Lab 15: ECG

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EECE 2150 Circuits/Signals: Biomed Apps

Introduction

In this lab, an Electrocardiogram (ECG) was implemented using the instrumentation amplifier from the previous lab, followed by sequential high/low filters and gain steps. In the first part of this lab, an ECG signal was acquired using the instrumentation amplifier and this was viewed on the oscilloscope tool of the ADALM. In the following parts of this lab, the ECG signal was processed in the analog domain; the digital version of this ECG signal was then obtained for more processing in MATLAB (digital domain).

Part I – First Measurement of your ECG Signal

Q1: After observing the initial ECG signal on the oscilloscope, it was clear there is a lot of processing required to achieve a clean signal. The input signal from the electrodes was small, and barely any features could be seen; the output of the instrumentation amplifier (with a **gain of 25**) was similar, with very small features.

The electrodes were placed on the body in the following manner, with the leads of the electrodes connected to the instrumentation amplifier as specified.

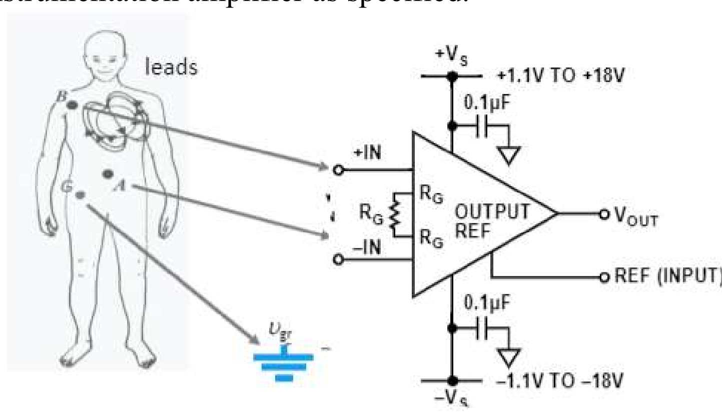

Figure 1. Electrode Pad/Lead Placement

Furthermore, the initial instrumentation amplifier resulted in the following initial signals:

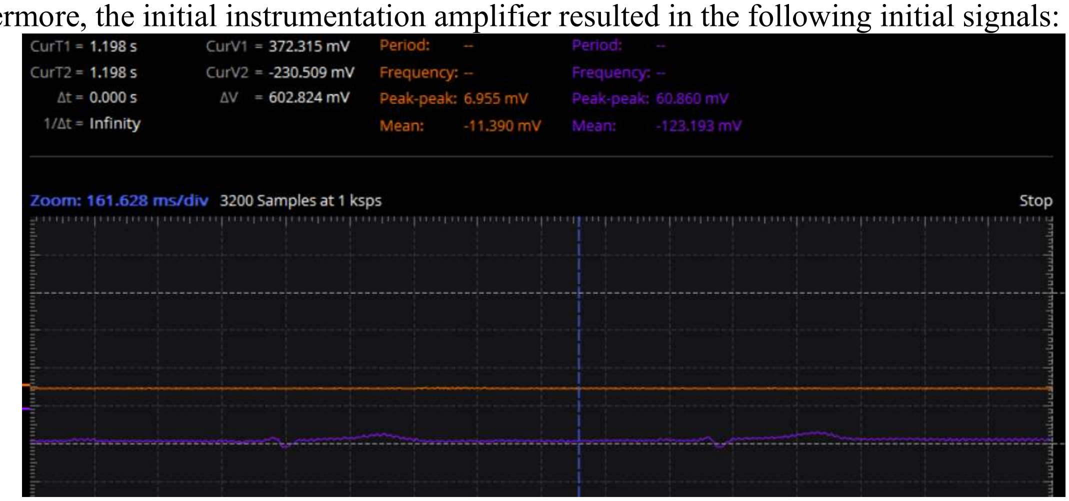

Figure 2. Initial Oscilloscope Trace

Part II – Circuit Design to Optimize the ECG Signal

Q2:

a.)

