1. Introduction:

ECG is much popular method to analysis the heart problems. Electrocardiography has been in clinical use for the diagnosis and monitoring of heart abnormalities for more than a century. It remains the best and least invasive method for the task it performs. ECG measurement systems have followed trends in technological advancement becoming more reliable, able to perform a wider range of functions and simpler to use as time has progressed. ECG is a part of bioelectric signal, which is generating in our body cause of mechanical or chemical reactions. These signals carry too much information’s.

2. Origin of Bioelectric Signal:

The use of electric stimulation in physiological disease detection and diagnosis started after Glavani introduced concept of bioelectric signal in 18th century. These bioelectric signals are mainly generated by muscles and nerves due to migration of ions which generates potential differences. Potential differences are also generated by the electrochemical changes accompanied with the conduction of signals along the nerves to or from the brain [1]. These signals along with the muscle artefacts and noise are of the order of a few microvolt and gives rise to the electrical activity when recorded.

Ionic migrations are generating bioelectric potential at cellular level. A cell consists of an ionic conductor separated from the outside environment by a semi permeable membrane which acts as the selective ionic filter to the ions [2]. Cells are surrounded by ionic body fluids. These can conduct bioelectric signal. These body fluids mainly consist of sodium ($\text{Na}^+$), potassium ($\text{K}^+$) and chloride ($\text{Cl}^-$). The membrane of excitable cells readily permits the entry of $\text{K}^+$ and $\text{Cl}^-$ but doesn’t allow the flow of $\text{Na}^+$ due to difference of ionic mobility. This results in the concentration gradient across the membrane. The concentration gradient causes certain electrochemical reactions and processes occurring within the cell and the potential measured is called the resting potential. A cell in the resting state is called polarized. Most cells maintain a resting potential of the order of -60 to -100mV until some disturbance or stimulus upsets the equilibrium [2].
When stimulated, cell undergoes contraction, an action potential is generated. Action potential being the basic component of bioelectric signal provides information on the nature of physiological activity. The distribution of the positively charged ions on the outer surface and negatively charged ions inside the cell membrane results in the difference of potential across it and cell becomes, in effect, a tiny biological battery [2].

When a cell is excited by ionic currents or an external stimulus, the membrane changes its characteristics and begins to allow Na\(^+\) ions to enter the cell. This leads to avalanche effect. Na\(^+\) ions rush into the cell. K\(^+\) ions also try to leave the cell as they were in higher concentration inside the cell in the preceding resting state, but cannot move as fast as Na\(^+\) ions [2]. Now inside of the cell is accumulated by positive ions which reverse the polarity that was in the case of resting cell. A new state of equilibrium is reached after the rush of Na\(^+\) ions stops. This change represents the beginning of the action potential, with a peak value of about +20mV for most cells. An exciting cell displaying an action potential is said to be depolarized; this process is called depolarization.

![Action potential](http://content.answcdn.com/main/content/img/oxford/Oxford_Sports/0199210896.action-potential.1.jpg)

After a certain period of being in the depolarized state the cell becomes polarized again and returns to its resting potential via a process known as repolarisation. This
is analogous process of depolarization, except that instead of Na\(^+\) ions, this principal ions involved in repolarisation are K\(^+\) ions. During this process permeability of Na\(^+\) ions decreases and that of K\(^+\) ions increases. The membrane permeability changes for Na\(^+\) ions spontaneously decreases near the peak of the depolarization, those for K\(^+\) ions are beginning to increase [1]. Hence, during repolarisation, the predominant membrane permeability is for K\(^+\) ions. The action potential is always the same for a given cell, regardless of the method of excitation or the intensity of the stimulus beyond a threshold: this is regarded as all-or- none or all-or-nothing phenomenon. After an action potential, there is a period during which a cell cannot respond to any new stimulus, known as the absolute refractory period (about 1 ms in nerve cells) [1]. This is followed by relative refractory period (serves ms in nerve cells), when another action potential may be triggered by a much stronger stimulus than in the normal situation [1].

