Final Project: **Heartbeat Sensor**

ECE 20008-005

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Abstract:

The goal of this lab is to create a functional heartbeat sensor. The first step to accomplish this is to set up an infrared transmitter/receiver that will first pick up our heartbeat. If we only have the transmitter and receiver set up, it is difficult to distinguish the heartbeat signal; therefore, we cascade the output of the receiver with an active bandpass filter. Although our final signal will still have quite a bit of noise, this active bandpass filter helps to isolate the heartbeat signal. The final major component of the project is the comparator, which will take the analog output from the filters, and convert them into a digital signal, or a square wave. This will help us get a clear look at the frequency of our heart rate. Finally, in order to visually see what our heartbeat signal looks like on our breadboard, we will allow the digital output to control an NMOS transistor like a switch, which will then turn on & off an LED bulb.

Equipment Used:

1. Breadboard and wires
2. **Waveforms** application
    a. Function Generator
    b. Network Tool
    c. Power Supply
    d. Oscilloscope
    e. Voltmeter
3. **AD2**
4. **Resistors**: 100(x2), 1k(x2), 10k(x3), 100k (x2), 1M, 2.2k, 22k(x2), 220k [Ω]
5. **Capacitors**: 1uF, 4.7uF, 10uF
6. **LED**
7. **IR204** (transmitter)
8. **PT204-6B** (receiver)
9. **LM324N** (op-amp)
10. **LM339** (comparator)
11. **RFD3055LE** (NMOS transistor)

Task 1: Transmitter & Receiver

Objective:

In this task, we will be setting up an infrared transmitter and receiver which we will use to pick up our heartbeat as a signal.

Procedure:

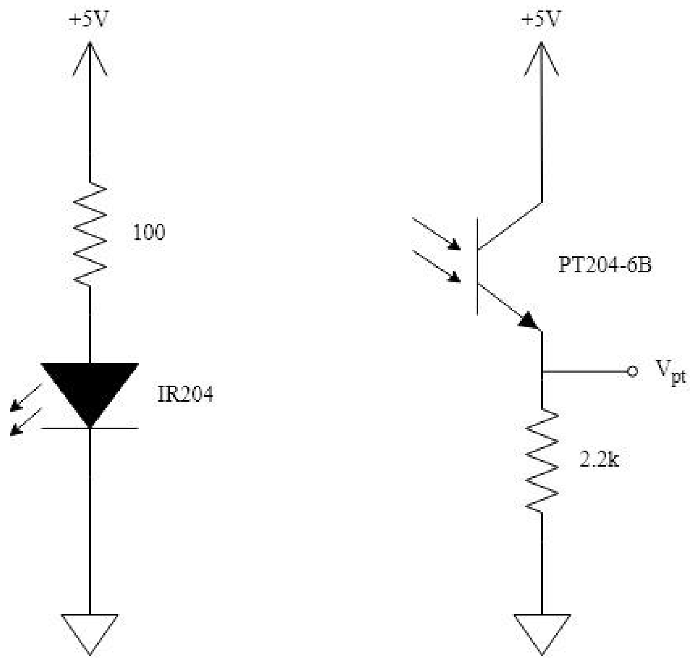

Figure 1.1: Transmitter (left) & Receiver (right) diagram

- We started by calculating the resistance of the resistor above the IR204 diode
  - This was done by looking at the max power rating of the resistors in our kit
  - The goal here was to maximize the current running through the IR204 diode without making the resistor exceed its max power rating
- After this, we experimentally designed for the resistor below the PT204-6B
  - We started by using 2.2kΩ (value used in previous lab)
  - We wanted the output, v_{PT}, to have an offset less than or equal to 4.6V
  - The 2.2kΩ gave us a good offset voltage, so that's what we used

Results/Calculations:

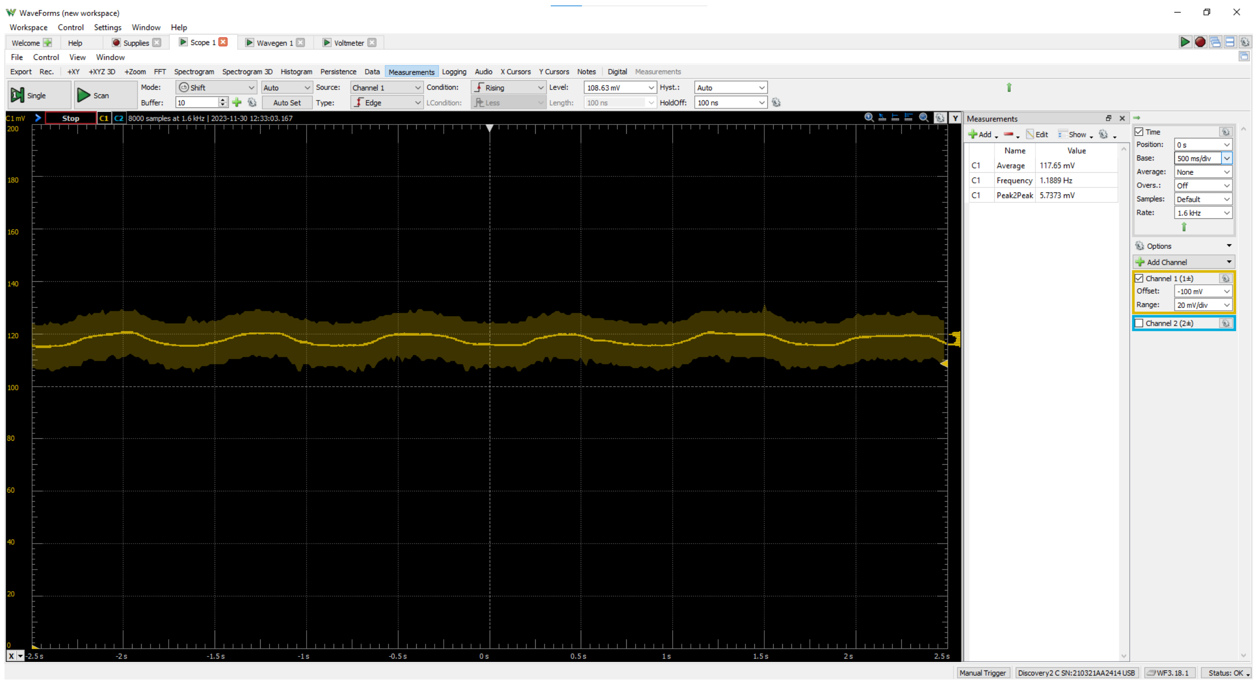

Figure 1.2: Analog output (V_{PT}) of receiver

<u>Resistor Calculation</u>:

$$I_D^2 \cdot R_D < P_D$$

I_D = 50mA (half of max power rating of diode)

P_D = 0.25W (max power rating of resistor)

R_D < 100Ω

Conclusion:

After designing the necessary values for the resistors in this section, we tested the output of the circuit when we placed a finger in between the two diodes. The output of this test can be seen in Figure 1.2; here, you can see a pretty clear sinusoidal signal, which corresponds to our heartbeat.

Task 2: Active Low Pass Filter

Objective:

Here, we will design an active low pass filter that will have a cutoff frequency around 3.3Hz (corresponding to ~200bpm). The filter will also be designed to have a gain of 11.

Procedure:

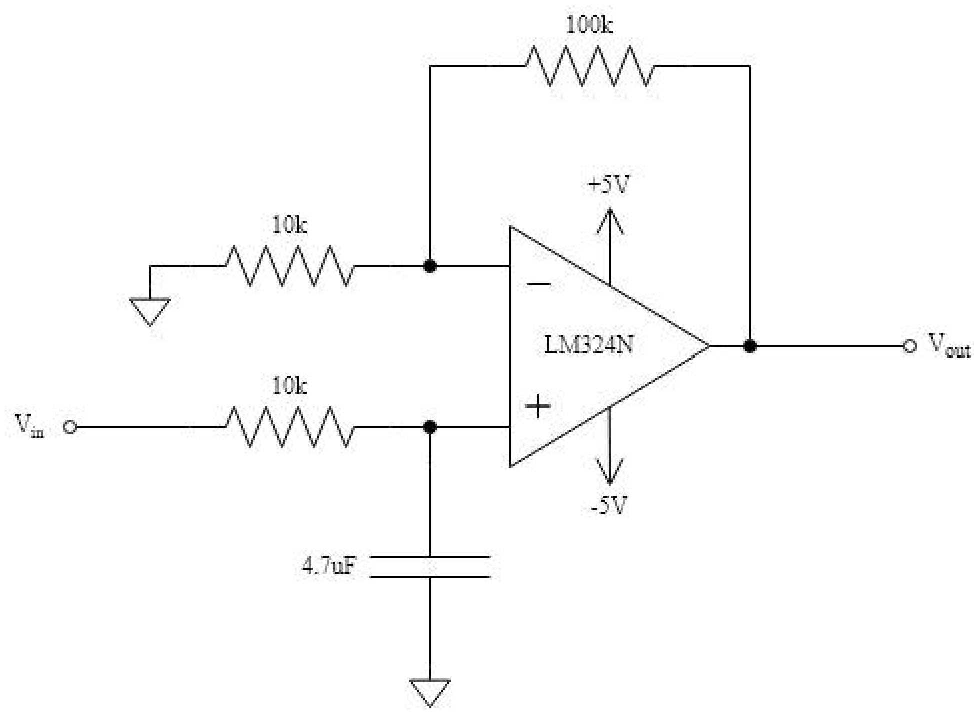

Figure 2.1: Active Low Pass Filter

- We started by designing for the resistor and capacitor values we would need to use in this active low pass filter configuration
    - The equations and calculation can be found below in the results section
- After constructing the circuit shown in figure 2.1, we ran it through a frequency response analysis using the network tool of the Waveforms application
    - The result of this can be found below in figure 2.2

