AN EXPERT SYSTEM FOR ECG EVALUATION

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING

CHECKED
1995

By

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MARCH, 1990

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CANDIDATE'S DECLARATION

I hereby certify that the work that is being presented in the dissertation entitled, "AN EXPERT SYSTEM FOR ECG EVALUATION", in partial fulfilment of the requirements for the award of the degree of Master of Engineering in Electrical Engineering submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee, India, is an authentic record of my own work carried out for a period of 7 months from August, 1989 to March 1990 under the guidance of Dr SC Saxena, Professor, and Dr Vinod Kumar, Reader, Department of Electrical Engineering, University of Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for award of any other degree or diploma.

(AKS CHANDELE)
Major

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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Reader

Dated ; 23 March, 1990.

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Roorkee
23 March 1990

AKS CHANDELE
Major

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1 **GENERAL**

The aim of this dissertation is to develop AN EXPERT SYSTEM FOR :G EVALUATION. The ECG has a lot of diagnostically important ıformation about the condition of the heart. Visual system for ıterpretation of ECG has some inherent shortcomings. An automatic ıowledge based system would overcome these problems and produce a ›re objective evaluation.

This dissertation is organised in the following five chapters :-

Chapter 1. This gives a brief description of the physiology and function of the source of the ECG - the Heart. This is followed by an introduction to the ECG, method of recording and its usefulness as a diagnostic tool. The various methods of interpretation of ECG have been compared. Other investigation techniques used to ascertain the condition of the heart have been touched upon.

Chapter 2. This chapter gives an overview of expert systems, their components, applications and development tools with particular reference to systems for medical diagnosis.

Chapter 3. This describes the various methods adopted for obtaining ECG data for evaluation.

Chapter 4. This chapter covers the selection and extraction of various ECG parameters. The creation and application of knowledge base for evaluation has been described.

Chapetr 5. The concluding chapter, it covers the problem areas and the future extension of this work.

1.2 HEART PHYSIOLOGY AND FUNCTION

The heart is one of the most critical organs of the human body. The function of the heart is the rhythmic pumping of blood. In fact it functions like two pumps - one to move blood into the lungs and the other to push it into the circulatory system of the body. This function is performed by alternate contraction and relaxation of the muscular structure of its walls. The walls are made of muscle fibres which are the basic functional unit of the muscular system [Ref1,7,12].

The heart consists of several layers (Fig 1). The endocardium is the innermost layer which consists of a smooth lining of cells. Such cells are also found in the inside of the blood vessels of the body. The layer next to endocardium is the myocardium which constitutes the mass of the heart muscle cells. It is their coordinated contraction and relaxation which causes the chambers of the heart to pump the blood. The myocardium is thinner in the atria than in the ventricles and thickest in the left ventricle. The myocardium is covered by a layer of fat called the epicardium. The coronary blood vessels that supply blood to the heart itself run through this layer. The pericardial sac which encloses the heart is formed by the outermost two layers of the pericardium which have a small amount of lubricating fluid between them. Although the heart consists of several layers, it is only the myocardium that generates currents large enough to be detected and recorded on the surface of the body.

HEART LAYERS

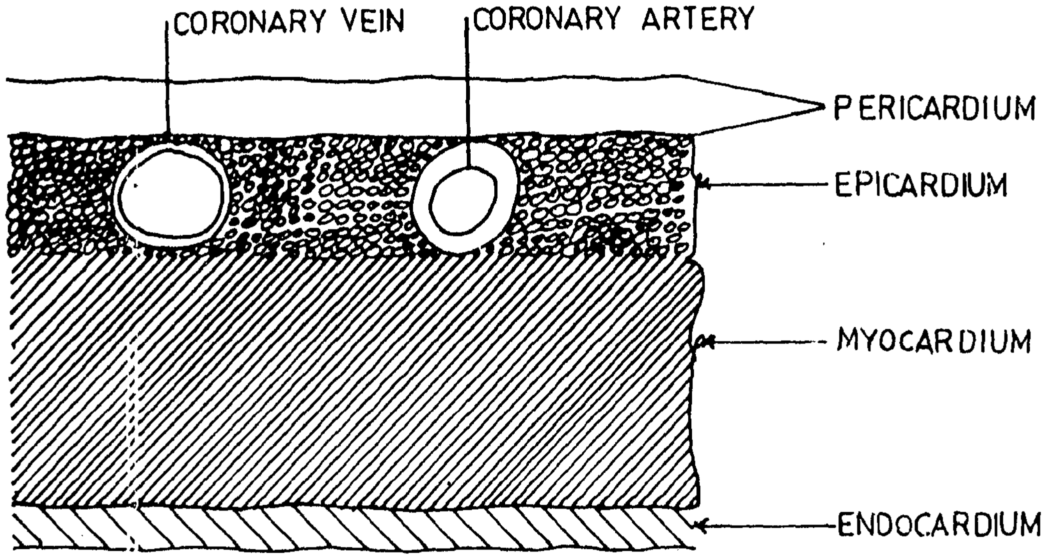


FIG NO 1

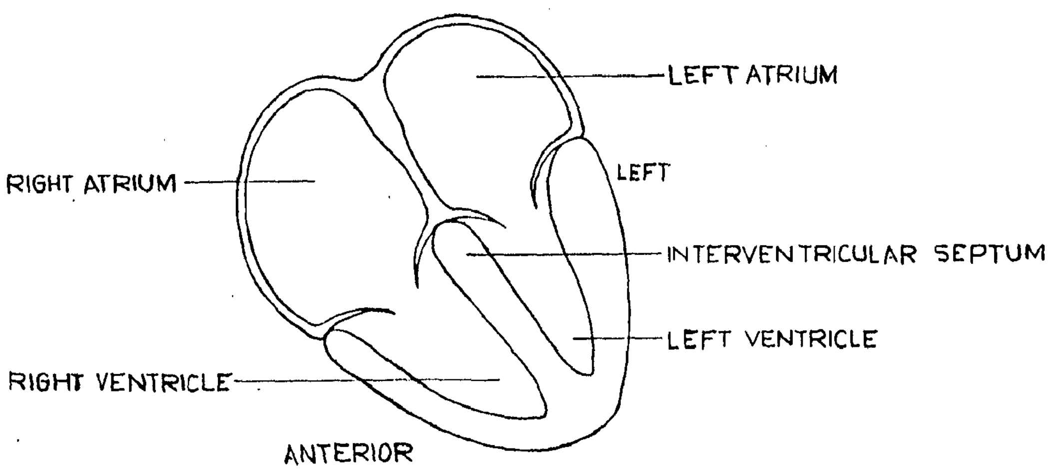


FIG. NO 2

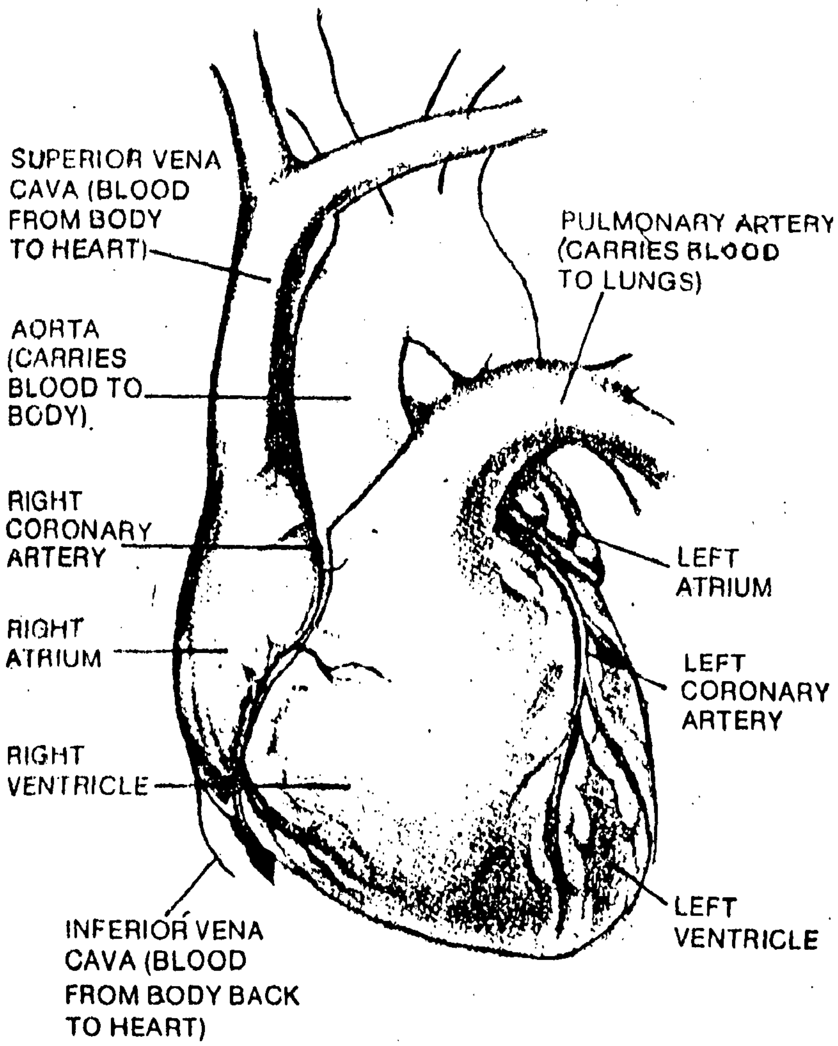

SUPERIOR VENA CAVA (BLOOD FROM BODY TO HEART)
AORTA (CARRIES BLOOD TO BODY).
RIGHT CORONARY ARTERY
RIGHT ATRIUM
RIGHT VENTRICLE
INFERIOR VENA CAVA (BLOOD FROM BODY BACK TO HEART)
PULMONARY ARTERY (CARRIES BLOOD TO LUNGS)
LEFT ATRIUM
LEFT CORONARY ARTERY
LEFT VENTRICLE

FIG. NO 3

The heart comprises of four chambers, namely the right and left atria and the right and left ventricles (Fig 2 & 3). The right atrium receives oxygen deficient and carbondioxide rich blood from different parts of the body through superior and inferior vena cava. The blood is passed from right atrium to the right ventricle which pumps it out to the lungs for purification, that means rich in oxygen content. The left atrium receives the purified oxygen rich blood from the lungs and passes it to the left ventricle which pumps it out to the circulatory network of the body through aorta, the network of arteries and capillaries. Valves located between these chambers are made in such a shape so that the blood can flow in only one direction. This prevents the backward flow of blood when the blood filled chamber is contracted.

Each cycle commences with the atrial systole which lasts about 0.1 sec. This is followed by the ventricular systole. During this period the atria are in diastole, which lasts about 0.7 sec. The ventricular systole lasts for about 0.3 secs, after which the ventricles are in diastole which lasts about 0.5 secs. Before the end of the ventricular diastole (0.1 sec), a fresh cardiac cycle commences. The normal cardiac rhythm is about 75 cycles per minute which falls to about 55 during sleep and can rise to over 100 during intense activity or exertion.

1.3 THE ELECTROCARDIOGRAM

The stimulation and contraction of the heart is accompanied by changes in the potentials of the cardiac cells. The normal resting cardiac cell is polarised as a result of an ionic gradient across the cell wall produced by a sodium pump which reduces the intra cellular and increases the extracellular sodium concentration. The ionic balance is preserved by a high intracellular and low extracellular potassium concentration. It is the potassium gradient across the cell membrane which is mainly responsible for the electrical potential difference across it. This is known as the membrane potential and is between 80 to 90 milivolts; the protoplasm being negatively charged with respect to the external surface [Ref 7, 13].

When the membrane is electrically stimulated, there is a sudden onrush of sodium ions across the membrane and the cell becomes depolarised. The protoplasm loses its negative charge and acquires a positive charge of 20 to 30 milivolts. The total variation in potential is, therefore, of the order of 100 to 120 milivolts. After some time, impermeability to sodium is rapidly restored and repolarization of the membrane takes place. The membrane potential once again reaches its initial preexcitation level of minus 80 to 90 milivolts with respect to outside of membrane. Cardiac cells are connected by electrically conducting junctions and membrane depolarisation spreads as a wave through the entire myocardium . It is the movement of this depolarisation wave and the ensuing wave of repolarisation, which is detected on the surface of the body.

The Electrocardiogram (ECG) is a graphic representation of the electrical activity of the heart. This electrical activity has a waveform as shown in Fig 4. Its exact shape depends on the location

<u>ECG WAVE</u>

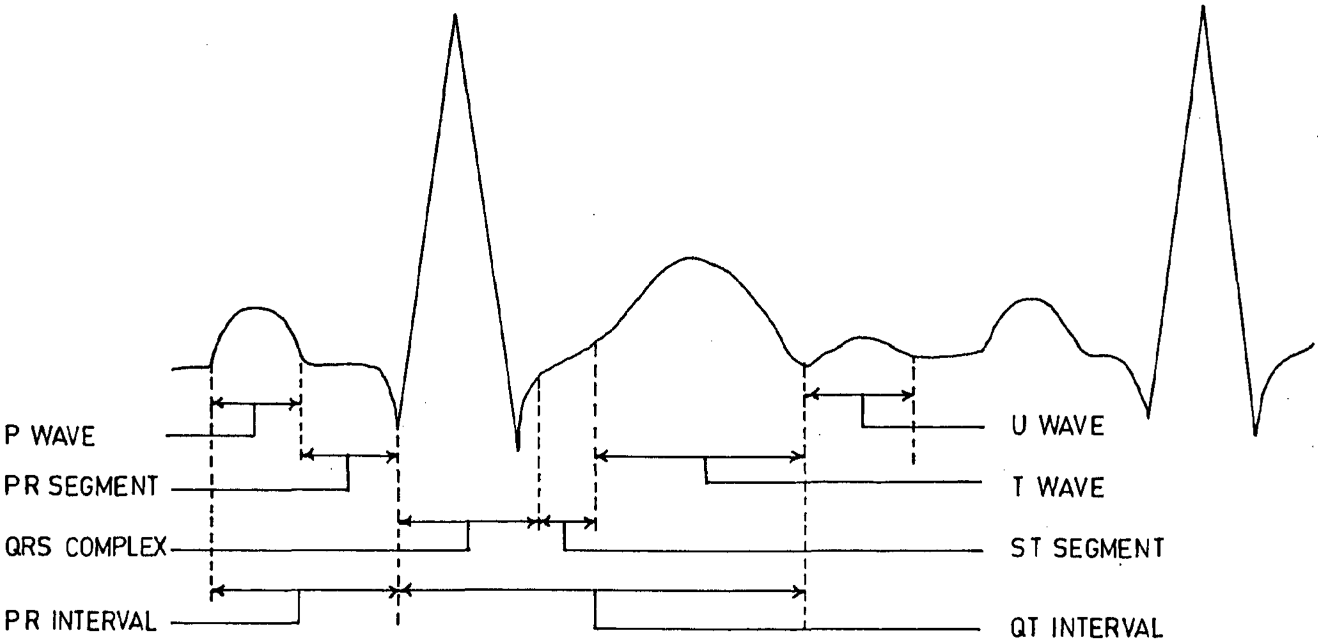


FIG. NO 4

of the electrodes and the condition of the heart. Each cycle of cardiac activity consists of three main components [Ref 1, 7] :-

(a) Atrial depolarisation (contraction of the atria).

(b) Ventricular depolarisation (contraction of the ventricles).

(c) Atrial and ventricular repolarisation (relaxation of the heart muscles).

These three activities are shown in Fig 4. The first rounded pulse, known as the P wave, corresponds to atrial depolarisation. The steep impulse which follows this wave is known as the QRS complex and corresponds to ventricular contraction. The T wave corresponds to the repolarisation (relaxation) of the myocardium. The repolarisation of atrium is very slow and can hardly be noticed since it is hidden in the ventricular repolarisation. Sometimes another rounded wave, the U wave, follows the T wave. The source of the U wave is uncertain. It is sometimes recorded from normal hearts, but when large, it is often a sign of drug effect or electrolytic imbalance.

The gaps between these waves, which usually appear as straight lines, are called 'segments'. These segments are named after the waves they separate, e.g., ST segment between the S and T waves. The 'intervals' are also named after the waves at their beginning and end, e.g., PR interval indicates the duration from onset of P wave to end of R wave. Thus the measurement is from the beginning of the first wave (unlike in the case of segments where measurement starts at the end of the first wave). An interval ends with the start of the wave at its end just like a segment does, with one exception that is

P WAVES

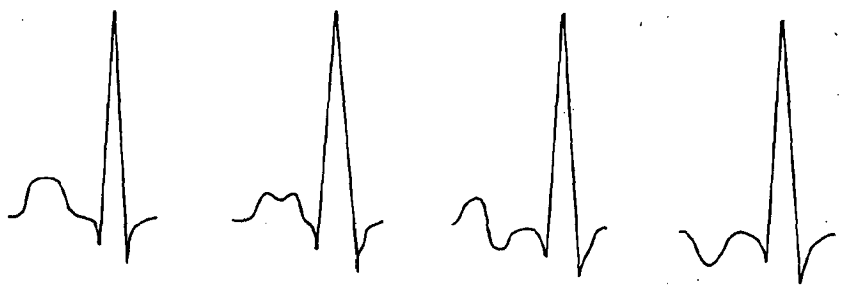


FIG NO 5(a)

QRS COMPLEXES

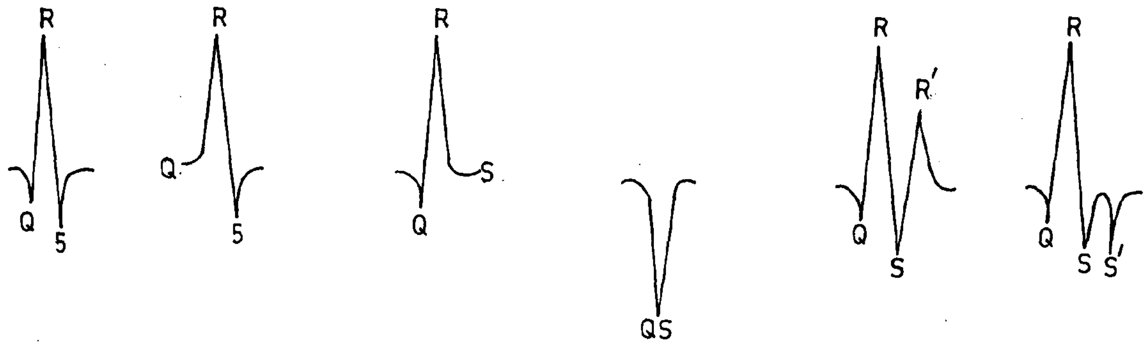


FIG NO 5 (b)

T WAVES

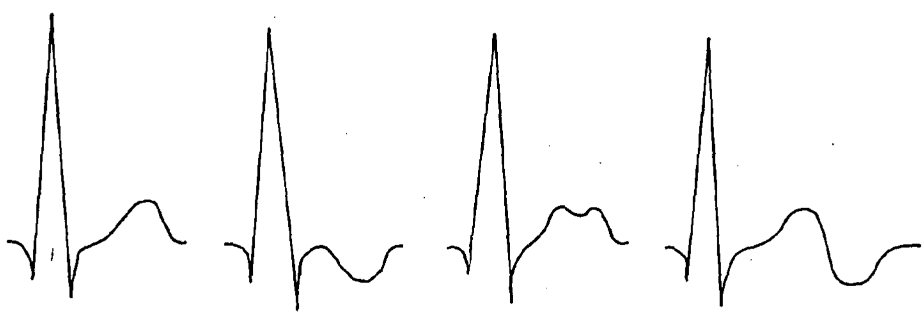


FIG NO 5 (c)

QT interval which is measured from the start of the Q wave to the end of the T wave [Ref 7, 12].

The P wave may be positive,negative,notched or biphasic (Fig 5a). The QRS complex has several components. The R wave is the first upward deflection ; the Q wave is a downward deflection that precedes the R wave ; the first downward deflection after the R wave is the S wave. If the entire complex is negative, it is called QS. There may be a second R wave which is designated as R'. A second S wave, if present, is called S' (Fig 5 b). To be separately labeled as part of the QRS complex, a wave must cross the base line. Every wave changes direction once, but a second change which does not cross the base line is called a 'notch'. The end of the QRS complex is indicated by an abrupt chnage in the direction of the wave. This is the beginning of the ST segment. This point is called J point. The ST segment may be 'elevated' (above) or 'depressed' (below) the level of the base line. The T wave may be positive, inverted, notched or biphasic (Fig 5 c).

1.4 ECG RECORDING

It is conventional to use a series of different electrode positions to record the ECG. It helps to view the conduction of electrical signal in the heart from different angles and directions. Each pair of electrode positions is called a lead. The ECG consists of 12 leads representing 12 different electrical views of the heart. These are :-

(a) **Frontal Plane Leads**

(i) Bipolar Standard Leads (I, II, III).

(ii) Augumented Limb Leads (aVR, aVL, aVF).

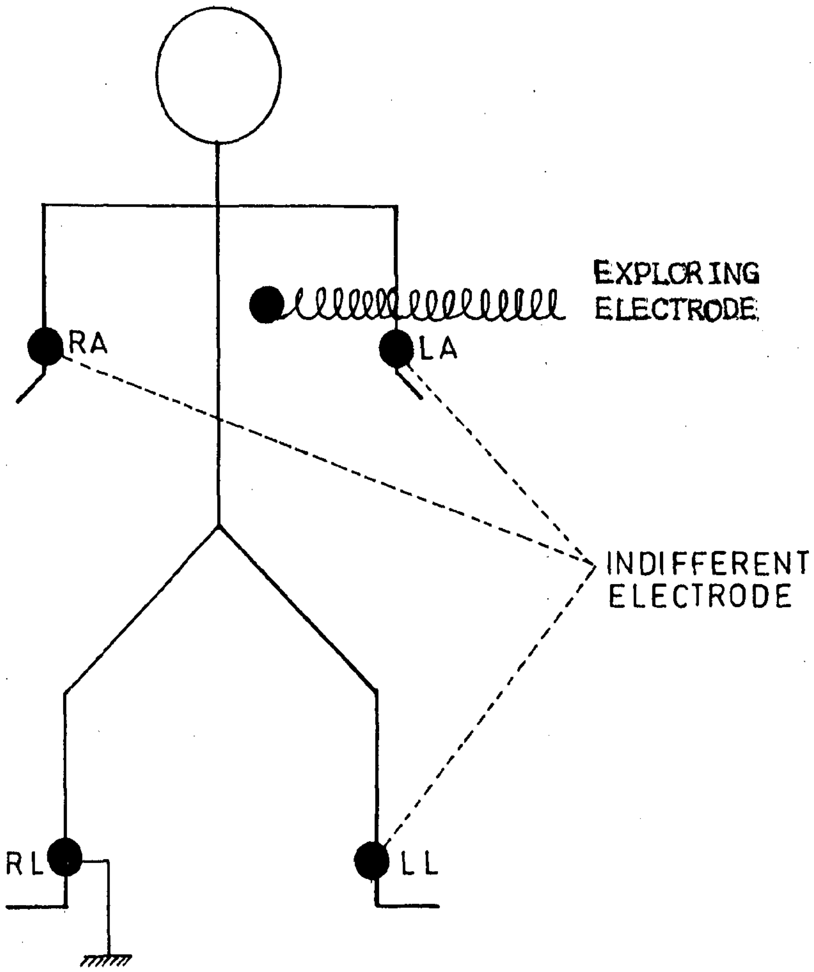


FIG NO 6

(b) **Transverse Plane Leads**

Precordial (Chest) Leads (V1 to V6).

The 12 lead ECG is recorded using five electrodes. Four electrodes are attached to each one of the limbs and the fifth one is a mobile electrode which is placed at different positions (V1 - V6) on the chest to record potential in transverse plane. The electrode attached to the right leg is used as an earth connection. (Fig 6) [Ref 7, 12, 13].

The standard (bipolar) leads record the potential difference between the two limbs :-

Lead I = LA - RA (Difference between Left arm and Right arm).

Lead II = LL - RA (Difference between Left leg and Right arm).

Lead III = LL - LA (Difference between Left leg and Left arm).

The relationship between them is based on Einthovan's equilateral triangle (Fig 7).

Lead II = Lead I + Lead III

The relationship between standard leads and unipolar augmented leads are as follows :-

$$aVR = \frac{I+II}{2}$$

$$aVL = \frac{I-III}{2}$$

$$aVF = \frac{II+III}{2}$$

The augmented limb leads record the unipolar or independent potential of the selected limb. The spatial relationship among the six frontal plane leads is given in Fig 8.

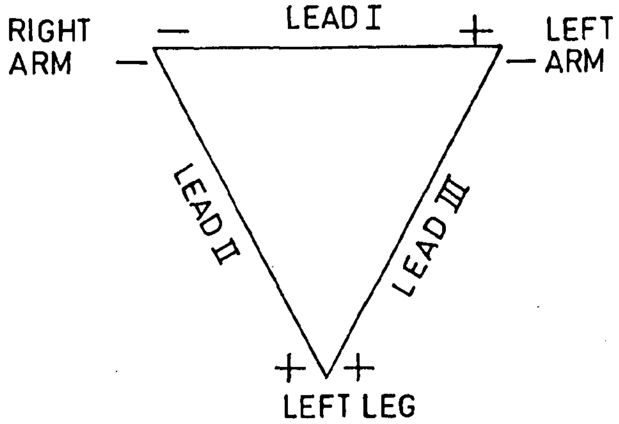


FIG. NO 7

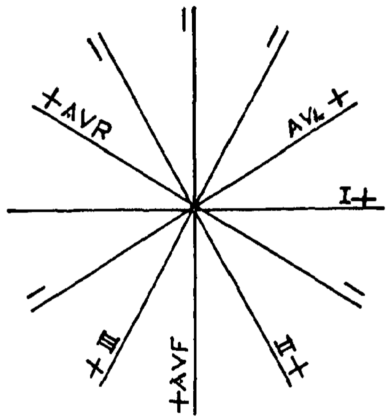


FIG.NO 8

PRECORDIAL LEADS

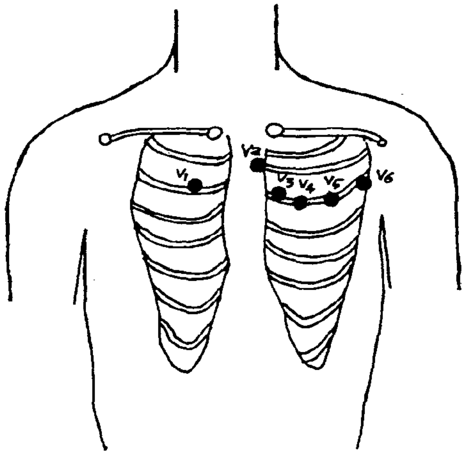


FIG.NO 9(a)

POSTERIOR

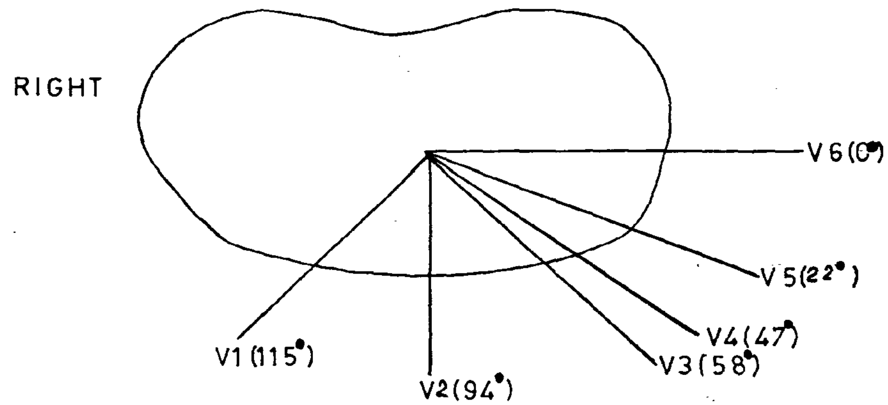


FIG.NO 9(b)

The precordial (chest) leads record the varitaion in the transverse plane. The location and relationship between these six leads (VI to V6) is as shown in Fig 9. a & b.

