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Section 005
Station 3

Final Project
12/04/2025
Lab Partner: Luke Trahin

Heart Rate Monitor – Final Project

Abstract

This project works to create a heart rate monitor utilizing sensors to get the input signal. To design this monitor we first had to set up the sensor, which we used a phototransistor with an infrared LED and receiver for. The problem with the input we receive from this is that it isn't very strong, meaning it has a low amplitude, and it has noise. To solve these issues, we decided to run the signal through non-inverting high and low pass filters to create a band pass filter that would also have some gain. To ensure that all realistic heart rates are allowed to pass through our filter, we set our cutoffs from 40bpm to 200bpm. Now that the noise has been filtered out and our signal has been amplified, we needed a way to better display our results, as our signal was currently analog. We wanted to convert to digital, so we utilized a comparator to set the high signal to 5V and the low signal to –5V. This makes the output easier to read and also allows us to use an LED to display the heartrate. The 5V or –5V signal can be put into a pmos which can be used as a voltage-controlled circuit to either power or not power an LED.

To design the actual values being used in each part of the circuit, some experimentation is needed, as the finger being measured can impact the circuit. The pigmentation of the finger can affect the signal and will lead to different resistances needing to be used from person to person from the infrared receiver. Additionally, the output of the receiver's amplitude needs to be known to know how large the gain on the filters needs to be for the comparator to be able to recognize the signal. Besides these components, we know the other specifications needed to calculate the other component values, as we already know our cutoff frequencies. To create this circuit physically, we need to use the components IR204, PT204-6B, LM324, LM339, and the RFD3044LE.

Introduction

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This lab utilizes a phototransistor to receive a user's heart rate and turns it into a heart rate monitor. The problem with the infrared led and receiver is that it has an extremely low output magnitude signal and there is noise within that signal. To get the monitor to output your true heart rate the filter’s noise needs to be filtered out and the magnitude of the signal needs to be amplified. Once this is done it helps to convert the signal from analogue to digital using a comparator to create a square wave output. This is easier to read and allows an led to be also output the heart rate. In total this project consists of creating a receiver for the heart rate, filtering the signal through the reasonable range of frequencies that a heart would beat at, amplifying the signals magnitude, and changing the output from analogue to digital.

Theory

Phototransistor:

The infrared light and receiver functions by putting the user’s finger between the two and receiving the signal of the blocked light from the blood pumping through the finger. The Rd value is calibrated to maximize the current and therefore brightness of the led and the Re must be calibrated to the pigmentation of the person using the sensor, because the more infrared light that passes through, the higher the current will be.

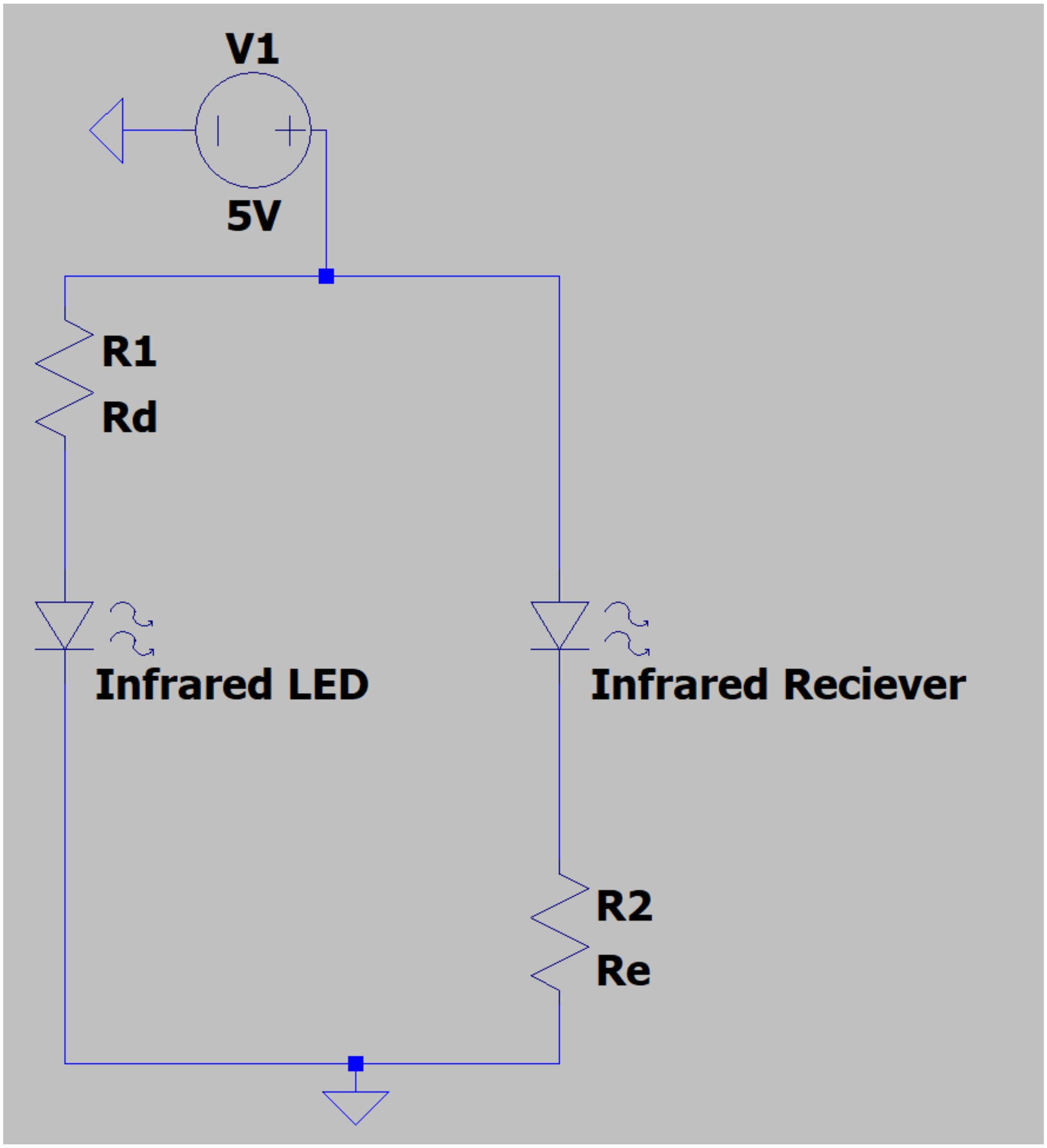

Figure I: Phototransistor circuit schematic

High Pass Filter:

The purpose of the high pass filter is to filter out all frequencies of the signal that are lower than 40 bpm and to amplify the magnitude of the signal through creating a large gain.

