MICROCOMPUTER-BASED ARRHYTHMIA MONITOR FOR AMBULATORY PATIENTS

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by
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ABSTRACT

This thesis discusses the feasibility of a microcomputer-based arrhythmia monitor for ambulatory patients.

The arrhythmia monitor is designed with a commercially available microcomputer(VIC-20). The system continuously monitors the ECG and detects arrhythmias. The arrhythmia monitor does not store the normal ECG. It detects and stores only arrhythmias. The monitor is capable of capturing eight different arrhythmias. In order to conserve memory the arrhythmic ECG is compressed before it is stored in ring buffers. Three algorithms have been programmed for ECG data compression. The algorithms are fast and cause clinically insignificant distortion of the ECG.

Future work on the monitor is also suggested and discussed.

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CHAPTER 1

INTRODUCTION.

Cardiac disease is commonly associated with abnormalities of the heart rhythm . Disturbances of the heart rhythm and/or conduction of the cardiac impulse are called arrhythmias. They can be detected by electronic devices called "arrhythmia monitors".

The electrical instability produced by cardiac arrhythmias may create abnormalities of the mechanical activity of the heart. The cardiac output may decrease significantly and some arrhythmias can be fatal. In many cases, arrhythmias can be successfully treated with drugs or electrical devices(cardioversion, pacemakers). Arrhythmia detection and treatment is one of the most important activities of heart specialists [25].

During an acute heart attack patients are treated in a coronary care unit(CCU) for a few days. During this time the cardiac rhythm is monitored by a simple cardiotachometer with preset high and low heart-rate alarms. In some CCUs, a computer may be used to monitor arrhythmias. Unfortunately, the patient is only monitored for a few days in the CCU, after which he or she is moved to a room with little or no monitoring [20]. The primary responsibility of the CCUs is to intercept and treat life threatening arrhythmias. In some cases, after discharge from the CCU, the patient is monitored

by radiotelemetry while still in the hospital so as to obtain a record of the ECG under stress, walking, eating, etc. Certain arrhythmias may be detected during these activities and treated accordingly. Personal radiotelemetry is not practical outside the hospital because large radiated power is required to transmit the ECG over long distances.

Over the past several years, a number of attempts have been made to develop a small portable device for monitoring the ECG of ambulatory patients [36, 37, 39, 42, 43]. The Holter recorder is currently the most popular device for capturing infrequent and transient arrhythmias but it provides for only 24 hours of continuous ECG recording which represents only a small fraction of the time during which monitoring might be useful. Holter monitors are simple recorders. The 24 hour ECG is later analysed by a technician, who views the Holter recording played back at 60 times real time. An oscilloscope triggers on each R-wave during the play back so that single normal complexes almost superimpose while abnormal complexes stand out because of their different shapes. Whenever the technician detects an abnormal complex he backs up the tape and takes another look at the complex, and if he feels that the signal should be analysed by the cardiologist he obtains a permanent record which is subsequently analysed in detail by a cardiologist. Alternative methods include both in-house and commercial scanning services that may make use of a computer system for analysis.

The Holter monitor has a number of disadvantages. 1) It might not capture the arrhythmia of interest because the arrhythmia might not occur on the day of the recording. 2) Even if the Holter monitor captures the arrhythmia, it might not be found by the technician whose job is tedious, time consuming, and subject to a great deal of human error. 3) The ECG is analysed by the cardiologist after a delay, sometimes of a few days. 4) In some hospitals, the Holter recording is analysed by special computer systems, but still there is significant time lag between the recording and the diagnosis.

In order to fill in the gap in patient monitoring discussed above there is a need for an intelligent and portable arrhythmia monitoring system, for use on ambulatory patients [43], with the following characteristics. 1)The monitor should continuously monitor the ECG of ambulatory patients living and working outside the hospital. 2) It should only detect and store arrhythmias and not the normal ECG. 3) Unlike a Holter monitor, its use should not be limited to a 24 hour period. It should be suitable for use on ambulatory patients for several weeks. 4) It should be portable and battery operated with low power consumption so that there is no need to replace the batteries for weeks. 5) It should be simple so that it can be used even by nonspecialists. 6) It should only respond to programmed abnormal ECGs and be flexible in its design so that it can be easily modified to meet the demands of individual patients and

physicians. A microcomputer is the best choice for such an application.

The microprocessor should satisfy the following specifications:

1) low power consumption; this implies a CMOS microprocessor.

2) single 5V power supply.

3) minimum number of support chips.

4) adequate speed to carry out arrhythmia analysis, data compression etc., in real time.

In order to keep the power consumption low, the monitor should be designed with CMOS digital ICs and low power analog ICs.