Unipolar leads, designated by the letter V, use an exploring electrode placed on a chosen site and linked with an indifferent electrode whose potential is close to zero. The indifferent electrode is formed by connecting all three limb electordes (i.e., both arms and left leg) in the case of chest leads, or in the case of augmented unipolar limb leads (aVR, aVL, aVF) by connecting the two limb electrodes which are not being used as exploring electrodes.

Modern ECG equipment have a selector switch with the help of which all the 12 recordings are made without altering the lead configuration. Typical recordings obtained of the various leads are shown in Fig 10.

1.5 OTHER INVESTIGATION TECHNIQUES

Diagnosis of cardiac condition should not be made based on evaluation of ECG alone. It should be viewed in totality alongwith results of other investigations. Some of these techniques are described below :-

(a) **ECHOCARDIOGRAPHY.** This technique uses ultra sound waves to study the disposition and movement of valves and other structures of the heart. Ultra sound waves get reflected from interfaces between blood and other solid tissues. A narrow ultra sound beam is rapidly osciliated back and forth over a sector and a two dimensional map is obtained from the reflected waves. This image accurately reproduces the movement of various structures of the heart [Ref 13].

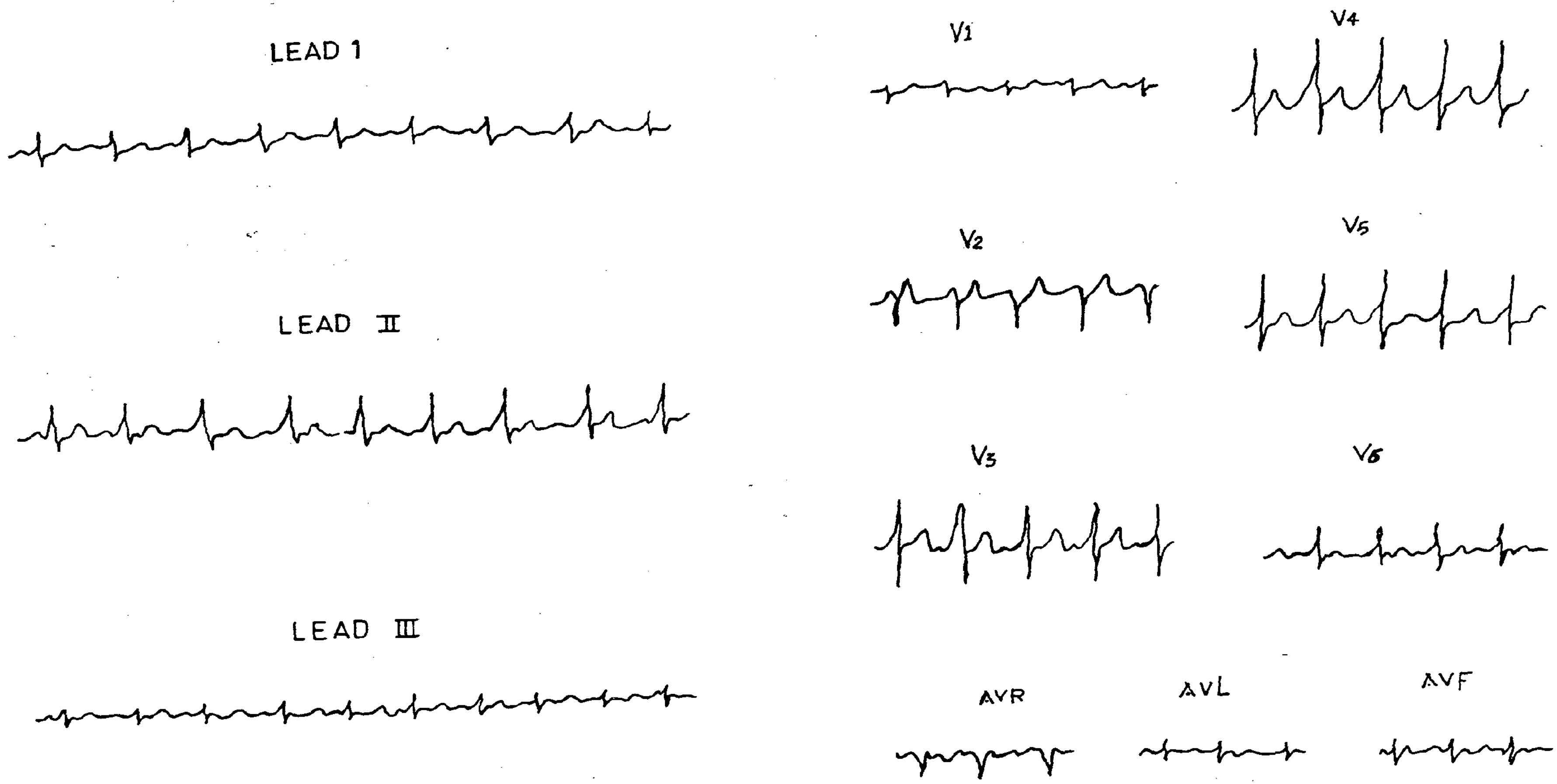


FIG NO10

(b) **RADIOGRAPHY.** A X-ray picture is helpful in determining the shape and size of the heart and the state of pulmonary blood vessels. Sometimes a baruim swallow picture is necessary for obtaining better results of specific areas. [Ref 7, 13].

(c)**RADIOSCOPY.** An image intensifier is used to screen the heart and detect disorders, such as abnormal cardiac pulsations and valvular calcification. It is particularly useful during cardiac catheterisation and pacemaker implantation. [Ref 7, 13].

(d)**ANGIOGRAPHY.** This is an invasive technique . A catheter is inserted into a vein and can be advanced into the right atrium/ right ventricle and the pulmonary artery. The catheterisation normally takes place under radioscope control. Catheters allow radio opaque contrast medium to be injected into the chambers of the heart to obtain better results. Angiography helps to check ventricular function by making pressure measurements. Blood samples are withdrawn from different sites in the heart and by measuring the oxygen saturation shunts, if any, between the right and left or left and right chambers can be detected. Also pulmonary and systemic blood flow can be calculated. [Ref 7, 13]

(e)**RADIONUCLIDE SCANNING.** Radionuclides having short half life are used in this technique. They emit gamma rays which can be detected on the surface. Usually the radioisotope is introduced into the blood stream and it mixes with the circulating blood from where it can be detected with the help of a gamma camera. This is particularly helpful in distinguishing between ischaemic and non ischaemic myocardium. [Ref 7, 13].

(f)**VECTORCARDIOGRAPHY.** Vectorcardiography (VCG) is another method of recording the electrical activity of the heart. In this technique the spatial vectorcardiogram is recorded in all three planes i.e., frontal,sagittal and horizontal, whereas the ECG is a two dimensional representation recording the electrical potential in one axis only. The VCG is achieved with the help of the orthogonal (Frank) lead system. The recording is in the shape of of a loop in each of the three planes, from which a stereoscopic three dimensional representation is obtained. Spatial VCG is not yet as common and popular as ECG. Its use is restricted to a few medical establishments since the equipment is expensive and definite diagnostic criteria have yet to be formulated. [Ref 5, 7].

1.6 ECG AS A DIAGNOSTIC TOOL

Electrocardiography plays an essential role in the diagnosis and investigation of heart disease. Nowadays ECG has become a diagnostic tool almost as common as the stethescope and the BP instrument. Its purpose is well known even in the non medical community. Its main advantages are that it is a simple, painless, harmless, non invasive technique which provides a faithfull representation of the condition of the heart. Its main value lies in the elucidation of cardiac arrhythmias and conduction defects and in the diagnosis and localisation of myocadial infarction. It also provides important information about problems such as digitalis toxicity, electrolytic disturbances and hypertrophy of the various chambers of the heart.

The information that a physician obtains from an ECG is as follows ;-

(a) The easiest to determine is the frequency of the heart beat. Also, whether it is beating rhythmatically or not ? It helps to determine whether the heart is functioning like a single integrated unit or portions of it are 'misfiring' sometimes.

(b) Abnormalities, if any, in the heart are detected by studying the ECG in terms of physiologically known relationship between various heart events and their electrocardiographic manifestation. The absence or deviation from normal in respect of any particular segment of the ECG helps to localize the disorder.

(c) Diagnosis are based on empirically formulated criteria. An ECG data bank and the physicians own experience are of importance in such diagnosis.

It should not be presumed that it is easy to diagnose cardiac disorders from ECG. There are enormous difficulties with the interpretation. The ECG is always viewed in the light of the clinical findings and the results of other investigation. Extensive use of ECG over the last one century has shown that it is a very useful diagnostic tool. There are continual efforts to develop new tools and techniques to make ECG diagnosis more accurate and reliable.[Ref 5,7].

1.7 METHODS USED FOR INTERPRETATION OF ECGs

The following are the three different methods used :-

(a) Visual.

(b) Semi automatic.

(c) Fully automatic/expert system.

(a) **VISUAL METHOD**

The ECG was discovered in 1887 and was put into experimental use in the first decade of this century. By 1930s, its usefulness was realized and it was put into general use. The visual method was first adopted for interpretation of ECGs and is still considered to be most reliable. Despite the expensive research work in the field of automation of diagnosis of ECG, the procedures are still far away from the state of perfection. Lot of research effort is being put by many research groups and individual workers to achieve the state of highly accurate and reliable diagnosis. [Ref 5, 7, 24].

Diagnosis based on ECG are highly dependent on the quality of recordings. It is, therefore, essential that utmost care is taken while recording the ECG. Before commencing interpretation, the physician should check the complete ECG strip and ensure that it has been recorded correctly. Then he should proceed to interpret the ECG in the following manner :-

(i) The first step is to determine the heart rate and rhythm.

(ii) The next step is to recognize the various curves of the ECG by their amplitude, slope, duration and sequence. These are then identified and named based on predecided criteria.

(iii) Having recognized and identified each curve, he then compares the amplitude, slope and duration of each curve with values which are considered standard. Those which are outside the established normal range are identified.

(iv) The abnormal recordings are finally classified based on an established set of rules as either :-

(aa) Typical of a particular condition.

(ab) Consistent with a number of different conditions.

(ac) Abnormal but not specific to any condition.

In most cases when a simple or resting ECG is not sufficient to diagnose or localize a heart condition, an exercise ECG is undertaken. Treadmill test is the most extensively used form of exercise test for this purpose. The subject is put through the test in stages with the ECG being continuously monitored. This is carried on till there is pain in chest or any diagnostically significant changes appear in the ECG. The test is terminated when the subject is exhausted or complains of pain in any part of the body or weakness. The ECG is monitored for some period after the test to observe any changes that may occur or to know how the heart is returning to its normal state of functioning. [Ref 5, 7, 9, 16].

(b) <u>SEMI AUTOMATIC METHOD.</u>

As the knowledge of the usefulness of ECG as a diagnostic tool has increased so has the work load in the recording and interpretation. The ECG being a relatively simple and rythmatically recurring waveform is well suited for analysis by automatic methods. The shortage of adequately trained personnel for interpretation work has led to the application of computer aided data processing techniques in the diagnosis of ECG. It has also helped cardiologists to be relieved from routine work.

Computer helps to extract automatically, without human intervention, clinically useful measurements of the ECG.

Computer interpretation of ECG involves the following three stages:-

(i) Recording of ECG.

(ii) Analysis of the signal.

(iii) Classification of the signal.

RECORDING OF ECG

The technique of recording ECG with the help of the electrocardiograph has already been described. Some additional processing is required to be carried out on the signal if it is to be used for computer analysis. This includes amplification, transmission, filtering and analog to digital data conversion. ECG for computer analysis should be recorded with extreme care because, unlike the human brain, the computer does not have the ability to discriminate between the ECG signal and any artifacts that might creep in. Electrodes are properly placed so as to ensure good contact with the skin. Noise and other interfering signals must be avoided by adopting necessary precautions while recording. The signal is in the range of milivolts and requires amplification. Filtering is necessary to remove power line or any other high frequency or transients interference. For accurate reproduction of ECG wave, a frequency response of 0.05 to 200 HZ is required. The ADC should have a sampling rate higher than 500 samples/sec and an amplitude resolution of 0.1% [Ref 9. 20, 22].

ANALYSIS OF THE SIGNAL

This involves extraction of the diagnostically important parameters of the ECG wave to include amplitudes, wave duration/angles, zero crossings and wave areas. A number of different methods have been used for the analysis of ECG wave [Ref 15, 17, 21]. Frequency analysis of the wave pattern has been carried out by some researchers [Ref 10, 11,]. Some other have adopted the technique of resolving the waves into sine and cosine function components and reconstructing the wave with fourier terms [Cady at al 1961]. The matched exponential functions technique was suggested by Young and Higgins (1963). Natrajan and Padmanabhan (1973) resolved the ECG into a fourier series. Other research workers have made use of data compression techniques and recursive filters. The technique used during the current work for the extraction of parameters is based on amplitude, slope, duration and zero crossing. This is described in detail in the next chapters of the dissertation.

CLASSIFICATION OF THE SIGNAL

After the parameters have been extracted, the following options are open :-

(i) The extracted data is presented to a cardiologist for his diagnosis.

(ii) Diagnosis is carried out automatically by the computer based on predetermined criteria which are based on the knowledge and experience of cardiologists.

Most of the computer based ECG analysis programmes available today are semi automatic type. They help in extraction of diagnostically significant features which are later on used by the physicians for interpretation. Where the computer is connected to an on line monitor, it can set off alarms when predesignated thresholds are violated.

AUTOMATIC METHOD

In this method, the computer compares the information extracted with criteria laid down by experts and than classifies the ECG wave in different categories. Each classification is associated with a certain degree of probability. Besides the information obtained from the ECG, a large number of other factors are taken into consideration before arriving at a conclusion. Some of these are :-

(a) **Age of the subject.** There is considerable difference in the ECG of children and adults.

(b) **Height. Weight and Body Structure.** ECG of fat people have reduced amplitudes.

(c) **Blood Pressure.**

(d) **Past History of Clinical Problems.**

(e) **Other factors.** Such as smoking, pulmonary disease, effect of drugs etc.

Such a system would also include information obtained through other investigations (described earlier) to help to formulate an opinion [Ref 7, 12].

CHAPTER 2
EXPERT SYSTEMS

2.1 INTRODUCTION

Artificial intelligence (AI) deals with comprehending and creating human faculties which are regarded as intelligence. There is no sacrosanct definition of artificial intelligence and it spreads across a variety of disciplines. It has two broad objectives :-

(a) To discover how the human brain works by modelling human intelligence.

(b) To build such intelligent machines that can assist or replace humans resulting in one or more of the following advantages :-

(i) Reduced costs.

(ii) Improved efficiency.

(iii) Increased speed.

(iv) Undertake tasks which are too dangerous for humans.

(v) Multiplication of expert human capabilities.

The work in this field started with the advent of computers and researchers have ever since tried to devise a machine which would have human traits such as learning, reasoning, understanding language, game playing etc. [Ref 6, 18]. Even after almost four decades, no machine, has yet been built which possesses 'intelligence' as humans do nor does this goal appear achievable in the foreseeable future. Some of the human traits in emulating which the researchers have met with varying degrees of success are as follows :-

(a) Natural language understanding.

(b) Perception systems for vision, touch, speech.

(c) Problem solving (Expert/Knowledge Based Systems).

(d) Game playing.

(e) Knowledge representation.

(f) Learning.

One of the most important gains of research in the field of problem solving is the development of expert systems. These are programmes that use human like reasoning processes rather than computational techniques to solve problems. The expertise of a human expert is obtained and encoded and then used to produce a computer solution to the problem. A human expert who can solve the problem is essential before an expert system can be designed and developed.

An expert system is capable of modelling the reasoning of a human expert. It has explicit knowledge and provides a consultation facility for users. The knowledge must be stated in a clear language. It is generally in the form of rules which form the knowledge base of the system. The system is interactive, permitting the user to access the knowledge base in the manner of consultation. The user may supply information to the computer or it may question the user till sufficient information is available to reach a useful conclusion.

The knowledge base of an expert system is developed by a knowledge engineer in consultation with a subject expert. A knowledge engineer is a person who casts the knowledge of the expert in the formal language used by the computer. The knowledge expressed in this way should be understandable to the expert so that he can ensure that his knowledge has been correctly interpreted and can be modified if required.

EXPERT SYSTEM

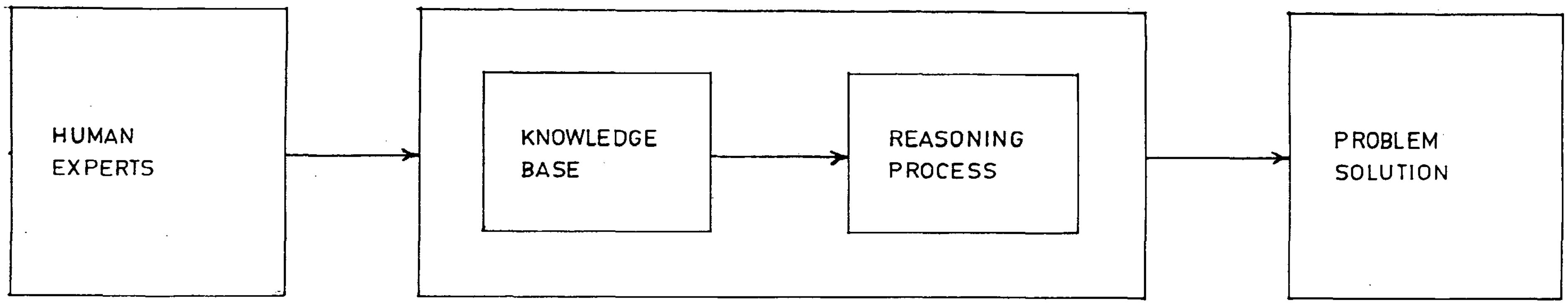


FIG NO 11

The reasoning of expert system is often associated with a degree of uncertainity. This uncertainity is usually expressed by a numerical probability. The reasoning can be designed to work either forward or backwards. It could work backwards from a number of possible conclusions to fit the evidence available or work forwards from the evidence to produce likely conclusions.

The terms Expert Systems and Knowledge Based Systems are often used interchangeably. There is very small difference between them. Expert systems refer to a particular approach involving the acquistion of knowledge from a human expert. A Knowledge Based System is more general and does not emphasise a particular knowledge aquisition process. [Ref 6, 18].

2.2 COMPONENTS OF AN EXPERT SYSTEM

The three basic components of an expert/knowledge based system are as follows (Fig 12) :-

(a) Knowledge And Data Base.

(b) Inference Engine.

(c) User Interface.

2.2.1 KNOWLEDGE AND DATA BASE

A knowledge base is the basic component of an expert system. It represents the knowledge of facts and other problem related information as also heuristics such as judgements, intution and experience. The knowledge base is created through an expert knowledge acquistion process. A knowledge base differs from a data base in as much that it contains probabilistic information and can be modified by experts alone. A data base, on the other hand, stores only

COMPONENTS OF EXPERT SYSTEM

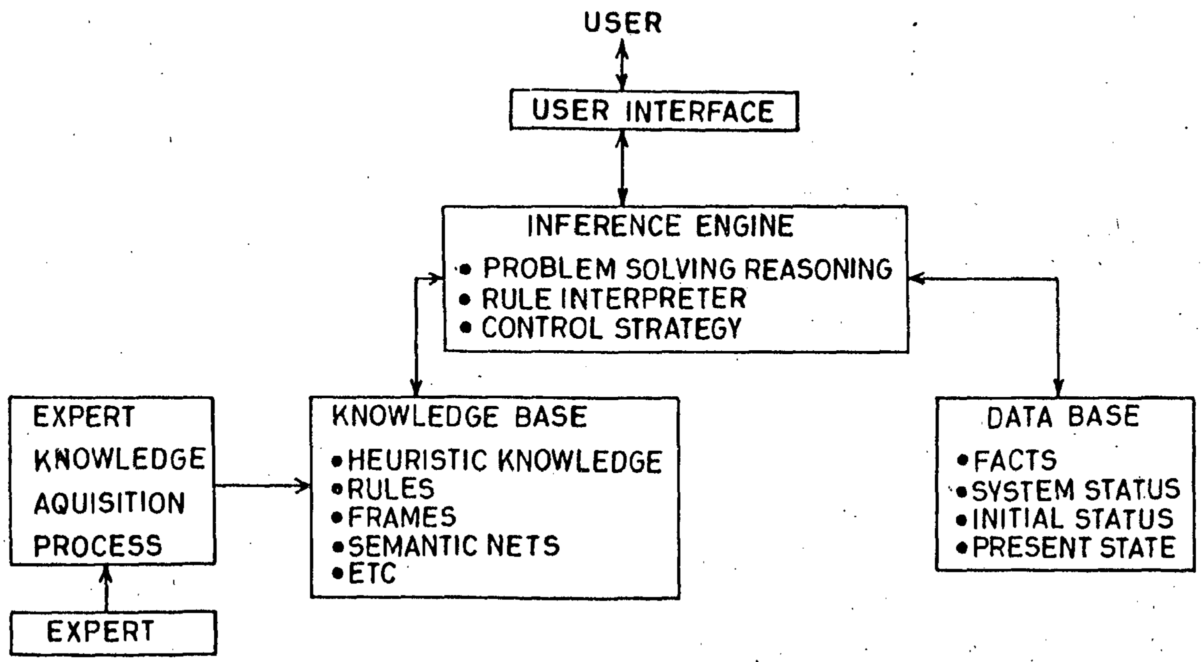


FIG. NO 12

facts which are clear cut and definite. A data base can, therefore, be modified by any operator familiar with data processing.

2.2.2 INFERENCE ENGINE

The inference engine is a mechanism which is responsible for interpreting the knowledge and carrying out logical deductions using both data and knowledge base available with the system. It also implements necessary modification to the knowledge base, if required. It includes strategy component which organises and controls the application of the inference process.

2.2.3 USER INTERFACE

This is responsible for establishing two way communication between the user and the system. The system obtains all required information about the problem through this and provides its conclusions to the user.

2.3 APPLICATIONS OF EXPERT SYSTEMS

Present day applications of expert systems can be divided into the following three groups :-

(a) **CLASSIFICATION**

- (i) Medical Diagnosis.
- (ii) Chemical Analysis.
- (iii) Equipment Fault Diagnosis.
- (iv) Prospecting (Oil/Minerals).

(b) **PLANNING AND RESOURCE ALLOCATION**

- (i) Machine Shop Scheduling.
- (ii) Route Planning.
- (iii) System Configuration.
- (iv) Military Unit Deployment and Target Allocation.

(c) **SITUATION INTERPRETATION AND MONITORING**

(i) Intensive Care Patient Monitoring.

(ii) Industrial Plant Monitoring.

(iii)Technical Situation and Threat Assessment.

2.4 BUILDING AN EXPERT SYSTEM

The four major steps in building an expert system are. [Ref 18] :-

(a) Analysis of the problem.

(b) Designing the expert system.

(c) Building a prototype.

(d) Testing the prototype.

2.4.1 ANALYSIS

This involes firstly deciding which problem we want to solve with the help of the expert system. Once the choice has been made it is necessary to determine what are the benifits that will accrue by using an expert system to solve the selected problem. The next step is to decide on the expert(s) who have to be consulted to build the knowledge base and then proceed to collect the information to formulate the knowledge base.

2.4.2 DESIGN

In this stage the knowledge that has been collected is organised in a manner so that it can be utilised for problem solving. If necessary, additional knowledge is acquired and added to the existing knowledge base. A formal structure is created for the knowledge base. The most commonly used knowledge representation technique is the IF - THEN RULES (Fig 13). Another widely used

KNOWLEDGE REPRESENTATION BY RULES

FACTS

B = 10
B = A+C
C = 6

RULES

1. IF X = Y+Z, THEN Z = X−Y
2. IF X = Y+Z THEN X = Z+Y

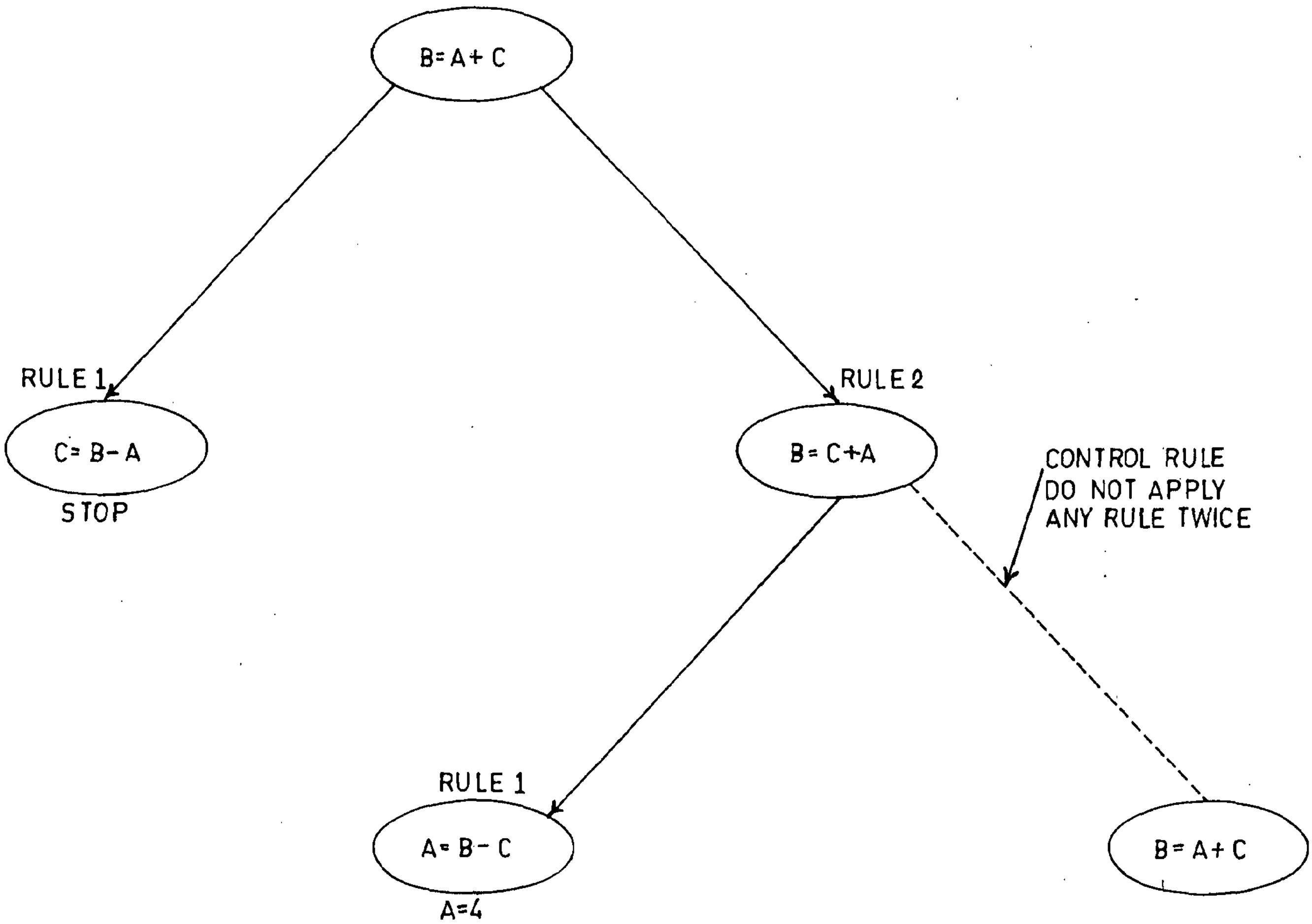


FIG. NO 13

KNOWLEDGE REPRESENTATION BY NETWORK

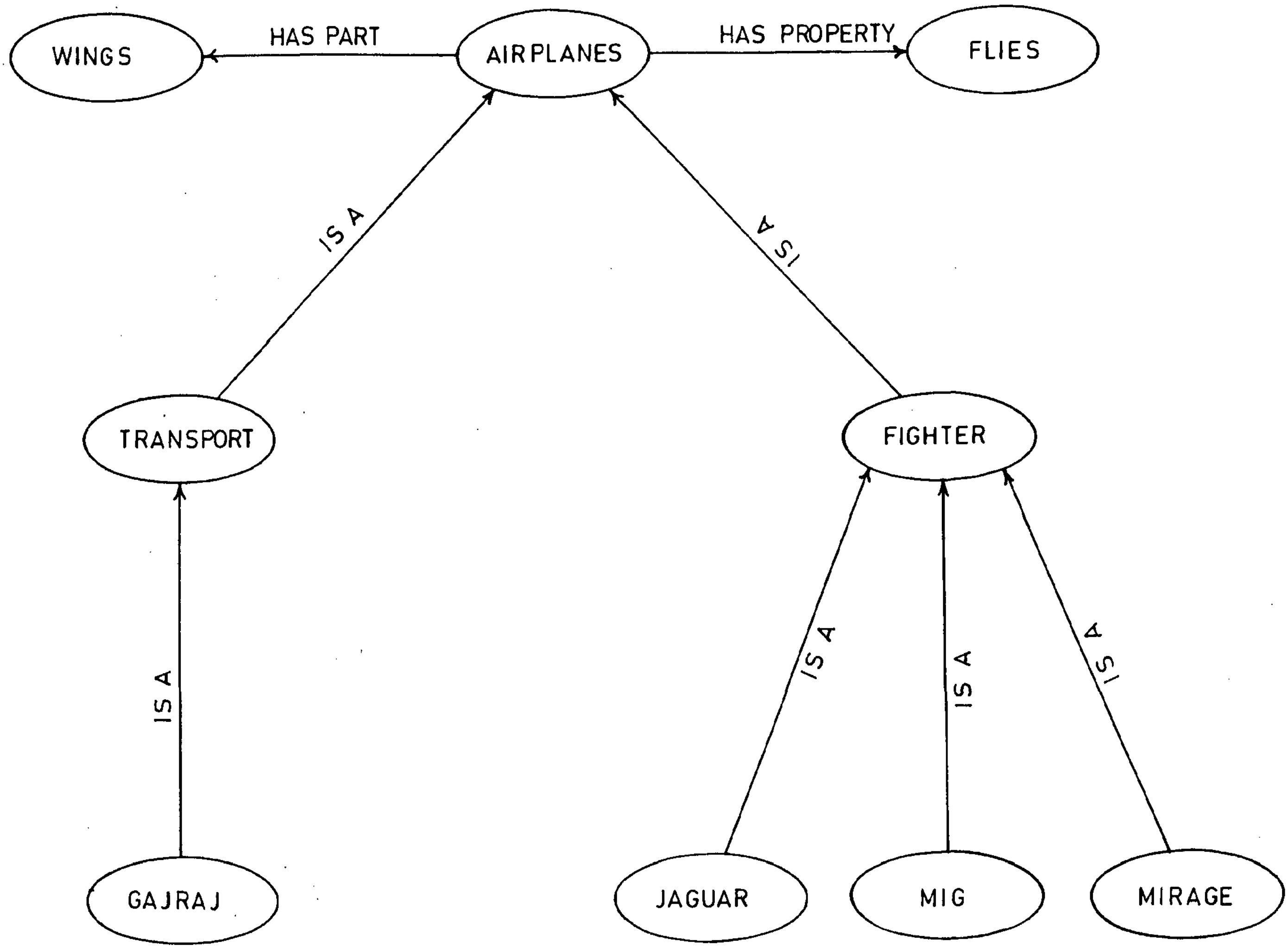


FIG.NO 14

method of implementing is the use of SEMANTIC NETWORKS (Fig 14). Any queries that the user is likely to have and their possible answers are incorporated in the program. This is an ongoing process with the knowledge base and question answer bank being expended as and when more knowledge is acquired.