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$$f = \frac{1}{2\pi R_3 C_1}$$

$$Gain = 1 + \frac{R_2}{R_1}$$

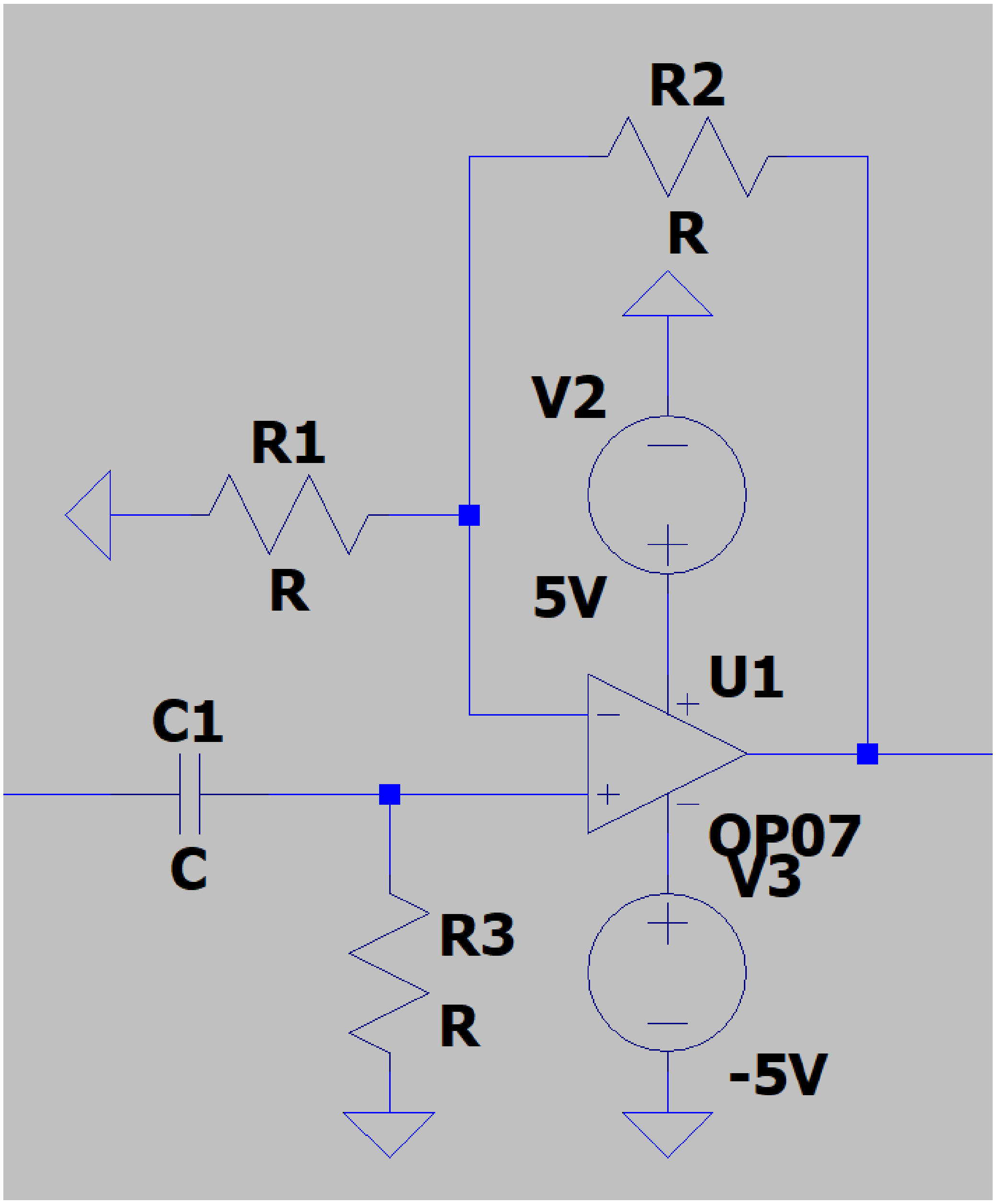

Figure II: Non-Inverting High Pass Filter circuit schematic

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Low Pass Filter:

The purpose of the low pass filter is to filter out all frequencies of the signal that are higher than 200bpm and to amplify the magnitude of the signal through creating a large gain.

$$f = \frac{1}{2\pi R_3 C_1}$$

$$Gain = 1 + \frac{R_2}{R_1}$$

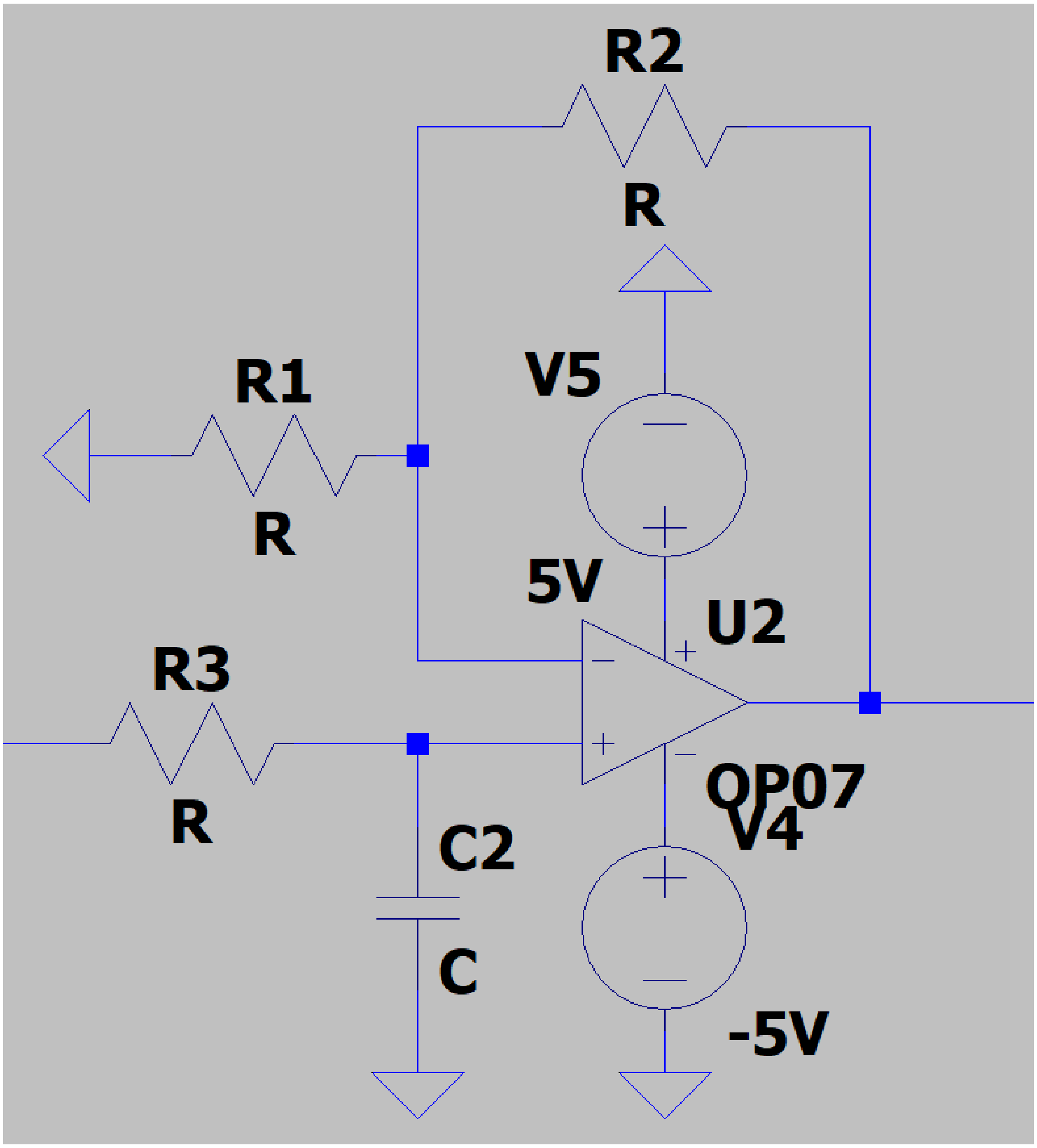

Figure III: Non-Inverting Low Pass Filter circuit schematic

Comparator:

The comparator's job is to take in an analogue input and turn it into a digital output. It does this in this circuit by taking in the signal from the filters and either outputting a high voltage of 5V when the signal is high, or a low voltage of –5 volts when the signal is low.

$$f = \frac{1}{2\pi RC}$$

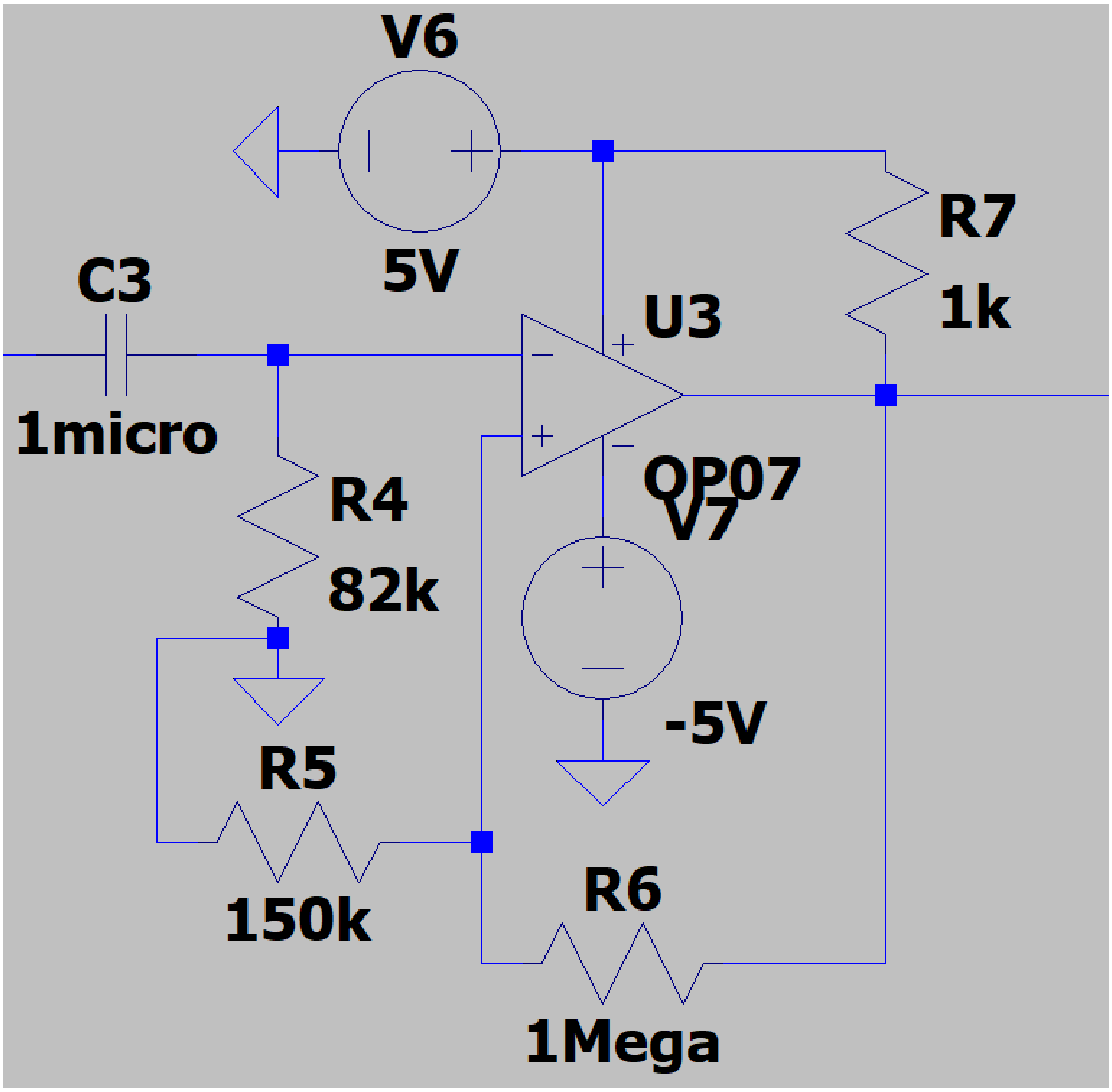

Figure IV: Comparator circuit schematic

Indicator:

The purpose of the indicator is to take the either 5V or –5V output of the comparator and use that to turn on and off an led. This can be accomplished by using a pmos transistor as a voltage-controlled switch.

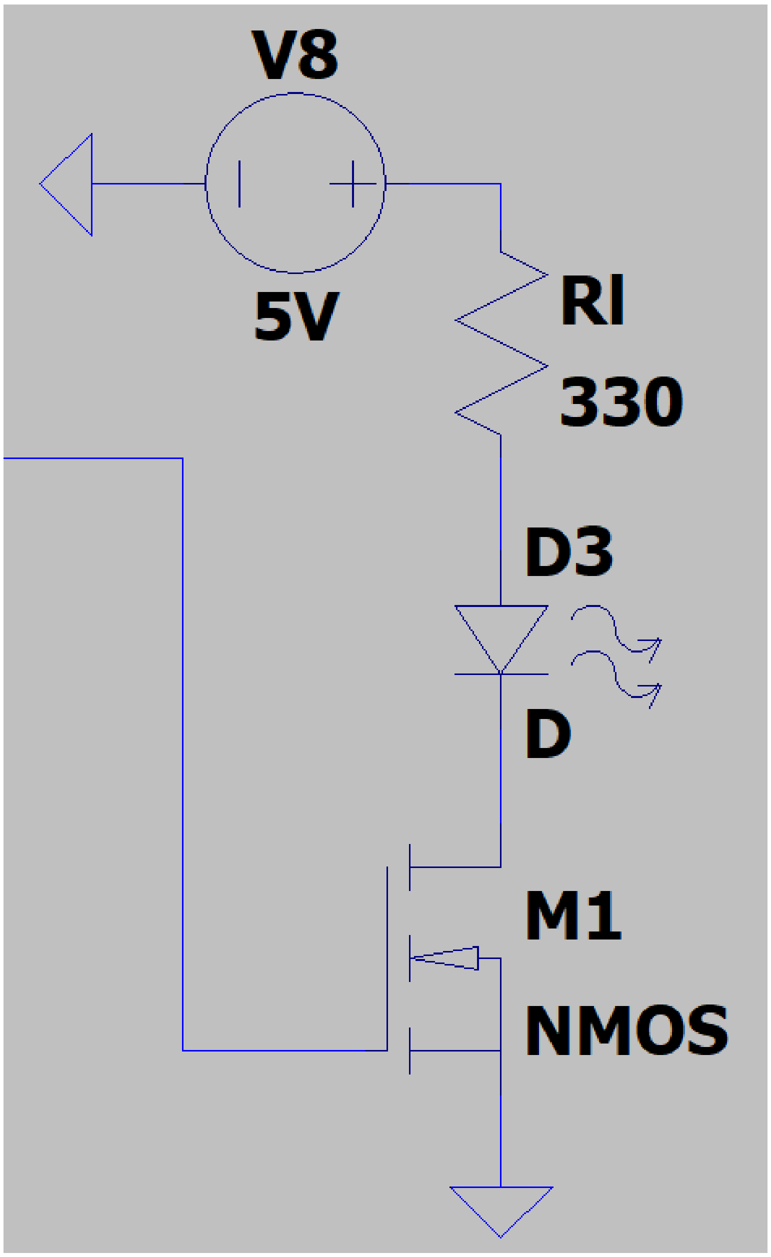

Figure V: Indicator circuit schematic

Design/Calculations

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Phototransistor:

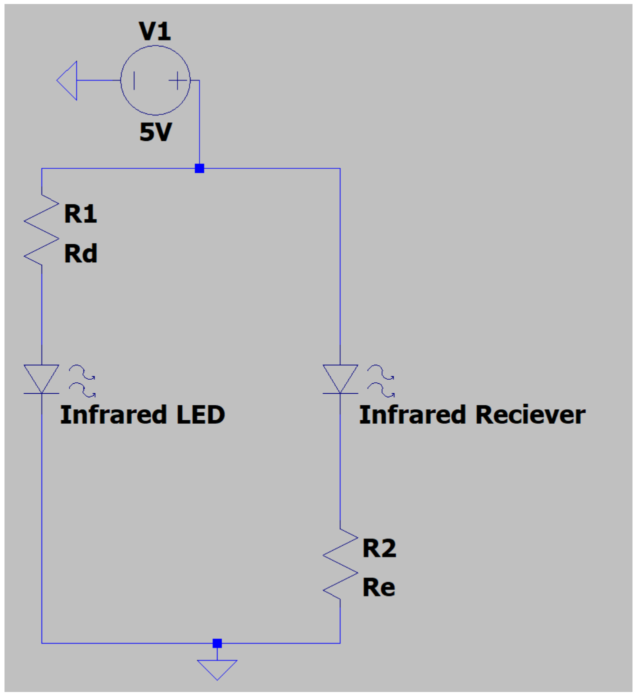

Figure VI: Phototransistor circuit schematic

$$R_d = 82\ \Omega\ \parallel\ 82\ \Omega$$

$$R_e = 10k\ Potentiometer$$

High Pass Filter:

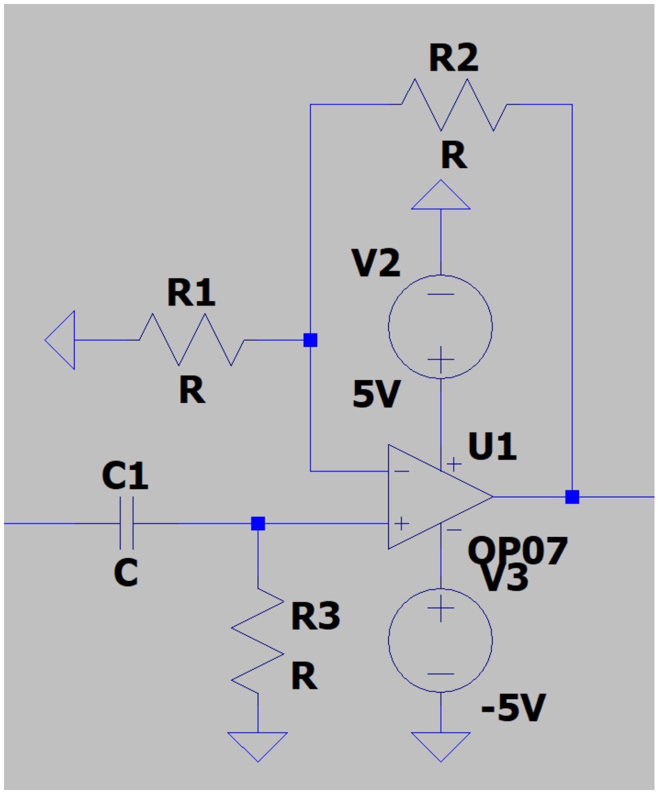

Figure VII: Non-Inverting High Pass Filter circuit schematic

$$Cutoff\ =\ 40\ bpm\ =\ 0.668Hz$$

$$f=\frac{1}{2\pi R_3 C_1}=0.668Hz$$

$$R_3C_1=0.238$$

Used Values

$$R_3C_1=(2.2k\Omega)(100\mu F)=0.22$$

$$f=\frac{1}{2\pi R_3 C_1}=0.723Hz$$

$$Gain\ =\ 1+\frac{R_2}{R_1}=16$$

$$R_1=10k\,\Omega$$

$$R_2=150k\,\Omega$$
$$R_3=22k\,\Omega$$

$$C_1 = 100\mu F$$

Low Pass Filter:

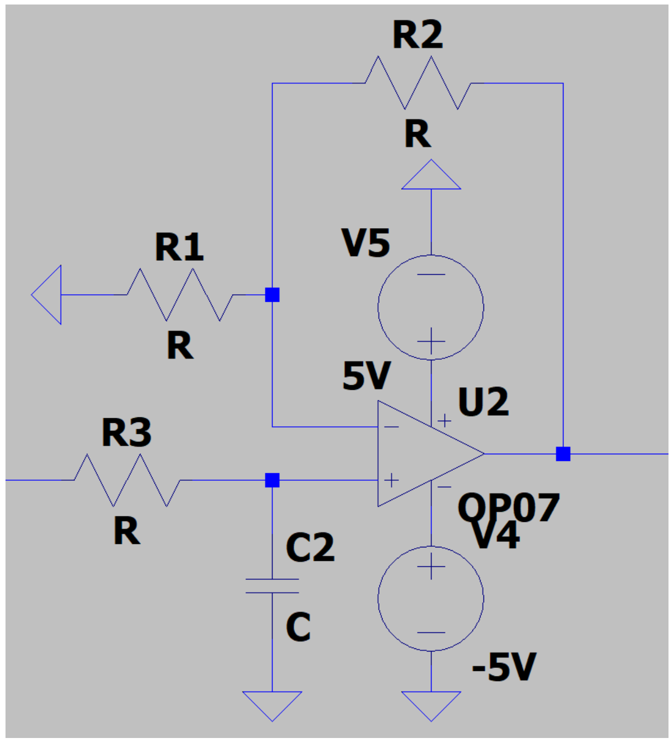

Figure VIII: Non-Inverting Low Pass Filter circuit schematic

$$Cutoff = 200bpm = 3.34Hz$$

$$f = \frac{1}{2\pi R_3 C_1} = 3.34Hz$$

$$R_3 C_1 = 0.0476$$

Actual

$$R_3 C_1 = (4.7k\Omega)(1\mu F)$$

$$f = \frac{1}{2\pi R_3 C_1} = 3.386Hz$$

$$Gain = 1 + \frac{R_2}{R_1} = 16$$

$$R_1 = 10k\,\Omega$$

$$R_2 = 150k\,\Omega$$

$$R_3 = 4.7k\,\Omega$$

$$C_1 = 1\mu\,F$$

Comparator:

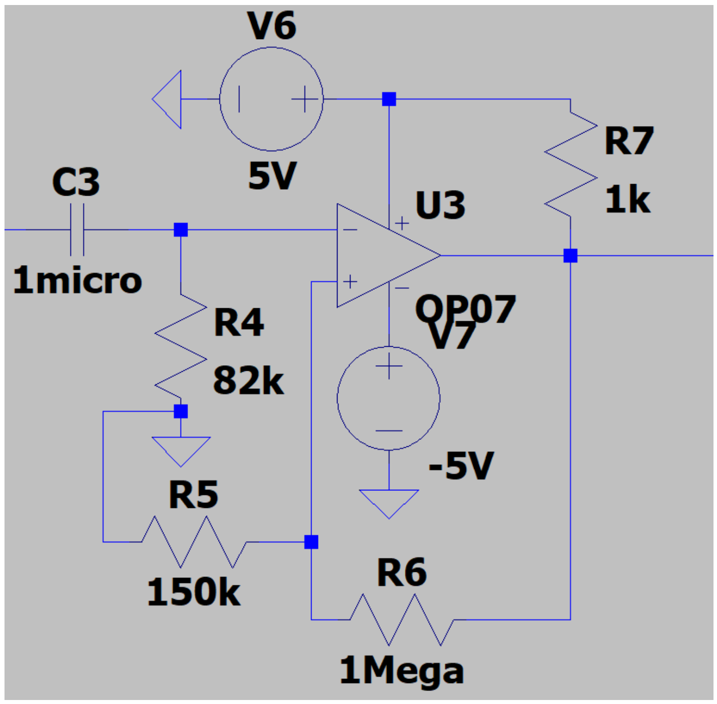

Figure IX: Comparator circuit schematic

$$Cutoff = 2Hz$$

$$f = \frac{1}{2\pi RC} = 2Hz$$

$$RC = 0.0795$$

Actual

$$RC = (82k\Omega)(1\mu F) = 0.0795$$

$$f = \frac{1}{2\pi RC} = 1.941Hz$$

$$R_4 = 82k\,\Omega$$

$$C_3 = 1\mu\,F$$

$$R_5 = 150k\,\Omega$$

$$R_6 = 1M\,\Omega$$

The values of R7 and R8 were found experimentally after previous calculations didn't lead to a working comparator.

Indicator:

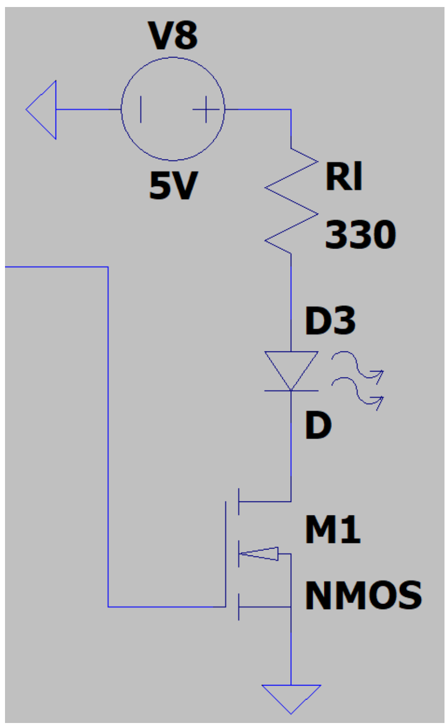

Figure X: Indicator circuit schematic

Specifications: 1.8V & 10mA

$$3.2 = 10m \cdot R_l$$

$$R_l = 320$$

Results

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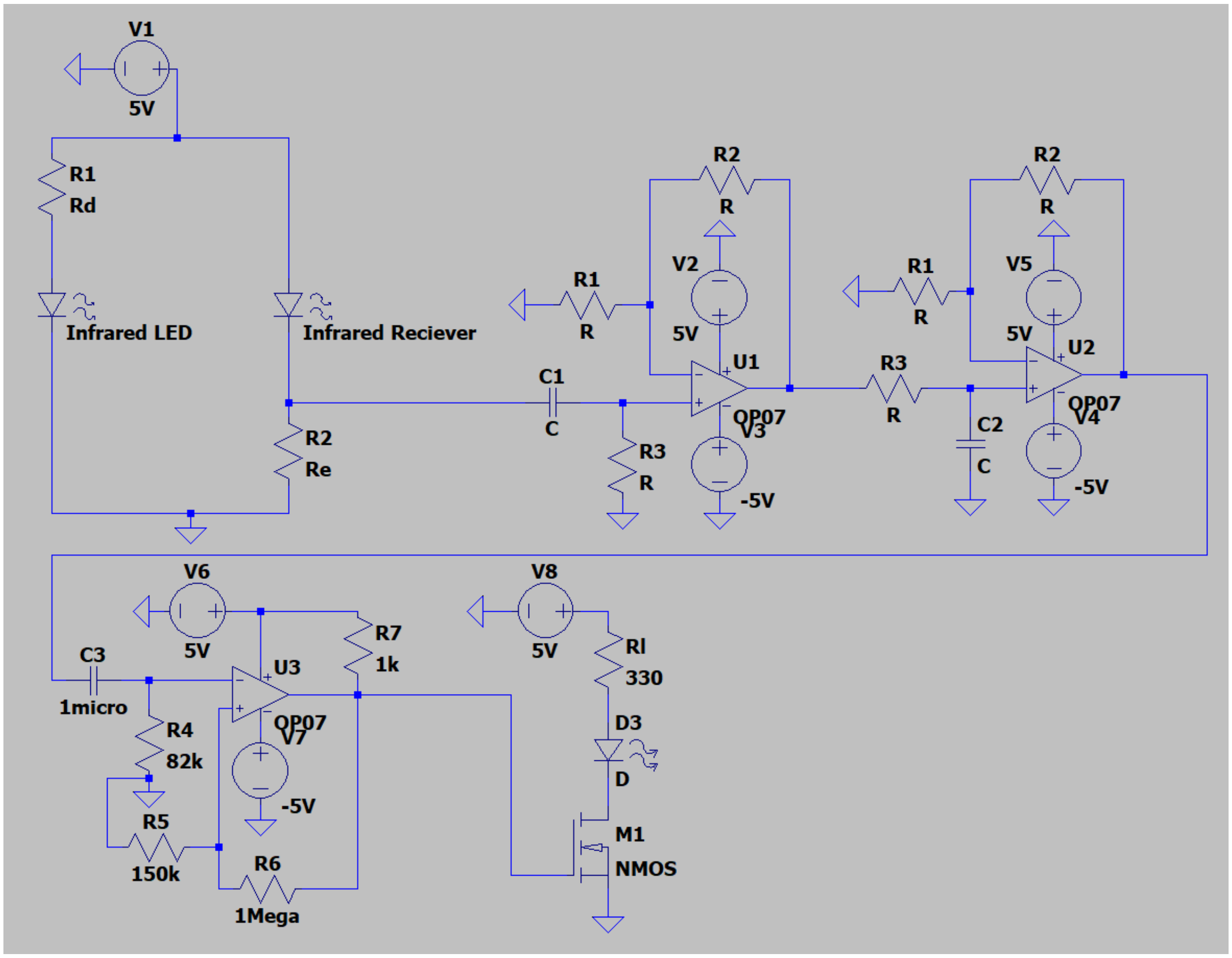

