Analog ECG Monitor

EC412 Analog Electronics Project

Abstract

Electrocardiography (ECG or EKG) machines or electrocardiographs are commonly used in hospitals to record the electrical activity of a patient's heart. In this project an ECG monitor circuit was designed and built on a breadboard.

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May 1, 2018

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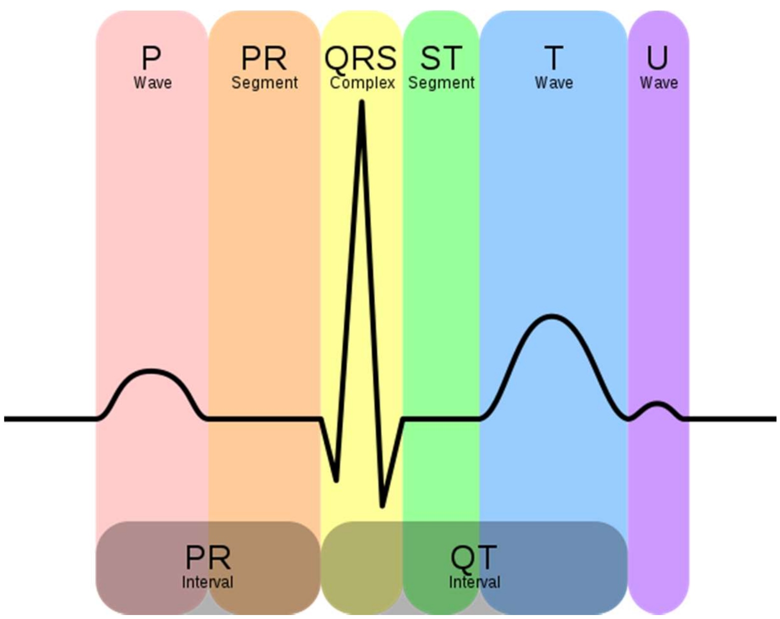
Introduction

When the human heart beats, the electrical charges within its cells move in and out, shifting through each cell's membrane with each pulse. This pattern of charge distribution is known as depolarization and repolarization depending on which direction the charges are moving with respect to the heart. Electrodes can be placed on a patient's skin to detect the changes in voltage that result from the shifts in charge. This voltage signal can be processed and monitored using an electrocardiograph. An electrocardiogram is produced when this signal is graphed versus time. The process of recording an electrocardiogram is known as electrocardiography (ECG or EKG). ECG tests are commonly performed on patients to monitor their heart. Clinicians can obtain information about how well a patient's heart is functioning by studying there ECG waveform. Figure I. shows the ideal ECG waveform for a single heartbeat. [1] The purpose of this project was to design a circuit that could capture and clearly display a person's ECG waveform by using electrodes to measure the electrical activity of their heart.

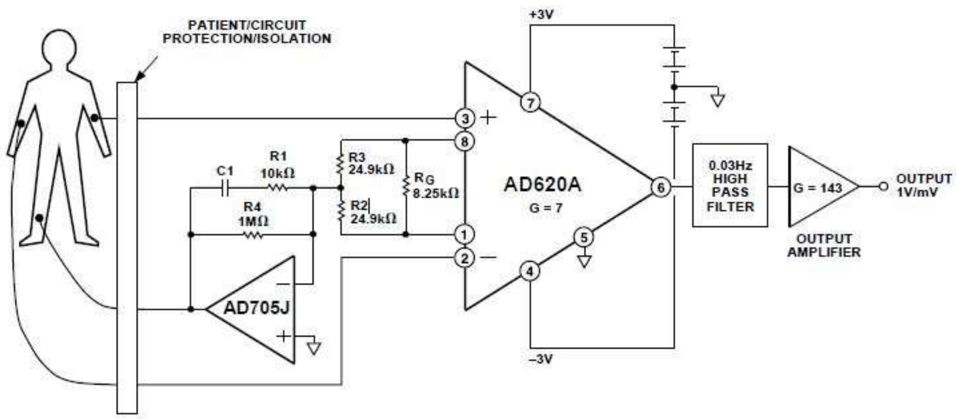
Figure I. – Representation of a normal ECG waveform [1]



Technical Approach

The design of my ECG monitor circuit is based on the circuit in Figure II., which is an ECG monitor circuit that is listed as one of the application circuits on the datasheet of Analog Device's AD620A Low Power Instrumentation Amplifier. [2]

Figure II. – AD620A Medical ECG Monitor Circuit [2]



