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The use of high resolution phonocardiography in the assessment of artificial heart valves

Muslmani, Bassam Mohamed, M.S.

The University of Arizona, 1992

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THE USE OF HIGH RESOLUTION PHONOCARDIOGRAPHY IN THE ASSESSMENT OF ARTIFICIAL HEART VALVES

by

Bassam Muslmani

A Thesis submitted to the Faculty of the

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

In Partial Fullfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN ELECTRICAL ENGINEERING

In the Graduate College

THE UNIVERSITY OF ARIZONA

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Olgierd A. Palusinski, Ph.D. — Date

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ABSTRACT

A non-invasive research tool to assess mechanical prosthetic heart valves using high resolution phonocardiography and signal processing was developed. The theory and motivation responsible for this system along with the actual hardware design and software coding will be presented. Studies employing this experimental system on patients with mechanical heart valves followed by the Sections of Cardiothoracic Surgery and Pediatric Cardiology at University Medical Center have revealed that the leaflets of normally functioning bileaflet mechanical heart valves do not close synchronously. The degree of asynchronous closure of the valve leaflets ranged from 3 msec to 4 msec to 5.5 msec. In addition, the data collected revealed that the closing sounds created by the prosthetic valves had significant frequencies above 10 kHz.

CHAPTER 1

INTRODUCTION

1.1 HEART VALVE BASIC

1.1.1 HISTORICAL DEVELOPMENT OF PRESENT-DAY MECHANICAL AND BIOLOGICAL HEART VALVES

Thirty - five years have elapsed since Hufnagel implanted the first mechanical valve in the descending aorta and 32 years since Harken first implanted artificial mechanical valves at the aortic level in 1960. From 1960 onwards mechanical and biological valves were developed simultaneously. Mechanical valves are constructed from rigid, nonphysiological biomaterial. The biological valves on the other hand simulate their natural counterparts more closely than mechanical valves. This is due in part to the tissue (homograft or allograft derived from human cadaver aortic valves) with which the valves are made. The second period of valve development involves Kay's description of disk valves and the first heterologous implants by Binet in France. Since then, new models with improved hemodynamic conditions and advantageous modifications have been developed. The most significant of these developments was the utilization of bileaflet valves in 1977. Since then slight modifications and improvements have been made in attempts to eliminate the risks and complications of previous models. All of the valves presently used throughout the world have antecedents in different centers and surgical teams. Thanks to the collaboration of numerous doctors, engineers, and medical firms, efforts are being made to achieve an ideal valve to substitute for natural valves without risks or complications.

1.1.2 CURRENT STATUS OF MECHANICAL PROSTHETIC VALVES

There exist many forms of mechanical valves currently in use like the caged-ball valve, the caged-disk valve, the tilting disk valve and the bileaflet tilting disk valve to name a few. Figure 1 illustrates the major categories of prosthetic valves.

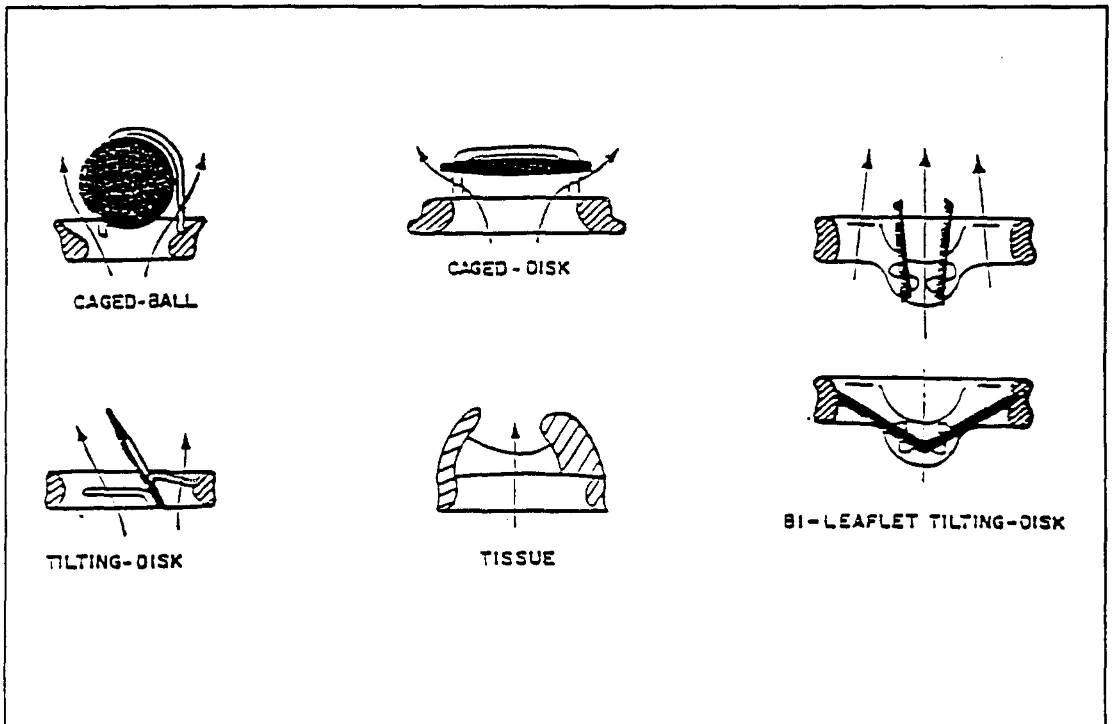

Figure 1 design and flow patterns of major categories of current prosthetic valves (1).

A mechanical valve prosthesis is composed of three basic components:

1- the solid, but mobile, flow occluder around which blood must flow.

2- the cage-like superstructure that restricts and guides occluder motion.

3- the valve body or base.

A major advantage of mechanical prosthetic heart valves when compared to bioprosthetic heart valves is their durability and their unlimited supply. Trial and error has shown that stellite, titanium and pyrolytic carbon are probably best suited for construction of heart valves. The most preferable is pyrolytic carbon. Pyrolytic carbon has both favorable mechanical properties, such as high strength, fatigue, and wear resistance, and exceptional biocompatibility, including thromboresistance[1]. The cages of mechanical valves available today are composed of either relatively pure titanium, cobalt-chromium alloy or have carbon disks and all supports covered with carbon. The sewing rings needed for suturing of device into the heart are made of dacron or teflon. This is the major site for valve-tissue interaction.

1.1.3 MAJOR VALVES COMPLICATIONS AND PROBLEMS OF MECHANICAL VALVES

1.1.3.1 THROMBOEMBOLISM

Approximately, 100,000 valves are implanted worldwide each year. Approximately 20% of late deaths following valve replacement (one month or more postoperatively[1]) are prosthesis-associated complications. Chronic anticoagulation is necessary for all patients receiving mechanical valves due to thromboembolic complications. However, patients receiving long-term anticoagulation are susceptible to hemorrhage. Valve infection occurs at the valve-host interface and can be extremely difficult to cure without removing the valve.

1.1.3.2 HEMODYNAMIC

All prosthetic valves present some degree of obstruction to forward flow. Clot formation, calcification and tissue overgrowth are the major factors in valve obstruction. The design of mechanical valves allows for a small leakage when valves are closed in order to wash the disc surfaces and decrease clot formation. However, severe leakage due to catastrophic failure of mechanical valve due to fracture of disc can cause death.

1.1.4 CONCLUSION

In general, it can be stated that the currently used mechanical prosthetic heart valves are durable and have an acceptable hemodynamic performance, however, complications related to the valve prothesis are a major factor in a patient's prognosis. A recent Dutch study indicates that the failure rate of heart valves is higher than previously thought. A study quoted in the Arizona Daily Star (FEB'92) said that deaths attributable to the valves may have been underestimated because of misdiagnosis or because most of the recipients who have died were not in hospitals and no autopsy was done. Because long-term outlook for patients after valve replacement strongly depends on valve-related factors, this research study which focuses on the early assessment of prosthetic valve is crucial.

1.2 BASIC FUNDAMENTALS OF THE HEART

1.2.1 BASIC STRUCTURE AND ELECTRICAL ACTIVITY

The heart weighs less than a pound and is about the size of the average fist, about 6 in. long along its major axis or dimension. The heart itself is a hollow organ which is composed of four chambers with a system of one way valves, the fluid equivalent of a diode, which provide for filling the chambers of the heart with little backflow or regurgitation of blood. The walls of the heart are made of muscle which is surrounded by a fiberlike sac called the pericardium. The inside of the heart is lined by a strong thin membrane called the endocardium. A wall or septum divides the heart into a double-pump configuration. This gives rise to the "left heart" versus "right heart" idea. Each side of the heart is again divided into an upper chamber, the atrium, and a lower chamber, the ventricle. The atria collect blood from the body and lungs. The ventricles are muscular and function as pumps. During contraction of the heart muscle, the blood is ejected from the ventricles into arteries (systole), and the blood returns to the ventricles during relaxation (diastole). The right ventricle receives systemic venous blood via the right atrium and pumps it into the pulmonary artery. After oxygenation in the pulmonary capillaries, the blood returns via the pulmonary veins and the left atrium pumps it into the aorta. The concept of the heart as a double pump is shown in Figure 2.

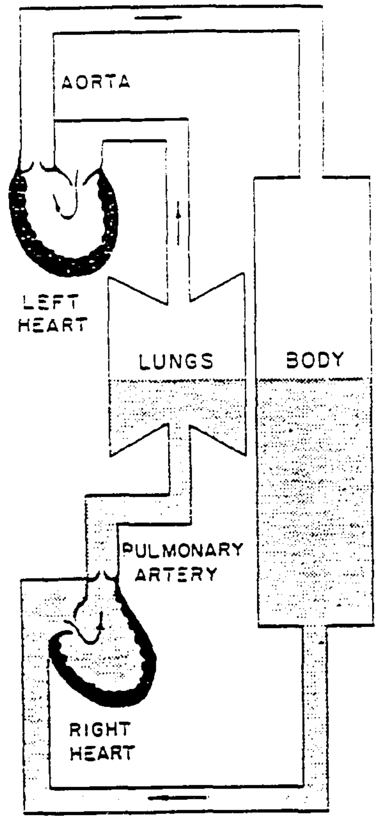

Figure 2 the concept of the heart as a double pump (2)

The electrocardiogram (ECG) which is the record produced by an electrocardiograph displays the electrical activity of the heart as measured on the body surface. A typical ECG waveform is shown in Figure 3. The spread and regression of the electrical impulse over the cardiac muscle are represented by the P wave, PR segment, QRS complex, ST segment, T wave and TP interval of the electrocardiogram. The P wave represents the spread of activation from the sinoatrial node through the atrial muscle. The PR segment records a physiologic delay in transmission of the impulse through the atrioventricular node. The QRS complex corresponds to the spread of activation over the ventricular muscle. The ST segment represents the time interval between completion of depolarization and the beginning of repolarization. The T wave corresponds to the spread of repolarization over both ventricles. The TP interval represents the resting state of the cardiac muscle. Additional information on the cardiac conduction system can be obtained in many physiology or electrocardiography textbooks. Human physiology by Sherman et al.[4] and Electrocardiography by Liebman et al.[5] provide in-depth treatments of this material.

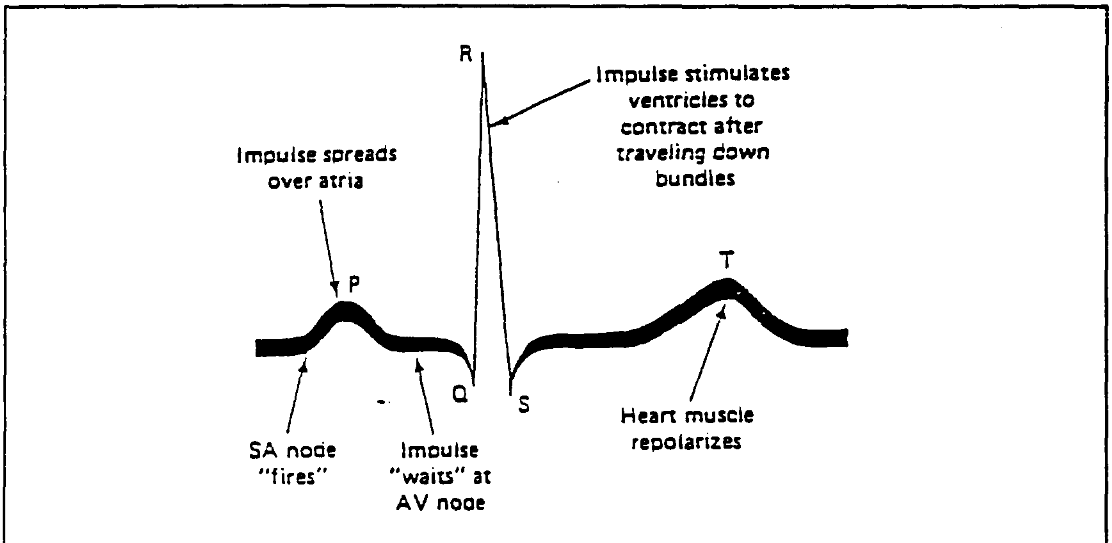

Figure 3 ECG waveform obtained at the body's surface (3)

1.2.2 ACOUSTIC EVENTS

Heart valves are passive structures, and their closing and opening are determined by the pressure difference between atria and ventricles and between ventricles and arteries. These pressure differences develop due to contraction of the heart which in turn is initiated by the electrical impulse. Thus accurate timing of the closure and opening of the heart valves can be accomplished only by referencing to the electrocardiogram. For this purpose the heart sounds have to be converted into electrical currents and recorded (phonocardiography) simultaneously with a suitable reference as shown in Figure 4.

There exist four heart sounds as shown in figure 4 : S1, S2 which consists of A2 and P2, S3 and S4. The first heart sound is produced by a sudden closure of the mitral and tricuspid valves associated with myocardial contraction, rapid rise of ventricular pressure, and early movement of the blood into arteries. On the phonocardiogram as many as four components can identified in the first heart sound. The first component results from ventricular and early motion of blood toward the tricuspid and mitral valves. The second component represents closure of the tricuspid and mitral valves. The third component is associated with the opening of the aortic and pulmonary valves and the beginning of blood ejection. The fourth component coincides with the maximal ejection of blood from the aorta.

The second heart sound results from vibrations set up by the closure of aortic and pulmonary valves. Since aortic closure occurs a fraction of a second earlier than the pulmonary valve closure, the second heart sound consists of two components - aortic and pulmonary. The third heart sound results from vibrations occurring during the early diastolic phase of rapid ventricular filling of a vigorous heart. The fourth heart sound, also called an atrial sound, is caused by an accelerated flow of blood into the ventricles consequent upon atrial contraction. This sound is seldom heard in normal subjects because of its low amplitude, short duration, and blending with the succeeding first sound.

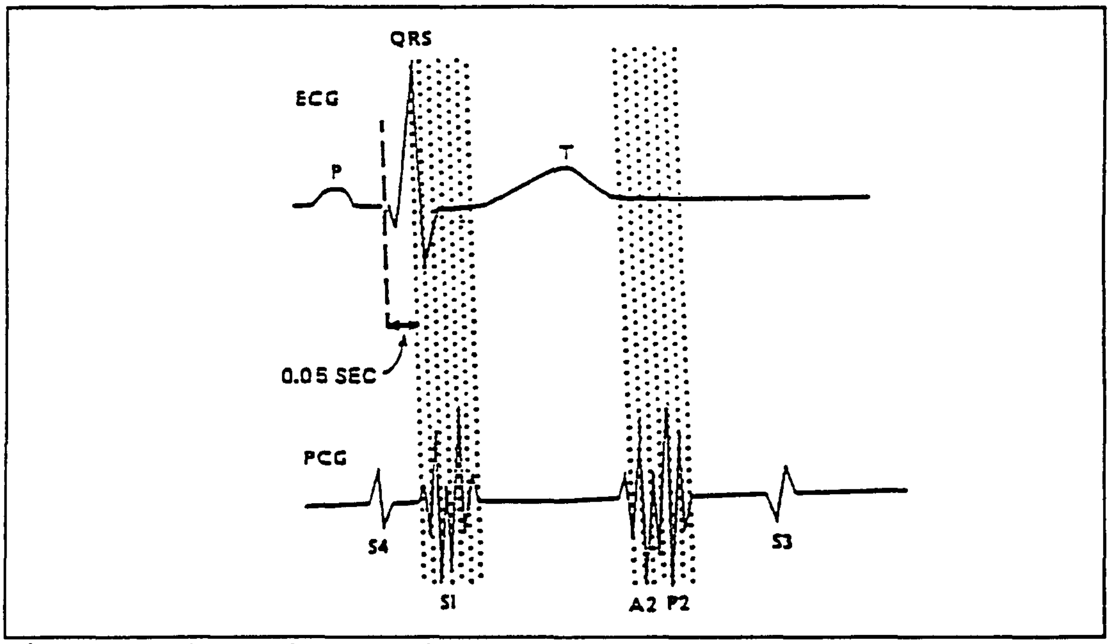

Figure 4 the reference between ECG and heart sounds (2).

