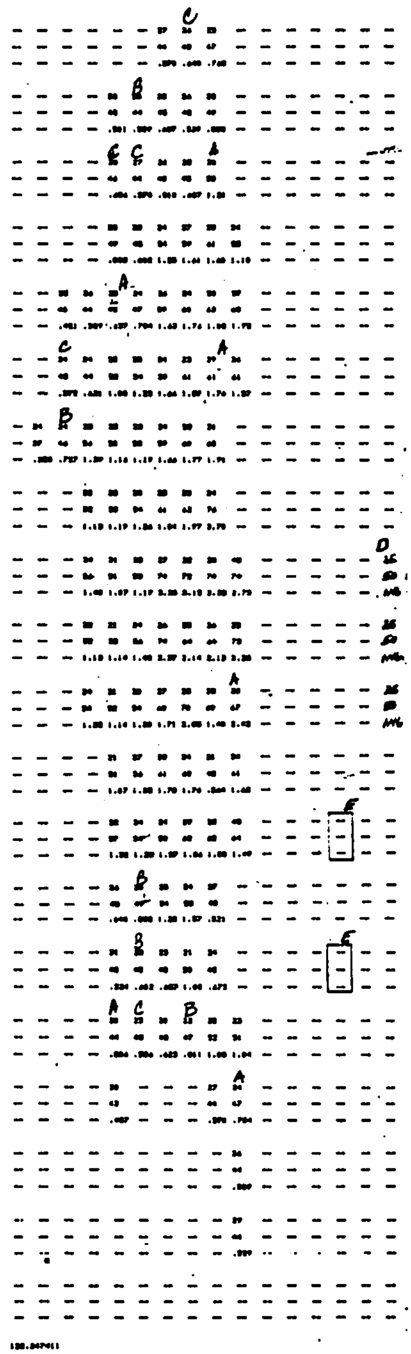
ILLUSTRATION OF THE FAR WALL
SELECTION CRITERIA

FIGURE 2.14



BEFORE POST PROCESSING

FIGURE 2.15



FIBYFIS AFTER POST PROCESSING

FIGURE 2.16

Program FIBYFI5 prints out the stored near wall, far wall pairs and their volumes. Figures 2.15 and 2.16 are reductions of the product of FIBYFI5.

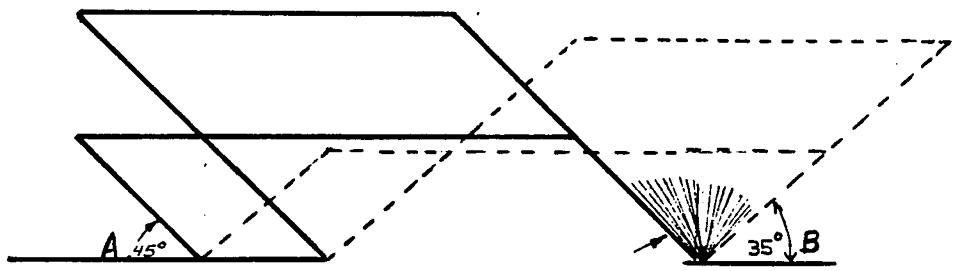
CHAPTER 3

EXPERIMENTAL PROCEDURES AND RESULTS

Two different data collection procedures were used. The first procedure, referred to as the non-clinical procedure, was primarily concerned with collecting and interpreting bladder scans, and determining an optimum starting scan position. The second procedure, referred to as the clinical procedure, allowed evaluation of the effectiveness of the system in an actual clinical environment. The system and software were modified as necessary to improve the accuracy. The electronic gain control settings were not changed during either procedure, but were different for the two procedures. Settings used in the clinical procedure are given in Appendix B.

Non-Clinical Procedure

30 subjects ranging in age from 23 to 50, and in good general health were scanned. The subjects were requested to refrain from urinating for at least one hour before the scanning. With the subjects on the examination table, the transducer was positioned and coupled to the skin with ultrasonic jelly placed over the abdomen. Scans were



positions at which
"A" scans are collected
as the Pantograph moves
from A to B

ILLUSTRATIONS OF THE MAXIMUM TRANSVERSE
ANGLES ATTAINED BY THE PANTOGRAPH

FIGURE 3.1a

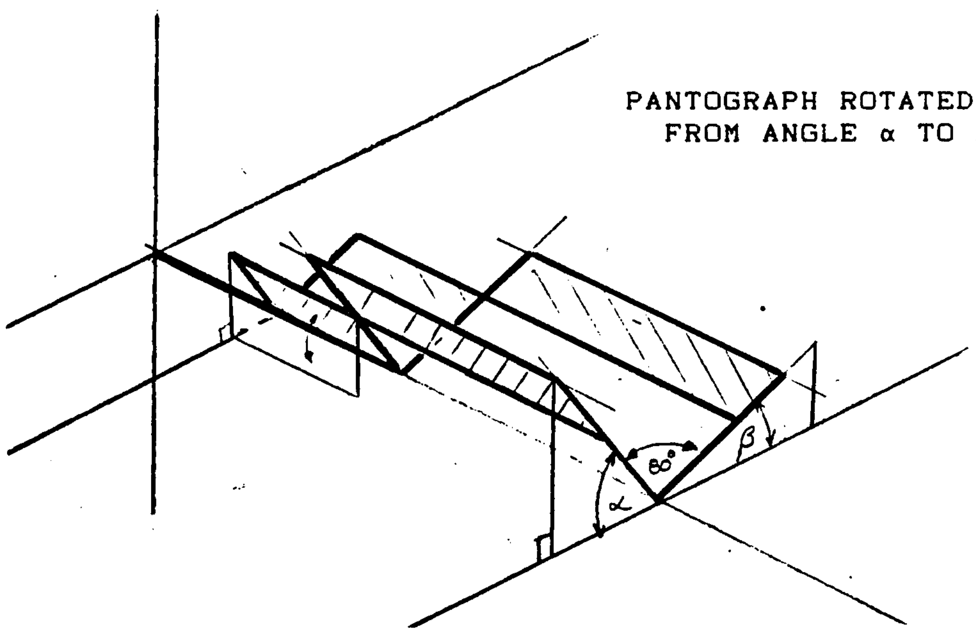


ILLUSTRATION OF THE MAXIMUM LONGITUDINAL
ANGLES ATTAINED BY THE PANTOGRAPH

FIGURE 3.1B

viewed on the oscilloscope screen and the transducer was moved through its extreme angles to ensure that the entire bladder was covered, see Figure # 3.1 a,b. If part of the bladder were not covered, the transducer was repositioned. When a starting location was selected, distances from the pubic bone and from the illiac spine were recorded to aid in determining the optimum a starting position. Data was collected using program PSCAN. The pantograph was moved laterally and one slice (20 "A" scans) was collected, sampled, and stored to computer memory. Data was transferred onto the diskette and a beeper sounded indicating that the pantograph could be moved 5° in the longitudinal direction for the next scan. The 5° shift was accomplished by one rotation of the small crank, see Figure 2.8. Usually, three scans were collected on each subject.