This circuit can be split up into several different stages. The components C1, R1, and R4 that are around the AD705J Picoampere Input-Current Bipolar Op Amp create a low-pass filter that is part of the right leg drive section of this ECG monitor circuit, which I will discuss in further detail in the results section. The next stage includes R3, R2, RG, and the AD620A integrated circuit, which together make up the input stage. An instrumentation amplifier, like the AD620A, is used in this ECG monitor circuit because instrumentation amplifiers in general are capable of having a very high differential gain, which is needed to amplify the polarization wave signals created by the heart that are on the order of a few millivolts, and a very high Common Mode Rejection Ratio (CMRR), which is need to attenuate the input common mode 60Hz noise that comes from power lines. The node between R3 and R2 is a common mode voltage "tap" for the right leg drive circuit, while RG is used to set the gain of the instrumentation amplifier. See Appendix I for the derivation of the gain of a generic instrumentation amplifier. Lastly, the purpose of the high pass filter after the AD620A is to reduce the noise in the signal and the output amplifier amplifies the signal before it is output.

The final design of my ECG circuit can be seen in Figure IIIa. The main differences between my circuit and the one in Figure II are that I used a AD422 Instrumentation Amplifier instead of the AD620A because the AD620A was not in stock, I decided to omit the high pass filter and used a notch filter instead, and my circuit does not have a right leg drive circuit because I could not get it working. Despite the fact that my right leg drive circuit does not work, the right leg electrode is still attached to the "patient's" right leg because it drastically improves the output signal quality.

Figure IIIa. - Final ECG Circuit

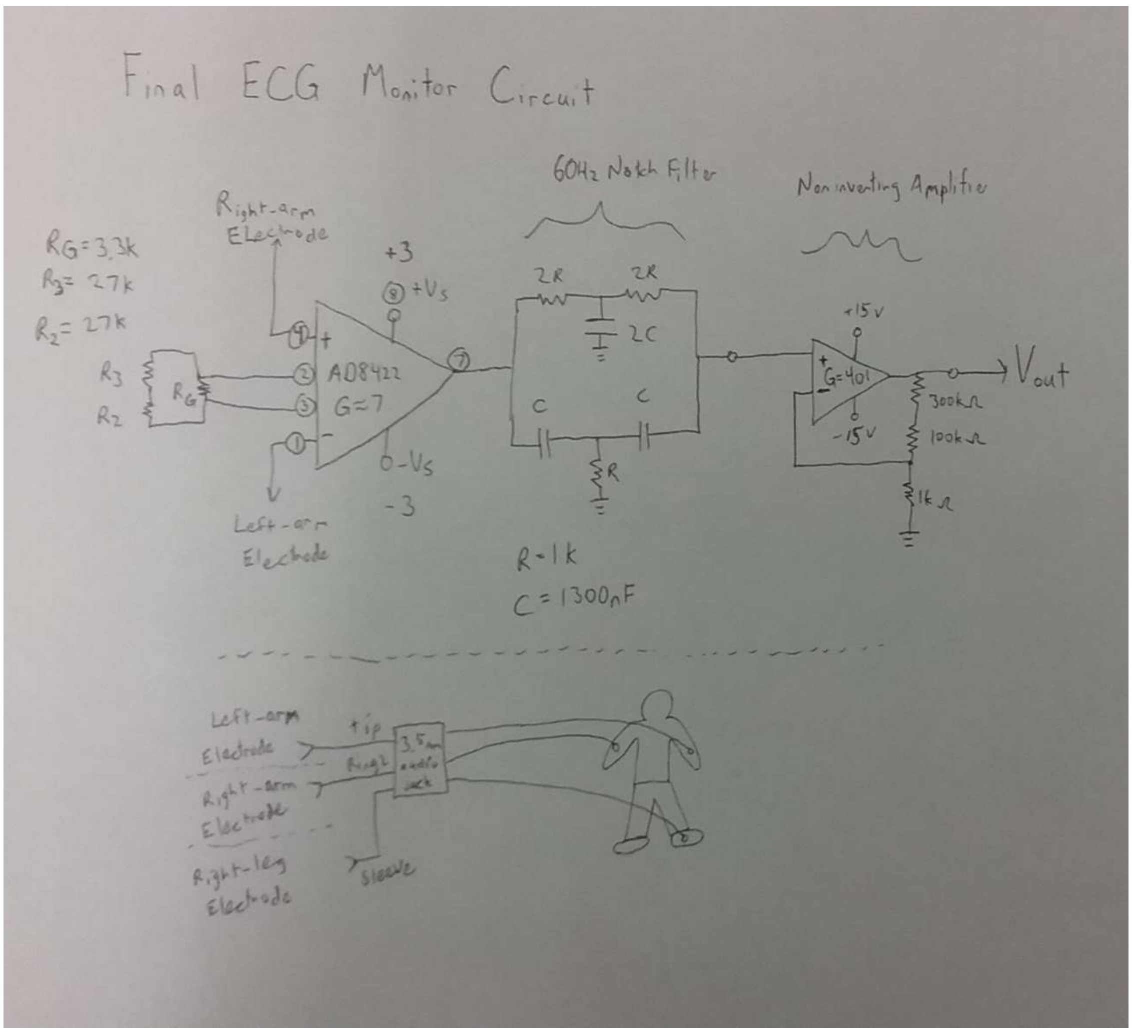
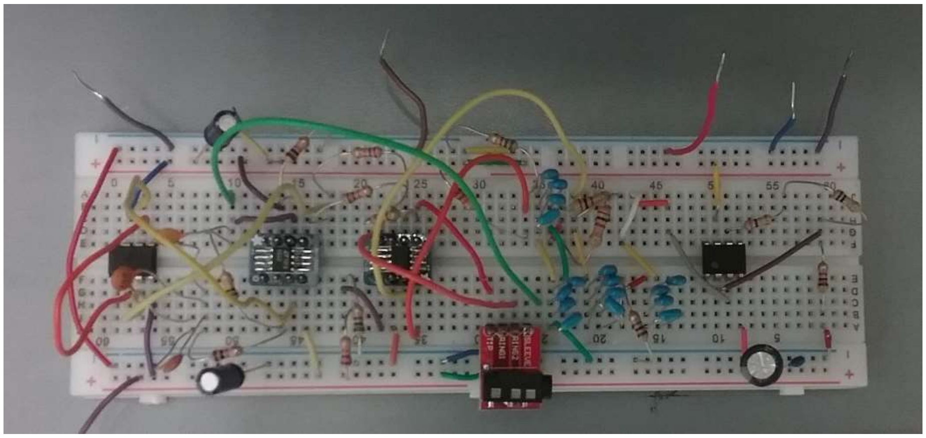


