CMPE 460 Laboratory Exercise 8

Heartrate Monitor

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Your Signature: ____________________

1 Abstract

Photoplethysmography is a technique widely used in the medical field to non-incisively measure oxygen saturation, blood pressure, heart rate, and much more. This is done by sending a infrared and red light either through the finger, or reflected off the finger, and then measuring the amount of light absorbed by the bone, tissue, and blood. Due to the properties of the bone, tissue, and blood, the only variable light absorption is found in the arterial blood. The variable light absorption can then be used to calculate the heart rate. However, due to the imperfect variation in light absorption, the signal must first be filtered. Utilizing a TLC277 Operational Amplifier, an active High-Pass Filter with a cutoff frequency of 0.75Hz and an active Low-Pass Filter with gain with a cutoff frequency of 4Hz, were designed and constructed. A function generator was used in place of a reflective object sensor, such as the OPB745, to mimic a heart beat, the output of the Low-Pass filter was then connected to a 100Ω current limiting resistor and over-voltage protection circuit and connected to the MSP432 micro controller. Code was written to read the signal from the filter circuit, using the ADC, and then was converted to beats per minute and outputted to the terminal via UART. The program successfully displayed the heart rate.

2 Design Methodology

Prior to designing the circuitry, research had to be conducted on utilizing Reflective Object Sensors, such as the OPB745, for a heart rate monitor. Reflective Object Sensors emit an infrared light via infrared diode and detects reflected light using either a phototransistor or photodarlington. In the case of the OPB745, a photodarlington is used. Since photolethysmography requires both infrared and red light, these sensors are unable to be used, however, they are able to be used for simply heart rate monitoring.

The filter circuitry was then designed to be simulated as seen in Figure 1. In order to achieve a cutoff frequency of 0.75Hz for the High-Pass Filter(HPF), a capacitor value of 21.22μF and resistor value of 10kΩ was used. Creating the transfer function:

$$H(\omega) = \frac{\omega}{\omega + \frac{1}{10k\Omega * 21.22\mu F}}$$

For the Low-Pass Filter(LPF), a capacitor value of 10μF and resistor value of 3.9kΩ was used to achieve a cutoff frequency of 4Hz. With transfer function of:

$$H(\omega) = \frac{\frac{1}{3.9k\Omega * 10\mu F}}{\omega + \frac{1}{3.9k\Omega * 10\mu F}}$$

While the HPF was designed to have a gain of 1, the LPF was designed to have a gain of 100. This was achieved by using a 99kΩ feedback resistor and a 1kΩ resistor connected to ground. These filters were then implemented using a TLC277 Operation Amplifier. In order to ensure minimal current draw, a voltage follower was placed before the filter circuitry. Finally, to protect the micro controller, an over-voltage protection circuit was designed utilizing a 100Ω resistor connected to two Schottky diodes.

