

Design a Simple Model of Electrocardiograph

B. Z. Shakhreet

Department of Diagnostic Radiology, Faculty of Applied Medical Sciences, KAU, Jeddah, KSA
Tel: +966582958803, email: bshakhreet@yahoo.com

Abstract: The electrocardiograph is an electronic instrument used to produce a written record of the electrical activity of the heart. The electrical waveform produced by the heart is called an electrocardiogram or ECG (sometimes EKG after the German spelling). The various features of the ECG can be related to the pumping activity of the heart and is thus used in the diagnosis of the heart disease.

The electrocardiograph system described in this module is a simplified one, but it will perform the same basic functions as a more sophisticated commercial instrument. It has been designed to demonstrate the underlying principles of electrocardiograph operation in terms of the functions of individual stages and their interrelationships in the system. Although the simplified version may not include special features found on more complex commercial instruments, an understanding of the operating principles of this model should help you in properly using commercial instruments and in understanding its operation and maintenance manual.

Keywords: ECG, Cardiac, Heart, Electric circuit.

I. INTRODUCTION

The electrical information – in the form of an electrocardiogram (ECG or EKG from the German spelling) – can be correlated to the mechanical activity of the heart and is used by the cardiologist to determine any malfunctions. In addition to its use in diagnosis, the electrocardiograph is also essential for monitoring the heart activity of patients who are recovering from heart attacks or who have undergone heart surgery.

An understanding of cardiovascular physiology, proper ECG measurement techniques and the operation and maintenance of the electrocardiograph is thus essential for the biomedical equipment technician.

An electrocardiogram (called ECG or EKG for short) is a recording of the naturally occurring rhythmic activity of the heart. This electrical activity of the heart is based on the ability of the excitable muscle tissue (such as the heart muscle or myocardium) to change rapidly its membrane permeability to Na^+ and K^+ ions. When these ions move across the cell membrane, a varying electric field resulted that is recorded as electrical activity of the heart.

After the onset of “electrical depolarization”, the cardiac muscle changed from its relaxed (or diastolic) to its contractile (or systolic) phase. The return from contraction to relaxation occurs after the “electrical repolarization”.

The normal heart rhythm is established by a specialized bundle of neuromuscular tissue usually called “the pacemaker” or “the sinoatrial” (SA) node of the heart (see Figure 1). Electrical impulses are generated spontaneously by this pacemaker, which initiates in turn the heart cycle. At the onset of the heart cycle, impulses from the SA node induce the right atrium to depolarize. This depolarization

spreads across the atrium causing the atrium to contract forces blood into the ventricles. The ventricular contraction phase of the heart cycle is brought about by depolarization of the ventricles through the “atrioventricular” (AV) node and the Purkinje system. The Purkinje system is a specialized conduction system bringing impulses to the ventricular muscle from the SA node. In addition, the Purkinje system provides a delay time allowing the atria to pump blood into the ventricles before ventricular contraction. This impulse conduction system permits the ventricles to be depolarized in a relatively short time. If the heart relied on impulse conduction through ventricular musculature, total conduction would not occur in a short interval due to long conduction delay of the muscle. Impulse speed through the Purkinje system is much faster than through the cardiac muscle itself.

The heart goes through a periodic sequence of electrical depolarizations and repolarizations which initiate the mechanical events of pumping blood. Mechanically, the phases of the Heart are divided as two phases, diastole and systole. During diastole both atria contract emptying blood into the ventricles, and during systole the ventricles contract.

In complex commercial instruments, Metal electrodes in the contact with the skin surface are used to pickup weak ECG signal which are then amplified and displayed by an oscilloscope and/or strip chart recorder.

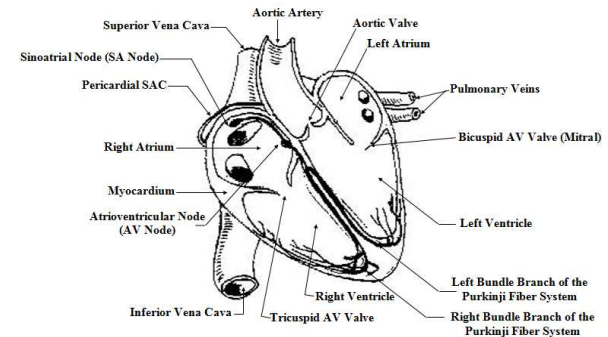


Figure 1 A schematic diagram of a longitudinal section of the human heart showing the right and left atria and ventricles, the SA node, the AV node and the Purkinji system.

