Project #1

# <u>ECG Signal Measurement</u>

BE 5344

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## Introduction:

Electrocardiogram (ECG) is a technique that measures the heart rhythm and its electrical signal to identify abnormalities in patients. The heart's core function is to deliver blood throughout the body in two main circuits: Pulmonary and Systemic. Both of these circuits ensure that the oxygen to all the body and remove the waste product- carbon dioxide. The heart also has specialized “cardiac tissues that are called inherent rhythmicity” which can start “the electrical sequence of depolarizations and repolarization” (1). Since the heart's electrical signals are the “echoes of the depolarization and repolarization of the heart is sent through the rest of the body” (3) therefore the electrodes that are attached to the subjects will be able to collect the data in the waveform (1).

The conduction of this experiment is to furthermore enhance the knowledge about how to filter all the interfering noises and collect the improved data from the ECG signals. Aside from that, a better understanding of how impactful the resistor has on the collected signals. In this experiment, Matlab is one of the most important software that enables the acquired data to be undisrupted by the surrounding noise, therefore, providing better and clear ECG signals of the heart's electrical activity. A better comprehension of using this software and how the resistors influence the results will provide a great assistance on how to create a better AI to eliminate the flaws when acquiring ECG data from patients.

## Methods and Materials:

*Materials*:

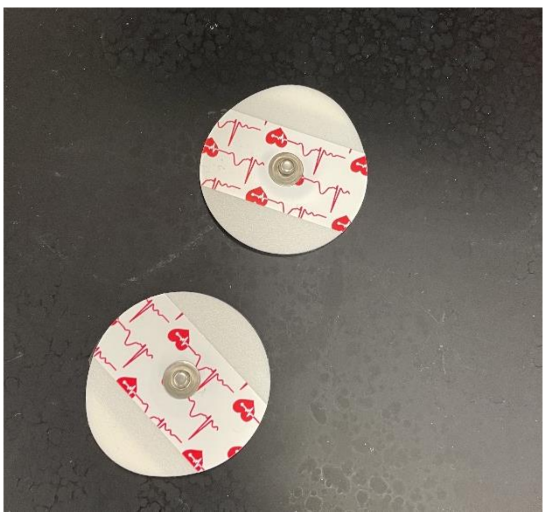

Figure-1: ECG sensors.


Figure-2: Oscilloscope.


Figure-3: Multimeter.

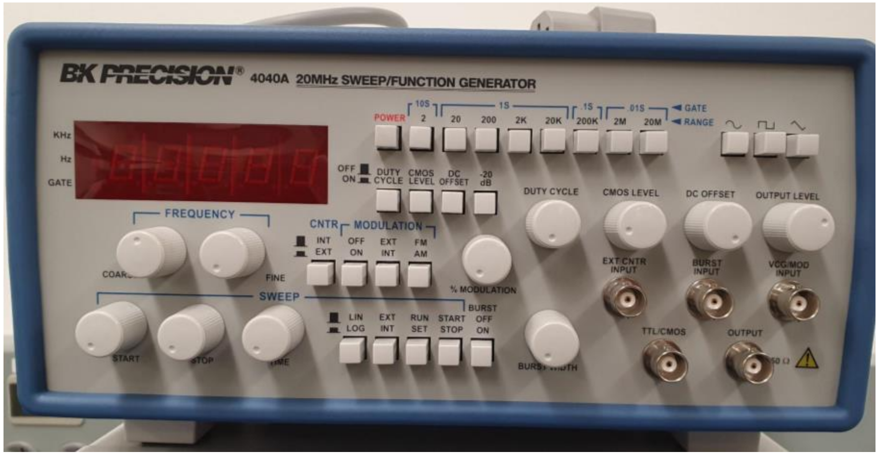


Figure-4: Function Generator.


Figure-5: DC power supply.