Transducer placement was varied from scan to scan on some subjects, but remained in the same location for other subjects. At the completion of the first scan the operator ran program FIBYFI5 to ensure all or most of the bladder was covered. If a large portion was missed the transducer would be repositioned and the scan repeated.

Non-Clinical Results

The optimum starting transducer location was determined to be midline of the body two to three inches superior to the pubic bone. For large bladder volumes, the entire bladder may not have been entirely covered.

The majority of calculated non-clinical data volumes were found to be greater than their measured volumes (mean error of 20.35 cc.'s with a standard deviation of 17.46) . Volumes of scans collected on the same subject, one after another, showed large variations in the calculated volumes, Figure 3.2 is a plot of ten such sets. The mean errors of the sets of data plotted in Figure 3.2 range from 25.7 to -20.3 cc.'s, the averages for the mean errors and standard deviations are 8.6 and 17.7 cc.'s respectively.

Clinical Procedure

Twenty one symptomatic patients and ten asymptomatic subjects were scanned in the clinical setting. Patients were scanned for residual urine after a PEAK-O-METER exam (which measures urinary flow rates) was performed . After the scanning was completed the patients were catheterized to determine the volume retained, if any. The scanning procedure for data collected in the clinical setting was essentially the same procedure used for non-clinical data collection. The number of scans collected from asymptomatic subjects in the clinical setting varied.

All subjects were asked to lie on the examination table with their abdomens exposed. The examination table was moved about so the transducer was directly above the midline of the body, 2 to 3 inches superior to the pubic bone. This location was determined to be the optimum starting position in the non-clinical work. Jelly was placed on the abdomen and the transducer lowered on to the skin. The transducer was moved to a position approximately 10 to 15 degrees from perpendicular. The pantograph was moved to its maximum transverse angles, (see Figure # 3.1a), and the oscilloscope was watched to assure that the starting position did not need be relocated to cover most of the bladder. The transducer was also moved through the longitudinal angle range to check for a bladder section volume. The starting position never needed to be changed. If no bladder section volumes were present, it was assumed that the total volume was small and the procedure continued. The transducer was then moved to a position approximately 50 to 60 degrees from perpendicular. Program PSCAN was started and the scanning proceeded. The length of time needed to complete the collection of the 16 slices was approximately 2.5 minutes. The transducer was removed at the completion of the scanning, the patients were catheterized, and asymptomatic subjects were asked to urinate into a graduated cylinder, which took approximately two minutes.

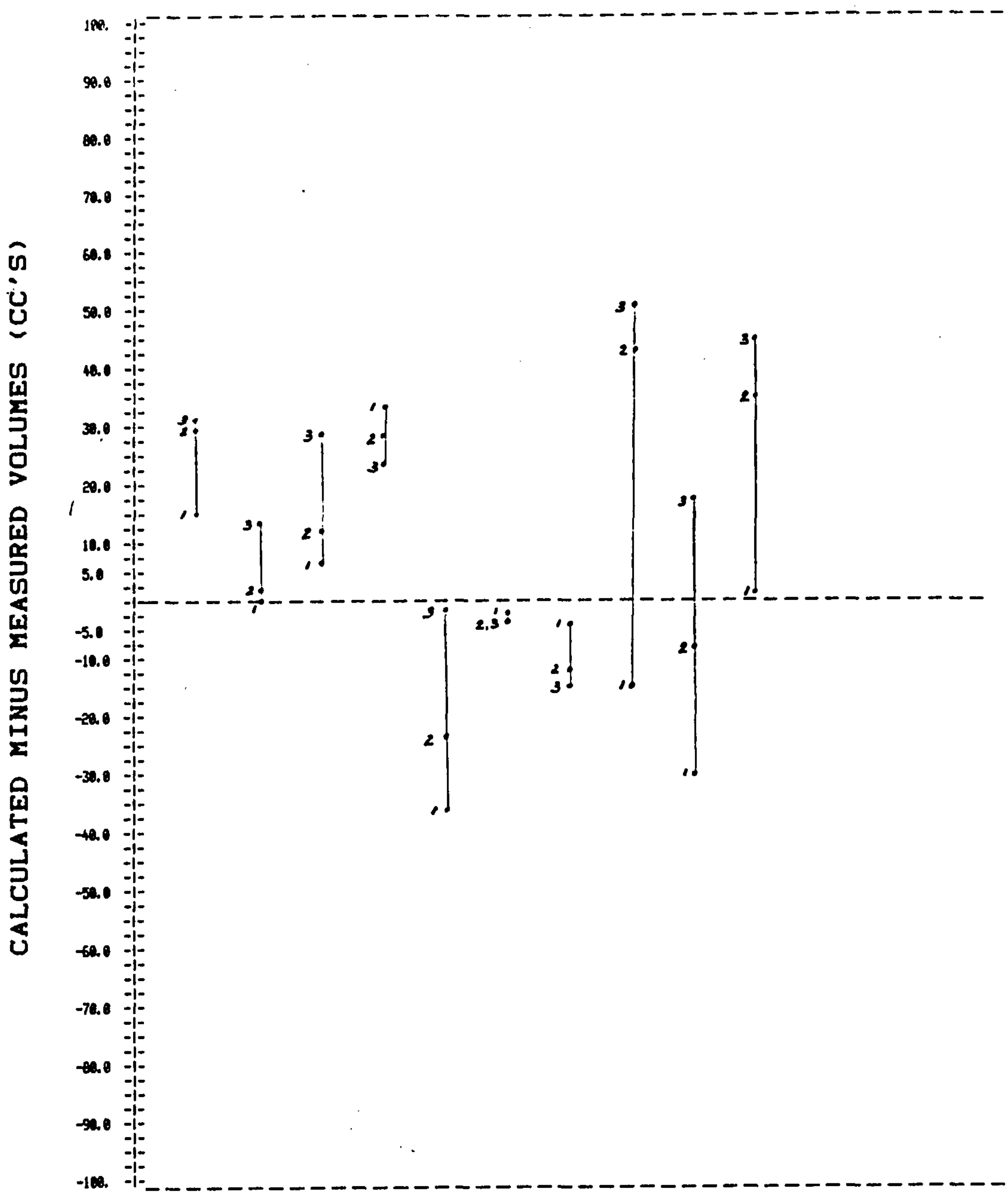
Patients were catheterized and asymptomatic subjects were asked to urinate into a graduated cylinder.