The wave of excitation while propagating in the muscle causes its contraction. The contraction wave always follows the excitation wave because of its lower velocity. This phenomenon is found with the skeletal muscles, heart muscles and the smooth muscles [2]. In its turn, every contraction of a muscle results in the production of an electric voltage. This voltage occurs in the muscle in such a way that the moving muscle section is always negative with respect to its surroundings. After complete contraction, repolarisation takes place resulting in the relaxation of the muscles and its returning to the original state.

![Diagram](image)

**Fig-2.**electrical activity associated with one contraction in a metal
The bioelectric signals of clinical interest, which are often recorded, are produced by the coordinated activity of large groups of cells. In this type of synchronized excitation of many cells, the charges tend to migrate through the body fluids towards the still unexcited cell areas. Such charge migration constitutes sets up an electric current and hence sets up potential difference between various portions of body, including its outer surface. Each potential can be conveniently picked up by placing conducting plates (electrodes) at any two points at the surface of the body and measured with the help of a sensitive instrument. These potentials are highly significant for diagnosis and therapy.

3. Ag-AgCl Electrode:-

One of the important desirable characteristics of the electrodes designed to pick up signals from biological objects is that they should not polarise. This means that electrode potential must not vary considerably even when current is passed through them [2]. Silver- silver chloride (Ag-AgCl) electrodes have been found to yield acceptable standard of performance as they are found to give almost noise free characteristics. They are also found to be acceptable from the point of view of long term drift. Electrodes generally made of stainless steel are generally not acceptable for high sensitive physiological recordings because stainless steel electrodes in contact with a saline electrolyte produce a potential difference of $10mV$ between the electrodes, whereas this value is $2.5mV$ for silver-silver chloride electrodes [2]. Standing voltage of not more than $0.1mV$ with a drift over 30 min. of about $0.5mV$ was achieved in properly selected silver-silver chloride electrodes by Venables and Sayer (1963). These electrodes are also nontoxic and are preferred over other electrodes like zinc-zinc sulphate, which also produce low offset potential characteristics, but are highly toxic to exposed tissues [2]. Silver-silver chloride meets the demands of medical practice with their highly reproducible parameters and superior properties with regard to long term stability.

Silver- silver chloride electrodes are normally prepared by electrolysis [2]. Two silver discs are suspended in a saline solution. The positive pole of a dc supply is connected to the disc to be chlorided and negative pole to the other disc. A current at the rate of
1 mA/cm² of surface area is passed through the electrode for several minutes. A layer of silver chloride is thus deposited on the surface of the anode. Positive charged sodium ions generate hydrogen when they reach the cathode surface. These chemical changes are as:

**Reaction at the Anode**

\[
\text{NaCl} \rightarrow \text{Na}^+ + \text{Cl}^- \\
\text{Cl}^- + \text{Ag}^+ \rightarrow \text{AgCl}
\]

**Reaction at cathode**

\[
2\text{Na}^+ + 2\text{H}_2\text{O} + 2 \text{e}^- \rightarrow 2\text{NaOH} + \text{H}_2
\]

Optimal coating of silver chloride applied to a silver electrode minimizes the electrical impedance and thus increases its sensitivity.

4. **The Heart:**

The heart, located in the mediastinum, is the central structure of the cardiovascular system. It is protected by the structures of the sternum anteriorly, the spinal column posteriorly, and the rib cage. Heart is responsible for pumping blood throughout the body. The heart is composed of four chambers; two atriums and two ventricles. The right atrium receives blood returning to the heart from the whole body. That blood passes through the right ventricle and is pumped to the lungs where it is oxygenated and goes back to the heart through the left atrium, and then the blood passes through the left ventricle and is pumped again to be distributed to the entire body through the arteries.

![Fig 3: Blood circulation scheme](image-url)
Fig-2 shows the complete processing of blood circulation in our body. The right atrium collects impure blood from the superior and inferior venacavae. During atrial contraction, blood is passed from the right atrium to the right ventricle through the tricuspid valve. During ventricular systole, the impure blood in the right ventricle is pumped out through the pulmonary valve to the lung for purification (oxygenation) [1].

![Heart Diagram](http://www.a-fib.com/Overview.htm)

The left atrium receives purified blood from the lungs, which is passed on during atrial contraction to the ventricle via the mitral valve. The left ventricle is the largest and most important cardiac chamber [1]. The left ventricle contracts the strongest among the cardiac chambers, as it has to pump out oxygenated blood through the aorta against the pressure of the rest of the vascular system of the body.

