Design of a Noninvasive Pulse Rate Meter

Cobi Finkelstein   Erin LaBounty

Performed for BME 3012 & 3013
Submitted on March 4, 2016

Contents

List of Figures

Abstract

The purpose of this project was to design a noninvasive pulse rate meter. The design team decided to create a four-stage system for identifying the pulse using optical sensors. The first stage is the input, where an infrared LED shines light at a patient's finger while a photodiode receives light on the other end. The change in blood volume in the patient's finger changes the light in the patient's finger, which creates a current across the photodiode. The second stage is the current-to-voltage converter, whereby the current created by the change in light levels effects a change in voltage. This voltage is passed to the third stage, which is filtering, which attenuates the low-frequency DC offset as well as the high-frequency noise. The final stage is amplification, whereby the filtered signal is amplified so that it may be read by other means, such as a microcontroller.

1 Introduction

Pulse rate can be measured in a number of ways. For this project, the focus was measuring pulse rate using light. When the heart contracts, blood is pushed out to the extremities, including a person's fingers. The blood volume in the finger increases when the heart contracts and decreases when the heart is at rest. This difference can be measured using an LED and a photodiode. When the blood volume in the finger increases from contraction of the heart, the photons sensed by the photodiode from the LED is decreased because the blood in the finger blocks some of them. This causes the measured voltage of the photodiode to decrease. When the heart is at rest, the blood volume in the finger decreases and more photons are able to be sensed by the photodiode from the LED and the voltage measured for the photodiode increases. These peaks can be plotted to find pulse rate by counting the number of peaks in a certain amount of seconds and multiplying that times 60 to obtain pulse rate in beats per minute.

2 Design Considerations, Component Selections, and Calculations

The design of the device is separated into four functional blocks. First, the signal is acquired through an LED and photodiode. Then, the signal from the photodiode goes through a voltage-to-current converter. A filter then processes this signal, and an amplifier allows it to be read by an external source. From this, the team created an initial block diagram for the device, which is shown in Fig. 1.
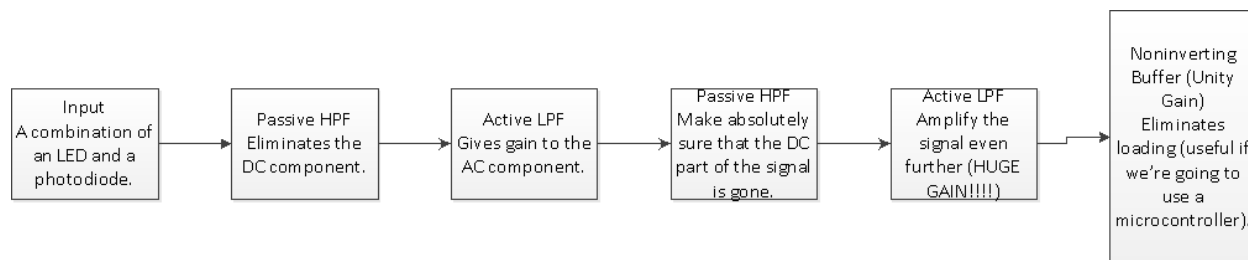

Figure 1: Block diagram of the design.

For the input, the infrared LED was chosen because the photodiode is more sensitive to light at a wavelength of 850 nm, which is in the infrared range (refer to Fig. 2).
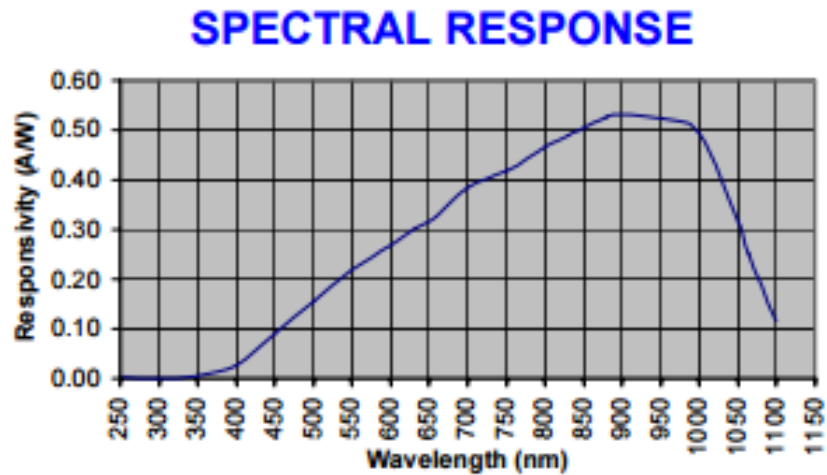
Figure 2: Sensitivity curve of the photodiode.