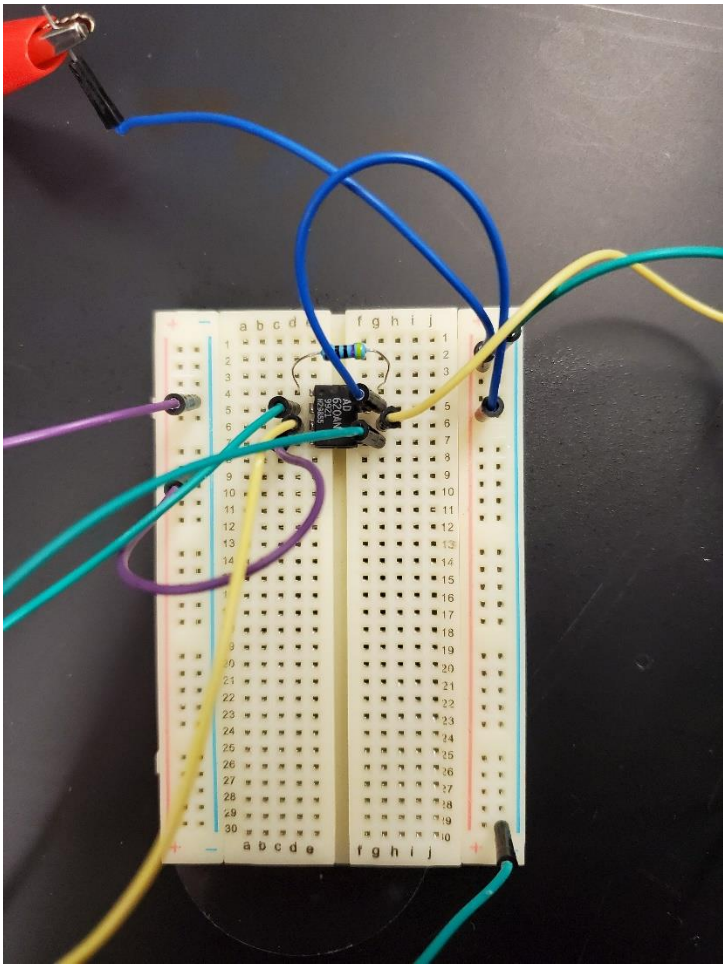

Figure-6: Data collection circuit consisting of resistors, AD620 operational amplifier, breadboard.

*__Methods:__*

The following circuit was constructed on a breadboard:

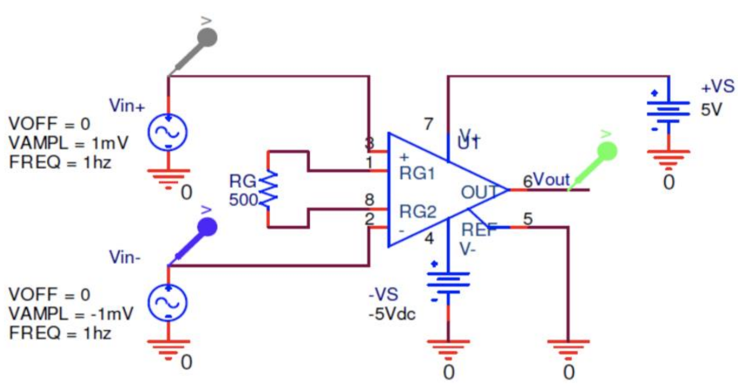


Figure-7. Data acquisition circuit's diagram.

- Two electrode leads were attached to a subject's wrist and opposite ankle. Then they were connected to the input of the circuit at Vin+ and Vin- which are pin 3 and 2 of the AD620 Op-Amp, respectively
- A dual rail voltage of ±5V was supplied to the circuit at pins 4 and 7 of the op-amp
- Data was then acquired by visualizing the output signal on an oscilloscope
- Resistor values were then changed to see the difference in ECG signal.
    - Resistor values used- 150Ω, 470Ω, 4.7kΩ, 10kΩ
- A digital filter was used to filter out a clean ECG signal for data analysis [code provided in appendix]

**Results, Discussion, and Data Processing:**

Obtained .cvs files from oscilloscope were processed using Matlab and the code is provided in the appendix. Overall, 4 resistors were tested, and the signal processing was performed on the 4 acquired data sets.

Figure-8 displays the ECG signal obtained from the acquisition circuit using a 10kΩ resistor. The output signal is contaminated by multiple peaks caused by noise, which makes it difficult to distinguish the characteristic components of the ECG signal. Thus, a filter is required to remove the noise and result in a clean ECG signal that can be analyzed.

