Lab 15-16

ECG Circuit – Analog Filtering and A/D Conversion & Digital Signal Manipulation of the ECG signal

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1. Introduction

The purpose of this lab has three parts: the first part is to remove the DC signal components of the signal and the high-frequency noise. The second part is to acquire the ECG signal. The last part is to use MATLAB to build a digital filter and analyze the acquired signal and find some parameters of the signal. In general, in this lab, we have carefully processed the ECG signal in the analog domain to reduce noise and prepared it for analog to digital conversion and then acquired a sampled (digital) version of your ECG signal in MATLAB using the NI USB-6001

2. Results

Part I:

Remove DC signal components:

To remove the DC component of the signal coming out of the AD627 chip we used a high-pass filter. The high-pass filter circuit looks like Fig. 1.

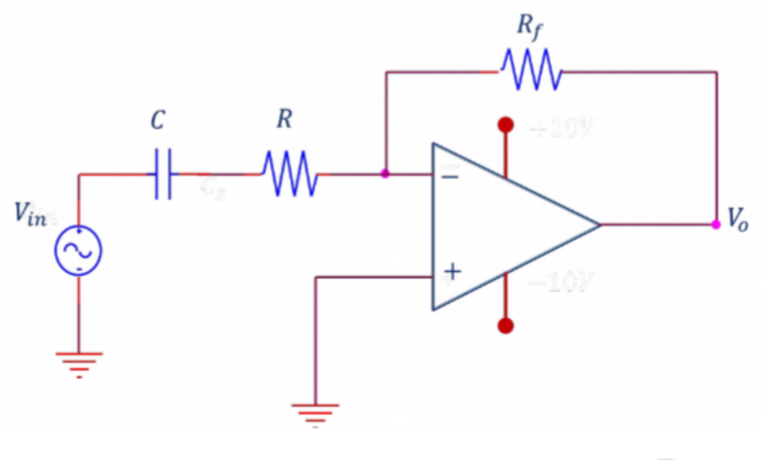

Fig. 1 High-pass filter circuit

In this circuit, we assumed the value of RC is 0.32, C is $0.1\ \mu F$, R is $320\ k\Omega$, and the gain is 1. We use $300\ k\Omega$ resistor to replace R. As a result, cut-on frequency ω_c in rad/s and f_c in Hz are given by:

$$\omega_c = \frac{1}{RC}$$
$$f_c = \frac{1}{2\pi RC}$$

The value of ω_c was calculated as 3.125 rad/s, and the value of f_c was calculated as 0.5 Hz. The circuit's ability to function as a high-pass filter is due to the capacitor C's frequency-dependent impedance, which blocks low-frequency signals while allowing high-frequency signals to pass. The operational amplifier ensures that the filtered signal is amplified and appears at the output.

We test the circuit with a sine wave with 0.1 Hz in frequency and 500 mV in amplitude. The output wave was displayed in oscilloscope and shown in Fig. 2.