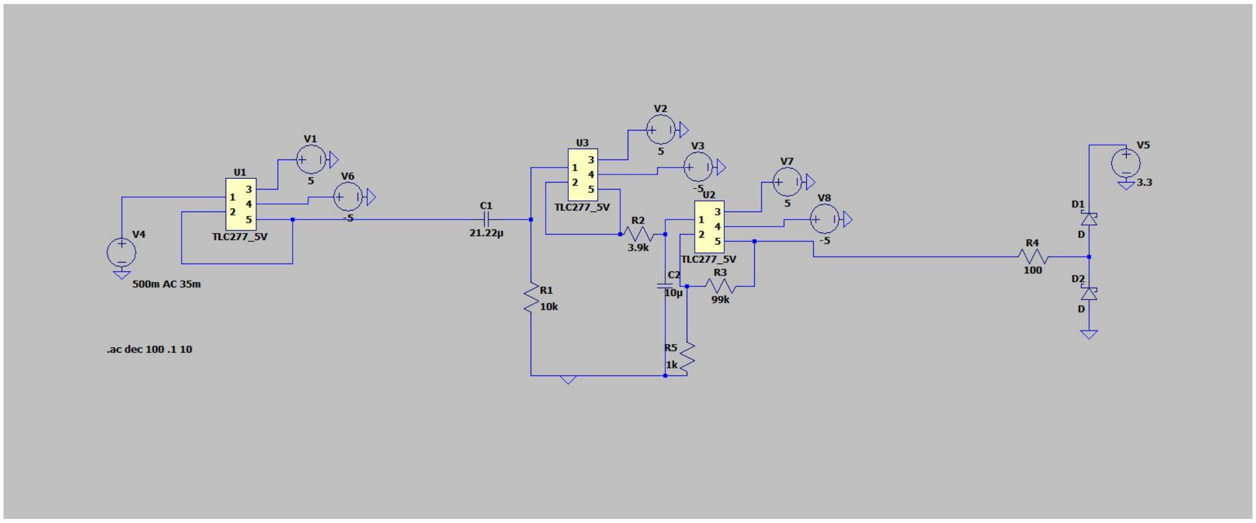

Figure 1: Heart Rate Monitor Filter Schematic

Code was then written to sample the output signal through the ADC and store the ADC values into an array. While the ADC was sampling, the Timer32 module was counting the time, in milliseconds, it takes for the ADC to fill the array. The ADC array was then parsed through to find the number of rising edges and falling edges. These were then divided by the time and multiplied by 60 to find the Beats Per Minute(BPM).

3 Results and Analysis

The circuit was first simulated using LTSpice to ensure validity as seen in Figure 2. It can be seen that the output gain of the circuit increases until roughly 2Hz, in which the gain decreases.