Clinical Results

Figure 3.3 is a graph containing the clinical study data; Figure 3.4 is a graph of the same data after post-processing; Figure 3.5 is a graph containing the clinical study data calculated by the original PEAKDET algorithm. The necessity to modify the original PEAKDET algorithm was apparent when it failed to find bladder volumes and severely underestimated the bladder volumes for several of the symptomatic subjects. The mean error of the estimated volumes for the symptomatic subjects was found to be -20.24 cc.'s with a standard deviation of 39.3 cc.'s, for the asymptomatic subjects the mean error was found to be -17.36 cc.'s. The error was improved for symptomatic and asymptomatic subjects to 4.7 and 1.29 cc.'s respectively when the final algorithm and post processing were used. Note that the majority of clinical volumes calculated shown in Figure 3.4 are below their measured volumes while the majority of pre-clinical volumes calculated are above their measured volumes.

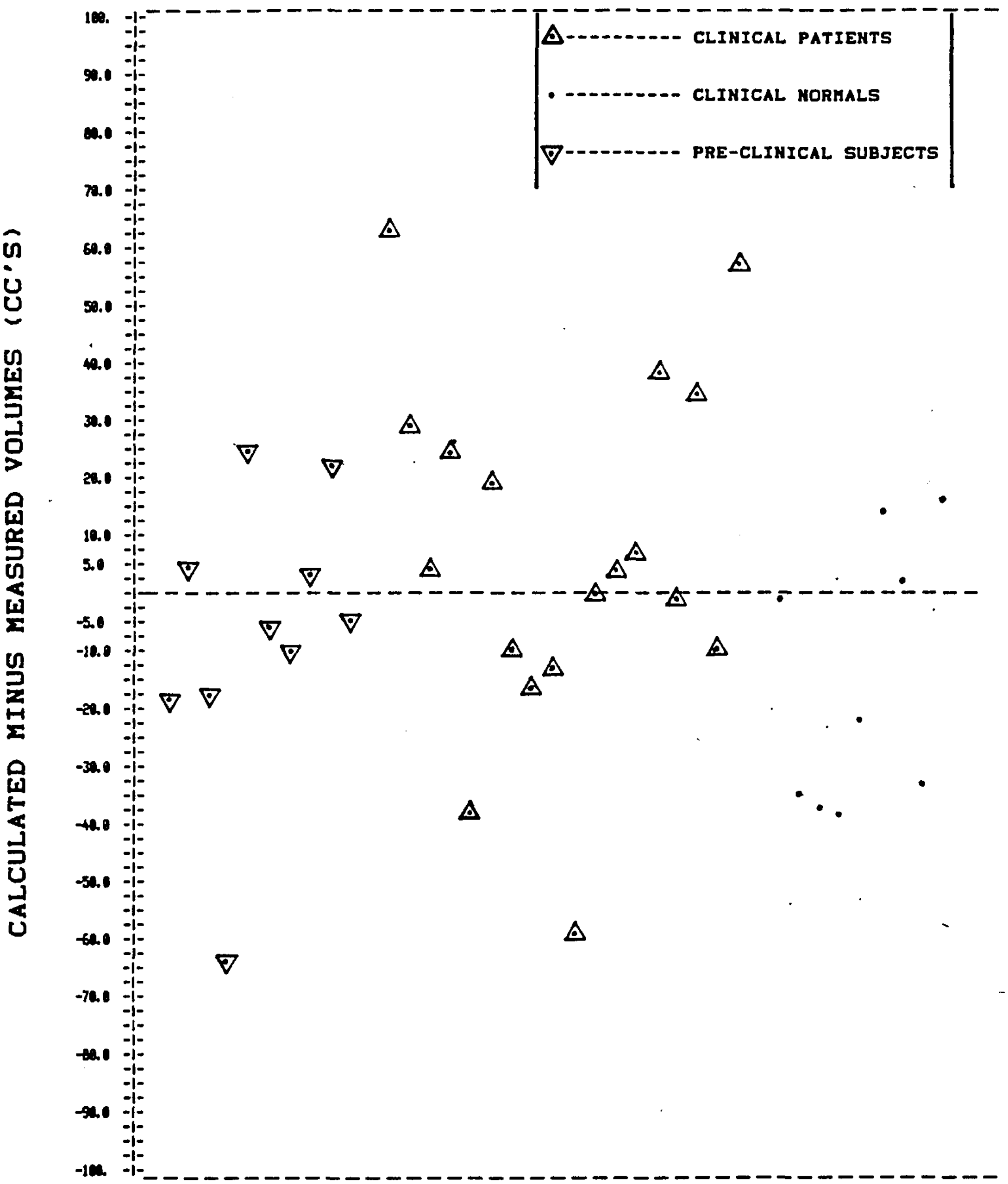
Modifications

The original version of PEAKDET was modified to more intelligently recognize a bladder section within an "A" scan. Table 3.1 is a compilation of the effects of individual and combined changes on the calculated volumes of the