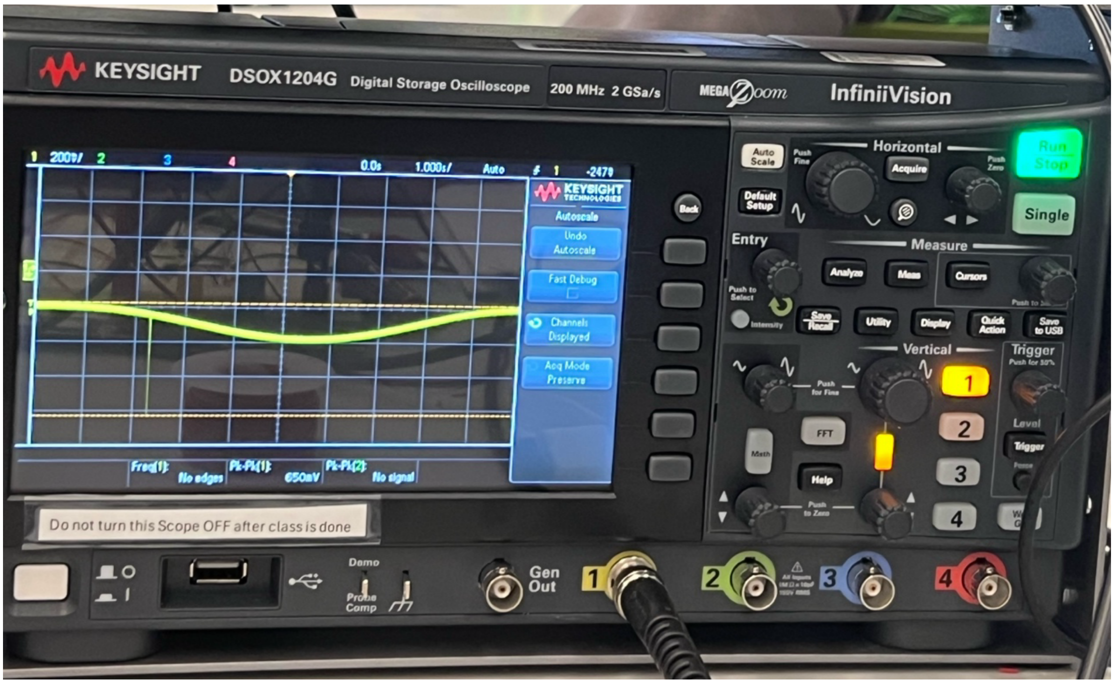

Fig. 2 Output of high-pass filter with frequency under the cut-on frequency

According to the figure, we could calculate the gain by formula: $A = \frac{V_{out}}{V_{in}}$, and the value agreed with the expectation. We also tested the frequency lower than cut-on frequency, and found the gain was increasing depending on the increase of the frequency of input wave. The result of tests could prove the circuit can work correctly as a high-pass filter to remove the DC signal components.

Removal of high-frequency noise:

To remove the high-frequency noise of a signal, we should use a low-pass filter. We connected a circuit on the protoboard like circuit shown in Fig. 3.