In 17th and 18th Centuries, many other investigators have also studied ECG where the harnessing of electricity, observations of its effects on animal tissues and the discovery of ‘animal electricity’ was established.

In ECG, one cardiac signal consists of the P-QRS-T waves as seen in Figure 2. The plurality of the clinically

useful information in ECG is found in the intervals and amplitudes defined by its characteristics (feature wave peaks and time durations). The improvement of rapid and accurate methods for automatic ECG feature extraction is of main importance, particularly for the examination of long recordings.^[1]

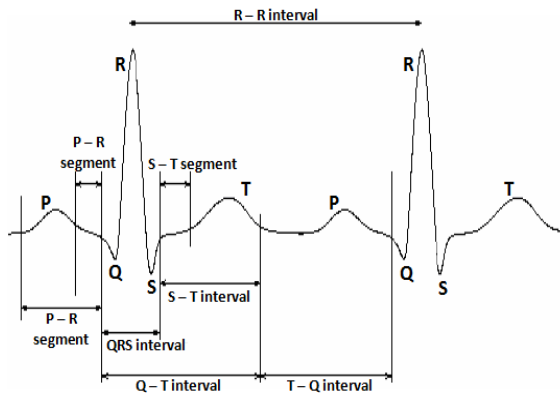


Figure 2 A Sample ECG Signal showing P-QRS-T Wave.

The ECG characteristic extraction system provides essential characteristics (intervals and amplitudes) to be used in subsequent automatic analysis. Currently, detection of these characteristics done and number of techniques has been proposed.^[2,3,4]

Electrocardiogram is particularly authentic for patient observation and diagnosis. The extracted characteristic from the ECG signal plays a vital in diagnosing the cardiac problems and diseases. The most and main importance is to develop a quick and accurate methods for automatic ECG feature extraction. So, it is necessary that the characteristic extraction system carries out accurately. The objective of characteristic extraction is to find as few particulars as possible within ECG signal that would allow successful abnormality detection and efficient predictions.

Recently, several studies and algorithms have been developed for the exertion of classifying and analyzing the ECG signal. The sorting or classifying method proposed during the last decade includes Fuzzy Logic methods, digital signal analysis, Hidden Markov Model, Artificial Neural Network, Support Vector Machines, Genetic Algorithm, Self-Organizing Map, Bayesian and other method with each approach exhibiting its own disadvantages and advantages. This paper provides a new simple designation and operation of ECG monitor system. In addition, the individual circuit stages are examined through their input-output characteristics.

Early, ECG characteristic extraction studied and lots of transformations as well as and advanced techniques proposed for accurate and fast ECG feature extraction.

A characteristic extraction method using support vector machines and wavelet transform was proposed.^[5] A new process to the characteristic extraction for credible heart rhythm recognition presented. The characteristic vector of ECG data achieved where two diverse feature extraction methods applied. Using the wavelet transform, the

coefficients of the transform as the features of each ECG segment can be extracted.

An algorithm, based on the wavelet transform, for feature extraction from ECG signal and recognition of abnormal heartbeats presented.^[6] A method for choosing an optimal mother wavelet from a set of orthogonal and bi-orthogonal wavelet filter bank by means of the best correlation with the ECG signal developed. The first step of approached is to remove noise of the ECG signal by a soft or hard threshold with limitation of 99.99 reconstructs ability and then each PQRST cycle is decomposed into a coefficients vector by the optimal wavelet function. The coefficients, approximations of the last scale level and the details of the all levels, used for the ECG analyzed. The coefficients divided of each cycle into three segments that are related to T-wave, QRS complex P-wave. The summation of the values from these segments provided the feature vectors of single cycles.

