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Report

A PC Based Cost Effective Advanced Cardio Signals Monitoring System

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Abstract: In this paper, a low cost and simple portable PC based ECG monitoring system was presented. The main aim of this project is to implement a simple ECG monitoring system in laboratory conditions using components available in the local market. Normally, in twelve leads ECG, Lead-2 offers the most valuable information to diagnose the heart condition. In this project, Lead-2 is implemented in hardware together with computer interfacing. Twelve leads machine can be made simply using the same circuit twelve times for each lead or time division multiplexing with corresponding increase in complicacy. The electrical signal obtained and processed from circuit was fed to sound card of the computer through audio port and then, signals were shown using built-in virtual oscilloscope of MATLAB named soft scope. The detailed circuit development, noise reduction, filtering and installation, as well as the results, are presented.

Keywords: Electrocardiography, Biomedical Monitoring, Heart Rate, ECG, Virtual Oscilloscope, Interfacing

1. Introduction

The human heart is controlled by a series of electrical discharges from specific localized nodes within the myocardium. These discharges propagate through the myocardium and stimulate contractions in a co-ordinated manner in order to pump deoxygenated blood via the lungs for oxygenation and back into the vascular system. The physical action of the heart is therefore induced by a local periodic electrical stimulation. As a result, a change in potential of the order of 1mV can be measured during the cardiac cycle between two surface electrodes attached to the patient's upper torso [8], [9]. This signal is known as the electrocardiogram (ECG). In a normal heart, each beat begins with the stimulation of the senatorial (SA) node, high up in the right atrium (Figure 1) which causes depolarization of the cardiac muscle in this locality [1]. This stimulation is both regular and spontaneous and is the source of the primary pacemaker within the heart with an intrinsic frequency of 100 to 120 beats per minute (bpm). It is to be noted that the resulting heart rate is often lower than this because of the complex set of chemical exchanges that occur between the initial stimulation and the subsequent depolarization of the surrounding cardiac tissue. The impulse spreads from the SA node to depolarize the atria (the upper two cavities). The electrical signal then reaches the atrio-ventricular (AV) node, located in the right atrium. Normally, an impulse can only reach the ventricles via the AV node since the rest of the myocardium is separated from the ventricles by a non-conducting fibrous ring [1], [2].

As the AV node is activated it momentarily delays conduction to the rest of the heart and so acts as a safety mechanism by preventing rapid atrial impulses from spreading to the ventricles at the same rate. If the AV node fails to receive impulses it will take over as the cardiac pacemaker (at a much lower frequency of 40 to 60 bpm). The SA node will inhibit this pace making whenever its impulses reach the AV node. Once the impulse has passed the AV node, it enters the bundle of His. This conducting network spreads out into the inter-ventricular septum and divides into left and right bundle branches. As the impulse moves through this region and into the posterior and anterior fascicles it stimulates depolarization of the ventricles. There is a ventricular pacemaker 2 (with a beat frequency of 15 to 40 bpm) which takes over as the main pacemaker if the AV node fails. After the depolarization of the ventricles, a transient period follows where no further ionic current can be flow through the myocardium. This is known as the refractory period and lasts at least 200 ms [3]. There is then a recharging (depolarization) of the ventricular myocardium to its resting electrical potential and the heart is then ready to repeat the cycle.

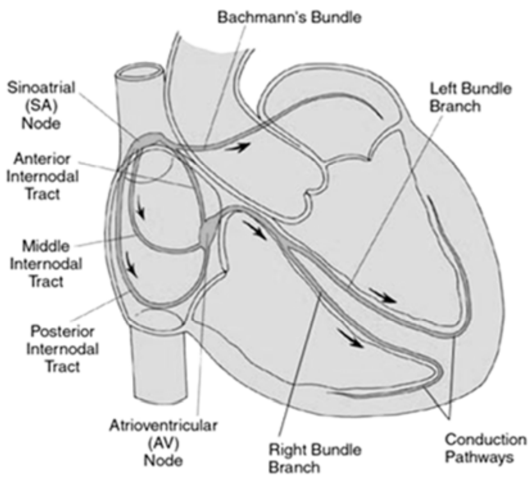

Figure 1. *Source nodes of electrical Simulation within the heart.*

Electrocardiography or ECG is the transthoratic interpretation of electrical activity of the heart overtime captured and externally recorded by skin electrodes. It is one of the best ways to measure and diagnose abnormal rhythms of the heart resulting from several risk factors [2]. However, commercial ECGmachines are still beyond the reach of mass people of developing countries, like Bangladesh, even in India, where death rate due to heart diseases is increasing at an exponential rate. For example, a 12 lead portable ECG machine may cost even $3,500.00 offering sophisticated facilities. Considering these issues, we have decided to implement a PC based low cost ECG monitoring and diagnosis unit utilizing available technologies and infra-structure. One of our main objectives is to familiarize ourselves with the challenges of biomedical signal acquisition and processing. Usually, ECG leads II and V5 provide the most functional information in the context of medical diagnosis. Inthis project, lead 2 was implemented in hardware together with computer interfacing via audio port. A twelve lead machine can be made simply using same circuit 12 times for each leads or time division multiplexing with corresponding increase in complicacy.

2. ECG Waveform Generation and Recording

A typical ECG waveform comprises of an initial P-wave, followed by the main 'QRS' complex and then a trailing T-wave (Figure 2). These waves are defined as follows:

a. P-wave – The low voltage fluctuation caused by the depolarization of the atria prior to contraction. The atria contain very little muscle and thus the voltage change is quite small.
b. QRS complex – The largest-amplitude portion of the ECG caused by the ventricular depolarisation. The time during which ventricular contraction occurs is referred to as the *systole*. Although atrial repolarisation occurs simultaneously, it is not seen due to the low amplitude of the signal generated by this process.
c. T-wave – Caused by ventricular repolarisation.

