"I declare that I have read this report and in my opinion, it is suitable in term of scope and quality for the purpose of awarding a Bachelor Degree in Electronics Engineering (Industrial Electronic)"

LOW YIN FEN @ YVONNE
Lecturer
Faculty of Electronics and Computer Engineering (FKEKK)
National Technical University College of Malaysia (KUTKM)
Locked Bag 1200
Ayer Keroh, 75450 Malacca.

Signature : ______________________

Supervisor : MISS LOW YIN FEN

Date : 1/07/05

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PC-BASED PATIENT MONITORING SYSTEM; DEVELOPMENT OF ECG AMPLIFICATION CIRCUIT

KHAIRUL NIZAM BIN OTHMAN

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Kolej Universiti Teknikal Kebangsaan Malaysia

MARCH, 2005

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Name of Author : KHAIRUL NIZAM BIN OTHMAN

Date : ______________________________

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To my family and friends

Without whom, I am nothing...

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ABSTRACT

The Electrocardiograph (ECG) is a recording or display of the time-variant voltages generated by the electrical activity of the heart. This ECG waveform is analyzed by the cardiologist in diagnosis various diseases and conditions associated with the heart. This project concern with the recording and displaying of ECG waveform in real-time approach. The particular ECG bio-electric amplifier is designed and developed to interface with PC through parallel port. The scope of this project is focusing on the hardware part only. Three electrodes are connected to the human body, one with right arm, one with left arm and the other with right leg as a reference or ground to extract ECG signal from human body. The electrical signal appeared at the input of the ECG amplifier is typically less than 1 mV and it is essential to amplify the signal amplitude at least 100 times for further processing and to have significant voltages for use with the display device (oscilloscope or monitor). The problem of amplification the signal is that there is a lot of noise interference which appear at input from ac power lines, ambient signal and etc. The output signal from ECG amplifier will interface with PC via 8 bit analog ADC then display on the PC.

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ABSTRAK

Electrocardiograph (ECG) adalah merakamkan paparan masa-perubahan voltan yang dijanakan oleh aktiviti elektrik dalam jantung. Bentuk gelombang ECG dianalisa oleh ahli kardiologi dalam mengenalpasti pelbagai penyakit dan kondisi yang dihasilkan oleh jantung. Projek ini adalah menumpukan rakaman dan paparan yang oleh ECG dalam masa nyata. Penguat biologi ini direkabentuk dan dibangunkan kepada antaramuka komputer peribadi melalui peyambung selari. Tiga elektrod akan disambungkan ke badan manusia iaitu di bahagian lengan tangan kanan, lengan tangan kiri dan kaki kiri sebagai rujukan ke bumi bagi memisahkan isyarat badan manusia. Isyarat yang yang dihasilkan oleh badan biasanya kurang daripada 1mV dan ia mesti digandakan sekurang-kurangnya 100 kali untuk ke proses selanjutnya untuk voltan masukan yang digunakan oleh perkakasan (osiloskop atau monitor). Masalah penggandaan isyarat ini adalah terlalu banyak hingar dan ganguan yang dihasilkan oleh talian kuasa, isyarat ambian dan sebagainya. Keluaran isyarat dari penguat ECG akan diantaramukakan kepada komputer menerusi penukar isyarat analog ke digital.

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LIST OF SYMBOLS

V	-	Volt
dB	-	Decibel
s	-	Second
m	-	mili
M	-	Mega
Hz	-	Hertz
μA	-	micro ampere

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CHAPTER I

INTRODUCTION

1.1 The Electrocardiogram

An electrocardiogram (ECG) is a graphic tracing of the electric current generated by the heart muscle during a heartbeat. It provides information on the condition and performance of the heart. Electrocardiograms are made by applying electrodes to various parts of the body to lead off the tiny heart current to the recording instrument. The four extremities and the chest wall have become standard sites for applying the electrodes. Standardizing electrocardiograms makes it possible to compare them as taken from person to person and from time to time from the same person. The normal electrocardiogram shows typical upward and downward deflections that reflect the alternate contraction of the atria (the two upper chambers) and of the ventricles (the two lower chambers) of the heart.

The first upward deflection (refer Figure 1.1 of ECG waveform), P, is due to atrial contraction and is known as the atrial complex. The other deflections, Q, R, S,

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and T, are all due to the action of the ventricles and are known as the ventricular complexes. Any deviation from the norm in a particular electrocardiogram is indicative of a possible heart disorder. Information that can be obtained from an electrocardiogram includes whether the heart is enlarged and where the enlargement occurs, whether the heart action is irregular and where the irregularity originates, whether a coronary vessel is occluded and where the occlusion is located, and whether a slow rate is physiological or caused by heart block. The presence of high blood pressure, thyroid disease, and certain types of malnutrition may also be revealed by an electrocardiogram.