Figure IIIb. - Final ECG Circuit on Breadboard

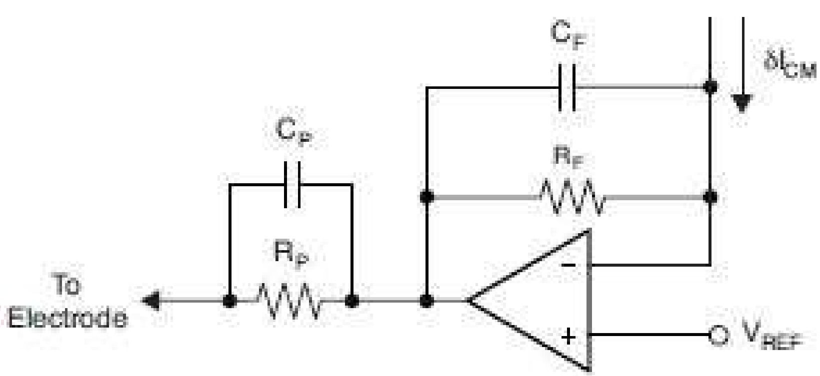


Note: That I left the disconnected right-leg drive circuitry on my breadboard for presentation purposes.

Results

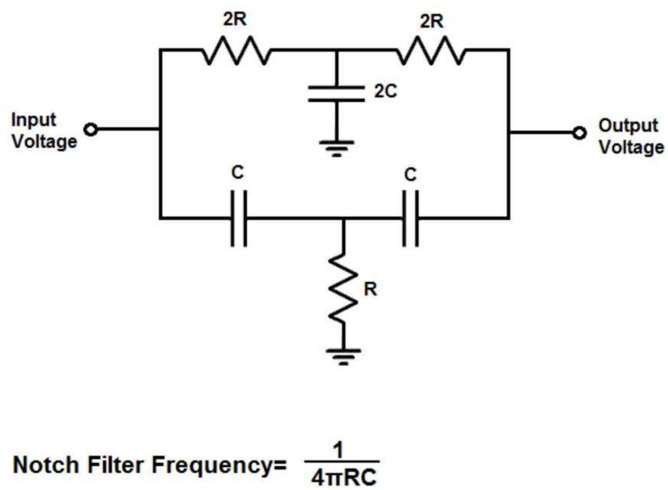
The main shortcoming of my final ECG circuit is that I could not get the right leg drive circuit, show in Figure IV, to function properly. The purpose of this circuit is to drive the common-mode signal from the right and left arm electrodes back into the patient's right leg electrode. This in theory should cause the patient's reference voltage to closely track or fluctuate with the common-mode signal thereby attenuating it and increasing the circuits CMRR. [4] I tried adding an op-amp buffer at the input (I_{CM}) of the right leg drive circuit, as well as, several other different variations, but even though I could see the 60Hz common-mode signal, whenever I connected it to the right leg electrode the output of the circuit would either become more noisy or flat line.