2.4.4 TESTING

In this phase the prototype is tested and modifications are carried out if necessary. The sequence of actions is as given in the flow chart (Fig 15).

2.5 EXPERT SYSTEM DEVELOPMENT TOOLS

2.5.1 LANGUAGES.

New programming languages were developed for work in the field of artificial intelligence since it was mainly concerned with symbolic processing rather than numerical processing. Scientific programming languages such as FORTRAN were not suitable since they dealt primarily with numbers. LISP and PROLOG are two such languages developed.

LISP. This was the first language specially developed for expert systems. Over the years it has improved into a highly flexible processing environment. It has the following features :-

(a) List processing language ; program and data held in lists.

(b) Declarative language ; action and objects are expressed as functions.

(c) Interpreted language ; fully interactive programming.

(d) A code can be complied for efficiency.

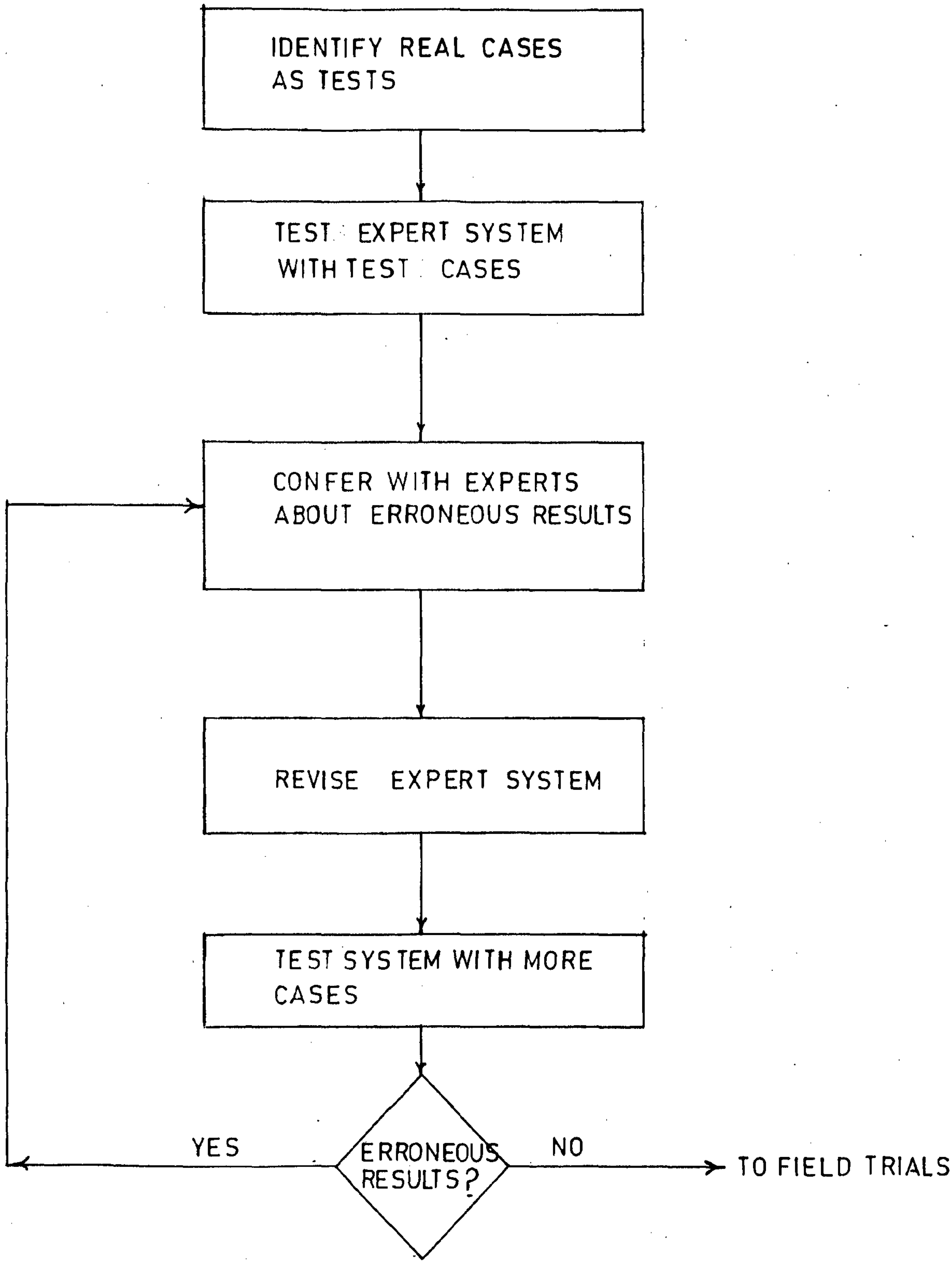

IDENTIFY REAL CASES AS TESTS
TEST EXPERT SYSTEM WITH TEST CASES
CONFER WITH EXPERTS ABOUT ERRONEOUS RESULTS
REVISE EXPERT SYSTEM
TEST SYSTEM WITH MORE CASES
ERRONEOUS RESULTS?
YES
NO
TO FIELD TRIALS

FIG. NO 15

The above features facilitate rapid prototyping which is desirable for work in a new field such as designing of expert systems.

PROLOG. This language has been developed more recently. It is based on logic. Its features are :-

(a) Declarative language based on logic; programme expressed as a set of true relationships in no particular order.

(b) Solves problems by back tracking; it has built in control mechanism suitable for expert systems.

(c) Interpreted and interactive.

(d) Can be partially compiled to improve efficiency.

2.5.2 EXPERT SYSTEM SHELLS

An expert system may be built by using a standard shell or frame work [Ref 18]. A shell is a specially created software package which permits data or knowledge to be entered and manipulated in predefined ways. It has no knowledge base of its own. A designated format is used to encode and enter the knowledge base into the shell, which consists of an inference mechanism (engine), data base and interfacing facility.

2.6 PROBLEMS OF VISUAL INTERPRETATION

Visual measurements are approximate and imprecise. They suffer from inter observer variability. There are bound to be differences in judgement between individuals. This is particularly important in the recognition of diagnostically significant parameters of the ECG wave. For example, there may be variances in identifying the on set and off set of various waves by different individuals. This would naturally cause a difference in the resulting interpretation.

The work load of ECG diagnosis has increased tremendously in the last few years. It is estimated that approximately 80 million ECGs are recorded annually in the European Community. In a developing country like India too ECG facilities are now available even in small towns. The availability of trained personnel to diagnose ECGs has not matched the requirement. Only a small percentage of recorded ECGs are analysed by trained cardiologists. Others are liable to make incorrect or misleading interpretation.

In large hospitals cardiologists are always very busy. It may be quite some time before a cardiologist is available for interpreting the ECG. This is not an acceptable situation for patients suffering from serious cardiac disorders where time is very crucial.

2.7 EXPERT SYSTEMS FOR DIAGNOSTIC PURPOSES

Expert systems are designed to utilize the knowledge of experts when they are not available. The purpose is not to replace experts, but instead to 'capture' their knowledge and experience which they have gained over years by working in a particular field. Based on this knowledge, expert systems allow their users to reach conclusions which the experts themselves would have arrived at.

One of the earliest applications of expert systems was in the field of medical diagnosis. Systems were developed with the aim of assisting physicians. The physician provides to the computer details of the patients medical history, results of laboratory tests, clinical examination and other relevant information. The expert system is then able to suggest possible ailments and their treatment. It also helps them to check their diagnosis against that of proved experts. Details of some medical expert systems are given in Table 1.

An expert system for ECG evaluation would serve two purposes. It would help in routine medical check up. A large number of people could be screened in a short time for possible cardiac malfunctioning. In addition it would be useful in near real time diagnosis of persons suffering from cardiac disorders. Such a system would not suffer from inter observer differences in interpretation. There would be no variance in the extraction of parameters and their subsequent analysis.

2.8 STEPS INVOLVED IN THE DEVELOPMENT OF AN EXPERT SYSTEM FOR ECG EVALUATION

The procedure adopted for development of this expert system is as follows :-

(a) Obtain ECG data for evaluation.

(b) Decide which parameters of the ECG wave are to be extracted.

(c) Develop and test an algorithm for extraction of parameters.

(d) Create a knowledge base.

(e) Apply the knowledge base.

(f) Carry out modifications, if necessary.

Table - 1

System	Function	Domain	Institution
HODGKINS	Planning	Medical Diagnosis	M.I.T.
PIP	Diagnosis	Medicine	M.I.T.
CASNET	Diagnosis	Medicine	Rutgers University
INTERNIST	Diagnosis	Medicine	University of Pittsburgh
MYCIN	Diagnosis	Medicine	Stanford University
PUFF	Diagnosis	Medicine	Stanford University
MDX	Diagnosis	Medicine	Ohio State University
RX	Date Analysis & Interpretation	Determination of casual relationships in medicine	Satnford University
ABEL	-same-	-same-	M.I.T.
ALVEN	Signal interpretation	Medicine-left ventrical performance	University of Toronto
VM	Monitoring	Patient respiration	Stanford University
GUIDON	Computer aided instruction	Medical diagnosis	Stanford University
BUGGY	-same-	Diagnostic skills	BBN
TEIRESIAS	Knowledge Acquisition	Diagnostic	Stanford University
EXPERT	-same-	Medical consultation	Rutgers University
KMS	Expert system construction	Medical Diagnosis	University of Maryland
EXPERT	-same-	Medical consultation	Rutgers University
MECS-AI	-same-	Medical consultation using time oriented data	Tokyo University
Digitalis Therapy Advisor	Consultation	Medicine	M.I.T.
ONCOCIN	-same-	Medical treatment	Stanford University

CHAPTER 3

ECG DATA

FOR

EXPERT SYSTEM DEVELOPMENT

ECG DATA FOR DEVELOPEMENT OF EXPERT SYSTEM

3.1 INTRODUCTION

The first step in the development of an expert system is the acquisition of raw ECG data. This can be obtained by the following three methods :-

(a) Actual recording of ECG from various subjects.

(b) Generation of ECG using hardware.

(c) Generation of ECG using software.

3.2 ACTUAL RECORDING OF ECG

Actual recording of ECG is the simplest of the above techniques. It is the most faithful representation of the electrical activity of the heart and does not involve any approximation. However, there is the possibility of undesirable interference and noise being picked up which may prove to be a disadvantage during development stage. Also since a large ECG data bank is required, the recording may take considerable time and many times it may not be feasible to record all the expected ECG wave variations due to the nonavailability of suitable subjects. The analog ECG data would have to be filtered, amplified and digitised to be made suitable for processing by computer.

The actual ECG data used for testing this system was acquired with the help of a PC-AT supplemented by add on timer card and ADC card. The set up is a shown in Fig 16. Selection of leads (I, II, III, aVR, aVL, aVF, V1 - V6) was carried out by an auto lead selector which could select one lead at a time for a duration of 3 secs. The ECG signal was amplified in two stages, total gain being 4000 (50 x 80).

After amplification the signal was filtered to remove the power line interference. This was followed by a low pass filter of 0.05 Hz to 100 Hz. The sampling rate of the ADC was set at 100 cycles per sec with the help of suitable interrupts generated by the timer card. The conversion time of ADC was 42 micro secs. The digital data was recorded in files on floppy disks for subsequent interpretation.

3.3 SYNTHETIC GENERATION OF ECG USING HARDWARE

Electronic circuits can be designed for the synthetic generation of wave forms resembling ECGs. Such a circuit would include multivibrators, filters, amplifiers and switches. However, it would be a complicated circuit and would have limited flexibility in the variation of various parameters. Some circuits are being commercially marketed for the calibration and testing of electrocardiographs but these have limited utility in the design and development of a system for analysis of ECGs due to few available variations.

3.4 SYNTHETIC GENERATION OF ECG USING SOFTWARE

This method provides the maximum flexibility in terms of the parameters that can be varied. Another advantage is that this data would already be in digitial form. Different types of ECG waves can be generated and used for development and testing of the system. A software for generation of synthetic ECG wave was developed for the testing of this system. The synthesiser is capable of generating three main component wave of the ECG - P, R and T waves separately (Fig 17). The complete ECG was obtained by combining these three components (Fig 18). Provision was made for either generating these waves based on data of predecided 'normal' ECG wave template or alternately by

SET UP FOR RECORDING OF ECG DATA

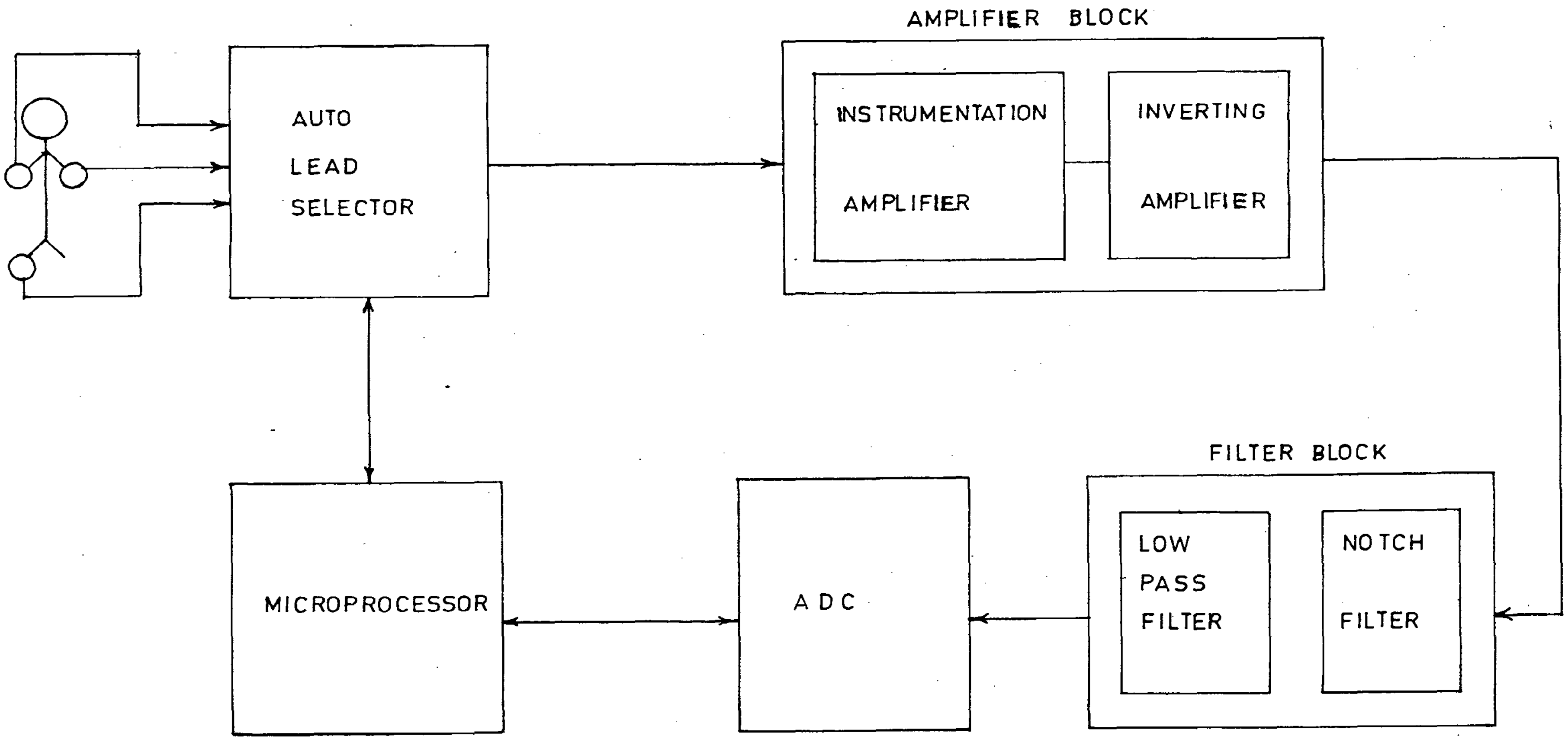
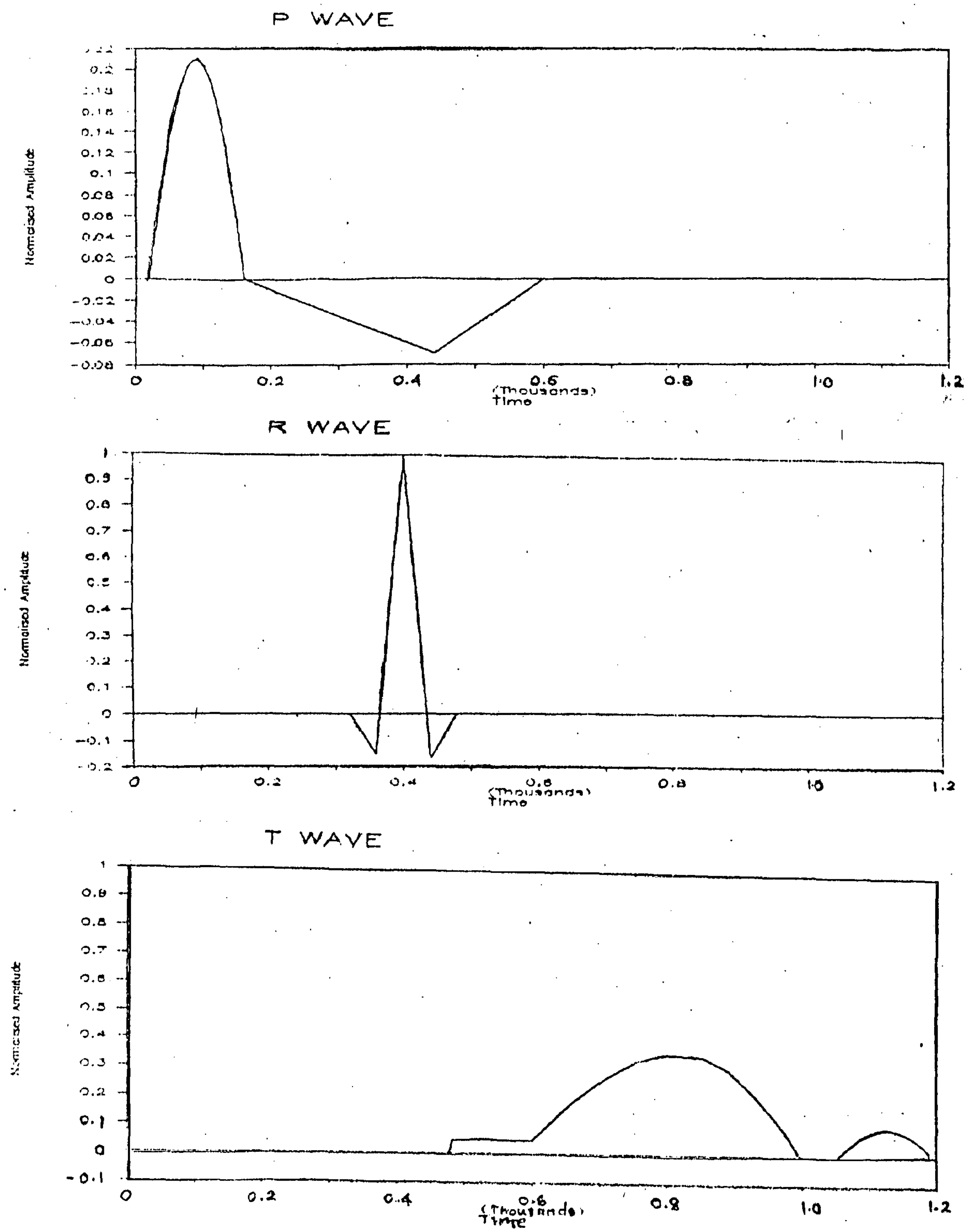


FIG.NO 16



P WAVE
Normalised Amplitude
(Thousands)
Time
R WAVE
Normalised Amplitude
(Thousands)
Time
T WAVE
Normalised Amplitude
(Thousands)
Time

FIG NO 17

feeding modified data to generate ECG wave with various parameters of our own choice. In addition to the P, R, T and normal ECG wave, provision has been made to generate four demostration waves representing different cardiac disorders. Flow chart of this programme is given in Fig 19. Programme listing is at Appx 'A'.

Some other important features of this software are as follows :-

(a) Upto six ECG wave cycles can be generated.

(b) ECG rate can be selected from one of the following values - 50, 60, 70, 80 or 90 beats per minute (bpm).

(c) The amplitide of the waves can be varied by feeding an amplitide factor (0 - 1.2).

(d) The frequency of the ECG can be varied by introducing a frequency change factor (-.2 to +.2).

(e) The sampling rate of the waveform is 1200 samples/sec.

(f) The data generated can be stored in a file for subsequent use. Sample ECG waves generated with this software are illustrated in Fig 20.