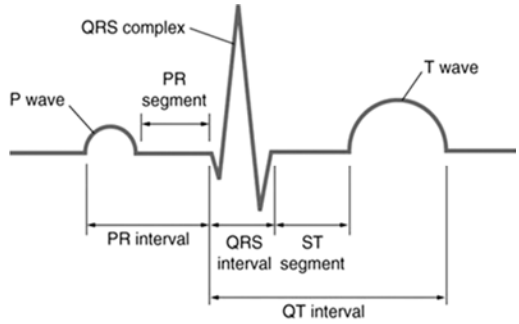

Figure 2. *A typical ECG waveform for one heart beat.*

The time between ventricular contractions, during which ventricular filling occurs, is referred to as the *diastole*. Although the R-peak is often the largest amplitude component, the morphology of a healthy ECG can vary greatly from patient to patient with the P or T-waves sometimes dominating or merging with the QRS complex. Swapping the two electrodes over gives an inverted signal with the R-peak being the lowest (or most negative) part of the signal. The time averaged heart rate is usually calculated by counting the number of beats in a 60 second time period. The instantaneous heart rate is the time between successive R-peaks (an RR interval).

2.1. Lead Configurations

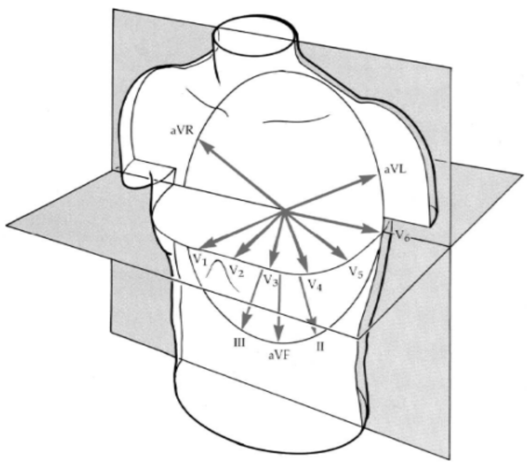

Figure 3. *Electrical vectors for the standard ECG lead configurations.*

The choice of location on the thorax for the electrodes used to record the ECG is dictated by the type of clinical information required. Since the voltage difference between a pair of electrodes (known as a lead) is only representative of the variations along one axis from the heart (Figure 3), there is no three-dimensional activity information in single lead 7 measurements [5]. However, there are standard lead configurations for acquiring 3-D information about the electrical activity of the heart. Figure 4 shows many of the standard positions for 12-lead ECG recordings and figure 3 shows the standard vectors that are visualized by these leads.

For example, lead II represents the electrical activity vector from the centre point (close to the heart) to the left leg. Lead V5 represents the vector from electrode position V5 (as in Figure 4) to the heart. The potential must be measured with respect to some common ground and this is often taken to be the right leg. When a serious heart problem is suspected, a clinician will usually order a full (12-lead) ECG recording to be made. This gives a detailed picture of a patient's cardiac activity, and any possible problems, such as QT-syndrome (significant changes in the time between the Q and T points on each cycle) and ST-elevation (a significant rise in the point of inflection between the S and T points). However, since visual inspection is often used to evaluate these features, and this can be done on only a few cycles of the ECG, the recording is short (typically 10 seconds long). Routine analysis of the ECG does not normally involve such a high number of vectors being recorded. Even in an intensive therapy unit (ITU), when data from many lead configurations is available, only one or two leads are routinely monitored. Typically, leads II and V5 are chosen since they offer the most useful information in the context of medical diagnosis.

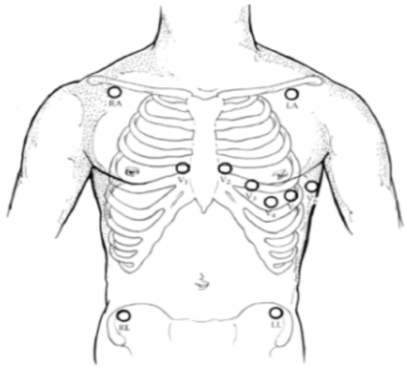

Figure 4. *Ten of the Standard Electrode Positions for 12-Lead ECG Recording.*

For this project, we selected lead 2 to be implemented in hardware together with computer interfacing. A twelve lead machine can be made simply using same circuit 12 times for each leads or time division multiplexing with corresponding increase in complicacy.

3. The ECG Circuit Implemented for the Project

3.1. Circuit Description

There are many possible choices for standard ECG circuits which are used commercially to provide amplifying and filtering action for the ECG signal. We had to make a choice which was simple but robust and could be implemented in laboratory conditions using components available in the local market. Our ECG amplifying circuit uses 6 op-amps (model TL084), 3 pairs of cross-coupled diodes along with 17 resistors and 2 capacitors. The circuit has 3 inputs to pick the LEAD-II ECG signal- the positive (In+), the negative (In-) and the body (ground) terminal and the output goes to the audio port of the sound card of a PC via an ordinary sound cord. The functions of the prominent parts of the circuit are elaborated separately in the following section:

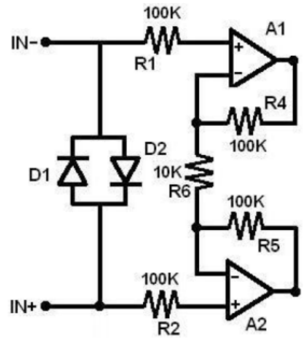

Figure 5. *Input Buffer.*

1) Input Buffer: The IN+ and IN- leads are input to the buffer amplifiers A1 and A2 via two 100k resistors. Buffering with high input impedance amplifiers at the start is crucial for an ECG circuit, because as we are dealing with mV range signals, we have to ensure that the input current is very small to prevent any loss of voltage at the very beginning.
2) Cross-coupled diodes: A pair of cross-coupled diodes is provided between all possible combinations of input pairs (D1-D2 between IN+ and IN-, D3-D4 between IN+ and Body, D5-D6 between IN- and Body) to ensure safety for the subject. These diodes will ensure that the voltage between two input terminals will never cross 0.7 V for any ac cycle. This 700mV threshold will not curtail the input signals in any way because all natural ECG voltages are smaller than this value.
3) Source-boosting Signal: Any ECG amplifier is the part of a man-instrument system. This statement implies that the human body acts as a source which is the part of the circuit. When we are dealing with very small magnitude signals it is a standard practice to boost the source by a bias voltage. We have done this by providing $V_{dd/2}$ bias to the Body terminal via a 10k resistor.

