Laboratory Report 15 & 16
ECG Circuit Analog Filtering and A/D Conversion [1]
Digital Signal Manipulation of the ECG Signal [2]
EECE 2150

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1 Introduction

In these two labs we have worked on creating our own ECG measuring device as well as filtering captured ECG signals both with analog filters and digitally in MATLAB.

2 Results

2.1 Lab 15

2.1.1 High Pass Filter

First step in our analog filtering was to create a high pass filter. It is necessary to strip our signal from all DC components produced by the operation of our electric circuit. To do this, we have used the AD627 chip to build a high pass filter. Since we wanted to cut off the lowest possible frequencies, we picked our cutoff frequency to be $f_c \leq 2Hz$. In order to achieve this goal, we have picked the following components to build the circuit:

Component	Value
Capacitors	$4x0.826\mu F$ (4 in parallel)
R	$297k\Omega$
R_f	$293k\Omega$

This setup achieves the cutoff frequency we need

$$f_c = \omega_c/2\pi = \frac{\frac{1}{RC}}{2\pi} = \frac{1}{4 \cdot 0.826 \cdot 297 \cdot 10^{-3}} \div 2\pi \approx \boxed{0.161Hz}$$

The gain of this filter was chosen to be 1, since we decided to use gain on the next filter.

2.1.2 Low Pass Filter

The next step in filtering was to add a Low-Pass Filter in order to remove high-frequency noise that is not necessary for ECG signal. We have selected to recreate filter from the manual shown on *Figure TK*. After discussing with professor, we have agreed that since valuable frequencies for ECG signal go up to $400Hz$, we should select the cutoff frequency to be $f_c = 400Hz$ as well. Then, we selected the following components for our circuit:

Component	Value
Capacitor	$0.002\mu F$
R	$200k\Omega$
R_s	$200k\Omega$

Demonstration The final setup used for the lab is shown on *Figure 1*

2.1.3 Acquiring ECG Signal

Next, we have used our circuit in order to acquire first ECG signal on the scope in order to test our filters before collecting samples for further digital filtering. However, our signal still remained quite noisy (*Figure 2*), so we have discussed it with professor and agreed that we should attempt to add gain to the circuit in order to get rid of some noise. Since we aimed for the output voltage of both filters to be around $V_{out} \approx 1V$, we have changed the resistor R in our *Low Pass Filter* in order to achieve a gain of approximately $A \approx 40$ from $R = 200k\Omega$ to $R = 7.8M\Omega$ since $A = \frac{7.8M}{200k} = \boxed{39}$.

This has helped us to achieve a much cleaer signal shown on *Figure 3*

2.1.4 Acquiring ECG Signal using the NI A/D

The final step of this lab was to record several samples for further investigation in MATLAB using NI A/D. The circuit connected to A/D is shown on *Figure TK* and all the samples we collected are on *Figure 4-Figure 10*. We have also scaled the last signal - *Figure 11*.

2.2 Lab 16

In this lab we have used one of the samples collected in the end of *Lab 15*, specifically *Figure 10* and continued our analysis using digital filtering in MATLAB. Specifically, we have decided to attempt *Exercise 1* and *Exercise 2*

Why do you think the second vector is [1 0]? - This vector is [1 0] in flipmord refers to amplification. Since we don't need our signal to be amplified, we leave the first number as **1**. Flipmord also allows us to amplify the frequencies we filter out. Since we want these frequencies to be completely cut from the cignal, we set the second number to **0**. Hence, this vector is **[1 0]**.

The code used for MATLAB filtering is shown on *Listing 1*, the results of the first filter (Parks-McClellan) is shown on *Figure 11*.

We did not see a lot of difference after we have applied digital filters to out recorded signal. However, after we discussed it with professor, we were told that our analog filters did their job well enough for additional filtering to have much smaller effect than anticipated. The final filtered signal is shown on *Figure 12*.

3 Discussions and Conclusions

Conclusion In these two labs we have finished our studies of electric signals in this semester by creating a basic ECG measuring device.

References

[1] Dr. Iman Salama, Northeastern University (2021a). *Lab 15 - ECG Circuit Analog Filtering and A/D Conversion*.

[2] Dr. Iman Salama, Northeastern University (2021b). *Lab 16 - Digital Signal Manipulation of the ECG Signal*.