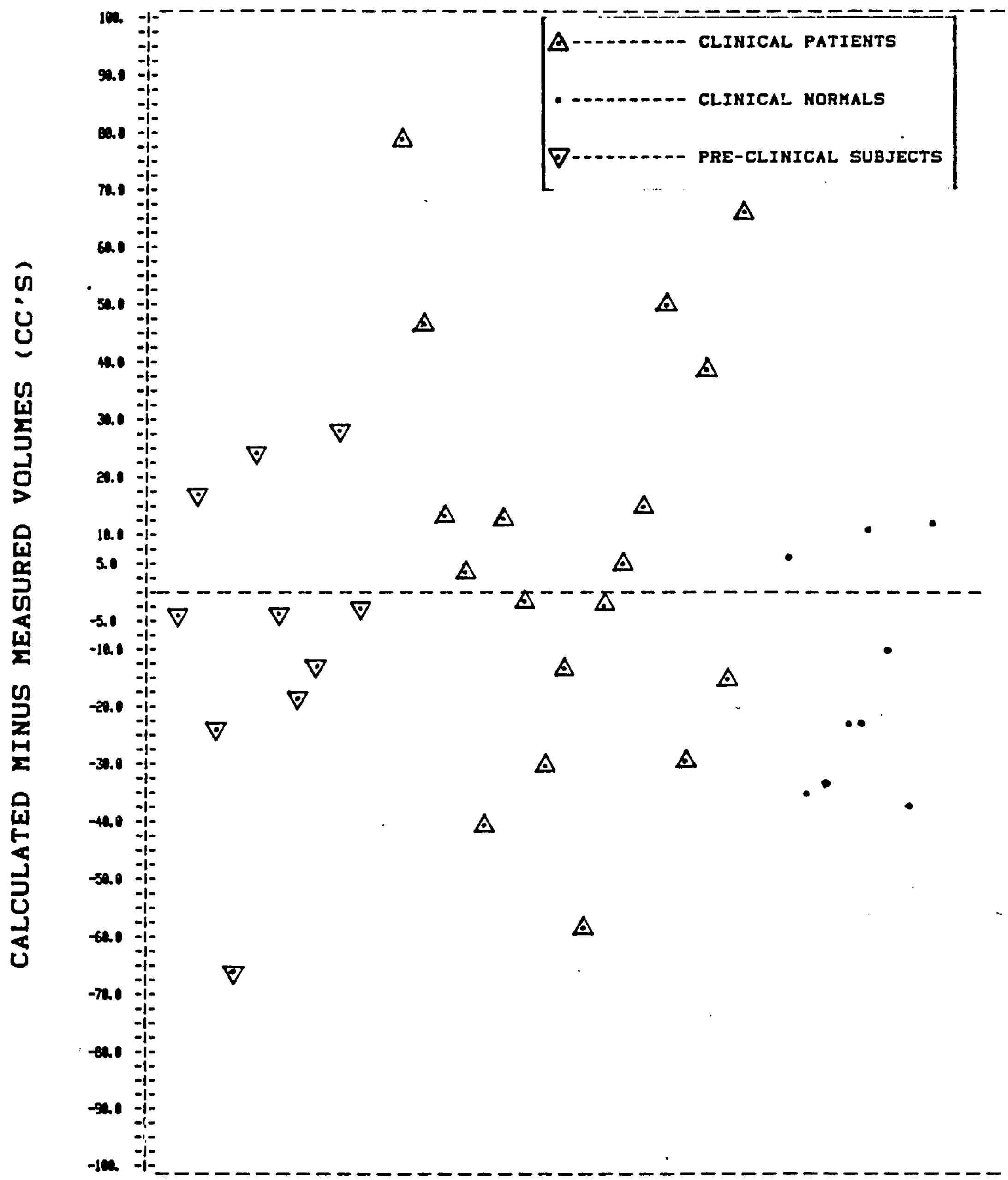
GRAPH OF ERROR VOLUMES RESULTING
FROM THREE CONSECUTIVE SCANS
OF NON-CLINICAL SUBJECTS

FIGURE 3.2



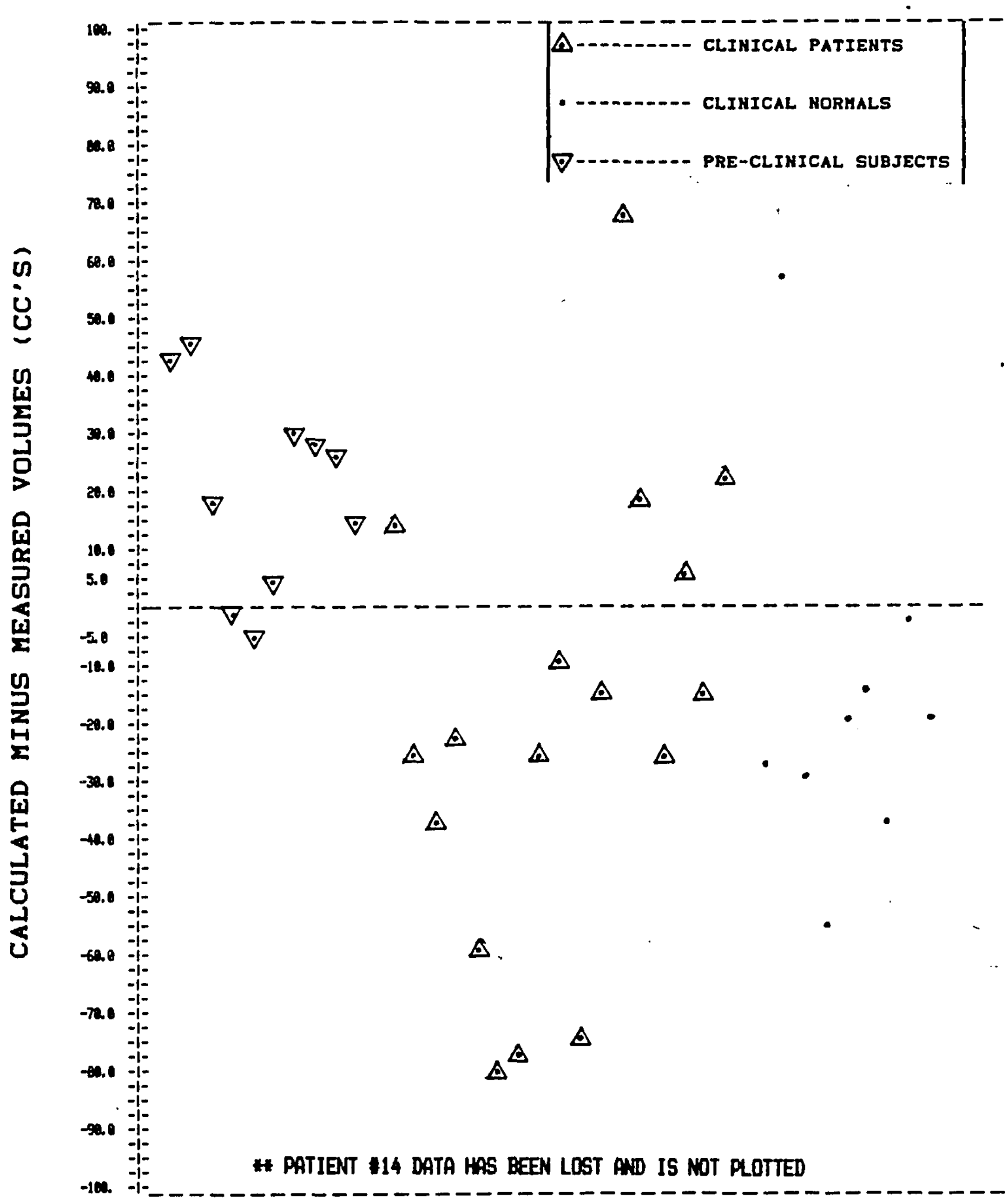
GRAPH OF ERROR VOLUMES OF THE STUDY DATA
AFTER MODIFICATIONS WERE MADE

FIGURE 3.3



GRAPH OF ERROR VOLUMES OF THE STUDY DATA
AFTER MODIFICATIONS AND POST PROCESSING

FIGURE 3.4



GRAPH OF ERROR VOLUMES PRIOR TO
MODIFICATIONS OF PEAKDET

FIGURE 3.5

study data; the resulting mean errors (cc.'s) and standard deviations (cc.'s) are also included. The most significant changes were:

1.) deepening the bladder search from approximately 8.2 to 12.4 cm. (sample number 53 to 80)

2.) requiring the far bladder wall to have a minimum thickness, in addition to minimum amplitude

3.) accepting bladder section volumes calculated from section widths as small as .7725 cm. (5 samples)

4.) reducing the minimum required far wall amplitude to be equal to the flat region threshold (baseline threshold + 7)

5.) beginning the flat region search at a depth of 2.47 cm. and requiring any flat regions found before a depth of 3.09 cm to be 1.08 cm wide (7 samples)

Less significant modifications were:

1.) calculating the baseline threshold from 8 sample values and rounding off to the nearest integer

2.) ignoring flat region samples that equal the flat region threshold instead of considering them as valid flat region samples or as noise

3.) accepting samples equal to the far wall threshold as valid far wall samples

Results of Modifications

Table 3.1 is a tabulation of bladder volume estimates that were recalculated after each modification to the PEAKDET algorithm. Columns C thru O represent the results of the various modifications made to the algorithm, column P is the result of the final algorithm and column Q is a post processed version of column N. Each modification had an effect on the calculated volumes of the study data.