From the suggestion of peers and lab staff, a 100 Ω resistor was used to power the LED, and a 1 MΩ resistor was used to convert the current to voltage. Fig. 3 shows the circuit diagram for this part of the circuit.
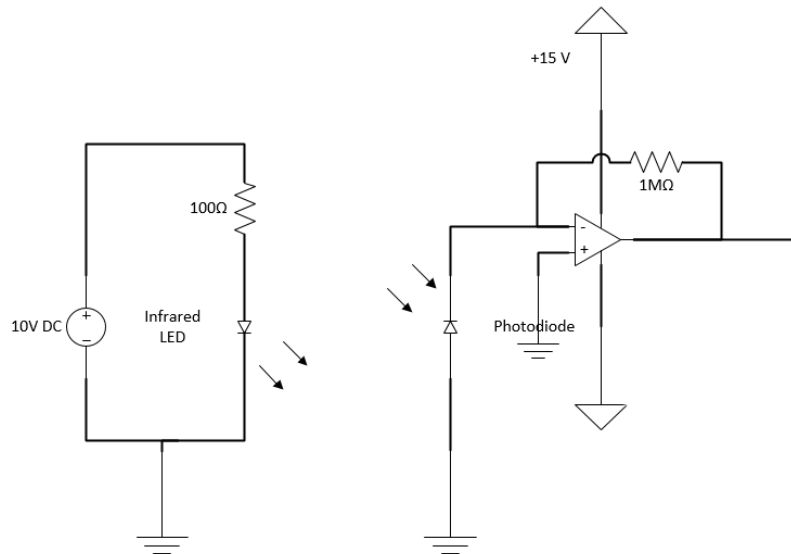

Figure 3: Diagram for LED and photodiode drivers.

The team then needed to house the LED and photodiode so that they were in-line. Fig. 4 shows the design of the machined part of the device, which comprises two plastic sleeves which house the photodiode and LED, as well as a larger plastic tube which holds these sleeves. Special thanks go to Tom at the Chem. Eng. machine shop for helping us out with this part of the project.
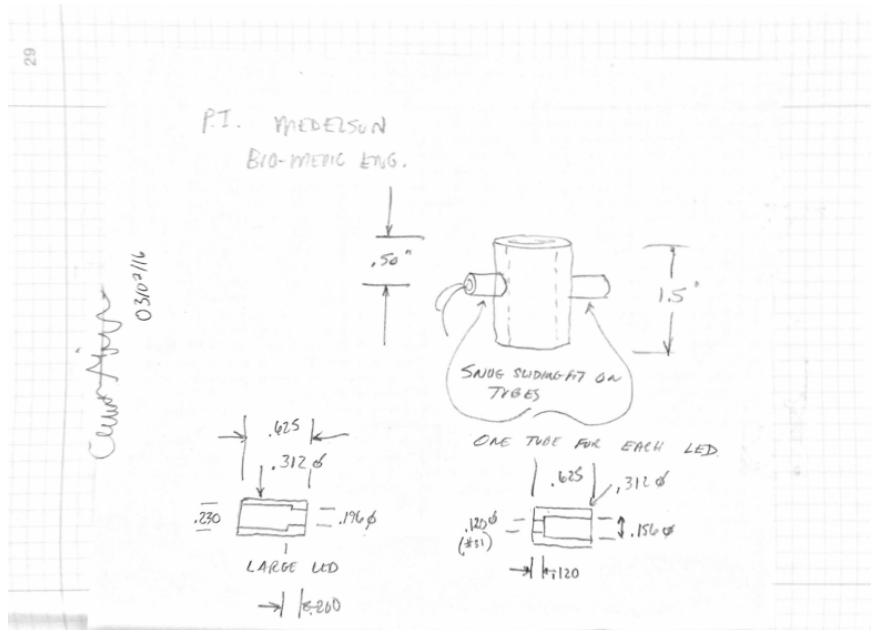
Figure 4: Drawing for container of LED and photodiode.