3.5 STANDARDISATION OF ECG DATA

There is a need for standardization in computerised electrocardiography. This has been widely accepted and an international project sposored by the European Commission was launched in 1980 to establish common standards for quantitative electrocardiography (CSE) [Ref 23, 25]. This project has carried out numerous studies in the past decade. It is felt that we adopt the

Normal ECG Wave (Using stored data)

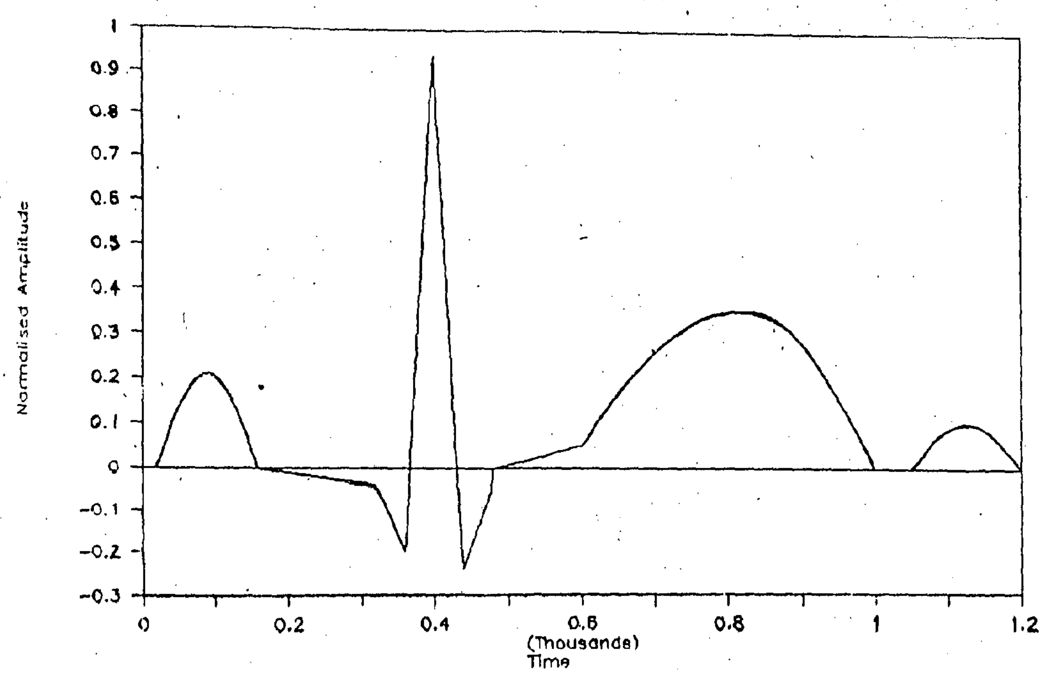


FIG NO 18

ECG SYNTHESISER FLOW CHART

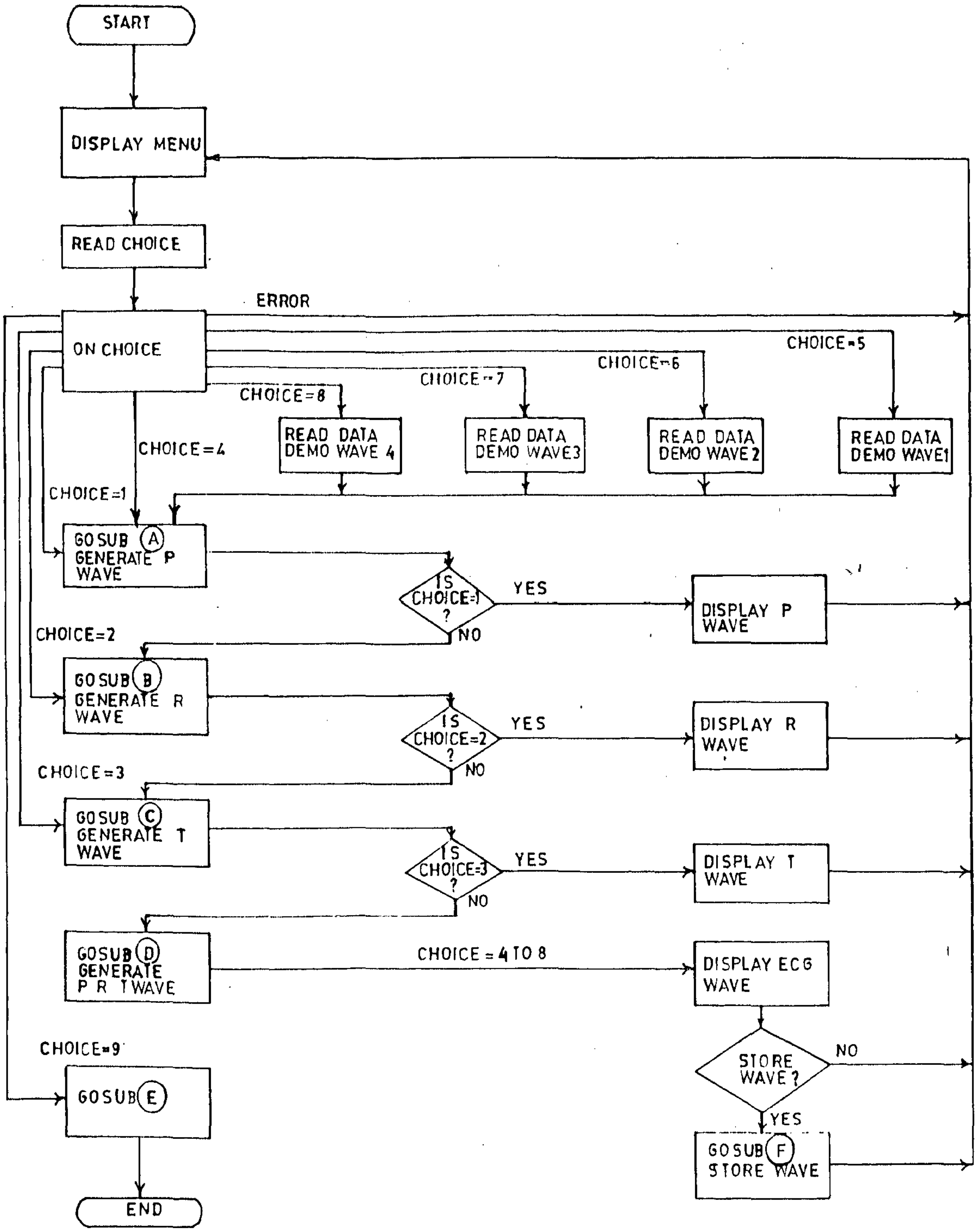


FIG. NO 19

SYNTHETIC ECG WAVE (SAMPLE 1)

No of cycles = 6

Amplitude Facter = 0.6

Frequency = 80 bpm

Frequency Change Facter = -0.2

T wave biphasic, ST segment elevated

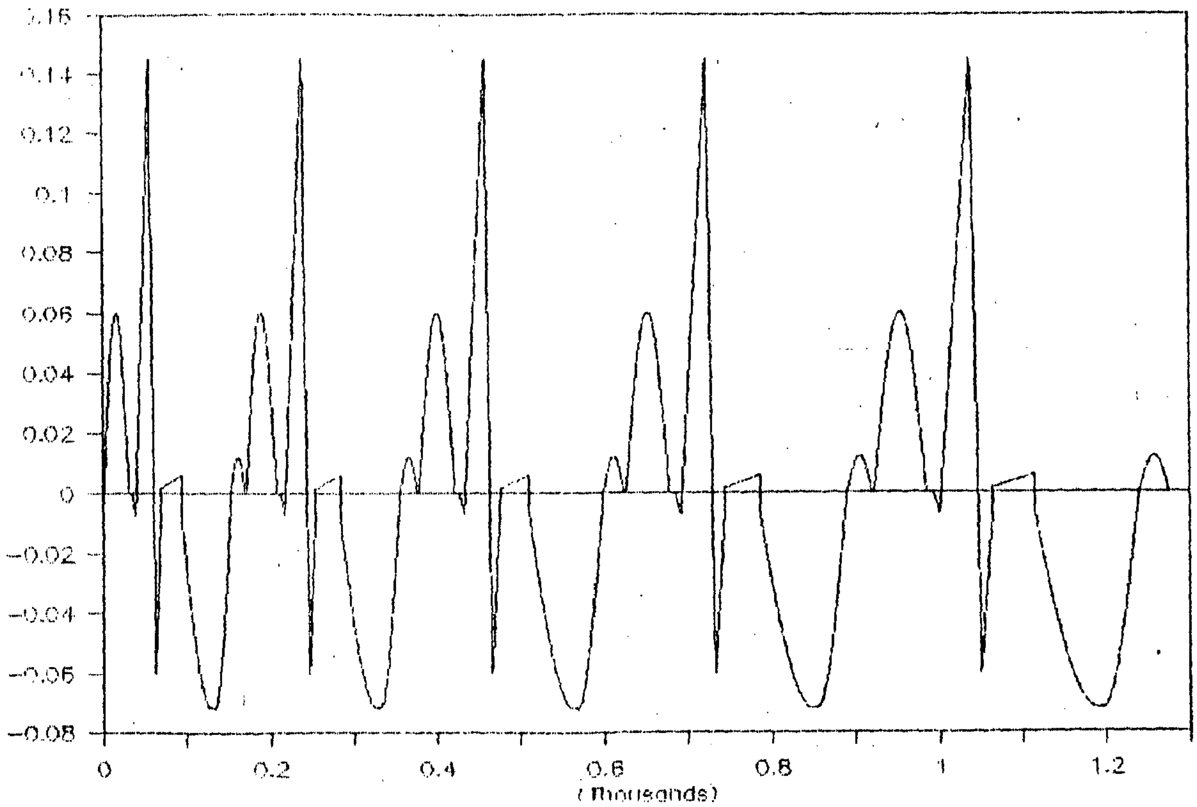


FIG. NO 20 (a)

SYNTHETIC ECG WAVE (SAMPLE 2)

No of cycles = 5

Amplitude Factor = 1

Frequency = 70

Frequency Change Factor = 0.1

Normal wave

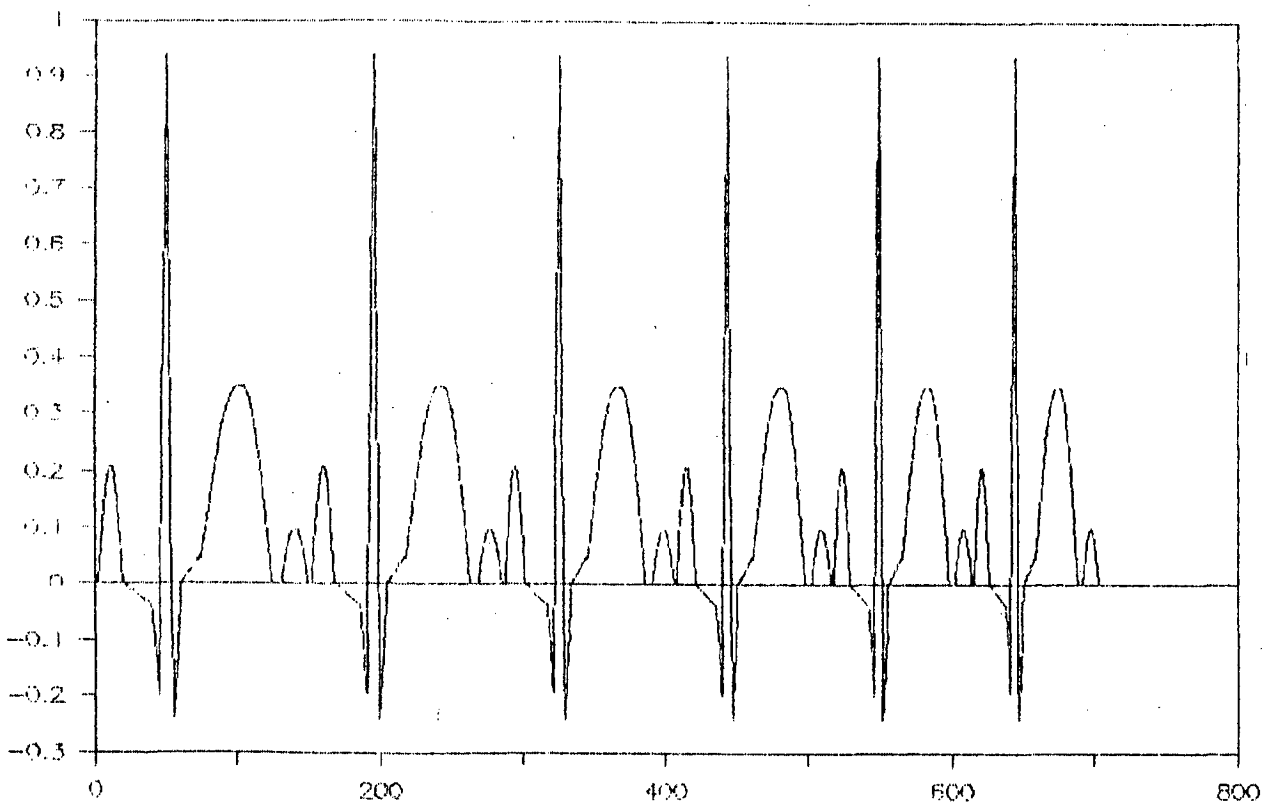


FIG.NO 20(b)

SYNTHETIC ECG WAVE (SAMPLE 3)

No of cycles = 4

Amplitude Factor = .8

Frequency = 60

Frequency Change Factor = -.1

T wave inverted

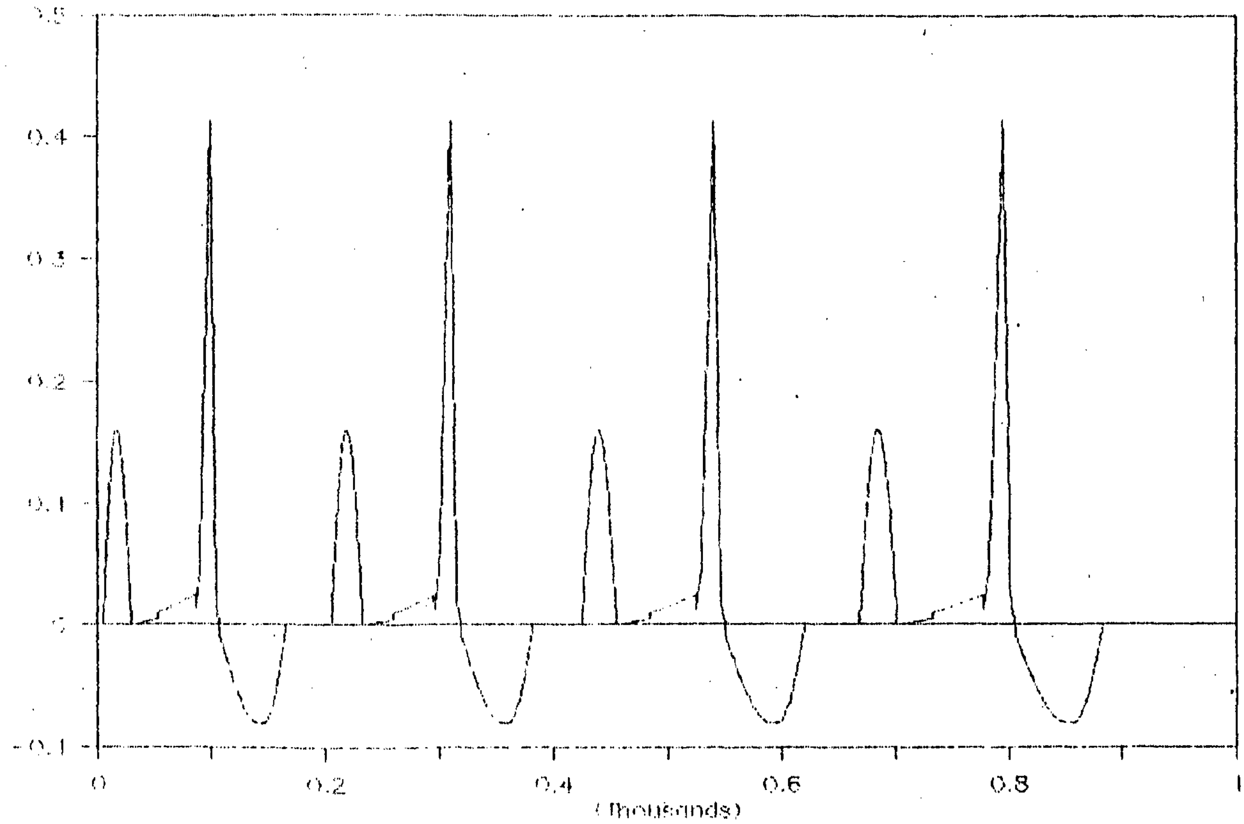


FIG. NO 20 (c)

same standards for the obvious advantages.Standardization should cover the following aspects :-

(a) Common definitions of the various components of the ECG wave e.g., the on and offset of the P, QRS and T waves etc.

(b) Common standards for measurement to include amplificationn factor, resolution and sampling rate of analog to digital conversion.

(c) Standards for diagnostic classification should be uniform.

(d) Standards for transmission, encoding and storing of computer processed data. This will help to link various systems to each other and ensure that data processed by one system is compatible with another.

(e) Creation of ECG data banks.

Table 2 gives an overview of the areas of computerised electrocardiography requiring standardization [Ref 25].

TABLE 2

Overview of the Computerized Electrocardiography Requiring Standardisation.

1. **Signal acquisition**

(a) Patient factors - patient identification, lead location, preparation.

(b) Lead systems - 12 leads, Frank, hybrid, multiple chest, etc.

(c) Hardware standard - number of simultaneous channels, bandwidth, A/D conversion rate, record length.

(d) Transmission of data.

2. **Signal analysis**

(a) Preprocessing - noise detection and suppression, rejection criteria.

(b) Beat classification schemes - time domain features, correlation coefficient, orthogonal functions.

(c) Analysis of dominant single beats versus composite beat, analysis of single versus multiple beats, composite features versus composite beat, construction of composite beat: modal versus median versus mean composite.

(d) Wave recognition algorithms determining primary fiducial points (onsets and offsets of P, QRS, T waves).

3. **Feature extraction**

(a) Reference leval (baseline) determination.
(b) Minimum wave requirements and wave labelling.
(c) Parameter extraction:

simple basic mearsurements, amplitudes and duration of waves, intervals;

derived parameters: areas, ratios, axes, vectors, spatial parameters, etc.

4. **Interpretation** - Diagnostic classification.

CHAPTER 4

DEVELOPMENT OF THE SYSTEM

4.1 SELECTION OF PARAMETERS

After review of existing literature and consultation with experts it was established that Lead II of the ECG was the diagnostically most significant. The following parameters of the wave were selected for extraction (Fig 21) :-

(a) Amplitides

(i) P - segment.(1)

(ii) Q - segment.(2)

(iii)R - segment.(3)

(iv) S - segment.(4)

(v) T - segment.(5)

(b) Durations

(i) P - segment.(6)

(ii) Q - segment.(7)

(iii)R - segment.(8)

(iv) S - segment.(9)

(v) T - segment.(10)

(vi) Relaxation period.(11)

(vii)Total cycle time.(12)

The segments can be identified as follows [Ref 15, 21] :-

(i) The first zero crossing after Rmax is onset of S-segment.

(ii) The zero crossing at the end of S - segment is the onset of T-segment.If there is no zero crossing after Rmax then S-segment is absent. The increase in the signal level after few samples is the onset of T-segment.

PARAMETERS SELECTED FOR EXTRACTION

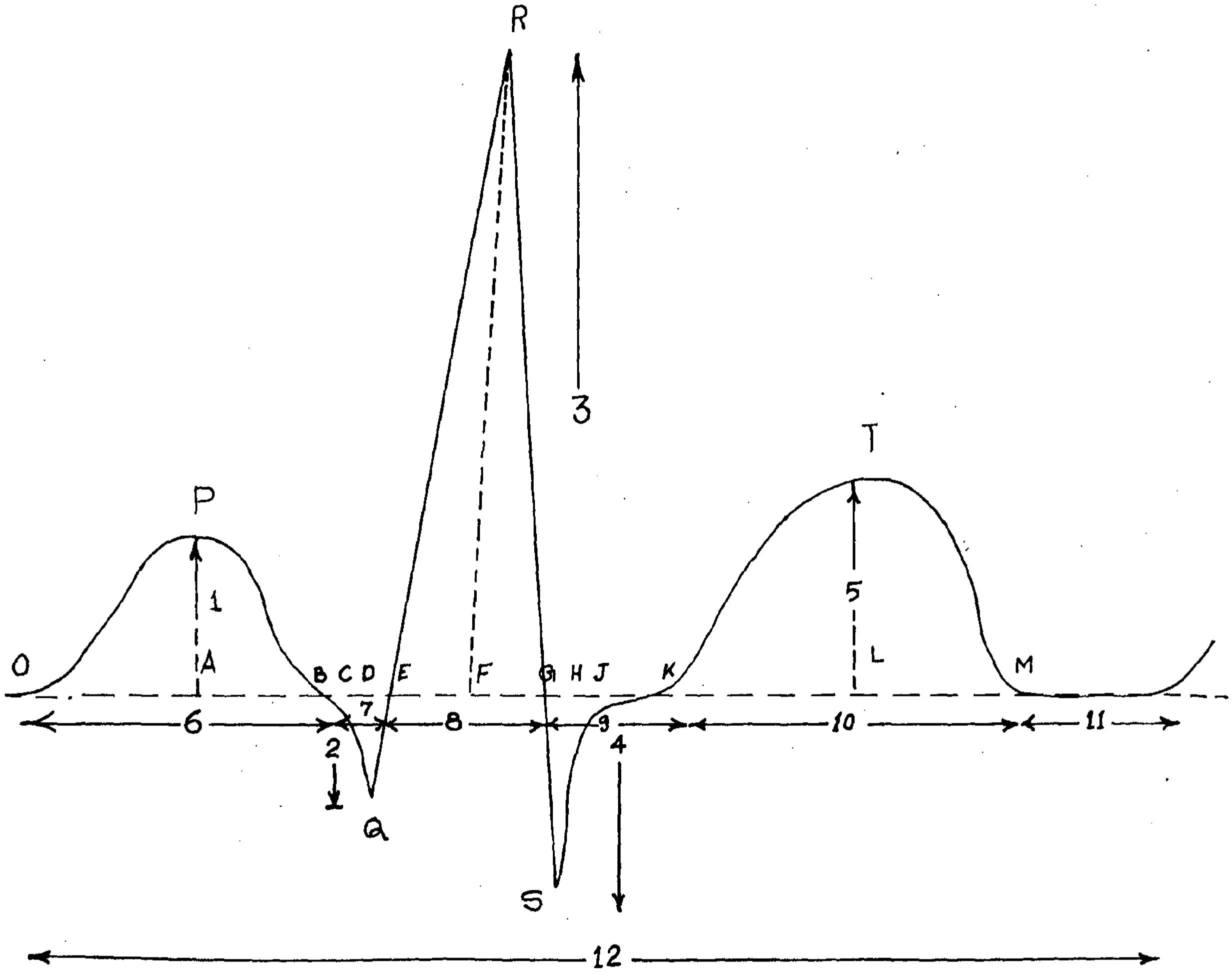


FIG. NO 21

(iii)The zero crossing at the end of the T-segment is the onset of the relaxation period. The absence of increase above zero level after S-segment indicates the absence of T-segment or that the T-segment is inverted.

(iv) The increase in amplitide after relaxation period is the onset of P-segment. The absence of increase after relaxation period indicates the absence of P-segment or that the P-segment is inverted.

(v) The zero crossing at the end of segment is the onset of Q-segment. The absence of crossing is indication of missing Q-segment.

(vi) The zero crossing at the end of Q-segment is the onset of R-segment.

In addition to the above the following were also considered important from the point of view of evaluation and were to be extracted/calculated :-

(a) **ECG rate.** This was to be calculated by finding the average cycle time of a number of samples.

(b) **ECG rhythm.** By setting limiting values for permissible beat to beat variation, it was to be established whether the rhythm was regular or not.

(c) **ST Segement Elevation/Depression.** The elevation/depression of the ST segment with respect to the base line is an important parameter in diagnosis of cardiac condition.

First synthètic ECG (Fig 22.a) was subjected to frequency analysis. The frequency spectrum of the wave was found seperately for sample 540 to 1540 (excluding the QRS complex) and samples 660 to 1660 (including QRS complex). As can be seen from from Fig 22.b, the inclusion of the QRS complex caused an increase in the relative strength of higher frequencies (40 - 60, 80 - 100).

Similiarly an actual ECG wave (Fig 22.c) was analysed. Samples taken were from 435 - 515 (excluding QRS) and 445 - 515 (including QRS). Frequency spectrum is as shown in Fig 22.d.

Further experiments were conducted. However, no clear cut technique could be envolved for the identification of segments based on frequency analysis.

4.3 <u>EXTRACTION OF PARAMETERS OF SYNTHETIC ECG WAVE</u>

An alogrithm for extraction of parameters using a synthetic ECG wave was developed first (Fig 23). A normal ECG wave using stored parameters was generated and a programme written to extract its parameters. The first QRS complex was identified based on threshold values for the slope as also amplitide criterion. The other complexes were identified based on their relationship with respect to the QRS complex and amplitide and duration criteria. Once this programme had been successfully tested on the normal ECG wave, it was modified to cater for the following variations in the wave :-

(a) R - segment, upright of inverted.

(b) S - segment, present or absent.

(c) T - segment, upright, inverted or absent.

(d) P - segment, upright, inverted or absent.

(e) Q - segment, present or absent.

SYNTHETIC ECG WAVE

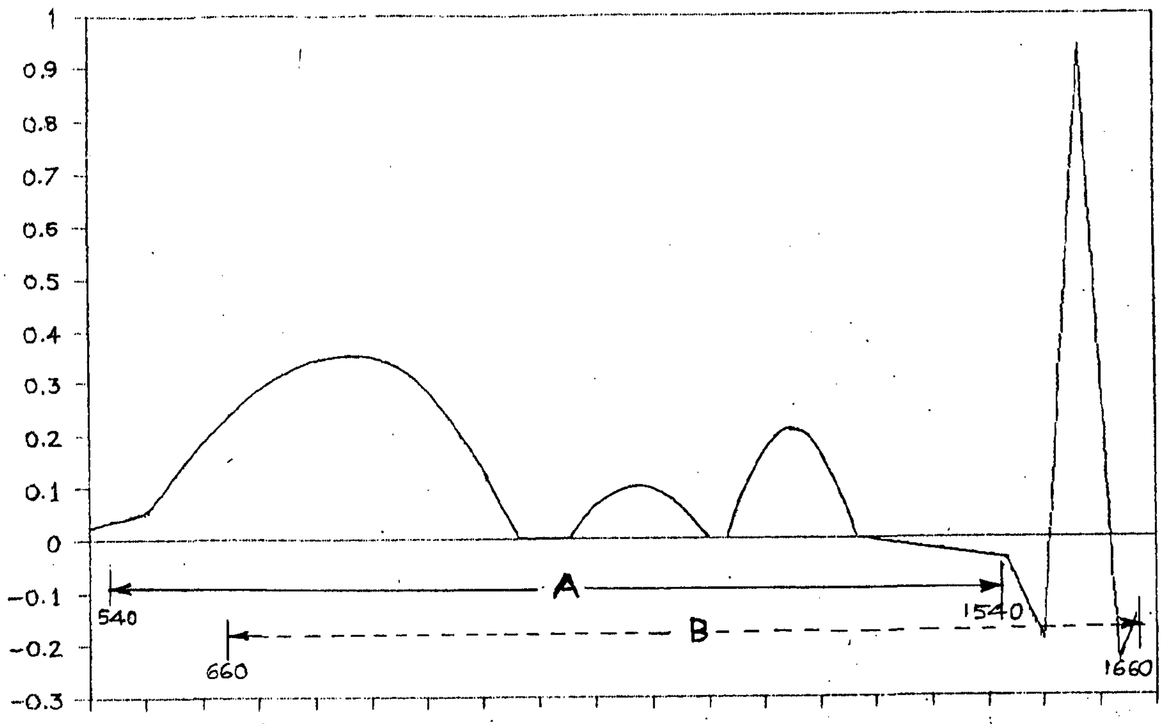


FIG NO 22 (a)

FREQUENCY ANALYSIS

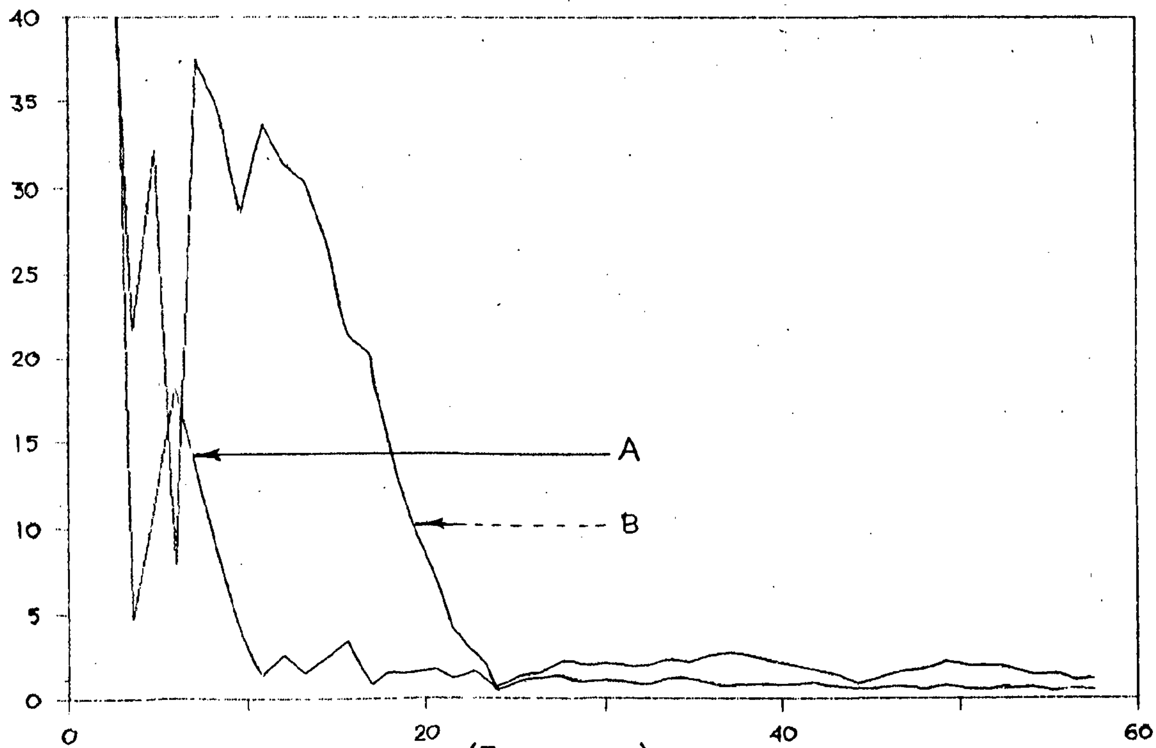


FIG NO 22 (b)