This being a feasibility study of a microcomputer-based arrhythmia monitor for ambulatory patients, it was decided that the prototype of the arrhythmia monitor initially should be designed around a commercially available microcomputer, keeping in mind the requirements of a realistic arrhythmia monitor for ambulatory patients. The arrhythmia monitor is designed around the popular VIC-20 microcomputer. The reasons for using the VIC-20 microcomputer are: 1) the 6502 microprocessor[9] of the VIC-20 is fast enough to meet the requirements of the ambulatory arrhythmia monitoring system, 2) CMOS versions of the microprocessor and support chips are readily available so that these may be used in the final design[27], and 3) the VIC-20 is cheap and readily available.

CHAPTER 2

ELECTROPHYSIOLOGY OF THE HEART.

2.1 Heart

Figure 2-1 illustrates the structure of the heart. The heart is a pulsatile four chambered pump about the size of the fist with a somewhat pointed end that is directed towards the feet and the left side [12]. At the top are the two thin walled chambers called the atria which serve principally as entryways to the ventricles, but they also pump weakly to help move the blood into the ventricles. The ventricles supply the main force that propels the blood through the lungs and the peripheral circulatory system. Venous blood low in oxygen content, from all parts of the body, is brought to the heart by the superior and inferior vena cava, which drain into the right atrium. From the right atrium the blood flows into the right ventricle through the tricuspid valve. When the right ventricle is full, it pumps the blood into the pulmonary artery through the pulmonic valve. The pulmonary artery then carries the blood to the lungs for oxygenation. The oxygenated blood is then taken to the left atrium by the pulmonary vein. From the left atrium the blood flows into the left ventricle through the mitral valve. The left ventricle then pumps the blood into the aorta through the aortic valve. The aorta carries the blood to the different parts of the body.