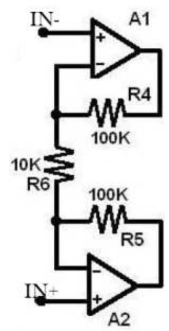

Figure 6. *Common Mode Input Rejection.*

4) Common Mode Input Rejection: The R4-R5-R6 resistor network provides common mode rejection for this circuit. If equal common mode voltages are present at the IN+ and IN- terminals then the voltages present at the head of R4 and R5 are also equal and the network will remain idle. But in case of the presence of unbalanced common mode inputs at IN+ and IN- the two input currents will be different which is always undesirable. But the unbalanced voltage present at the head of R4 and R5 will provide a compensating current through any one of the two resistors, which will make the two currents equal and thus provide common mode rejection.

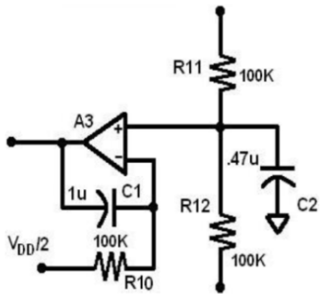

Figure 7. *Low Pass Filtering.*

5) Low Pass Filtering of Low Frequency Muscle Noises: Ideally we want to omit low frequency muscle noises (dc to 0.5Hz) from the ECG signal. Maintaining such high precision is not possible in a practical circuit. The IN+ and IN- inputs face two low pass filters in the form of R11-C2 and R12-C2. The capacitor C1 places a Miller effect reduction capacitor in parallel with C2. This increases the equivalent capacitance and brings down the cut-off frequency. Together these low pass filters separate muscle noises of the range bellow ~.5 Hz and subtract it from the original signal so we are able to remove the major low frequency muscle noise components.

6) Differential Amplifier: The main amplifying action is provided by the differential amplifier A5 which provides a gain of the magnitude of 20. To apply both the IN+ and IN- signals to the negative input terminal of A5 (in Figure 9) the IN+ signal has to be inverted by A4. Now a $V_{dd/2}$ bias is provided to the positive inputs of both A4 and A5, so that, effect input offset present between the amplifier input terminals can be reduced. Subtracting the IN+ signal from the IN- signal will provide us the final LEAD-II signal.

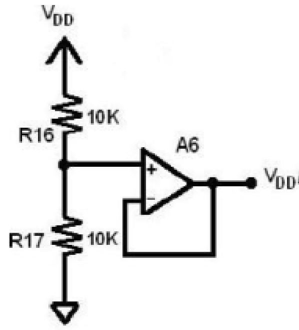

Figure 8. *Bias Supply.*

7) Bias Supply: A simple voltage divider formed by R16 and R17 along with the buffer amplifier A6 provides us with the Bias voltage $V_{dd}/2$ from the V_{dd} bias supply (a 9V battery). The final circuit, which we implemented for this project is given in Figure 9:

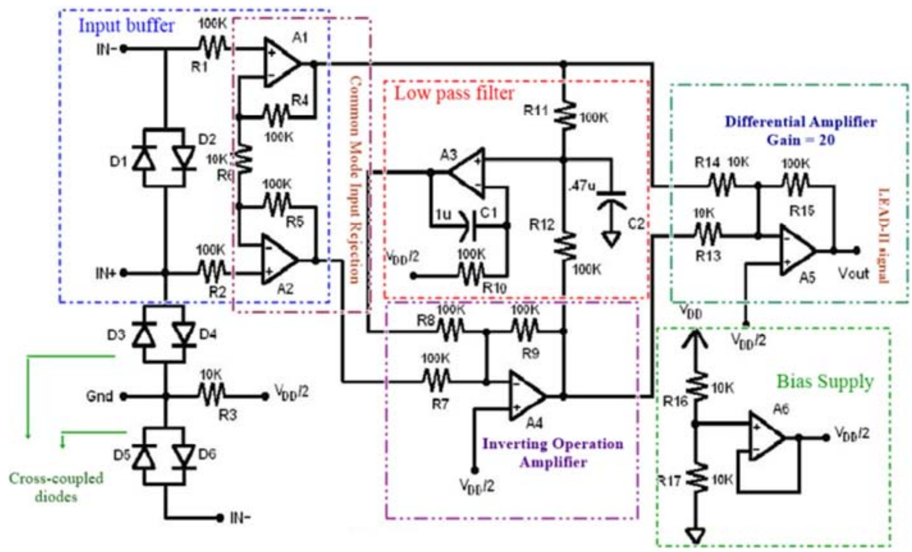

Figure 9. *The Final Circuit Implemented for the Project.*

A Word on the Choice of Amplifier: When we are dealing small magnitude signals like ECG we have to pick amplifiers with high input impedances. The most appropriate choice in this case would have been the instrumentation amplifiers, like INA32. But unfortunately it is not available in local market. So our pick was the TL084 which is a more prudent choice than the most common op-amps of the µa741 class since it has significantly higher input impedance.

Figure 10. *An ECG Clamp (Electrode).*

3.2. The Choice of Electrodes

The heart contracts after getting an electrical stimulus of the electro-conduction system. The muscle cells generate the action potential. This potential creates electrical currents that spread from the heart throughout the body [3]. The spreading currents create difference in electrical potential between various locations in the body and this potential is detected through surface electrode attached to the skin. We have used ECG clamps as our receiving electrodes which have a metallic interface with the skin which works as an antenna to pick up the ECG signal available in the body surface. Conducting gel has been used to increase the conductivity of the path formed between the clamp and the body surface. These clamps can be used multiple times unlike the ordinary one-time electrodes.