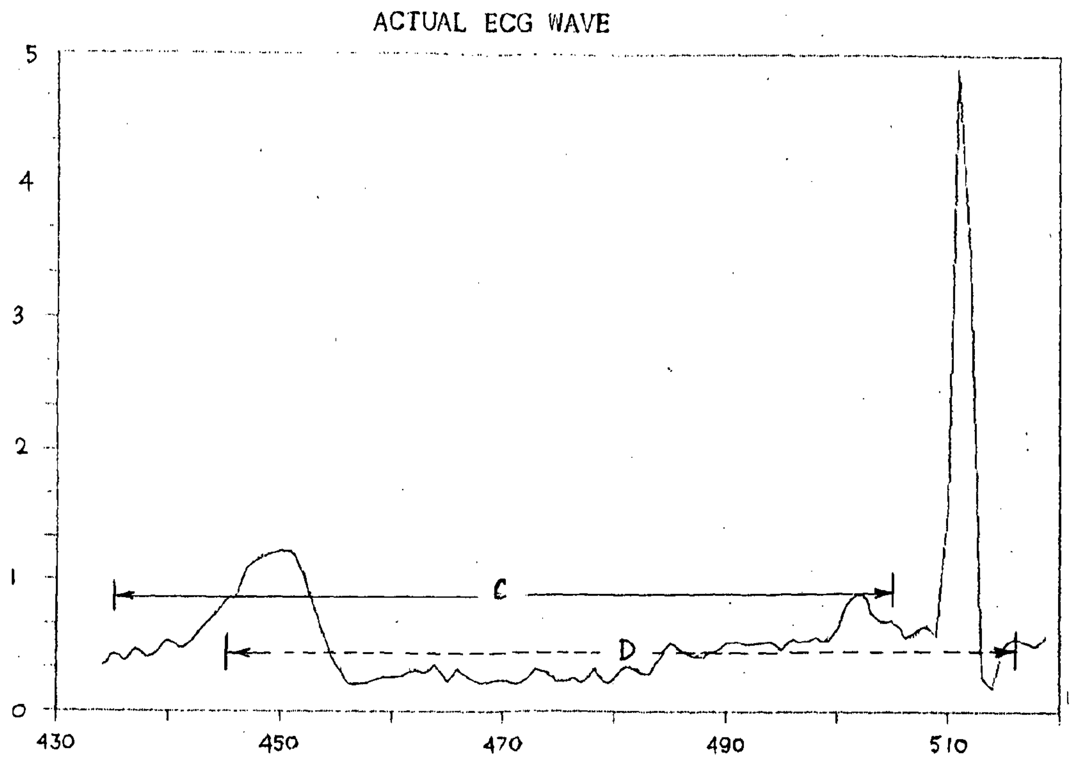


FIG NO 22 (c)

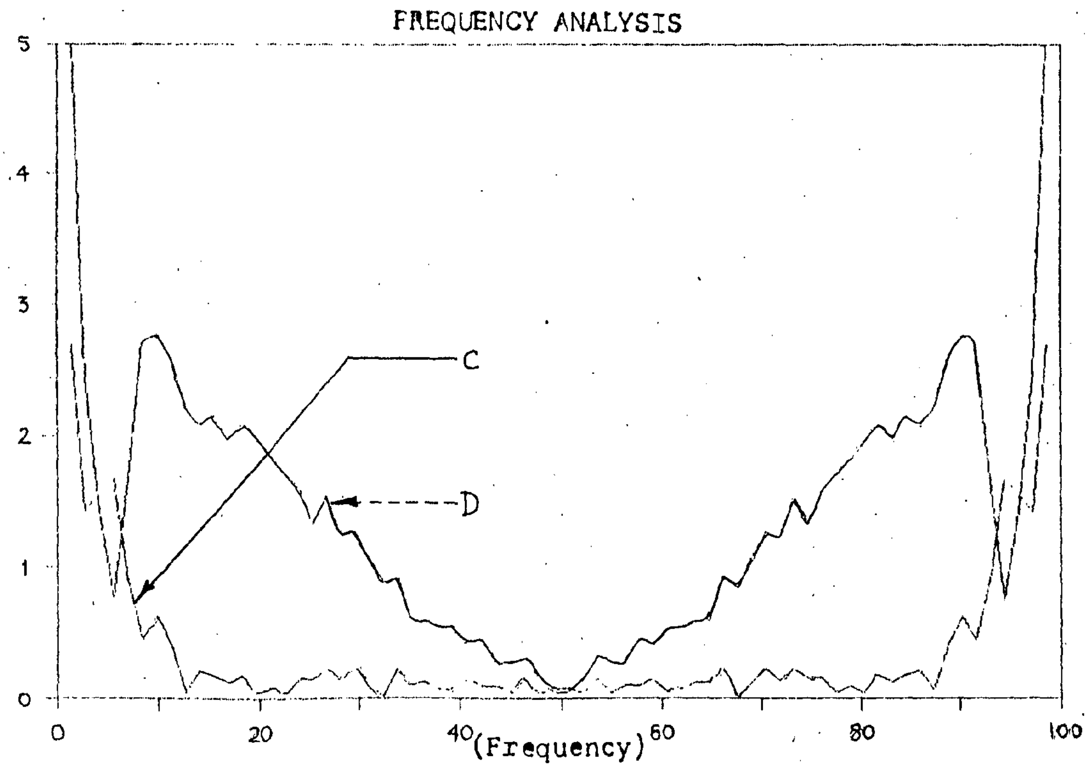


FIG NO 22 (d)

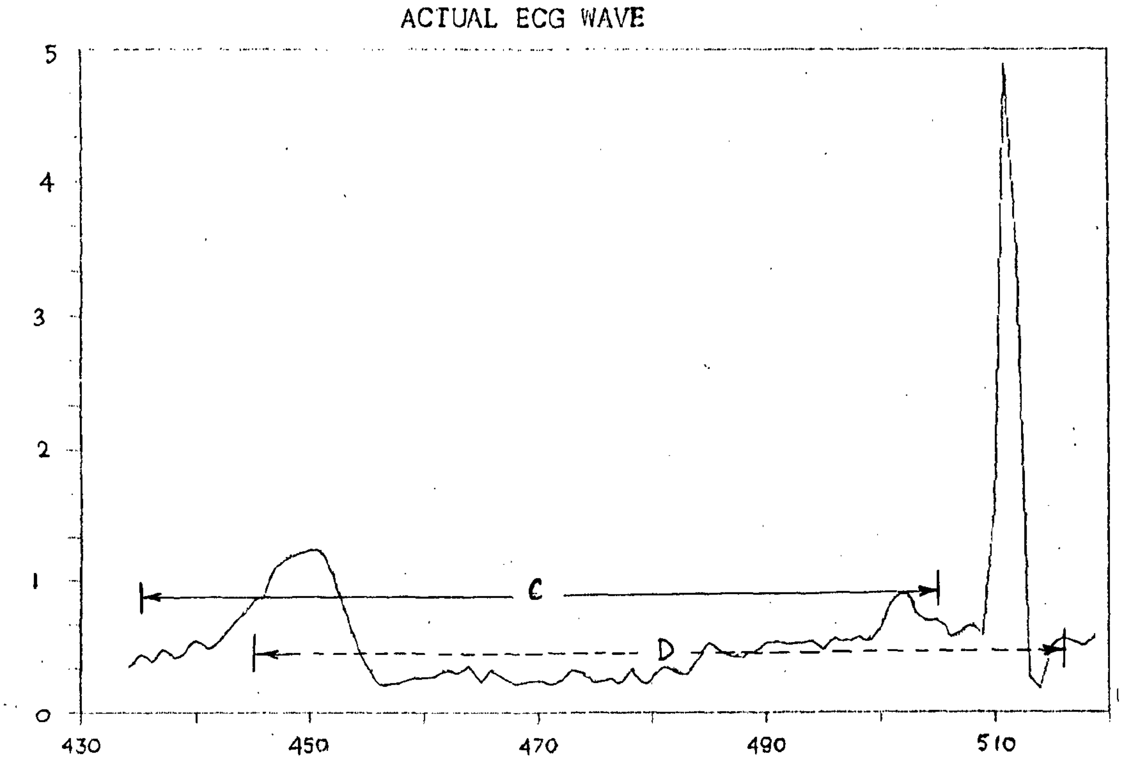


FIG NO 22 (c)

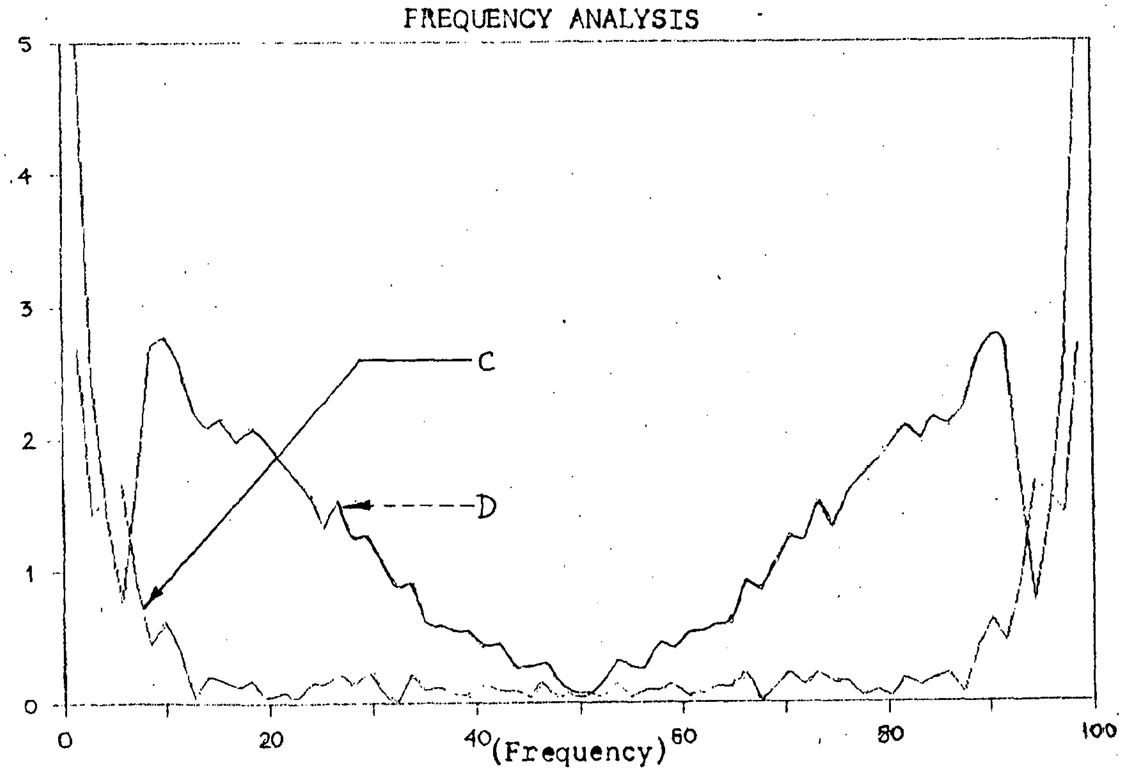


FIG NO 22 (d)

ALGORITHM FOR EXTRACTION OF PARAMETERS OF SYNTHETIC ECG WAVE

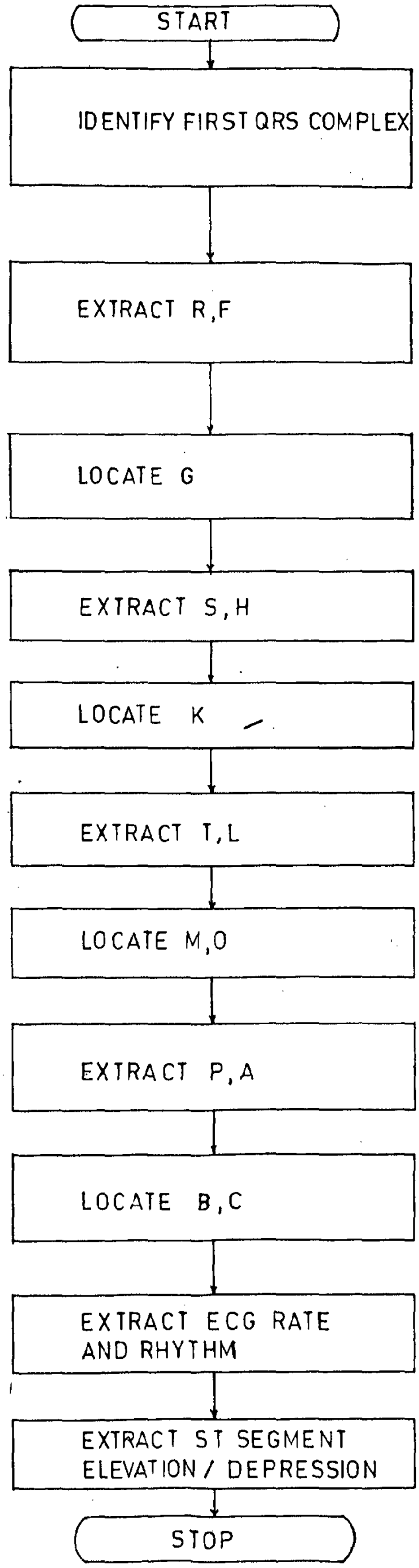


FIG NO 23

SYNTHETIC ECG WAVE

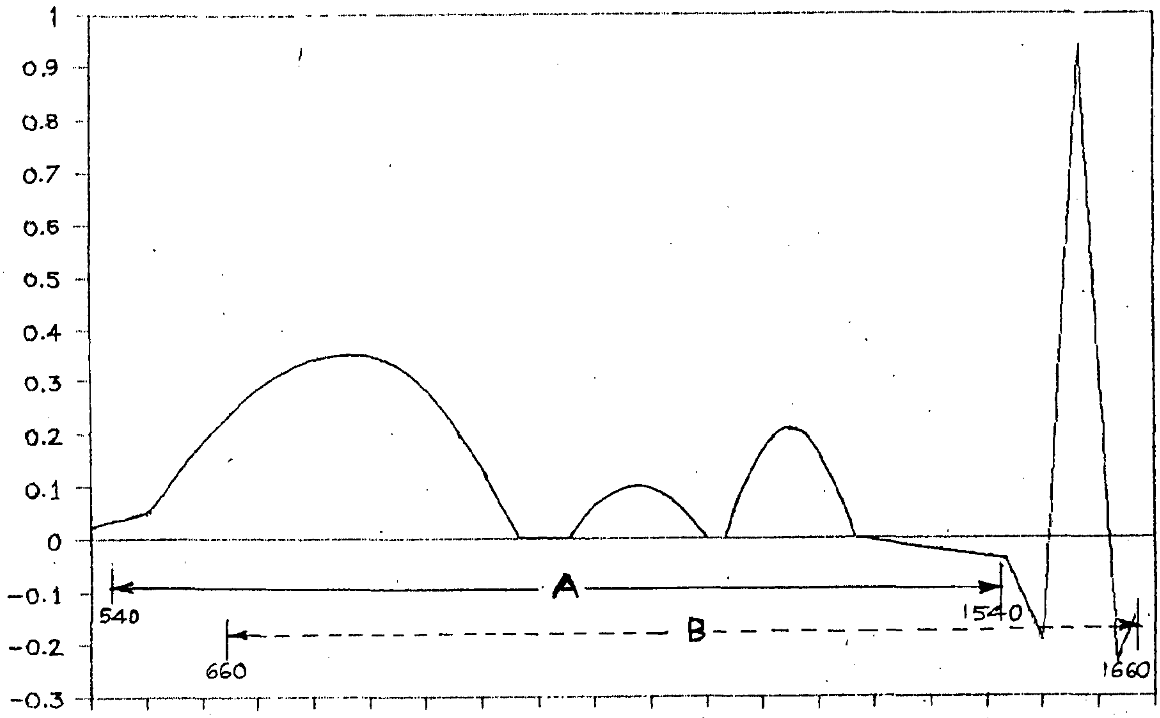


FIG NO 22 (a)

FREQUENCY ANALYSIS

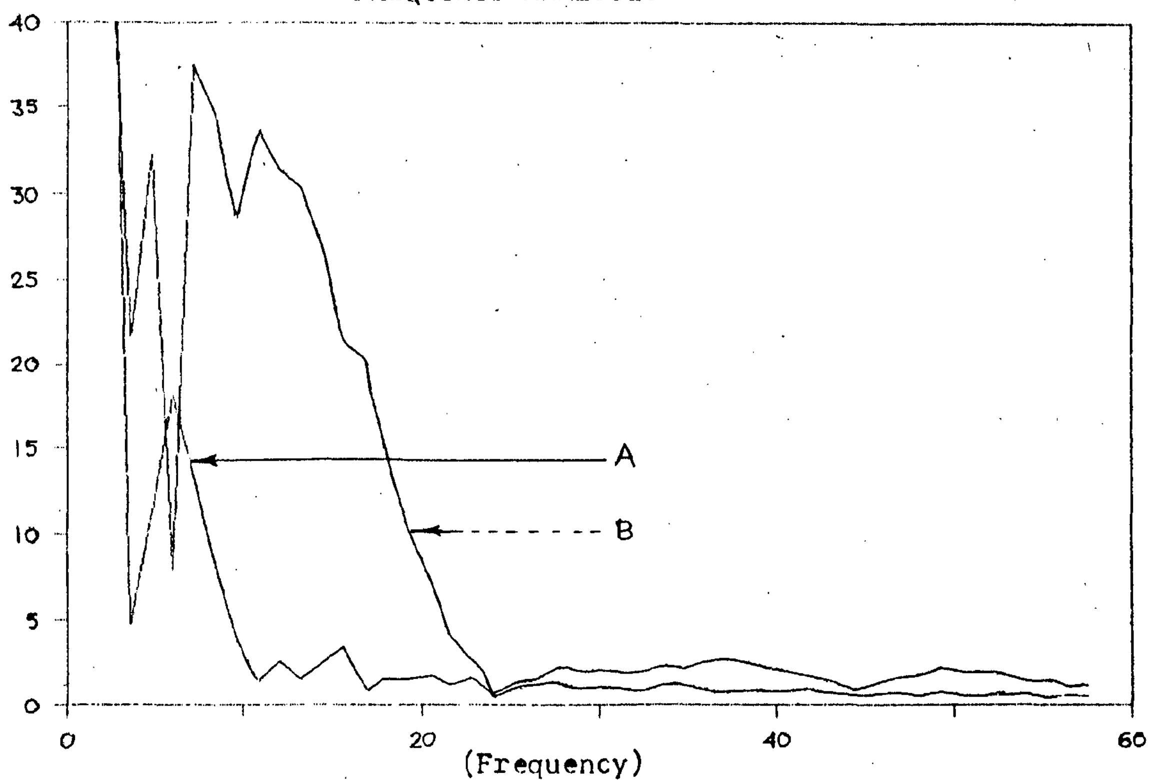


FIG NO 22 (b)

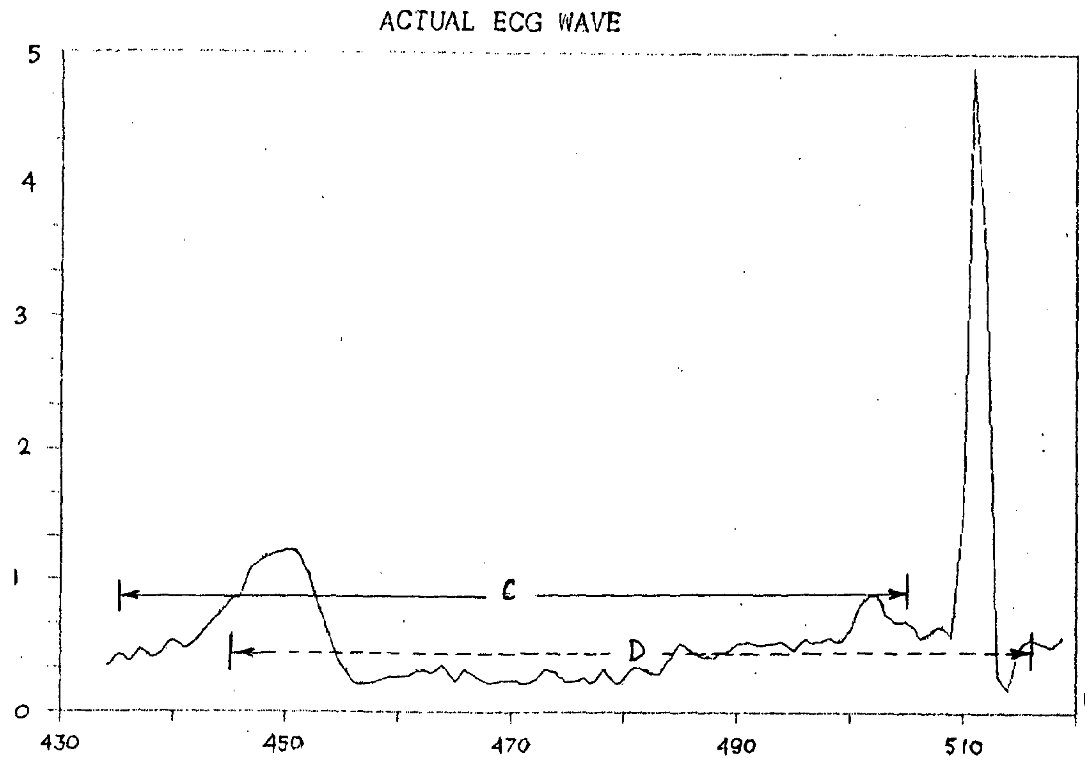


FIG NO 22 (c)

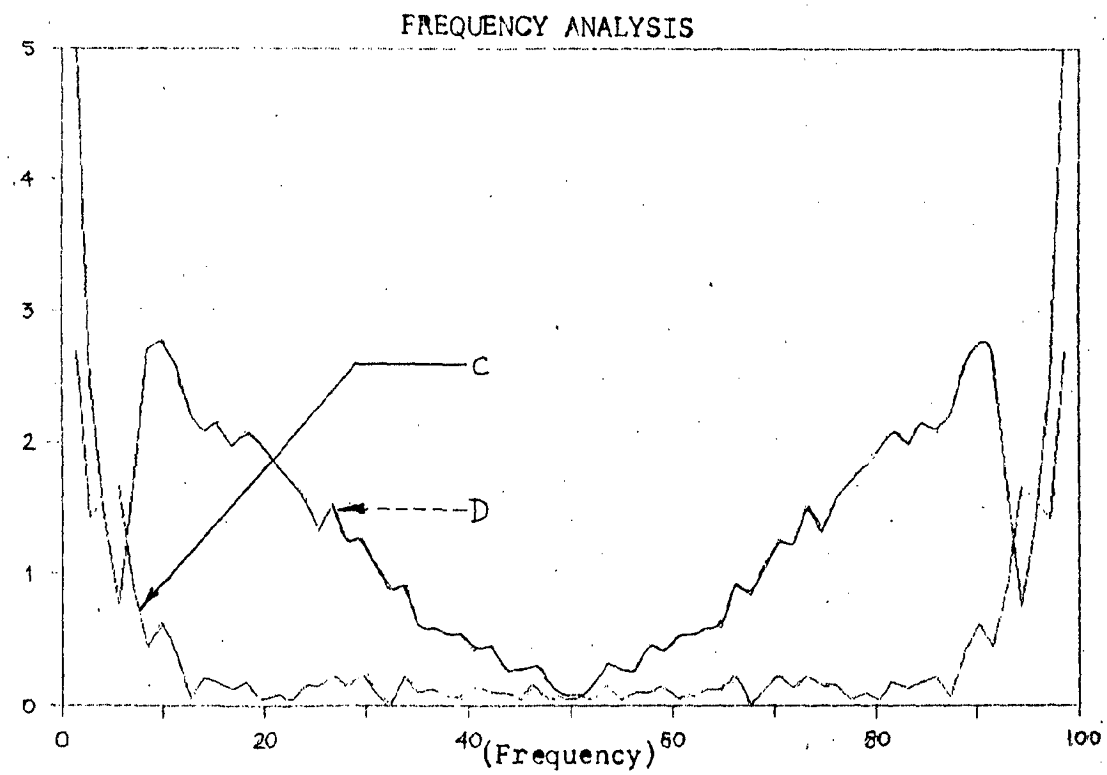


FIG NO 22 (d)

ALGORITHM FOR EXTRACTION OF PARAMETERS OF SYNTHETIC ECG WAVE

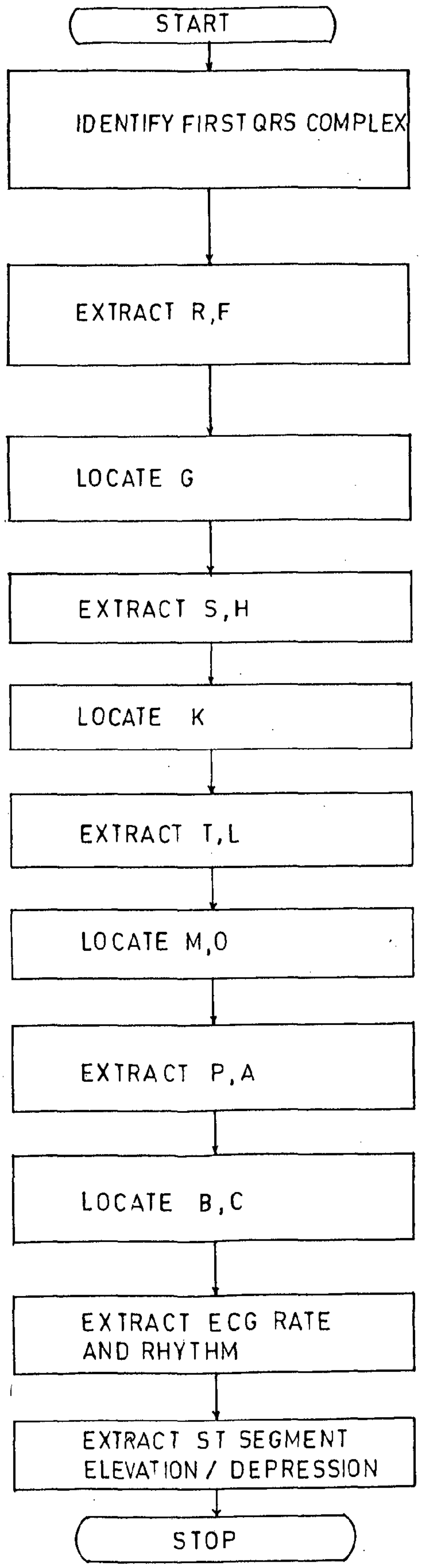


FIG NO 23

In the next step, the programme was modified to extract the ECG rate, rhythm and the ST segment elevation/depression.

4.4 EXTRACTION OF PARAMETERS OF ACTUAL ECG WAVE

Having successfully extracted the parameters of synthetic ECG wave, the next step in the development process was the extraction of parameters of actual ECG wave. The following differences in the two types of ECG data resulted in addtional processing :-

(a) The start and end pionts of the actual ECG data recording were not known.

(b) The base level of the actual data was not known.

(c) There was drift in the base level.

These problems were tackled as described in subsequent paragraphs.

The first QRS complex was identified in the normal manner. Based on the known duration of the cardiac cycle the next QRS complex was located. However, the intervening period was checked for any QRS complex that might have been missed due to either excessive base level drift or an abnormally short cycle time. This check was carried out using absolute amplitide criterion.

Having established the first and second QRS complex, subsequent QRS complexes were then identified based on the now known cycle time. The fluctuation of the base level is a random fluctuation and, therefore, no compensation could be applied to remove it. The next best alternative available was to select for analysis that particular wave where the base level drift was minimum. The absolute values of the QRS complex were compared to identify the pair of waves where the base level drift was minimum. A threshold level for the drift was set, and in case the best pair of waves violated this threshold, the user was warned that the data quality was poor and the resultant analysis would be unreliable. However, in case the drift was very large (beyond a maximum permissible threshold) further processing was to be abandoned and the user informed accordingly. During this selection process, the first eight or lesser number of complete waves (provision was made to exclude the incomplete waves) were examined and the best wave selected for further processing.

The next step was to ascertain the base level of the signal. The value of signal during relaxation period (i.e., between the offset of the T - segment and the onset of the next P - segment) was selected as the base level. This value also varied considerably and some technique had to be worked out to select the most representative value of this relaxation period. After considerable trial and error with different methods, a statistical technique was adopted which gave consistent and acceptable results. This involved finding out a block of values during this period which had the maximum frequency of occur -rence. Having indentified this block, the average of all the values in this block was calculated to arrive at the selected value of the base level. Amplitides of all other segments were now to be extracted with respect to this base level. The programme for extraction of ECG rate, rhythm and ST segment elevation/duration remained unchanged. A modified alogrithm for extracting parameters of actual ECG wave is given in Fig 24. A sample set of various parameters extracted is given in Table 3.