CHAPTER 2

AVAILABLE METHODS OF EVALUATING HEART VALVES

2.1 Research Justification

The malfunction of natural and prosthetic heart valves is a serious cardiological problem. A need exists for clearly detecting malfunctions as early as possible. The method used for this detection should preferably be non-invasive, accurate, sensitive, quick, systematic, and relatively inexpensive. Diagnostic equipment employed should be easily portable to the patient's bed side. High Resolution Phonocardiography (HRP) offers an alternative means for early detection of valves defects and meet all the criteria listed above. The hypothesis of HRP is that the analysis of sounds created by mechanical valves can be used to reliably detect valve problems (the theory is that any alteration in valve properties due to calcification, tissue ingrowth, clot formation, cracking or tearing should cause changes in the opening or closing sounds of the valve). Any valve dysfunction due to the above reasons should be associated with either changes in the patterns of leaflet closure or in the frequency content of the valve sounds. Presently, cardiologists use phonocardiography, echocardiography and fluoroscopy as noninvasive procedures for evaluating valvar integrity. Each of these methods, however, is sensitive only to malfunctions of an advanced nature, and as a result are not totally successful.

2.2 CURRENT NONINVASIVE METHODS

Many attempts were made in the last decade to improve clinical results of valve replacement by improving the design and material of prosthetic heart valves. Malfunction of the implanted prosthesis resulting from thrombus remains a substantial postoperative hazard. However, the design is still not perfect and the patient is still required to go through some postoperative checkup in order to detect any malfunction of the valves at the early stages. Some of the non-invasive methods available for such detection are:

1- FLUOROSCOPY

2- PHONOCARDIOGRAPHY

3- DOPPLER ECHOCARDIOGRAPHY

2.2.1 FLUOROSCOPY

2.2.1.1 DEFINITION AND MECHANICS

Production of the fluoroscopy image:

Fluoroscopy is the direct examination of the patient by means of x-rays bombarding a fluoroscopic screen in a darkened room. Because it permits instantaneous visual observation of the part of the body under observation, fluoroscopy is extremely valuable for diagnostic purposes. The fluoroscope consists essentially of an x-ray tube properly housed and mounted so that the x-ray from it strike a screen. These fluorescent substances on the screen convert x-ray radiation into visible light. In the passage of x-rays through various types of matter, the beam is modified to a degree depending on the absorptive power of the portion of matter traversed. For this reason, when a patient is placed between the x-ray tube and the fluorescent screen, a shadow image of the part of the body under examination is formed on the screen. The denser parts of the body, absorbing more radiation, produce blacker shadows because fewer x-rays actually reach the screen through them to illuminate it.

2.2.1.2 Drawbacks

Patients will be exposed to x-rays. Some of the biological effects of x-rays may be manifested by skin changes, by changes in the development of finger or toe nails, by changes in the blood and other deep-seated tissues, and possibly by genetic effects. In addition, the fluoroscopy method lacks the sensitivity which is required in the detection of early valve degeneration.

2.2.1.3 Summary

In summary this method is somewhat outdated and cannot be used for early diagnostics of valve degeneration[8,9].

2.2.2 PHONOCARDIOGRAPHY

2.2.2.1 DEFINITION

A phonocardiograph is a recording of the heart sounds and murmurs. It represents a graphic representation of the sounds that originate from the heart. The phonocardiogram is a very powerful tool in the medical setting because of its ability to evaluate the heart sounds and murmurs with respect to the electrical and mechanical events in the cardiac cycle. Although many murmurs and sounds can be accurately characterized by phonocardiography, this technique occasionally fails to register certain sounds (i.e. soft, high pitched murmurs). The phonocardiogram makes possible the accurate timing of sounds and events that are too rapid for the human ear to detect. Graphic recording also provides a permanent objective record of events with which subsequent comparison can be made. Such records are especially valuable in following a patient's progress and evaluating the results of surgery.

2.2.2.2 Drawbacks

Phonocardiography has been used on patients with heart valves implants for the purpose of early detection of valve malfunction, however, due to the limited resolution of this method it has been extremely difficult to relate the phonocardiogram to the generation of the sound and the functioning of the valve which consequently renders phonocardiography to be useless in detecting early heart valve problems.

2.2.2.3 Summary

In summary standard phonocardiographic techniques of evaluating sound intensity and timing are not sensitive to early changes in valve function[8,9].

2.2.3 DOPPLER ECHOCARDIOGRAPHY

2.2.3.1 DEFINITION

Another method used in the diagnostic of prosthetic valves is echocardiography. Conventional imaging echocardiography is used to evaluate valvular diseases, myocardial disease and congenital heart disease. Two types of Doppler equipment have been developed for interrogating flow in the cardiac chambers and peripheral vessels. The first type of Doppler ultrasound system used was the continuous wave (CW) Doppler. In CW Doppler systems, there are two transducers - one is continuously transmitting an ultrasound beam while the other is continuously receiving backscattered pulses. Thus, Doppler signals from all blood flow along the path of the ultrasound beam are received. There is no range resolution meaning that one cannot interrogate flow in a specific chamber of the heart. Examination of intercardiac flow with CW Doppler is like aiming a flashlight beam at the heart. In CW Doppler, sampling is continuous, the sampling rate is infinite, and there is no limit to the ability to display very high velocities. In the pulsed Doppler system, there is one transducer which alternately transmits and receives the ultrasound signal. Thus, a short burst of ultrasound is transmitted at a rate called the pulse repetition frequency (PRF). The back scattered signal is received with the same transducer. One of the advantages of the pulsed Doppler is the ability of the operator to selectively sample signals arising from red blood cell flow at a given depth in a range cell called the sample volume. Pulsed Doppler has a major advantages of range resolution - One can sample blood flow in a specific small area whose location and depth can be varied. Additional information on this subject can be obtained from the textbook written by Feinberg[2].

2.2.3.2 Drawbacks

Pulsed Doppler is limited by the maximum frequency shifts that can be detected at each depth. The limit on the maximum detectable frequency shift is explained by the sampling theorem. The ultrasound pulse must travel down to the selected depth and back before the next pulse can enter the heart, in order to avoid ambiguity. Therefore, the pulse repetition frequency (PRF) or sampling rate is limited at each depth. At shallow depth, the PRF and, therefore, the maximum detectable frequency is higher than at deeper depth. The maximum detectable frequency is called the Nyquist limit. If a frequency shift occurs which exceeds the Nyquist limit, then the equipment cuts off the true signal, and displays it ambiguously in the opposite channel or direction. This phenomenon is called frequency aliasing.

2.2.3.3 Summary

Doppler technology has improved the capabilities to detect heart problems. It can detect obstruction or leakages caused by malfunctioning prosthetic valves. However, valve abnormality can not be accurately quantitated during the early stages of valve dysfunction[8,9].

CHAPTER 3

TRANSDUCERS

3.1 PIEZOELECTRIC EFFECT

3.1.1 HISTORICAL BACKGROUND AND APPLICATIONS

The piezoelectric effect was discovered by Pierre and Jacques Curie in 1880. It remained a mere curiosity until the 1940s. The property of certain crystals to exhibit electrical charges under mechanical loading was of no practical use until very high input impedance amplifiers enabled engineers to amplify their signals. In the 1950s, electrometer tubes of sufficient quality became available and the piezoelectric effect was commercialized.

The charge amplifier principle was patented by W.P. Kistler in 1950 and gained practical significance in the 1960s. The introduction of MOSFET solid state circuitry (replacing electrometers) and the development of highly insulating materials such as Teflon greatly improved performance and propelled the field of piezoelectric measurement into virtually all areas of modern technology and industry. Piezoelectric measuring systems are active electrical systems. That is, the crystals produce an electrical output only when they experience a change in load. However, it is a misconception that piezoelectric instruments are suitable for only dynamic measurements. Quartz transducers, paired with adequate signal conditioners, offer excellent measuring capability. There are countless examples of applications where quartz based transducers accurately and reliably measure short-term static or near DC measurements with high impedance transducers and charge amplifiers.

The inverse piezoelectric effect refers to mechanical stressing (and deformation) of crystals when electrically excited. This effect has many applications including watches and high frequency resonators.

Piezoelectric measuring devices are widely used today in the laboratory, on the production floor and as original equipment. They are used in almost every conceivable application requiring accurate measurement and recording of dynamic changes in mechanical variables such as pressure, force and acceleration.

3.2 PIEZOELECTRIC TRANSDUCERS

3.2.1 PRESSURE MEASUREMENTS

In order to generate an electrical output from a pressure input, that pressure must first be converted into a proportional displacement or strain. This strain is then transmitted to an electrical transduction element which generates the required signal. Thus, most transducers are comprised of two main components, one mechanical and one electrical. In pressure transducers, the mechanical element is the diaphragm, and the electrical element is the quartz crystal or the semiconductor bridge.

Quartz is the heart of piezoelectric pressure transducers. Its characteristics of long-term stability, high rigidity and strength, wide measuring range and wide temperature range make it the ideal sensing element for dynamic pressure transducers. Pressure measurements with ranges up to 150,000 psi, temperatures up to 350 degree C, rise times of 1 microsecond, and resonant frequencies up to 500 kHz are all possible with piezoelectric pressure transducers.

While quartz-based pressure transducers are ideally suited for measuring dynamic events, they cannot perform truly static measurements. Although the electrical charge delivered under a static load can be registered, it cannot be stored for an indefinite period of time. For static measurements, highly insulated materials must be used in the transducer cables and connectors to insure a maximum discharge time constant and optimal operation of the charge amplifier (i.e. minimal drift). Since quartz has a very high insulation resistance (bigger than 10^{13} ohms), short-term static pressure measurements are more feasible than with any other piezoelectric material. Quartz-based piezoelectric systems can routinely measure large pressures for minutes and perhaps even hours. Low level pressures can be measured "statically" for much shorter intervals.

3.3 ACCELEROMETERS

3.3.1 MEASURING ACCELERATION

Piezoelectric accelerometers consist essentially of three elements: the transducer body, the piezoelectric sensing element and the seismic mass. The sensing element is preloaded between the transducer body and the seismic mass by a preloading element as shown in Figure 5. Because of the constant seismic mass, the force acting on the measuring element is proportional to the acceleration in accordance with Newton's first law: F=ma. An electrical charge is generated proportional to the force (and hence the acceleration).

Piezoelectric accelerometers with their inherent characteristics of low mass, high rigidity and subsequent high resonant frequency are ideally suited for measuring dynamic events like shock and vibration. However, because they are basically AC coupled devices, piezoelectric accelerometers are not suitable for measuring constant accelerations like those generated in a centrifuge.

In addition to the characteristics mentioned above, most accelerometers incorporate built-in-charge-to-voltage converters for low impedance voltage output. The low end frequency response is usually limited to 0.05 to 1 Hz, which is more than adequate for most shock and vibration applications. For ultra-low frequency (near DC) measurements, a high impedance accelerometer must be used with an external charge amplifier.

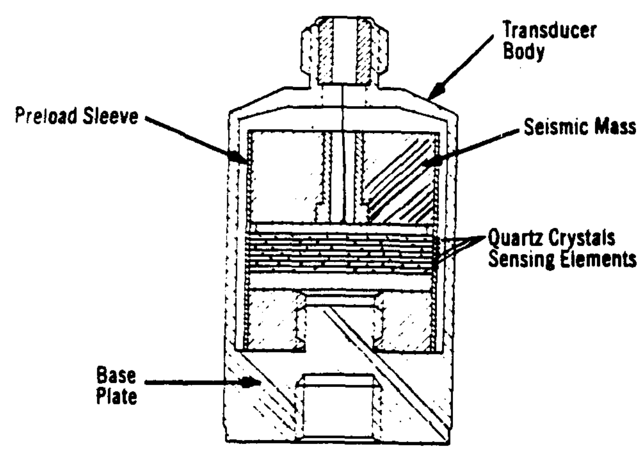

Figure 5 typical transducer (2).

CHAPTER 4

DESIGN SPECIFICATIONS AND ANALYSIS

4.1 SYSTEMS REQUIREMENTS

This section describes the overall system that is required to successfully record and analyze the valve sounds recorded from the body surface. This system can be partitioned into three major categories: (1- charge amplification, 2- filtering 3- Analog to Digital conversion) as shown in Figure 6 below.

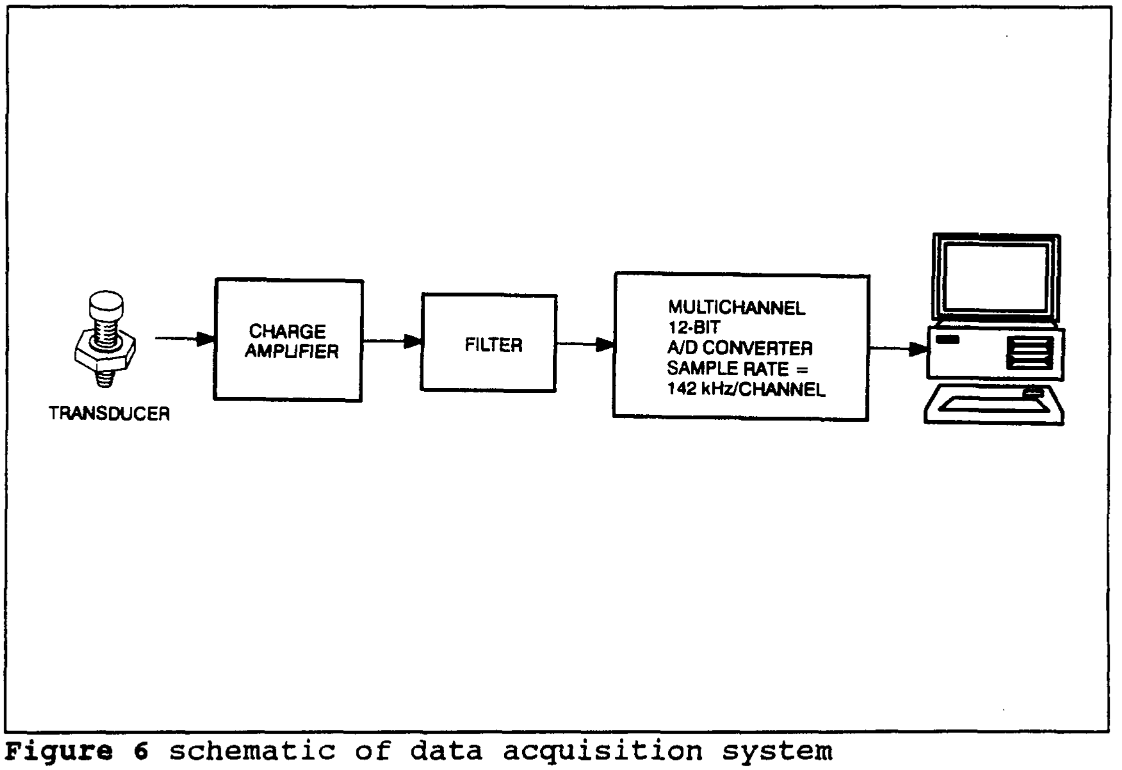

Figure 6 schematic of data acquisition system

4.1.1 Charge Amplifier Requirements

Since we used a piezoelectric transducer (Columbia Transducer MOD.200-P SER. 162) to measure the valve sounds a charge amplifier was designed to meet all the requirements needed to amplify the surface charge off the transducer.
Since piezoelectric materials have a high but finite resistance, the charge leaks through the leakage resistor whenever a static deflection x is applied[3]. Therefore it is quite important that the input impedance of the external voltage measuring device be at least of an order of magnitude higher than that of the piezoelectric transducer.
The need of a high input impedance coupled with the requirement of very low input current was satisfied by using the CA3130 Operational Amplifier where FET transistors are used in the input circuit as shown in Figure 7.