The circulatory path for blood flow through the lungs is

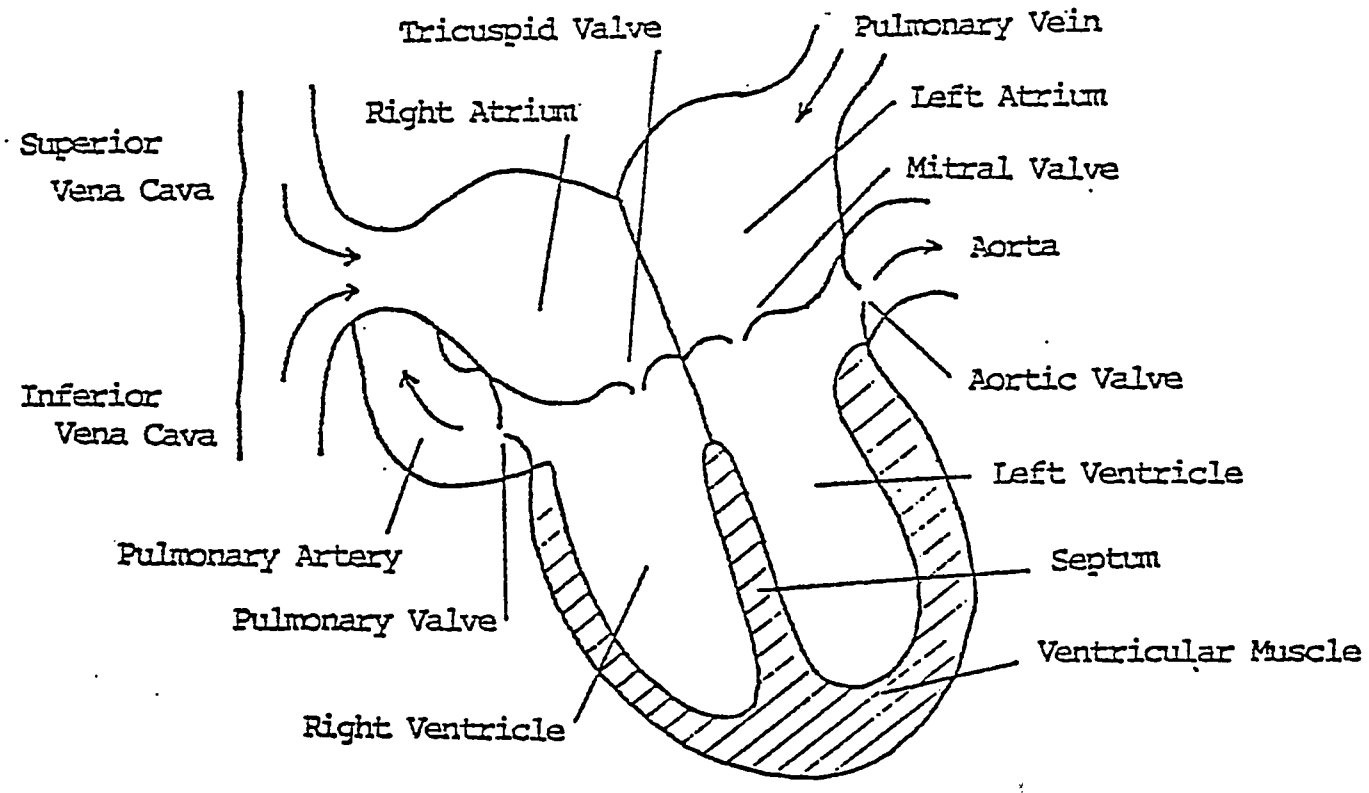

Figure 2-1: Anatomy of the heart

called the pulmonary circulation and the circulatory system that supplies oxygen and nutrients to the cells of the body is called the systemic circulation. The heart muscle receives its own blood supply from the coronary arteries which surround the heart. The coronary arterial system is a special branch of the systemic circulation.

The heart pumping cycle is divided into two major parts: systole and diastole. Systole is defined as the period of contraction of the heart muscles, specifically, the ventricular muscle at which time the blood is pumped into the pulmonary artery and the aorta. Diastole is the period of

dilation of the heart chambers as they fill with blood.

2.2 Electrical Control Of The Heart.

The heart contains specialized impulse generating and conducting fibres. This is the specialized conducting system. The origin of the electrical impulse is the SA node, which is formed by a group of cells in the wall of the right atrium, near the entry of the vena cava. In the normal heart the SA node is the normal pace maker and originates impulses at about 70 per minute. The rate is modulated by the autonomic nervous system, being increased by the sympathetic nervous system and decreased by the parasympathetic nervous system.

The wave of excitation, generated by the SA node, is conducted throughout the atria at a speed of 1 m/sec, covering the atria in about 1/12 of a second. The action potential causes the atria to contract, participating to a certain extent in the pumping of blood into the ventricles. On reaching the boundary between the atria and the ventricles, the impulse enters the atrioventricular node(AV node). The AV node is located in the lower part of the wall between the two atria. The AV node delays the spread of excitation for about 0.11s. to allow emptying of the atria and filling of the ventricles before ventricular contraction can begin.

From the AV node, the action potential is conducted to the ventricular muscle by a special conduction system. This conduction system consists of a short common part called the bundle of His, two bundle branches one on each side of the

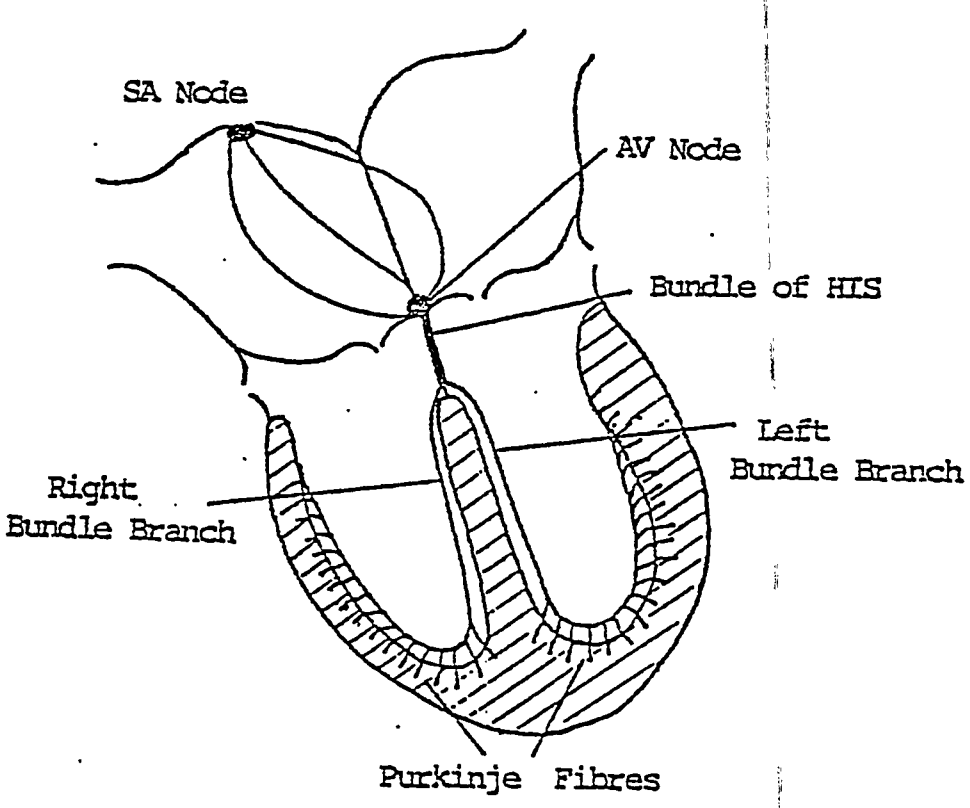

Figure 2-2: Conduction system of the heart.

septum, and sub-branches called the Purkinje fibres. Figure 2-2 illustrates the conduction system of the heart. The conduction speed through the ventricles is high, about 6 times faster than along ordinary muscles. Therefore the impulse reaches most cells of the ventricles almost simultaneously. The ventricles therefore contract as a strong unit pumping blood out of the heart.