5. **Cardiac Cycle: -**

There are two phases of the cardiac cycle:
**Systole:** The ventricles are full of blood and begin to contract. The mitral and tricuspid valves close (between atria and ventricles). Blood is ejected through the pulmonic and aortic valves.

**Diastole:** Blood flows into the atria and through the open mitral and tricuspid valves into the ventricles.

The heart rate (HR) or cardiac rhythm is controlled by specialized pacemaker cells that from the *sino-atrial* (SA) node located at the junction of the superior vena cava and the right atrium [1]. The normal heart rate is about 70 bpm. The heart rate is lower during sleep, but abnormally low heart rates below 60 bpm during activity could indicate a disorder called *bradycardia*. The instantaneous heart rate could reach values as high as 200 bpm during vigorous exercise or athletic activity; a high resting heart rate could be due to illness, disease or cardiac abnormalities and is termed *tachycardia* [1].

Electrical heart activity is based on depolarization and re-polarization of myocardial cells. The electrical impulse starts in the *sino-atrial* node (natural pacemaker) flowing through the atriums to reach the atrio-ventricular node and generating the atrium contraction. The current then flows through the His Bundle reaches the ventricles and flows through them generating the ventricular contractions. Finally, the current reaches the Purkinje fibers and re-polarization of the heart tissue occurs.

### 6. Electrocardiogram:

#### 6.1. History of ECG

#### 6.2. Introduction of ECG

Electrocardiogram (ECG) also known as heart waves, are the projection vectors of the summed electrical activities of heart over time. ECG is thus a set of interpretative signals or vectors which indicates the electrical activity of the heart over time with respect to different reference planes. Normal ECG signals are quasi-periodical, rhythmically repeating and synchronized.

The ECG is the electrical manifestation of the contractile activity of the heart, and can be recorded fairly easily with surface electrode on chest and limbs. The rhythm of the heart in terms of *bpm* may be easily estimated by counting the readily identifiable
waves. More important is the fact that the ECG wave shape is altered by cardiovascular diseases and abnormalities such as myocardial ischemia and infarction, ventricular hypertrophy, and conduction problems [1].

6.3. **ECG Electrode Placement & ECG Leads**

12 Lead ECG configurations:

![ECG Lead Diagram](image)

**Fig 5: Montage Electrodes assembly for 12 Lead ECG**

In ECG lead refers to the voltage between two electrodes. In 12 Lead ECG total 10 surface electrodes are attached to various specified positions on the body as shown in the figure 2. A suitable gel is used to provide impedance match between the electrodes and the skin. The 10 electrodes are classified as: 4 limb electrodes, Right Arm (RA), Left Arm (LA), Left Leg (LL) and Right Leg (RL); and 6 chest electrodes, V1-V6.
Table 1: The positions for electro placement

<table>
<thead>
<tr>
<th>Electrode Name</th>
<th>Placement of Electrode on Body part</th>
</tr>
</thead>
<tbody>
<tr>
<td>RA</td>
<td>On the Right Arm by prevent bony part</td>
</tr>
<tr>
<td>LA</td>
<td>On the Left Arm by prevent bony part</td>
</tr>
<tr>
<td>RL</td>
<td>On the Right Leg by prevent bony part</td>
</tr>
<tr>
<td>LL</td>
<td>On the Left Leg by prevent bony part</td>
</tr>
<tr>
<td>V1 or C1</td>
<td>The fourth intercostals space just to the right of the sternum</td>
</tr>
<tr>
<td>V2 or C2</td>
<td>The fourth intercostals space just to the left of the sternum</td>
</tr>
<tr>
<td>V3 or C3</td>
<td>Between the V2 and V4 leads</td>
</tr>
<tr>
<td>V4 or C4</td>
<td>The fifth intercostals space in the mid – calvicular line</td>
</tr>
<tr>
<td>V5 or C5</td>
<td>Same level as the V4 lead but at the anterior axillary line</td>
</tr>
<tr>
<td>V6 or C6</td>
<td>Same level as the V4 &amp; V5 lead but at the midaxillary line</td>
</tr>
</tbody>
</table>

A total of 12 Leads are derived from these 10 electrodes. These 12 leads are classified as 3 limb leads, 3 augmented limb leads and 6 precordial leads. Out of this 12 leads, limb leads are bipolar while all other leads are unipolar leads. The definition for all 12 leads is as follows,

1. **Lead I** – is the signal between negative RA and positive LA electrodes.
2. **Lead II** – is the signal between negative RA and positive LL electrodes.
3. **Lead III** – is the signal between negative LA and positive LL electrodes.