Appendices

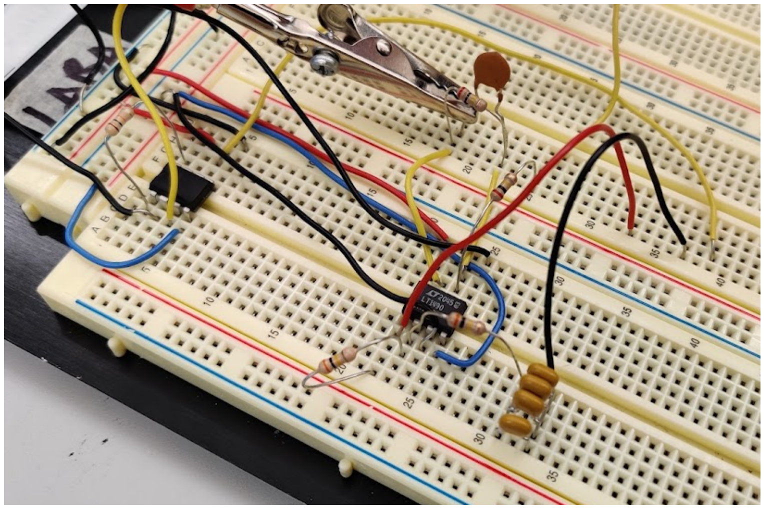

Figure 1: Analog Filter Setup

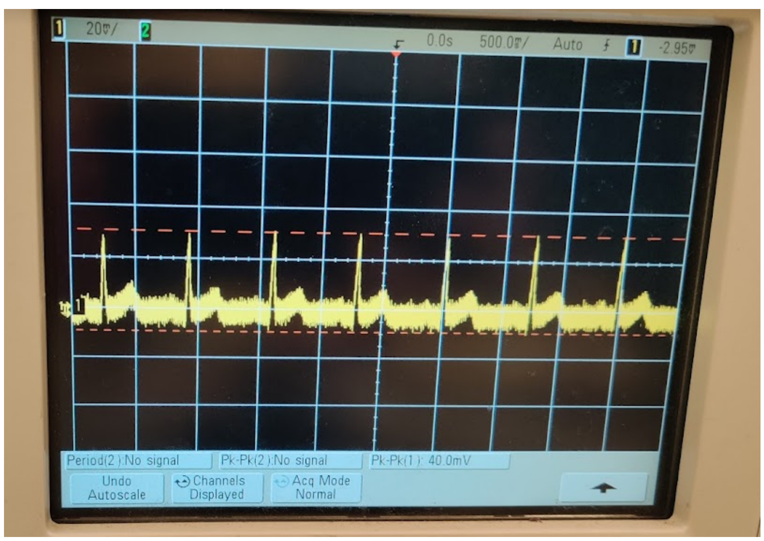

Figure 2: Initial Analog Filtering

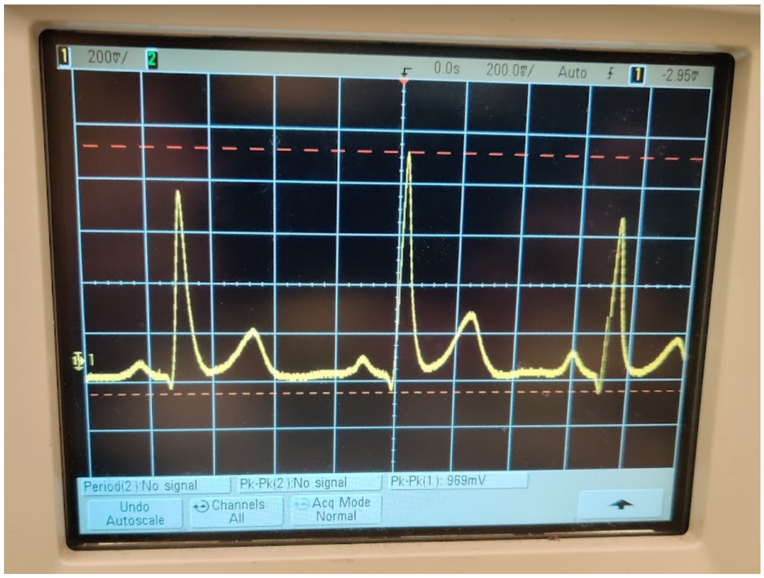

Figure 3: Analog Filtering with Amplification

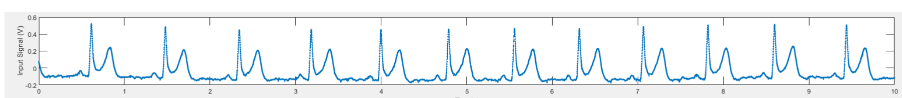

Figure 4: Lab 15, Sample 1, Subject A

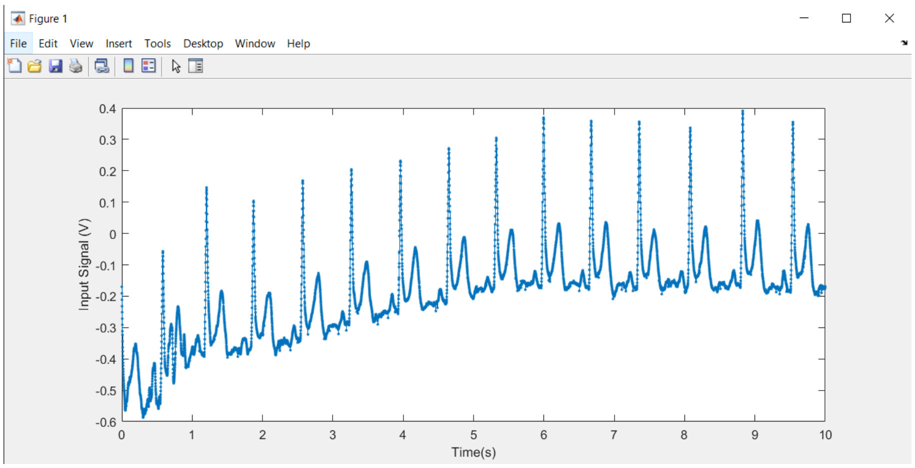

Figure 5: Lab 15, Sample 2, Slow Motion, Subject A

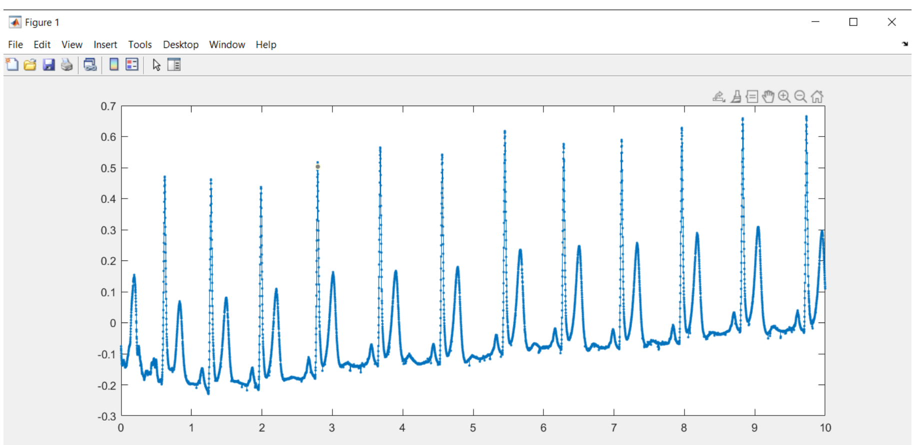

Figure 6: Lab 15, Sample 3, High Heart Rate, Subject A

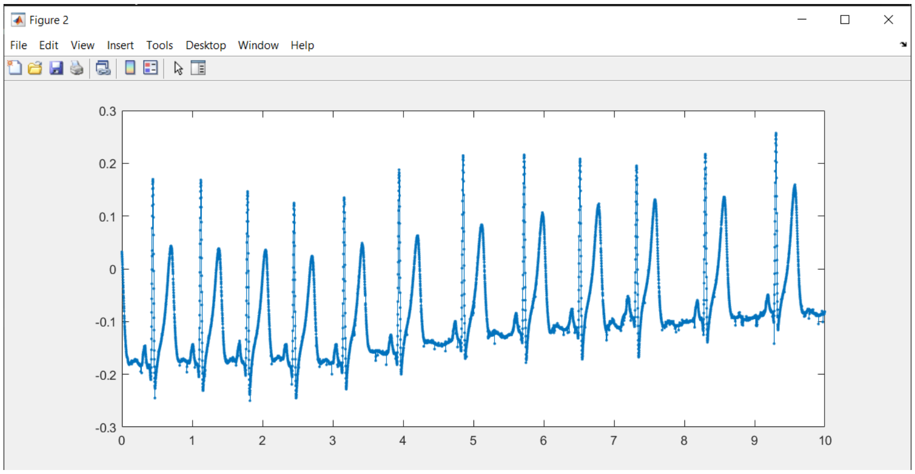