2.3 The Electrocardiogram(ECG).

The electrical activity of the heart can be studied by recording potentials on the body surface. A recording of the electrical activity of the heart is called the electrocardiogram. Figure 2-3 illustrates a typical electrocardiogram.

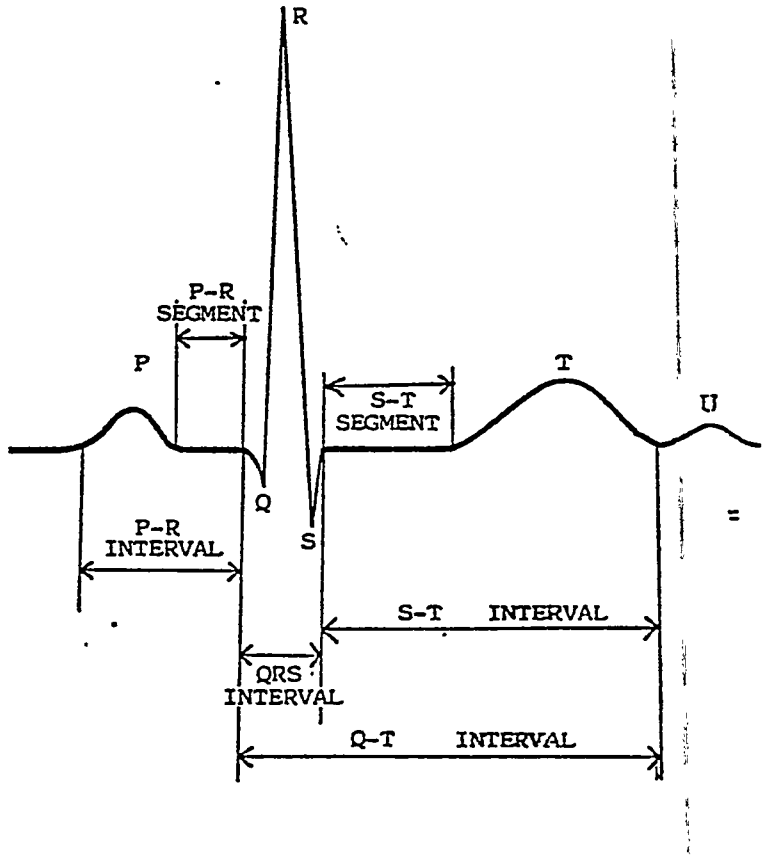

Figure 2-3: A typical electrocardiogram.

When the individual muscle fibres depolarize, potential changes occur on the surface of the body. At rest, muscle fibres are polarized, the inside of the cell membrane being about -90mv with respect to the outside. The potential is maintained by active transport of ions through the membrane. During muscle activation, an action potential is produced which is due to sudden change in Na^+ permeability of the cell membrane, so that Na^+ enter the cell and cause the interior to go positive. This is called depolarization. After about half a second repolarization occurs. During repolarization the transmembrane potential returns to the original state and the interior of the muscle becomes negative