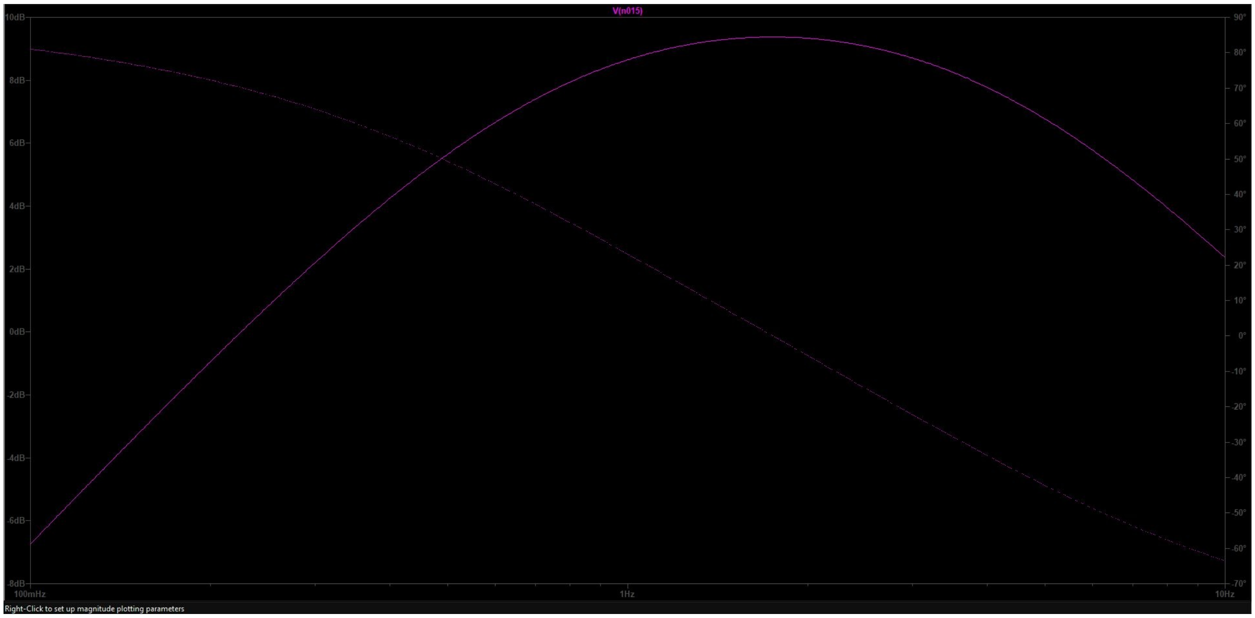

Figure 2: LTSpice Vout

The heart rate monitor circuit was then constructed, utilizing a 22μF capacitor in the HPF. A function generator with frequency 2Hz, AC voltage of 35mV, and DC voltage of 500mV was then connected to the input of the HPF. It was found that the actual cutoff frequency of the filter was closer to 0.7Hz as the capacitor value had to be increased to be a realistic value. The gain and cutoff frequency of the LPF were then found to be roughly 100.75 and 3.75Hz respectively. It can be seen in Figure 3 that the input, in orange, and output, in green, match in frequency while the output voltage is amplified to be 3.6V.

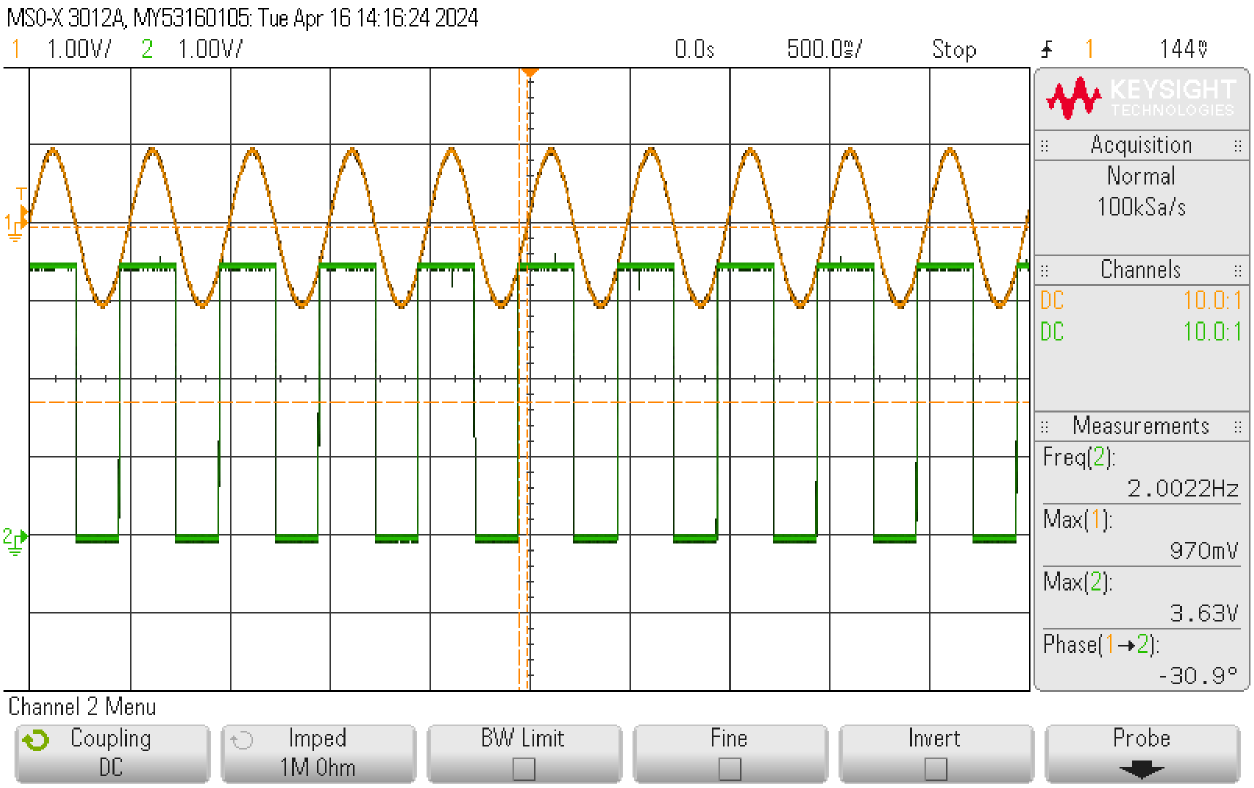

Figure 3: Heart Rate Monitor Input vs Output Oscilloscope Capture

The output was then connected to the MSP432 to process the signal into BPM. It can be seen in Figure 4, that when the input signal was roughly 2Hz, the code outputs a BPM of 95 which translates to a frequency of 1.6Hz.