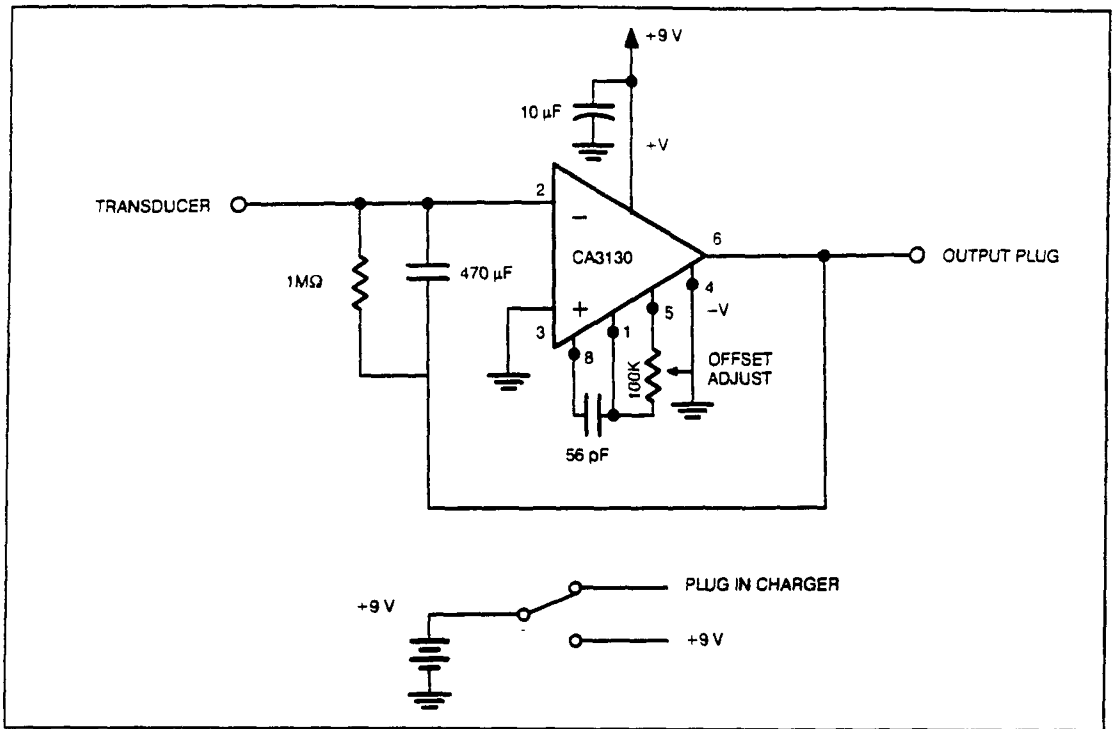

Figure 7 the CA3130 Operational Amplifier design

One equivalent circuit representation for the charge amplifier is as follows based on a input of a charge generator. This circuit is shown in Figure 8.

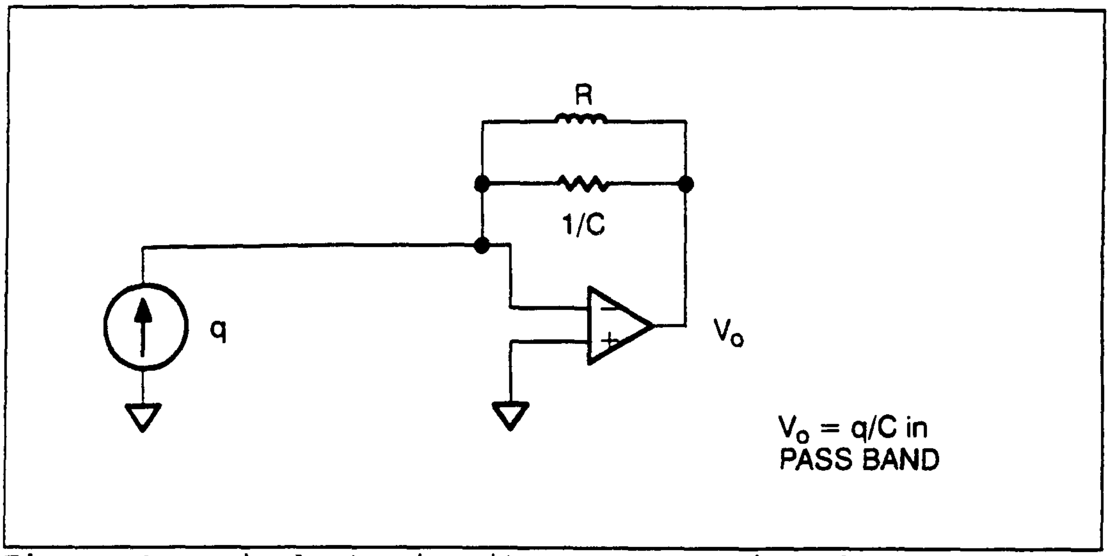

Figure 8 equivalent circuit representation for the charge amplifier with a charge generator as input.

Analysis:

The circuit has a charge generator q defined by

$$q = kx \quad (k = \text{proportionality constant, c/m})$$
$$(x = \text{deflection})$$

and since we know that

$$i = c\, dv/dt$$

however,

$$i = dq/dt$$

which implies that $\quad i = dq/dt = c\, dv/dt$

which can be written as $q = cv$ or $v = q/c$ ---> (R = 1/C)

On the other hand we have $V = iR$

however,

$$i = dq/dt$$

which implies $V = R\, dq/dt$ ---> (L = R)

LAPLACE transformation : $1/C \;//\; SR = (SR/C)/(1+SRC/C)$

$$= (SR)/(1+SRC)$$

----> $V(out) = (-q/C)\,(SR)/(1+SRC)$

Another simplified representation of the equivalent circuit can be generated by converting the charge generator to a current generator i(t). This is shown in Figure 9.

$$i(t) = dq/dt = k\, dx/dt$$

the output of the piezoelectric transducer can be fed directly into the negative input of the integrator because the FET op-amp negative input is a virtual ground. Hence, long cables can be used without changing transducer sensitivity or time constant, as is the case with voltage amplifiers.

with a current generator as input we have:

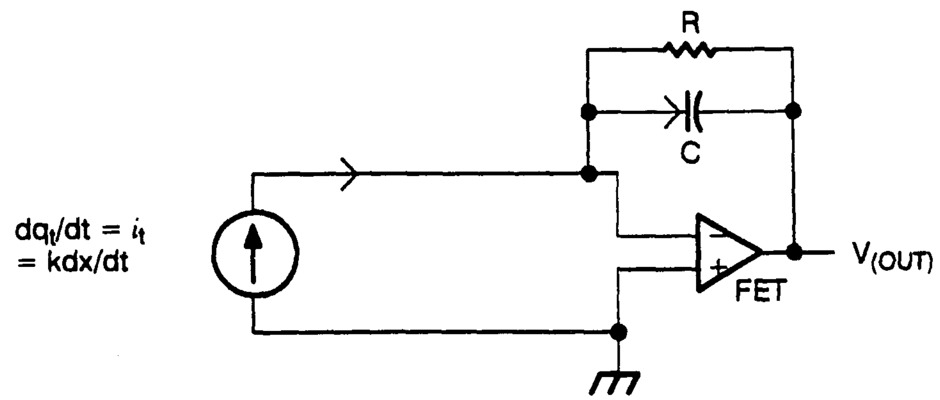

Figure 9 equivalent circuit based on current generator as input.

V(out) = R//C (-Sq)

LAPLACE transformation

(R//1/SC) = (R/SC)/1+RSC/SC)

= (R/1+RSC)

Again, this will lead to the same V(out)

V(out) = (-q/C) (SRC/1+SRC)

The circuit behaves like a high pass filter, with a time constant

tau = RC = 1 x 10^6 x 470 x 10^{-6} = 470 1/sec

The high pass filter responds only to frequencies above $f = 1/2\pi RC$ to reduce high amplitude, low frequency signals associated with cardiac motion and native heart sounds. The filter response is shown in Figure 10.

$f = 1/2 \times 3.14 \times 470 = 339\ \mu Hz$

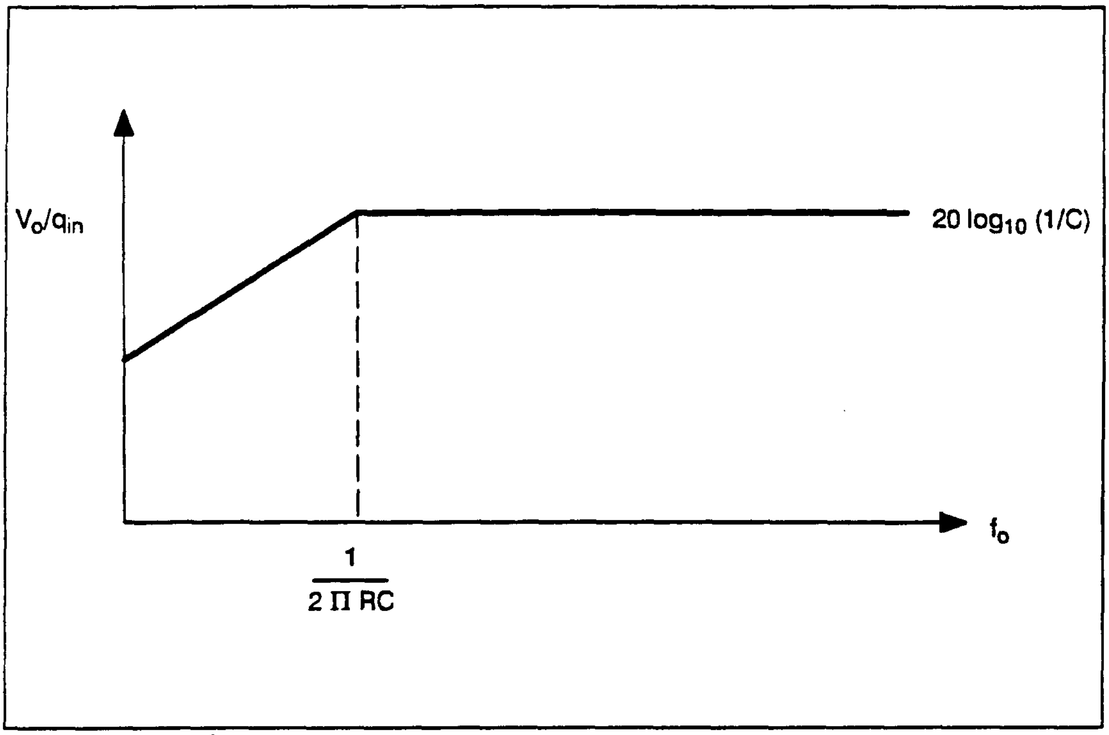

Figure 10 filter response

The op-amp was powered using a 9V battery with the capability of it being recharged from an external source without it being removed. The use of dc power supply was efficient in eliminating the power-line hum inherent in dc power supplies connected to the ac line.

The circuit was shielded from external electromagnetic influences by the use of chassis box. This is shown in Figure 11.

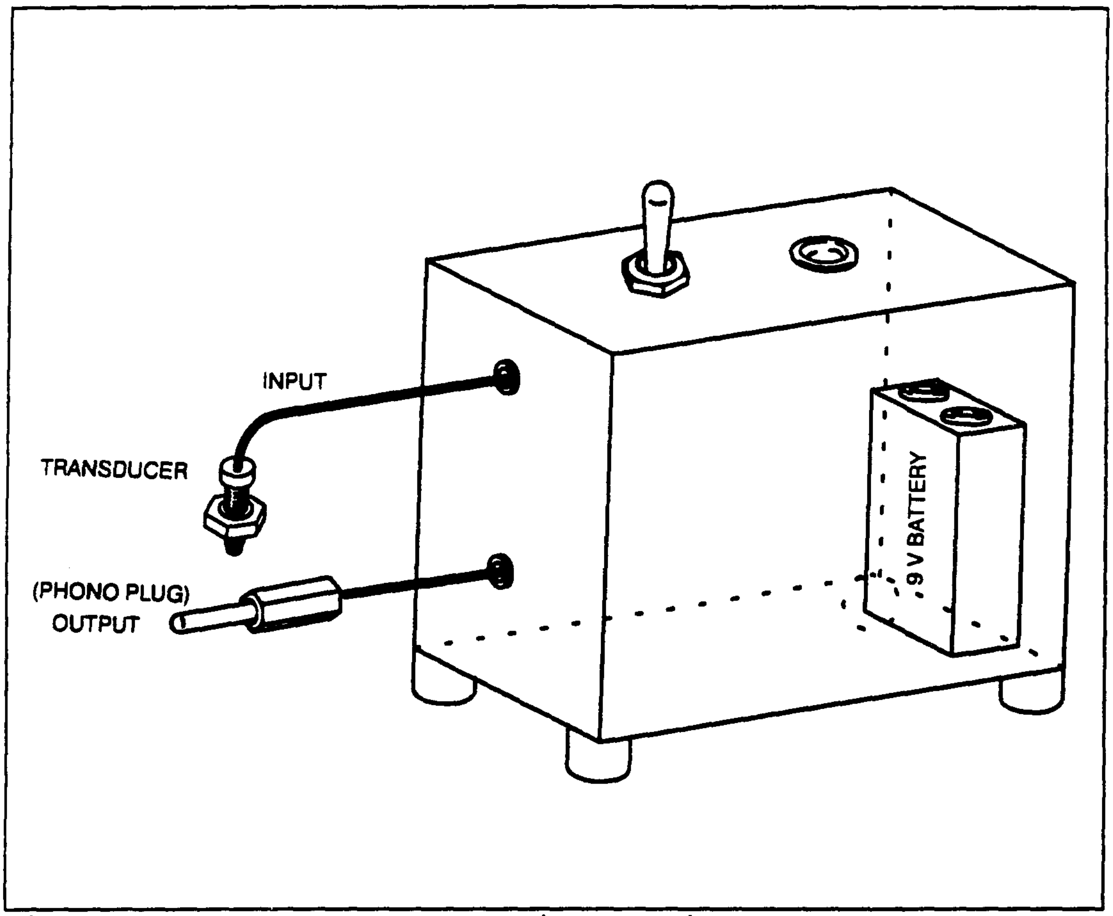

Figure 11 photo of hardware with the input and output shown.

4.1.2 Bandpass Filtering

In data acquisition, analog filtering in high speed information processing systems is used to eliminate components of signal and noise at frequencies greater than one-half the sampling frequency (71 kHz) in order to avoid aliasing -

intermodulation of unwanted high-frequency components of the signal with harmonics of the sampling frequency, to produce spurious signals at low frequencies. The cutoff frequency was set to approximately 40 kHz. This frequency is significantly above the frequencies of interest on this project. The amplifier and filter used for this purpose is a Radio Shack (Realistic MPA-40) which is commonly used and is commercially available.

4.1.3 Analog to Digital Conversion

The output signal of the amplifier and filter was recorded by a Mackintosh II CX computer via a MacADIOS II analog to digital converter (ADC). This ADC is manufactured to support the Apple Mackintosh II computer. The recorded data was both acquired and analyzed using custom - modified versions of the MacADIOS[6] II software which accompanies the ADC hardware. The ADC is an eight channel, high speed 12 bit analog to digital converter. Software which supports the MacADIOS II ADC hardware was modified to meet the signal acquisition and analysis requirements for the artificial heart valve signal. The acquisition program had a sampling rate of 142 kHz. The quantized data are initially stored in the computer memory and saved on the system's hard disk drive. These recordings were retrieved at a later time for spectral analysis using another modified version of the MacADIOS software.