Columns C through K present data collected with a common modification; the far wall threshold is set equal to the flat region threshold. Columns D through F have a common flat region width of 5 samples, but have differing far wall thickness requirements (7,6,5 samples respectively-); column F had the best mean error (-14.3 cc.'s) and standard deviation (27 cc.'s) of this group.

Columns G through I present volumes calculated with a common flat region requirement increased to 7 samples and having differing far wall widths (7,6,5 samples respectivel-y); column I had the best mean error (-9.5 cc.'s) and standard deviation (26.9 cc.'s) of this group. Columns G through I also had additional common modifications concerni-ng selection of the near and far walls which had little effect on the calculated volumes. Columns J and K have a common far wall requirement of 7 samples and differing flat region widths (7 and 6 respectively); note that column D has the same far wall requirement but with a flat region requirement of 5 samples. Column K has the smallest mean error of this group (-21.6 cc.'s), but column J has the smallest standard deviation (25.8 cc.'s).

TABLE 3.1

CALCULATED VOLUMES RESULTING
FROM MODIFICATIONS AND POST PROCESSING

COLUMN	REQUIREMENTS--DESCRIPTION
A	MEASURED VOLUME
B	ORIGINAL PEAKDET ALOGRITHM CALCULATIONS
C	BLADDER SECTION SEARCH EXTENED
D	FAR WALL WIDTH REQUIREMENT = 7 SAMPLES; FLAT REGION WIDTH REQUIRED = 5 SAMPLES
E	FAR WALL WIDTH REQUIREMENT = 6 SAMPLES; FLAT REGION WIDTH REQUIRED = 5 SAMPLES
F	FAR WALL WIDTH REQUIREMENT = 5 SAMPLES; FLAT REGION WIDTH REQUIRED = 5 SAMPLES
G	FAR WALL WIDTH REQUIREMENT = 7 SAMPLES; FLAT REGION WIDTH REQUIRED = 7 SAMPLES; NEW NEAR AND FAR WALL PEAK REQUIREMENTS
H	FAR WALL WIDTH REQUIREMENT = 6 SAMPLES; FLAT REGION WIDTH REQUIRED = 7 SAMPLES; NEW NEAR AND FAR WALL PEAK REQUIREMENTS
I	FAR WALL WIDTH REQUIREMENT = 5 SAMPLES; FLAT REGION WIDTH REQUIRED = 7 SAMPLES; NEW NEAR AND FAR WALL PEAK REQUIREMENTS
J	FAR WALL WIDTH REQUIREMENT = 7 SAMPLES; FLAT REGION WIDTH REQUIRED = 7 SAMPLES; NEW NEAR AND FAR WALL PEAK REQUIREMENTS REMOVED
K	FAR WALL WIDTH REQUIREMENT = 7 SAMPLES; FLAT REGION WIDTH REQUIRED = 6 SAMPLES
L	FAR WALL WIDTH REQUIREMENT = 11 SAMPLES; FLAT REGION WIDTH REQUIRED = 5 SAMPLES; FAR WALL THRESHOLD = 3 ABOVE BASELINE
M	FAR WALL WIDTH REQUIREMENT = 9 SAMPLES; FLAT REGION WIDTH REQUIRED = 5 SAMPLES ;FAR WALL THRESHOLD = 5 ABOVE BASELINE
N	FAR WALL WIDTH REQUIREMENT = 11 SAMPLES; FLAT REGION WIDTH REQUIRED = 7 SAMPLES ;FAR WALL THRESHOLD = 3 ABOVE BASELINE
O	FAR WALL WIDTH REQUIREMENT = 9 SAMPLES; FLAT REGION WIDTH REQUIRED = 7 SAMPLES ;FAR WALL THRESHOLD = 5 ABOVE BASELINE
P	FINAL ALGORITHM
Q	FINAL ALOGORITM AFTER POST PROCESSING

PATIENT NO.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
2	132	146	235	171	181	178	179	189	185	161	167	184	182	164	161	195	211
3	90	64	154	104	107	110	108	112	114	95	99	93	102	78	89	119	137
5	164	127	349	119	135	133	121	137	166	120	120	173	129	171	128	168	181
6	132	109	175	135	137	143	140	141	148	135	137	143	133	137	130	156	136
7	65	6	44	15	21	23	17	23	25	14	15	19	19	15	15	27	25
8	80	0	175	74	78	87	79	82	92	77	78	71	71	70	69	99	93
9	148	71	171	115	123	126	121	128	132	109	112	128	118	118	112	138	147
10	30	4	25	4	8	12	4	9	13	1	1	6	2	1	1	14	0
12	305	296	XXX	321	296	271	333	308	284	313	325	376	361	352	337	292	292
13	125	51	XXX	47	48	59	50	50	62	43	48	56	52	50	48	66	67
14	175	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	175	173
15	20	5	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	24	25
16	94	161	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	101	109
17	310	329	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	348	360
18	29	3	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	28	0
19	124	130	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	158	163
20	15	0	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	6	0
21	230	252	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	287	296
CLINICAL NORMS																	
1	35	8	23	22	27	30	24	30	33	15	19	18	18	10	8	34	41
2	258	315	401	215	209	210	222	216	217	215	217	228	222	223	215	223	222
3	258	229	344	224	216	208	231	222	215	226	230	235	235	231	231	221	225
4	170	115	154	98	109	116	106	118	126	101	105	98	101	92	101	132	147
5	96	77	90	71	70	68	77	77	74	72	75	73	75	69	69	74	73
6	44	25	83	23	28	46	25	30	49	16	22	21	26	13	17	58	55
7	44	30	113	30	38	50	32	40	54	29	32	30	29	24	24	46	34
8	108	71	92	61	65	66	66	71	72	56	63	67	62	57	53	75	74
9	22	20	40	34	32	34	38	37	39	23	32	37	35	24	21	38	34
PRE-CLINICAL																	
1	176	219	184	147	150	154	153	156	160	147	151	162	152	155	146	157	172
2	192	238	257	158	183	199	163	189	206	161	162	195	146	190	146	196	209
3	126	144	160	97	99	104	100	102	108	98	100	99	94	95	88	108	102
4	75	74	79	3	8	15	3	9	15	2	2	12	7	5	2	11	9
5	61	56	76	63	66	64	65	69	67	49	57	53	65	43	48	85	85
6	52	56	91	40	42	43	42	45	45	33	38	43	41	35	33	46	48
7	89	119	124	57	65	78	59	67	81	57	58	57	46	50	44	79	70
8	67	95	95	57	62	65	60	66	70	53	57	50	45	44	38	70	80
9	76	102	105	93	96	92	98	100	97	89	92	108	97	98	88	98	104
10	50	64	67	28	36	41	30	38	45	27	28	39	31	35	29	45	47
MEANS	XXX	-8	40	-22	-18	-15	-18	-14	-10	-25	-22	-14	-20	-21	-27	-1.9	-.6
STD. DEV.	XXX	36	50	28	27	27	29	28	27	26	27	32	31	29	27	29	32