ALGORITHM FOR EXTRACTION OF PARAMETERS OF ACTUAL ECG WAVE

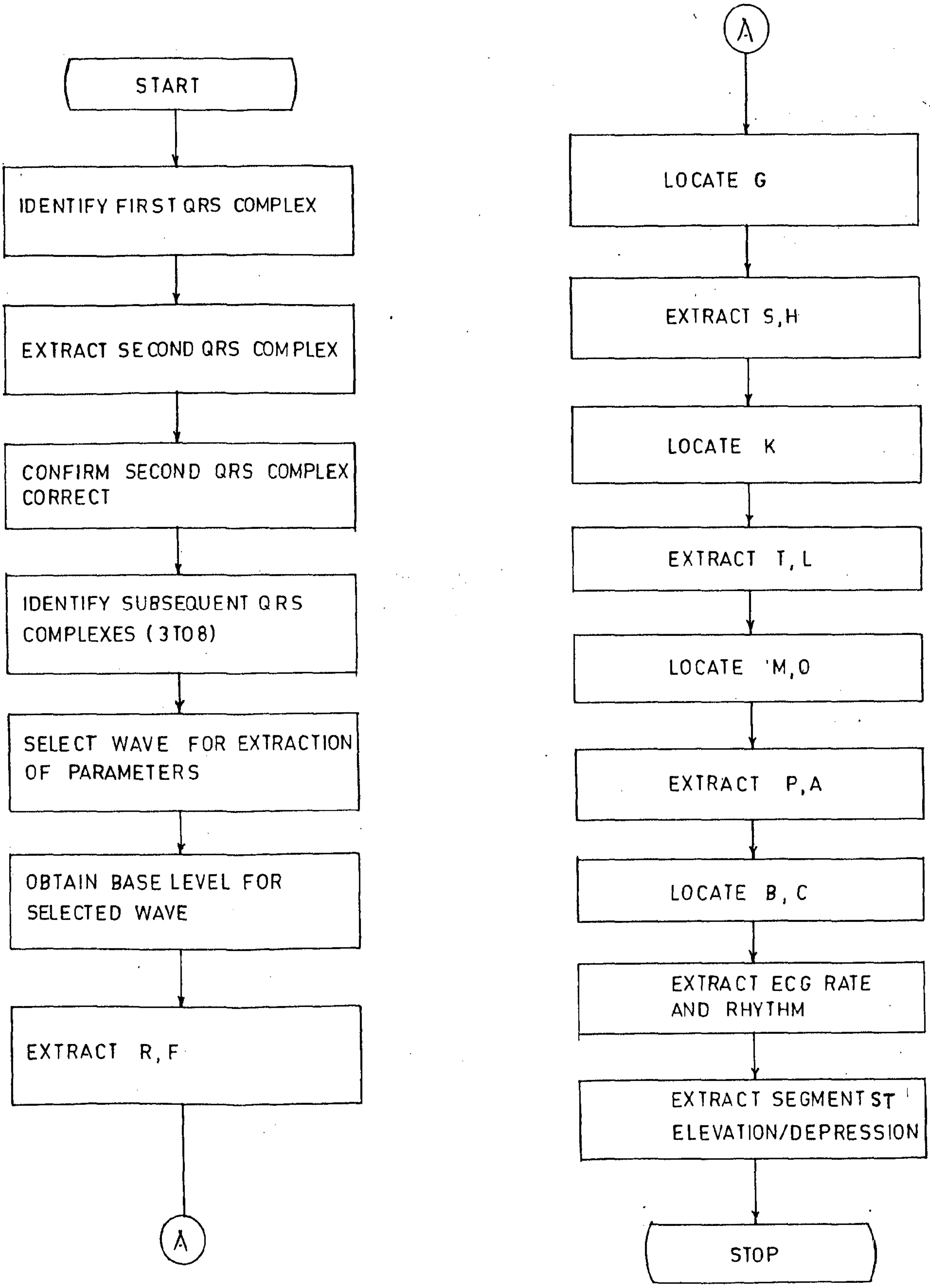


FIG. NO 24

TABLE 3

NAME OF ECG RECORD- e02512.ecg

WAVE 1	R 1 = 1.1355 mv	F 1 = 30
WAVE 2	R 2 = 1.3265 mv	F 2 = 100
WAVE 3	R 3 = 1.2275 mv	F 3 = 178
WAVE 4	R 4 = 1.1635 mv	F 4 = 268
WAVE 5	R 5 = 1.3985 mv	F 5 = 349
WAVE 6	R 6 = 1.2945 mv	F 6 = 429
WAVE 7	R 7 = 1.3195 mv	F 7 = 511
WAVE 8	R 8 = 1.2945 mv	F 8 = 583

SELECTED WAVE = 7

P= .1265 mv Q= .0225 mv R= 1.3195 mv S=-9.350001E-02 mv
T= .2355 mv D= 506 F= 511 H= 514 L= 532
A= 502

SELECTED WAVE -NORMALISED AMPLITUDES

NP= 9.586964 %
NQ= 1.705191 %
NR= 100 %
NS=-7.086018 %
NT= 17.84767 %

SELECTED WAVE -X AXIS POINTS

O= 495	A= 502	B= 504	D= 506	E= 506
F= 511	G= 513	H= 514	K= 515	L= 532
M= 537				

SELECTED WAVE -SEGMENT DURATIONS

TO= .4 secs TP= 8.999999E-02 secs TQ= .02 secs TR= .07 secs TS= .02 secs
TT= .22 secs TC= .82 secs PR= .11 QRS= .19 QT= .31

TABLE 3 (CONTD)

```
YMF(ST)= 63    FR(ST)= 2       YSTO= 6334    YBASE= 6254.5
ST SEG(E/D)=-.795 mm


ECG RATE

TC(1)=  .7 secs
TC(2)=  .78 secs
TC(3)=  .9 secs
TC(4)=  .81 secs
TC(5)=  .8 secs
TC(6)=  .82 secs
TC(7)=  .72 secs
TC(AV)=  .79 secs

ECG RATE= 75.94936 BPM

                                         CNT3= 5     CNT4= 4
                                     ECG RHYTHM VERY IRREGULAR
```

4.5 CREATION OF KNOWLEDGE BASE

The purpose of this evaluation of ECG wave is to conclude whether :-

(a) The ECG is normal or abnormal.

(b) If abnormal, whether it can be identified as being typical of any particular disorder

OR

(c) Abnormal, but cannot be specifically identified.

The knowledge base for this system has, therefore, been structured in two parts. In the first part conditions for normality are laid down. The second part lays down the features with the help of which specific disorders can be identified.

(a) RULES FOR NORMALITY

Normal values of the segments in the various leads have been laid down by experts. One such set is given in Table 4 [Ref 7] ECG of all the leads should meet the criteria for normality before it can be finally classified as such. In this system, however, we have used only lead 2. A set of normal values for different segments of this lead has been formulated from various literature and after consultation with experts. This is given in Table 5. On the basis of these values ECG waves can be classified as normal or abnormal.

TABLE-4

NORMAL RANGES & VARIATIONS IN THE ADULT TWELVE-LEAD ELECTROCARDIOGRAM

A true understanding of the normal range and the normal variation of the ECG depends upon a basic understanding of both normal and abnormal cardiac electrophysiology. It must be remembered that many of the configurations tabulated below may represent cardiac abnormalities when interpreted in the context of the entire tracing and in the light of the clinical history and physical examination. Therefore, the information contained in the following table is intended to be used only as a rough preliminary guide

Lead	P	Q	R	S	T	ST
I	Upright deflection	Small. < 0.04 s and < 25% of R.	Dominant. Largest deflection of the QRS complex.	< R, or none	Upright deflection	Usually isoelectric; may vary from +1 to −0.5 mm.
II	Upright deflection	Small or none	Dominant	< R, or none	Upright deflection	Usually isoelectric; may vary from +1 to −0.5 mm.
III	Upright, flat, diphasic, or inverted, depending on frontal plane axis	Small or none, depending on frontal plane axis or large (0.04–0.05 s or > 25% of R).	None to dominant, depending on frontal plane axis	None to dominant, depending on frontal plane axis	Upright, flat, diphasic, or inverted, depending on frontal plane axis	Usually isoelectric; may vary from +1 to −0.5 mm.
aVR	Inverted deflection	Small, none, or large	Small or none, depending on frontal plane axis	Dominant (may be QS)	Inverted deflection	Usually isoelectric; may vary from +1 to −0.5 mm.
aVL	Upright, flat, diphasic, or inverted, depending on frontal plane axis	Small, none, or large, depending on frontal plane axis	Small, none, or dominant, depending on frontal plane axis	None to dominant, depending on frontal plane axis	Upright, flat, diphasic, or inverted, depending on frontal plane axis	Usually isoelectric; may vary from +1 to −0.5 mm.
aVF	Upright deflection	Small or none	Small, none, or dominant, depending on frontal plane axis	None to dominant, depending on frontal plane axis	Upright, flat, diphasic, or inverted, depending on frontal plane axis	Usually isoelectric; may vary from +1 to −0.5 mm.
V_1	Inverted, flat, upright, or diphasic	None (may be QS)	< S, or none (QS); small r' may be present	Dominant (may be QS)	Upright, flat, diphasic, or inverted*	0 to +3 mm
V_2	Upright; less commonly, diphasic or inverted.	None (may be QS)	< S, or none (QS); small r' may be present	Dominant (may be QS)	Upright; less commonly, flat, diphasic, or inverted.*	0 to +3 mm
V_3	Upright	Small or none	R <, >, or = S	S >, <, or = R	Upright*	0 to +3 mm
V_4	Upright	Small or none	R > S	S < R	Upright*	Usually isoelectric; may vary from +1 to −0.5 mm.
V_5	Upright	Small	Dominant (< 26 mm)	$S < SV_4$	Upright	
V_6	Upright	Small	Dominant (< 26 mm)	$S < SV_5$	Upright	

*Inverted in infants, children, and occasionally in young adults

TABLE 5

ECG PARAMETERS	NORMAL VALUES		PERMISSIBLE DEVIATION	
	AMPLITUDE (mv)	DURATION (sec)	AMPLITUDE (mv)	DURATION (sec)
P- Segment	0.15	0.09	+(-) 0.10	+(-) 0.03
P-Q Interval	-	0.15	-	+(-) 0.05
Q- Segment	0.25	0.02	+(-) 0.10	+(-) .01
R- Segment	1.30	0.04	+(-) 0.30	+(-) 0.02
Q-R-S Interval	-	0.09	-	+(-) 0.04
T- Segment	0.30	0.21	+(-) 0.15	+(-) 0.05
Q- T Interval	-	0.40	-	+(-) 0.10
One Cycle	-	0.84	-	+(-) 0.20

(b) **RULES FOR ABNORMAL CONDITIONS**

(i) **ABNORMAL CONDITION 1 - COMPLETE HEART BLOCK**

If number of P peaks >> R Peaks (2:1)

OR

If QRS rate is slow (< 55)

(ii) **ABNORMAL CONDITION 2 - RIGHT ATRIAL HYPERTROPHY**

If P segment is tall, slender (Pamp > .25 mv, TP<.06 sec)

OR

If ST segment is depressed (Below - .5 mm)

OR

If T segment is inverted (Tamp <0)

(iii) **ABNORMAL CONDITION 3 - LEFT ATRIAL HYPERTROPHY**

If P segment is upright, broad and tall (Pamp> .25 mv, TP> .10 sec.

OR

ST segment is depressed (Below - .5 mm)

(iv) **ABNORMAL CONDITION 4 - NODAL ESCAPE**

If QRS rate is slow < 55

OR

QRS rate is slightly irregular

(v) **ABNORMAL CONDITION 5 - HYPERKALAEMIA**

If T segment is tall, slender (Tamp > .6 mv, TT <.16 Sec)

OR

QRS interval is prolonged (QRS > .15 Sec)

(vi) **ABNORMAL CONDITION 6 - ATRIAL TACHYCARDIA**

If QRS rate is high (> 90)

OR/AND

P segment is inverted (Pamp < 0)

(vii) **ABNORMAL CONDITION 7 - MYOCARDIAL INFARCTION**

If Q segment is abnormal (Qamp > .3 mv or < .10 mv or TQ > .03 sec)

OR

ST segment is elevated (Above .1 mm)

OR

QRS interval is prolonged (QRS > .15 sec)

OR

QT interval is prolonged (QT > .40 sec)

OR

T segment is inverted)Tamp < 0)

OR

R segment is inverted (Ramp < 0)

(viii) **ABNORMAL CONDITION 8 - LEFT VENTRICULAR HYPERTROPHY**

If ST segment is depressed and T segment is inverted (ST below - .5 mm, Tamp < 0)

OR

If QRS interval is prolonged (.1 sec < QRS <.12 sec)

(ix) **ABNORMAL CONDITION 9 - RIGHT VENTRICULAR HYPERTRPHY**

If P segment is tall and T segment is inverted

(ST below - .5mm, T amp < 0)

OR

If R segment is tall and T segment is inverted

(Pamp > .25mV, Tamp < 0)

and ST segment is depressed

(ST below - .5mm)_

(x) **ABNORMAL CONDITION 10 - ATRIAL FIBRILLATION.**

If QRS rhythm is very irregular

The programme checks the extracted parameters of the ECG wave against these rules to see if they conform to any particular classification. The relevant condition is displayed. In case the wave conforms to more than one classification, all are displayed. In the event of the system being unable to classify the condition, this is communicated. However, the extracted parameters are available for interpretation by the users.

4.6 TESTING THE SYSTEM

The system was continuously tested in stages as it was developed. Initially the testing was with the synthetic ECG data. This was limited to extraction of parameters. Parameters extracted automatically were compared by viewing the ECG data using LOTUS. Subsequently the actual ECG data was used. In the first phase the extraction of parameters was tested for correctness. In the second phase the knowledge base was applied and the ECG evaluated. Disease classification by the system was confirmed with already known classification. The results were found satisfactory. However, due to insufficient ECG data the testing was limited to the few recorded samples available.

Listing. Programme listing is given at Appendix B.

CHAPTER 5

CONCLUSION

5.1 Problems Faced

5.2 Future Extension of the Work

5.1 PROBLEMS FACED

In any extensive work of this nature,problems are bound to arise. Some of the major problems faced are briefly described.

The first problem was the nonavailability of adequate ECG data. Though synthetic ECG data was generated for developing and to some extent testing the system, the lack of actual ECG data remained a severe handicap throughout. No ECG data bank is as yet available in India. American Heart Association and European Community (CSE Working Group) have prepared their own data banks. Despite effort made by the department to procure the latter, it could not be obtained in time for this work.

Some actual data recorded at Military Hospital, Roorkee, was available. The sampling rate of this data was 100 cycles/second. This sampling rate was inadequate for extracting diagnostically significant information from the ECG. Moreover the data recording was of poor quality, suffering from extensive base line fluctuations.

As described earlier, nowadays expert system shells are commercially available which help in the building of the system. Once again, such a shell could not be procured by us.

5.2 FUTURE EXTENSION OF THE WORK

Due to the problems enumerated above and some other constraints, gaps remain in the system developed. Only lead 2 (which is diagnostically most significant) has been evaluated. Other leads require to be evaluated also. The choice of leads to be evaluated can be decided by consultation with experts, till finally all 12 are analysed.

The knowledge base requires to be extended to include patient weightage factors such as age, weight, blood pressure, past medical history etc. Results of other investigations (ref 1.5) and derived inferences should be incorporated. As mentioned earlier, this would become simpler after the expert system shell has been procured.

Once the above additions have been made it would result in a comprehensive and useful expert system for ECG evaluation. The present work leads the way to that objective.

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APPENDICES

APPENDIX A
(SYN. ECG)

```
) REM PROGRAMME TO GENERATE ,DISPLAY AND STORE SYNTHETIC ECG WAVE
) '***** WELCOME TEXT *****
) CLS :KEY OFF :SCREEN 1:BEEP
) LOCATE 12,14 :PRINT "WELCOME TO"
) LOCATE 16,12:PRINT "ECG SYNTHESISER "
) LOCATE 25,12:PRINT "MAJ AKS CHANDELE"
) FOR I=1 TO 10000:NEXT I
) SCREEN 2
) DIM Y(1200),X(1200)
)0 SCREEN 0:BEEP
l0 LOCATE 2,35:PRINT "INDEX"
20 LOCATE 4,25:PRINT "1.P WAVE "
30 LOCATE 6,25:PRINT "2.R WAVE"
40 LOCATE 8,25:PRINT "3.T WAVE"
50 LOCATE 10,25:PRINT "4.NORMAL ECG WAVE"
50 LOCATE 12,25:PRINT "5.DEMO WAVE 1"
70 LOCATE 14,25:PRINT "6.DEMO WAVE 2"
30 LOCATE 16,25:PRINT "7.DEMO WAVE 3"
70 LOCATE 18,25:PRINT"8.DEMO WAVE 4"
)0 LOCATE 20,25:PRINT "9.QUIT"
l0 LOCATE 22,25: INPUT "PRESS SELECTED NUMERAL & RETURN -    ",ANS$
20 CHOICE=VAL(ANS$):IF CHOICE <1 OR CHOICE >9 THEN BEEP:LOCATE 22,25:PRINT SPAC
$(90):GOTO 210
30 IF CHOICE >=4 AND CHOICE <9 THEN 240 ELSE 390
40 PRINT "Number of cycles to be generated ?(1-6)": INPUT  NREP
50 IF NREP>=1 AND NREP<7 THEN 260 ELSE 240
50 PRINT "Amplitude factor?(0-1.2)": INPUT AF
70 IF AF >=0 AND 1.2>=AF THEN 280 ELSE 260
30 PRINT "Frequency?(50,60,70,80,90 bpm)": INPUT FT
70 IF  FT=50 OR FT=60 OR FT=70 OR FT=80 OR FT=90 THEN 300 ELSE 280
)0 IF FT=50 THEN FR=6/30
l0 IF FT=60 THEN FR=6/36
20 IF FT=70 THEN FR=6/42
30 IF FT=80 THEN FR=6/48
40 IF FT=90 THEN FR=6/54
50 PRINT "Frequency change factor?(-.2 TO +.2)": INPUT CT
50 IF .2>=ABS(CT) THEN 370 ELSE 350
70 CF=(1+CT)
30 RF=FR
70 ON CHOICE GOSUB 400,640,900,1150,1880,1900,1920,1940,3840:GOTO 100
)0 '***** SUB ROUTINE TO GENERATE P WAVE *****
l0 CLS:LOCATE 12,30:PRINT "P WAVE"
20 LOCATE 20,5 :PRINT "PRESS <M> TO USE MODIFIED DATA FILE,ANY OTHER KEY TO USE
STORED DATA FILE "
30 LOCATE 22,5 :INPUT "ENTER YOUR CHOICE AND PRESS RETURN - ",D$
40 IF D$=" " THEN 460
50 IF D$="M" OR D$="m" THEN 2020
50 CLS:LOCATE 2,25:PRINT "P WAVE (USING STORED DATA)"
70 GOSUB 3340
30 CLS:SCREEN 2:OPEN "I",#1,"Y.PRN"
70 X1=0:Y1=150
)0 FOR I=1 TO 1200
```

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```
510 INPUT #1,A,B:A=A*AF:B=B*FR
520 X2=B*.52:Y2=-A*100+150
530 LINE (X2,Y2)-(X1,Y1)
540 X1=X2:Y1=Y2
550 NEXT I
560 CLOSE
570 IF D$="M" OR D$="m" THEN GOTO 620
580 LOCATE 2,25:PRINT"P WAVE (USING STORED DATA)"
590 IF FR=1 AND AF=1 THEN LOCATE 16,6:PRINT"P"
600 IF FR=1 AND AF=1 THEN LOCATE 21,28:PRINT "P1"
610 GOTO 630
620 LOCATE 2,25:PRINT "P WAVE (USING MODIFIED DATA)"
630 GOTO 3470
640 '***** SUBROUTINE TO GENERATE R WAVE *****
650 CLS :LOCATE 12,30
660 PRINT"R WAVE"
670 LOCATE 20,5 :PRINT "PRESS <M> TO USE MODIFIED DATA FILE,ANY OTHER KEY TO USE
 STORED DATA FILE "
680 LOCATE 22,5 :INPUT "ENTER YOUR CHOICE AND PRESS RETURN - ",D$
690 IF D$=" "THEN 710
700 IF D$="M" OR D$="m" THEN 2020
710 CLS:LOCATE 2,25:PRINT"R WAVE (USING STORED DATA)"
720 GOSUB 3340
730 CLS:SCREEN 2:OPEN "I",#2,"Y.RRN"
740 X1=0:Y1=150
750 FOR I=1 TO 1200
760 INPUT #2,C,D:C=C*AF:D=D*FR
770 X2=D*.52:Y2=-C*100+150
780 LINE (X2,Y2)-(X1,Y1)
790 X1=X2:Y1=Y2
800  NEXT I
810 CLOSE
820 IF D$="M" OR D$="m" THEN 880
830 LOCATE 2,25:PRINT "R WAVE (USING STORED DATA)"
840 IF FR=1 AND AF=1 THEN LOCATE 22,23:PRINT"Q"
850 IF FR=1 AND AF=1 THEN LOCATE 6,27:PRINT"R"
860 IF FR=1 AND AF=1 THEN LOCATE 22,30:PRINT"S"
870 GOTO 890
880 LOCATE 2,25:PRINT "R WAVE (USING MODIFIED DATA)"
890 GOTO 3470
900 '***** SUBROUTINE TO GENERATE T WAVE *****
910 CLS :LOCATE 12,30
920 PRINT "T WAVE"
930 LOCATE 20,5 :PRINT "PRESS <M> TO USE MODIFIED DATA FILE,ANY OTHER KEY TO USE
 STORED DATA FILE "
940 LOCATE 22,5 :INPUT "ENTER YOUR CHOICE AND PRESS RETURN - ",D$
950 IF D$=" " THEN 970
960 IF D$="M" OR D$="m" THEN 2020
970 CLS:LOCATE 2,25:PRINT "T WAVE (USING STORED DATA)"
980 GOSUB 3340
990 CLS:SCREEN 2:OPEN "I",#3,"Y.TRN"
1000 X1=0:Y1=150
```

```
1010 FOR I=1 TO 1200
1020 INPUT #3,J,K:J=J*AF:K=K*FR
1030 X2=K*.5:Y2=-J*100+150
1040 LINE (X2,Y2)-(X1,Y1)
1050 X1=X2:Y1=Y2
1060 NEXT I
1070 CLOSE
1080 IF D$="M" OR D$="m" THEN GOTO 1130
1090 LOCATE 2,25:PRINT"T WAVE (USING STORED DATA)"
1100 IF FR=1 AND AF=1 THEN LOCATE 14,52:PRINT"T"
1110  IF FR=1 AND AF=1 THEN LOCATE 17,71:PRINT"U"
1120 GOTO 1140
1130 LOCATE 2,25:PRINT "T WAVE USING MODIFIED DATA"
1140 GOTO 3470
1150 '***** SUBROUTINE TO GENERATE NORMAL ECG WAVE *****
1160 CLS:LOCATE 12,30
1170 PRINT " NORMAL ECG WAVE "
1180 LOCATE 20,5 :PRINT "PRESS <M> TO USE MODIFIED DATA FILE,ANY OTHER KEY TO US
E STORED DATA FILE "
1190 LOCATE 22,5 :INPUT "ENTER YOUR CHOICE AND PRESS RETURN - ",D$
1200 IF D$=" " THEN 1220
1210 IF D$="M" OR D$="m" THEN 2020
1220 CLS:LOCATE 2,25:PRINT "NORMAL ECG WAVE (USING STORED DATA)"
1230 GOSUB 3340
1240 GOTO 1570
1250 CLS:SCREEN 2
1260 FOR N=1 TO NREP
1270 OPEN "I",#1,"Y.PRN"
1280 OPEN "I",#2,"Y.RRN"
1290 OPEN "I",#3,"Y.TRN"
1300 Y1=150
1310 IF N=1 THEN X1=0
1320 IF N=2 THEN X1=1200*RF*.52
1330 IF N=3 THEN X1=1200*RF*.52+1200*RF*.52*CF
1340 IF N=4 THEN X1=1200*RF*.52+1200*RF*.52*CF+1200*RF*.52*CF^2
1350 IF N=5 THEN X1=1200*RF*.52+1200*RF*.52*CF+1200*RF*.52*CF^2+1200*RF*.52*CF^3
1360 IF N=6 THEN X1=1200*RF*.52+1200*RF*.52*CF+1200*RF*.52*CF^2+(1200*RF*.52*CF^
3)+1200*RF*.52*CF^4
1370 FOR I=1 TO 1200
1380 INPUT #1,A,B:A=A*AF:B=B*FR
1390 INPUT #2,C,D:C=C*AF:D=D*FR
1400 INPUT #3,J,K:J=J*AF:K=K*FR
1410 Y2=-(A+C+J)*100+150
1420 IF N=1 THEN X2=(B*.52)
1430 IF N=2 THEN X2=(B*.52)+(1200*RF*.52)
1440 IF N=3 THEN X2=(B*.52)+(1200*RF*.52)+(1200*RF*.52*CF)
1450 IF N=4 THEN X2=(B*.52)+(1200*RF*.52)+(1200*RF*.52*CF)+(1200*RF*.52*CF^2)
1460 IF N=5 THEN X2=(B*.52)+(1200*RF*.52)+(1200*RF*.52*CF)+(1200*RF*.52*CF^2)+(1
200*RF*.52*CF^3)
1470 IF N=6 THEN X2=(B*.52)+(1200*RF*.52)+(1200*RF*.52*CF)+(1200*RF*.52*CF^2)+(1
200*RF*.52*CF^3)+(1200*RF*.52*CF^4)
1480 LINE (X2,Y2)-(X1,Y1)
1490 X1=X2:Y1=Y2
1500 NEXT I
```

```
1510 CLOSE
1520 FR=FR*CF
1530 NEXT N
1540 IF CHOICE =4 THEN GOTO 1600
1550 IF CHOICE =5 THEN GOTO 1720
1560 IF CHOICE =6 THEN GOTO 1760
1570 IF CHOICE= 7 THEN GOTO 1800
1580 IF CHOICE =8 THEN GOTO 1840
1590 GOTO 1700
1600 IF D$="M" OR D$="m" THEN GOTO 1690
1610 LOCATE 2,25:PRINT "NORMAL ECG WAVE (USING STORED DATA)"
1620 IF FR=1 AND AF=1 THEN LOCATE 16,7:PRINT "P"
1630 IF FR=1 AND AF=1 THEN LOCATE 23,23: PRINT "Q"
1640 IF FR=1 AND AF=1 THEN LOCATE 7,27: PRINT "R"
1650 IF FR=1 AND AF=1 THEN LOCATE 23,30: PRINT "S"
1660 IF FR=1 AND AF=1 THEN LOCATE 14,54: PRINT "T"
1670 IF FR=1 AND AF=1 THEN LOCATE 17,74: PRINT "U"
1680 GOTO 1700
1690 LOCATE 2,25:PRINT "NORMAL ECG WAVE (USING MODIFIED DATA)"
1700 LOCATE 1,24
1710 GOTO 3470
1720 LOCATE 2,30:PRINT "DEMO WAVE 1"
1730 LOCATE 4,30:PRINT "LEAD=2"
1740 LOCATE 6,30:PRINT "A V BLOCK"
1750 GOTO 1700
1760 LOCATE 2,30:PRINT "DEMO WAVE 2"
1770 LOCATE 4,30:PRINT "LEAD=2"
1780 LOCATE 6,30:PRINT "LEFT BUNDLE BRANCH BLOCK"
1790 GOTO 1700
1800 LOCATE 2,30:PRINT "DEMO WAVE 3"
1810 LOCATE 4,30:PRINT "LEAD=2"
1820 LOCATE 6,30:PRINT "LEFT VENTRICULAR HYPERTROPY"
1830 GOTO 1700
1840 LOCATE 2,30:PRINT "DEMO WAVE 4"
1850 LOCATE 4,30:PRINT "LEAD=2"
1860 LOCATE 6,30:PRINT "INFERIOR INFARCTION"
1870 GOTO 1700
1880 CLS:LOCATE 5,30:PRINT "DEMO WAVE 1"
1890 GOTO 3340
1900 CLS:LOCATE 5,30:PRINT "DEMO WAVE 2"
1910 GOTO 3340
1920 CLS:LOCATE 5,30:PRINT "DEMO WAVE 3"
1930 GOTO 3340
1940 CLS:LOCATE 5,30:PRINT "DEMO WAVE 4"
1950 GOTO 3340
1960 ' ******* STORED DATA *******
1970 READ A,B,C,D,E,F,G,H,J,K,L,P,P1,Q,R,S,T,T1,U
1980 RESTORE
1990 DATA 20,160,320,360,400,440,480,600,830,1000,1050,.21,-.07,-.15,1,-.17,.35,
.05,.1
2000 GOSUB 2470
```