II. ELECTRONIC COMPONENTS AND APPARATUS

This project involves the assembly, calibration and operation of the ECG Monitor system. The ECG Monitor includes both an oscilloscope and audio output display.

In the first part, the oscilloscope monitor assembled, calibrated and operated. The techniques of zeroing the differential amplifier and using the finger pad electrodes presented in this section and should be followed carefully. With a suitable cardiac input signal, the oscilloscope display used to study the ECG waveform characteristics. The second part adds the audio system consisting of the level detector, monostable multivibrator, UJT oscillator and power amplifier. An initial check is made on the operation of the audio system before it is connected to the output of the differential amplifier. The differences of triggering the audio oscillator directly by the cardiac waveform or by means of a multivibrator intermediary stage are studied. Finally, a heart rate measurement is made using the audio signal.

On the other hand, the electrocardiograph system used to obtain a written record of the electrical activity of the heart (an electrocardiogram). The potential picked up by the skin electrodes (Finger Pad) is on order of 1 millivolt in amplitude. The ECG therefore calibrated so that a 1 millivolt input signal corresponds to a 1 cm deflection on the strip-chart recorder. In addition to measuring the amplitude of the ECG waveform, the heart rate in beats per minute can be obtained by measuring the time between successive heartbeats.

A. Materials and Equipments

These materials and equipments used to construct a project:

- 1) Power Supply: $\pm 12V @ 500mA$.
- 2) ECG Input Switch: with circuits for input coupling, balancing and 1MV standard.
- 3) Differential Amplifier: breadboard or equivalent with 3 type 741 integrated circuit operational amplifiers,

3-10 kΩ Offset potentiometers and 1-1.5 kΩ Balanced potentiometer.

4) Power Amplifier: breadboard or equivalent with type 741 integrated circuit operational amplifier, 5 kΩ Offset potentiometer, 1MΩ Amplitude potentiometer and 1 each MJE3055 (NPN) and MJE2955 (PNP) power transistors.

5) Voltage Level Detector: breadboard or equivalent with 1 type 741 integrated circuit operational amplifier and 10 kΩ Offset potentiometer.

6) Monostable Multivibrator: breadboard or equivalent with 1 type 741 integrated circuit operational amplifier and three type 1N914 or equivalent Diode.

7) UJT Oscillator: breadboard or equivalent with 1 type 2N5088 NPN transistor and 2N2160 unijunction transistor.

8) Finger Pad Electrodes.

9) Oscilloscope: vertical sensitivity = 5mV/Div.

10) Ruler: metric with mm divisions.

11) Strip-Chart Recorder: basic recorder including only pen writing motor and chart paper drive system.

12) The component parts listed in Table 1.

Table 1 List of components part used in the ECG circuit

Number of Pieces	Values	Power	Type
6	1 K	0.5 W	Resistor
4	100 K	0.5 W	Resistor
3	47 K	0.5 W	Resistor
1	1 M	0.5 W	Resistor
1	220 Ω	0.5 W	Resistor
1	10 K	0.5 W	Resistor
2	15 Ω	0.5 W	Resistor
3	0.01 μF		Capacitor
1	0.1 μF		Capacitor
1	0.02 μF		Capacitor
3	1N914		Diode
1	2N2160		Unijunction Transistor
1	2N5088		NPN Transistor
6	741		OP-AMP
	22AWG		Solid Wire

B. Methods and Procedures

1. ECG OSCILLOSCOPE MONITOR ASSEMBLY

All the components inserted in the breadboard according to the schematic in Figure 3 and Figure 4. The ECG Input Switch were mechanically sliced alongside the Power Supply and locked together with the latch.

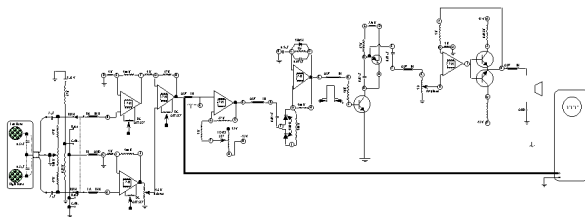


Figure 3 The Schematic Diagram Analysis.