CHAPTER 5

TEST PROCEDURES AND RESULTS

5.1 HYPOTHESIS

The hypothesis for this thesis is that the leaflets of normally functioning bileaflet mechanical valves do not close synchronously and that there is a time delay between them. Analysis of frequency spectra of sounds produced by prosthetic valves has been proposed as a method for assessing valve function. A study performed by Koymen[7] et al. suggested that the power spectra of the phonocardiogram signals recorded from patients with mechanical prosthetic heart valves have two dominant peaks in the frequency band of 200-500 Hz. Moreover, Sato and others[8,9] only defined frequencies less than 5 kHz which is significantly below the range of the dominant frequencies produced by mechanical valves recorded in this study. Closing sounds created by the bileaflet valves evaluated in this study had significant frequency components bigger than 10 kHz. A finding consistent with studies showing similar high frequencies in sounds produced by other properly functioning mechanical prosthetic valves[10,11].

5.2 TEST PROCEDURES

5.2.1 METHOD FOR ACQUIRING DATA

5.2.1.1 SUBJECT SELECTION

The subject population consisted of pediatric or adult patients who underwent valve replacement surgery in the department of Cardiovascular and Thoracic Surgery at the Arizona Health Sciences Center. These patients met the following criteria:

1. Have a single mechanical valve. Patients with more than one artificial valves were not included.
2. Be cooperative enough to allow recording of valve sounds without significant background noise.
3. Subjects/Parents were willing to give informed consent under a protocol approved by the university of Arizona Human Subjects Committee.

5.2.1.2 BACKGROUND DATA

The following information was obtained for each patient: a) name; b) age; c) sex; d) height and weight; e) number of valves and types; f) brief medical history.

5.2.1.3 SIGNAL ACQUISITION

The system was proven ready from the hardware and the software stand point. The patients that were recorded consisted of pediatric and adult patients who were doing routine follow up with Dr. Copeland at the Arizona Health Sciences Center. My thesis advisor Dr. Donnerstein and I, were given a separate room at the fifth floor of the University Medical Center to perform our recordings of the patients that met the qualification that were established under paragraph 5.2. There were three patients in total. Using the piezoelectric transducers as input to the filter the recording were completed. This data acquisition added less than 10 minutes to the time required for the checkup. All three patients were cooperative and excited about the study and the recording because they were able to see the closing valve sound on the computer screen while it was being recorded. A conductive gel was used between the transducer and the chest and the transducer was hand held on the chest close to the location of the artificial valve during the recording period. These audio signals then underwent direct analog-to-digital conversion for 10 seconds at 142 kHz sampling rate. This sampling frequency rate permitted unambiguous conversion of frequencies up to a Nyquist limit of 71 kHz, which is significantly above the frequencies of interest on this project. Digital data was originally saved on the system's internal hard drive and was retrieved at a later period for spectral analysis.

5.2.1.4 Spectral Analysis

Software[6] which supports the MacADIOS II hardware was modified to meet the signal acquisition and analysis requirements for our signal of interest. The acquisition programs were divided into two categories : 1- valve sound acquisition 2- Fast Fourier Transform

The valve sound acquisition program samples the PHONO input. It then displays messages to help the operator assign a name to the file that he/she would like to save the data under, valve type, valve location, valve size and microphone location. A grid is displayed before the save process starts to help the operator see the signal before recording it. The operator has the options of changing the gain, trigger threshold and replotting the signal with the new variables. Once the operator is satisfied with the plot, he/she can start the spooling process to save 10 seconds of data on the system's hard disk drive under the file name that the operator chooses.

The program based on FFT asks the operator to select the file that he/she would like to load. Once the file is loaded, the operator is required to input the scaling of the plot and the horizontal compression. A plot of the signal is presented on the screen and the operator is asked if he/she would like to replot with new variables (threshold, ...). The program then asks the operator to chose the window size . This window size is programmable and is usually set to encompass the signal. The operator is then to asked if he/she would like to perform FFT. Again, the option of choosing the scaling for the plot is available to the operator and so is the compression or expansion of the data.

This routine is repeated and an average FFT can be plotted for any number of signals. This plot can be saved under a special file name for later print.

5.3 RESULTS

Data collected from this study indicated that leaflets of valves do not close synchronously. (please see figures 12, 13, 14 for data). Leaflets close as they are captured in a stream of reversing blood flow and will impact the valve cage with a force related to valve inertia and the energy of this reversing stream. Asynchronous leaflets closure is to be expected under normal conditions and results from minor differences in forces applied to individual valve leaflets. The time interval between closure of leaflets varies somewhat from beat to beat due to individual valve leaflets striking the cage at different times. Figure 12 has a time delay of 4 msec. Figure 13 has a longer time delay of 5.5 msec while Figure 14 shows a time delay of 3 msec. An averaged FFT performed on multiple heart sounds from each patient revealed that the resonant frequencies of the power spectrum are in the ultrasonic range.

Figures 15 and 16 have a frequency peak at 18 kHz while Figure 17 has a resonant frequency of 18.5 kHz.

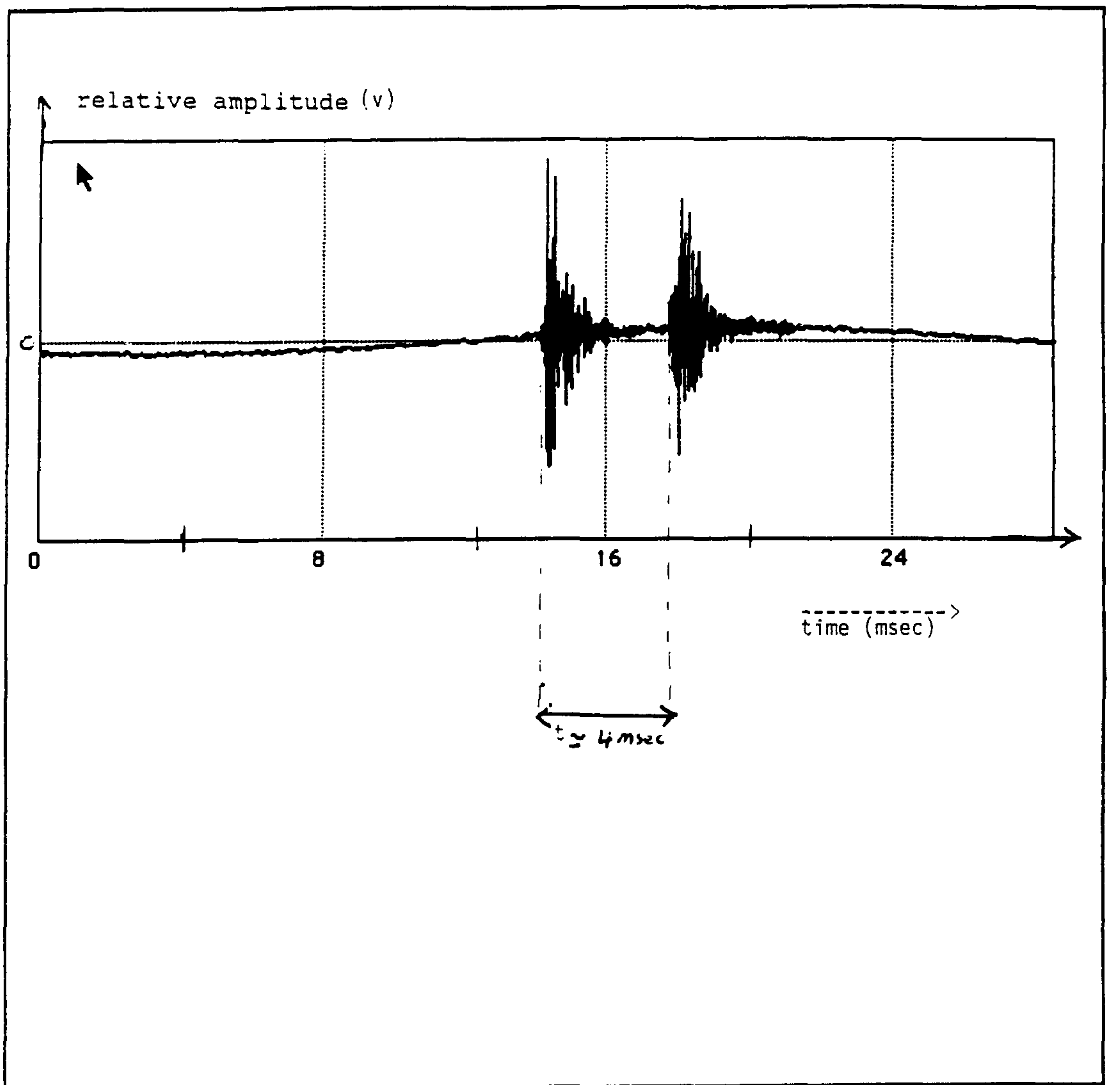

Figure 12 heart valve sound recorded from the body surface of patient 1.

Valve Type: Carbomedics

Valve Location: Aorta

Valve Size: 23mm

Microphone Location: Aortic Valve

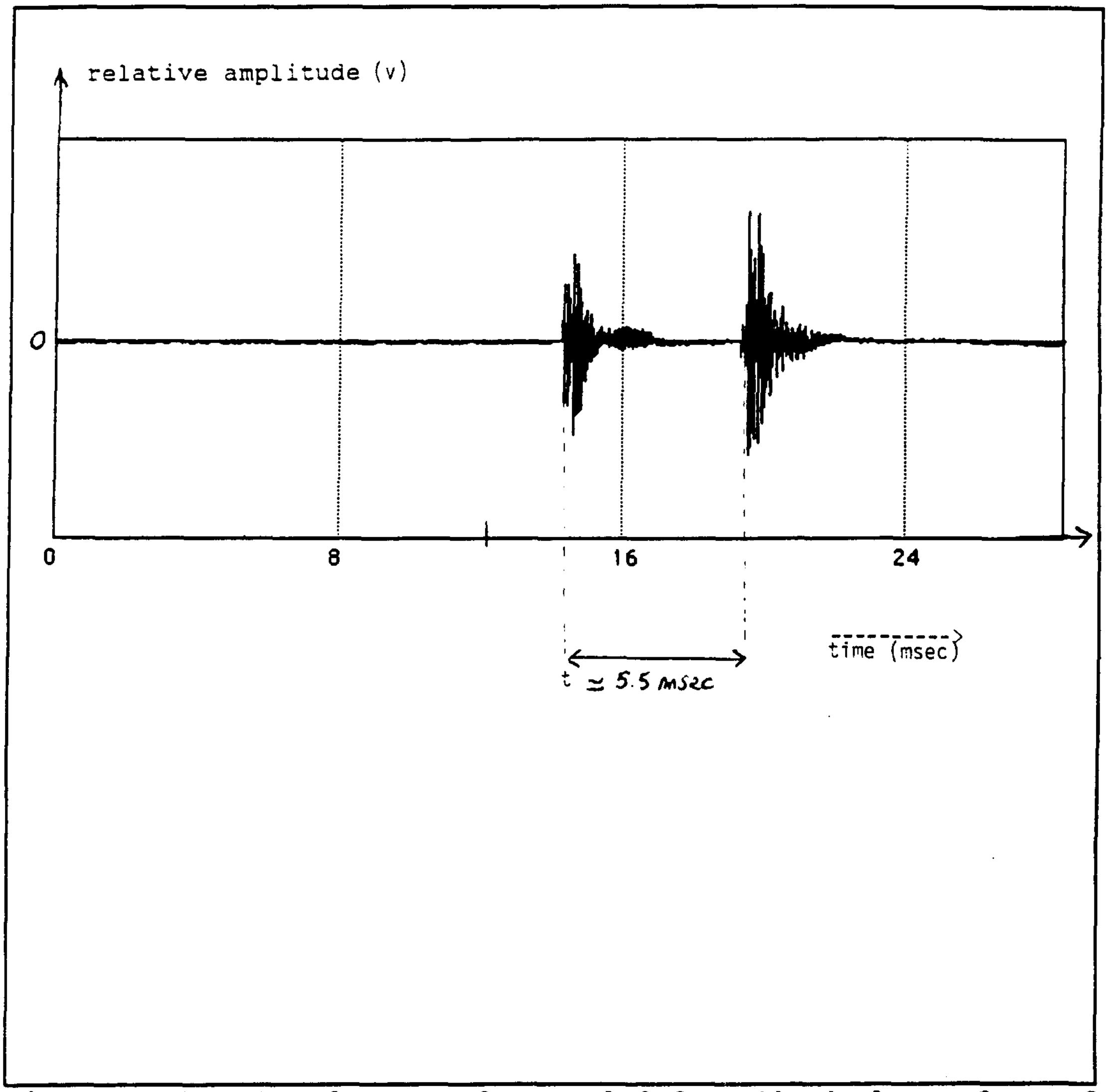

Figure 13 heart valve sound recorded from the body surface of patient 2.

Valve Type: Carbomedics

Valve Location: Aorta

Valve Size: 25mm

Microphone Location: Aortic Valve

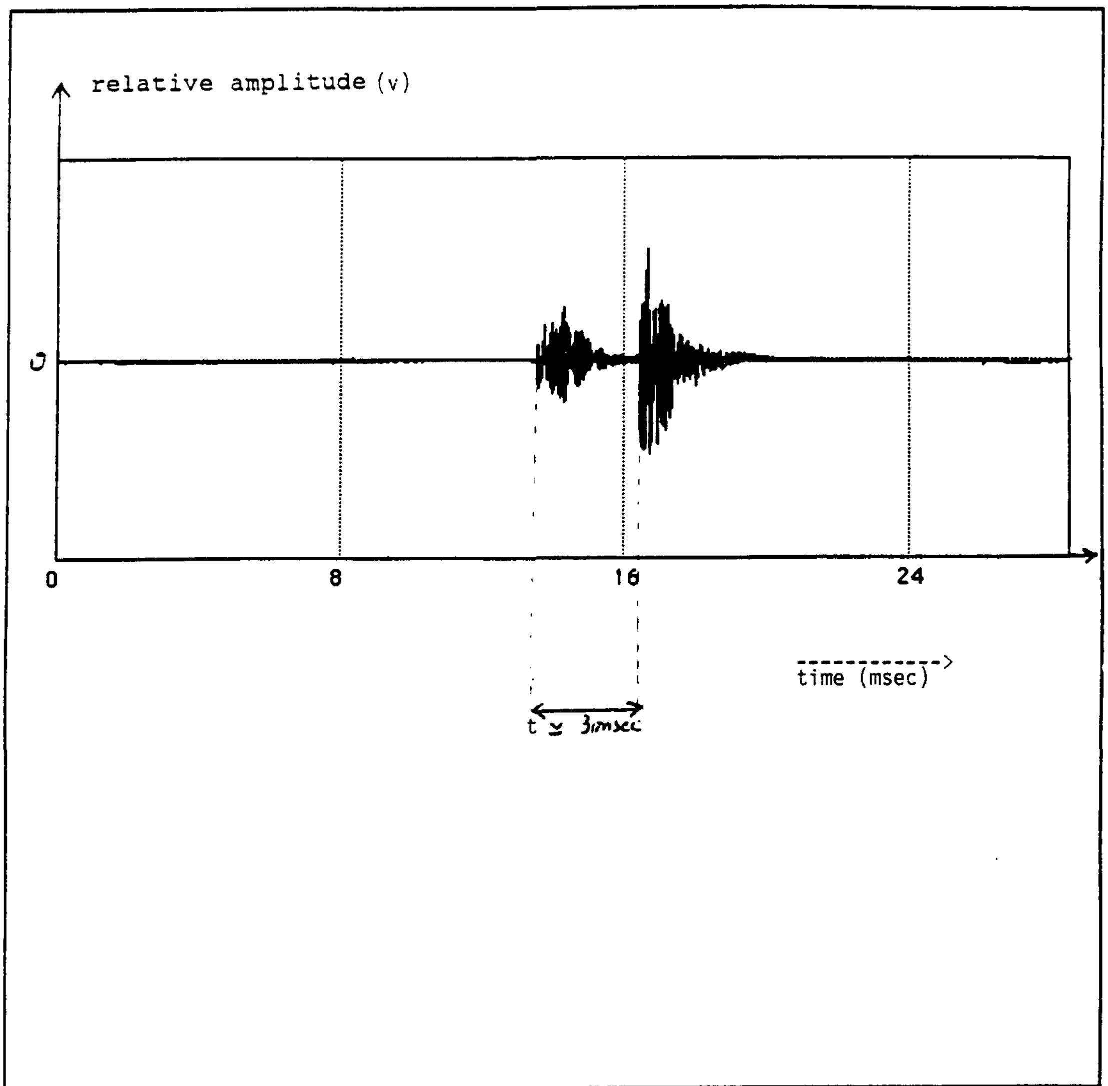

Figure 14 heart valve sound recorded from the body surface of patient 3.