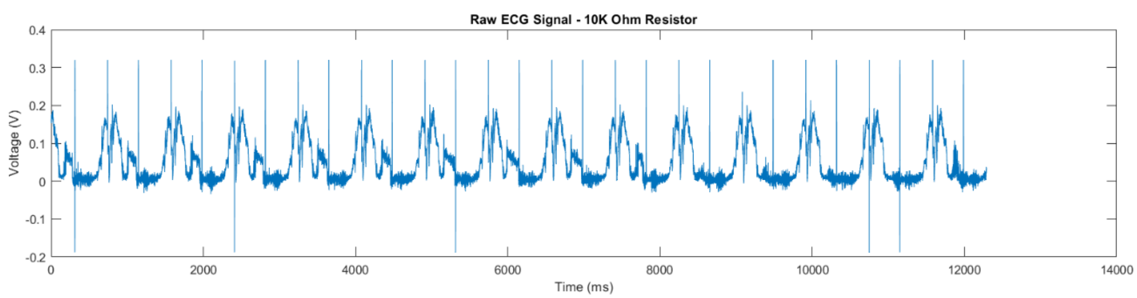


Figure-8: ECG data obtained from the data acquisition circuit

To determine the type of filter that should be used, the single-sided magnitude spectrum of the signal in the frequency domain was plotted and examined (Figure-9). As seen in the figure, there are many peaks at the high frequency range. A typical ECG signal has a frequency range of 0.1-250 Hz, so these high-frequency peaks are most likely caused by noise. To filter out these peaks, a low-pass filter was used.

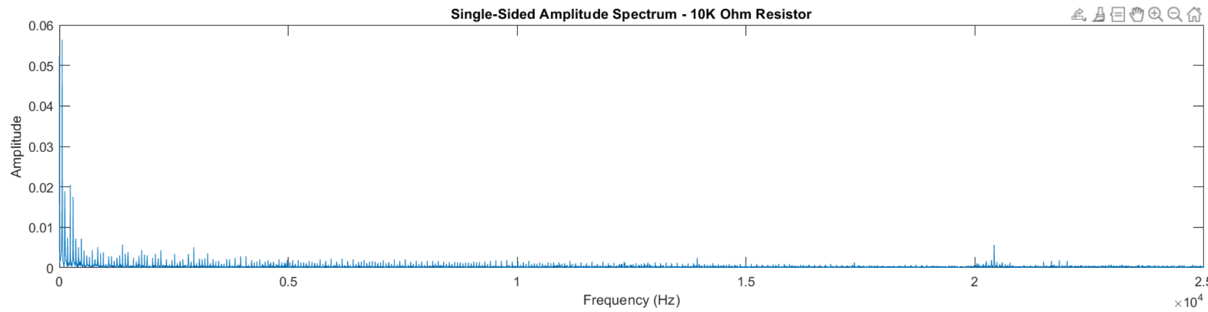


Figure-9: Single-Sided amplitude spectrum for the unfiltered ECG data

The Matlab function “fir1” was used to generate an FIR low-pass filter with a cut-off frequency of 310 Hz and a filter order of 30. Figure 10 and figure 11 display the magnitude and phase responses of the filter, and figure 12 shows the resulting filtered signal. After filtering the unwanted noise, we see a periodic waveform that contains a P wave, QRS complex, and a T wave. Although as seen in Figure 12, our P waves seem to be very high, and our Q and S downward deflections seem to be deeper compared to those of a standard ECG waveform.

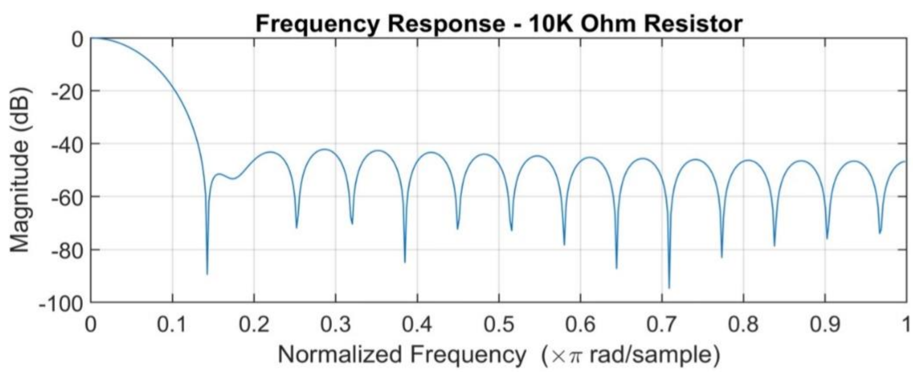


Figure-10: Magnitude response of the low-pass filter.