On the other hand, four tablespoons full of salt added to a cup of water and stir until the salt well mixed with water. The sponges removed from the holders and immersed in the salt-water solution. After that, the sponges squeezed to

eliminate any excess water and it placed back in the holders. Signal cable plugged into the Inputs of ECG Switch.

Any way, a rear power cable was inserted into power supply. A signal cables connected between Inputs A and B and GND to the Outputs RL, RA and LA on the ECG Input Switch. The hardware pictorial arranged to represent the bread boarding of an operating system as seen in Figure 5.

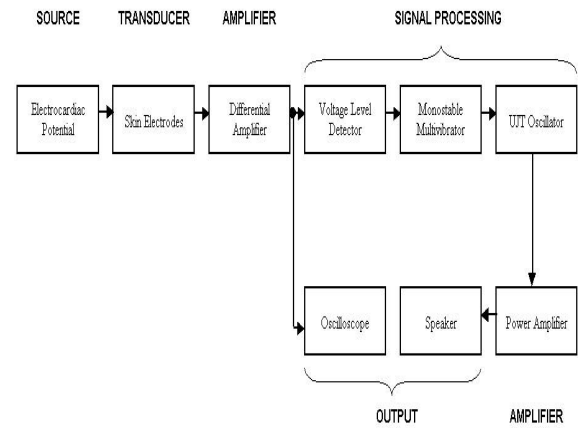


Figure 4 The Block Diagram Analysis.

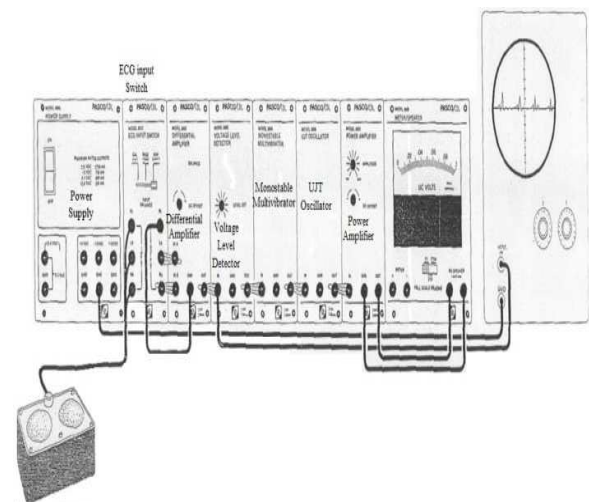


Figure 5 The hardware pictorial.

2. PRELIMINARY SET-UP:

Controls were sated as follows:

- a. Power Supply: switch is OFF.
- b. ECG Input Switch: switch (Base) is zero. Input balance is turned fully counterclockwise.
- c. Differential Amplifier: all controls turned fully counterclockwise.
- d. Oscilloscope: Use 1 Meg Probe → Scope input to DC → Vertical Sensitivity is 5mV/Div. → Horizontal Sweep is sated 5mS (not critical) → Trigger is Line → Ground Scope to GND jack on front panel of Power Supply → Set

ground reference on scope at center of screen.

Balancing The System:

For balancing the system, these procedures applied:

1. Power supply: power switch is turned to ON.
 2. ECG Input Switch: the switch is sated to Base (zero) position.
 3. Differential Amplifier:
 - a. Connect the scope probe to the spring point ① on the board (output of buffer amp A).
 - b. Adjust the output to ground level (within $\pm 5\text{mV}$) using the DC Offset control near buffer amp A.
 - c. Connect the scope probe to spring point ② on the board (output of buffer amp B).
 - d. Adjust the output to ground level (within $\pm 5\text{mV}$) using the DC Offset control near buffer amp B.
 - e. Connect the scope probe to spring point ③ on the board (output of Diff. Amp.).
 - f. Turn Balance control fully clockwise (front panel control).
 - g. Set scope vertical sensitivity to 50mV .
 - h. Adjust the output to ground level (within $\pm 10\text{mV}$) using DC Offset control on front panel.
 4. ECG Input Switch:
 - a. Set switch to RUN (Lead I) position. (Do not place hands on Finger Pad Electrodes at this time).
 - b. Measure the DC voltage difference at point's ② and ① on the Differential Amplifier board with the scope. Set the scope sensitivity to 1 Volt/Div .
 - c. Adjust the Input Balance on the ECG Input Switch until there is no difference in voltage between spring point's ② and ①.
 - d. Set the Switch to CALIB. (1 mV).
 5. Oscilloscope:
 - a. Attach the scope probe to the Output of the Differential Amplifier.
 - b. Set the vertical sensitivity of the oscilloscope to 5V/Div . Carefully turn the vertical sensitivity gain so that the 1 mV input signal gives exactly a deflection of 1 Div . on the oscilloscope.
 - c. Set the horizontal sweep on the scope to 0.5 sec/Div .
 6. Chart Recorder:
 - a. Place both hands on Fingertip Pad Electrodes. Make certain the two hands do not touch each other, as this will reduce the signal. There will be a tendency for the two thumbs to touch, therefore caution must be exercised. Turn on the Chart recorder.
 - b. Adjust the Amplitude and DC Offset controls on the power amplifier for best results on chart recorder. If the pen deflects too much to one side of the chart paper, adjust the balance control on the front panel of the differential amplifier to bring the pen back to the center position.
- 3. ECG STRIP-CHART MONITOR CALIBRATION AND OPERATION**
- In this section the Strip-Chart monitor will be used to observe the output signal of the differential amplifier.
- CALIBRATION:**
- a. Switch the ECG Switch to the 1mV calibrate position.
 - b. Adjust the amplitude control on the power amplifier to

produce a 1 cm deflection of the pen.

c. Turn on the paper drive and switch between the BASE (zero) and 1mV calibration positions several times. Stop the paper.

d. Check the amplitude of the trace for the desired 1 cm deflection. If this condition is not achieved, readjust the amplitude control on the power amplifier.

CHART SPEED CHECK:

The chart speed will be measured as follow these steps:

- a. Turn chart recorder ON.
- b. Using the sweep hand on a watch make a mark on the chart paper with a pen or pencil along the metal edge. At the end of 10 seconds make another mark and measure the distance between marks. Divide the measured distance by 10 to determine the paper speed in mm/Sec . Chart Speed = 24.8mm/Sec . The chart speed should be approximately 25 mm/Sec .

OPERATION:

- a. Turn the unit ON and have a subject place his/her hands on the finger pad electrodes.
- b. Adjust the amplitude and DC Offset controls on the power amplifier so that the trace is centered. (Setting may vary from subject to subject).
- c. Because finger pad electrodes are used in place of regular skin electrodes, the signal may be less than 1mV . Adjust the power amplifier amplitude control until a signal of approximately 15 mm is produced.

4. ECG OSCILLOSCOPE MONITOR OPERATION

In this section the oscilloscope monitor will be used to observe the output signal of the differential amplifier. The cardiac signal input to the differential amplifier is obtained from the Finger Pad Electrodes.

A standard skin electrodes placement for measuring cardiac potentials consists of electrodes placed on the right arm (RA), left arm (LA) and right leg (RL). This is referred to as the LEAD I configuration. The RA and LA connections are the inputs to the differential amplifier while the RL is the common or ground connection. The Finger Pad Electrodes act as the electrodes for the right arm (RA) and left arm (LA). A by-pass capacitor is connected from each electrode to a common line (RL) that is designated as ground. The capacitors serve as 60Hz filters.

ECG oscilloscope monitor operation is done through these steps:

1. Set the ECG Input Switch to the RUN (LEAD I) position and monitor the cardiac waveform on the oscilloscope.
2. Compare it with the waveform given in the Hardware pictorial.
3. Switch to the 1mV (CALIB.) position and back the RUN to check the calibration.
4. Compare the peak amplitude of the cardiac signal (QRS wave) with the 1mV reference level, and record the amplitude of the measured signal. (QRS Amplitude = 0.98mV).
5. There may be a lot of noise observed with the signal. This is 60Hz line voltage picked up through the subject acting as an antenna. By keeping the subject and

transducer away from near by AC lines and lights the noise will not be as great. Shielded cables will also cut down on 60Hz pick up.