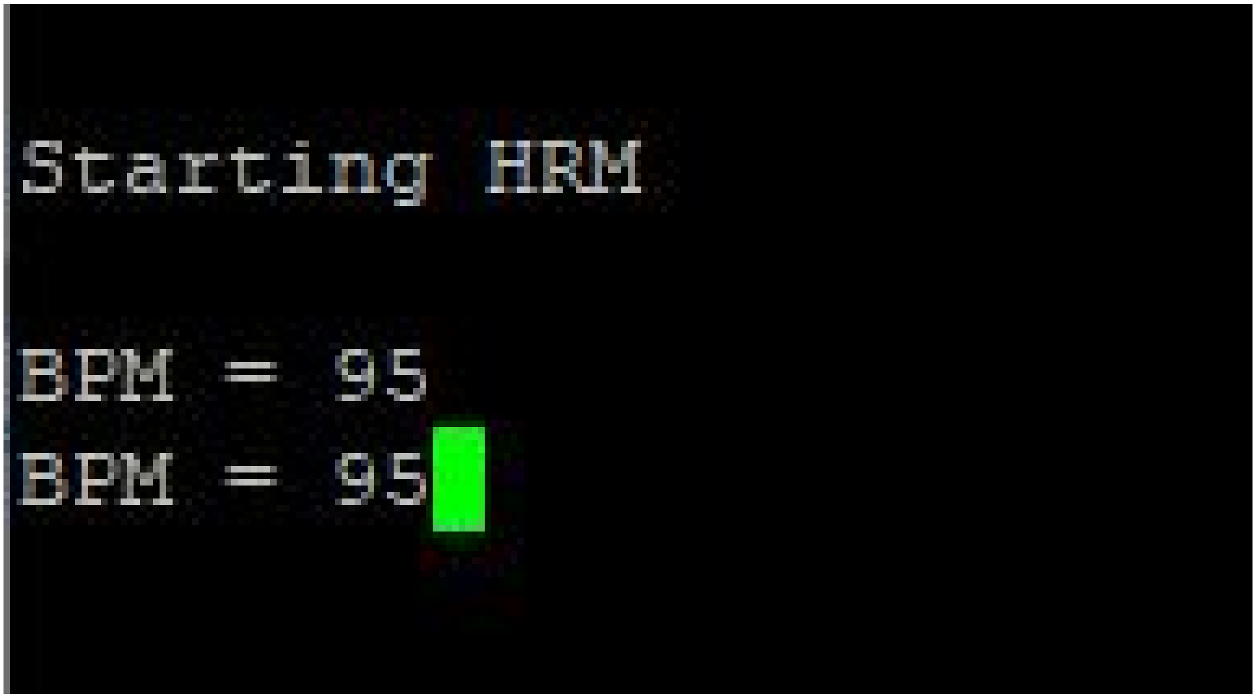

Figure 4: Heart Rate Monitor PuTTy Output

Finally, PCB's were created using KiCad to implement the heart rate monitor. Due to the OPB745 not being available on KiCad, the QRD1114 was used in its is place.