Next comes the filtering stage of the device. The team decided on a cutoff frequency of 0.05 Hz and 3 Hz, as the heart usually beats at a frequency between 1 and 2 Hz. To decide on components, the team used 1 to determine the high and low cutoff frequencies of the device. 1 uF capacitors were used because of their availability and ease of use, and the resistor values were derived from that. Fig. 5 shows the circuit diagram for this.

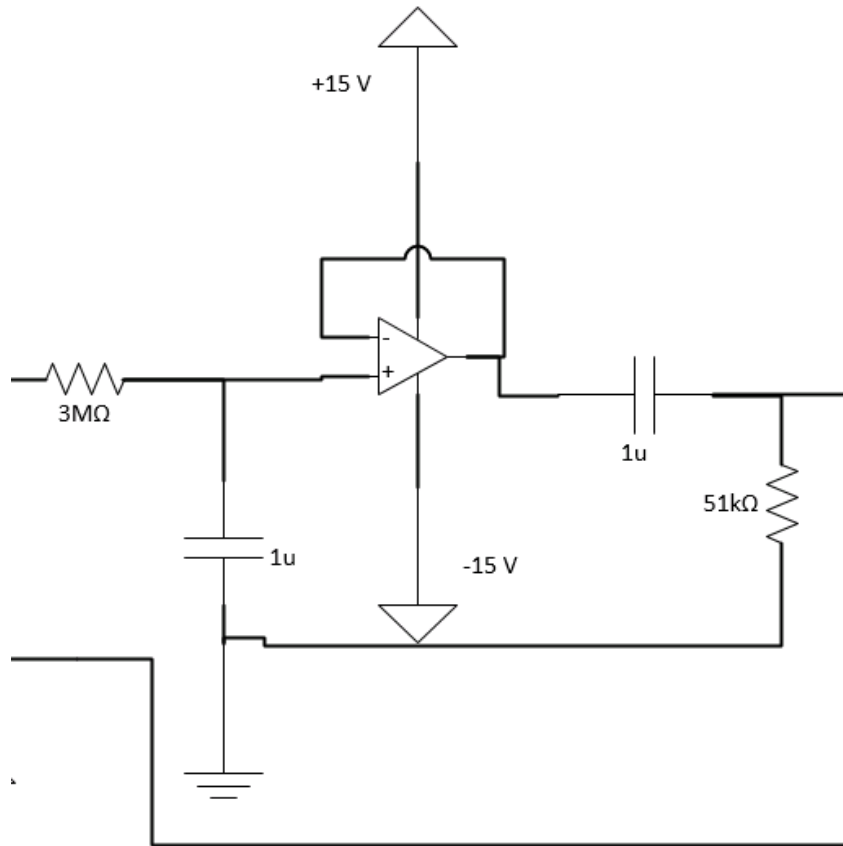$$f_c = \frac{1}{2\pi RC} \tag{1}$$

Figure 5: Diagram for active band-pass filter.

Finally, an amplifier brought the signal up to a readable level. a 1 kΩ resistor was used as the input resistor to the amplifier to make calculations simple, and a 200 kΩ resistor was used for a gain of 200, as per Eq. 2. The circuit diagram can be seen in Fig. 6