TABLE 3.1

Columns L through O present volumes calculated after varying several parameters including the far wall threshold. Columns L and N have common far wall thresholds (baseline threshold + 3) and far wall thickness requirements (11 samples), but differing flat region width requirements (5 and 7 samples respectively). Columns M and O have common far wall thresholds (baseline threshold + 5) and far wall thickness requirements (9 samples), but differing flat region width requirements (5 and 7 samples respectively). Of this group, column L has the smallest mean error (-13.64 cc.'s), but column O has the smallest standard deviation (26.5 cc.'s).

Column P represents volumes calculated by the final algorithm. Most of the volumes calculated are greater than those found in column F. This increase is due to additional modifications not tabulated in Table 3.1, based on engineering decisions. These decisions included:

1.) averaging the last eight samples to determine the baseline threshold

2.) ignoring samples in the flat region equal to the flat region threshold

3.) accepting samples of the far wall as valid far wall samples if they equaled to the flat region threshold, as opposed to ignoring them as in the flat region

4.) choosing the largest sample of the far regions as the location of the far wall

The most important features of the final algorithm (column P, Table 3.1) are:

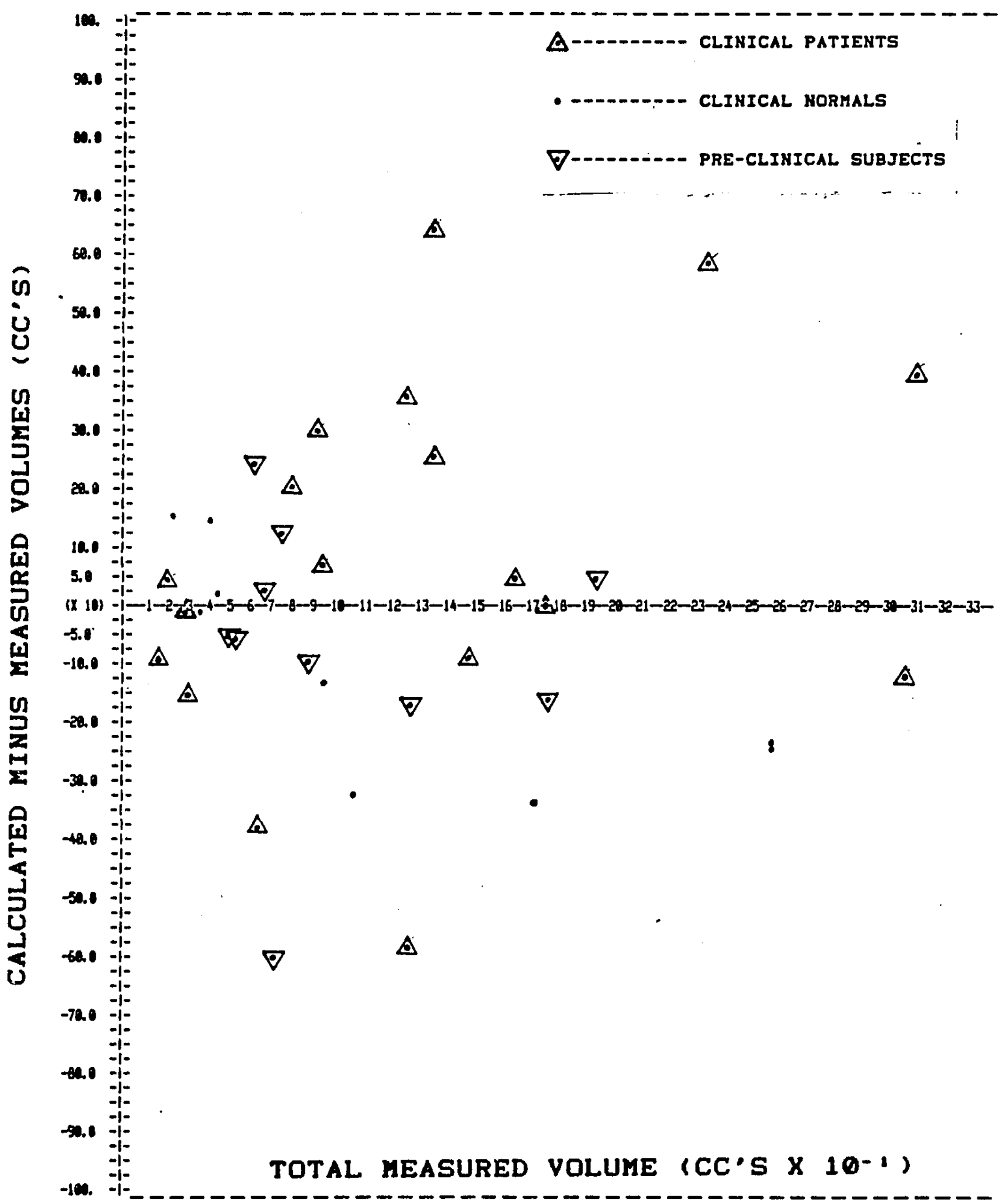
1.) a minimum far wall thickness requirement of 5 samples

2.) a minimum flat region width of 5 samples

3.) a far wall threshold requirement equal to the flat region threshold (baseline threshold + 7)

4.) an extended bladder section search depth (80 samples; 12.36 cm.)

Figure 3.3 is a plot of all the study data taken after all the modifications were implemented. Figure 3.4 is a plot, of this data after post processing and any clumps of extraneous volumes were subtracted from the total volume. The maximum errors are kept to within 50 cc.'s of the measured volumes of the study data. Figure 3.6 is a plot of all the study data volumes plotted against their respective error volumes calculated with the final alogorithm.