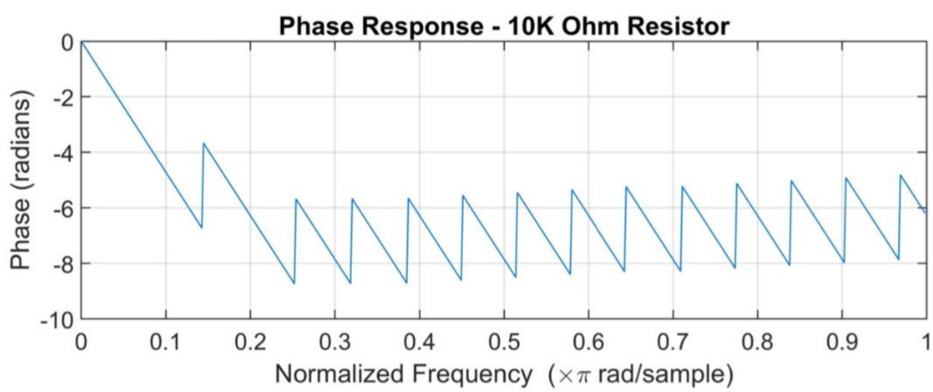


Figure-11: Phase response of the low-pass filter.

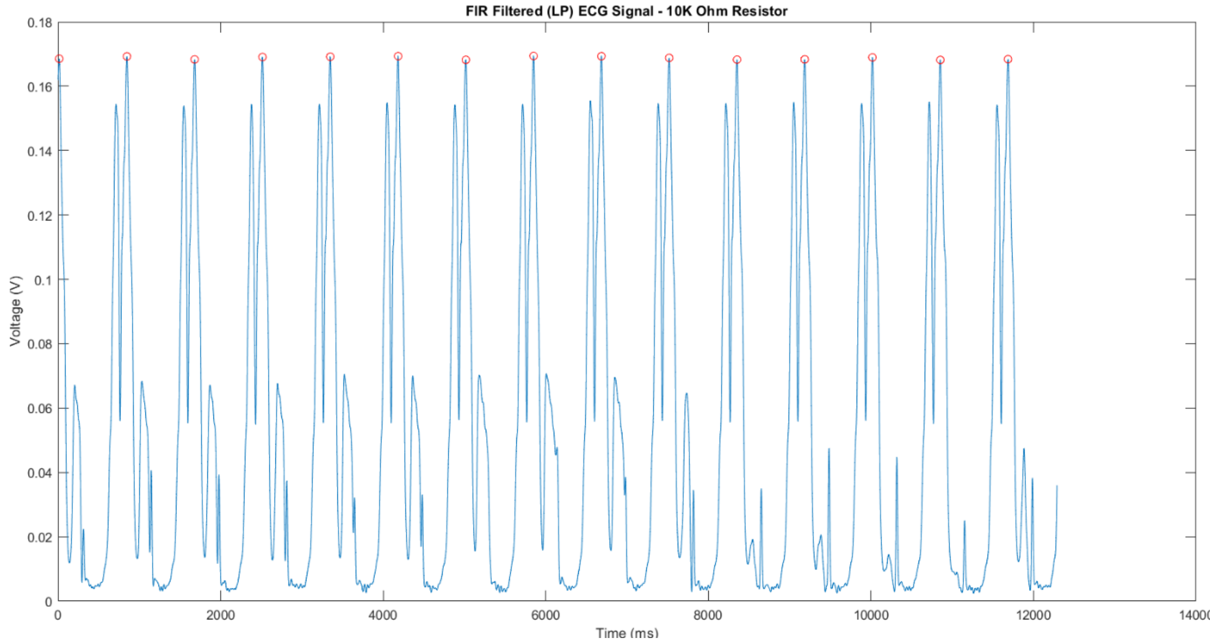


Figure-12: Filtered ECG signal using a low-pass filter.