```
2010 RETURN
2020 ' ******* MODIFIED DATA *******
2030 CLS:SCREEN 2:KEY OFF
2040 SCREEN 0:LOCATE 2,6:PRINT"STORED VALUES "
2050 LOCATE 3,10:PRINT"A=20"
2060 LOCATE 5,10:PRINT "B=160"
2070 LOCATE 7,10:PRINT "C=320"
2080 LOCATE 9,10:PRINT "D=360"
2090 LOCATE 11,10:PRINT "E=400"
2100 LOCATE 13,10:PRINT "F=440"
2110 LOCATE 15,10:PRINT "G=480"
2120 LOCATE 17,10:PRINT "H=600"
2130 LOCATE 19,10:PRINT "J=830"
2140 LOCATE 21,10:PRINT "K=1000"
2150 LOCATE 23,10:PRINT "L=1050"
2160 LOCATE 2,46:PRINT"STORED VALUES"
2170 LOCATE 3,50:PRINT "P=.21"
2180 LOCATE 5,50:PRINT"P1=-.07"
2190 LOCATE 7,50:PRINT "Q=-.15"
2200 LOCATE 9,50:PRINT "R=1"
2210 LOCATE 11,50:PRINT "S=-.17"
2220 LOCATE 13,50:PRINT"T=.35"
2230 LOCATE 15,50:PRINT"T1=.05"
2240 LOCATE 17,50:PRINT "U=.1"
2250 LOCATE 2,25:PRINT"ENTER NEW VALUE "
2260 LOCATE 3,30:INPUT "A= ";A
2270 LOCATE 5,30:INPUT "B= ";B
2280 LOCATE 7,30:INPUT "C= ";C
2290 LOCATE 9,30:INPUT "D= ";D
2300 LOCATE 11,30:INPUT "E= ";E
2310 LOCATE 13,30:INPUT "F= ";F
2320 LOCATE 15,30:INPUT "G= ";G
2330 LOCATE 17,30:INPUT "H= ";H
2340 LOCATE 19,30:INPUT "J= ";J
2350 LOCATE 21,30:INPUT "K= ";K
2360 LOCATE 23,30:INPUT "L= ";L
2370 LOCATE 2,65:PRINT "ENTER NEW VALUE"
2380 LOCATE 3,70:INPUT"P= ";P
2390 LOCATE 5,70:INPUT "P1= ";P1
2400 LOCATE 7,70:INPUT "Q= ";Q
2410 LOCATE 9,70:INPUT "R= ";R
2420 LOCATE 11,70:INPUT "S= ";S
2430 LOCATE 13,70:INPUT "T= ";T
2440 LOCATE 15,70:INPUT "T1= ";T1
2450  LOCATE 17,70:INPUT "U= ";U
2460 GOSUB 3340
2470 IF CHOICE =2 THEN GOSUB 2850
2480 IF CHOICE =3 THEN GOSUB 3100
2490 GOSUB 2640
2500 STOP
```

```
2510 '***** DATA FOR DEMO WAVE 1 *****
2520 A=30:B=180:C=520:D=545:E=600:F=630:G=650:H=651:J=875:K=1000:L=1001:P=.2:P1=
.02:Q=.04:R=.5:S=0:T=-.1:T1=0:U=0
2530 GOSUB 2630
2540 ' ***** DATA FOR DEMO WAVE 2 *****
2550 A=10:B=220:C=250:D=275:E=400:F=440:G=490:H=660:J=930:K=1080:L=1081:P=.1:P1=
-.01:Q=-.01:R=.25:S=-9.000001E-02:T=-.12:T1=.01:U=.02
2560 GOSUB 2630
2570 '***** DATA FOR DEMO WAVE 3 *****
2580 A=120:B=320:C=480:D=520:E=600:F=660:G=661:H=720:J=1050:K=1198:L=1199:P=.13
:P1=0:Q=.23:R=-.5:S=0:T=.22:T1=0:U=0
2590 GOSUB 2630
2600 '***** DATA FOR DEMO WAVE 4 *****
2610 A=120:B=300:C=360:D=410:E=480:F=540:G=541:H=720:J=780:K=840:L=841:P=.22:P1=
-.02:Q=.26:R=1:S=0:T=-.13:T1=0:U=.06
2620 GOSUB 2630
2630 '***** CALCULATION OF P WAVE *****
2640 OPEN "O",1, "Y.PRN"
2650 FOR X=1 TO A
2660 Y(X)=0
2670 NEXT X
2680 FOR X=A TO B
2690 Y(X)=P*SIN(3.1432*((X-A)/(B-A)))
2700 NEXT X
2710 FOR X=B TO F
2720 Y(X)=P1*((X-B)/(F-B))
2730 NEXT X
2740 FOR X=F TO H
2750 Y(X)=-P1*((X-H)/(H-F))
2760 NEXT X
2770 FOR X=H TO 1200
2780 Y(X)=0
2790 NEXT X
2800 FOR X=1 TO 1200
2810 PRINT #1,Y(X),X
2820 NEXT X
2830 CLOSE
2840 IF CHOICE =1 THEN 480
2850 ' ***** CALCULATION OF R WAVE *****
2860 OPEN "O",2,"Y.RRN"
2870 FOR X=1 TO 320
2880 Y(X)=0
2890  NEXT X
2900 FOR X=C TO D
2910 Y(X)=Q*((X-C)/(D-C))
2920 NEXT X
2930 FOR X=D TO E
2940 Y(X)=(((R-Q)/(E-D))*(X-D))+Q
2950 NEXT X
2960 FOR X=E TO F
2970 Y(X)=(((S-R)/(F-E))*(X-E))+R
2980 NEXT X
2990 FOR X=F TO G
3000 Y(X)=-S*((X-G)/(G-F))
```

```
3010 NEXT X
3020 FOR X= G TO 1200
3030 Y(X)=0
3040 NEXT X
3050 FOR X=1 TO 1200
3060 PRINT #2,Y(X),X
3070 NEXT X
3080 CLOSE
3090 IF CHOICE =2 THEN 730
3100 ' ***** CALCULATIN OF T WAVE *****
3110 OPEN "O",3,"Y.TRN"
3120 FOR X=1 TO  G
3130 Y(X)=0
3140 NEXT X
3150 FOR X= G TO H
3160 Y(X)=T1
3170 NEXT X
3180 FOR X=H TO J
3190 Y(X)=T*SIN((3.1432/2)*((X-(H-18))/(J-H)))
3200 NEXT X
3210 FOR X=J TO K
3220 Y(X)=T*COS((3.1432/2)*((X-J)/(K-J)))
3230 NEXT X
3240 FOR X=L TO 1200
3250 Y(X)=U*SIN((3.1432*(X-L)/(1200-L)))
3260 NEXT X
3270 FOR X=1 TO 1200
3280 PRINT #3,Y(X),X
3290 NEXT X
3300 CLOSE
3310 IF CHOICE =3 THEN 990
3320 GOTO 1250
3330 STOP
3340 '***** WAIT TEXT *****
3350 SCREEN 1
3360 LOCATE 8,14:PRINT "PLEASE WAIT"
3370 LOCATE 16,6:PRINT " ECG CALCULATIONS IN PROGRESS....."
3380 LOCATE 21,6:PRINT "TIME TO CALCULATE LESS THAN 90 SECS"
3390 LOCATE 23,15:PRINT "( A DOCTOR WILL TAKE ABOUT 15 MINUTES !)"
3400 IF CHOICE =5 THEN 2510
3410 IF CHOICE =6 GOTO 2540
3420 IF CHOICE =7 GOTO 2570
3430 IF CHOICE =8 GOTO 2600
3440 IF D$="M" OR D$="m" THEN GOSUB 2470
3450 GOSUB 1970
3460 RETURN
3470 LOCATE 24,27:PRINT"WANT TO STORE  DATA ? (Y/N)"
3480 X$=INPUT$(1)
3490 IF X$="Y" OR X$="y" THEN 3510
3500 IF X$="N" OR X$="n" THEN 3810 ELSE 3480
```

```
3510 PRINT "FILE NAME ? -":INPUT B$
3520 OPEN "I",#1,"Y.PRN"
3530 OPEN "I",#2,"Y.RRN"
3540 OPEN "O",#3,"Y.PPN"
3550 FOR I=1 TO 1200
3560 INPUT #1,A,B
3570 INPUT #2,C,D
3580 E=A+C
3590 PRINT #3,E
3600 NEXT I
3610 CLOSE 1,#2,#3
3620 OPEN "O",#1,B$
3630 FOR N= 1 TO NREP
3640 OPEN "I",#3,"Y.PPN"
3650 OPEN "I",#2,"Y.TRN"
3660 FOR I=1 TO 1200
3670 INPUT #3,E:E=E*AF
3680 INPUT #2,J,B:J=J*AF:B=B*FR
3690 Y(I)=(E+J)
3700 IF N=1 THEN X(I)=B
3710 IF N=2 THEN X(I)=B+1200*RF
3720 IF N=3 THEN X(I)=B+1200*RF+1200*RF*CF
3730 IF N=4 THEN X(I)=B+1200*RF+1200*RF*CF+1200*RF*CF^2
3740 IF N=5 THEN X(I)=B+1200*RF+1200*RF*CF+1200*RF*CF^2+1200*RF*CF^3
3750 IF N=6 THEN X(I)=B+1200*RF+1200*RF*CF+1200*RF*CF^2+1200*RF*CF^3+1200*RF*CF^
4
3760 PRINT #1,X(I),Y(I)
3770 NEXT I
3780 CLOSE
3790 NEXT N
3800 CLOSE
3810 LOCATE 25,26:PRINT"PRESS ANY KEY TO CONTINUE"
3820 ANS$=INPUT$(1):GOTO 100
3830 ' ***** SIGN OFF *****
3840 CLS:SCREEN 1:LOCATE 13,14:PRINT "GOODBYE !" :BEEP
3850 FOR I= 1 TO 10000:NEXT I
3860 LOCATE 1,1
3870 SCREEN 2
3880 SCREEN 0
3890 END
```

APPENDIX B
(EVL. BAS)

```
10 REM PROGRAMME FOR EVALUATION OF ECG WAVE
20 '***** DISPLAY MENU *****
30 KEY OFF:CLS:LOCATE 4,20:PRINT "EXPERT SYSTEM FOR EVALUATION OF ECG"
40 LOCATE 8,28:PRINT"1.EVALUATE ECG"
50 LOCATE 12,28:PRINT "2.DISPLAY AND AMEND RULES "
60 LOCATE 16,28:PRINT"3.APPEND KNOWLEDGE BASE"
70 LOCATE 20,28:PRINT "4.EXIT EXPERT SYSTEM"
80 LOCATE 23,20:INPUT "ENTER SELECTED NUMERAL AND RETURN-",ANS$
90 CHOICE=VAL(ANS$):IF CHOICE <1 OR CHOICE >4 THEN BEEP:LOCATE 22,20:PRINT SPACE
$(90):GOTO 80
100 ON CHOICE GOTO 350,110,300,5990
110 CLS:SCREEN 1:LOCATE 12,10 :PRINT"DISPLAY AND AMEND RULES"
120 FOR I=1 TO 8000:NEXT I
130 CLS:SCREEN 2:SCREEN 0:LOCATE 13,26:PRINT"RULES ARE FROM 1 TO 10"
140 LOCATE 23,20:INPUT "ENTER SELECTED NUMERAL RULE NUMBER AND RETURN-",ANS$
150 CHOICE=VAL(ANS$):IF CHOICE <1 OR CHOICE >12 THEN BEEP:LOCATE 23,20:PRINT SPA
CE$(90):GOTO 140
160 CLS:LOCATE 1,58:PRINT"PRESS F2 TO CONTINUE":LOCATE 1,1:PRINT"AMEND RULE AND
SAVE IN FILE <DC.BAS>"
170 ON CHOICE GOTO 180,190,200,210,220,230,240,250,260,270,280,290
180 CHAIN"DC.BAS",25,ALL
190 CHAIN"DC.BAS",75,ALL
200 CHAIN"DC.BAS",155,ALL
210 CHAIN"DC.BAS",215,ALL
220 CHAIN"DC.BAS",275,ALL
230 CHAIN"DC.BAS",335,ALL
240 CHAIN"DC.BAS",395,ALL
250 CHAIN"DC.BAS",475,ALL
260 CHAIN"DC.BAS",535,ALL
270 CHAIN"DC.BAS",605,ALL
280 CHAIN"DC.BAS",665,ALL
290 CHAIN"DC.BAS",725,ALL
300 CLS:SCREEN 1:LOCATE 12,14 :PRINT"APPEND RULES"
310 FOR I=1 TO 8000:NEXT I
320 SCREEN 2:SCREEN 0
330 CLS:LOCATE 1,58:PRINT"PRESS F2 TO CONTINUE":LOCATE 1,1:PRINT"ENTER RULE AND
SAVE IN FILE <DC.BAS>"
340 CHAIN"DC.BAS",665,ALL
350 CLS:SCREEN 1:LOCATE 12,10 :PRINT"EVALUATION OF ECG"
360 LOCATE 18,10:PRINT "ECG WAVE -LEAD 2"
370 FOR I=1 TO 8000:NEXT I
380 SCREEN 2:SCREEN 0
390 CLEAR,,2000
400 '***** READING ECG WAVE DATA *****
410 DIM X(600),Y(600),FR(600),YR(600),TC(200)
420 CLS:PRINT "PLEASE ENTER ECG FILE NAME":INPUT A$
430 CLS:PRINT "WHAT IS THE SAMPLING FREQUENCY":INPUT SR
440 CLS:PRINT "TOTAL NUMBER OF SAMPLES":INPUT SP
450 CLS:LOCATE 12,30 :PRINT "PLEASE WAIT..."
460 OPEN "I",#1,A$
470 FOR I=1 TO SP
480 INPUT #1,X,Y
490 LET X(I)=X
500 LET Y(I)=8000-Y
```

```
510 NEXT I
520 CLOSE #1
530 REM CHECK POLARITY OF FIRST QRS(SLOPE METHOD)
540 FOR I=2 TO .85*SR
550 IF ABS(Y(I+2)-Y(I))>350 THEN 570
560 NEXT I
570 IF Y(I+2)>Y(I) THEN 580 ELSE 590
580 GOTO 600:REM QRS IS UPRIGHT
590 GOTO 660:REM QRS IS INVERTED
600 REM EXTRACT FIRST QRS(AMP METHOD)
610 FOR I=1 TO .85*SR
620 IF R(1)<Y(I) THEN 630 ELSE 640
630 R(1)=Y(I):F(1)=X(I):R1=Y(I):F1=X(I)
640 NEXT I
650 GOTO 720
660 REM EXTRACT FIRST QRS(NEG)_
670 FOR I= 1 TO .85*SR
680 IF R(1)>=Y(I) THEN 690 ELSE 700
690 R(1)=Y(I):F(1)=X(I):R1=Y(I):F1=X(I)
700 NEXT I
710 GOTO 720
720 REM EXTRACT S(1),H(1)
730 S(1)=Y(F(1))
740 FOR I=F(1) TO F(1)+.1*SR
750 IF S(1)>=Y(I) THEN 760 ELSE 770
760 S(1)=Y(I):H(1)=X(I):S1=Y(I):H1=X(I)
770 NEXT I
780 REM ABS VALUE OF R1
790 AR1=(R1-S1)
800 REM EXTRACT T(1),L(1)
810 T(1)=-200
820 FOR I=(H(1)+1) TO F(1)+.4*SR
830 IF T(1)<Y(I) THEN 840 ELSE 850
840 T(1)=Y(I):L(1)=X(I)
850 NEXT I
860 REM EXTRACT R2,F2
870 FOR I=(F(1)+.1*SR) TO F(1)+.9*SR
880 IF R2<Y(I) THEN 890 ELSE 900
890 R2=Y(I):F2=X(I)
900 NEXT I
910 REM CHECKING FOR ANY MISSED QRS?
920 FOR I=F1+(.1*SR) TO F2-(.1*SR)
930 IF RX<Y(I) THEN 940 ELSE 950
940 RX=Y(I):FX=X(I)
950 NEXT I
960 FOR I=FX TO 1.2*FX
970 SX=Y(FX)
980 IF SX>=Y(I) THEN 990 ELSE 1000
990 SX=Y(I):HX=X(I)
1000 NEXT I
```

```
1010 ARX=ABS(RX-SX)
1020 IF(ARX/AR1)>=.65 THEN 1030 ELSE 1050
1030 IF (Y(FX+1)-Y(FX-1))>=400 THEN 1040 ELSE 1050
1040 R(2)=RX:F(2)=FX:GOTO 1060
1050 R(2)=R2:F(2)=F2
1060 REM EXTRACT R(3),F(3)
1070 IF (SP-F(2))>=(F(2)-F(1)) THEN 1080 ELSE GOTO 3270
1080 FOR I=1.1*F(2) TO (1.1*F(2)+(F(2)-F(1)))
1090 IF R(3)<Y(I) THEN 1100 ELSE 1110
1100 R(3)=Y(I):F(3)=X(I)
1110 NEXT I
1120 REM EXTRACT R(4),F(4)
1130 IF (SP-F(3))>=(F(3)-F(2)) THEN 1140 ELSE K=2:GOTO 1540
1140 FOR I=1.1*F(3) TO (1.1*F(3)+(F(3)-F(2)))
1150 IF R(4)<Y(I) THEN 1160 ELSE 1170
1160 R(4)=Y(I):F(4)=X(I)
1170 NEXT I
1180 IF ABS(R(4)-R(3))>=350 THEN K=2:GOTO 1540
1190 REM EXTRACT R(5),F(5)
1200 IF (SP-F(4))>=(F(4)-F(3)) THEN 1210 ELSE K=3:GOTO 1540
1210 FOR I=1.1*F(4) TO (1.1*F(4)+(F(4)-F(3)))
1220 IF R(5)<Y(I) THEN 1230 ELSE 1240
1230 R(5)=Y(I):F(5)=X(I)
1240 NEXT I
1250 IF ABS(R(5)-R(4))>=350 THEN K=3:GOTO 1540
1260 REM EXTRACT R(6),F(6)
1270 IF (SP-F(5))>=(F(5)-F(4)) THEN 1280 ELSE K=4:GOTO 1540
1280 FOR I=1.1*F(5) TO (1.1*F(5)+(F(5)-F(4)))
1290 IF R(6)<Y(I) THEN 1300 ELSE 1310
1300 R(6)=Y(I):F(6)=X(I)
1310 NEXT I
1320 IF ABS(R(6)-R(5))>=350 THEN K=4:GOTO 1540
1330 REM EXTRACT R(7),F(7)
1340 IF (SP-F(6))>=(F(6)-F(5)) THEN 1350 ELSE K=5:GOTO 1540
1350 IF (1.05*F(6)+(F(6)-F(5)))>=TS THEN 1360 ELSE 1370
1360 LET AC=SP:GOTO 1380
1370 LET AC=(1.05*F(6)+(F(6)-F(5)))
1380 FOR I=1.05*F(6) TO AC
1390 IF R(7)<Y(I) THEN 1400 ELSE 1410
1400 R(7)=Y(I):F(7)=X(I)
1410 NEXT I
1420 IF ABS(R(7)-R(6))>=350 THEN K=5:GOTO 1540
1430 REM EXTRACT R(8),F(8)
1440 IF (SP-F(7))>=(F(7)-F(6)) THEN 1450 ELSE K=6:GOTO 1540
1450 IF (1.025*F(7)+(F(7)-F(6)))>=SP THEN 1460 ELSE 1470
1460 LET AB=SP:GOTO 1480
1470 LET AB=(1.025*F(7)+(F(7)-F(6)))
1480 FOR I=F(7)+.5*SR TO AB
1490 IF R(8)<Y(I) THEN 1500 ELSE 1510
1500 R(8)=Y(I):F(8)=X(I)
```

```
1510 NEXT I
1520 IF ABS(R(8)-R(7))>=350 THEN K=6:GOTO 1540
1530 IF (SP-F(8))>=1.1*(F(8)-F(7)) THEN K=8 ELSE K=7
1540 '***** SELECTION OF WAVE *****
1550 LET MIN=50
1560 FOR N=2 TO K
1570 IF ABS(R(N)-R(N-1))<MIN THEN 1580 ELSE 1600
1580 IF ABS(R(N+1)-R(N))<50 THEN 1590 ELSE 1600
1590 MIN=ABS(R(N)-R(N-1)):V=N
1600 NEXT N
1610 IF MIN=50 THEN 1620 ELSE 1970
1620 BEEP:KEY OFF:CLS:LOCATE 12,24:PRINT"POOR QUALITY OF ECG RECORDING"
1630 LOCATE 23,18:PRINT"C=CONT"
1640 LOCATE 23,36:PRINT"M=MENU"
1650 LOCATE 23,54:PRINT"Q=QUIT"
1660 F$=INPUT$(1)
1670 IF F$="C" OR F$="c" THEN 1700
1680 IF F$="M" OR F$="m" THEN 30
1690 IF F$="Q" OR F$="q" THEN 5990 ELSE BEEP:GOTO 1630
1700 CLS:LOCATE 12,28:PRINT"PLEASE WAIT..."
1710 LET MN=50
1720 FOR N=2 TO K
1730 IF ABS(R(N)-R(N-1))<MN THEN 1740 ELSE 1760
1740 IF ABS(R(N+1)-R(N))<100 THEN 1750 ELSE 1760
1750 MN=ABS(R(N)-R(N-1)):V=N
1760 NEXT N
1770 IF MN=50 THEN 1780 ELSE 1970
1780 LET NM=100
1790 FOR N=2 TO K
1800 IF ABS(R(N)-R(N-1))<NM THEN 1810 ELSE 1830
1810 IF ABS(R(N+1)-R(N))<50 THEN 1820 ELSE 1830
1820 NM=ABS(R(N)-R(N-1)):V=N
1830 NEXT N
1840 IF NM=100 THEN 1850 ELSE 1970
1850 LET NN=100
1860 FOR N=2 TO K
1870 IF ABS (R(N)-R(N-1))<NN THEN 1880 ELSE 1900
1880 IF ABS(R(N+1)-R(N))<NN THEN 1890 ELSE 1900
1890 NN=ABS(R(N)-R(N-1)):V=N
1900 NEXT N
1910 IF NN=100  THEN 1920 ELSE 1970
1920 LET VV=1:FOR N=2 TO K
1930 LET SS=500
1940 IF ABS (R(N)-R(N-1))<SS THEN 1950 ELSE 1960
1950 SS=ABS (R(N)-R(N-1)):V=N
1960 NEXT N
1970 '***** EXTRACT PARAMETERS OF SELECTED WAVE *****
1980 N=V
1990 REM EXTRACT Q(N),D(N)
2000 M=INT(F(N-1)+((F(N)-F(N-1))/2))
```

```
2010 FOR I=F(N) TO 0 STEP -1
2020 IF Y(I-1)<Y(I) THEN 2030 ELSE 2040
2030 NEXT I
2040 Q(N)=Y(I):D(N)=X(I)
2050 FOR I= D(N) TO D(N)-3 STEP -1
2060 IF Q(N)>=Y(I) THEN 2070  ELSE 2080
2070 Q(N)=Y(I):D(N)=X(I)
2080 NEXT I
2090 REM EXTRACT P(N),A(N)
2100 P(N)=0
2110 FOR I=M TO D(N)
2120 IF P(N)<Y(I) THEN 2130 ELSE 2140
2130 P(N)=Y(I):A(N)=X(I)
2140 NEXT I
2150 FOR I=A(N) TO D(N)-1
2160 IF Y(I+2)<Y(I+1) THEN 2170 ELSE 2180
2170 CNT5=CNT5 +1:GOTO 2190
2180 CNT6=CNT6 +1
2190 NEXT I
2200 IF CNT6/CNT5>=.4 THEN 2220  ELSE 2210
2210 GOTO 2270:REM P WAVE IS POSITIVE
2220 P(N)=8000: PRINT "P WAVE IS INVERTED"
2230 FOR I=M TO D(N)-.04*SR
2240 IF P(N)>=Y(I) THEN 2250 ELSE 2260
2250 P(N)=Y(I):A(N)=X(I)
2260 NEXT I
2270 REM EXTRACT S(N),H(N)
2280 S(N)=Y(F(N))
2290 FOR I=F(N) TO F(N)+.1*SR
2300 IF S(N)>=Y(I) THEN 2310 ELSE 2320
2310 S(N)=Y(I):H(N)=X(I)
2320 NEXT I
2330 REM EXTRACT T(N),L(N)
2340 T(N)=-200
2350 FOR I=(H(N)+1) TO (.5*(F(N)-F(N-1)))+H(N)
2360 IF T(N)<Y(I) THEN 2370 ELSE 2380
2370 T(N)=Y(I):L(N)=X(I)
2380 NEXT I
2390 REM CHECKING POLARITY OF T WAVE
2400 FOR I=H(N) TO L(N)-1
2410 IF Y(I+2)>=Y(I+1) THEN 2420 ELSE 2430
2420 CNT7=CNT7+1:GOTO 2440
2430 CNT8=CNT8+1
2440 NEXT I
2450 IF CNT8>CNT7 THEN 2460 ELSE 2470
2460 STOP'T WAVE IS NEGATIVE
2470 REM T WAVE IS POSITIVE
2480 REM EXTRACT PARAMETERS OF (N-1) WAVE
2490 REM EXTRACT S(N-1),H(N-1)
2500 S(N-1)=Y(F(N-1))
```

```
2510 FOR I=F(N-1) TO F(N-1)+.1*SR
2520 IF S(N-1)>=Y(I) THEN 2530 ELSE 2540
2530 S(N-1)=Y(I):H(N-1)=X(I)
2540 NEXT I
2550 REM EXTRACT T(N-1),L(N-1)
2560 T(N-1)=-200
2570 FOR I=H(N-1) TO F(N-1)+.5*(F(N)-F(N-1))
2580 IF T(N-1)<Y(I) THEN 2590 ELSE 2600
2590 T(N-1)=Y(I):L(N-1)=X(I)
2600 NEXT I
2610 '***** DETERMINATION OF BASE LINE *****
2620 OPEN"I",#2,A$
2630 FOR I=1 TO A(N)
2640 INPUT #2,X,W:YR(I)=INT(W/100)
2650 NEXT I
2660 LET AA=(A(N)-(F(N)-F(N-1))/2)
2670 CLOSE #2
2680 CNT1=AA
2690 FOR J=AA TO A(N)
2700 CNT2=1
2710 Y(CNT1)=YR(J)
2720 IF CNT1 = 1 THEN 2760
2730 FOR K = AA TO CNT1-1
2740 IF Y(CNT1) = Y(K) THEN 2830
2750 NEXT K
2760 FOR I= J+1 TO A(N)
2770 IF Y(CNT1)=YR(I) THEN 2790
2780 GOTO 2800
2790 CNT2 = CNT2+1
2800 NEXT I
2810 FR(CNT1)=CNT2
2820 CNT1=CNT1+1
2830 NEXT J
2840 CNT1 = CNT1-1
2850 YMAX = FR(1)
2860 YAR =AA
2870 FOR I = AA+1 TO CNT1
2880 IF YMAX >= FR(I) THEN 2910
2890 YMAX =FR(I)
2900 YAR =I
2910 NEXT I
2920 YMF =Y(YAR)
2930 OPEN "I",#3,A$
2940 FOR I=1 TO SP
2950 INPUT #3,X,Y
2960 LET X=X(I)
2970 LET Y(I)=Y
2980 NEXT I
2990 CLOSE #3
3000 LET SUM=0
```