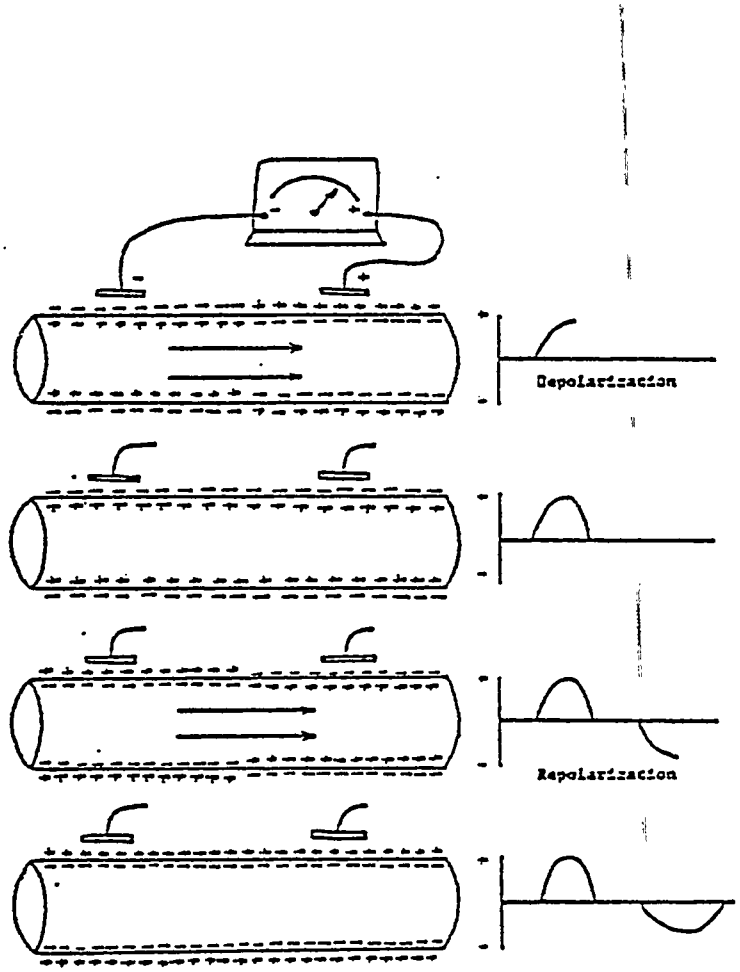

Figure 2-4: Depolarization and repolarization. (From [13])

once again. This depolarization and repolarization of the entire heart represents the sum of depolarizations and repolarizations of each cardiac cell. It can be measured with each heart beat, with the amplitude depending on the amount of muscle contracting and the period on the speed of action potential propagation. Figure 2-4 illustrates the depolarization and repolarization of a muscle fibre.

2.3.1 Relationship Between The Electrical(ECG) And The Mechanical Activity Of The Heart.

Figure 2-5 illustrates the relationship between the

atrial and ventricular contraction and the waves of the electrocardiogram. Before contraction of the muscle can occur, a depolarization wave must spread through the muscle to initiate the chemical processes of contraction. The P-wave results from a spread of the depolarization wave through the atria, and the QRS complex from a spread of the depolarization wave through the ventricles. Therefore, the P-wave occurs immediately before the beginning of contraction of the atria and the QRS complex occurs immediately before the beginning of contraction of the ventricles. The ventricles remain contracted until a few milliseconds after repolarization has occurred, that is, until after the end of the T-wave. The atria repolarize approximately 0.10 to 0.20s after the depolarization wave. However, this is just at the moment that the QRS complex is being recorded in the ECG. Therefore the atrial repolarization wave is usually obscured by the much larger QRS complex. A normal ECG, shown in figure 2-3, contains specific features traditionally named as the P-QRS-T waveform.

The T-wave is the ventricular repolarization wave. Ordinarily the ventricular muscle begins to repolarize in some fibres approximately 0.15s after the beginning of the depolarization wave, but in many other fibres, repolarization does not occur until as long as 0.30s after the onset of depolarization. Thus the process of repolarization extends over a fairly long period of about 0.15s. For this reason the T-wave in the normal ECG is a fairly prolonged wave, but the