3.3. Computer Interfacing

The output of the amplifier goes to the audio port of the sound card of a PC via an ordinary sound cord. The output can be shown on the monitor in one of two ways [5]:

a. Using a Visual Basic based virtual oscilloscope.
b. Using the built-in virtual oscilloscope of MATLAB named soft scope.

In this way, the ECG signal was collected from human body, processed in hardware circuitry and finally was displayed in computer. So, we designed a real time single lead ECG machine.

4. Signal Response of the Single Lead ECG Machine

The signal responses of our single lead ECG machine, together with the response in case of dried and loose electrodes are shown here.

4.1. True Signal Response

Signal response of a commercial 12 lead ECG machine is given in Figure 11:

Figure 11. *Signal response of a commercial 12 lead ECG machine.*

The signal response, we obtained from our single lead ECG machine is shown in Figure 12.

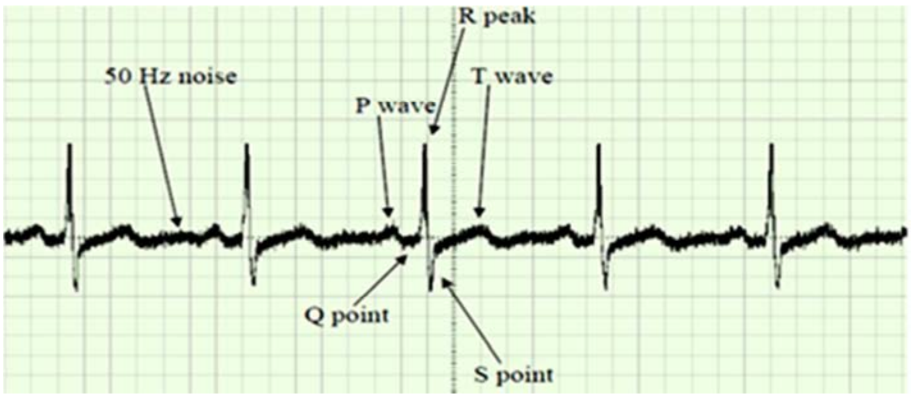

Figure 12. *Signal response of our single lead ECG machine.*

The frequency analysis of this ECG signal is given in Figure 13:

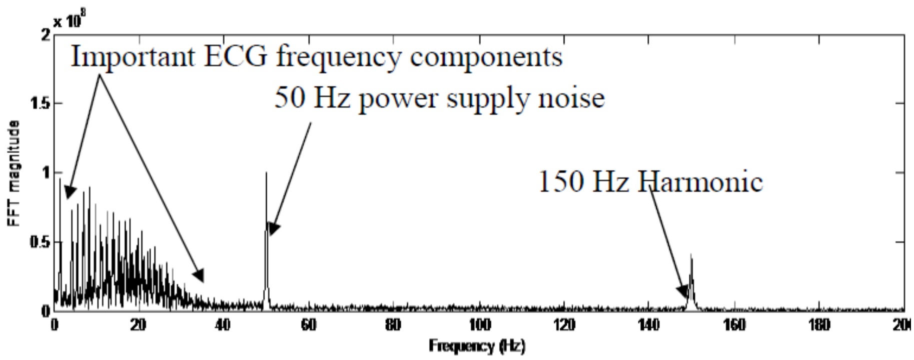

Figure 13. *Frequency analysis of the ECG signal shown in Figure 12.*

As seen from both figure 12 and figure 13, only 50 Hz noise and its harmonics are present here, which could not be removed because of reasons described later.

4.2. ECG Signal for Dry Electrode-Contact

If the path between the body and the electrode is not conducting enough, then signal reception will suffer. Conducting materials like gels can be used to increase the conductivity. If the conducting material is less conducting, then there may be interruption in the signal reception. Signal quality and regularity depends much on this conducting materials. We observed the consequence of reduced conductivity using a less conducting gel. The ECG signal observed in this case if given in Figure 14.

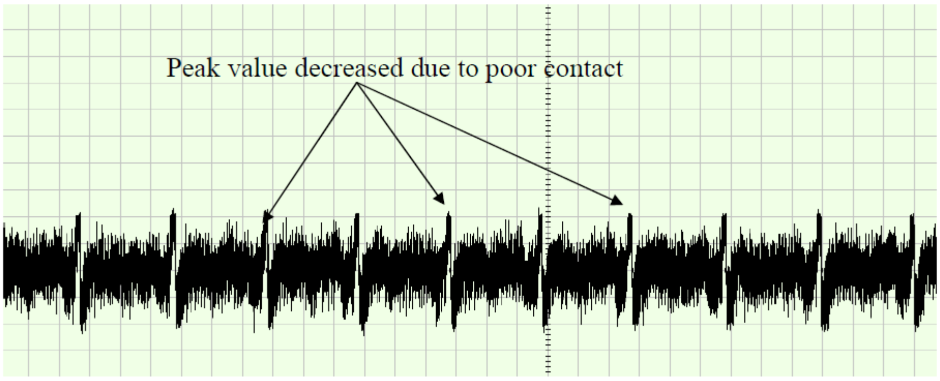

Figure 14. *ECG signal for poor electrode contact.*

4.3. ECG Signal for Loose Electrode-Contact

If the electrode is open, then signal is received. We used lead 2, as mentioned earlier, which is bipolar limb lead and requires 3 electrodes to receive the ECG signal. Two of them are used for differential signal reception and one is for body to improve the signal just like biasing of an amplifier. So, either of the IN+ or IN- electrodes is opened (electrodes for differential signal reception), then the amplifier cannot act as differential mode and therefore muscle noise cannot be removed. Again, if the body electrode is opened, then signal strength reduces. We observed these effects during the course of work. Figure 15 shows the effect of loose electrode.