Valve Type: St. Jude

Valve Location: Mitral

Valve Size: 29mm

Microphone Location: Mitral Valve

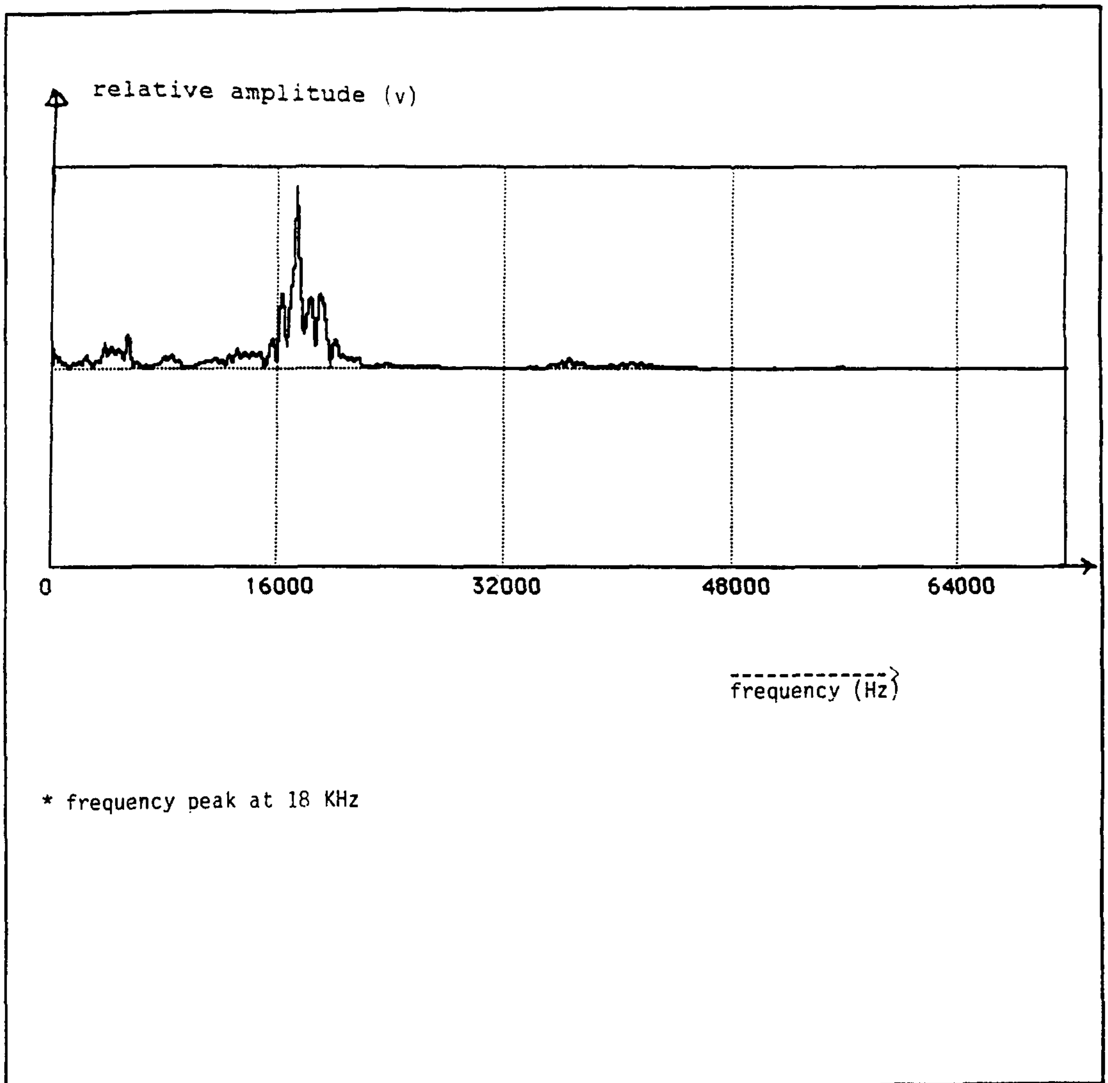

Figure 15 averaged Fast Fourier Transform on multiple heart valve sounds of patient 1.

Valve Type: Carbomedics

Valve Location: Aorta

Valve Size: 23mm

Microphone Location: Aortic Valve

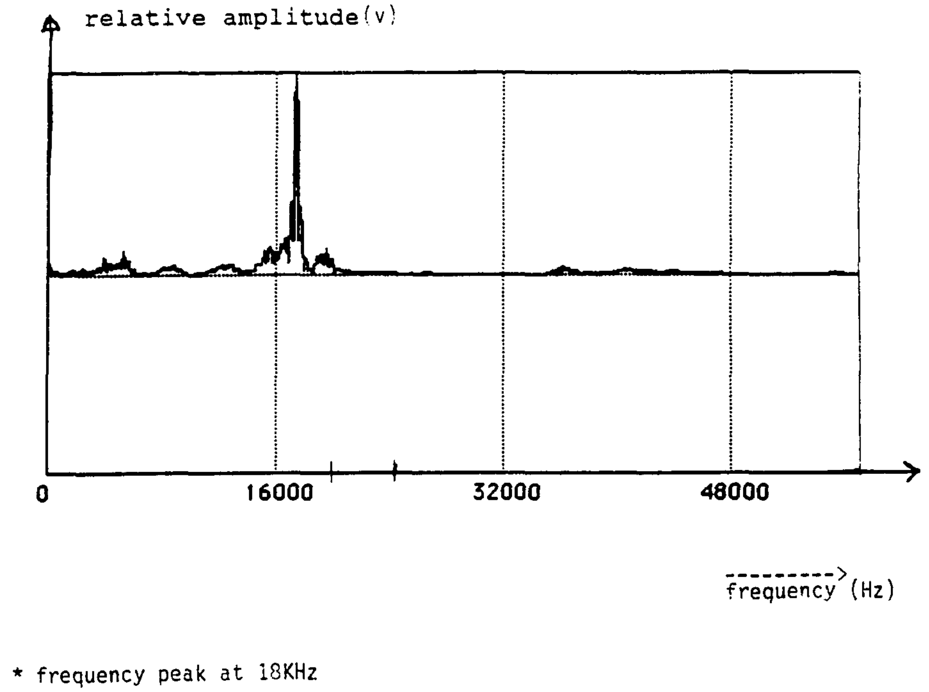

Figure 16 averaged Fast Fourier Transform on multiple heart valve sounds of patient 2.

Valve Type: Carbomedics

Valve Location: Aorta

Valve Size: 25mm

Microphone Location: Aortic Valve

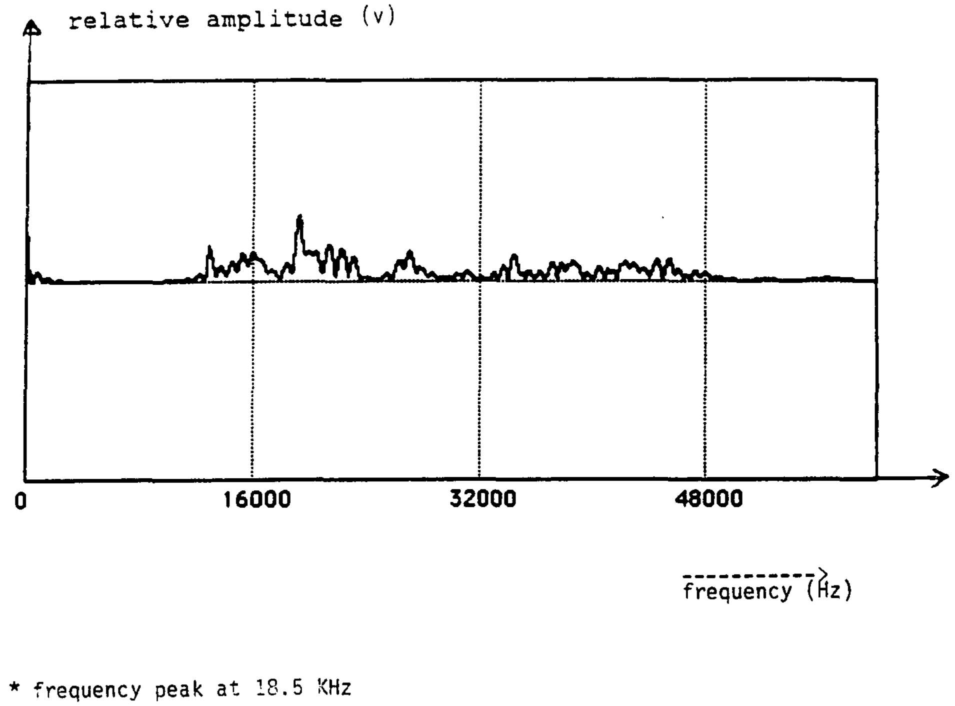

Figure 17 averaged Fast Fourier Transform on multiple heart valve sounds of patient 3.

Valve Type: St. Jude

Valve Location: Mitral

Valve Size: 29mm

Microphone Location: Mitral Valve

CHAPTER 6

CONCLUSION AND FUTURE DIRECTIONS

6.1 Concluding Remarks

After brief review of heart valves in general, other techniques of evaluating heart valves along with the drawbacks of each technique were presented to give the reader insight into what is available and a justification for this research study. This was followed by a detailed design specifications and the description of the overall system required for the recording of prosthetic heart valve sounds from the body surface. The relevant design issues were revealed in the detailed, stage-by-stage description of the system. Finally, the test procedures and studies performed with this custom-designed research tool and the results generated by this system were presented. This research has developed a custom-designed instrumentation which, when combined with digital data acquisition and the proper data analysis programs, can successfully detect and record the closing sounds of mechanical heart valves. This system includes a design that does not utilize extensive hardware and is portable. As for the reliability of this system, we can confidently conclude that we have developed a successful research tool for noninvasive detection and recording of artificial heart sounds.

6.2 Future Directions

Mechanical heart valves are the most used in heart valve implantation worldwide each year[1]. Despite recent advances in materials and designs of prosthetic valves, a certain percentage of patients develop complications related to implanted valves. Mechanical prostheses have the advantage of durability, however the incidence of thrombus formation is relatively high and patients are at continuous risk of thromboembolic complications despite careful anticoagulant therapy. Advanced thrombus formation on a prosthetic valve may restrict occluder movement and lead to hemodynamic catastrophe[8]. Early detection of prosthetic valve dysfunction is extremely critical because long term prognosis for patients after valve replacement strongly depends upon the ability to assess valve function. While echocardiography, cinefluoroscopy, and standard phonocardiography can confirm advanced valve dysfunction, none of these techniques has been shown to reliably detect early valve degeneration. Since current noninvasive methods cannot reliably detect early mechanical problems, this research study can be explored in an attempt to identify changes associated with valve degeneration. In theory, any significant alteration in mechanical valve properties (clot, sticking,cracking,....) should be associated with changes in frequencies of opening and closing sounds or changes in the pattern of leaflet closure. Changes could be reflected as alterations in:

1) Location of resonant frequency peaks of the valve sound

2) Amount of asynchrony

3) Decrease in amplitude of high resonant frequency content of heart sound

Future studies should investigate the leaflet closure patterns and frequency spectra of closing sounds of normally functioning bileaflet mechanical valves to determine if they remain stable over time and to observe if leaflet closure patterns and frequency spectra of closing sounds of bileaflet mechanical valves change in the presence of adverse alterations.