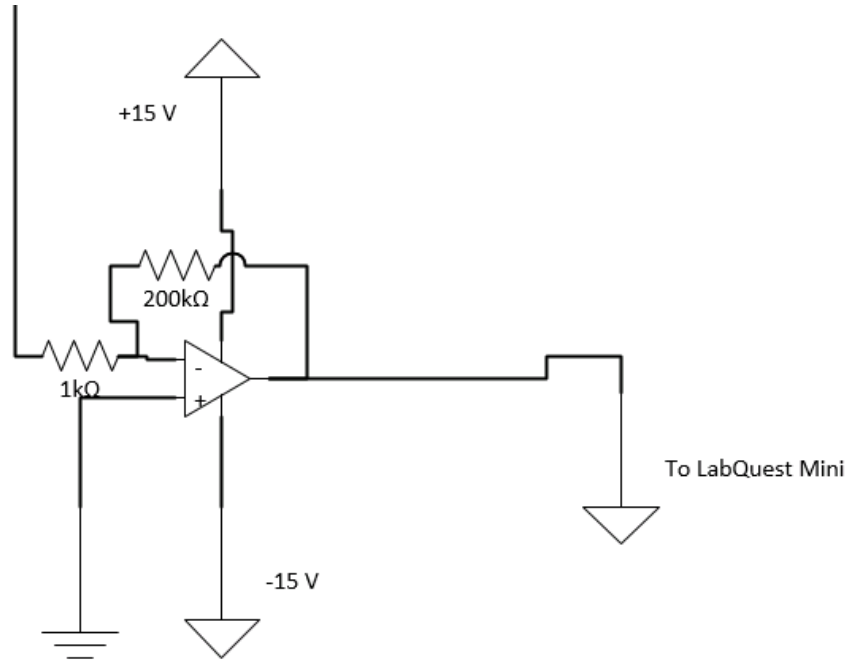$$A_V = -\frac{R_f}{R_i} \tag{2}$$

Figure 6: Diagram for inverting amplifier.

3   Device Evaluation

3.1   LED, Photodiode, and Current-to-Voltage Converter

With regard to the circuit schematic, just the LED and photodiode were tested first to make sure they were on and functioning. With the resistors used in the circuit schematic, we were able to get the photodiode to sense the LED when the tips are pointed directly at each other. The voltage across the photodiode jumped dramatically when the LED turned on, which validated its function. In addition, because the voltage increased dramatically when the LED was on, it verified the function of the current-to-voltage converter.

3.2   Active Band-Pass Filter

At first, the team had difficulty evaluating the band pass filter, as validating a cutoff frequency of 50 mHz requires an oscilloscope that can measure up to 20 seconds, which was not available. However, the team realized that DC is a signal of 0 Hz, so if there was no DC offset to the signal, then the filter worked, and it did. As for the low-pass aspect of the filter, the team was able to generate a Bode plot, seen in Fig. 7. Note how the cutoff frequency is approximately 3 Hz.
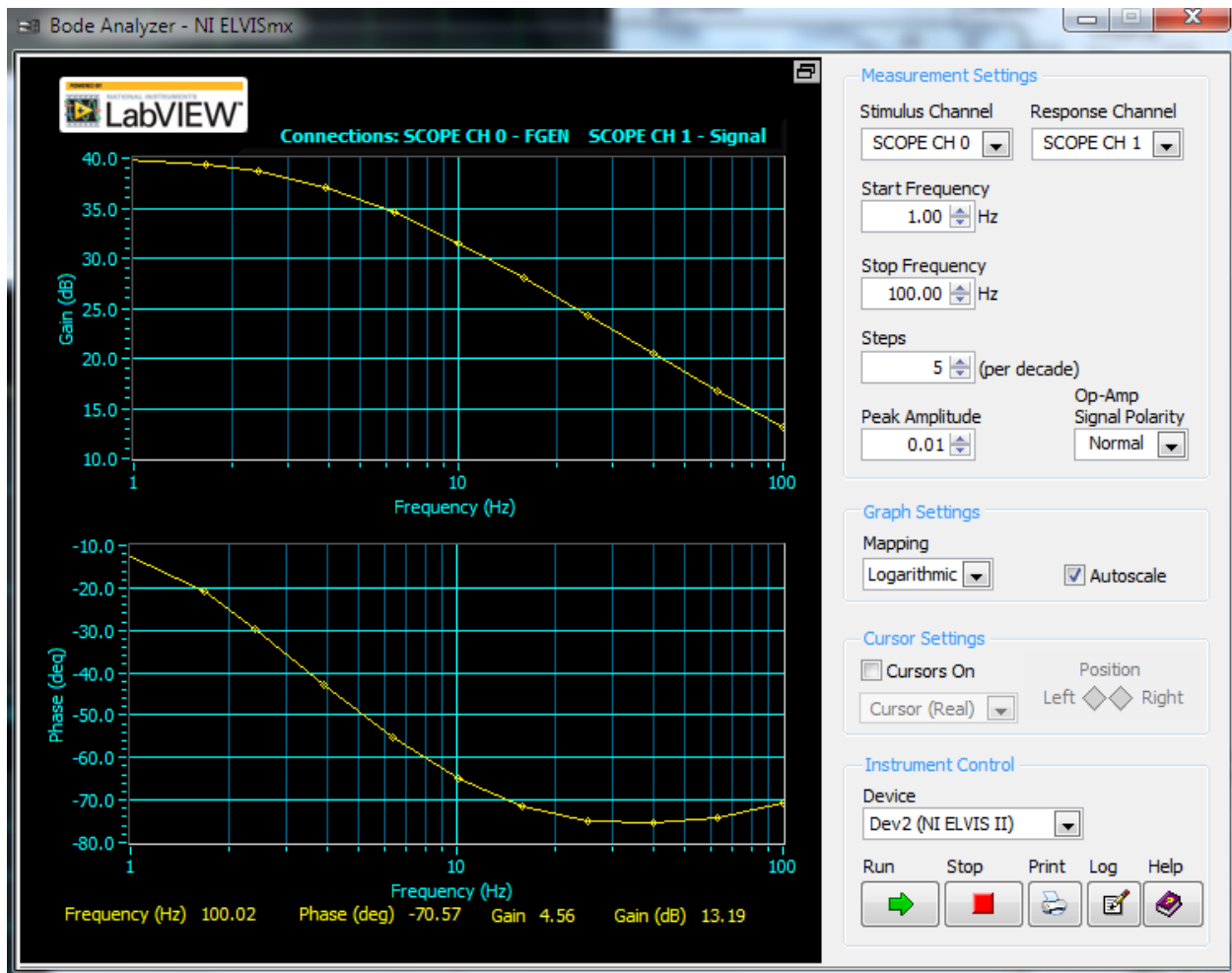
Figure 7: Bode plot for low-pass filter.