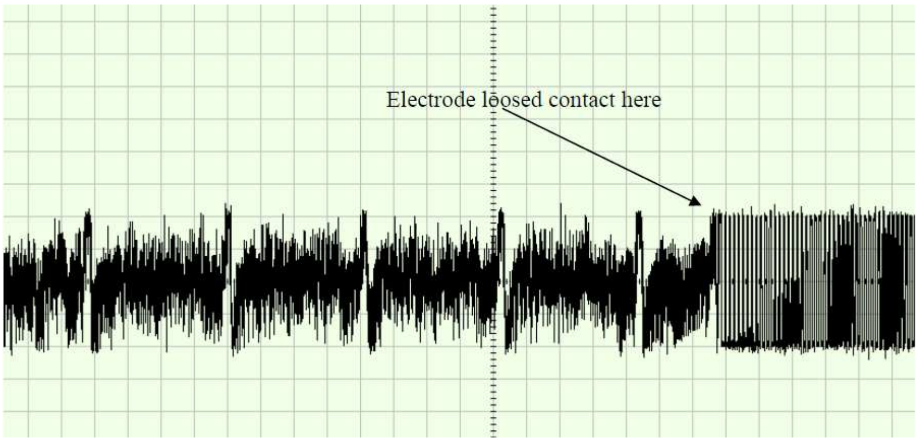

Figure 15. *Effect of loose electrode on ECG signal.*

Therefore, ECG signal responses and various effects on them are quite explainable.

Heart Rate Measurement: We processed the ECG signal to measure the heart rate and between 81 to 87 bpm.

5. Analysis

Following steps analyses the response of our ECG machine in detail:

1. Sources of Noise
2. Limitations in Computer Interfacing
3. Implementation Difficulties

5.1. Sources of Noise

Though, the signal response, we are getting from our ECG machine is quite recognizable, noises are still present here, as can be seen in the ECG signal. We identified the following sources of noise, which are disturbing the perfect shape of the ECG signal:

a) Power Supply Noise: This is the most prominent noise component, present in our ECG signal, which was also observed in the frequency analysis of the signal, in Figure 13. Power line is the source of this noise, which radiates EM wave at 50 Hz. The components, which are mostly responsible for catching this 50 Hz hum, are-

ECG Electrodes: ECG Electrodes, acting as antenna, catches both the ECG signals and the 50 Hz power supply Electro Magnetic Interference.

Other components: Human body also receives some 50 Hz hum, acting as antenna. Another component that also receives this noise is the audio port itself. Power supply noise, received by the electrodes and the human body is amplified by the ECG amplifier circuit, whereas, that, received by the audio port directly super-imposes on the final ECG signal. In this way, the 50 Hz noise vitiates the signal most.

b) Shielded Wires was not used: Shielded wires have conductive shield over its conducting metal, so that, it cannot act as antenna to receive any EM wave emanating from sources like power line or any other source. This kind of wires are very important to work with weak signals, like ECG signal, because, weaker signals are more vulnerable to noises than the stronger ones. So, shielded wires can be used to connect ECG electrodes and for computer interfacing to minimize EM noise.

c) Muscle Noise: Frequency spectrum of Muscle Noise spreads from 0 to 10 KHz. So, its spectrum super-imposes on ECG frequency bandwidth, which is from 0 to 100 Hz. Fortunately, muscle noise from .5 to 100 Hz does not effect the ECG signal much. Frequency components of muscle noise bellow .5 Hz causes base-line shift, which was removed by clever filtering, described in section 2.1. Higher frequency components of these noises are discarded by the computer audio port due to its limited audible bandwidth. But, still some muscle noises are present in our ECG signal, which manifests itself as random glitches.

d) Flicker Noise: Flicker noise generates from the op-amp input transistors and is also known as 1/f Noise, because, It increases with decreasing frequency. Some flicker noise may have been present in the ECG signal, as its frequency component is below 100 Hz.

e) Thermal Noise: Thermal noise, generated from resistors as well as transistors of the circuit, may be present here, which also slightly distorts the signal. As, ECG signal is a week signal (~ 2 mV), any noise, whatever small in magnitude, disturbs it more or less. So, the signal would be noiseless, if a noiseless environment could be created for the circuit.

5.2. Limitations in Computer Interfacing

Oscilloscope buries weak signals like ECG by 50 Hz power line noise, because it is prone to this noise more than the circuit. Computer interfacing becomes obvious then. Though, interfacing by DAQ card provides most accurate virtual scoping in the computer, but it is very costly. Interfacing via audio input port is a cheaper solution here. But, it has its following limitations:

a) Operating frequency band: The audio input port operates in the audio frequency band. As shown in the Figure 16, when a dc voltage of about .5 V is applied, virtual oscilloscope plots a sharp rising signal, which decreases rapidly. It proves that, audio input port cannot take dc or low frequency input.

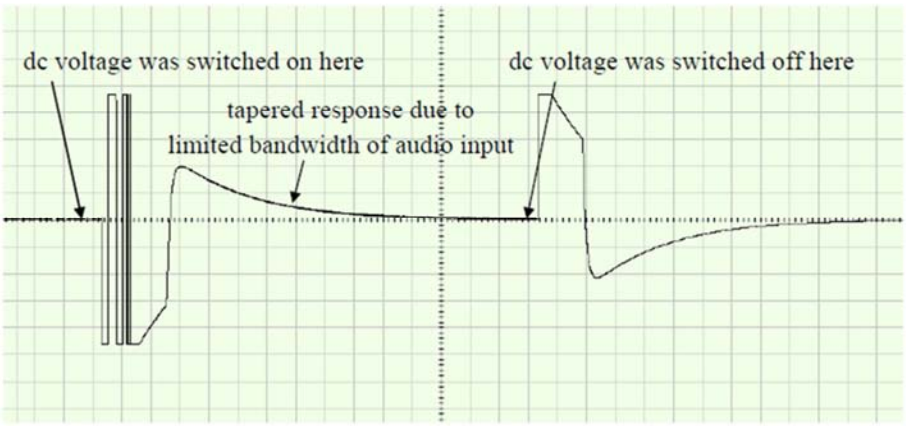

Figure 16. *Virtual scoping by computer interfacing to plot dc voltage.*

On the other hand, ECG signal has major frequency components bellow 40 Hz. So, distortion may be present due to low frequency rejection of the audio input port of the interfacing computer. In practice, we did not get any detectable ECG signal, when we interfaced with an old computer. Acceptable response is seen only with latest computer, which proves its better operating frequency range than the older one. So, the computer audio input port has to operate in ECG frequency band, to be used as virtual oscilloscope here.