The values of R and C used for the high pass filter were 200 kΩ and 1 μF respectively. The resulting cut-on frequency for this high pass filter is as follows:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 200k\Omega \times 1\mu F} = \mathbf{0.8\ Hz}$$

$$\omega_c = f_c \times 2\pi = (0.8Hz) \times 2\pi = \mathbf{5}\ \left(\frac{\mathbf{rad}}{\mathbf{sec}}\right)$$

b.)

In the design process, a 1st order high pass RC circuit was chosen in order to keep the overall circuit simple yet effective. The cutoff frequency was set to 0.8 Hz because we want to amplify the signals above ~0.5 Hz, keeping the dominant frequency content of the signal; the specific resistor and capacitor components were chosen to suit this goal cutoff frequency.

In designing this filter, there were some tradeoffs to consider. If the cutoff frequency was too high, then the filter could reject important components of the ECG signal; if the cutoff frequency was too low, then the filter could amplify noise that isn't part of the desired signal. Furthermore, if the in-band gain was too high, then the resulting output signal could saturate the op-amps; if the in-band gain was too low, then the output signal may be too small to distinguish important features.

Q2 (Again):

Testing a cutoff frequency of 10 Hz:

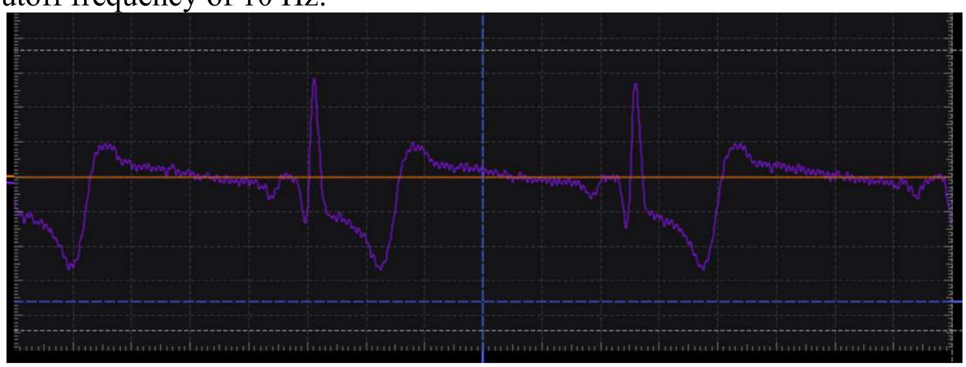

Figure 3. Testing 10 Hz Cutoff

Testing a cutoff frequency of 1000 Hz:

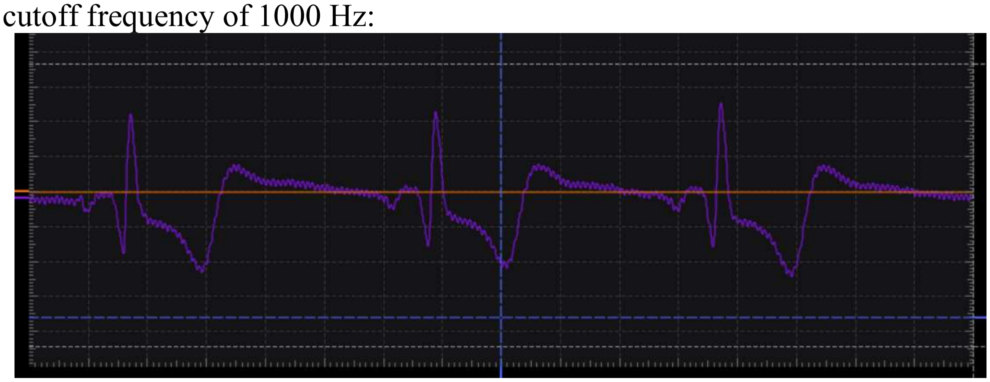

Figure 4. Testing 1000 Hz Cutoff

When the cutoff frequency is set to 10 Hz, the output ECG signal is less noisy and has a slightly smaller amplitude than the output ECG signal when the cutoff frequency is set to 1000 Hz.
The final cutoff frequency was set to be **33.8 Hz**. This was chosen because we want to amplify the signals below ~30 Hz to keep the dominant frequency content of the ECG signal. To obtain this cutoff frequency, R and C values of 4.7 kΩ and 1 μF were used respectively. The cutoff frequency for this low pass filter is calculated as follows:

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 4.7k\Omega \times 1\mu F} = \mathbf{33.8\ Hz}$$

$$\omega_c = f_c \times 2\pi = (33.8\ Hz) \times 2\pi = \mathbf{212.4}\ (\frac{\mathbf{rad}}{\mathbf{sec}})$$

The following figure shows the ECG signal after processing with high/low filters.