3.3   Amplifier

The amplifier is to further amplify the filtered signal before it is outputted. the amplifier is made using another op amp on the quad op amp used in the lab. Fig. 8 shows the signal before filtering and amplification.
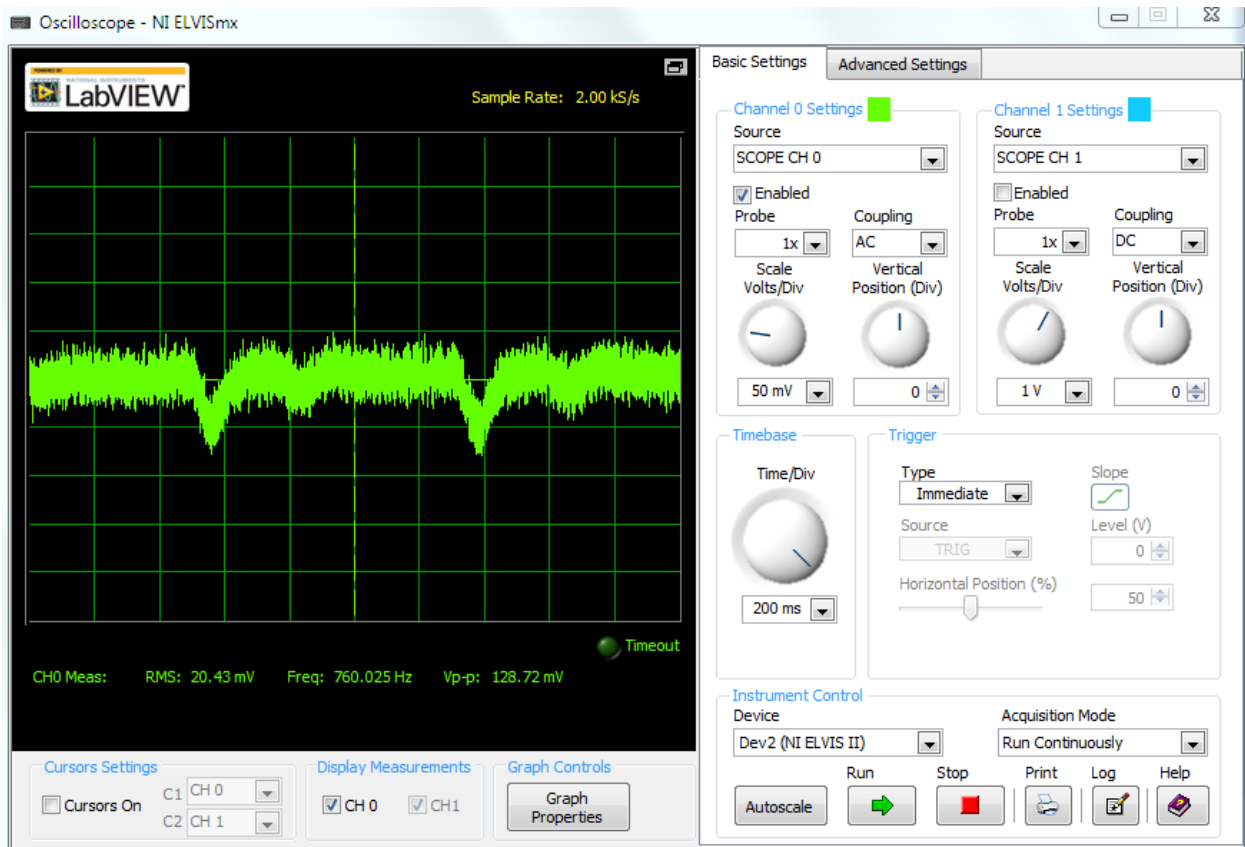
Figure 8: Device signal without filtering or amplification.