b) Slashdot Effect: Sampling rate of the audio input port is to set, so that, it does not work in more data rate than its capacity. Otherwise, Slashdot effect (data congestion) may result, the result of which is data rejection, signal distortion and delay.

c) Input Voltage Limitation: The maximum input voltage, that the audio input port can take is +/- 1 V. So, care should be taken, so that, gain of the ECG circuit is not too high. Otherwise, a clipped ECG signal is plotted and it may be difficult to identify an ECG signal, if the clipping is near the base line.

d) Audio Port Connection: The following care should be taken to interface the ECG circuit with the Computer:

1. Figure 17 shows the segments of an audio cord terminal.

The Tip and the Sleeve sections are +ve and -ve terminals and the tip section should be left open.

2. The port must be connected to the microphone input port of the computer, not to the speaker output port. Otherwise, no signal will be seen.

Figure 17. *Different sections of audio cord terminal.*

3. Volume control should be selected properly. Too high volume setting may clip off the signal and too low setting may diminish it.
4. Circuit ground and the output should be properly connected to the +ve and -ve terminal of the audio port. No signal is plotted if connections of these two terminals are swapped.

5.3. Implementation Difficulties

The ECG circuit has following hardware and software implementation difficulties:

a) Quality Op-Amp is required: As, ECG signal is very weak (around 2 mV in magnitude), op-amps of very high input impedance and low input offset voltage are required. Otherwise, the signal may drop within the circuit and may be lost. Op-amps like μa 741 can not be used here, because, its input impedance is only 2 MΩ with 5-6 mV input offset voltage. We used TL084, whose input impedance is 1012 Ω, but still, input offset voltage is 5-6 mV. Commercially, instrumentation amplifiers like INA321 are used to work with small signals like ECG, which has an input impedance of 1013 Ω and maximum input offset voltage is .5 mV. Unfortunately, instrumentation amplifiers are not available in local markets.

b) Hardware Filtering Difficulties: Frequency analysis indicates that, a 50 Hz notch filter of 6-8 Hz bandwidth would eliminate the power supply noise. Theoretically, hardware filters can be designed for this purpose, even with available components in the market, but practically, circuits of such small notch bandwidth at such low frequency are prone to oscillate, and are difficult to use. We tried several such notch filters, but, none of them could give stable response. So, software filtering is necessary.

c) Difficulty in Hardware Debugging: As, the ECG signal is very weak, so it is difficult to find out, where the signal is lost, if no signal is found at the final output. So, hardware debugging is very difficult.

d) Good Contact is Required: To take ECG signal from body by electrodes, a good contact is required. ECG Gels are used to improve the contact. Bad contacts due to out-dated gels or lack of soldering in electrode-clips may result a complete loss of the signal, as the signal is around 2 mV in magnitude. So, good contact must be ensured.

e) Selection of Power Source: The maximum bias voltage, at which TL084 can operate, is +/- 18 V. Though, gain of these op-amps increases with increasing bias voltage, but it is inconvenient to move with these large size power suppliers. We used 9 V batteries instead, though gain decreased much. Then, scale adjustment of the virtual oscilloscope was required in the computer.

f) Ordinary Oscilloscope is not Usable here: The input port of ordinary oscilloscope works as a good antenna to catch 50 Hz power supply noise, which is about .2-.5 V in magnitude. So, ECG signal, which is of around 50 mV after amplification by the ECG circuit, is small enough to be buried by this 50 Hz noise. For this reason, an ordinary oscilloscope is not usable to show the ECG signal and computer interfacing becomes essential to use virtual oscilloscopes.

g) Good Virtual Oscilloscope is to Choose: Good virtual oscilloscope is to choose to plot the signal in the computer. Otherwise, a distorted signal may be plotted. Figure 18 shows the effect of choosing a poor and a better oscilloscope in plotting the same ECG signal.

h) DAQ card is very costly: Use of DAQ (Data Acquisition) Card is best choice for virtual oscilloscope, which can plot dc to very high frequency signals conveniently. But, it is very costly and was not used in this project.

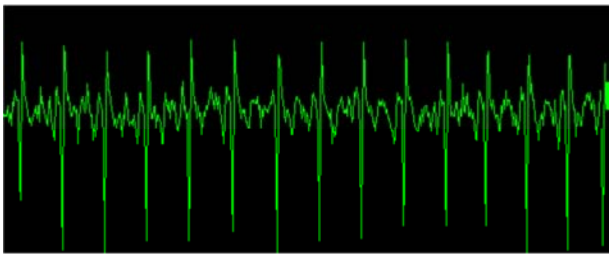

Figure 18(a). *ECG by a poor virtual oscilloscope (visual basic based).*

Figure 18(b). *ECG by a better virtual oscilloscope (MATLAB based).*

As, human interfacing is obvious at the input side of the ECG circuit, so the high power section must be well isolated from the input section. The interfacing computer should be well earthed-in. An isolation circuit that can be used to isolate the output of the ECG circuit from the computer is given in Figure 19, though we could not use it because of time limitation.