Figure XI: Heart Rate Monitor circuit schematic

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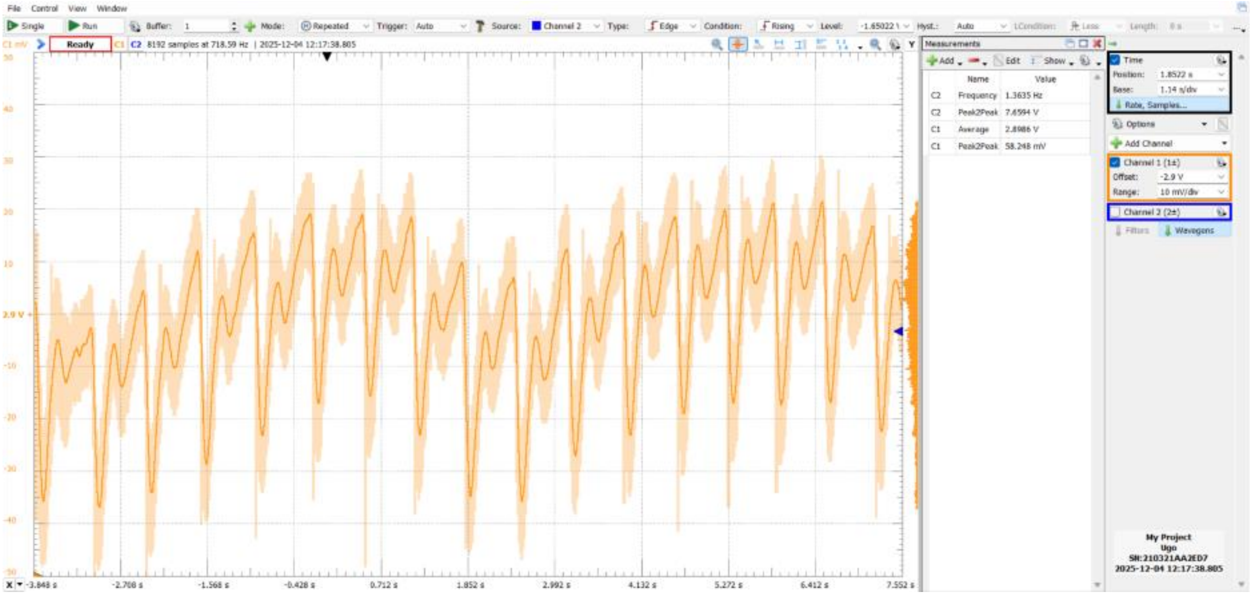

Figure XII: Infrared sensor output

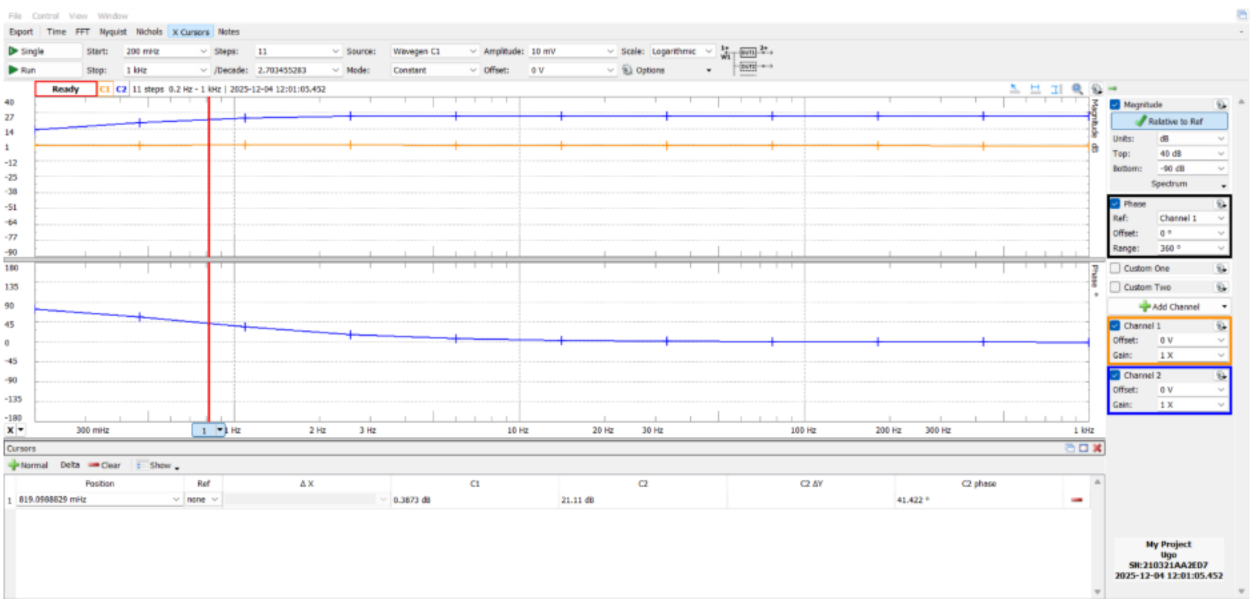

Figure XIII: FRA of High Pass Filter (dB)

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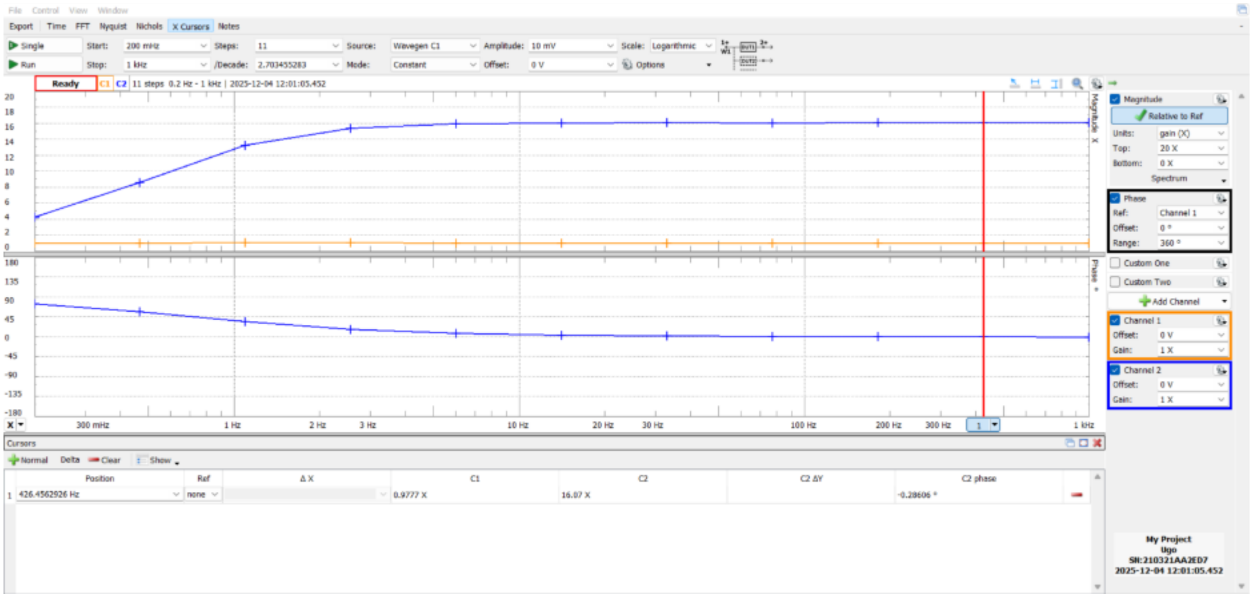

Figure XIV: FRA of High Pass Filter (Gain)