The peak to peak voltage for this is 128.72 mV. An example plot of the final output voltage is shown in Figure 9.
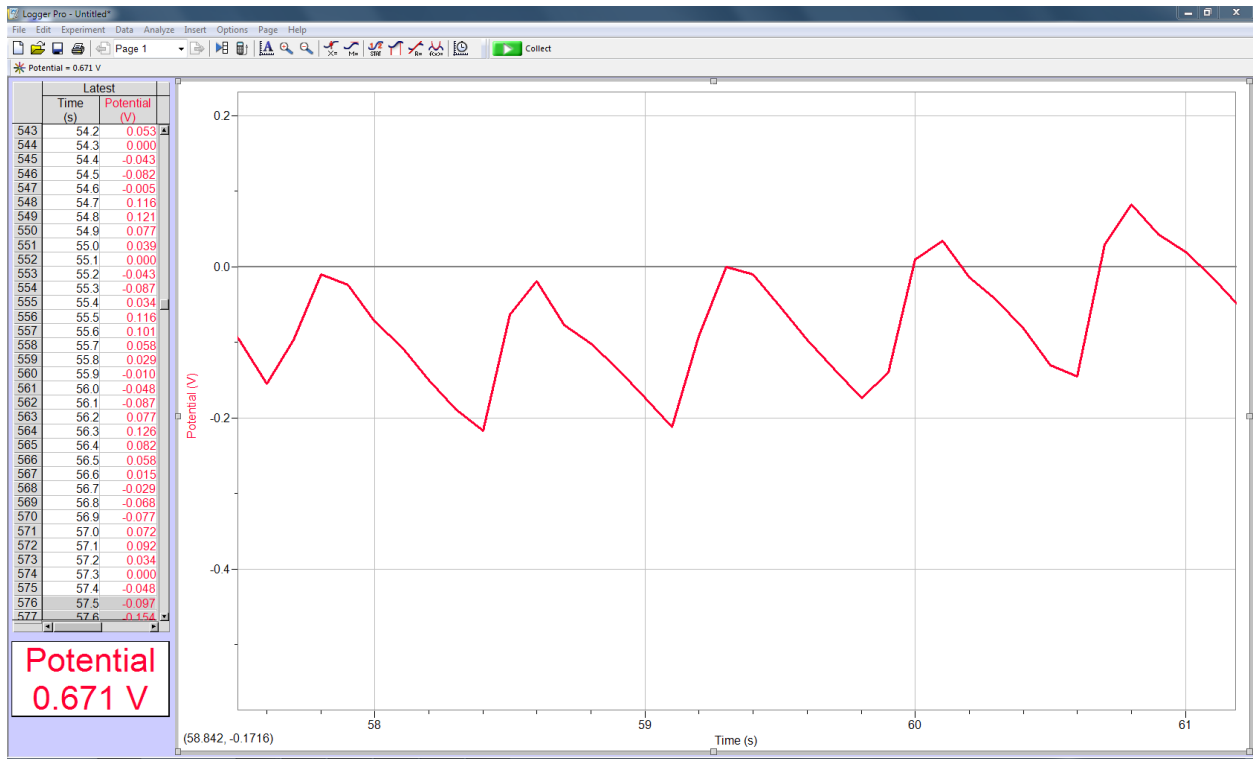
Figure 9: Fully processed waveform.

The peak to peak voltage for this waveform appears to be approximately 0.2 Volts or 200 mV. Compared to the peak to peak voltage of 128.72 mV before amplification, the new output waveform has clearly been amplified. The gain is approximately 200 mV divided by 128.72 mV, or 1.55.