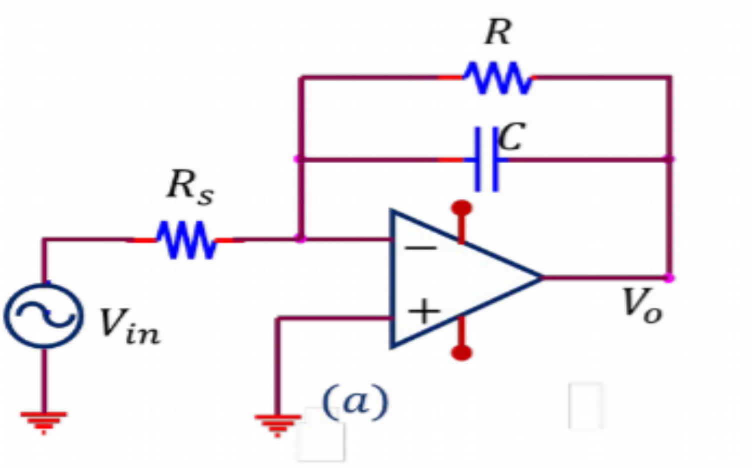

Fig. 3 Low-pass filter circuit

And the circuit on protoboard was displayed in Fig. 4

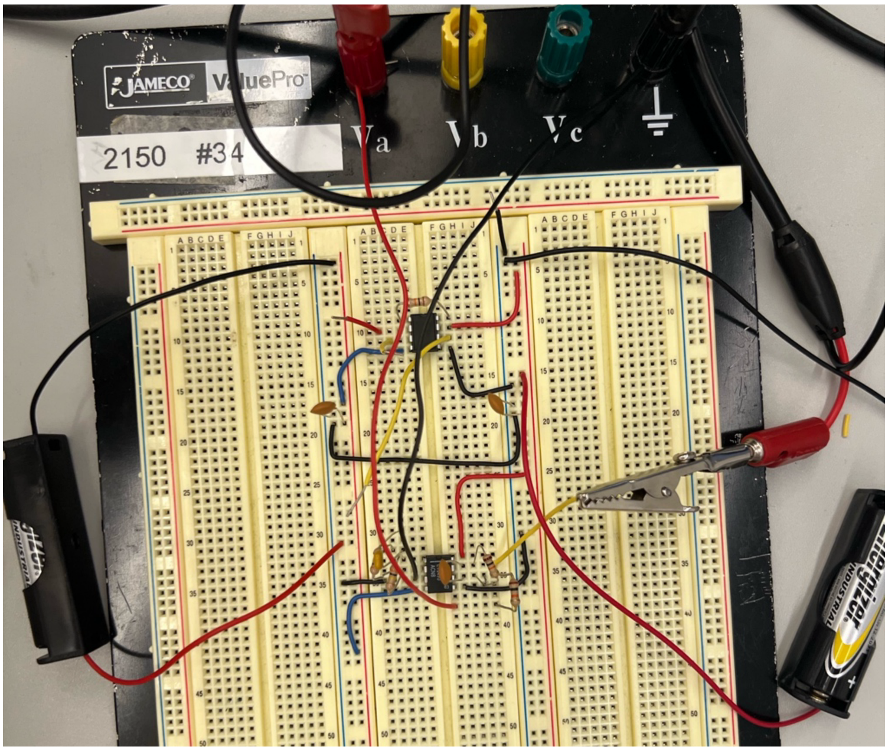

Fig. 4 Circuit on protoboard

We assumed the cut-off frequency f_c was 159 Hz. Moreover, the value of capacitor C is $0.1\ \mu F$, R is $10\ k\Omega$, and gain is 1. Therefore, the value of R_s is also $10\ k\Omega$.

In this circuit, the gain was calculated as:

$$Gain = \frac{V_{out}}{V_{in}} = -\frac{R}{R_s}$$

We tested the circuit. When the input signal was lower than cut-off frequency, it can pass the circuit.