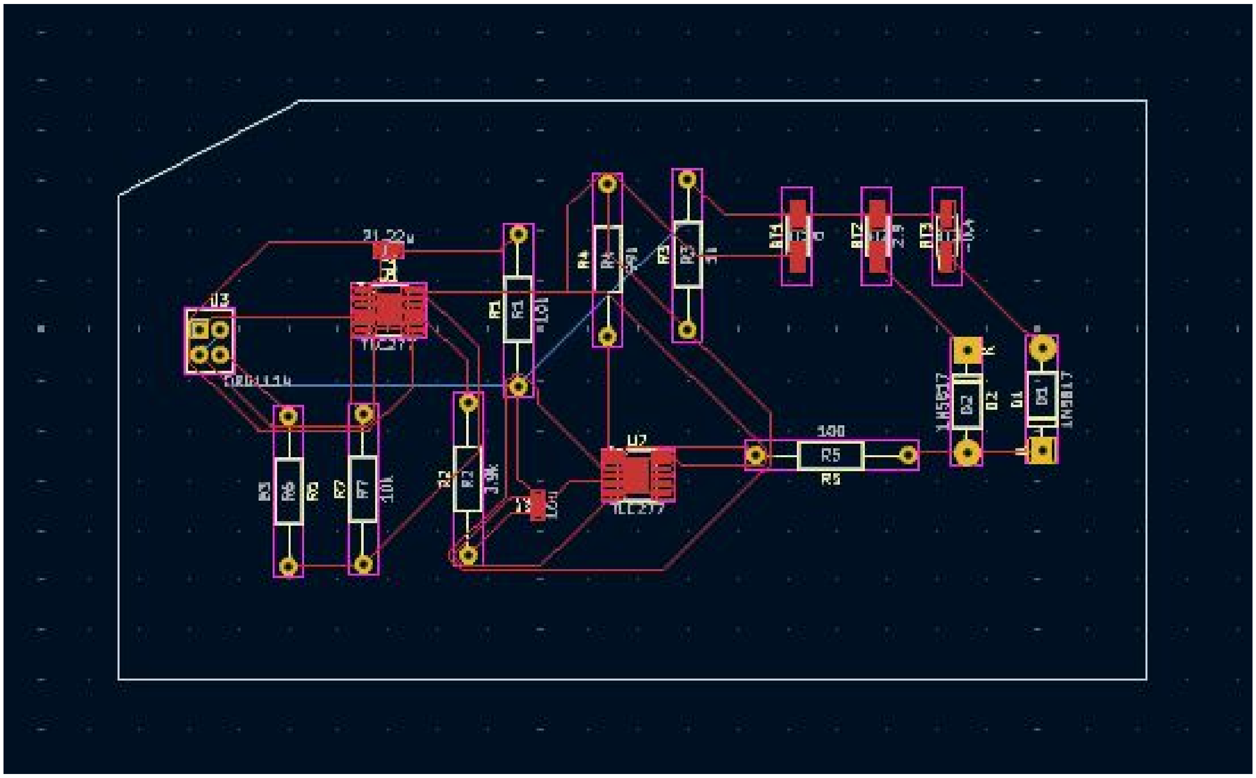

Figure 5: Heart Rate Monitor PCB 1

Figure 5 is the first PCB created, it can be seen that through-hole resistors were used instead of surface mount. This was due to the ability to run traces on the bottom of the PCB rather than all of the top to help manage the connections. An Electrical Rules Check (ERC) and Design Rules Check (DRC) was then run to ensure circuitry and placement validity. The gerber files were then generated and entered into OshPark to get an estimate.