APPENDIX I

LISTINGS OF ACQUISITION AND ANALYSIS SOFTWARE

DATA ANALYSIS PROGRAM LISTING

These subroutines listed in the following appendix were for the most part written by Dr. Richard Donnerstein, Associate professor, Department of pediatrics, University Medical Center, Tucson, Arizona. Some were derived from the MacADIOS[6] II SOFTWARE Series Instruction Manual by GW Instruments, Inc.

```
LIBRARY "turbodrivers interface"
LIBRARY "DataManipulation Interface"
tickssst&=0
ticksend& = 0
rr%=0:dem% = 0:index%=0
disker%=0
TY$="":SI$ = "":MI$ = "":LO$ = "":VL$=""
TYt$="":SIt$ = "":MIt$ = "":LOt$ = "":VLt$=""
PRINT
PRINT "VALVE SOUND ACQUISITION"
PRINT"We're now initializing some variables, it will take a moment."
    trigger%=0
   loops% = 0
    bank%=0              ' indicates multiplexor channel#0 as first digitized channel for
digitize()
   Period%=0

Slot%=3:eri%=0:points%=0:i=0:pnts&=0:hr%=500:trh%=500:Trig%=0
eri% =0:min!=0
GOSUB LoadTurboSymbols              ' Load TurboDriver Header File constants
PRINT "Connect    EKG      TO     AD0"
PRINT "Connect    PHONO    TO     AD7"
DIM STATIC er%(800),dev%(20),stats%(5)
DIM STATIC w0%(29999,50),rec1%(4)
rec1%(0) = 250
rec1%(1) = 9
rec1%(2) = 400
rec1%(3) = 511


PRINT "Please press ANY KEY when connections are complete"
GetKeyPress10:    key$= INKEY$  :  IF key$ = "" THEN GetKeyPress10
start1:
CLS
INPUT " NAME OF FILE TO SAVE?";F1$

PRINT  "VALVE TYPE";"<";TYt$;">";
INPUT TY$
IF TY$ = "" THEN TY$ = TYt$
TYt$ = TY$

PRINT  "VALVE LOCATION";"<";VLt$;">";
INPUT VL$
```

```
IF VL$ = "" THEN VL$ = VLt$
VLt$ = VL$

PRINT  "VALVE SIZE";"<";SIt$;">";
INPUT SI$
IF SI$ = "" THEN SI$ = SIt$
SIt$ = SI$

PRINT  "MICROPHONE TYPE";"<";MIt$;">";
INPUT MI$
IF MI$ = "" THEN MI$ = MIt$
MIt$ = MI$

PRINT  "MICROPHONE LOCATION";"<";LOt$;">";
INPUT LO$
IF LO$ = "" THEN LO$ = LOt$
LOt$ = LO$

dem% = 0
FOR index% = 1 TO LEN(TY$)
cha% = ASC(MID$(TY$,index%,1))
w0%(dem%,49) = cha%
dem% = dem% + 1
NEXT index%
w0%(dem%,49) = 13
dem% = dem% + 1

FOR index% = 1 TO LEN(VL$)
cha% = ASC(MID$(VL$,index%,1))
w0%(dem%,49) = cha%
dem% = dem% + 1
NEXT index%
w0%(dem%,49) = 13
dem% = dem% + 1

FOR index% = 1 TO LEN(SI$)
cha% = ASC(MID$(SI$,index%,1))
w0%(dem%,49) = cha%
dem% = dem% + 1
NEXT index%
w0%(dem%,49) = 13
dem% = dem% + 1
```

```
FOR index% = 1 TO LEN(MI$)
cha% = ASC(MID$(MI$,index%,1))
w0%(dem%,49) = cha%
dem% = dem% + 1
NEXT index%
w0%(dem%,49) = 13
dem% = dem% + 1

FOR index% = 1 TO LEN(LO$)
cha% = ASC(MID$(LO$,index%,1))
w0%(dem%,49) = cha%
dem% = dem% + 1
NEXT index%
w0%(dem%,49) = 13
dem% = dem% + 1



PRINT "DATA WILL BE COLLECTED FOR 10 SECONDS AT A RATE OF 140,000"
REM ************** Setup Inout(), Digitize() and Fastio() Parameters
**************

SetupFunctionParameters:
   trigger%=-1        ' trigger parameter set to -1 invokes EXTENDED mode
   loops% = 10000        ' specifies 10000 loops or "traces"
   dev%(0) = 0        ' Device Type for A/D converter, Mux Channel #0
   dev%(1) = 0        ' Offset code for A/D converter, Mux Channel #0
   bank%=0              ' indicates multiplexor channel#0 as first digitized channel for
digitize()
   Period%= 25         ' sets sample period for digitize()
REM ************** Setup TurboDriver GENERAL parameters ****************
SetupGeneralParameters:
   er%(DriveINDX) = 3
   er%(OptionsINDX) = OptNone        ' Specify no interrupts and no spooling to hard disk
   er%(OpModeINDX) = OpModeNorm  ' Normal I/O command

REM **************** Setup TurboDriver GRAPHICS Parameters
****************

SetupGraphicsParameters:
   er%(pppINDX) = 10                ' Plot 1 point in each pixel column
   er%(DotsINDX) = true            ' Plot lines, no dots (false=0)
   er%(GridINDX) = true             ' Display grid (true=1)
    er%(firstclearIndx) = true        ' Clear display prior first trace (true =1)
```

```
   er%(ClearIndx) = true                 ' Clear display after each trace (true = 1)

REM ***************** Setup TurboDriver Trigger parameters
*******************

SetupTriggerParameters:

   er%(TrOffINDX) = 0              ' Trigger offset code is set to A/D mux channel #0
   er%(TrDevTyINDX) = 0            ' Trigger device type code is set to A/D mux channel
#0
   er%(TrThreshINDX) = 500          ' Trigger threshold level is 500

REM ****************** Setup TurboDriver Digitize() parameters
****************

SetupDigitizeParameters:
  er%(DigLoopsHiINDX) = 0

REM ****************** Setup TurboDriver Channel parameters
****************

SetupChannelParameters:
   er%(ChLeftINDX(0)) = 10              ' Specify pixel column #10 as left edge of display
region
   er%(ChRightINDX(0)) = 510            ' Specify pixel column #470 as right edge of
display region
   er%(ChTopINDX(0)) = 70      ' Specify top edge of display region
   er%(ChBotINDX(0)) = 220     ' Specify bottom edge of display region
   REM    er%(ChTopINDX(0)) = 70     ' Specify top edge of display region
   REM    er%(ChBotINDX(0)) = 95     ' Specify bottom edge of display region
   er%(ChTPVINDX(0)) = 2048            ' Specify display region Top Plot Value
   er%(ChBPVINDX(0)) = -2048           ' Specify display region Bottom Plot Value
   er%(ChGridDxINDX(0)) = 2            ' Grid horizontal displacement
   er%(ChGridDyINDX(0)) = 16           ' Grid vertical displacement
  er%(ChDrawINDX(0)) = 1             ' Turn channel display ON


sca:
REM ------------------------- digitize() in Scan-Line mode -------------------

CALL setAD(0,1,3,VARPTR(eri%))
 er%(TrigINDX) = TrigNone    ' no trigger

DigitizeScan:             ' Here we run Digitize() in Scan-Line Recorder mode
   er%(ModeINDX) = modeScan           ' Specify Scan-Line Recorder mode
   er%(DigLoopsLowINDX) = 1           ' Specify 1 loop or "traces" (this must be done for
```

```
SCAN mode)
    points%=5000     ' We can acquire more date in scan-line mode

   CLS      ' Clear Screen
    PRINT "Below is Digitize() operating in Scan-Line Recorder mode."
   PRINT  "move mouse to stop"
   FOR i = 1 TO 100
    digitize     bank%, trigger%, points%, Period%,
VARPTR(w0%(0,0)),0,0,0,0,0,0,0,Slot%,  VARPTR(er%(0))
      IF er%(ErrorINDX) =0 THEN ne
    PRINT "We got an error.  er%(ErrorINDX) = "er%(ErrorINDX)
    PRINT "Please press SPACE TO continue, or 'a' to do it again"
   INPUT a$
   GetKeyPress6:    key$= INKEY$
   IF key$="a" THEN DigitizeScan ELSE IF key$ = "" THEN GetKeyPress6
   GOTO noscan
   ne:
   NEXT i
   noscan:
osc:
 er%(DigLoopsLowINDX) = 1
 Period%= 1
  pnts&=5000&
REM ------------------------- digitize() in Oscilloscope mode
--------------------
replot:
REM **************** Setup TurboDriver GRAPHICS Parameters
****************
SetupGraphicsParameters1:
   er%(ppplNDX) = 10                ' Plot 1 point in each pixel column
   er%(DotsINDX) = false           ' Plot lines, no dots (false=0)
   er%(GridINDX) = true            ' Display grid (true=1)
    er%(firstclearIndx) = true     ' Clear display prior first trace (true =1)
   er%(ClearIndx) = true            ' Clear display after each trace (true = 1)


 CLS      ' Clear Screen

er%(ModeINDX) = ModeOSC
 er%(TrigINDX) = TrigNormPos    ' Trigger on positive edge signal
DigitizeOscilloscope:
  PRINT "WOULD YOU LIKE TO CHANGE THRESHOLD < ";trh%;">";:INPUT hr%
  IF hr%=0 THEN hr%=trh%
```

```
   trh% = hr%
    er%(TrThreshINDX) = trh%
LOCATE 1,1
    PRINT  "Press any key or move mouse to stop display or change threshold"

doag:
     digitize  bank%, trigger%, pnts&, Period%, VARPTR(w0%(0,0)),0,0,0,0,0,0,0,Slot%,
VARPTR(er%(0))
   ERASERECT(VARPTR(rec1%(0)))
   FRAMERECT(VARPTR(rec1%(0)))
      CALL   plot(0,250,400,10,VARPTR(w0%(0,0)),2048,-2048,5000,10,0,1,0)
    stats%(3)=1
    stats%(4)=2
  MOVETO 20,240
     CALL stat (VARPTR(w0%(0,0)), 5000,VARPTR(stats%(0)))
    PRINT  stats%(2),stats%(1)
   IF er%(ErrorINDX) =0 THEN doag
   CLS
    PRINT "We got an error.  er%(ErrorINDX) = "er%(ErrorINDX)
    PRINT "Please press SPACE TO continue, or 'a' to do it again"
   GetKeyPress3:    key$= INKEY$
    IF key$="a" THEN DigitizeOscilloscope ELSE IF key$ = "" THEN GetKeyPress3

aa:
INPUT "Input <s>  to spool, <p> to plot again or <g> to change gain";a$
IF (a$ <>"s" AND a$<>"p"AND a$<>"g") THEN aa
IF a$ = "p" THEN replot
' ********* Initialize  EXTENDED  mode  Parameters  *********
er%(ModeINDX) = ModeREG                        ' Regular I/O, No graphics
er%(OptionsINDX) = OptSpoolHD                  ' Specify spooling feature
er%(OpModeINDX) = OpModeNorm                   ' Normal operation
er%(TrigINDX) = TrigNone                       ' No triggering
er%(FileNameINDX) = f%                         ' Specify a File name of "f%"
er%(SpoolINDX) = SpOut                         ' Specify a SPOOL OUT operation
er%(DigLoopsLowINDX) = 1                       ' Collect 1 trace of data
er%(DigLoopsHiINDX) = 0                        ' # of traces = 0 * 32768 + 1
bank% = 0                      '  analog input channel#0
Trig% = 0
trigger% = -1                  '  extended modes
pnts& =1428570&+100            '
Period% = 35                   '  Δt=10us,   50000 samples/sec/channel
CLS
PRINT
```

```
   PRINT  "Points = ";fpts&
  INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
```

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Source File: vlvsndpictfft2

```
   IF a$ = "y" OR a$ = "Y" THEN refft
 nfft:
   tt% = tt%+1
   IF tt% = amt% GOTO savedat
GOTO newplot
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
    INPUT "Would you like to change threshold (y or n)<n>";a$
  IF a$ <> "y" AND a$ <> "Y" THEN STOP
    INPUT "New threshold"; thr%
    GOTO rethresh
 savedat:
CLS
     INPUT "Would you like to plot average fft (y or n)<y>";a$
   IF (a$ = "n" OR a$ = "N") THEN noplfft
  refft1:
     PRINT  " maximum scale for plot<"ftscl&">";:INPUT fscl&
     IF fscl&=0 THEN fscl&=ftscl&
     ftscl& = fscl&
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
  INPUT " EXPAND or COMPRESS <E or C>";a$
   IF (a$ = "e" OR a$ = "E") THEN fcmp% = fcmp%/2
   IF (a$ = "c" OR a$ = "C") THEN fcmp% = fcmp%*2
   IF fcmp% = -4 THEN fcmp% = 1
   IF fcmp% < 1 THEN fcmp% = -2
   IF fcmp% > 8 THEN fcmp% = 8
    ftcmp% = fcmp%
     fpts& = 512*(fcmp%)
   IF fcmp% < 1 THEN fpts& = 256
```

```
CLS:FRAMERECT VARPTR(BND%(0))
 PENMODE(8)
    CALL  grid(2,5,205,60,572,2,100,5,114)
      CALL  plot(1,5,205,60,VARPTR(hsfave!(0)),fscl&,-fscl&,fpts&,fcmp%,2,1,0)
   fhscale! = fpts&/512
sc1&=fhscale!*2000:sc2&=fhscale!*4000:sc3&=fhscale!*6000:sc4&=fhscale!*8000
   LOCATE 17,1:PRINT PTAB(48);0;PTAB(152);sc1&;PTAB(266);sc2&;
   PRINT PTAB(380);sc3&;PTAB(494);sc4&
 LOCATE 19,5
  PRINT  "Points = ";fpts&
INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
 IF a$ = "y" OR a$ = "Y" THEN refft1
noplfft:
 SAVEFILE$=FILES$(0)
 IF SAVEFILE$="" THEN restart
CLS
PRINT "SAVING FILE...Please wait."
  CALL bsave("",SAVEFILE$,VARPTR(qrs%(0,0)),2,348600&,VARPTR(disker%))
 ffile$ = SAVEFILE$ + "fft"
   CALL bsave("",ffile$ ,VARPTR(hsfave!(0)),3,8350&,VARPTR(disker%))
GOTO restart
```

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Source File: vlvsndpictfft2

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Source File: vlvsndpictfft2

Symbol and Label Tables for: MAIN

SYMBOL	TYPE	STORAGE	ADDRESS
LENGTH%	INTEGER	LOCAL	0040C918
FILELENG%	INTEGER	LOCAL	0040C91A
DDD%	INTEGER	LOCAL	0040C91C
ITE%	INTEGER	LOCAL	0040C91E

A!	SINGLE	LOCAL	0040C920
B%	INTEGER	LOCAL	0040C924
T%	INTEGER	LOCAL	0040C926
F%	INTEGER	LOCAL	0040C928
NUM%	INTEGER	LOCAL	0040C92A
R!	SINGLE	LOCAL	0040C92C
Q!	SINGLE	LOCAL	0040C930
S!	SINGLE	LOCAL	0040C934
H%	INTEGER	LOCAL	0040C938
G%	INTEGER	LOCAL	0040C93A
X!	SINGLE	LOCAL	0040C93C
Z!	SINGLE	LOCAL	0040C940
C%	INTEGER	LOCAL	0040C944
P!	SINGLE	LOCAL	0040C946
O!	SINGLE	LOCAL	0040C94A
FLAGT%	INTEGER	LOCAL	0040C94E
A%	INTEGER	LOCAL	0040C950
T!	SINGLE	LOCAL	0040C952
BYTES&	LONG	LOCAL	0040C956
DISKER%	INTEGER	LOCAL	0040C95A
DPNT&	LONG	LOCAL	0040C95C
SCL&	LONG	LOCAL	0040C960
CMP%	INTEGER	LOCAL	0040C964
PTS&	LONG	LOCAL	0040C966
FTCMP%	INTEGER	LOCAL	0040C96A
FCMP%	INTEGER	LOCAL	0040C96C
THR%	INTEGER	LOCAL	0040C96E
TT%	INTEGER	LOCAL	0040C970
STA%	INTEGER	LOCAL	0040C972
SKIP&	LONG	LOCAL	0040C974
P&	LONG	LOCAL	0040C978
AMT%	INTEGER	LOCAL	0040C97C
Z%	INTEGER	LOCAL	0040C97E
II&	LONG	LOCAL	0040C980
I%	INTEGER	LOCAL	0040C984
J%	INTEGER	LOCAL	0040C986
HSFSQ2!	SINGLE	LOCAL	0040C988
FO$	STRING	LOCAL	0000005A
BL$	STRING	LOCAL	00000060
TY$	STRING	LOCAL	00000066
SI$	STRING	LOCAL	0000006C
MI$	STRING	LOCAL	00000072
LO$	STRING	LOCAL	00000078

CAR$	STRING	LOCAL	0000007E
VL$	STRING	LOCAL	00000084
EKG%()	INTEGER	LOCAL	000000A2
FI$()	STRING	LOCAL	002EB1DC
FFT%()	INTEGER	LOCAL	002EB454

Source File: vlvsndpictfft2

HSF2!()	SINGLE	LOCAL	002ED540
HSFAVE!()	SINGLE	LOCAL	002F589E
HSF!()	SINGLE	LOCAL	002FDBFC
HSF1!()	SINGLE	LOCAL	00305F5A
QRS%()	INTEGER	LOCAL	0030E2B8
TQRS%()	INTEGER	LOCAL	003B45BC
BND%()	INTEGER	LOCAL	003B86B0
BND1%()	INTEGER	LOCAL	003B86D2
BND4%()	INTEGER	LOCAL	003B86F4
BND2%()	INTEGER	LOCAL	003B8716
FF%()	INTEGER	LOCAL	003B8738
LOADFILE$	STRING	LOCAL	0000008A
FF%	INTEGER	LOCAL	0040C98C
A$	STRING	LOCAL	00000090
TSCL&	LONG	LOCAL	0040C98E
THLOC%	INTEGER	LOCAL	0040C992
SH%	INTEGER	LOCAL	0040C994
AXIS%	INTEGER	LOCAL	0040C996
HSCALE%	INTEGER	LOCAL	0040C998
FFPTS%	INTEGER	LOCAL	0040C99A
X%	INTEGER	LOCAL	0040C99C
INC%	INTEGER	LOCAL	0040C99E
UPBD&	LONG	LOCAL	0040C9A0
HH%	INTEGER	LOCAL	0040C9A4
KK%	INTEGER	LOCAL	0040C9A6
FTSCL&	LONG	LOCAL	0040C9A8
FSCL&	LONG	LOCAL	0040C9AC
FPTS&	LONG	LOCAL	0040C9B0
FHSCALE!	SINGLE	LOCAL	0040C9B4
SC1&	LONG	LOCAL	0040C9B8
SC2&	LONG	LOCAL	0040C9BC
SC3&	LONG	LOCAL	0040C9C0
SC4&	LONG	LOCAL	0040C9C4

SAVEFILE$	STRING	LOCAL	00000096
FFILE$	STRING	LOCAL	0000009C

STORAGE	MEMORY
LOCAL	4245964

LABEL	ADDRESS	LABEL	ADDRESS
RESTART	0000058C	NEXCAR	00000A9C
DEMOG	00000AC2	PLOTAG	00000DEE
RETHRESH	000014E2	NOTHRESH	00001ADA
REMARSH	00001B26	PRINTERT	00001A8E
REPLOT	00001CE6	PLOTAG1	00001D60
NEWPLOT	00001DB0	THR	000029A0
STPT	0000261E	THR1	00002A70
NFFT	000039F4	REFFT	0000310C
SAVEDAT	00003C0C	NOPLFFT	000045C0
REFFT1	00003CE0		