Figure 5. Final Circuit, ECG Signal

Using the signal generator, the upper and lower cutoff frequencies were determined to be ~35 Hz and ~1 Hz respectively, which are close to the design frequencies.

Q3:

The following figure includes a diagram describing the flow of the ECG circuit. The circuit begins with the AD627 (instrumentation amplifier), and passes the signal onto the high pass filter, low pass filter, and a gain phase before resulting in the final output.

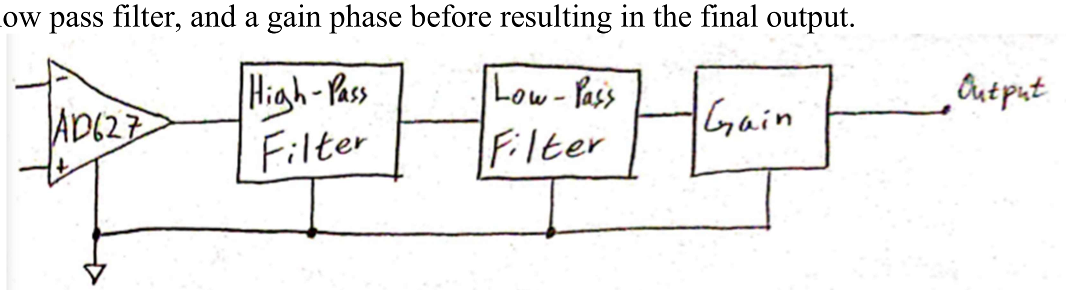

Figure 5. Circuit Flow Diagram

The following figure is the circuit diagram of the final ECG circuit; see *Figure 8* for exact resistor and capacitor values. The +IN/-IN (inputs) in this circuit were from the electrode leads and every ground connection shown is to a **common ground**. Also, the $+V_s$/$-V_s$ was established through 1.5 V batteries.

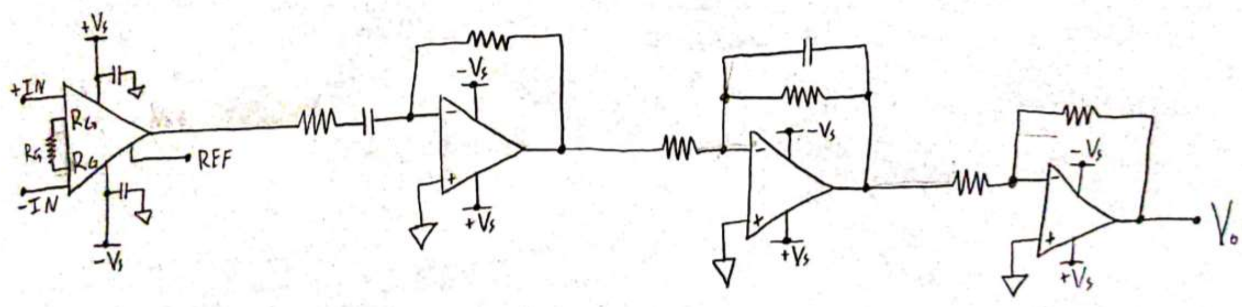

Figure 6. ECG Circuit Diagram

Finally, the physical circuit created through this lab is in the following figure. In this image, the oscilloscope leads and external batteries were excluded in order to decrease the complexity and make the photograph more understandable.