Results/Calculations:

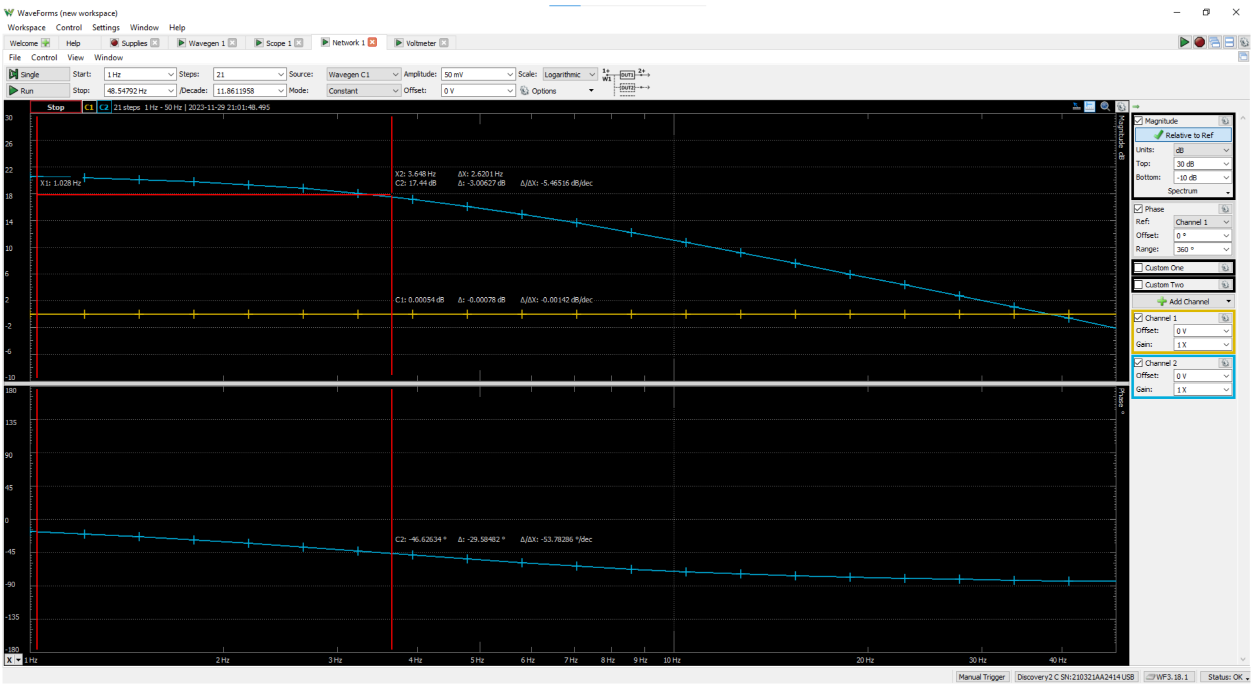

Figure 2.2: Active low pass filter FRA

	Ideal	Measured	% Error
-3dB Frequency	3.386 Hz	3.648 Hz	7.74%
Gain	11 (20.83dB)	10.52 (20.44dB)	4.36%

<u>Resistors Determining Gain:</u>

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

<u>Resistor/Capacitor Determining Cutoff Frequency:</u>

$$R_3 = \frac{1}{2\pi \cdot \omega_0 \cdot C}$$

$R_1 = R_3 = 10k\Omega$

$R_2 = 100k\Omega$

$C = 4.7uF$

Conclusion:

As seen in Figure 2.2, our active filter has a cutoff frequency of 3.648Hz, and a gain of 10.52. These numbers are very close to what we designed for, and the percent error for both are <8%. The goal of the filter is to smooth out the input signal by isolating frequencies that are close to what the average human heartbeat should be. This low pass filter will decrease the effect of high frequencies in our input signal, and will increase the amplitude of frequencies that are in the range of the average human heartbeat.

Task 3: Active High Pass Filter

Objective:

In this section, we design an active high pass filter. The cutoff frequency will be about 0.67Hz (corresponding to ~40bpm). This filter will also be designed to have a gain of approximately 11. In this section, will also obtain the frequency response for when the active high and low pass filters are cascaded together.