During the late 1960s, computerized ECG's came into use in many of the larger hospitals. This is involves array manipulation, analog processing, Boolean logic, and construction of a external drive circuit to provide visual alerts. This alert signal can also be used to drive audio signals. A typical single cardiac waveform of a normal heartbeat as it appears on electro-cardiograph charts is shown in Figure 1.1. The voltages produced represent pressures exerted by the heart muscles in one pumping cycle. It is one of the life signs monitored in many medical and intensive care procedures. Instrumentation is provided to alert medical staff to any changes detected in the cardiac function.

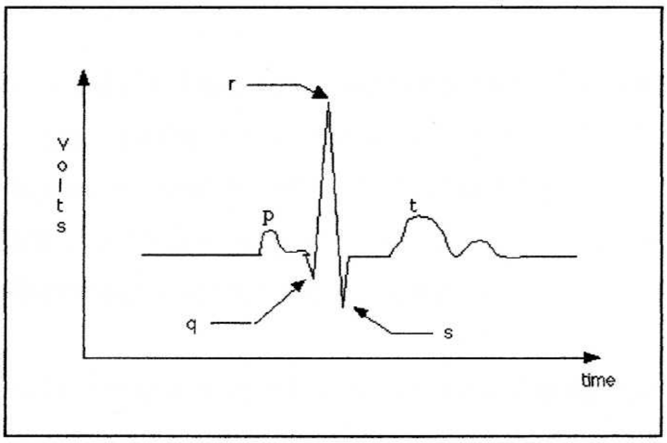

Figure 1.1: A Typical ECG Waveform

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1.2 The ECG waveform

An electrocardiogram is measurement of electrical activity of the heart (cardiac) muscle from the surface of the skin. As the heart performs its function of pumping blood through the circulatory system, a result of the action potentials responsible for the mechanical events within the heart is certain sequence of electrical events. In the resting state, cardiac muscle cells are 'polarized', with the inside of cell negatively charged with respect to its surroundings. The charge is created by different concentrations of ions such as potassium and sodium on either side of the cell membrane.

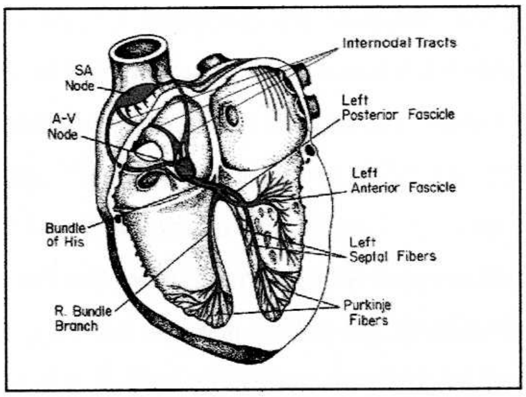

Figure 1.2: Locations of the nodes and bundles of the conduction system.

In response to certain stimuli, movement of these ions occurs, particularly a rapid inward movement of sodium. In this process, known as 'depolarization', rapid loss of internal negative potential results in an electrical signal. The mechanism of cell depolarization and repolarization is used by used by nerve cells to carry impulse and by muscle cells for triggering mechanical contractions.

There are certain cells in the heart capable of spontaneous depolarization. These cells are important in the generation of heart rhythm and exist in the sinoatrial (SA) node of the heart. Depolarization of the SA muscles causes them to contract and pump blood into the verticals, before depolarizing. The electrical signal the passes into the trioveticular (AV) node causing the ventricles to contract the pump blood into the pulmonary and systematic circulation. The ventricle muscles the repolarise again.

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1.3 Standard ECG Measurement

There are many ways in carrying out ECG monitoring. For example, ECG monitoring can be performed on a person when he or she is resting, sleeping, working or exercising. Each of this monitoring activity produces ECG signal that can be analysed to check for different kind of hard related disease complication. Recording duration for ECG monitoring can be carrying out for a few minutes, a few hours or event 24 hours depending on the situation.

Normal practice in ECG monitoring uses electrodes to detect the electrical signal generated from the heart beat. The number of electrodes used varies from 3 to 12 electrodes that are placed on different position of the body, depending on the type of signal to obtain. Usually 3 electrodes are sufficient for getting the basic ECG signal. For the purpose of this project only 3 electrodes are used.

Electrodes placement on the body to obtain accurate ECG signal is based on Einthoven's triangle law. The three adhesive electrodes are attached to the right arm, left arm and the left leg as shown in the figure 1.3. Lead I record the potential different between the left and the right arm, lead II between the right arm and the left leg and lead III between the left arm and the left leg. In other words, signal from lead one can be represented as I=II-III. Configurations of this leads are called bipolar limb leads because there measure the potential different between two limbs.