Figure IV. – General Right Leg Drive Circuit [4]



Despite the fact that I could not get the Right-Leg Drive circuit to work, the final output signal was not that noisy because my notch filter greatly reduce the 60Hz interference coming from the walls. I based my notch filter off the circuit shown in Figure V.

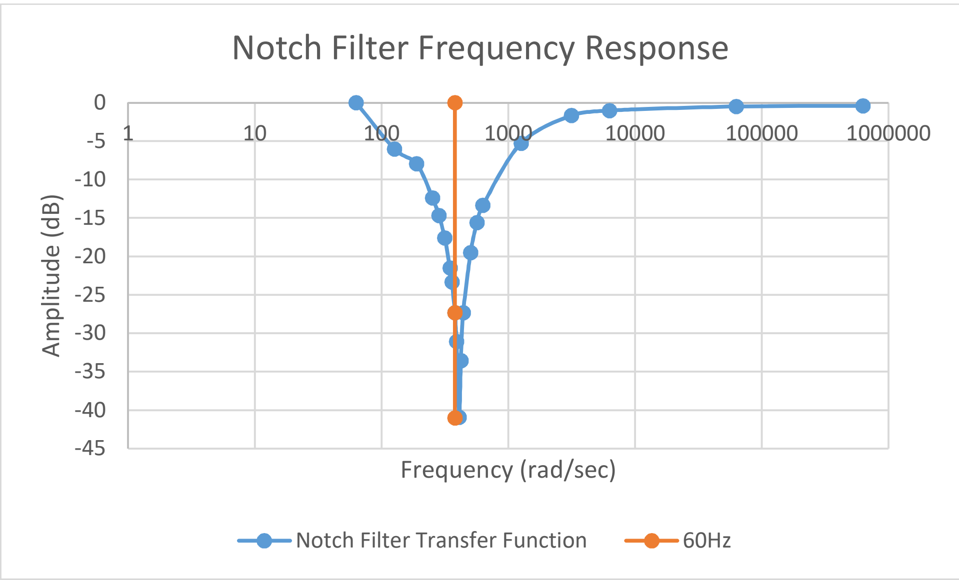
Figure V. – Notch Filter Design [3]



I used an online calculate to find that the required resistor and capacitor values, needed to create a notch filter with a filter frequency around 60Hz, were 1kΩ and 1327nF respectively. Since I did not have any 1327nF capacitors I used several capacitors in parallel to create an equivalent capacitance of 1300nF.

After using the online calculator to find the appropriate resistor and capacitor values for the notch filter I tested it and verified that its stop-band was around the desired 60Hz or 377rad/sec. [3]

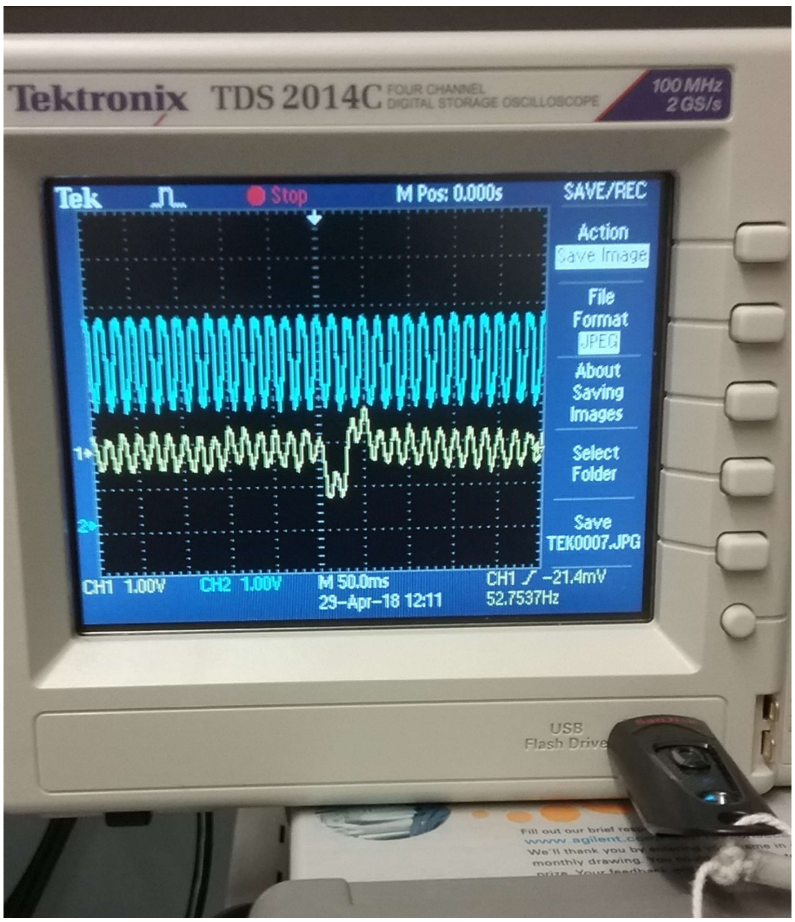
Graph I.