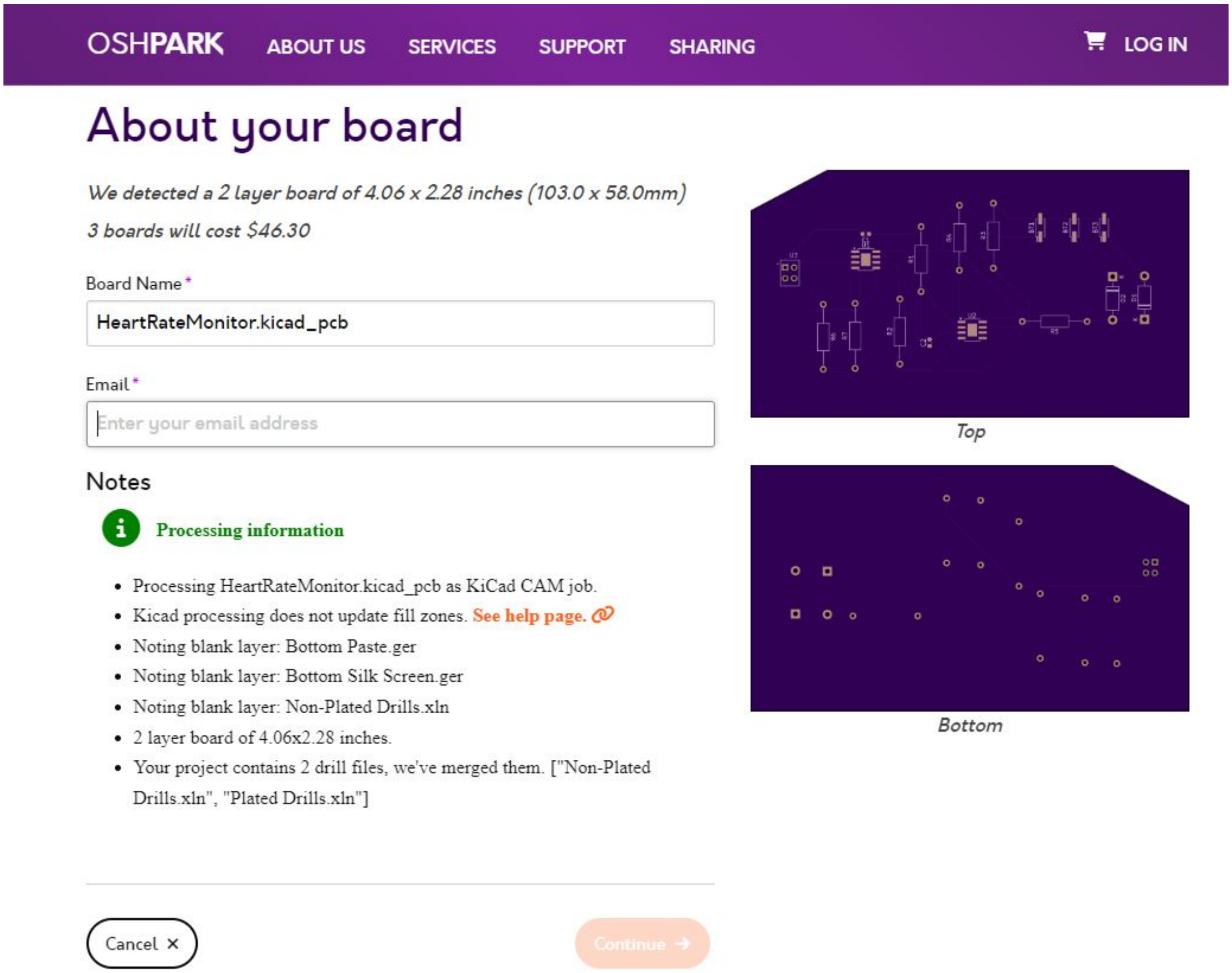

Figure 6: Heart Rate Monitor PCB 1 OshPark

Finally, the Bill of Materials (BOM) was generated for the PCB as seen in Figure 6.