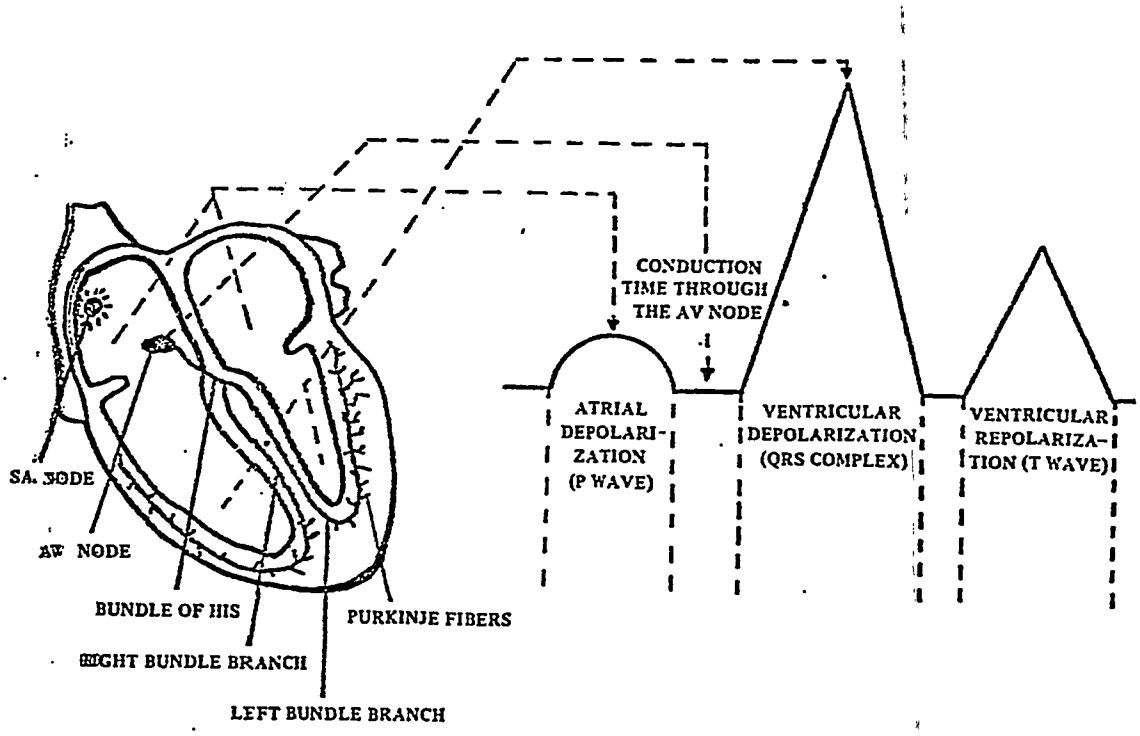

Figure 2-5: Contraction of the heart and the ECG. (From [40])

voltage of the T-wave is considerably less than the voltage of the QRS complex, partly because of its prolonged length.

2.4 ECG Lead System.

The potentials generated in the heart are conducted to the body surface. During each cardiac cycle the potential distribution changes in a regular, but quite complex way. It is therefore essential to choose standardized electrode positions when recording electrocardiograms. The most common lead systems are described in this section.

2.4.1 Bipolar Leads--Standard Leads 1,2,&3.

For each standard lead, potential changes between measuring points shown in figure 2-6 are recorded. A differential amplifier amplifies the difference between the potentials at two points which are simultaneously varying.

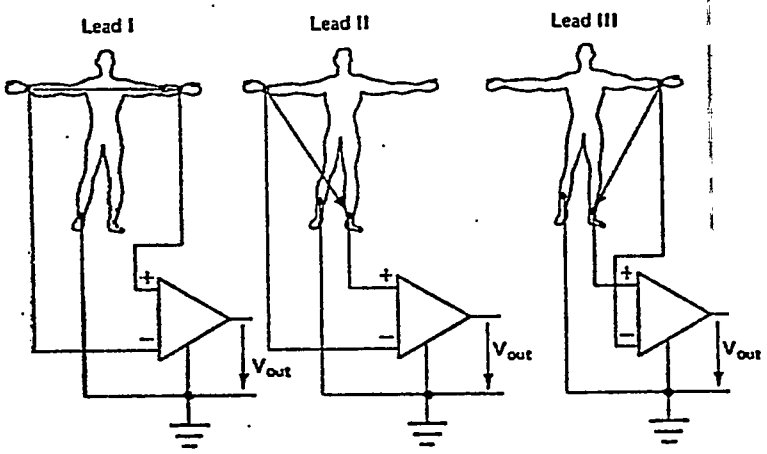

Figure 2-6: Standard bipolar limb leads. (From [8])

2.4.2 Unipolar Limbs Leads--aVR,aVL,& aVF.

Other views of the heart are obtained by connecting two equal large resistors to pairs of limbs. The centre of this resistive network feeds one terminal of the amplifier and the remaining lead feeds the other, as illustrated in figure 2-7. The leads are named for the remaining limb, aVR(augmented voltage right arm), aVL(augmented voltage left arm), aVF(augmented voltage foot).

2.4.3 Unipolar Chest(precordial) Leads--V1 to V6.

To obtain more detailed information on potential variation in different parts of the heart, electrodes are placed on the chest, close to the heart at anatomic points shown in figure 2-8. An indifferent electrode is formed by connecting three large resistors to the left arm, right arm,

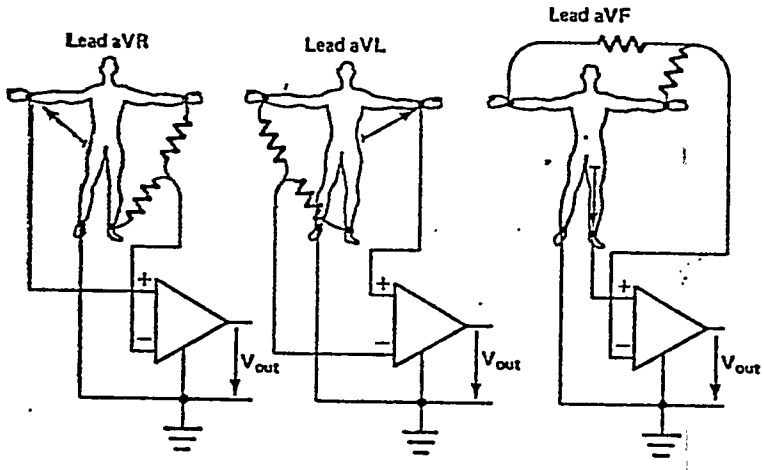

Figure 2-7: Unipolar leads. (From [8])

and left leg. The arrangement in which such a resistive network is used is known as the Wilson system. The other lead is connected sequentially to the electrodes shown in figure 2-8. It is routine practice in cardiology to use 12 leads, the 3 unipolar limb leads, 3 standard bipolar leads, and chest leads 1 through 6.