3.4   Entire Device

The entire device works well at measuring heart rate of an individual. Resting heart rate for an average person can range from 60 to 100 beats per minute. Fig. 10 plot of what the output voltage is when a finger is inserted into the device.
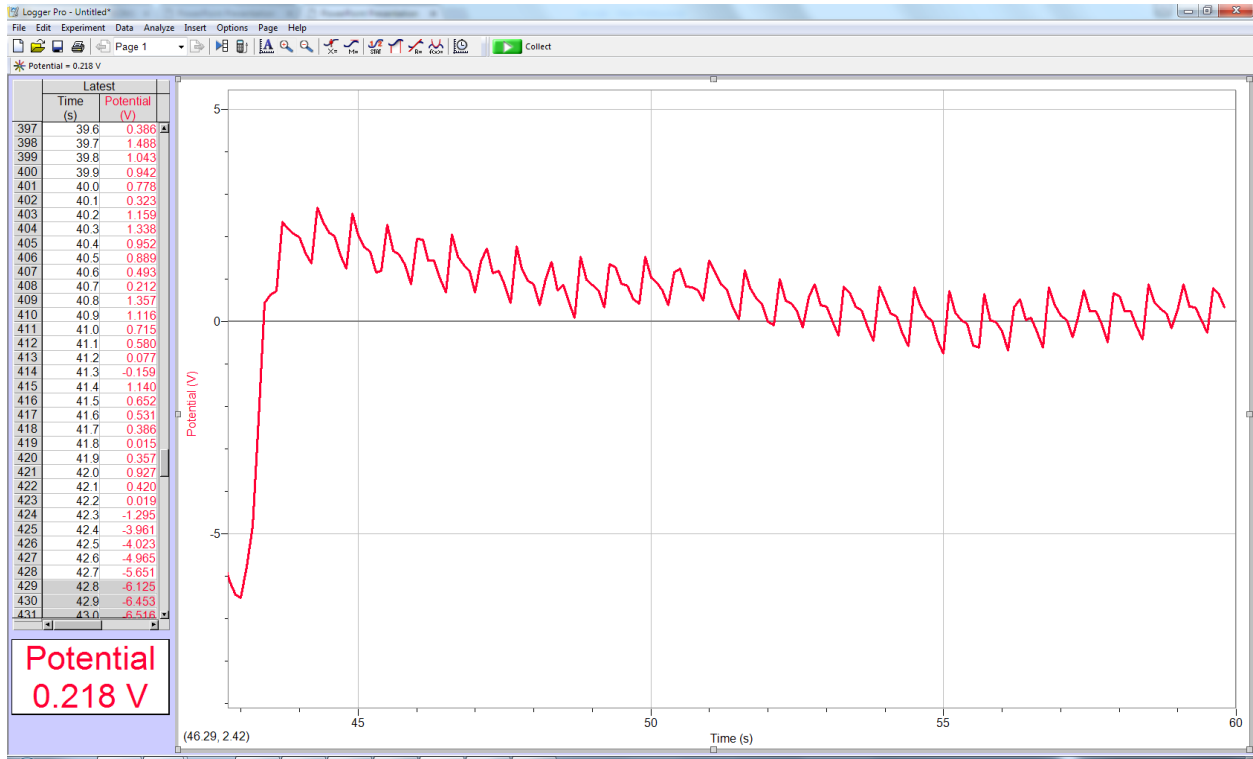
Figure 10: Example of output waveform.

The pulse rate can be found by counting the number of peaks in a specific time period. There are 11 peaks from 48.8 seconds to 55 seconds. That is 11 peaks in 6.2 seconds which times 60 is approximately 106 beats per minute, as shown in Eq. 3

$$BPM = 60 \times \text{Peaks/sec} \tag{3}$$

This heart rate is slightly higher than average but it shows that our device works at measuring pulse rate. The subject could have recently moved around and the measurements were not taken at a true resting heart rate, causing a higher BPM. Also the measurements are taken from a plot so there is room for error there as well. Overall, it is clear where the peaks are the correspond to heart contractions and it is relatively easy to find pulse rate in beats per minute from there.

4 Suggested Improvements

While this device represents the hard work and effort given by the design team, it is not perfect. There are some recommendations the team would like to make to improve the device in the future.