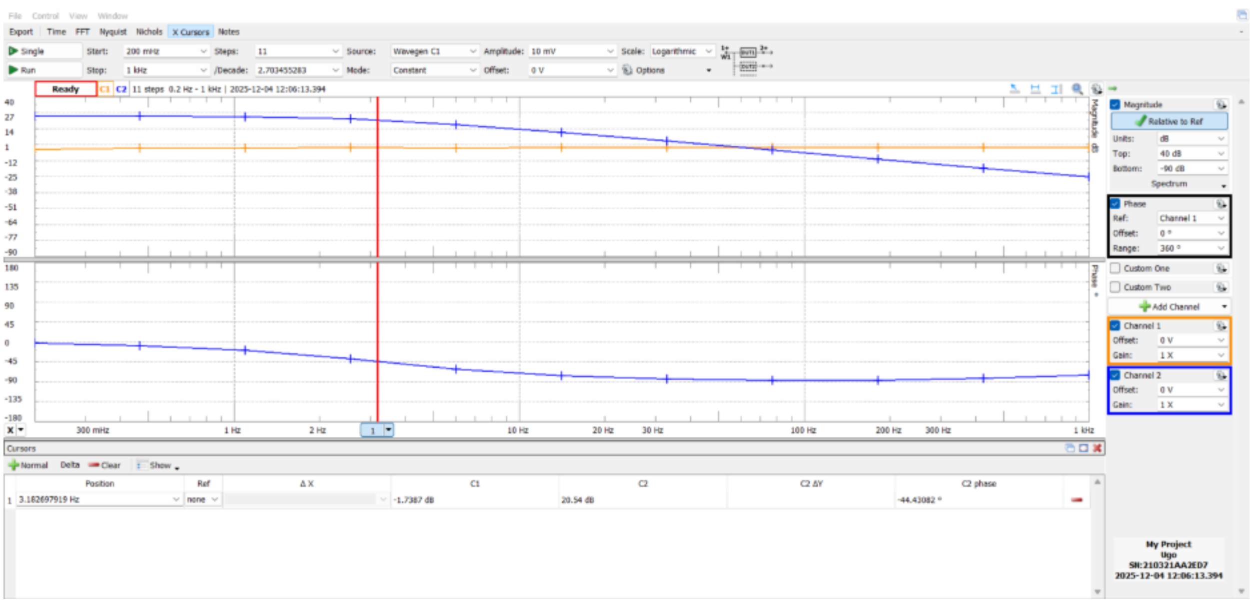

Figure XV: FRA of Low Pass Filter (dB)

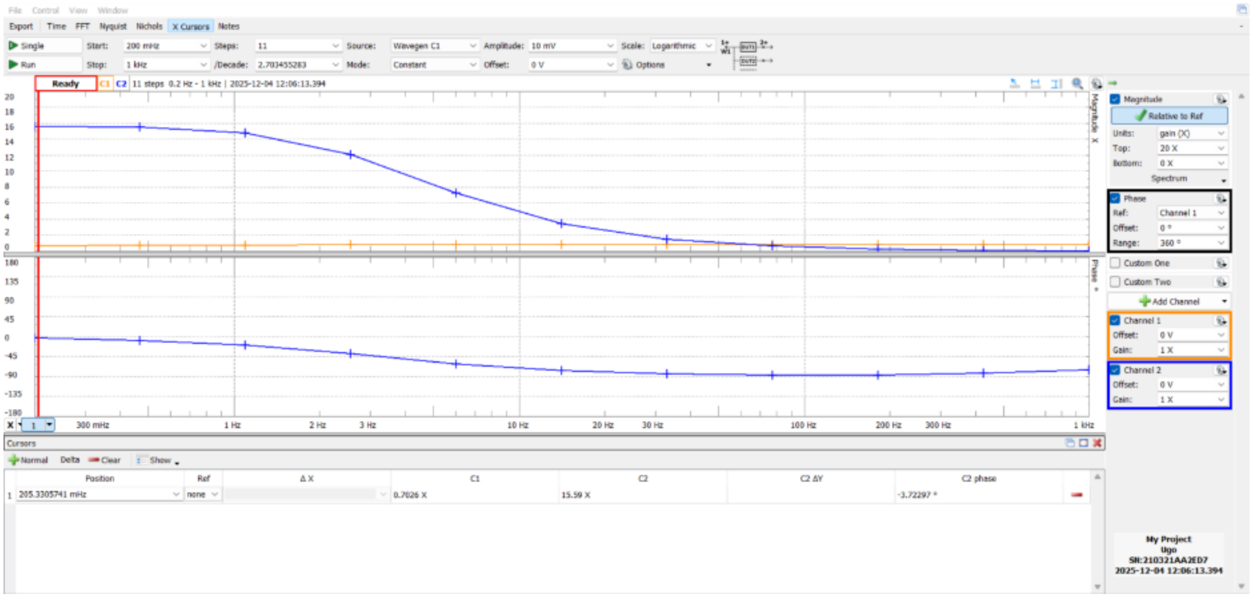

Figure XVI: FRA of Low Pass Filter (Gain)

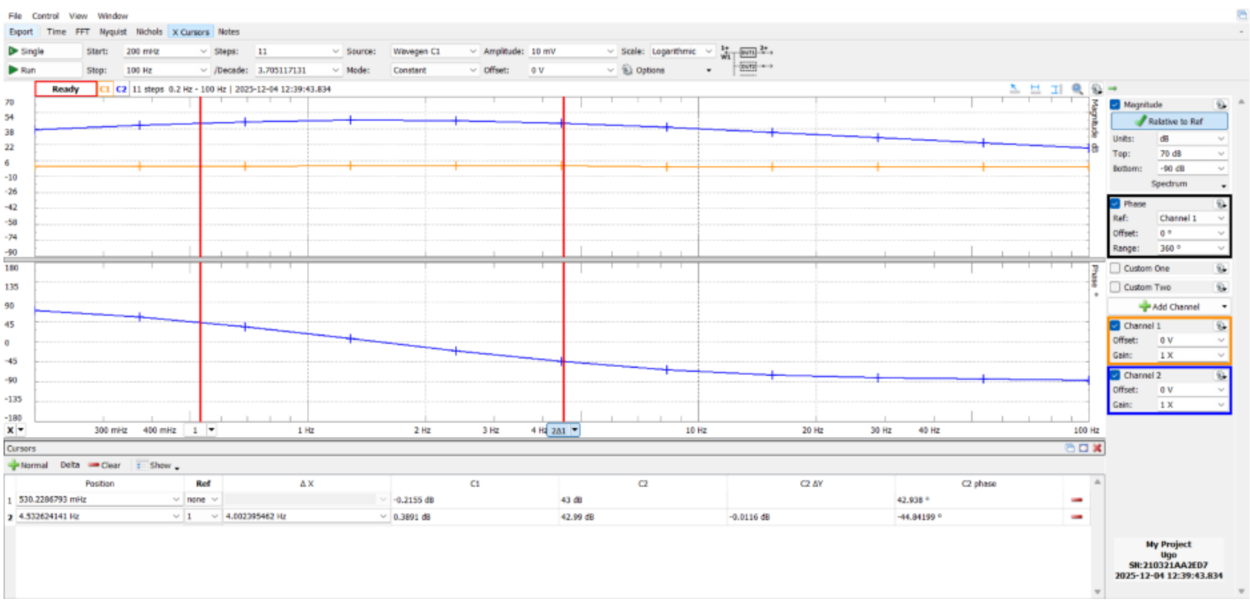

Figure XVII: Band Pass Filter (dB)