![Einthoven’s Triangle](image)
These three limb leads form the points of what is known as Einthoven's triangle as shown in figure 3, which is the theoretical triangle drawn around the heart with heart at centre. According to Einthoven’s law,

$$\text{Lead I} - \text{Lead II} + \text{Lead III} = 0.$$ 

4. **Lead aVR or Augmented vector right** – is the signal between the positive electrode on the right arm and the negative electrode which is a combination of the left arm electrode and the left leg electrode.

5. **Lead aVL or Augmented vector left** – is the signal between the positive electrode on the left arm and the negative electrode which is a combination of the right arm electrode and the left leg electrode.

6. **Lead aVF or Augmented vector foot** – is the signal between the positive electrode on the left leg and the negative electrode which is a combination of the right arm electrode and the left arm electrode.

7. **Precordial leads V1-V6** – is the signal between the corresponding positive V1-V6 electrode on the chest and the negative electrode formed by the Wilson terminal obtained by adding three limb leads.

(Note: **Wilson terminal** is formed by the average of the 3 limb leads and approximate ground. This is possible because of Einthoven's Law which states that I + (-II) + III = 0.)

6.4. **ECG waveform**

An ECG is a series of waves and deflections recording the heart’s electrical activity from a certain "view". Each part of wave corresponds to particular action in heart as shown in above figures 6-9. Many views, each called a lead, monitor voltage changes between electrodes placed in different position on the body.

The interior of the cell membrane is considered to be negative with respect to outside during resting conditions. When an electric impulse is generated in the heart, the interior part becomes positive with respect to the exterior. This change of polarity is called depolarisation. After depolarisation the cell comes back to its original state. This phenomenon is called repolarisation. The ECG records the electrical signal of the heart as the muscle depolarize (contract) and repolarize.
The SA node is the basic, natural cardiac pacemaker that triggers its own train of action potentials. The action potential of the SA node propagates through the rest of the heart, causing a particular pattern of excitation and contraction. The sequence of events and waves in the cardiac cycle is as follows [1]:

- The SA node fires.
- Electrical activity is propagated through the atrial musculature at comparatively low rates, causing slow -moving depolarization (contraction) of the atria. This results in the P wave in the ECG. Due to the slow contraction of the atria and their small size, the P wave is a slow, low amplitude wave, with an amplitude of about 0.1-0.2 mV and a duration of about 60-80 ms.
- The excitation wave faces a propagation delay at the atrio-ventricular (AV) node, which results in a normally isoelectric segment of about 60-80 ms after the P wave in ECG, known as the PQ segment. The pause assists in the completion of the transfer of blood from the atria to the ventricles.
• The His bundle, the bundle branch and the purkinje system of specialized conduction fibers propagate the stimulus to the ventricles at the high rate.

• The wave of stimulus spread from the apex of the heart upwards, causing rapid depolarization (contraction) of the ventricles. This results in the QRS wave of the ECG- a sharp triphasic wave of about $1mV$ amplitude and 80 ms duration.

• Ventricles muscle cells possess a relatively long action potential duration of about 300-350 ms. The plateau of the action potential causes normally iso-electric segment of about of the 100- 120 ms after the QRS, known as the ST segment.

• Repolarization (relaxation) of the ventricles causes the slow T wave, with an amplitude of 0.1-0.3 mV and duration of 120-160 ms.

### 6.5. ECG Parameters

Thus ECG analysis is an important method for monitoring patients. However, the efficiency of diagnosis relies heavily upon accurate analysis of the signal. ECG analysis Parameters are mainly depend upon the amplitude or duration of the different parts of ECG wave. By analyze these parameters doctor can get the information about any heart abnormality. If heart is not in normal conditions then parameter values will be change.