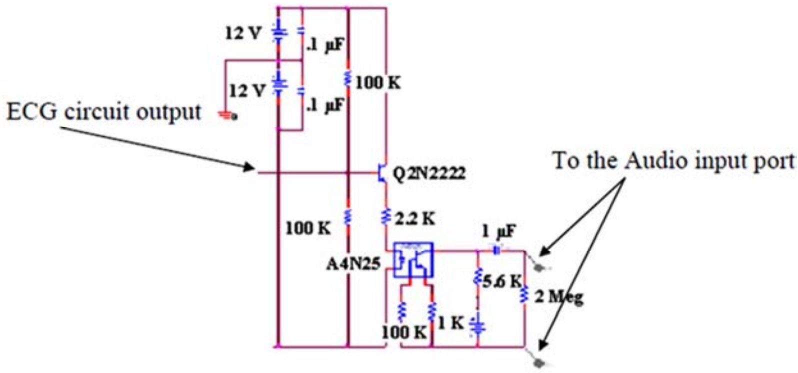

Figure 19. *An opto-coupler based isolation circuit for Computer interfacing.*

j) Amplitude Clipping: As, the gain of our ECG circuit was quite high, the peak of the QRS wave was clipping off at about 95% of its final value. So, some circuit components ought to be changed to minimize its gain and thus, to avoid amplitude clipping.

k) Difficulty in Signal Processing: We attempted for signal processing to eliminate noises, specially the 50 Hz noise from the ECG signal. But the clipped QRS wave created the problem here. The frequency response at the lower end of frequency was not smooth enough as it should be and split-peak was observed after signal processing, as shown in Figure 20. Suitable interpolation could be used here to smooth out the clipped peak before signal processing, which would be difficult due to the presence of noise at the peaks.

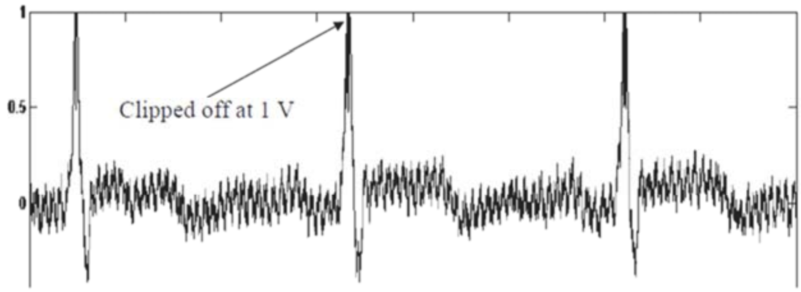

Figure 20. *A typical ECG signal of our single lead ECG Machine.*

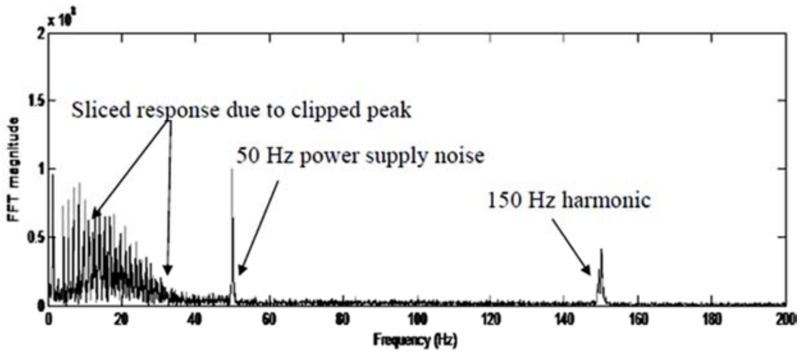

Figure 21. *FFT of the ECG signal of Figure 20.*

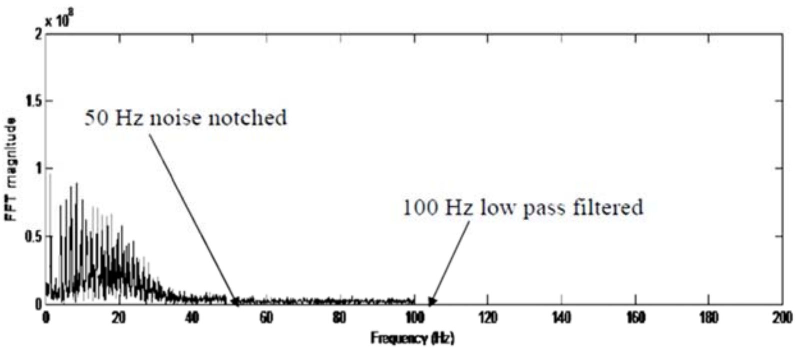

Figure 22. *Software Filtered.*

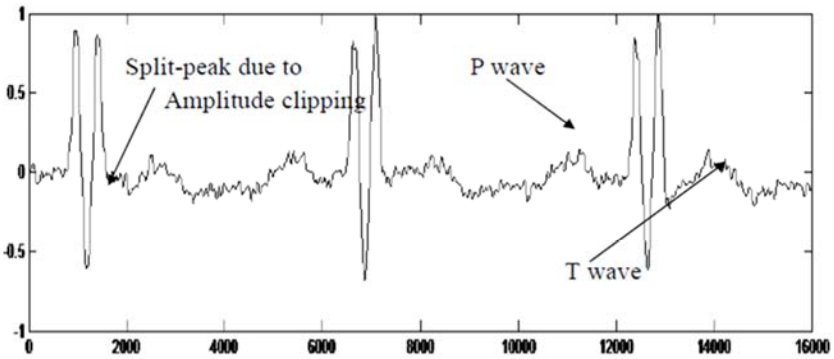

Figure 23. Filtered ECG signal after reconstruction.

Hardware as well as Software implementation difficulties, mentioned above, indicate that, this work deserves future improvements to evolve as a excellent home-made ECG machine.

6. Future Improvement

The following steps can be tried to improve our Single Lead Homemade ECG Machine in future:

1. Hardware Filtering.
2. Software Filtering.
3. Quality Input Amplifier.
4. Data Acquisition Card (DAQ) interfacing.
5. PCB formation.