Figure 7: Lab 15, Sample 4, Subject B

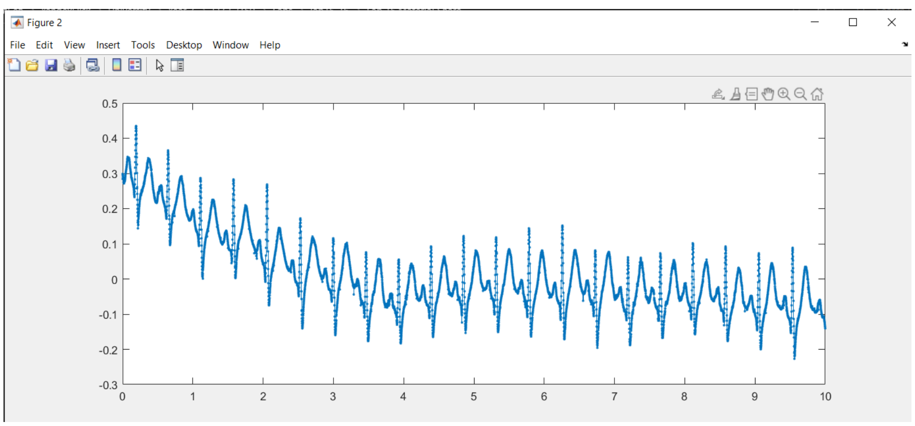

Figure 8: Lab 15, Sample 5, High Heart Rate, Subject B

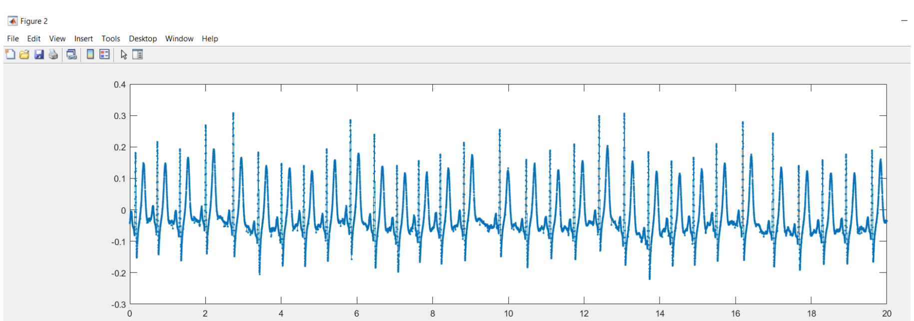

Figure 9: Lab 15, Sample 6, Long, Subject B

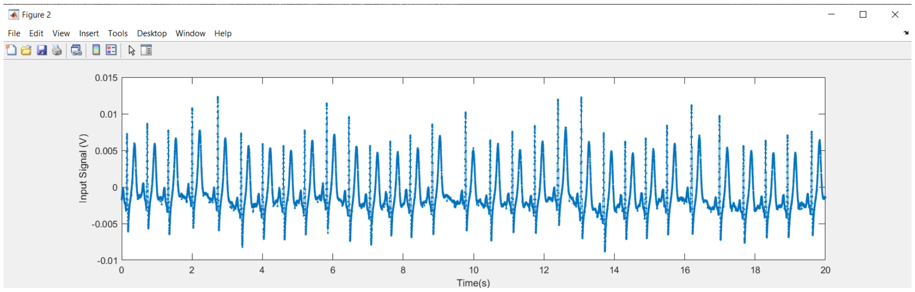

Figure 10: Lab 15, Sample 6, Long, Subject B, Scaled

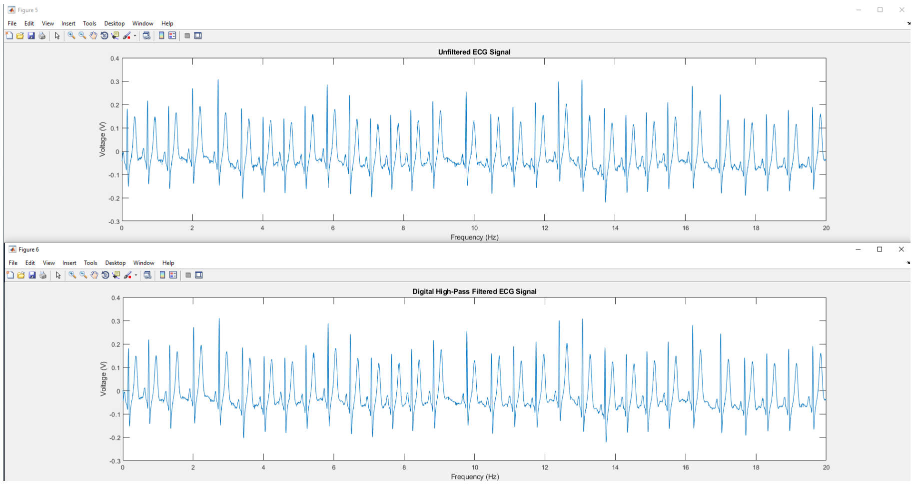

Figure 11: Lab 16, Parks-McClellan filter

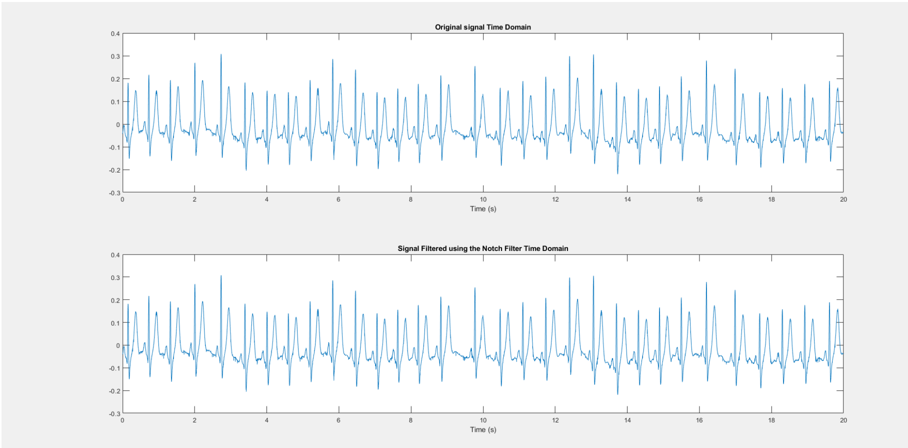

Figure 12: Lab 16, Final Filtered Signal

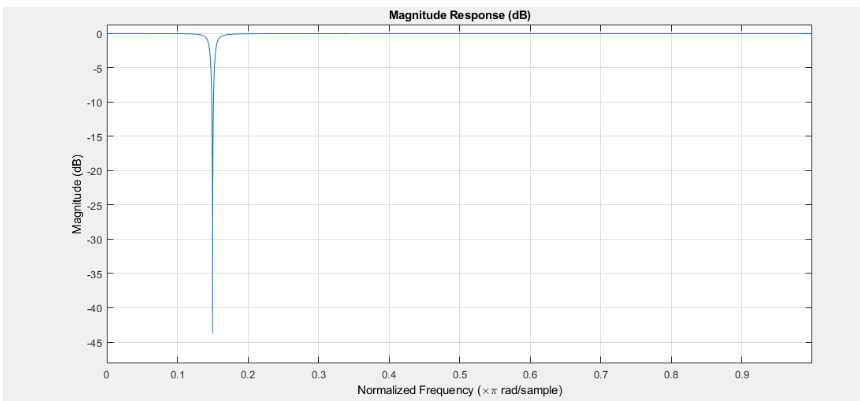

Figure 13: Lab 16, 60Hz Magnitude Response