![ECG wave showing various amplitude and time interval.](http://www.bem.fi/book/15/15.htm)
Amplitude:

P-wave — 0.25 mV  
R-wave — 1.60 mV  
Q-wave — 25% R wave  
T-wave — 0.1 to 0.5 mV

Table 2: Duration of different segment/wave

<table>
<thead>
<tr>
<th>Segment/Wave</th>
<th>Duration (msec)</th>
<th>Clinical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>P wave</td>
<td>80-100</td>
<td>Atrial Enlargement, Fibrillation, Flutter</td>
</tr>
<tr>
<td>PR segment</td>
<td>120-200</td>
<td>Pericarditis, Heart blocks, Atrial tachycardia</td>
</tr>
<tr>
<td>QRS complex</td>
<td>80-120</td>
<td>Ventricular hypertrophy, Myocardial Infraction</td>
</tr>
<tr>
<td>QT</td>
<td>200-400</td>
<td>Electrolyte abnormalities, Coronary Heart disease, Romano-Ward Syndrome.</td>
</tr>
<tr>
<td>ST segment</td>
<td>80-120</td>
<td>Coronary ischemia, Myocardial Infraction</td>
</tr>
<tr>
<td>T wave</td>
<td>120-160</td>
<td>Coronary ischemia, Wellens’ Syndrome, left ventricular hypertrophy, Hyperkalemia</td>
</tr>
<tr>
<td>U wave</td>
<td>20-40</td>
<td>Hypokalemia, Hypercalcemia, Thyrotoxicosis.</td>
</tr>
</tbody>
</table>

7. Configuration of BIOPAC MP150 and Simulator:

This section will explain in detail the set up for acquiring and visualizing real time ECG on a PC. The real time live (RTL) acquisition of ECG requires availability of a subject and associated set of hardware/software tools as indicated in the apparatus section. The presence of a subject is essential prerequisite for this mode of real time ECG acquisition and in many of the cases this is not fulfilled. For example, in a real world 24/7 scenario where it is vital to acquire real time ECG as and when required, availability of a subject becomes a major issue. Also in some of the cases user is interested in acquiring a specific kind of ECG with known abnormality for analysis of some heart disorder and availability of a subject with required abnormality in ECG when required is difficult to come by. Thus in such cases an ECG simulator with different in built ECG setting is used as source for electrode potential, and one can acquire real time virtual (RTV) ECG as and when required. Thus in this experimental set up, FLUKE PS420 Multi parameter simulator is employed as a source for electrode potentials for continuous real time acquisition of ECG.
Following sections will explain in detail various steps employed in acquiring ECG signal in both the RTL and RTV mode.

7.1 Acquisition protocol for 12 Lead ECG: - In recording real time ECG several standard acquisition protocols are often used. These are,

- 3 Lead ECG – one record 3 bipolar limbs lead using 4 limb electrodes.
- 6 Lead ECG – one record 3 bipolar limbs lead and 3 unipolar augmented limbs leads using 4 limb electrodes. If limb leads Lead I, Lead II and Lead III are available, one can derive three augmented leads aVR, aVL and aVF as follows,
  
  \[ aVR = -\frac{(\text{Lead I} + \text{Lead II})}{2} \]
  
  \[ aVL = \frac{(\text{Lead I} - \text{Lead III})}{2} \]
  
  \[ aVF = \frac{(\text{Lead II} + \text{Lead III})}{2} \]
- 7 Lead ECG – one can record 3 bipolar limbs lead, 3 unipolar augmented limbs lead as given in 6 Lead ECG protocol using 4 limbs electrodes. If one more movable precordial electrode is employed, one can derive precordial lead V1-V6, by measuring voltage between the positive chest electrode and the negative terminal formed by the Wilson terminal.
- 12 Lead ECG – here one record all 12 Leads directly by measuring voltages between the 10 electrodes and one Wilson terminal.

In this experiment, 7 Lead ECG protocol using 5 electrodes (4 limbs electrodes and 1 precordial electrode) is employed. The moving precordial electrode can be connected to any one of the V1-V6 electrode in succession to measure all 6 precordial ECG leads. However, here all 6 precordial leads cannot be measured simultaneously. Thus using this protocol one can record all 12 ECG leads using 5 electrodes only.