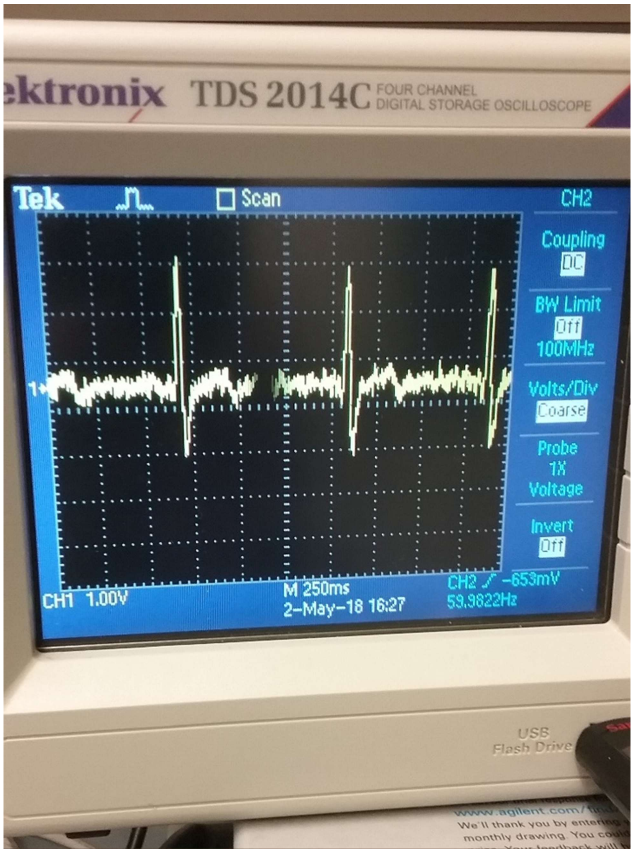
The data that was used to create Graph I was collected by sweeping a 1V peak to peak sine wave that was input into the notch filter from 10Hz to 500,000kHz and measuring the peak to peak voltage of the signal at the output of the filter. Graph I shows that the notch filter has a stop-band from about 12.7Hz (80 rad/sec) to about 175Hz (1100 rad/sec). This filter attenuates a 60Hz signal by around -30dB.

The yellow trace in Figure VI shows the output before the notch filter was added. The blue trace in Figure VI is the common-mode 60Hz noise output take from the node between resistors R2 and R3.

Figure VI. – ECG Waveform before Notch Filter Implementation



After adding the 60Hz notch filter, and experimenting with different bypass capacitors the final ECG waveform was obtained:



The level of detail that can be seen in this final ECG waveform is quite good. One can even make out the T wave right after the QRS complex. If I had more time I would have tried cascading some second-order active filter to further reduce the high frequency noise. I also would have like to try and make this circuit so that it could be power from a USB by adding a charge pump or some other positive-to-negative voltage converter.

References

[1] "Electrocardiography" https://en.wikipedia.org/wiki/Electrocardiography#Electrodes_and_leads

[2] "AD620 Low Cost Low Power Instrumentation Amplifier"
http://www.analog.com/media/en/technical-documentation/data-sheets/AD620.pdf

[3] "Notch Filter Calculator"
http://www.learningaboutelectronics.com/Articles/Notch-filter-calculator.php

[4] "Improving Common-Mode Rejection Using the Right-Leg Drive Amplifier"
http://www.ti.com/lit/an/sbaa188/sbaa188.pdf

[5] "High Performance, Low Power, Rail-to-Rail Precision Instrumentation Amplifier AD8422"
http://www.analog.com/media/en/technical-documentation/data-sheets/AD8422.pdf

[6] "OP-AMP Instrumentation Amplifier"
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