Listing 1: Final Lab 16 Code

```
fs=800;
% finding the filter order
[n,fo,ao,w] = firpmord([250 350],[1 0] ,[0.01 0.05],fs);
b = firpm(n,fo,ao,w);
% Evaluating the frequency response using freqz
[H,f]=freqz(b,1,16000,fs);

open('lab_15_long.fig');
import = get(gca,'Children');
frequency = get(import, 'XData');
ecg_data = get(import, 'YData');
close;
a=1;
figure;
plot(frequency, ecg_data);
title("Unfiltered ECG Signal");
xlabel("Frequency (Hz)");
ylabel("Voltage (V)");

figure();
filtered_signal = filter(b,a, ecg_data);
plot(frequency, filtered_signal);
title("Digital High-Pass Filtered ECG Signal");
xlabel("Frequency (Hz)");
ylabel("Voltage (V)");

%Apply notch filter (Part 2)
wo=60/(fs/2);% normalized center frequency of the notch filter
bw=wo/20;    % Q is chosen to be 20
[b,a]=iirnotch(wo,bw);
fvtool(b,a); % plot the frequency response of the filter
ECG_signal_filtered=filter(b,a,ecg_data);
figure(2)
subplot(2,1,1)
plot(frequency,ecg_data);
title('Original signal Time Domain')
xlabel('Time (s)');
subplot(2,1,2);
plot(frequency,ECG_signal_filtered);
title('Signal Filtered using the Notch Filter Time Domain')
xlabel('Time (s)');
```