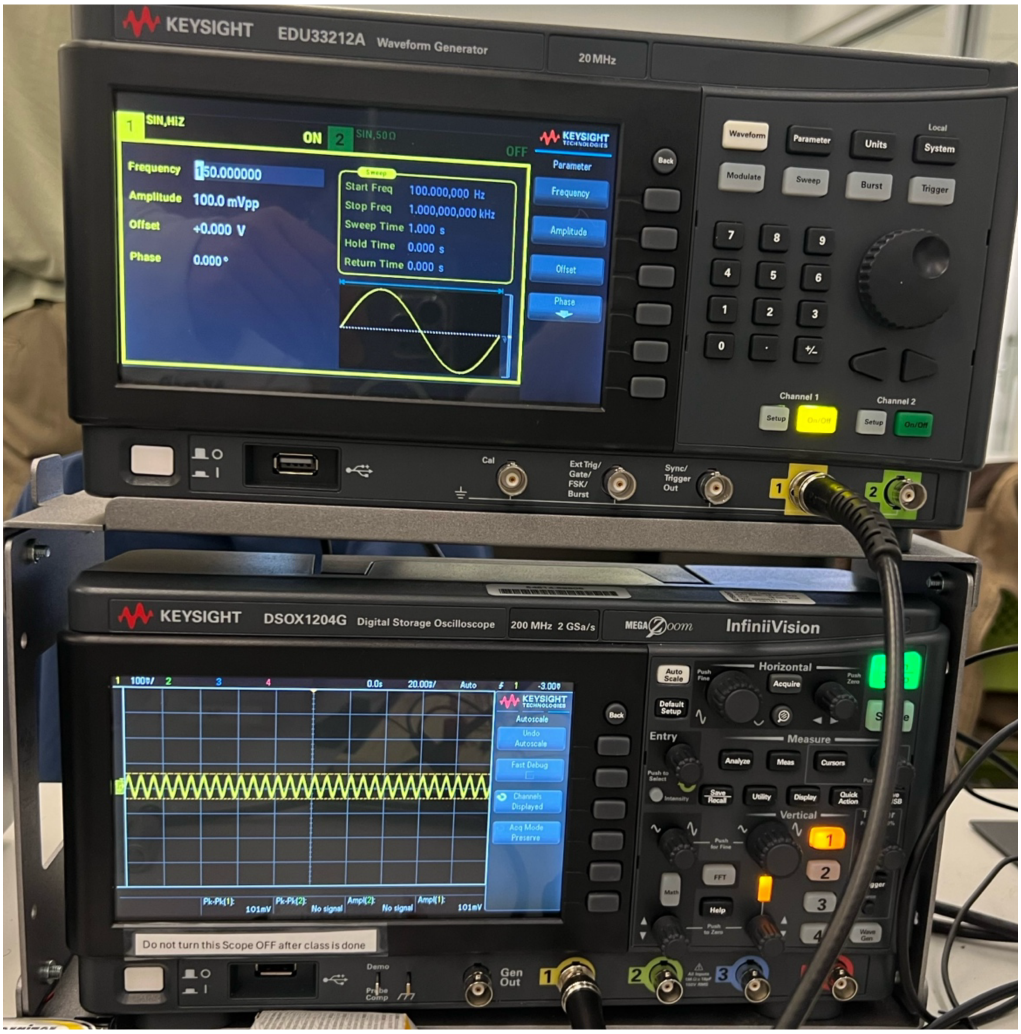

Fig. 5 Output signal with frequency lower than cut-off frequency

When the input signal was higher than cut-off frequency, it cannot pass the circuit, and the value of gain was decreased when frequency increased.

Fig. 6 Output signal with frequency higher than cut-off frequency

The results of tests agreed with expectation and proved that the circuit worked correctly as a low-pass filter.

Part II:

Use the above circuit, we acquire the ECG signal, and the graph was displayed on the oscilloscope and shown in Fig. 7.

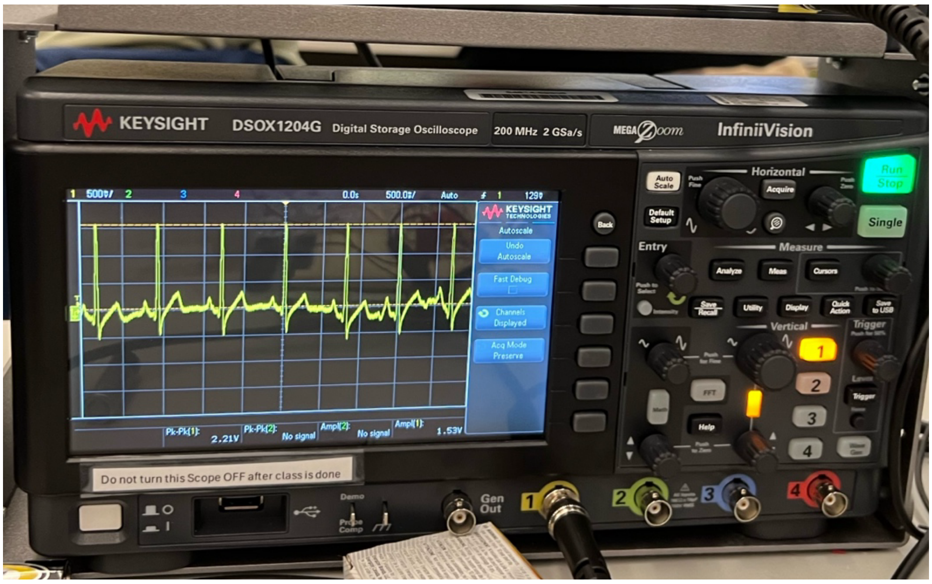

Fig.7 ECG signal

Part III:

Acquire the ECG signal with the NI-USB-6001 in MATLAB. First of all, design a Parks-McClellan filter using the loss-pass filter, and the figure was displayed in MATLAB shown in fig.8.