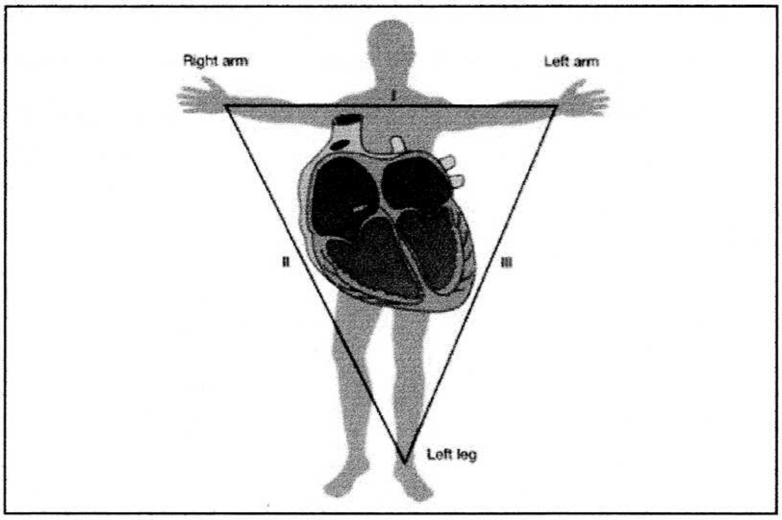

Figure 1.3: Einthoven's Triangle

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Electrodes are commonly placed on both wrists and the third one on the left ankle. Reason for placing the electrodes on the wrists rather than the forearms is because there is small different in potential between the upper arm and the wrists. Hence, a lead I signal recorded with electrodes on the wrists will differ with larger amplitude compared to lead I with electrodes placed on the forearms.

Contact between skin surface and electrodes could produce some resistance or impedance level. It is therefore important for the electrodes to be placed on the flat normal skin surface and with nobody hair or scar. This is because the presence of body hairs or others substances such as dead tissues could induce additional resistance and noise to the ECG signal.

Resistance due to contact between skin and electrodes can be reduced by proper placement of the electrodes on the skin surface. Besides this, abrasive skin prepping gel can be applied on the skin surface to increase the conductivity between the electrodes and skin. Conductive electrodes gel can be applied to the electrodes contact surface to improve conductivity and reduced impedance.

Electrical signals acquired from the electrodes are transferred to the amplification system through special leads wires. These leads wires are special as they have the property of low impedance compared to normal copper wires. Low impedance leads wire reduces unwanted noise generated into the original signals.

Lead wires connecting the electrodes to the amplifier inputs should be placed close together. This is to make sure that the loop areas formed between the lead wires are as small as possible in order to reduce magnetic interference. Magnetic interference is introduced due to the potential induced when there are two adjacent currents flowing in a loop. These currents form a conductive loop of changing magnetic flux density and are proportional to the area of the loop.

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1.4 Design Technical Background

1.4.1 ECG Sensor Requirements

The front end of an ECG sensor must be able to deal with the extremely weak nature of the signal it is measuring. Even the strongest ECG signal has a magnitude of less than 10mV, and furthermore the ECG signals have very low drive (very high output impedance). The requirements for a typical ECG sensor are as follow:

- Capability to sense low amplitude signals in the range of 0.05 -10mV
- Very high input impedance, > 5 MΩ
- Very low input leakage current, < 1 μA
- Flat frequency response of 0.05 - 100 Hz
- High Common Mode Rejection Ratio (CMRR)

1.4.2 Electrodes

Electrodes are used for sensing bioelectric potentials that are caused by muscle and nerve cells. ECG electrodes are generally of the direct-contact type. They work as transducers converting ionic flow from the body through an electrolyte into electron current and consequentially an electric potential able to be measured by the front end of the ECG system. These transducers, known as bare-metal or recessed electrodes, generally consist of a metal such as silver or stainless steel, with a jelly electrolyte that contains chloride and other ions (Figure 1.4).

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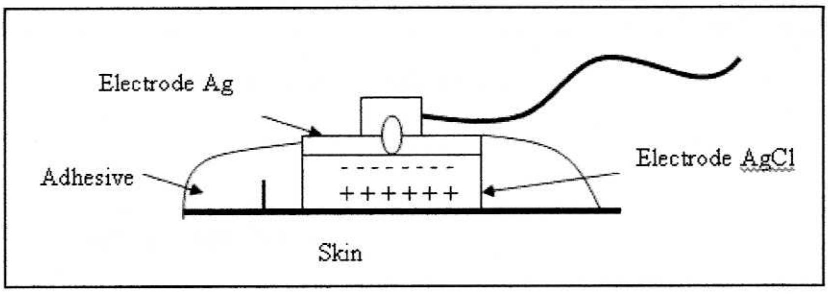

Figure 1.4: Recessed Electrode Structure

On the skin side of the electrode interface, conduction is from the drift of ions as the ECG waveform spreads throughout the body. On the metal side of the electrode, conduction results from metal ions dissolving or solidifying to maintain a chemical equilibrium using this or a similar chemical reaction:

$$Ag \leftrightarrow Ag^{+} + e^{-}$$

The result is a voltage drop across the electrode-electrolyte interface that varies depending on the electrical activity on the skin. The voltage between two electrodes is then the difference in the two half-cell potentials.