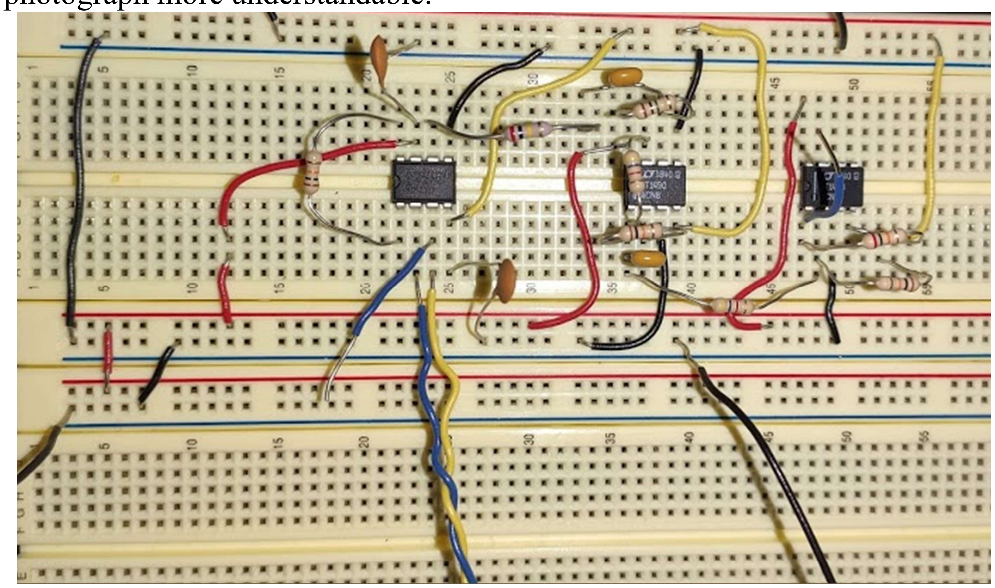

Figure 7. ECG Circuit

Why do we remove high frequency noise before A/D conversion?

High frequency noise must be removed before the A/D conversion because (if the sampling frequency is too low) aliasing of the signal will occur, with some of the high frequency noise appearing as low frequency noise in the digital representation.

What is the purpose of bypass capacitors?

The purpose of bypass capacitors is to filter the power supply, achieving a cleaner signal. However, after incorporating bypass capacitors into my circuit, the output signal did not have any less noise than before; because of this, it was decided to leave the bypass capacitors out of the final circuit.

Part III – Optimize the ECG Signal

<u>Q4:</u>

The circuit was working as expected at this stage of the lab, so the main changes made in order to get the best ECG signal was keeping muscles still and holding breath while acquiring data. The following circuit diagram shows the resistor and capacitor values used in the circuit to acquire the desired cutoff frequencies and gain stages, resulting in an output signal that "filled" the ±1.5 V.

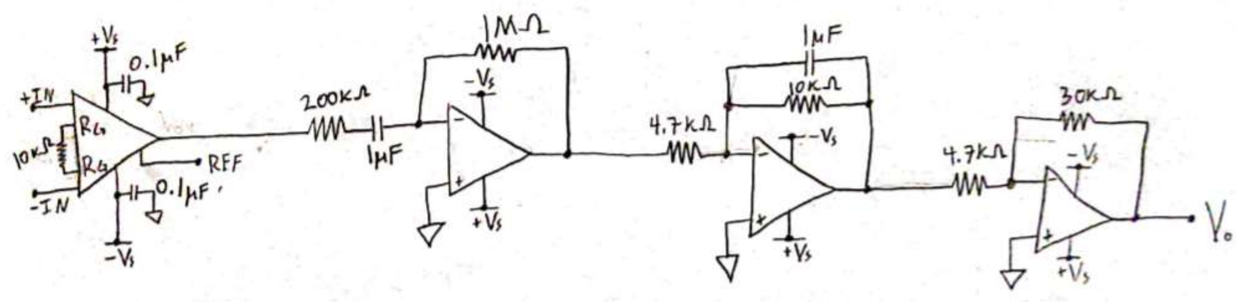

Figure 8. Final ECG Circuit Diagram

Furthermore, the three following figures are all images of this circuit implemented on the breadboard. Multiple images of this circuit were included for clarity. In these images, the oscilloscope leads and external batteries were excluded in order to decrease the complexity and make the photographs more understandable.