In order to obtain a three dimensional picture of the heart, a number of orthogonal systems have been developed [44]. These are used in vectorcardiography which will not be discussed in this thesis.

2.4.4 Leads System For The Ambulatory Arrhythmia Monitor.

In the standard bipolar limb leads, lead 2 produces the largest ECG signal. For the ambulatory arrhythmia monitor, the electrodes are placed in a simulated lead 2 configuration

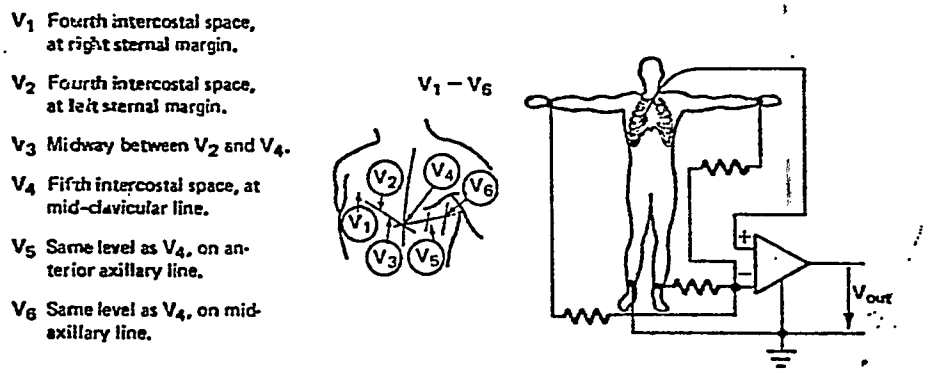

Figure 2-8: Precordial(Chest) leads. (From [8])

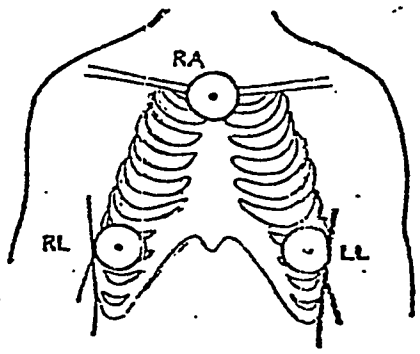

Figure 2-9: Lead configuration for the arrhythmia monitor. (From [31])

[31]. This configuration is shown in figure 2-9.

2.5 Analysis Of The ECG Curves.

The interpretation of the ECG is based on time and amplitude analysis of the ECG curves. Some normal values for amplitudes and durations of important ECG parameters are as follows:

	Amplitude
P-wave	0.25mv
R-wave	1.60mv
Q-wave	25% of the R-wave
T-wave	0.1 to 0.5mv

	Duration
P-R interval	0.12 to 0.20s
Q-T interval	0.35 to 0.44s
QRS interval	0.09s
P-wave interval	0.11s
ST segment	0.05 to 0.15s

For diagnosis, a cardiologist would typically look first at the heart rate. The normal value lies in the range 60 to 100 beats per minute. A slower rate is called bradycardia and a higher rate, tachycardia. He would then see if the cycles are of equal duration. If not an arrhythmia is suspected. The conduction time is determined by measuring the interval from the beginning of the P-wave to the first sign of ventricular depolarization, that is , the Q or R deflection(if the Q-wave is not clearly formed as is often the case). The P-R interval is normally 0.12 to 0.20s. A longer interval indicates delay in the spread of excitation from the atria to the ventricles, called AV block. The width of the QRS complex is normally 0.07 to 0.11s. An increase in the width indicates a delay of impulse conduction along the His-Purkinje system in

the ventricular walls. This condition is known as bundle branch block, which can be right or left sided.

In myocardial infarction(necrosis of the heart) there are some characteristic changes in the ECG which can confirm the diagnosis. The ECG also changes typically in the days following the infarction, so repeated recording is very informative. To a certain degree, the ECG changes are dependent on the extent and size of the infarction. Some infarctions are difficult to detect because of their locations.

There are a large number of different arrhythmias that can be detected in the ECG [6]. Figure 2-10 illustrates a few of the common ones. A detailed description of different arrhythmias will be given in a later chapter.

Electrocardiography is the most important method of examination for an exact diagnosis of any form of arrhythmia.