The same filtering process was done using 4.7kΩ, 470Ω, and 150Ω resistors in the acquisition circuit, adjusting the cut-off frequency as needed based on their single-sided magnitude spectrums. The outputs from the 4.7kΩ and 470Ω resistor circuits produced signals similar to that of the 10kΩ resistor circuit (Figure-13 and Figure-14). However, the signal for the 150Ω resistor, after filtering, did not match the standard waveform of a cardiac cycle (Figure- 15).

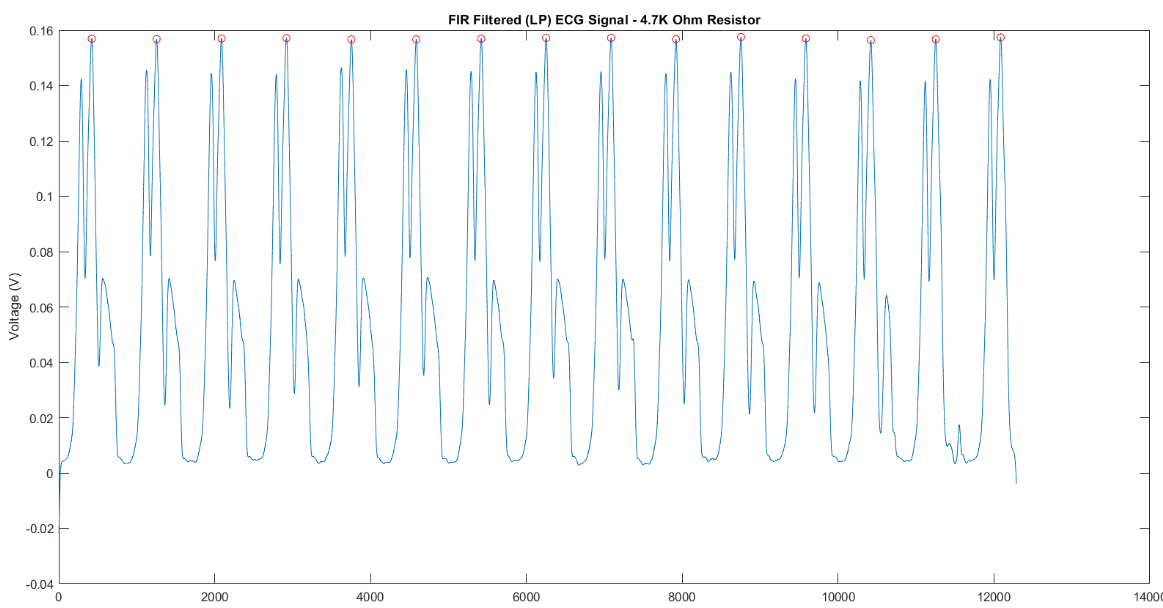


Figure-13: ECG data obtained from the acquisition circuit using a 4.7kΩ resistor after lowpass filtering.