GRAPH OF TOTAL VOLUMES VERSUS
ERROR VOLUMES

FIGURE 3.6

CHAPTER 4

DISCUSSION OF RESULTS

Discussion of Non-Clinical Results

One of the goals of the non-clinical experiments was to find an optimum starting position for the transducer orientation. This was determined to be 2 to 3 inches above the pubic bone on the midline of the body. Examination of the FIBYFIS plots showed that a small shift (1/2 inch either side of midline), could result in an incomplete bladder scan. A movement of the same magnitude in the longitudinal direction had little effect on coverage of the bladder by the scans. With a starting position further away from the pubic bone the resulting echoes would be more attenuated and the range of angles of transducer movement over which the bladder could be detected would be diminished.

The large errors between consecutive sets of data taken on subjects (see Figure 3.2) may have resulted from an accelerated filling rate caused by late ingestion of fluid, additional time delay after completion of the first scan, or the peristaltic filling of the bladder, (see Campbell's Urology pages 106-107). Also, possible error in the scanning geometry due to "play" in the gears of the pantograph may have contributed to the error in calculations. Observing the speed with which the bladders filled confirmed the need for a quick and simple procedure.

Discussion of Clinical Results

The majority of clinical data collected on symptomatic subjects was below measured volumes, unlike the data collected in the non-clinical environment, which were above the measured volumes. This result had implications for the two groups of clinical subjects (symptomatic and asymptomatic).

An implication gleaned from the asymptomatic data was that the sensitivity settings can effect the calculated volumes, but that the effect is uniformly felt throughout the data collected with these settings. That is, if the settings caused one volume to go down, it would cause all volumes to go down. An additional implication gleaned from the symptomatic subjects was that the depth of search for the bladder was insufficient, especially for fatter subjects.

The optimum starting position was used for all the collected clinical data, and proved to be quite acceptable. Bladders with excessively large volumes could not be completely covered by the scan despite the starting positio- n. This is of little consequence if knowledge of residual bladder volume is of primary concern, because enough of the total volume would be revealed to warrant catheterization.

Six of the symptomatic subject data sets were not used in the data base. Urine was spilled during catheterization of one of the patients. One of the sets was taken from an obese patient in which the original calculation yielded 0 cc's (cathterization yielded over 250 cc's). Inspection of this data implied that the total depth of the search may not have been sufficient, or that the position of the bladder had been changed due to the excess fat as suggested by the attending physician. Fat "floats" the bladder having the effect of moving it toward the head when the patient is laying on his back. One patient's catheterization was delayed, because a smaller catheter was needed, and another was not performed due to severe pain and bleeding. One patient had an excessively large volume which could not be scanned completely, though this warranted catheterization it was not possible to compare the measured volume to the calculated volume with any accuracy. One patient was scanned twice due to perceived insufficient coupling; the results were not greatly different. The second of the two results is included in the data base, the other anomalies referred to are not included.

Having the ability to position the bed and patient under the transducer decreased the amount of time needed for a scan, which should have improved accuracy. Lack of a uniform coupling system and a "force of contact to skin" parameter raised questions concerning the effects of these on accuracy.

Discussion of the Results of Modifications

The modification having the greatest impact on the accuracy of the study data was the extension of the bladder section search which revealed previously undetected bladder sections of symptomatic subjects. Indeed, entire bladders went undetected before the extension was implemented (compare column A to the initial calculated volume, patients 6 through 9, of Table 3.1). This extension also produced extremely large volume errors because noise samples were now considered as very weak far walls on several of the "A" scans.

To remedy the weak far wall problem minimum requirements were imposed on far wall thickness and amplitude. Different far wall thresholds were tried (columns J through M Table 3.1), but the amplitude of choice was equal to the flat region threshold. Only one set of data volumes (pre-clinical subject #4, Table 3.1) failed to respond favorably to this threshold value. Comparison of the volumes of columns B through D of Table 3.1 with column A will show that imposing a required minimum thickness for the far wall proved to be crucial for accurate bladder volume calculations. However, it should be noted that the volume differences resulting from the varied thicknesses were not significant (±10 cc.'s) except in a few cases.

To more reliably select valid small bladder sections the flat region width requirement was eased from 7 samples to 5 samples. The effect of this change alone is difficult to assess because previously selected bladder sections would most probably still be selected, and any bladder sections 5 samples wide would generally contain very small volumes. However, examination of individual "A" scans suggested that searching for small bladder sections was an appropriate action, having the desired result of increasing accuracy albeit a small contributor.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

An ultrasonic method using the "A" scan mode of signal detection has been devised to determine bladder volumes. This method collects "A" scans and searches for characteristics which define bladder sections. If a bladder section is found a volume is calculated for that section and a total volume is found by summing these smaller sectional volumes. The data presented in Figure # 3.3 illustrates that it is possible to estimate bladder volumes to within 50 cc's of actual volume. Extending the search for a urine filled bladder section to a depth of 12.36 cm. (sample number 80) had the greatest impact on the data. Other changes which had significant effects were: allowing a minimum flat region width to be .7725 cm (5 samples), imposing width requirements on the far wall, and changing the far wall threshold requirements.

The preferred beginning scanning position was determined to be 2 to 3 inches superior to the pubic bone on the midline of the body. This should completely cover bladders with volumes of 100 ml. or less and scans of bladders with volumes in excess of 100 ml. should reveal enough of the volume to warrant catheterization.

Post processing corrects for missing data entries in straight forward logical manner, and also ignores individual entries which do not connect to the bulk of volume entries. However, separate groups of data would contribute to the total calculated volume though only one of the groups may be actual bladder. Scans which don't appear to completely cover the bladder pose a problem, however suggestions for correcting this problem follow.

Recommendations

The evolution of the present system into a truly portable system will greatly enhance its effectiveness as a diagnostic aid. The present system and procedure requires scheduling and transportation of patients. Having the system ready at all times in the examination area would be of more use than the present arrangement. The following recommendations will help to facilitate the transition from semi-portable to fully portable.

The pantograph and the stand which supports it should be replaced with a new apparatus so that the system will be less cumbersome. A device which would reliably couple the ultrasound signal into the body at any incident angle would be helpful. If the system is to be truly portable the Apple II plus should be replaced by a single board computer. By using a 6502 based single board computer, additional software development would be minimal.

Though a faster processor would be convenient it would not be essential to the operation. An A/D board has been designed to replace the oscilloscope and can interface to the Apple II plus. Appendix E contains documentation on the board.

Electrically erasable proms could be used as a temporary storage medium to be copied on to a diskette later, or a disk drive could be installed. An algorithm to determine if the bladder is within the physical limits of the scanning procedures should be developed. This could be accomplished by framing the bladder. That is, develop a transducer holder which could move the head of the transducer throughout the proposed maximum angles of the scan. If more that one or two valid data samples appear along any side, the starting position would be adjusted to compensate for it.