```
3010 FOR I=AA TO A(N)
3020 IF Y(I)>=(YMF*100) AND Y(I)<(YMF*100+100)THEN GOTO 3030 ELSE 3040
3030 SUM=SUM+Y(I)
3040 NEXT I
3050 YBASE=SUM/FR(YAR)
3060 '***** PRINT PARAMETERS *****
3070 CLS
3080 REM INPUT AMP & TIME CONVERSION FACTORS
3090 AF =.001
3100 TF=.01
3110 LET Z=8000-YBASE
3120 LOCATE 2,24:PRINT "NAME OF ECG RECORD-  ";A$
3130 PRINT
3140 FOR I=1 TO 8
3150 IF 0<F(I) THEN PRINT "       WAVE"I,,"R"I"="  (R(I)-Z)*AF"mv",;"  F"I"="F(I)
3160 NEXT I
3170 PRINT
3180 PRINT"SELECTED WAVE =" N
3190 PRINT
3200 PRINT "P="(P(N)-Z)*AF"mv","Q="(Q(N)-Z)*AF"mv","R="(R(N)-Z)*AF"mv","S="(S(N)
-Z)*AF"mv","T="(T(N)-Z)*AF"mv"
3210 PRINT "A="A(N),"D="D(N),"F="F(N),"H="H(N),"L="L(N)
3220 PRINT
3230 PRINT "DETERMINATION OF BASE LINE"
3240 PRINT
3250 PRINT"YMF="YMF,,"FR="FR(YAR),,"YBASE="YBASE
3260 IF VV=1 THEN 3270 ELSE 3320
3270 LOCATE 23,24:PRINT" QUALITY OF ECG RECORDING UNACCEPTABLE"
3280 LOCATE 24,29:PRINT "PRESS  ANY KEY TO ABANDON"
3290 FOR I=1 TO 2:SOUND 1000,4
3300 SOUND 1600,4:NEXT I
3310 ANS$=INPUT$(1):CLS:GOTO 30
3320 LOCATE 23,18:PRINT"C=CONT"
3330 LOCATE 23,36:PRINT"M=MENU"
3340 LOCATE 23,54:PRINT"Q=QUIT"
3350 F$=INPUT$(1)
3360 IF F$="C" OR F$="c" THEN 3390
3370 IF F$="M" OR F$="m" THEN 30
3380 IF F$="Q" OR F$="q" THEN 5990 ELSE BEEP:GOTO 3320
3390 CLS
3400 '***** DETERMINE NORMALISED AMPS *****
3410 NR=(R(N)-Z)/(R(N)-Z):PRINT
3420 NP=(P(N)-Z)/(R(N)-Z):PRINT "SELECTED WAVE -NORMALISED AMPLITUDES"
3430 NQ=(Q(N)-Z)/(R(N)-Z):PRINT
3440 NS=(S(N)-Z)/(R(N)-Z)
3450 NT=(T(N)-Z)/(R(N)-Z)
3460 PRINT "NP="NP*100"%"
3470 PRINT "NQ="NQ*100"%"
3480 PRINT "NR="NR*100"%"
3490 PRINT "NS="NS*100"%"
3500 PRINT "NT="NT*100"%"
```

```
3510 '***** EXTRACT SEGMENT DURATIONS *****
3520 REM EXTRACT E(N)
3530 FOR I= D(N)+1 TO F(N)
3540 IF YBASE-Y(I)>= 0 THEN 3550 ELSE 3570
3550 E(N) =X(I)
3560 GOTO 3580
3570 NEXT I
3580 REM EXTRACT G(N)
3590 FOR I=F(N)+1 TO H(N)+1
3600 IF YBASE-Y(I) <0 THEN 3610 ELSE 3630
3610 G(N)=X(I)
3620 GOTO 3650
3630 NEXT I
3640 REM EXTRACT M(N-1)
3650 FOR I=L(N-1) TO A(N)
3660 IF (YBASE-Y(I))<0 THEN GOTO 3670 ELSE 3690
3670 M(N-1)=X(I)
3680 GOTO 3710
3690 NEXT I
3700 REM EXTRACT M(N)
3710 FOR I=L(N) TO 1.2*L(N)
3720 IF (YBASE-Y(I))<0 THEN GOTO 3730 ELSE 3750
3730 M(N)=X(I)
3740 GOTO 3770
3750 NEXT I
3760 REM EXTRACT O(N)
3770 FOR I=A(N) TO 0 STEP -1
3780 IF (YBASE-Y(I))<0 THEN GOTO 3790 ELSE 3810
3790 O(N)=X(I)
3800 GOTO 3840
3810 NEXT I
3820 REM EXTRACT B(N)
3830 IF Q(N)<0 THEN 3840 ELSE 3890
3840 FOR I= A(N)+1 TO D(N)+1
3850 IF (YBASE-Y(I))<0 THEN GOTO 3860 ELSE 3880
3860 B(N)=X(I)
3870 GOTO 3940
3880 NEXT I
3890 FOR I=A(N)+1 TO D(N)+1
3900 IF Y(I)<Y(I+1) THEN 3910 ELSE 3920
3910 NEXT I
3920 B(N)=X(I)
3930 REM EXTRACT K(N)
3940 FOR I=H(N)+1 TO L(N)+1
3950 IF (YBASE-Y(I))>=0 THEN 3960 ELSE 3980
3960 K(N)=X(I)
3970 GOTO 3990
3980 NEXT I
3990 REM EXTRACT CYCLE TIME
4000 TC=F(N)-F(N-1)
```

```
4010 REM EXTRACT P SEG
4020 TP=B(N)-O(N)
4030 REM EXTRACT Q SEG
4040 TQ=E(N)-B(N)
4050 REM EXTRACT R SEG
4060 TR=G(N)-E(N)
4070 REM EXTRACT T SEG
4080 TT=M(N)-K(N)
4090 REM EXTRACT S SEG
4100 TS=K(N)-G(N)
4110 REM EXTRACT PR INTERVAL
4120 PR=D(N)-O(N)
4130 REM EXTRACT QRS DURATION
4140 QRS=H(N)-O(N)
4150 REM EXTRACT QT INTERVAL
4160 QT=M(N)-D(N)
4170 REM EXTRACT RELAX SEG
4180 TO=TC-(TP+TQ+TR+TS+TT)
4190 PRINT
4200 PRINT"SELECTED WAVE -X AXIS POINTS"
4210 PRINT
4220 PRINT "O="O(N),"A="A(N),"B="B(N),"D="D(N),"E="E(N),"F="F(N),"G="G(N),"H="H(
N),"K="K(N),"L="L(N),"M="M(N)
4230 PRINT
4240 PRINT"SELECTED WAVE -SEGMENT DURATIONS"
4250 PRINT
4260 PRINT"TO="TO*TF"secs";"  TP="TP*TF"secs";"  TQ="TQ*TF"secs";"  TR="TR*TF"se
cs";"  TS="TS*TF"secs";"  TT="TT*TF"secs";"  TC="TC*TF"secs";" PR="PR*TF;" QRS="
QRS*TF;" QT="QT*TF
4270 LOCATE 23,18:PRINT"C=CONT"
4280 LOCATE 23,36:PRINT"M=MENU"
4290 LOCATE 23,54:PRINT"Q=QUIT"
4300 F$=INPUT$(1)
4310 IF F$="C" OR F$="c" THEN 4340
4320 IF F$="M" OR F$="m" THEN 30
4330 IF F$="Q" OR F$="q" THEN 5990 ELSE BEEP:GOTO 4270
4340 CLS
4350 LOCATE 12,28:PRINT"PLEASE WAIT.."
4360 '***** ST SEG ANALYSIS *****
4370 OPEN"I",#2,A$
4380 FOR I=1 TO K(N)
4390 INPUT #2,X,W:YR(I)=INT(W/100)
4400 NEXT I
4410 CLOSE #2
4420 CNT1=H(N)
4430 FOR J=H(N) TO K(N)
4440 CNT2=1
4450 Y(CNT1)=YR(J)
4460 IF CNT1 = 1 THEN 4500
4470 FOR K = H(N) TO CNT1-1
4480 IF Y(CNT1) = Y(K) THEN 4570
4490 NEXT K
4500 FOR I= J+1 TO K(N)
```

```
4510 IF Y(CNT1)=YR(I) THEN 4530
4520 GOTO 4540
4530 CNT2 = CNT2+1
4540 NEXT I
4550 FR(CNT1)=CNT2
4560 CNT1=CNT1+1
4570 NEXT J
4580 CNT1 = CNT1-1
4590 YMAX = FR(1)
4600 YAR =H(N)
4610 FOR I = H(N)+1 TO CNT1
4620 IF YMAX >= FR(I) THEN 4650
4630 YMAX =FR(I)
4640 YAR =I
4650 NEXT I
4660 YMF =Y(YAR)
4670 OPEN "I",#3,A$
4680 FOR I=1 TO K(N)
4690 INPUT #3,X,Y
4700 LET X=X(I)
4710 LET Y(I)=Y
4720 NEXT I
4730 CLOSE #3
4740 LET SUM=0
4750 FOR I=H(N) TO K(N)
4760 IF Y(I)>=(YMF*100) AND Y(I)<(YMF*100+100)THEN GOTO 4770 ELSE 4780
4770 SUM=SUM+Y(I)
4780 NEXT I
4790 YSTO=SUM/FR(YAR)
4800 REM PRINT PARAMETERS
4810 CLS :KEY OFF
4820 PRINT "ST SEG ANALYSIS"
4830 PRINT
4840 ED=(YBASE-YSTO)/100
4850 IF FR(YAR)=0 THEN 4860 ELSE 4870
4860 LOCATE 3,20:PRINT "UNABLE TO DETERMINE ST SEG ELEV/DEP":GOTO 4900
4870 PRINT"YMF(ST)="YMF,"FR(ST)="FR(YAR),"YSTO="YSTO,"YBASE="YBASE,"ST SEG(E/D)=
"ED"mm"
4880 IF ED>.1 THEN ST=1:PRINT "ST SEG ELEVATED":GOTO 4900
4890 IF ED<-.5 THEN ST=2:PRINT "ST SEG DEPRESSED"
4900 PRINT
4910 PRINT
4920 PRINT "ECG RATE"
4930 PRINT
4940 '***** DETERMINE ECG RATE *****
4950 IF 0<F(1) AND 0<F(2) THEN TC(1)=F(2)-F(1):TS=1:PRINT "TC(1)="TC(1)*TF"secs"
4960 IF 0<F(2) AND 0<F(3) THEN TC(2)=F(3)-F(2):TS=2:PRINT "TC(2)="TC(2)*TF"secs"
4970 IF 0<F(3) AND 0<F(4) THEN TC(3)=F(4)-F(3):TS=3:PRINT "TC(3)="TC(3)*TF"secs"
4980 IF 0<F(4) AND 0<F(5) THEN TC(4)=F(5)-F(4):TS=4:PRINT "TC(4)="TC(4)*TF"secs"
4990 IF 0<F(5) AND 0<F(6) THEN TC(5)=F(6)-F(5):TS=5:PRINT "TC(5)="TC(5)*TF"secs"
5000 IF 0<F(6) AND 0<F(7) THEN TC(6)=F(7)-F(6):TS=6:PRINT "TC(6)="TC(6)*TF"secs"
5010 IF 0<F(7) AND 0<F(8) THEN TC(7)=F(8)-F(7):TS=7:PRINT "TC(7)="TC(7)*TF"secs"
5020 '***** DETERMINE ECG RHYTHM *****
```

```
5030 FOR I=1 TO 7
5040 IF TC(MAX)<TC(I) THEN 5050 ELSE 5060
5050 TC(MAX)=TC(I)
5060 NEXT I
5070 LET TC(MIN)=200
5080 FOR I= 1 TO 7
5090 IF TC(I)<TC(MIN) THEN 5100 ELSE 5120
5100 IF TC(I)=0 THEN 5120
5110 TC(MIN)=TC(I)
5120 NEXT I
5130 TCAV=(TC(1)+TC(2)+TC(3)+TC(4)+TC(5)+TC(6)+TC(7))/TS:PRINT "TC(AV)="TCAV*TF"
secs"
5140 PRINT
5150 E=6000/TCAV:PRINT "ECG RATE="E"BPM"
5160 IF E >55 AND E<90 THEN ECG=1:REM ECG RATE IS NORMAL
5170 IF E<55 THEN ECG=2:REM ECG RATE IS SLOW
5180 IF E>90 THEN ECG=3:REM ECG RATE IS FAST
5190 LOCATE 12,30
5200 FOR I=2 TO 8
5210 IF O<F(I) AND O<F(I-1) THEN 5220 ELSE 5230
5220 NEXT I
5230 LET J=I-1
5240 LET CNT3=0
5250 FOR I=2 TO J-1
5260 IF ABS(TC(I)-TC(I-1))>=4  THEN 5270 ELSE 5280
5270 CNT3=CNT3+1
5280 NEXT I
5290 FOR I=2 TO J-1
5300 IF ABS(TC(I)-TC(I-1))>=8  THEN 5310 ELSE 5320
5310 CNT4=CNT4+1
5320 NEXT I
5330 LOCATE 16,32:PRINT"CNT3="CNT3,"CNT4="CNT4
5340 IF CNT3>=3 THEN 5350 ELSE 5390
5350 IF 1>=CNT4 THEN 5360 ELSE 5370
5360 ER=2:LOCATE 20,28:PRINT "ECG RHYTHM SLIGHTLY IRREGULAR":GOTO 5440
5370 IF CNT4>1 THEN 5380 ELSE 5390
5380 ER=3:LOCATE 20,28:PRINT"ECG RHYTHM VERY IRREGULAR":GOTO 5440
5390 IF (TC(MAX)-TCAV)>=30 THEN 5380
5400 IF (TCAV-TC(MIN))>=30 THEN 5380
5410 IF (TC(MAX)-TCAV)>=20 THEN 5360
5420 IF (TCAV-TC(MIN))>=20 THEN 5360
5430 ER=1:LOCATE 20,28:PRINT "ECG RHYTHM REGULAR"
5440 LOCATE 23,18:PRINT"C=CONT"
5450 LOCATE 23,36:PRINT"M=MENU"
5460 LOCATE 23,54:PRINT"Q=QUIT"
5470 F$=INPUT$(1)
5480 IF F$="C" OR F$="c" THEN 5510
5490 IF F$="M" OR F$="m" THEN 30
5500 IF F$="Q" OR F$="q" THEN 5990 ELSE BEEP:GOTO 5440
5510 CLS
5520 '***** NORMALITY CRITERIA TABLES *****
5530 IF .05<(P(N)-Z)*AF AND (P(N)-Z)*AF<.25 THEN 5540 ELSE LOCATE 4,26:PRINT"P W
AVE AMP ABNORMAL":GOSUB 5670
5540 IF .06<TP*TF AND TP*TF<.12 THEN 5550 ELSE LOCATE 5,26:PRINT "P WAVE DURATIO
N ABNORMAL":GOSUB 5670
5550 IF -.25<(Q(N)-Z)*AF AND (Q(N)-Z)*AF<-.05  THEN 5560 ELSE LOCATE 6,26:PRINT
"Q WAVE AMP ABNORMAL":GOSUB 5670
5560 IF .01<TQ*TF AND TQ*TF<.03 THEN 5570 ELSE LOCATE 7,26:PRINT "Q WAVE DURATIO
N ABNORMAL":GOSUB 5670
```

```
5570 IF 1 <(R(N)-Z)*AF AND (R(N)-Z)*AF<1.6 THEN 5580 ELSE LOCATE 8,26:PRINT "R W
AVE AMP ABNORMAL":GOSUB 5670
5580 IF .02<TR*TF AND TR*TF<.06 THEN 5590 ELSE LOCATE 9,26:PRINT "R WAVE DURATIO
N ABNORMAL":GOSUB 5670
5590 IF -.3<(S(N)-Z)*AF AND (S(N)-Z)*AF <-.1 THEN 5600 ELSE LOCATE 10,26:PRINT"S
 WAVE AMP ABNORMAL":GOSUB 5670
5600 IF .02<TS*TF AND TS*TF<.04 THEN 5610 ELSE LOCATE 11,26:PRINT "S WAVE DURATI
ON ABNORMAL":GOSUB 5670
5610 IF .15 <(T(N)-Z)*AF AND (T(N)-Z)*AF<.45 THEN 5620 ELSE LOCATE 12,26:PRINT "
T WAVE AMP ABNORMAL":GOSUB 5670
5620 IF .16<TT*TF AND TT*TF<.26 THEN 5630 ELSE LOCATE 13,26:PRINT "T WAVE DURATI
ON ABNORMAL":GOSUB 5670
5630 IF .64<TC*TF AND TC*TF<1.04 THEN 5640 ELSE LOCATE 14,26:PRINT "WAVE CYCLE T
IME ABNORMAL" :GOSUB 5670
5640 IF QQ=1 THEN GOTO 5690
5650 LOCATE 16,26:PRINT "ECG WAVE NORMAL"
5660 GOTO 5690
5670 LET QQ=1:LOCATE 16,26:PRINT "ECG WAVE ABNORMAL"
5680 RETURN
5690 LOCATE 23,18:PRINT"C=CONT"
5700 LOCATE 23,36:PRINT"M=MENU"
5710 LOCATE 23,54:PRINT"Q=QUIT"
5720 F$=INPUT$(1)
5730 IF F$="C" OR F$="c" THEN 5760
5740 IF F$="M" OR F$="m" THEN 30
5750 IF F$="Q" OR F$="q" THEN 5990 ELSE BEEP:GOTO 5690
5760 CHAIN"DC.BAS",20,ALL
5770 LOCATE 23,20:PRINT"D=DISPLAY WAVE"
5780 LOCATE 23,40:PRINT"M=MENU"
5790 LOCATE 23,54:PRINT"Q=QUIT"
5800 F$=INPUT$(1)
5810 IF F$="M" OR F$="m" THEN 30
5820 IF F$="D" OR F$="d" THEN 5840
5830 IF F$="Q" OR F$="q" THEN 5990 ELSE BEEP:GOTO 5780
5840 '***** DISPLAY ECG WAVE *****
5850 CLS
5860 SCREEN 2
5870 OPEN "I",#1,A$
5880 FOR I= 1 TO 599
5890 INPUT #1,X,Y
5900 LET X(I+1)=X
5910 LET Y(I+1)=150+(Y-YBASE)/15
5920 LINE (X(I+1),Y(I+1))-(X(I),Y(I))
5930 NEXT I
5940 LOCATE 2,24:PRINT"ECG RECORD NAME-"A$
5950 LOCATE 23,24:PRINT "PRESS ANY KEY TO RETURN TO MENU"
5960 ANS$=INPUT$(1)
5970 CLS:SCREEN 0
5980 GOTO 30
5990 '***** QUIT *****
6000 CLS:SCREEN 1:LOCATE 13,15:PRINT "GOODBYE !":BEEP
6010 FOR I= 1 TO 8000:NEXT I
6020 LOCATE 1,1
6030 SCREEN 2
6040 SCREEN 0
6050 END
```

(DC.BAS)

```
10 REM DISEASE CLASSIFICATION RULES
15 CLS:CHAIN"DAT.BAS",31,ALL
20 CLS:GOTO 30
25 LOCATE 12,1:LIST 30-48
30 'RULE FOR ABNORMAL CONDITION 1(COMPLETE HEART BLOCK)
40 IF E=2 THEN 60 'ECG RATE IS SLOW
50 GOTO 90
60 PRINT "COMPLETE HEART BLOCK"
70 DC=1
75 LOCATE 12,1:LIST 90-128
90 'RULE FOR ABNORMAL CONDITION 2(RIGHT ATRIAL HYPERTROPHY)
100 IF (P(N)-Z)*AF>.25 AND TP*TF<.06 THEN 140'P PEAK IS TALL & SLENDER
110 IF ST=2 THEN 140'ST SEG IS DEPRESSED
120 IF (T(N)-Z)*AF<0 THEN 140'T WAVE IS INVERTED
130 GOTO 160
140 PRINT "RIGHT ATRIAL HYPERTROPHY"
150 DC=2
155 LOCATE 12,1:LIST 160-188
160 'RULE FOR ABNORMAL CONDITION 3(LEFT ATRIAL HYPERTROPHY)
170 IF (P(N)-Z)*AF>.25 AND TP*TF>.1 THEN 200'P PEAK TALL & BROAD
180 IF ST=2 THEN 200'ST SEG DEPRESSED
190 GOTO 220
200 PRINT "LEFT ATRIAL HYPERTROPHY"
210 DC=3
215 LOCATE 12,1:LIST 220-248
220 'RULE FOR ABNORMAL CONDITION 4(NODAL ESCAPE)
230 IF E=2 THEN 260'ECG RATE IS SLOW
240 IF ER=2 THEN 260'ECG RHYTHM IS SLIGHTLY IRREGULAR
250 GOTO 280
260 PRINT "NODAL ESCAPE"
270 DC=4
275 LOCATE 12,1:LIST 280-308
280 'RULE FOR ABNORMAL CONDITION 5(HYPERKALAEMIA)
290 IF (T(N)-Z)*AF>.6 AND TT*TF<.16 THEN 320'T WAVE TALL AND SLENDER
300 IF QRS*TF>.15 THEN 320'QRS IS PROLONGED
310 GOTO 340
320 PRINT "HYPERKALAEMIA"
330 DC=5
335 LOCATE 12,1:LIST 340-368
340 'RULE FOR ABNORMAL CONDITION 6(ATRIAL TACHYCARDIA)
350 IF E=3 THEN 380'ECG RATE IS FAST
360 IF(P(N)-Z)*AF<0 THEN 380'P WAVE IS INVERTED
370 GOTO 400
380 PRINT "ATRIAL TACHYCARDIA"
390 DC=6
395 LOCATE 12,1:LIST 400-428
400 'RULE FOR ABNORMAL CONDITION 7(MYOCARDIAL INFARCTION)
410 IF (Q(N)-Z)*AF>.3 OR (Q(N)-Z)*AF<.1 THEN 460'Q WAVE IS ABNORMAL
420 IF ST=1 THEN 460'ST SEG IS ELEVATED
430 IF QRS>.15 THEN 460
440 IF QT>.4 THEN 460
450 GOTO 480
```

(DC.BAS)

```
10 REM DISEASE CLASSIFICATION RULES
15 CLS:CHAIN"DAT.BAS",31,ALL
20 CLS:GOTO 30
25 LOCATE 12,1:LIST 30-48
30 'RULE FOR ABNORMAL CONDITION 1(COMPLETE HEART BLOCK)
40 IF E=2 THEN 60 'ECG RATE IS SLOW
50 GOTO 90
60 PRINT "COMPLETE HEART BLOCK"
70 DC=1
75 LOCATE 12,1:LIST 90-128
90 'RULE FOR ABNORMAL CONDITION 2(RIGHT ATRIAL HYPERTROPHY)
100 IF (P(N)-Z)*AF>.25 AND TP*TF<.06 THEN 140'P PEAK IS TALL & SLENDER
110 IF ST=2 THEN 140'ST SEG IS DEPRESSED
120 IF (T(N)-Z)*AF<0 THEN 140'T WAVE IS INVERTED
130 GOTO 160
140 PRINT "RIGHT ATRIAL HYPERTROPHY"
150 DC=2
155 LOCATE 12,1:LIST 160-188
160 'RULE FOR ABNORMAL CONDITION 3(LEFT ATRIAL HYPERTROPHY)
170 IF (P(N)-Z)*AF>.25 AND TP*TF>.1 THEN 200'P PEAK TALL & BROAD
180 IF ST=2 THEN 200'ST SEG DEPRESSED
190 GOTO 220
200 PRINT "LEFT ATRIAL HYPERTROPHY"
210 DC=3
215 LOCATE 12,1:LIST 220-248
220 'RULE FOR ABNORMAL CONDITION 4(NODAL ESCAPE)
230 IF E=2 THEN 260'ECG RATE IS SLOW
240 IF ER=2 THEN 260'ECG RHYTHM IS SLIGHTLY IRREGULAR
250 GOTO 280
260 PRINT "NODAL ESCAPE"
270 DC=4
275 LOCATE 12,1:LIST 280-308
280 'RULE FOR ABNORMAL CONDITION 5(HYPERKALAEMIA)
290 IF (T(N)-Z)*AF>.6 AND TT*TF<.16 THEN 320'T WAVE TALL AND SLENDER
300 IF QRS*TF>.15 THEN 320'QRS IS PROLONGED
310 GOTO 340
320 PRINT "HYPERKALAEMIA"
330 DC=5
335 LOCATE 12,1:LIST 340-368
340 'RULE FOR ABNORMAL CONDITION 6(ATRIAL TACHYCARDIA)
350 IF E=3 THEN 380'ECG RATE IS FAST
360 IF(P(N)-Z)*AF<0 THEN 380'P WAVE IS INVERTED
370 GOTO 400
380 PRINT "ATRIAL TACHYCARDIA"
390 DC=6
395 LOCATE 12,1:LIST 400-428
400 'RULE FOR ABNORMAL CONDITION 7(MYOCARDIAL INFARCTION)
410 IF (Q(N)-Z)*AF>.3 OR (Q(N)-Z)*AF<.1 THEN 460'Q WAVE IS ABNORMAL
420 IF ST=1 THEN 460'ST SEG IS ELEVATED
430 IF QRS>.15 THEN 460
440 IF QT>.4 THEN 460
450 GOTO 480
```

```
60 PRINT "MYOCARDIAL INFARCTION"
70 DC=7
75 LOCATE 12,1:LIST 480-508
80 'RULE FOR ABNORMAL CONDITIN 8(LEFT VENTRICULAR HYPERTROPHY)
90 IF ST=2 AND (T(N)-Z)*AF<0 THEN 520'ST SEG DEPRESSED & T WAVE INVERTED
00 IF QRS>.12 OR QRS<.1 THEN 520'QRS PROLONGED
10 GOTO 540
20 PRINT "LEFT VENTRICULAR HYPERTROPHY"
30 DC=8
35 LOCATE 12,1:LIST 540-578
40 'RULE FOR ABNORMAL CONDITION 9(RIGHT VENTRICULAR HYPERTROPHY)
50 IF (P(N)-Z)*AF>.25 AND (T(N)-Z)*AF<0 THEN 590'P PEAK TALL & T INVERTED
60 IF (R(N)-Z)*AF.1.25 AND (T(N)-Z)*AF<0 THEN 590'R PEAK TALL & T INVERTED
70 IF ST=2 THEN 590'ST SEG DEPRESSED
80 GOTO 610
90 PRINT "RIGHT VENTRICULAR HYPERTROPHY"
00 DC=9
05 LOCATE 12,1:LIST 610-628
10 'RULE FOR ABNORMAL CONDITION 10(ATRIAL FIBRILLATION)
20 IF ER=3 THEN 640'ECG RHYTHM VERY IRREGULAR
30 GOTO 670
40 PRINT "ATRIAL FIBRILLATION"
50 DC=10
65 LOCATE 12,1:LIST 670-688
70 'RULE FOR ABNORMAL CONDITION 11
90 GOTO 730
10 DC=11
25 LOCATE 12,1:LIST 730-748
30 'RULE FOR ABNORMAL CONDITION 12
70 DC=12
000 IF DC=0 THEN 1010 ELSE 1020
010 CLS:LOCATE 12,28:PRINT"ABNORMAL CONDITION NOT IDENTIFIED"
020 CHAIN"DAT.BAS",8020
```