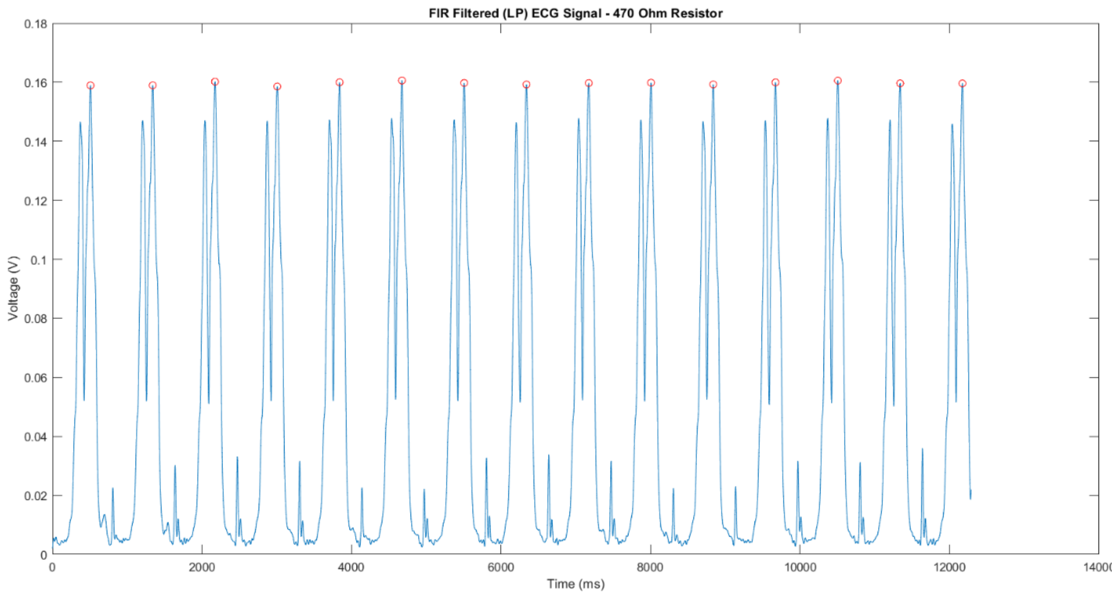


Figure-14: ECG data obtained from the acquisition circuit using a 470Ω resistor after lowpass filtering.

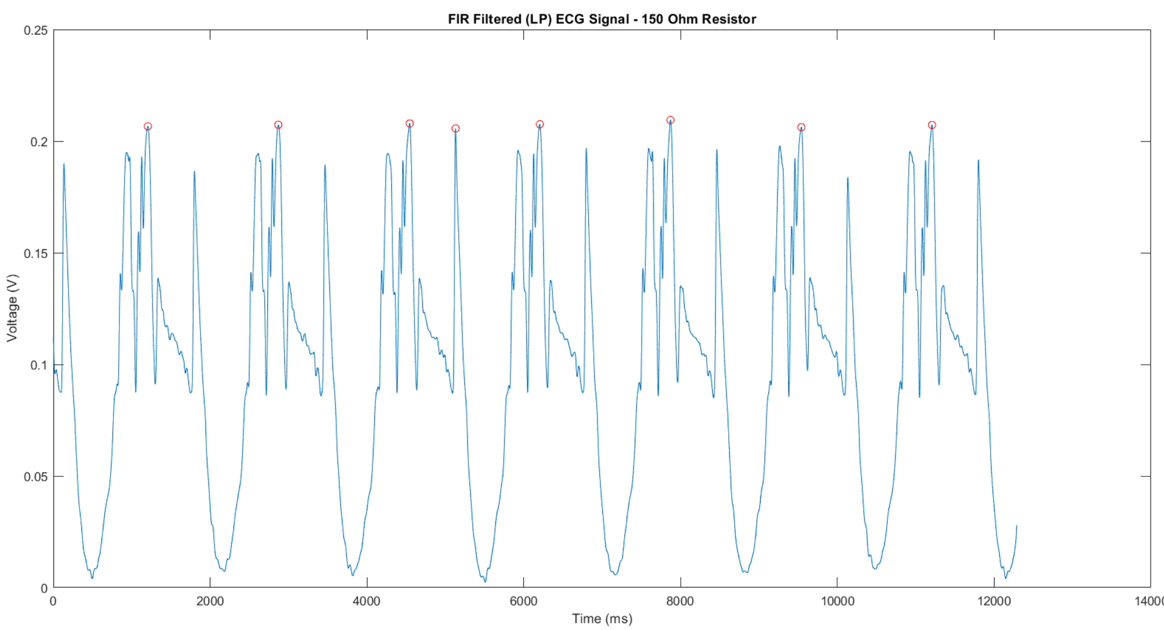


Figure-15: ECG data obtained from the acquisition circuit using a 150Ω resistor after lowpass filtering.

Using the filtered ECG data, we then calculated heart rate based on the R peaks. The Matlab function "findpeaks" was first used to detect all the R peaks within the filtered ECG signal, which are plotted in red as shown in Figure 12. The time interval between two adjacent R peaks ($t_{RR}$) was then found and converted from milliseconds to seconds. Here x(2) and x(1) are two adjacent R peaks and the difference of these gave us the interval between consecutive R peaks. To calculate heart rate, we multiplied the reciprocal of that interval by 60 seconds to get the number of heart beats per minute. The heart rate estimated from each data set acquired from the circuit using different resistor values is listed in Table 1.

$$t_{RR} = x(2) - x(1) \text{ (ms)}$$

$$t_{RR} = t_{RR} \times 10^{-3} \text{ (s)}$$

Heart Rate:

$$HR = 1/t_{RR} \times 60 \text{ (bpm)}$$

Table-1: Heart rates calculated from data obtained from the acquisition circuit using different resistor values.