Procedure:

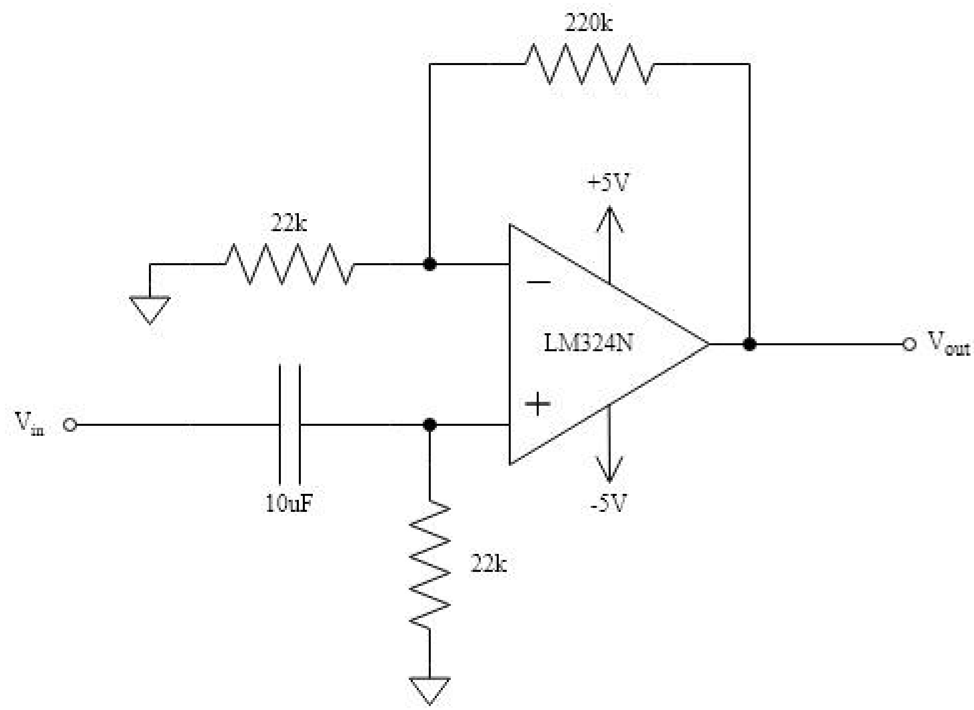

Figure 3.1: Active High Pass Filter

- Similar to the active low pass filter, we start by designing the resistor and capacitor values needed in this active high pass filter configuration
    - The equations and calculations are essentially the same as the active low pass filter, and can be found below in the results section
- After constructing the circuit shown in figure 3.1, we conducted a frequency response analysis of the high pass filter by using the network tool
    - The result of this can be found below in figure 3.2
- We then cascaded the high pass filter with the low pass filter, then obtained an FRA; shown in Figure 3.3 below

Results/Calculations:

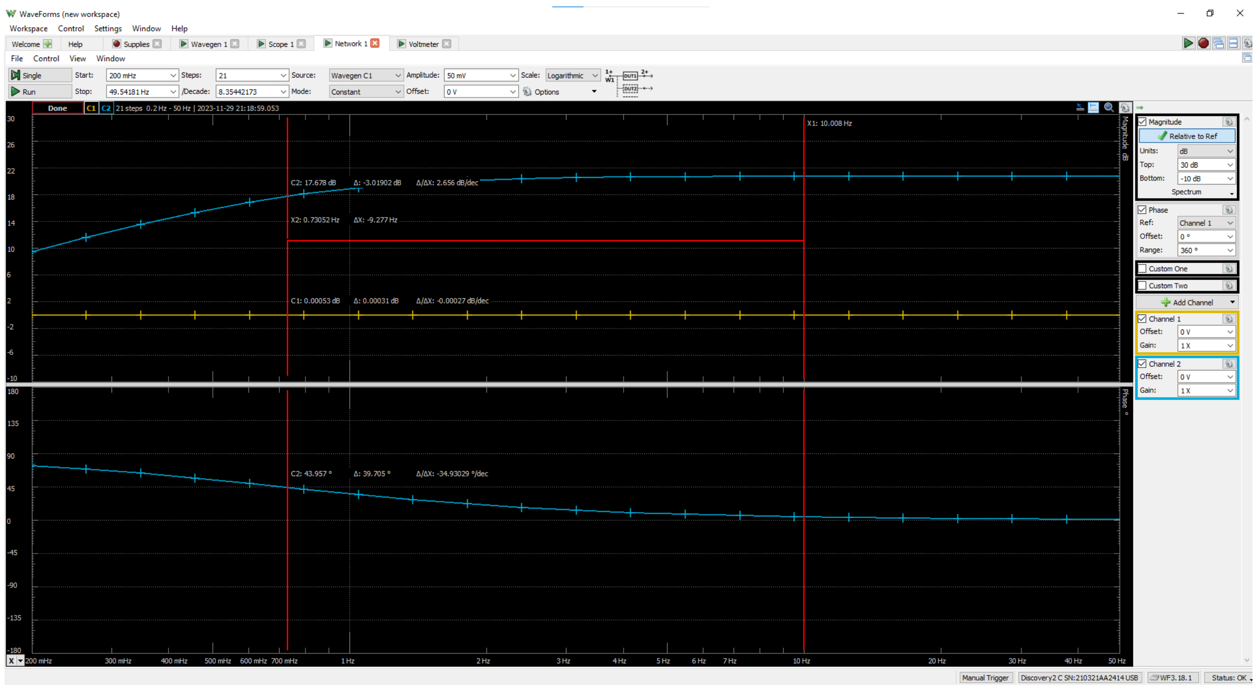

Figure 3.2: Active high pass filter FRA

	Ideal	**Measured**	**% Error**
-3dB Frequency	0.723 Hz	0.731 Hz	1.11%
Gain	11 (20.83dB)	10.812 (20.678dB)	1.71%

<u>Resistors Determining Gain:</u>

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

<u>Resistor/Capacitor Determining Cutoff Frequency:</u>

$$R_3 = \frac{1}{2\pi \cdot \omega_0 \cdot C}$$

$R_1 = R_3 = 22k\Omega$

$R_2 = 220k\Omega$

$C = 10uF$

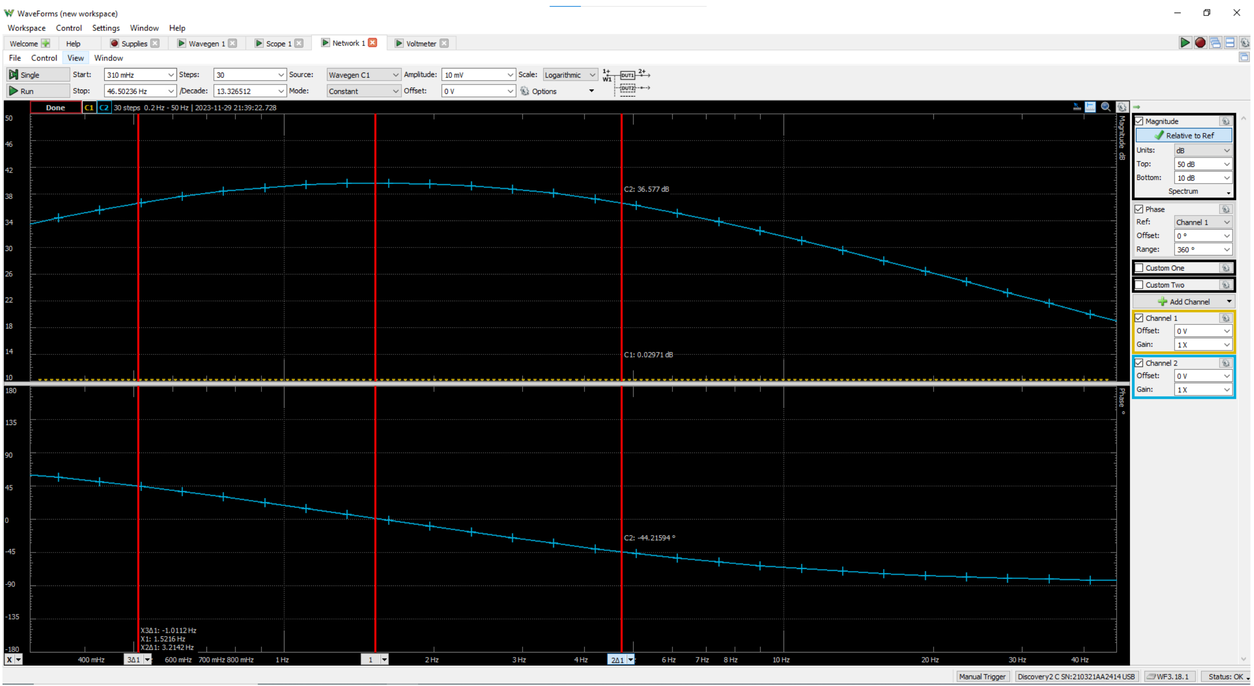

Figure 3.3: Bandpass filter FRA *(LPF cascaded w/ HPF)*

Lower Cutoff Frequency: **0.5104 Hz** (ideally 0.7Hz)
Upper Cutoff Frequency: **4.7358 Hz** (ideally 3.3Hz)
Q Factor: **0.36**

Conclusion:

As seen in figure 3.2, our active high pass filter functions very closely to what we designed it to be. Both the gain and the cutoff frequency have a percent error of <2%. So individually, our high pass filter is working as expected. The FRA of the active low pass filter cascaded with the active high pass filter can be seen in Figure 3.3 above. We noticed that the cutoff upper/lower cutoff frequencies moved quite a bit after the filters were cascaded. The upper cutoff frequency now has an error of 44%, and the lower cutoff frequency error is 27%. This is not ideal, as it will allow some frequencies to pass through the filter that couldn't possibly be a result of our heartbeat. However, this bandpass filter still does successfully encapsulate the range of heartbeats that may be tested on our circuit.