6.1. Hardware Filter

We tried several 50 Hz Notch Filters and the 100 Hz Low Pass Filters, but none of them could give stable response, as mentioned in section 5.3. Among them, the best two are as in figure 24 and 25.

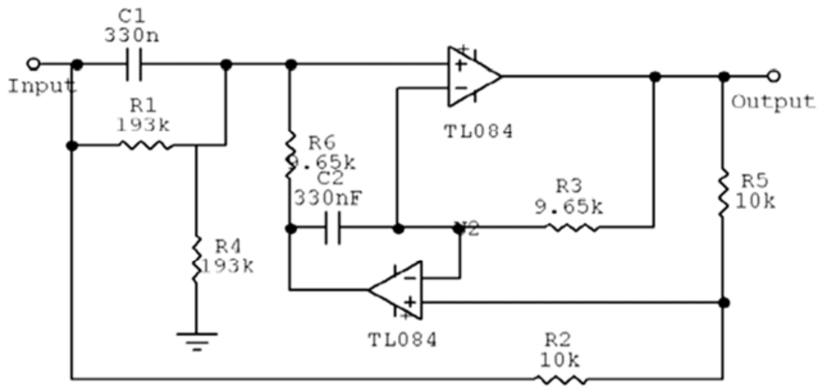

Figure 24. The 50 Hz notch filter.

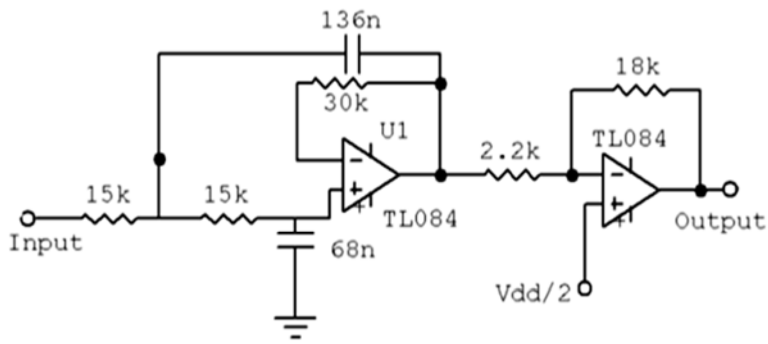

Figure 25. The 100 Hz low pass filter.

So, these two filters can be tried to improve to incorporate in the signal lead ECG machine.

6.2. Software Filtering

Hardware- circuit response of a commercial 12 lead ECG machine, without and with software filtering is shown in figure 26. Comparing figure 26 (a) with figure 12, both of which are software filtering, we can hope for excellent response from our designed machine incorporating software filter.

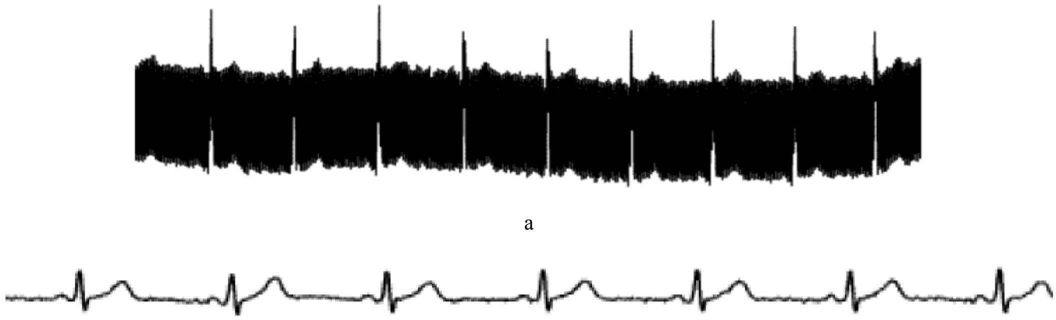

Figure 26. *ECG signal from a 12 lead commercial ECG Machine (a) Before software filtering (b) After software filtering.*

The software filters, which can be tried in future, are:

1. 50 Hz Notch Filter.
2. 0.5 Hz High Pass Filter (HPF).
3. 100 Hz Low Pass Filter (LPF).
4. Empirical Mode Decomposition (EMD) Filter or Moving Average Filter for smoothing.

6.3. Real Time Heart Rate Measurement

We used signal processing on off-line ECG data to measure the heart rate. In future, the ECG signal can be tried to process for real time heart rate measurement.

6.4. Quality Input Amplifier

In our ECG signal measurement, we used IC-TL084CN as input buffer amplifier. But a better choice is IC-INA326/INA118, as mentioned in section 5.3. These kinds of high quality instrumentation amplifiers can be tried to incorporate.

6.5. Interfacing by DAQ Card

Data Acquisition (DAQ) Card is best choice for computer interfacing, which is mentioned previously. So, it can be employed together with the isolation circuit, proposed in section 5.3.

6.6. PCB Formation

Bread board, where we implemented our machine, suffers from some common problem like frequent loose connections. PCB is better choice for this kind of hardware circuit implementation. Moreover, soldered connections of PCB, being a good connection can reduce some circuit noise.

7. Cost Estimation

We estimated the cost of our single lead home home-made ECG Machine to be 1.23 USD The estimation chart is given in the Table-1.

Table 1. *Cost estimation of single lead ECG machine.*

Name of component	Quality	Market price in USD
Resistance	18	0.11
Capacitance	2	0.075
Diode	6	0.15
IC- TL084CN	2	0.375
Battery	1	0.50
Audio Input Cable	1	0.25
Crocodile clip	5	0.375
Wire	-	0.375
Lead	3	0.3
PCB	1	99
Total		**1.23**

8. Conclusion

ECG is a very important and effective heart monitoring system. Heart patients can get better medical care if they can keep one handy. Unfortunately, commercial ECG machines are too costly to use at home. Our home-made single lead ECG machine can emerge as a cheaper solution here. Before that, it deserves future improvements to reach that much.

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