7.2 Electrode Montage and connection to TSD 155C Multi lead ECG cable: - This section explains the electrode configuration and assembly for acquiring 12 lead ECG using 5 lead electrodes for both RTL and RTV mode. The 5 electrodes are connected to TSD 155C Multi lead cable, which incorporates a built in Wilson terminal. One can directly acquire Leads I, II, III, aVR, aVL, aVF and one movable precordial lead from TSD 155C.
Real Time Live Acquisition: In this mode, a total of 5 surface ECG electrodes are employed. They are, RA, LA, LL, RL and any one of the V1-V6 electrodes as shown in the figure. A suitable gel (GEL100 Electrode gel) is to be applied to provide proper impedance match between the skin and the electrodes. Shielded electrode leads (EL 500 series Ag-Agcl) or reusable electrodes (EL258) should be used in order to minimize the power line interference and to improve signal to noise ratio. These electrodes are connected to the corresponding 5 jumper electrodes of the TSD155C Multi lead ECG cable as indicated by the colour code. The colour code for various electrodes is as given below.

Table 3: Colour code for ECG Electrode Placement

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Colored wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL</td>
<td>Red</td>
</tr>
<tr>
<td>RL</td>
<td>Green</td>
</tr>
<tr>
<td>RA</td>
<td>White</td>
</tr>
<tr>
<td>LA</td>
<td>Black</td>
</tr>
<tr>
<td>V1-V6</td>
<td>Brown</td>
</tr>
</tbody>
</table>

a. Real Time Virtual Acquisition: In this mode, a total of 5 jumper electrodes coming out from TSD155C Multi lead ECG cable are directly connected to the corresponding output, RA, LA, LL, RL and any one of the V1-V6 position of the simulator as shown in the figure 4. The simulator is to be switched on and configured properly for ECG simulation. One can configure simulator for ECG amplitude, rate and different kind of arrhythmia or disorders.
7.3 ECG amplifier modules (ECG 100C) configuration:

The electrocardiogram amplifier module (ECG100C) is a single channel, high gain, differential input, bio-potential amplifier. These modules are pre calibrated and provide notch filter for removing 50/60 Hz power line frequency. To set notch filter for 50 Hz (line frequency in India), both the switches provided at the back of the module should be down as shown in the figure. In this experiment a total of 3 ECG 100C modules are employed to obtain three channels output i.e. Lead I, Lead II and one precordial lead (refer figure 5). All the three ECG modules should be snapped with UIM100C module of MP150 DAQ system.
Fig 10: Hardware set up for ECG acquisition through MP 150 DAQ system.

Here UIM100C is the universal interface module between the external modules and MP150. Set the first ECG100C nearest to UIM100C to channel 1 given on top. Set the second ECG100C to channel 3 and third one to channel 2. Configure all ECG100C modules as follows,

Gain 500  
Mode Norm  
35 Hz LPF ON  
HP 0.5 Hz

Once all the ECG100C modules are configured and snapped with UIM100C, plug the TSD155C into the front panels of the ECG100C as follows (refer figure 5),

Lead I – first ECG100C module – channel 1.
Lead II – third ECG100C module – channel 2.
Chest – second ECG100C module – channel 3.
7.4 Biopac MP150 DAQ set up:

MP150 is a PC based acquisition system. It takes input signals coming from the external modules through UIM100C universal interface (which is snapped to it) and converts them to digital signals and sends them to computer through high speed Ethernet port using crossover Ethernet cable (RJ-45 10 base -T), present at the back panel. For this system to interface with PC, an Ethernet LAN card should be installed with all required drivers on the PC. MP150 should be ON and connected to the computer. Check front panel of MP150 for following observations,

- Power – Green light.
- Activity – Amber light.
- Busy – Green light.

Note :- neither of the Activity and Busy light should be blinking as it indicates error in connection. Once the MP150 system is up and connection established with PC, one can acquire 3 channels coming from 3 ECG amplifier modules i.e. Lead I, Lead II, and one chest lead to PC via Ethernet port.

References:

1. Rangrajan M. Rangayyan, ” Biomedical Signal Analysis- A case study approach”, IEEE press series on Biomedical Engineering, pages 14-25, 2002