Task 4: Comparator

Objective:

In this section we will design a comparator with hysteresis. At the input of the comparator, we implement a high pass filter with a cutoff at ~2Hz to minimize any offset.

Procedure:

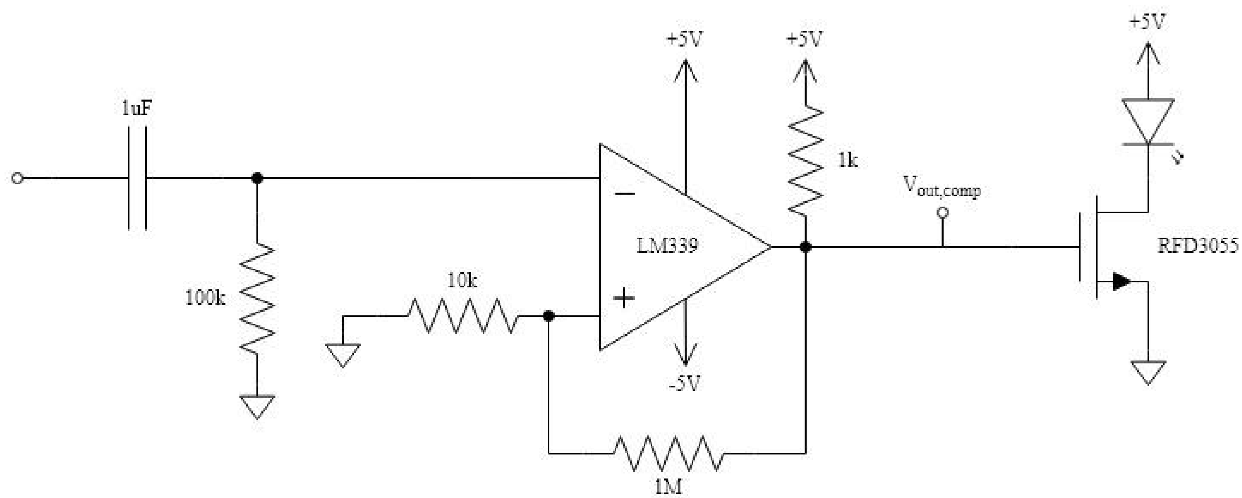

Figure 4.1: Comparator & Switch Diagram

- The resistor/capacitor combination at the negative input of the LM339 form a high pass filter with a cutoff frequency of ~1.59Hz
- The 1MΩ and 10kΩ resistors control v_{hyst}, which helps keep the comparator output from being triggered by noise.
  - The 10kΩ resistor was designed experimentally
- The output of the comparator is connected to the gate of an NMOS transistor. This allows the transistor to act as a switch for the LED; when the comparator output is high, the switch is on, when the output is low, the switch is off.

Results/Calculations:

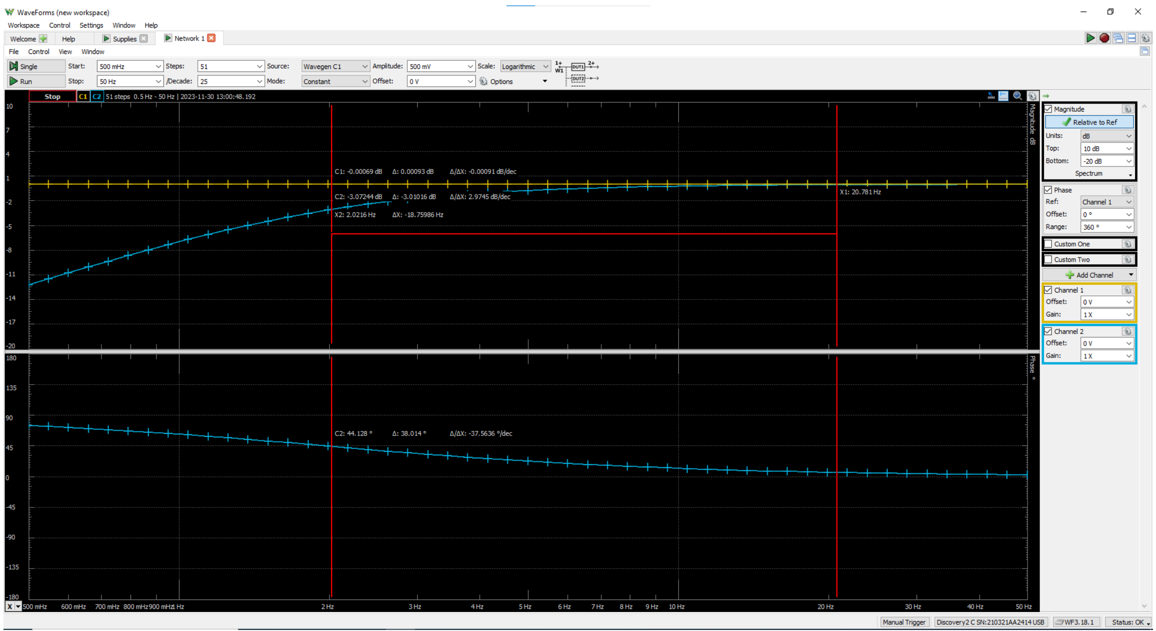

Figure 4.2: Comparator high pass filter

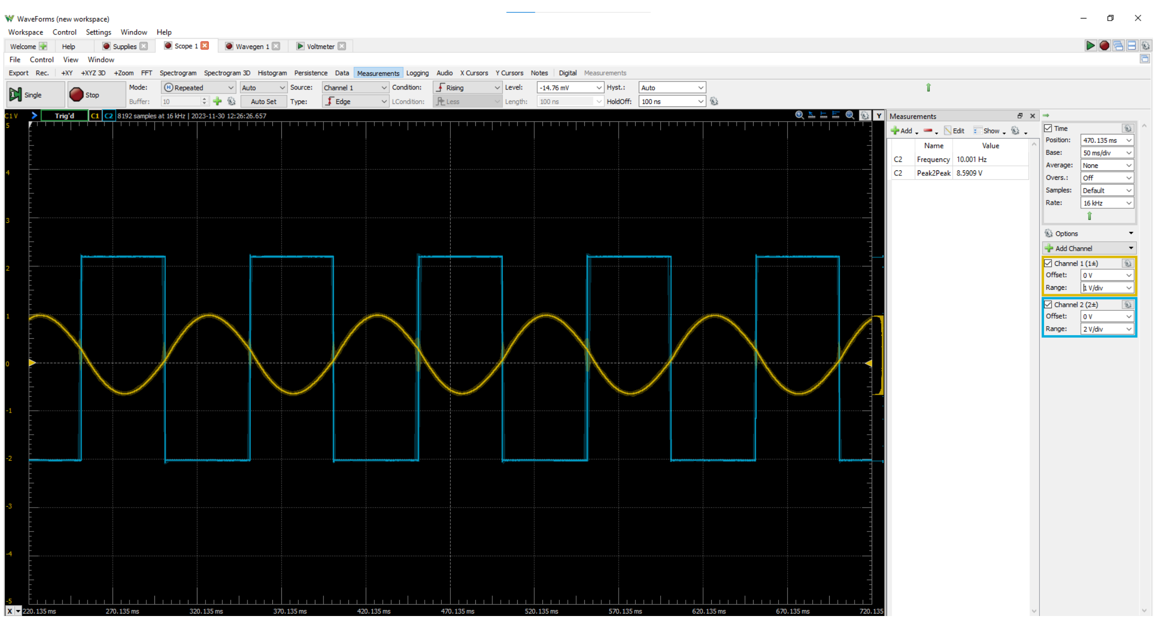

Figure 4.3: Comparator output (blue) given sinusoidal input (yellow)

$$v_{hyst} = (10) \cdot \frac{R1}{R1+1M\Omega}$$

$R_1 = 10k\Omega$

$\mathbf{v_{hyst} \approx 100mV}$

Conclusion:

Shown in Figure 4.2 is a frequency response of the high pass filter at the negative input of the comparator. The goal of this filter is to try and eliminate any remaining offset from the input signal. The goal was to make the filter have a cutoff frequency of 2Hz, and we settled on 1.6Hz. When designing v_{hyst}, we altered R_1 while testing the full circuit with our fingers between the IR204 and PT204-6B diodes. When testing, we were trying to find a value that gave us the best output, with a reasonable value for v_{hyst}. Figure 4.3 above shows the output of the comparator in blue when the input is a clean sinusoidal wave. As can be observed from the plot, our comparator is working as expected.

Task 5: Heartbeat Sensor

Objective:

In this section, we will combine all the parts from task 1-4 to complete our heartbeat sensor. The sensor will be tested by placing a finger in between the IR204 and PT204-6B diodes. Then, using the oscilloscope, we will measure the output of the comparator; the frequency of the output will correspond to our heartbeat.