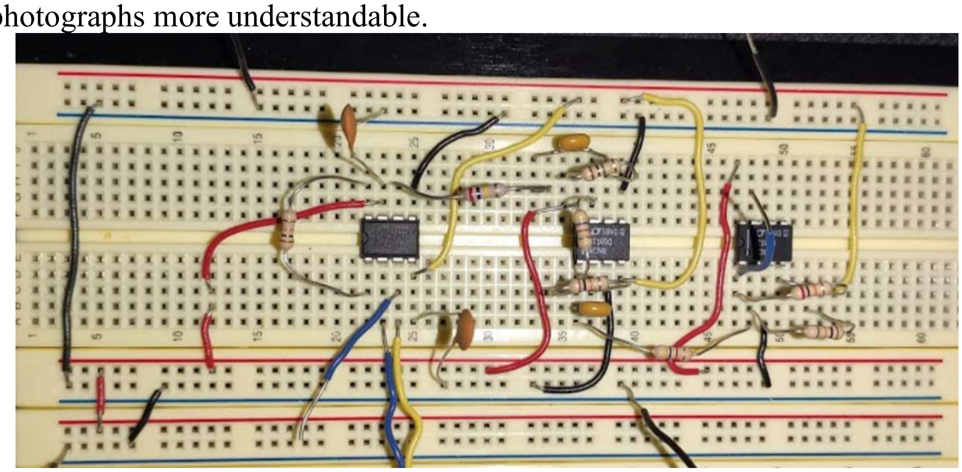

Figure 9. Final ECG Circuit, Part 1

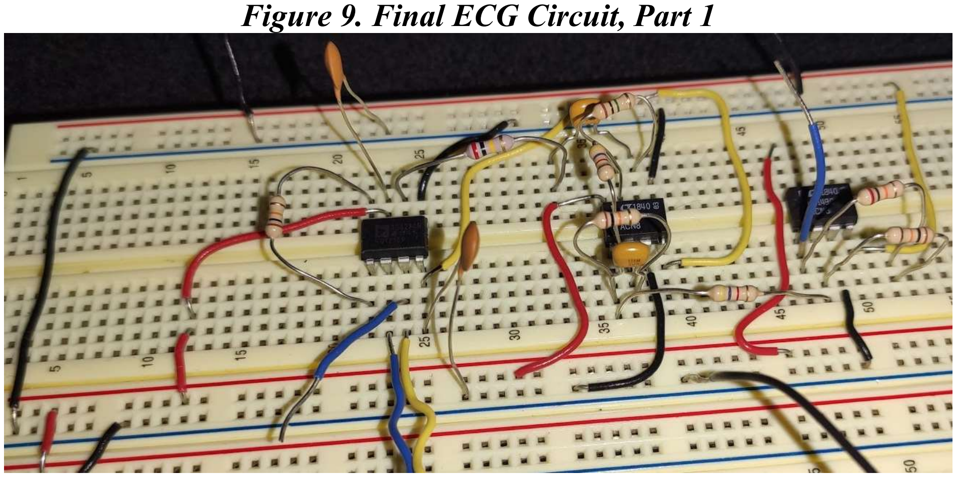

Figure 10. Final ECG Circuit, Part 2

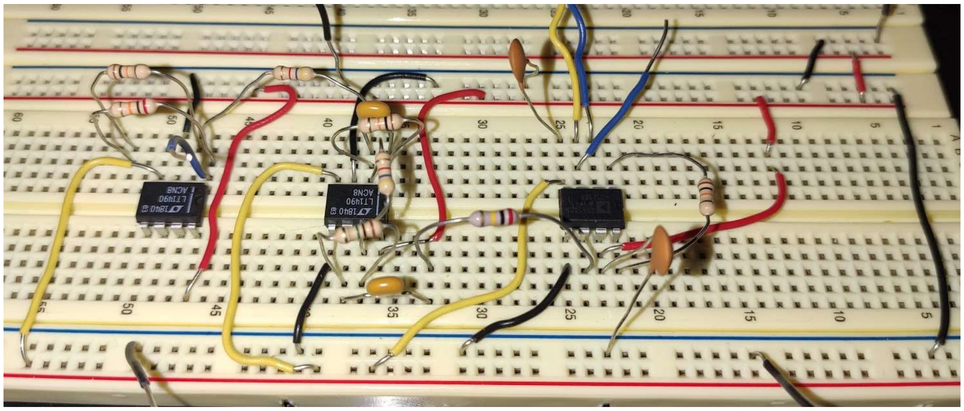

Figure 11. Final ECG Circuit, Part 3

Part IV – Acquire ECG Signals Using Scopy

<u>Q4 (Again):</u>

The signal acquired through the created ECG circuit was plotted on axes scaled in units of volts and time. The following plot is the result of plotting the ECG signal—the voltage as recorded by the A/D.