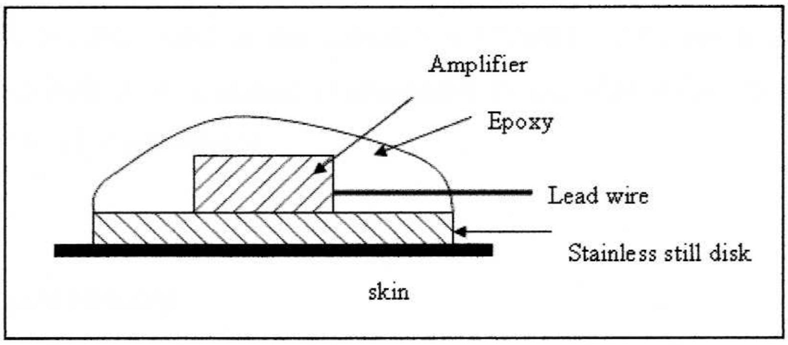

Figure 1.5: Dry Electrode Structure

Plain metal electrodes like stainless steel disks can be applied without a paste. The theory of operation is the same but the resistivity of the skin-electrode interface is much greater. They are useable when proper electrostatic shielding against

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interference is applied and the electrode is connected to an amplifier with very high input impedance, but the voltage measured will be considerably less than that obtained with an electrode utilizing an electrolyte.

1.4.3 Differential Amplifier

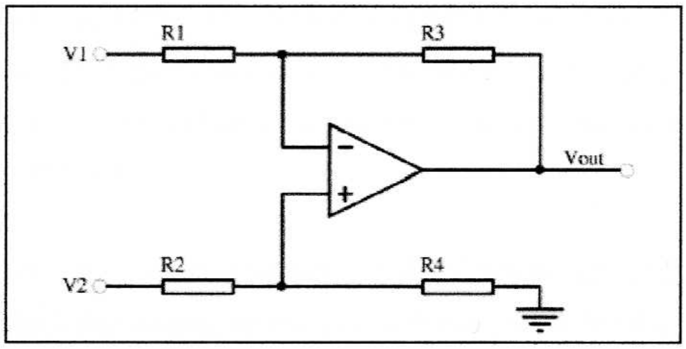

Figure 1.6: Differential Amplifier in ECG System

A normal differential amplifier in an ECG system works as shown in Figure 1.6. A lead of data is formed by the differential amplification of the voltage picked up from two electrodes on both wrists- A common ground exists between the two points when the third electrode is connected to the left ankle. The advantage offered by this topology is that of the high CMRR afforded by a differential amplifier- The differential amplifier used in the system has a CMRR of 90 which means noise common to both input channels is attenuated to less than 0.0001% of its input amplitude at the amplifiers output.

1.4.4 Signal Filtering

Removal of the undesirable noise requires filtering. Noise can be filtered through the use of analog circuitry or digital signal processing. The weak nature of the ECG signal and the noise affecting it requires that a range of filters to be implemented. A filter is a device that passes electric signals at certain frequencies or

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frequency ranges while preventing the passage of others. Filters are often used in electronic systems to emphasize signals in certain frequency ranges and reject signals in other frequency ranges. Bandpass, notch, low-pass, high-pass and all-pass are the five basic filter types.

The three approaches to implementing analog filters using circuitry are Active, Passive and Switched-Capacitor. The order of a filter is usually equal to the total number of capacitors and inductors in the circuit and represents the severity with which signals outside of the filter's pass-band will be attenuated. A higher order filter is desirable due to its greater ability to discriminate between signals at different frequencies, but does require an increased number of components and consequently an increase in cost and size.

Active filters are circuits that make use of amplifying units, especially operational amplifiers (op amps), as the active device in combination with some resistors and capacitors to provide an LRC-like filter performance at low frequencies. Active filters have high input impedances, low output impedances and are able to provide gain. They don't require inductors and as such are not hampered by the high tolerance and gain spacing of these devices. Through the use of low tolerance capacitors and resistors, good accuracy can be obtained. Disadvantages include the limited bandwidth of the amplifying units and noise produced by these units. Active filter is chosen to be implemented to the circuitry because passive filter is more cumbersome to be configured compared to the active filter.

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