Procedure:

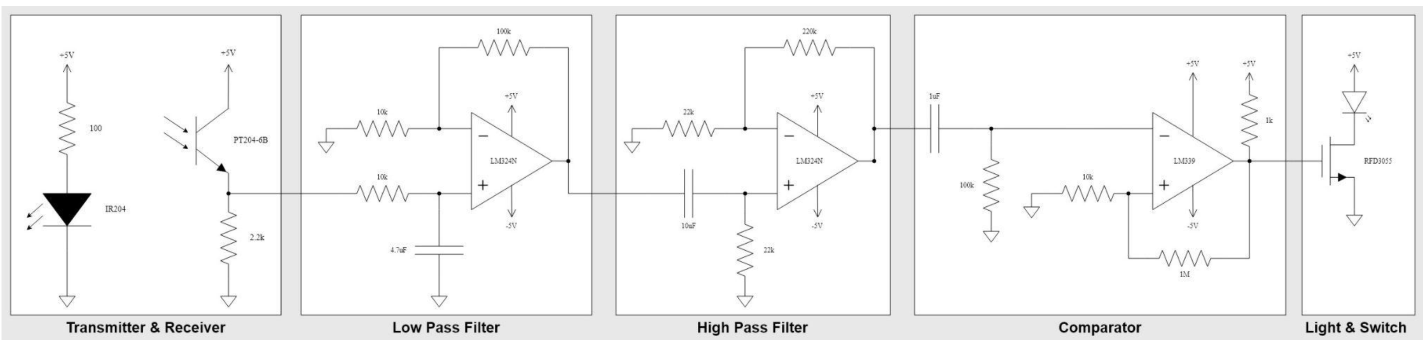

Figure 5.1: Heartbeat Sensor Circuit Diagram

- This task simply entails taking all the components of the previous tasks and combining them to form our heartbeat sensor.
  - The connections made are all shown in figure 5.1 above

Results/Calculations:

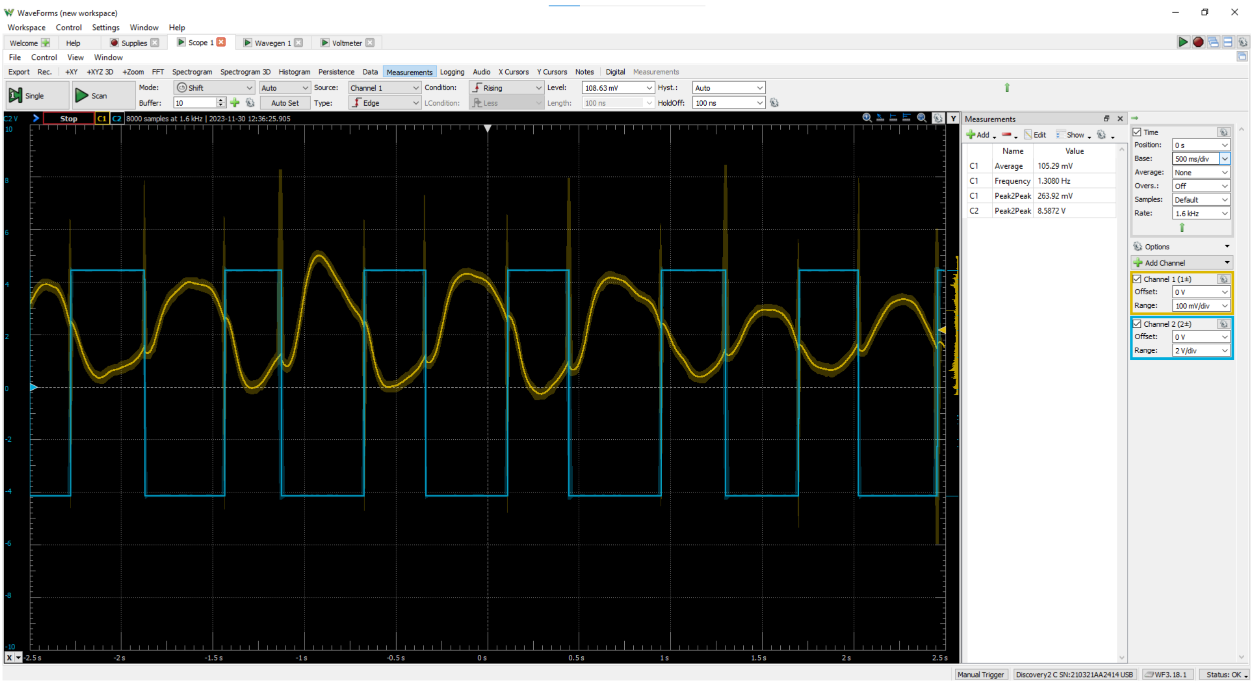

Figure 5.2: Filter output given analog input (yellow) & Comparator output (blue)

Conclusion:

The yellow signal in figure 5.2 above shows the output of the cascaded active filters when we have our finger placed between the two diodes. The blue signal is the output of the comparator. From the figure we can conclude that our heartbeat sensor is working as it should, and when we look at the frequency of the square wave, we can determine the approximate heartbeat of the person who placed their finger between the diodes. To find the approximate heart rate in beats per minute, we multiply the frequency by the 60; doing so, we can see that the person being measured had a heartbeat of approximately 78.5 bpm at the time this screenshot was taken.