***** 0 errors

Microsoft QuickBASIC Listing 05/20/92 Page 1

Source File: vlvsndpictfft2

Program Unit: MAIN Entry: 00000022

```
 '****NOTE!!!! this version suppresses validity test*******
 LIBRARY "DataManipulation Interface"
 length%=0:fileleng%=0:ddd%=0:ite% = 0
 a=0:b%=0:t%=0:f%=0:num%=0:r=0:q=0:s=0:h%=0:g%=0:x=0:z=0:c%=0:p=o:flagt%=0
 a%=0:t!=0:bytes&=0:disker%=0:dpnt&=0:scl&=0:cmp%=0:pts&=0:ftcmp%=8:fcmp%=8
 thr%=0:tt%=0:sta%=0:skip&=0:p&=0:amt%=0:z%=0:ii&=0:l%=0:j%=0:hsfsq2!=0
 fo$ = "":bl$ = SPACE$(155)
 TY$ = "":SI$ = "":MI$ = "":LO$ = "":car$="":VL$ = ""
 DIM STATIC ekg%(29999,50),fi$(100),fft%(4200),hsf2!(8400),hsfave!(8400)
 DIM STATIC hsf!(8400),hsf1!(8400)
 DIM STATIC qrs%(8300,40),TQRS%(8300),BND%(3),BND1%(3),BND4%(3),BND2%(3),ff%(4200,40)
 BND%(0) = 5:BND%(1) = 60:BND%(2) = 205:BND%(3) = 572
 BND4%(0) = 5:BND4%(1) = 60:BND4%(2) = 205:BND4%(3) = 460
 BND1%(0) = 10:BND1%(1) = 60:BND1%(2) = 110:BND1%(3) = 460
 BND2%(0) = 130:BND2%(1) = 60:BND2%(2) = 230:BND2%(3) = 460
 FOR a% = 0 TO 100
 fi$(a%) = STR$(a%)
 NEXT a%
 CLS
  restart:
 PRINT "SELECT THE DATA FILE YOU WISH TO USE"
 LOADFILE$=FILES$(1,"DATA")
 IF LOADFILE$="" THEN restart
 CLS
 PRINT LOADFILE$
 PRINT "LOADING FILE...Please wait."
 CALL filelen ("",LOADFILE$,VARPTR(bytes&),VARPTR(disker%))
 CALL bload("",LOADFILE$,VARPTR(ekg%(0,0)),bytes&,VARPTR(disker%))
 PRINT bytes&
 TEXTSIZE(10)
 TEXTFACE(0)
     dpnt& =(bytes&/2)-1
 ite% = 1
```

```
FOR ddd% = 0 TO 500
car$ = CHR$(ekg%(ddd%,49))
IF ekg%(ddd%,49) = 13 THEN ite% = ite% + 1: GOTO nexcar
IF ite% = 1 THEN TY$ = TY$ + car$:GOTO nexcar
IF ite% = 2 THEN VL$ = VL$ + car$:GOTO nexcar
IF ite% = 3 THEN SI$ = SI$ + car$:GOTO nexcar
IF ite% = 4 THEN MI$ = MI$ + car$:GOTO nexcar
IF ite% = 5 THEN LO$ = LO$ + car$:GOTO nexcar
IF ite% = 6 THEN demog
 nexcar:
NEXT ddd%
 demog:
FOR ddd% = 0 TO 500
     qrs%(ddd%,20) = ekg%(ddd%,49)
NEXT ddd%
FOR ff% = 0 TO 4150
          fft%(ff%) = 0
          hsfave!(ff%) = 0
NEXT ff%

CLS
PRINT  LOADFILE$
```