5. ECG AUDIO MONITOR ASSEMBLY

The audio monitor system is built next by adding four more stages to the differential amplifier. The assembly procedures are:

1. Voltage Level Detector: insert the power cable into the differential amplifier.
 2. Mono stable Multi vibrator: insert the power cable into the voltage level detector.
 3. UJT Oscillator: insert the power cable into the mono stable multi vibrator. Then, connect a cable from the Input of the UJT oscillator to the Output of the mono stable multi vibrator.
 4. Power Amplifier: insert the power cable into the UJT oscillator. After that connect a cable from the Input of the power amplifier to the Output of the UJT oscillator.
 5. Function Generator: insert the power cable into the power amplifier. Connect a cable from the Output of the function generator to the Input of the mono stable multi vibrator.
 6. Meter / Speaker: connect a cable from one of the speaker input jacks to the Output of the power amplifier. Then connect a cable from the other speaker jack to GND on the power amplifier.
- #### 6. AUDIO SYSTEM CHECK
1. Turn the power ON.
 2. Function Generator Set-Up:
 - a. DC Offset: zero volts (GND level).
 - b. Amplitude: $5V_p/p$ (sym about GND).
 - c. Frequency: 1 Hz.
 - d. Waveform: square.
 3. A pulsed 1KHz signal should be heard.
 4. Measure the outputs of the mono stable multi vibrator, UJT oscillator and power amplifier. Compare them with the waveforms shown in the Hardware Pictorial.
 5. Adjust the power amplifier gain control to obtain a comfortable speaker volume.
 6. Remove the function generator from the system.
 7. Connect a cable from the Output of the differential amplifier to the Input of the voltage level detector.
 8. Connect a cable from the Output of the voltage level detector to the Input of the monostable multivibrator.

7. ECG AUDIO MONITOR OPERATION

ECG audio monitor operation is done through these steps:

1. Check the zero and balance settings on the differential amplifier.
2. Attach the scope to the Output of the differential amplifier.
3. Set the ECG Switch to RUN (LEAD I) and monitor the oscilloscope for a cardiac reading with a subject's hand placed on the Finger Pad Electrodes. NOTE: the subject should be sitting and refrain from moving around. Any slight movement will cause false triggering. This is due to the fact that we are monitoring very small signals.
4. If a cardiac signal is present, then adjust the voltage level detector until the cardiac signal triggers the audio oscillator circuits (monostable multivibrator, UJT

oscillator and power amplifier)

5. Count the number of audio pulses occurring in 15 seconds and multiply by four to get the heart rate in beats per minute.
6. Record the heartbeat rate below: HEARTBEAT RATE: 69 bpm.

III. RESULTS AND DISCUSSION

A. Recording

The cardiac potential in a human subject can now be detected and recorded. An alternate method of obtaining the ECG waveform is to use an electronic ECG simulator.

Switch the input selector to the RUN position. Turn on the Chart Recorder. Mark the paper to indicate the start of the recorded signal by quickly switching to the BASE position and then back to RUN. Then, continue to run the recorder for approximately 15 seconds, and then turn it off.

B. Analyzing the ECG

Measure the length of 10 beats on the chart paper and record the value. Length of 10 beats is 220 mm. Compute the heart beat rate using the formula:

$$\text{BEATS/MIN} = (\text{Chart Speed}/10 \text{ BEAT LENGTH}) \times 10 \text{ Beats} \times 60 \text{ SEC/MIN.}$$

In our experiment, the chart speed is 24.8 mm/sec. Then the heart rate per minute is about 68 bpm.

C. Interesting Experiments with the Electrocardiograph

While the subject is having the ECG taken, the subject should suddenly tense the muscles in the body. The electrical activity of the muscles will be recorded in the same way as the ECG and the result will be a waveform with a tremendous amount of noise and wandering baseline.

To produce as good an ECG as possible it is important that the subject be relaxed and there be a minimum of muscle activity. For this reason actual patients are frequently requested to lie down when an ECG is taken.

Again, while the ECG is being taken have the subject take a deep breath and hold the breath for about 10 seconds. Immediately afterwards have the subject completely exhale and hold this condition for 10 seconds. Compare the two ECGs. It will be noted that the inhale ECG is smaller in amplitude than the exhale ECG.