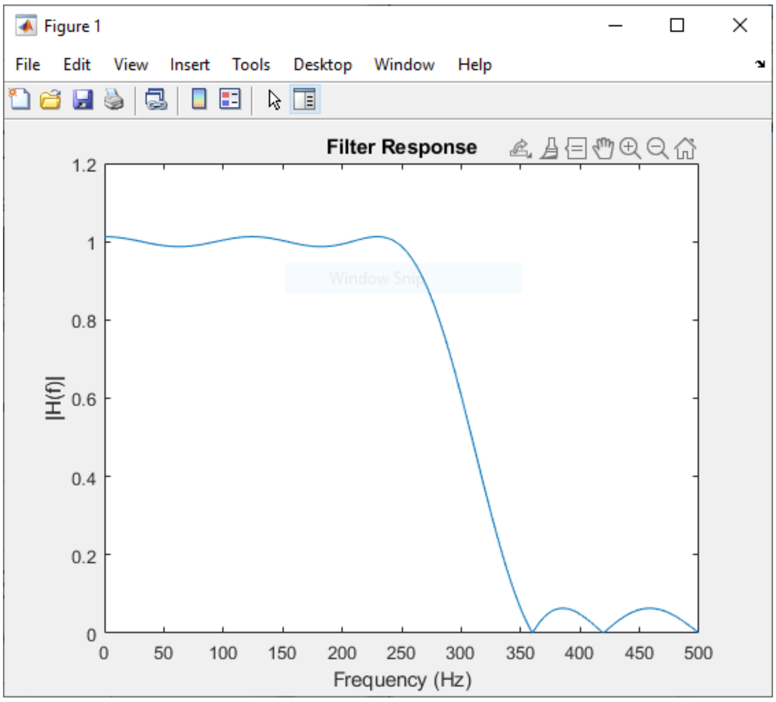

Fig. 8 Filter response.

This is likely a low-pass filter designed to suppress unwanted frequencies higher then 300 Hz, allowing other frequencies to pass.

Then use the same method to design a 60Hz notch filter to remove the 60Hz interference. And the results were displayed in the following figures.

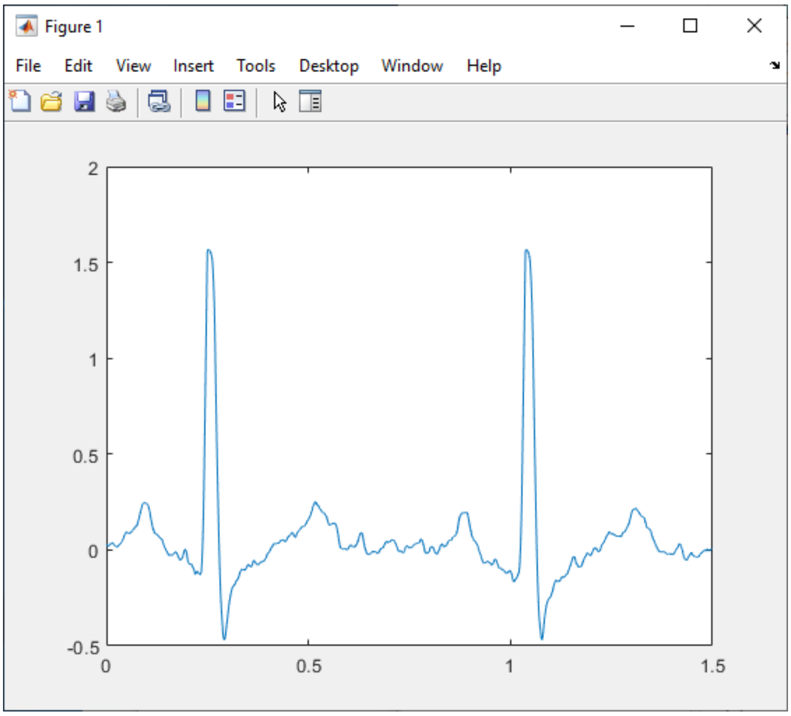

Fig. 9 ECG signal in MATLAB

The peaks represent individual heartbeats detected in the ECG signal. The filtering process removed noise and unwanted frequency components, making the peaks more distinct for detection.