	A	B	C	D	E	F
1	Reference	Value	Datasheet	Footprint	Qty	DNP
2	BT1	5	~	Connector_PinHeader_2.00mm:PinHe	1	
3	BT2	2.9	~	Connector_PinHeader_2.00mm:PinHe	1	
4	BT3	-0.4	~	Connector_PinHeader_2.00mm:PinHe	1	
5	C1	21.22u	https://www.digikey.com/en/products/detail/m	Capacitor_SMD:C_0603_1608Metric	1	
6	C2	10u	https://www.digikey.com/en/products/detail/ta	Capacitor_SMD:C_0603_1608Metric	1	
7	D1,D2	1N5817	http://www.vishay.com/docs/88525/1n5817.p	Diode_THT:D_DO-41_SOD81_P10.16	2	
8	R1,R7	10k	https://www.digikey.com/en/products/detail/ya	Resistor_THT:R_Axial_DIN0207_L6.3	2	
9	R2	3.9k	https://www.digikey.com/en/products/detail/ya	Resistor_THT:R_Axial_DIN0207_L6.3	1	
10	R3	1k	https://www.digikey.com/en/products/detail/st	Resistor_THT:R_Axial_DIN0207_L6.3	1	
11	R4	99k	https://www.digikey.com/en/products/detail/ya	Resistor_THT:R_Axial_DIN0207_L6.3	1	
12	R5	100	https://www.digikey.com/en/products/detail/ya	Resistor_THT:R_Axial_DIN0207_L6.3	1	
13	R6	83	https://www.digikey.com/en/products/detail/ya	Resistor_THT:R_Axial_DIN0207_L6.3	1	
14	U1,U2	TLC277	http://www.ti.com/lit/ds/symlink/tlc272.pdf	Package_SO:SOIC-8-1EP_3.9x4.9mn	2	
15	U3	QRD1114	https://www.digikey.com/en/products/detail/oi	65463:ONS_QRD1114	1	
16						
17						

Figure 7: Heart Rate Monitor PCB 1 BOM

4 Questions

What is the ERC and DRC for?
The Electrical Rules Check (ERC) ensures the circuits validity. This is done by checking to see if connections are floating, shorted, or open between components, power is driven, and traces are wide enough to support their current. The Design Rules Check (DRC) then verifies the PCB design meets manufacturing constraints as components are usually larger than their footprint.

Did your circuit cutoff frequencies match your expected/calculated values?
Within a certain margin of error, yes, our cutoff frequencies matched. The margin of error was due to the tolerance on the resistors and capacitors used, while they were specified to be the value needed, their actual measured values were slightly different. It was more apparent in the resistor than the capacitors.

Did the gain of the circuit match the expected/calculated values?
Within a margin of error, yes. As with the cutoff frequencies, the tolerance on the resistors allowed for their measured values be different than their expected values.

5 Conclusions

This exercise explored photoplethysmography through the simulation and creation of a heart rate monitor. The heart rate monitor was created by first using a function generator set to a frequency of 2Hz, AC voltage of 35mV, and a DC voltage of 500mV. This was then connected to a voltage follower to ensure low current draw throughout the circuit. A High Pass Filter with cutoff frequency of 0.75Hz was then connected, followed by a Low Pass Filter with cutoff frequency of 4Hz. Finally, the output was connected to a current limiting resistor as well as a over-voltage protection circuit to protect the micro controller. Code was then written to sample the ADC at a rate of 1000Hz, saving the values into an array. The array was then parsed through to find the number of rising and falling edges, this was then divided by the time elapsed during sampling and multiplied by 60 to find beats per minute. The beats per minute where then successfully displayed on the terminal via PuTTy.

6 References

Cheriyedath, S. (2019, February 27). Photoplethysmography (PPG). News-Medical. https://www.news-medical.net/health/Photoplethysmography-(PPG).aspx#: :text=Photoplethysmography%20(PPG)%20is%20a%20simple,related%20to%20our%20cardiovascular%20system.

ROHM SemiConductor. (n.d.). pulse sensor ROHM. https://www.rohm.com/electronics-basics/sensor/pulse-sensor#: :text=Reflection%2Dtype%20pulse%20sensors%20(Optical,using%20a%20photodiode%20or%20phototransistor.

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Student's Name: Hunter Culverhouse Gloria MBaka Section: 01

Demo		Point Value	Points Earned	Date
Demo	Pre-Lab (Individual)	10	10 H	AJT 4/3
	LTspice and Plots for HRM	10	10	MT 4/16
	Completed HRM	20	20	MT 4/16
	PCB Design and Layout (Individual)	10	10	MT 4/16

Bonus: Working HRM with OPB745 (10 pts) ________________________

To receive any grading credit students must earn points for both the demonstration and the report.