| Resistor Value | Heart Rate |
|---|---|
| 10kΩ | 72.03 bpm |
| 4.7kΩ | 72.03 bpm |
| 470Ω | 72.12 bpm |
| 150Ω | 36.06 bpm |

Heart rate of 72 bpm is within the range of the regular heart rate of a healthy human. This value was achieved when the data acquisition circuit utilized resistor values such as 470Ω, 4.7kΩ, and 10kΩ. The heart rate calculated from the data acquisition system that utilized 150Ω resistor, gave a very low heart rate value which can be considered as an incorrect value.

Table-2. Gain values obtained from the data acquisition circuit for various resistor values.

| Resistor Value | Gain |
|---|---|
| 10kΩ | 5.94 |
| 4.7kΩ | 11.5106383 |
| 470Ω | 106.106383 |
| 150Ω | 330.333333 |

As can be seen from Table-2, gain increases as the resistance value decreases. One con to decreasing the resistance is that the signal worsens and noise increases. It can be seen in the above graph of 150 Ω, it has one of the worst signal representation out of four graphs that we obtained with four different resistors.

## Conclusion:

In conclusion, the signals that were filtered using Matlab provided a better and clearer ECG signal once the interfered noise has been removed. Aside from that, it has been observed that the higher the resistor value of the data acquisition circuit, the noisier the collected signal is. On the other hand, lower resistance value provides higher gain. It was also observed that the very low resistor value, such as 150Ω, provided incorrect value for the heart rate. The reason can be due to the speed of data collection, and it can be concluded that for this system low resistor values will not be useful.. Using extremely low resistor values out of range might provide incorrect or noisier data that will not be useful even if low resistance value provides high gain value.

**References:**

[1] Pflanzer, R., & McMullen, W. (n.d.). *Electrocardiography (Ecg I) Introduction*. BIOPAC SYSTEMS. Retrieved August 27, 2013, from L05%20ECG%20Introduction.pdf.

**Appendix:**

```
clear all
close all
clc


%% 4.7K Ohm Resistor
%Import and plot raw ECG data
data = readmatrix('4.7 kohm ECG signal.csv'); %imports data from Excel into a matrix
A = data(:,2); %extracts just the voltage values (col #2)
figure
subplot(2,1,1)
plot(A)
title('Raw ECG Signal - 4.7K Ohm Resistor')
xlabel('Time (ms)')
ylabel('Voltage (V)')

%Generate frequency magnitude and phase spectra using FFT
fs = 50000; %sampling frequency (Hz)
L = length(A); %length of signal
y = fft(A);
ds = abs(y/L); %double-sided amplitude spectrum
ss = ds(1:(L/2)+1);
ss(2:end-1) = 2*ss(2:end-1); %single-sided amplitude spectrum
f = (0:L/2)*fs/L; %frequency axis in Hz
subplot(2,1,2)
plot(f,ss)
xlabel('Frequency (Hz)')
ylabel('Amplitude')
title('Single-Sided Amplitude Spectrum - 4.7K Ohm Resistor')

%FIR lowpass filter
fn = fs/2; %Nyquist frequency
fc = 100; %cut-off frequency
n = 50; %filter order
b = fir1(n,fc/fn);
z = filtfilt(b,1,A);
figure
plot(z)
title('FIR Filtered (LP) ECG Signal - 4.7K Ohm Resistor')
xlabel("Time (ms)")

ylabel("Voltage (V)")



%Detect R peaks
[pk,x] = findpeaks(z,'MinPeakHeight',0.15); %finds all peaks w/ amplitudes >=0.15 V; stores their indices in vector x
```

```
hold on
plot(x,pk,'ro')


%Computing heart rate
t_RR = x(2)-x(1); %interval b/w 2 adjacent R peaks (in milliseconds)
bpm = (1/(t_RR*10^(-3)))*60 %heart rate (beats per minute)

%Frequency and phase response of lowpass FIR filter
figure
subplot(2,1,1)
freqz(b) %frequency response
title('Frequency Response - 4.7K Ohm Resistor')
subplot(2,1,2)
phasez(b) %phase response
title('Phase Response - 4.7K Ohm Resistor')
```