The author believes that a correlation exists between noise in the region between near wall and far wall and acceptable far wall height and width. By averaging the noise and adjusting the far wall requirements appropriately this can be studied.

Some concern was expressed over the amount of pressure used to force the transducer down onto the subjects. The pressure varied per patient. It may be possible to use a scheme similar to the angle measuring potentiometer to measure depth of the transducer penetration.

A study of the order in which the preprocessing subroutines are called should be performed to determine the optimum order of execution. An algorithm which could eliminate extraneous groups of data would result in more reliable post - processing volumes, see Figures 2.15 and 2.16 position D.

It would also be interesting to recalculate all the collected volumes found in this research with a conical volume approximation instead of the approximations for pyramid volumes. Since the diverging ultrasonic beam is more closely related in form to a cone than a pyramid it seems more accurate results should appear.

Finally, a comprehensive study of the effects of varying the sensitivity settings should be devised and conducted on subjects. Though this was attempted to some extent in the work performed for this thesis, it would be beneficial for the experimental system to be used more effectively.

APPENDIX A

The Gould OS 4042 A/D conversion rate is varied by the sweep rate set on the OS 4040 oscilloscope. The maximum coversion rate is 10 Mhz when the sweep rate is set to 50 us. The rate decreases in proportion to the sweep rate. The chosen rate of conversion for the system is 500 Khz (2 us conversion).

10 Mhz equals 100 ns, 500 Khz equals 2 us.
100ns/50 us = 2 us/x
1 ms = x
Therefore the sweep rate is set to 1 ms.

there are 5120 bytes of memory to the A/D and the screen is 10 cm wide:

10cm x 1 ms / 5120 byte = 1.95 us/byte

are needed.

The assumed speed of sound through urine is 1545 mtr/s, or 154500 cm/s. But, this considers traveling to and returning from a target, therefore this number is halved to give:

77.25 cm/s or .07725 cm/us.

APPENDIX B

INSTRUMENT SETTINGS

OS 4040

PARAMETER	SETTING
time/cm	1 ms/cm
expand	x 20
trigger slope	+/-
trigger coupling	dc
trigger source	external (from SONO II)
horizontal mode	store TY button
vertical mode	CH 1
channel 1 input couple	DC button in
channel 1 amplitude	2 V/cm

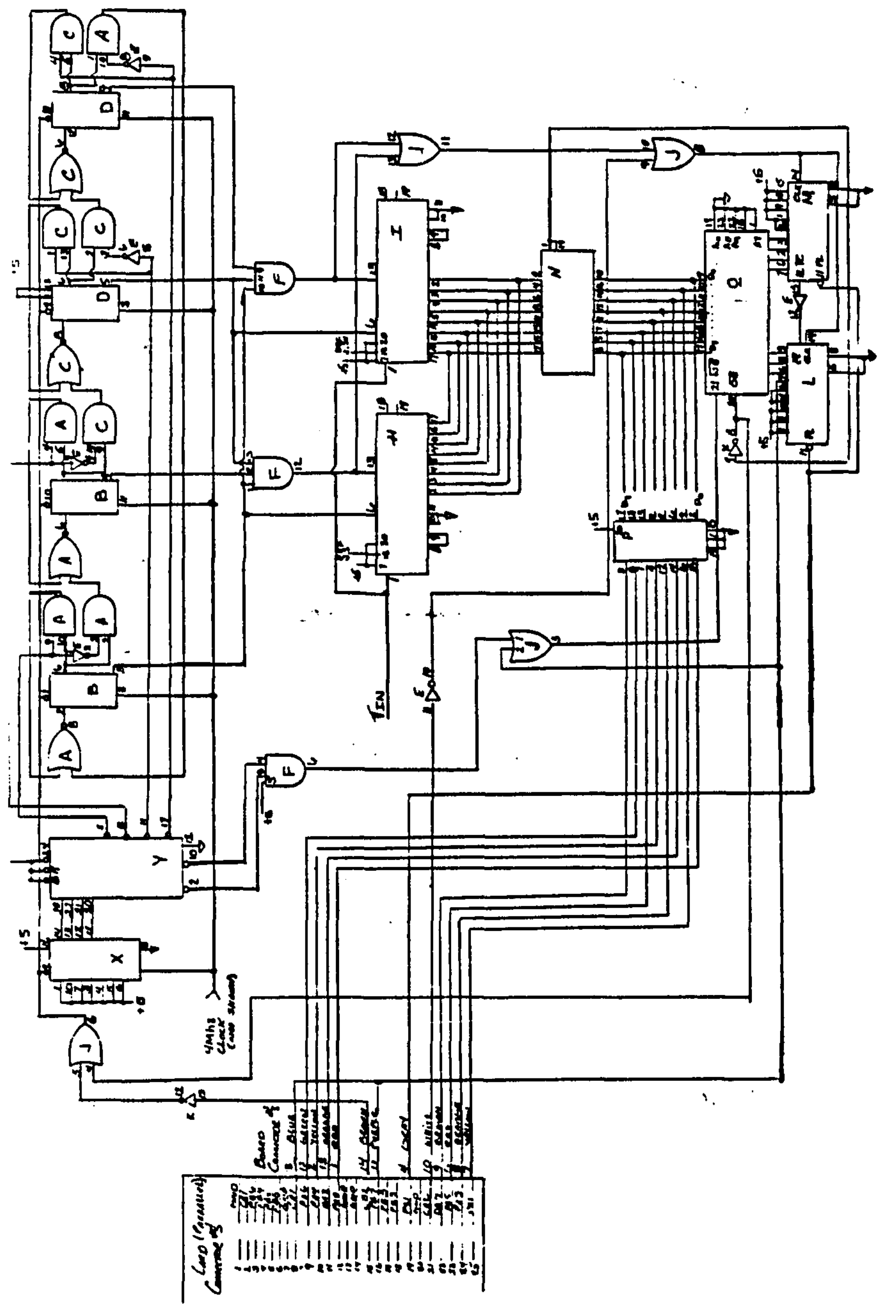
SONO II

PARAMETERS	SETTING
attenuators	20 db
initial gain	0
slope gain	0
delay gain	0
reject gain	9

APPENDIX C

PARTS LIST FOR A/D BUILT FOR THE APPLE II PLUS

LETTER DESIGNATION	PART NUMBER
A, C	74LS51
B, D	74LS74
E, K	74LS04
F	74LS11
H, I	ADC 0820
J	74LS32
L, M	74LS191
N, P	74LS244
O	HM-6116P-3
X	74LS163
Y	74LS154
CLOCK	4 MHZ



SKEMATIC OF THE A/D
FOR THE APPLE II

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