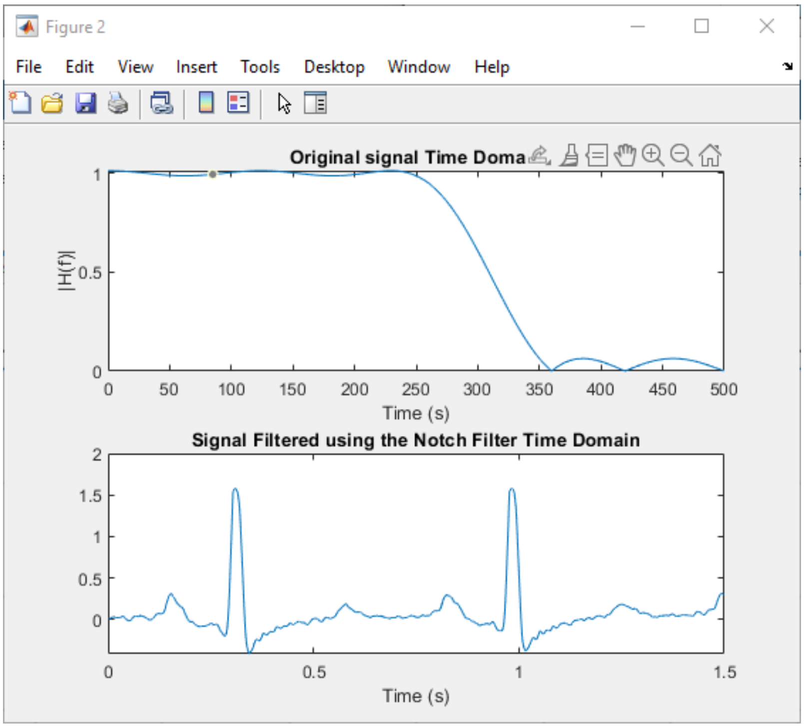

Fig. 10 Combination of original and filter signals

This figure highlighted how the filter selectively attenuates unwanted frequencies while preserving the frequencies needed to analyze the heart signal, resulting in a clean time-domain signal suitable for heartbeat detection.

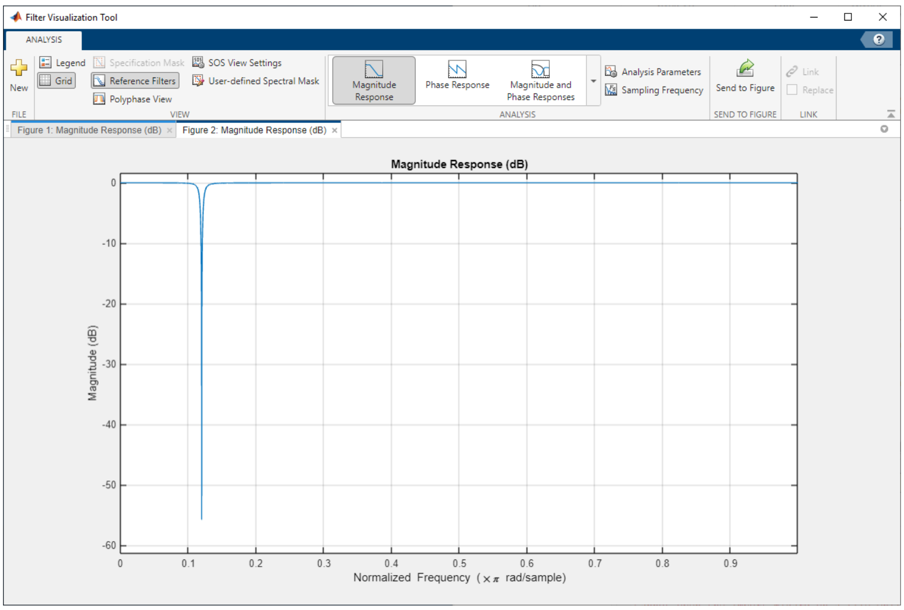

Fig. 11 Magnitude response

This confirms that the filter is designed to suppress a specific frequency band (notch filter) to clean the signal while maintaining frequencies important for heartbeat detection.

To measure the heartbeat rate, which could be calculated by:

$$Heartrate = \frac{Number\ of\ peaks}{Interval\ in\ seconds}$$

And it can also be given by threshold detection, and the result was about 72 BPM, which agreed with expectation.

3. Discussions and Conclusions

This lab consists of two parts: we can summarize the first part as an improvement of circuit to remove the impact of DC composition and high-frequency noise. And the second part is to acquire the ECG signal and built a digital filter to do the same work as previous part. We can prove the effect of the digital filter by observing the relative plots.

In the first part, we combined a low-pass filter and a high-pass filter to reduce the impact of external factors on ECG signals. The second part is to create a digital filter on MATLAB and obtain the corresponding images and data to prove the workability of the filter. Both parts mainly prove the effectiveness of the filter, thereby reducing the impact of external factors on signal acquisition and analysis.

Reference:

[1] Dr. Iman Salama. "ECG Circuit – Analog Filtering and A/D Conversion & Digital Signal Manipulation of the ECG signal " Northeastern University.