Microsoft QuickBASIC Listing 05/20/92 Page 2

Source File: vlvsndpictfft2

```
PRINT  "VALVE TYPE ";TY$
PRINT  "VALVE LOCATION  ";VL$
PRINT  "VALVE SIZE ";SI$
PRINT  "MICROPHONE TYPE "; MI$
PRINT  "MICROPHONE LOCATION "; LO$
 plotag:
      INPUT "maximum scale for plot<1000>";scl&
     IF scl&=0 THEN scl&=1000
   INPUT "HORIZONTAL COMPRESSION (MUST BE >10)<50>";cmp%
    IF cmp%=0 THEN cmp%=50
     pts& = cmp%*400
   CLS:FRAMERECT VARPTR(BND4%(0))
       CALL  grid(2,5,205,60,460,4,50,5,100)
       CALL  plot(0,5,205,60,VARPTR(ekg%(0,0)),scl&,-scl&,pts&,cmp%,2,1,0)
    MOVETO 5, 14: PRINT  scl&
    MOVETO 10, 114: PRINT  "   0"
```

```
MOVETO 5, 214: PRINT  -scl&
LOCATE 17,1:PRINT PTAB(58);"0";PTAB(248);cmp%*200;PTAB(448);cmp%*400
 PRINT  "Compression =";cmp%
INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
IF a$ = "y" OR a$ = "Y" THEN plotag
 PRINT  "threshold <"; thr%;">";
 INPUT a$
IF a$ <> "" THEN thr% = VAL(a$)
rethresh:
   tt%=0  'initial QRS complex is 0
     PRINT  "Initial start point (must be >4300) <";sta%;">";
   INPUT a$
   IF a$ <> "" THEN sta% = VAL(a$)
  IF sta% < 4300 THEN sta% =4300
     PRINT "Number of points to skip following detection of threshold (must be >5000) <";skip&;">";
   INPUT a$
   IF a$ <> "" THEN skip& = VAL(a$)
   IF skip&<5000 THEN skip&=5000
  p&=sta%
  amt% = 0
  FOR j% = 0 TO 49
  FOR I% = 0 TO 29999
     IF (j% = 0 AND I% < sta%) THEN nothresh
     IF ekg%(I%,j%) < thr% THEN nothresh
     I% = I% - 4096
     IF I%<0 THEN I% = 30000 + I%:j% = j% -1
       CALL movedata (VARPTR(ekg%(I%,j%)),VARPTR(qrs%(0,amt%)),8200&)
     amt% = amt% +1
     IF amt% > 40 THEN remarsh
     ii& = I% + skip&
      IF ii& > 89997& THEN I% = ii& - 89997&:j% = j% +3:GOTO printert
      IF ii& > 59998& THEN I% = ii& - 59998&:j% = j% +2:GOTO printert
      IF ii& > 29999& THEN I% = ii& - 29999&:j% = j% +1:GOTO printert
     I% = ii&

   printert:
     PRINT  I%,j%
nothresh:

    NEXT I%
    NEXT j%
```

```
remarsh:
```



```
tt% = 0
    CALL movedata (VARPTR(qrs%(0,tt%)),VARPTR(TQRS%(0)),8200&)
   CLS
   IF amt%>20 THEN amt% = 20
    PRINT  "Number of complexes found = ";amt%
    INPUT "WINDOW SIZE (8 = 256,9 = 512,10 = 1024,11 =2048,12 = 4096,13 = 8192)<13>";cmp%
replot:
   IF cmp%=0 THEN cmp%=8
   IF cmp% > 13 THEN cmp% = 13
    pts& = 2^cmp%:tscl&=scl&
Plotag1:
   thloc% = 60 + (530 - sh%)/cmp%
newplot:
     CALL movedata (VARPTR(qrs%(4096-pts&/2,tt%)),VARPTR(TQRS%(0)),pts&)
 CLS:FRAMERECT VARPTR(BND%(0))
  PENMODE(8)
      CALL grid(2,5,205,60,572,2,100,4,143)
     axis%=pts&/512
   IF pts& = 256 THEN axis% = -2
      CALL plot(0,5,205,60,VARPTR(TQRS%(0)),scl&,-scl&,pts&,axis%,2,1,0)
   CALL PENSIZE(2,1)
  PENMODE(10)
   CALL PENSIZE (1,1)
   MOVETO 5, 14: PRINT  scl&
   MOVETO 10, 114: PRINT  "   0"
   MOVETO 5, 214: PRINT  -scl&
    hscale% = pts&/512
   LOCATE 17,1:PRINT PTAB(48);0;PTAB(191);hscale%;PTAB(334);hscale%*2;PTAB(476);hscale%*3
   LOCATE 19,5
    PRINT  "Points = ";pts&, "threshold = ";thr%
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
  INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
  IF a$ <> "y" AND a$ <> "Y" THEN thr
```

```
LOCATE 21,5
PRINT  bl$
LOCATE 21,5
stpt:
' PRINT  "         Startpoint for plot (0 to 500)<";sh%;">";:INPUT shst$
'IF shst$="" THEN sh%=tsh% ELSE sh%=VAL(shst$)
'IF sh% > 500 THEN GOTO stpt
'tsh% = sh%
LOCATE 21,5
PRINT  bl$
LOCATE 21,5
PRINT  "     maximum scale for plot<"tscl&">";:INPUT scl&
IF scl&=0 THEN scl&=tscl&
tscl& = scl&
LOCATE 21,5
PRINT  bl$
LOCATE 21,5
INPUT "WINDOW SIZE (8 = 256,9 = 512,10 = 1024,11 =2048,12 = 4096,13 = 8192)<13>";cmp%
IF cmp%=0 THEN cmp%=8
IF cmp% > 13 THEN cmp% = 13
pts& = 2^cmp%
GOTO Plotag1
thr:
```



```
INPUT "Would you like to start again (y or n)<n>";a$
IF a$ <> "y" AND a$ <> "Y" THEN thr1
GOTO restart
thr1:
LOCATE 21,5
PRINT  bl$
LOCATE 21,5
INPUT "Perform fft? (y or n)<y>";a$
IF a$ = "n" OR a$ = "N" THEN nfft
CALL itos(VARPTR(TQRS%(0)),VARPTR(hsf!(0)),0,pts& + 5)
CALL fft(VARPTR(hsf!(0)),cmp%)
CALL movedata (VARPTR(hsf!(0)),VARPTR(hsf1!(0)),2*pts& +10)
```

```
    CALL mul (VARPTR(hsf!(0)),VARPTR(hsf1!(0)),0,pts& + 5,1)
    ffpts% = pts&/2
  FOR x% = 0 TO ffpts%
       hsfsq2! = (hsf!(2*x%) + hsf!(2*x% +1))
      hsf2!(x%) = SQR(hsfsq2!)
  NEXT x%
    inc% = 4096/ffpts%
    upbd&=ffpts%
  FOR hh% = upbd& TO 0 STEP -1
     FOR kk% = 0 TO (inc% - 1)
         hsf2!(hh%*inc%+kk%) = hsf2!(hh%)
     NEXT kk%
  NEXT hh%
  FOR hh% = 0 TO 4096
      hsfave!(hh%) = hsfave!(hh%) +  hsf2!(hh%)
  NEXT hh%
 refft:
CLS
    PRINT  "      maximum scale for plot<"ftscl&">";:INPUT fscl&
    IF fscl&=0 THEN fscl&=ftscl&
    ftscl& = fscl&
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
  INPUT " EXPAND or COMPRESS <E or C>";a$
   IF (a$ = "e" OR a$ = "E") THEN fcmp% = fcmp%/2
   IF (a$ = "c" OR a$ = "C") THEN fcmp% = fcmp%*2
   IF fcmp% = -4 THEN fcmp% = 1
   IF fcmp% < 1 THEN fcmp% = -2
   IF fcmp% > 8 THEN fcmp% = 8
    ftcmp% = fcmp%
    fpts& = 512*(fcmp%)
   IF fcmp% < 1 THEN fpts& = 256
  CLS:FRAMERECT VARPTR(BND%(0))
  PENMODE(8)
     CALL grid(2,5,205,60,572,2,100,5,114)
       CALL plot(1,5,205,60,VARPTR(hsf2!(0)),fscl&,-fscl&,fpts&,fcmp%,2,1,0)
    fhscale! = fpts&/512
sc1&=fhscale!*2000:sc2&=fhscale!*4000:sc3&=fhscale!*6000:sc4&=fhscale!*8000
    LOCATE 17,1:PRINT PTAB(48);0;PTAB(152);sc1&;PTAB(266);sc2&;
    PRINT PTAB(380);sc3&;PTAB(494);sc4&
   LOCATE 19,5
```

```
PRINT "Please press SPACE to begin collecting 10 seconds of data"
GetKeyPress2:    key$= INKEY$  :  IF key$ = "" THEN GetKeyPress2
PRINT "we are now saving 10 seconds of data"
CALL setAD(0,1,3,VARPTR(eri%))
BEEP
fastio  Trig%, pnts&, 1,Period%,0,0, VARPTR(w0%(0,0)),Slot%, VARPTR(er%(0))
BEEP
INPUT "HIT RETURN TO SAVE"; a$
CALL bsave ("HD1:",F1$ +
"vlvsndfast",VARPTR(w0%(0,0)),2,3000000&,VARPTR(disker%))
GOTO start1

REM  ****************  TurboDriver  Header  File  **************
LoadTurboSymbols:
REM This routine loads symbols that are used with MacADIOS Extended modes
trh%=500:hr%=0:pnts&=0:points%=0:trigger%=-1:banks%=0:loops%=0:eri%=0
Trig%=0
BigNumMult! = 32768&       ' helpful symbol
true = 1                   ' useful symbol
false = 0

ErrorINDX  = 0         ' Error Value, index

ModeINDX = 1           ' Mode, index
ModeREG  = 0           ' Regular Mode
ModeOSC  = 1           ' Oscilloscope Mode
ModeSPEC  = 2          ' Spectrum Analyzer Mode
ModeChart  = 8         ' Chart Recorder Mode
modeScan = 9           ' Scan Line Recorder Mode
ModeSCROLL  = 16       ' Scrolling Strip Chart Mode

OptionsINDX = 2        ' Options, index
OptNone  = 0           ' No options
OptInINTS = 1          ' Inner loop Interrupts
OptOutINTS = 2         ' Outer loop interrupts
OptSpoolHD = 3         ' Spool to Hard Disk

OpModeINDX = 3         ' Operational Mode, index
OpModeNorm = 0         ' Normal I/O Mode
OpModeUpdate  = 1      ' Update Display area
OpModeDemo  = 2        ' Demonstration Mode
OpModebench  = 3       ' Benchmark Mode
```

```
pppINDX = 8                ' points/pixel, index
ScrollPixINDX = 9          ' Pixels/scroll, index
DotsINDX = 10              ' Dots on/off, index
GridINDX = 11              ' Grid control, index
firstclearIndx = 12        ' First Clear, index
ClearIndx = 13             ' Clear, index
SaveINDX = 14              ' Save in memory, index

TrigINDX = 16              ' Trigger control, index
TrigNone = 0               ' No trigger
TrigExtPos = 2             ' External trigger, positive edge
TrigExtNeg = 3             ' External trigger, negative edge
TrigAutoPos = 4            ' Auto-trigger, positive edge
TrigAutoNeg = 5            ' Auto-trigger, negative edge
TrigNormPos = 8            ' Norm-trigger, postive edge
TrigNormNeg = 9            ' Norm-trigger, negative edge

TrOffINDX = 17             ' Trigger source offset code, index
TrDevTyINDX = 18           ' Trigger source device type code, index
TrThreshINDX = 19          ' Trigger threshold level, index

IntTaskINDX = 25           ' Interrupt command, index
IntINSTALL = 0             ' Install interrupts command
IntDeINSTALL = 1           ' De-install interrupts command
IntSTATUS = 2              ' Request interrupt status command
IntTicksINDX = 24          ' Interrupt rate, index

FileNameINDX = 26          ' File name value, index
SpoolINDX = 27             ' Spool Command, index
SpOut = 0                  ' Spool out command
SpIn = 1                   ' Spool in command
DELETEFILE = 2             ' Delete file command
SpAllocate = 3             ' Allocate space on hard disk for file
DriveINDX = 28             ' Hard disk SCSI address, Index
SpPtsHiINDX = 31           ' Spool points high value, Index
SpPtsLoINDX = 32           ' Spool points Low value, Index
SpLpsHiINDX = 33           ' Spool loops high value, Index
SpLpsLoINDX = 34           ' Spool loops low value, Index
SpChanINDX = 35            ' Number of channels spooled, Index
SpPerHiINDx = 36           ' Sample period high value, Index
SpPerLoINDX = 37           ' Sample period low value, Index
SpTimeHiINDX = 38          ' Spool time high value, Index
SpTimeLoINDX = 39          ' Spool time low value, Index
```

```
DigLoopsLowINDX = 40    ' Digitize's Loops low, index
DigLoopsHiINDX  = 41    ' Digitize's Loops high, index

PtsHiINDX  = 48         ' Points high, index
PtsLowINDX  = 49        ' Points low, index
LoopsHiINDX  = 51       ' Loops high, index
LoopsLowINDX  = 50      ' Loops low, index
TicksToINDX  = 52       ' Ticks till interrupt, index

MinPerMultINDX  = 54    ' Minimum sample period value multiplier, index
MinPerINDX  = 55        ' Minimum sample period value, index

REM Note that the following code loads 9 arrays with 8 values each
FOR n = 0 TO 7
   ChDrawINDX(n)  = 319 + n*64      ' Channel on/off control, Index
   ChLeftINDX(n)  = 256 + n*64      ' Display region left pixel coord, Index
   ChRightINDX(n)  = 257 + n*64     ' Display region Right pixel coord, Index
   ChTopINDX(n)  = 258 + n*64       ' Display region Top pixel coord, Index
   ChBotINDX(n)  = 259 + n*64       ' Display region Bottom pixel coord, Index
   ChTPVINDX(n)  = 266 + n*64       ' Display region top plot value, Index
   ChBPVINDX(n)  = 267 + n*64       ' Display region bottom plot value, Index
   ChGridDxINDX(n)  = 286 + n*64    ' Grid horizontal displacement value, Index
   ChGridDyINDX(n)  = 287 + n*64    ' Grid vertical displacement value, Index
NEXT n
RETURN
```

```
'****NOTE!!!! this version suppresses validity test*******
LIBRARY "DataManipulation Interface"
length%=0:fileleng%=0:ddd%=0:ite% = 0
a=0:b%=0:t%=0:f%=0:num%=0:r=0:q=0:s=0:h%=0:g%=0:x=0:z=0:c%=0:p=o:flagt%=0
a%=0:t!=0:bytes&=0:disker%=0:dpnt&=0:scl&=0:cmp%=0:pts&=0:ftcmp%=8:fcmp%=8
thr%=0:tt%=0:sta%=0:skip&=0:p&=0:amt%=0:z%=0:ii&=0:l%=0:j%=0:hsfsq2!=0
fo$ = "":bl$ = SPACE$(155)
TY$ = "":SI$ = "":MI$ = "":LO$ = "":car$="":VL$ = ""
DIM STATIC ekg%(29999,50),fi$(100),fft%(4200),hsf2!(8400),hsfave!(8400)
DIM STATIC hsf!(8400),hsf1!(8400)
DIM STATIC
qrs%(8300,40),TQRS%(8300),BND%(3),BND1%(3),BND4%(3),BND2%(3),ff%(4200,40)
BND%(0) = 5:BND%(1) = 60:BND%(2) = 205:BND%(3) = 572
BND4%(0) = 5:BND4%(1) = 60:BND4%(2) = 205:BND4%(3) = 460
BND1%(0) = 10:BND1%(1) = 60:BND1%(2) = 110:BND1%(3) = 460
BND2%(0) = 130:BND2%(1) = 60:BND2%(2) = 230:BND2%(3) = 460
FOR a% = 0 TO 100
fi$(a%) = STR$(a%)
NEXT a%
CLS
restart:
PRINT "SELECT THE DATA FILE YOU WISH TO USE"
LOADFILE$=FILES$(1,"DATA")
IF LOADFILE$="" THEN restart
CLS
PRINT LOADFILE$
PRINT "LOADING FILE...Please wait."
CALL filelen ("",LOADFILE$,VARPTR(bytes&),VARPTR(disker%))
CALL bload("",LOADFILE$,VARPTR(ekg%(0,0)),bytes&,VARPTR(disker%))
PRINT bytes&
 TEXTSIZE(10)
 TEXTFACE(0)
    dpnt& =(bytes&/2)-1
ite% = 1
FOR ddd% = 0 TO 500
car$ = CHR$(ekg%(ddd%,49))
IF ekg%(ddd%,49) = 13 THEN ite% = ite% + 1: GOTO nexcar
IF ite% = 1 THEN TY$ = TY$ + car$:GOTO nexcar
IF ite% = 2 THEN VL$ = VL$ + car$:GOTO nexcar
IF ite% = 3 THEN SI$ = SI$ + car$:GOTO nexcar
IF ite% = 4 THEN MI$ = MI$ + car$:GOTO nexcar
IF ite% = 5 THEN LO$ = LO$ + car$:GOTO nexcar
IF ite% = 6 THEN demog
```

```
nexcar:
NEXT ddd%
demog:
FOR ddd% = 0 TO 500
    qrs%(ddd%,20) = ekg%(ddd%,49)
NEXT ddd%
FOR ff% = 0 TO 4150
        fft%(ff%) = 0
        hsfave!(ff%) = 0
NEXT ff%

CLS
PRINT  LOADFILE$
PRINT  "VALVE TYPE ";TY$
PRINT  "VALVE LOCATION  ";VL$
PRINT  "VALVE SIZE ";SI$
PRINT  "MICROPHONE TYPE "; MI$
PRINT  "MICROPHONE LOCATION "; LO$
plotag:
     INPUT  "maximum scale for plot<1000>";scl&
    IF scl&=0 THEN scl&=1000
   INPUT "HORIZONTAL COMPRESSION (MUST BE >10)<50>";cmp%
    IF cmp%=0 THEN cmp%=50
    pts& = cmp%*400
   CLS:FRAMERECT VARPTR(BND4%(0))
      CALL  grid(2,5,205,60,460,4,50,5,100)
      CALL  plot(0,5,205,60,VARPTR(ekg%(0,0)),scl&,-scl&,pts&,cmp%,2,1,0)
    MOVETO 5, 14: PRINT  scl&
    MOVETO 10, 114: PRINT  "  0"
    MOVETO 5, 214: PRINT  -scl&
     LOCATE  17,1:PRINT  PTAB(58);"0";PTAB(248);cmp%*200;PTAB(448);cmp%*400
    PRINT  "Compression =";cmp%
   INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
    IF a$ = "y" OR a$ = "Y" THEN plotag
     PRINT  "threshold <"; thr%;">";
    INPUT a$
    IF a$ <> "" THEN thr% = VAL(a$)
rethresh:
    tt%=0  'initial QRS complex is 0
       PRINT  "Initial start point (must be >4300) <";sta%;">";
     INPUT a$
     IF a$ <> "" THEN sta% = VAL(a$)
    IF sta% < 4300 THEN sta% =4300
```

```
      PRINT "Number of points to skip following detection of threshold (must be >5000)
 <";skip&;">";
     INPUT a$
     IF a$ <> "" THEN skip& = VAL(a$)
     IF skip&<5000 THEN skip&=5000
    p&=sta%
    amt% = 0
    FOR j% = 0 TO 49
    FOR I% = 0 TO 29999
       IF (j% = 0 AND I% < sta%) THEN nothresh
       IF ekg%(I%,j%) < thr% THEN nothresh
       I% = I% - 4096
       IF I%<0 THEN I% = 30000 + I%:j% = j% -1
        CALL movedata (VARPTR(ekg%(I%,j%)),VARPTR(qrs%(0,amt%)),8200&)
       amt% = amt% +1
       IF amt% > 40 THEN remarsh
        ii& = I% + skip&
        IF ii& > 89997& THEN I% = ii& - 89997&:j% = j% +3:GOTO printert
        IF ii& > 59998& THEN I% = ii& - 59998&:j% = j% +2:GOTO printert
        IF ii& > 29999& THEN I% = ii& - 29999&:j% = j% +1:GOTO printert
       I% = ii&

    printert:
      PRINT  I%,j%
nothresh:

     NEXT I%
     NEXT j%
remarsh:
tt% = 0
    CALL movedata (VARPTR(qrs%(0,tt%)),VARPTR(TQRS%(0)),8200&)
   CLS
   IF amt%>20 THEN amt% = 20
    PRINT  "Number of complexes found = ";amt%
    INPUT "WINDOW SIZE (8 = 256,9 = 512,10 = 1024,11 =2048,12 = 4096,13 =
8192)<13>";cmp%
replot:
   IF cmp%=0 THEN cmp%=8
   IF cmp% > 13 THEN cmp% = 13
    pts& = 2^cmp%:tscl&=scl&
Plotag1:
   thloc% = 60 + (530 - sh%)/cmp%
newplot:
```

```
    CALL movedata (VARPTR(qrs%(4096-pts&/2,tt%)),VARPTR(TQRS%(0)),pts&)
   CLS:FRAMERECT VARPTR(BND%(0))
   PENMODE(8)
     CALL grid(2,5,205,60,572,2,100,4,143)
    axis%=pts&/512
   IF pts& = 256 THEN axis% = -2
     CALL plot(0,5,205,60,VARPTR(TQRS%(0)),scl&,-scl&,pts&,axis%,2,1,0)
   CALL PENSIZE(2,1)
   PENMODE(10)
   CALL PENSIZE (1,1)
   MOVETO 5, 14: PRINT  scl&
   MOVETO 10, 114: PRINT "   0"
   MOVETO 5, 214: PRINT  -scl&
    hscale% = pts&/512
   LOCATE 17,1:PRINT
PTAB(48);0;PTAB(191);hscale%;PTAB(334);hscale%*2;PTAB(476);hscale%*3
   LOCATE 19,5
    PRINT  "Points = ";pts&, "threshold = ";thr%
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
   INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
   IF a$ <> "y" AND a$ <> "Y" THEN thr
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
stpt:
   ' PRINT  "          Startpoint for plot (0 to 500)<";sh%;">";:INPUT shst$
   'IF shst$="" THEN sh%=tsh% ELSE sh%=VAL(shst$)
   'IF sh% > 500 THEN GOTO stpt
   'tsh% = sh%
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
    PRINT  "     maximum scale for plot<"tscl&">";:INPUT scl&
    IF scl&=0 THEN scl&=tscl&
    tscl& = scl&
   LOCATE 21,5
   PRINT  bl$
   LOCATE 21,5
    INPUT "WINDOW SIZE (8 = 256,9 = 512,10 = 1024,11 =2048,12 = 4096,13 =
8192)<13>";cmp%
   IF cmp%=0 THEN cmp%=8
```

```
IF cmp% > 13 THEN cmp% = 13
pts& = 2^cmp%
GOTO Plotag1
thr:
INPUT "Would you like to start again (y or n)<n>";a$
IF a$ <> "y" AND a$ <> "Y" THEN thr1

GOTO restart
thr1:
LOCATE 21,5
PRINT bl$
LOCATE 21,5

INPUT "Perform fft? (y or n)<y>";a$
IF a$ = "n" OR a$ = "N" THEN nfft
CALL itos(VARPTR(TQRS%(0)),VARPTR(hsf!(0)),0,pts& + 5)
CALL fft(VARPTR(hsf!(0)),cmp%)
CALL movedata (VARPTR(hsf!(0)),VARPTR(hsf1!(0)),2*pts& +10)
CALL mul (VARPTR(hsf!(0)),VARPTR(hsf1!(0)),0,pts& + 5,1)
ffpts% = pts&/2
FOR x% = 0 TO ffpts%
    hsfsq2! = (hsf!(2*x%) + hsf!(2*x% +1))
    hsf2!(x%) = SQR(hsfsq2!)
NEXT x%
inc% = 4096/ffpts%
upbd&=ffpts%
FOR hh% = upbd& TO 0 STEP -1
    FOR kk% = 0 TO (inc% - 1)
        hsf2!(hh%*inc%+kk%) = hsf2!(hh%)
    NEXT kk%
NEXT hh%
FOR hh% = 0 TO 4096
    hsfave!(hh%) = hsfave!(hh%) + hsf2!(hh%)
NEXT hh%
refft:
CLS
PRINT "      maximum scale for plot<"ftscl&">";:INPUT fscl&
IF fscl&=0 THEN fscl&=ftscl&
ftscl& = fscl&
LOCATE 21,5
PRINT bl$
LOCATE 21,5
INPUT " EXPAND or COMPRESS <E or C>";a$
```

```
    IF (a$ = "e" OR a$ = "E") THEN fcmp% = fcmp%/2
    IF (a$ = "c" OR a$ = "C") THEN fcmp% = fcmp%*2
    IF fcmp% = -4 THEN fcmp% = 1
    IF fcmp% < 1 THEN fcmp% = -2
    IF fcmp% > 8 THEN fcmp% = 8
     ftcmp% = fcmp%
      fpts& = 512*(fcmp%)
    IF fcmp% < 1 THEN fpts& = 256
   CLS:FRAMERECT VARPTR(BND%(0))
   PENMODE(8)
      CALL grid(2,5,205,60,572,2,100,5,114)
       CALL plot(1,5,205,60,VARPTR(hsf2!(0)),fscl&,-fscl&,fpts&,fcmp%,2,1,0)
     fhscale! = fpts&/512
       sc1&=fhscale!*2000:sc2&=fhscale!*4000:sc3&=fhscale!*6000:sc4&=fhscale!*8000
     LOCATE 17,1:PRINT PTAB(48);0;PTAB(152);sc1&;PTAB(266);sc2&;
     PRINT PTAB(380);sc3&;PTAB(494);sc4&
   LOCATE 19,5
    PRINT "Points = ";fpts&
   INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
   IF a$ = "y" OR a$ = "Y" THEN refft



nfft:
    tt% = tt%+1
   IF tt% = amt% GOTO savedat
GOTO newplot
   LOCATE 21,5
   PRINT bl$
   LOCATE 21,5
    INPUT "Would you like to change threshold (y or n)<n>";a$
   IF a$ <> "y" AND a$ <> "Y" THEN STOP
    INPUT "New threshold"; thr%
   GOTO rethresh
savedat:

CLS
    INPUT "Would you like to plot average fft (y or n)<y>";a$
   IF (a$ = "n" OR a$ = "N") THEN noplfft
  refft1:
     PRINT " maximum scale for plot<"ftscl&">";:INPUT fscl&
     IF fscl&=0 THEN fscl&=ftscl&
     ftscl& = fscl&
```

```
 LOCATE 21,5
 PRINT  bl$
 LOCATE 21,5
INPUT " EXPAND or COMPRESS <E or C>";a$
 IF (a$ = "e" OR a$ = "E") THEN fcmp% = fcmp%/2
 IF (a$ = "c" OR a$ = "C") THEN fcmp% = fcmp%*2
 IF fcmp% = -4 THEN fcmp% = 1
 IF fcmp% < 1 THEN fcmp% = -2
 IF fcmp% > 8 THEN fcmp% = 8
 ftcmp% = fcmp%
  fpts& = 512*(fcmp%)
 IF fcmp% < 1 THEN fpts& = 256
CLS:FRAMERECT VARPTR(BND%(0))
PENMODE(8)
   CALL  grid(2,5,205,60,572,2,100,5,114)
    CALL  plot(1,5,205,60,VARPTR(hsfave!(0)),fscl&,-fscl&,fpts&,fcmp%,2,1,0)
  fhscale! = fpts&/512
     sc1&=fhscale!*2000:sc2&=fhscale!*4000:sc3&=fhscale!*6000:sc4&=fhscale!*8000
  LOCATE  17,1:PRINT  PTAB(48);0;PTAB(152);sc1&;PTAB(266);sc2&;
  PRINT  PTAB(380);sc3&;PTAB(494);sc4&
 LOCATE 19,5
 PRINT  "Points = ";fpts&
INPUT "WOULD YOU LIKE TO REPLOT (y or n)<n>";a$
 IF a$ = "y" OR a$ = "Y" THEN refft1
noplfft:
 SAVEFILE$=FILES$(0)
 IF SAVEFILE$="" THEN restart
 CLS
 PRINT "SAVING FILE...Please wait."
  CALL  bsave("",SAVEFILE$,VARPTR(qrs%(0,0)),2,348600&,VARPTR(disker%))
  ffile$ = SAVEFILE$ + "fft"
   CALL  bsave("",ffile$  ,VARPTR(hsfave!(0)),3,8350&,VARPTR(disker%))
 GOTO restart
```

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