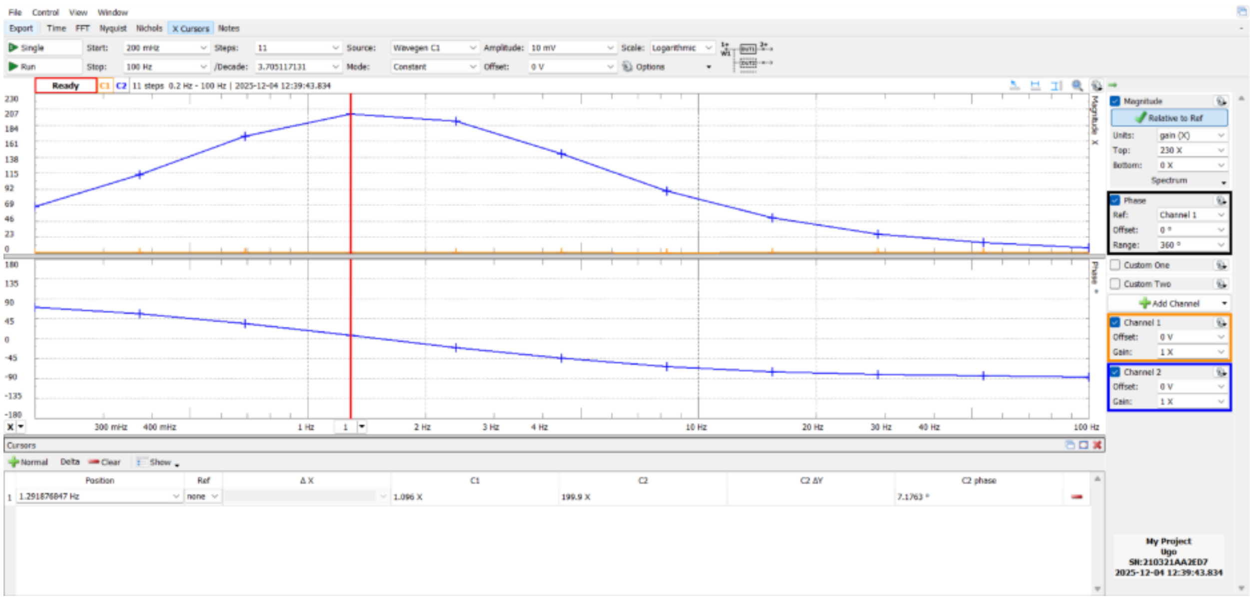

Figure XVIII: Band Pass Filter (Gain)

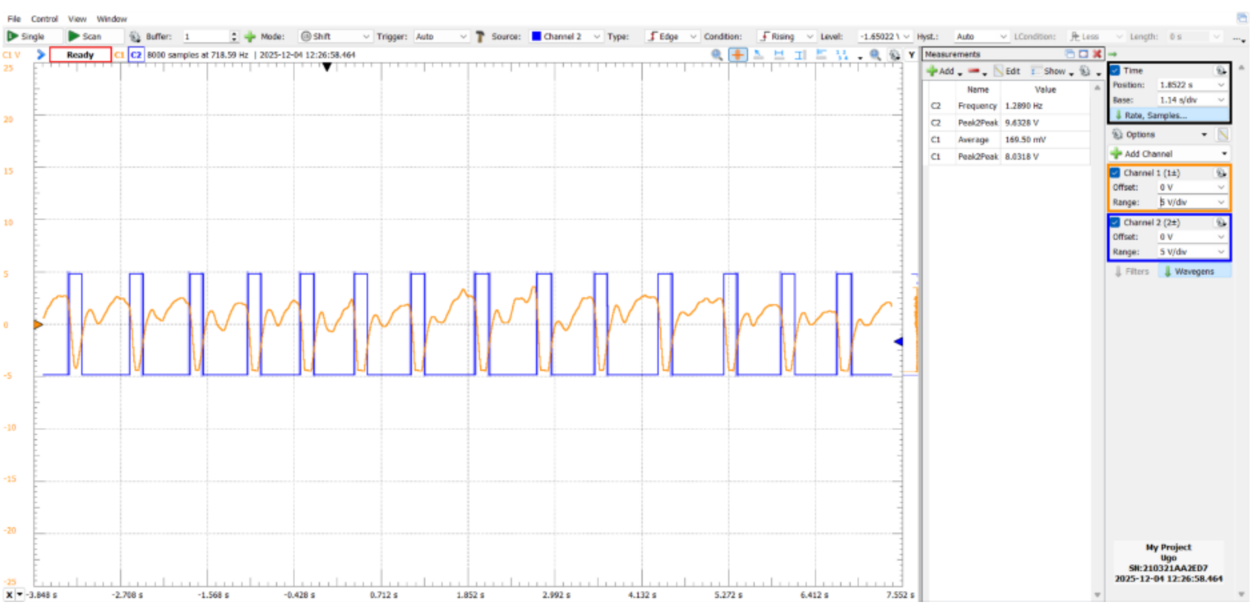

Figure XIV: Graph of final and initial outputs

	High P Cutoff (Hz)	Low Pass Cutoff (Hz)	BP Low Cutoff (Hz)	BP High Cutoff (Hz)
Actual	0.82	3.18	0.53	4.00
Expected	0.72	3.39	0.72	3.39

Ideal	0.67	3.34	0.67	3.34
%Error From Expected	13.28	6.00	26.69	18.19
%Error From Ideal	22.60	4.70	20.66	19.82

Figure XX: Filter Cutoff Frequencies and Error

	High Pass Gain	Low Pass Gain	Band Pass Gain
Actual	16.07	15.59	199.90
Theoretical	16	16	256
%Error	0.44	2.56	21.91

Figure XXI: Filter Gain and Error

Output Frequency (Hz)	Output Heart Rate (BPM)
1.29	77.34

Figure XXII: Final Monitor Output

Conclusion

This lab utilized infrared sensors, a band pass filter that also acted as an amplifier, a comparator, and an indicator in the form of an LED which all combined together to created a heartbeat monitor that measures your heartbeat by placing your finger between a led and sensor. One of the first problems we had in the lab was getting our signal from the infrared receiver. The output was either not there or extremely inconsistent, which we solved by changing our rd and re resistor values. Our initial rd value was 100 ohms but we decided to lower it in order to increase the brightness of the infrared led. The re value needed to be adjusted quite frequently as it was dependent on the pigmentation of the finger being measured, so we replaced it with a 10k potentiometer to allow for real time adjustment. Our next hurdle came in the form of our high and low pass filter calculations. We accidentally switched the cutoff frequencies for our filters, causing us to filter out all relevant frequencies, but we were able to realize this when running FRA's on each of the filters. Once the filter values were calculated correctly, they had relatively low error with the high pass's being 13.28% and the low pass's being 6%. Part of this error could be due to our FRA only taking 11 steps, due to the long amounts of time it takes for each step size to be measured at the low frequencies we were operating at. The low amount of steps means less accuracy in our results, but this means its not coming from our actual circuit. Our issues with the comparator mainly centered around our gain not being high enough for the comparator to pick up on our signal and flip from 5V to –5V. After increasing the gain on both of our filters to 16 this problem was fixed. Overall our sensor worked extremely well and was able to complete all of the specifications outlined for us in the lab manual.