The reason for this situation is straightforward. As the lungs expand or collapse, the position of the heart is slightly changed. As shown in Figure 6, the heart is a dipole. As the angle of this dipole, with respect to a line drawn between the two shoulders, changes from being perpendicular to the line between the shoulders to parallel to the same line, the signal recorded on the arms will go from a minimum to a maximum.

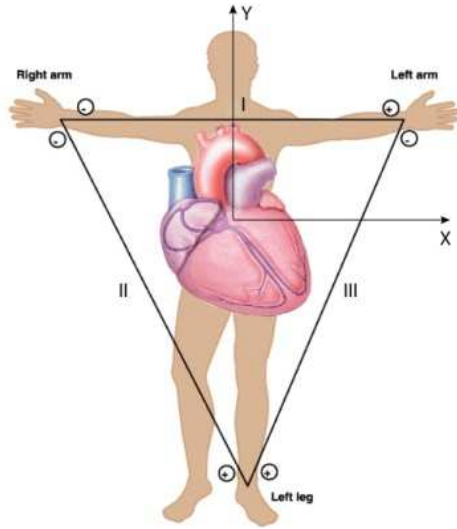


Figure 6 System of limb lead ECG showing the heart dipole and how it projects onto each of the three limb potentials.

AUTHOR'S PROFILE



Bassam Zuhdi Shakhreet, Jordanian graduated from Universiti Sains Malaysia since 2006. He hold PhD in Medical Physics and a certificate from Saudi Commission for Health Specialist as senior specialist in radiology technology "Medical Physics". Right now, He is working in King Abdulaziz University, Faculty of Applied Medical Sciences, Department of Diagnostic Radiology (Jeddah - Saudi Arabia) as

assistant Prof.

Address: Department of Diagnostic radiology, Faculty of Applied Medical Sciences, King Abdulaziz University, P.O. Box 80324, Jeddah 21589, Saudi Arabia.

Email: bshakhreet@yahoo.com, bzshakhreet@kau.edu.sa

IV. CONCLUSION

For this design especially, the built system can be a very useful tool for teaching heart beat abnormalities for medical student in a modern and attractive way.

A comprehensive library of many abnormalities in the heart signals was recorded and can be demonstrated to the students in the medical physics lab.

The amplitude of the ECG wave is affected by the electrical resistance of the pathways to the distant electrodes.

The recorded voltages represent only the difference between the influences of simultaneous and opposite electrical dipoles in a complicated pattern.

REFERENCES

- [1] S. Z. Mahmoodabadi, A. Ahmadian, and M. D. Abolhasani, "ECG Feature Extraction using Daubechies Wavelets," Proceedings of the fifth IASTED International conference on Visualization, Imaging and Image Processing, 2005, pp. 343-348.
- [2] Juan Pablo Martínez, Rute Almeida, Salvador Olmos, Ana Paula Rocha, and Pablo Laguna, "A Wavelet-Based ECG Delineator: Evaluation on Standard Databases," IEEE Transactions on Biomedical Engineering, 2004, Vol. 51, No. 4, pp. 570-581.
- [3] Krishna Prasad and J. S. Sahambi, "Classification of ECG Arrhythmias using Multi-Resolution Analysis and Neural Networks," IEEE Transactions on Biomedical Engineering, 2003, vol. 1, pp. 227-231.
- [4] Cuiwei Li, Chongxun Zheng, and Changfeng Tai, "Detection of ECG Characteristic Points using Wavelet Transforms," IEEE Transactions on Biomedical Engineering, 1995, Vol. 42, No. 1, pp. 21-28.
- [5] Qibin Zhao, and Liqing Zhan, "ECG Feature Extraction and Classification Using Wavelet Transform and Support Vector Machines," International Conference on Neural Networks and Brain, ICNN&B '05, 2005, vol. 2, pp. 1089-1092.
- [6] B. Castro, D. Kogan, and A. B. Geva, "ECG feature extraction using optimal mother wavelet," The 21st IEEE Convention of the Electrical and Electronic Engineers in Israel, 2000, pp. 346-350.