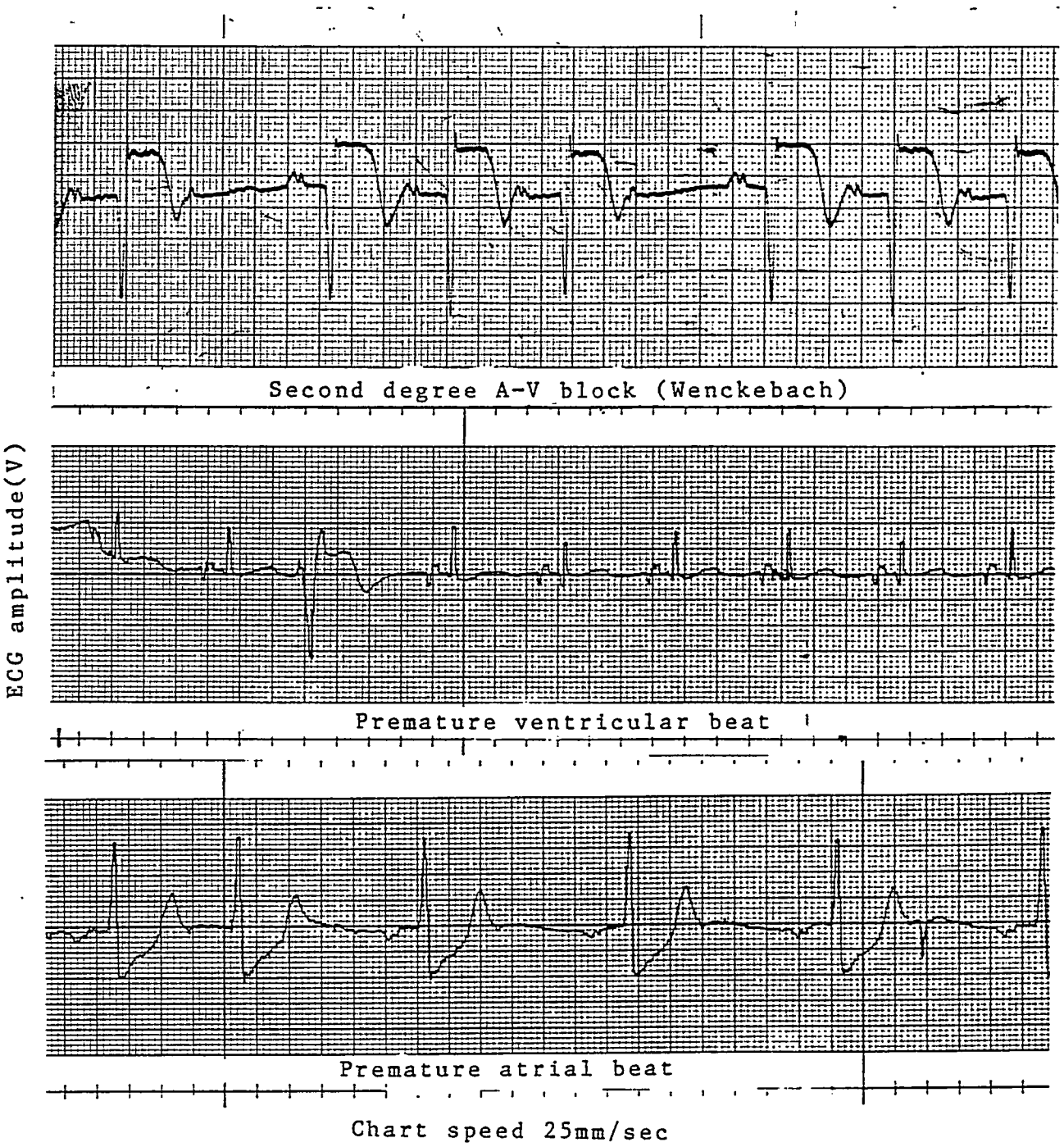

Figure 2-10: Arrhythmic electrocardiograms.

CHAPTER 3

HARDWARE DESIGN.

As mentioned earlier, the prototype of the ambulatory ECG monitoring system was designed around the popular VIC-20 microcomputer, using the specifications of a realistic arrhythmia monitor for ambulatory patients, as outlined in chapter 1.

3.1 Overall System.

Figure 3-1 is a simplified block diagram of an ambulatory ECG monitoring system which shows the basic building blocks of the system. The electrocardiogram, detected by the electrodes, is amplified and then digitized by an A/D converter. The processor then stores the digitized signal in the memory. The R-wave detector informs the processor of the occurrences of QRS complexes, which then analyses the signal for arrhythmias and generates alarms whenever it detects an arrhythmia. Figure 3-2 gives a detailed block diagram of the arrhythmia monitoring system for ambulatory patients. The main component of the system is the VIC-20 microcomputer [8]. The arrhythmia monitor consists of the following parts: ECG amplifier, R-wave detector, noise integrator, lead-fail detector, frequency divider, alarm driver and display, and VIC-20 microcomputer.

Except for the VIC-20, all the digital circuits were designed with CMOS digital ICs. The advantages of using CMOS ICs are: 1) low power consumption, 2) high noise immunity, and