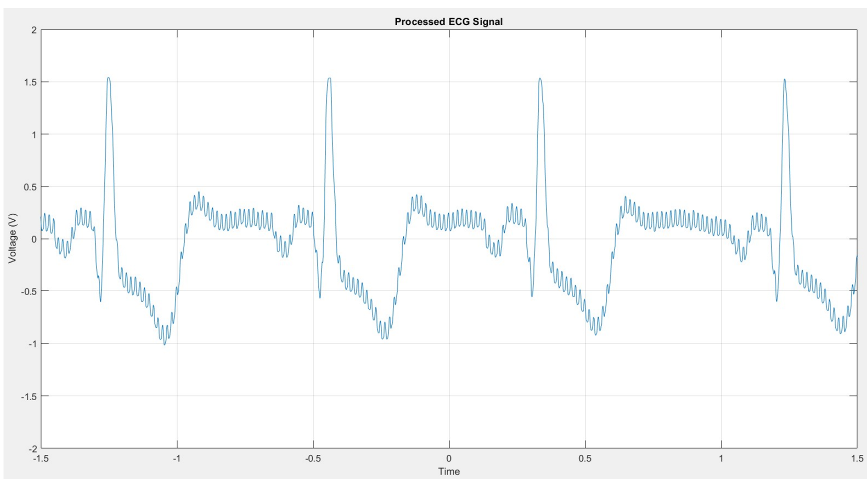

Figure 12. ECG Signal from Scopy

Additionally, the following plot is the result of plotting the actual voltage at the input electrodes.

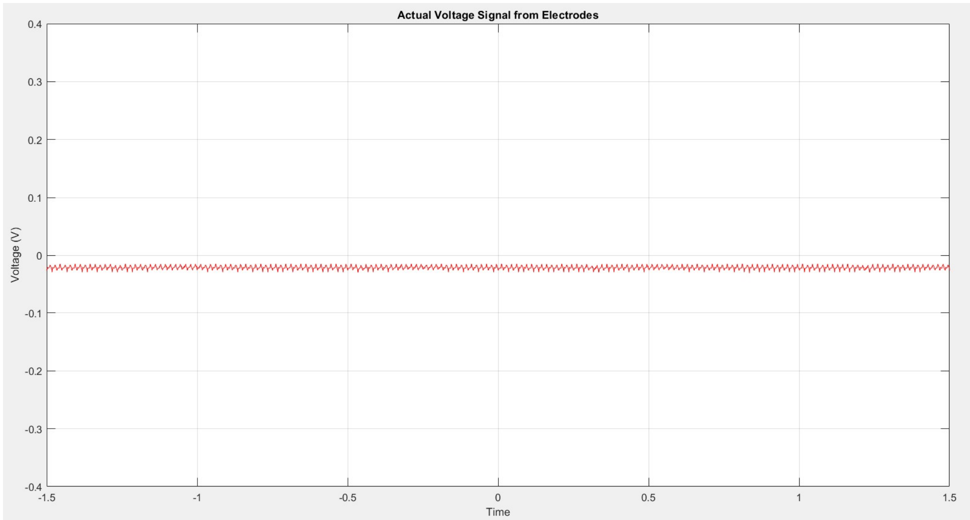

Figure 13. Actual Voltage at Electrodes

From the plots shown in *Figure 12* and *Figure 13*, we see the stark difference between the initial input signals (directly from the electrodes) and the output ECG signal.

Conclusion

Through this lab, experience was gained in the following: implementing instrumentation amplifiers, implementing high/low filters, circuit design, and signal processing (specifically with ECG signals). Using the instrumentation amplifier, high and low active filters, and gain steps, we were able to achieve a clean ECG signal. Overall, this lab was an effective assignment to learn the material and to gain a deeper understanding of circuit design.