First, the housing could be improved. As of now, the LED and photodiode are not completely snug within their plastic sleeves. They could be glued in there, or, perhaps, bound with silicon to their sleeves.

Second, the team would like to add some microcontroller support, so that the signal can be processed even further. For example, the team could add an Arduino to the output of

the device, and have a seven-segment display show the current heart rate of the patient and warn the user if the heart rate is outside of the normal range. The final device can be seen in Figs. 11, 12, and 13
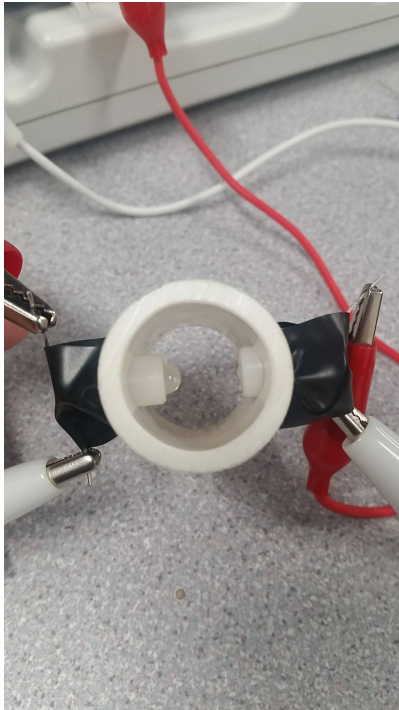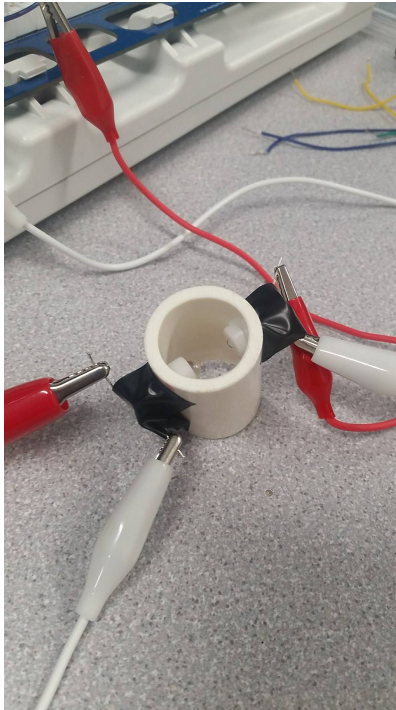

Figure 11: Final device, top view.

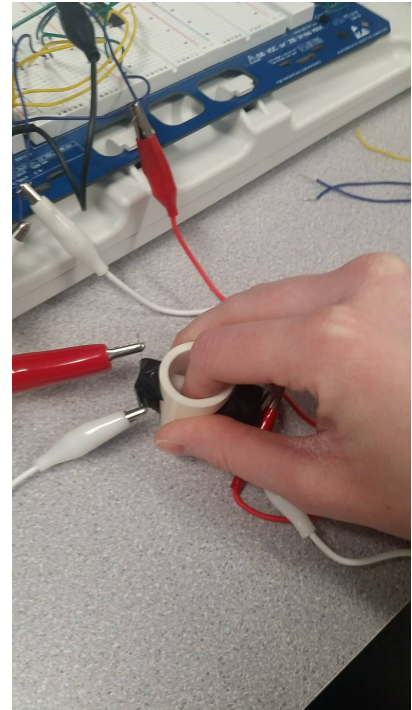Figure 12: Final device, isometric view.

Figure 13: Final device being used.

A   List of Materials

The following materials were used to make the device:

- TL-074 Op-Amp IC

- QED233 Infrared LED

- PDB-C134 Photodiode

- Resistors (in Ω:)

    500, 1k, 51k, 200k, 1M, 3M

- Capacitors:

    1μF

- LabQuest Mini & Voltage Probe

B   Design Specifications

This design is intended for use with a 10 V power supply and a heart frequency between 1 and 2 Hz. Results may vary if heart rate is above 3 Hz.
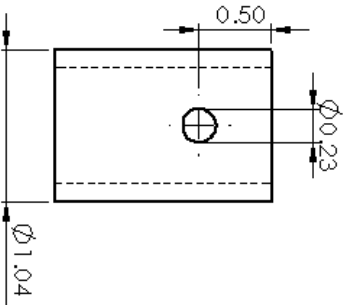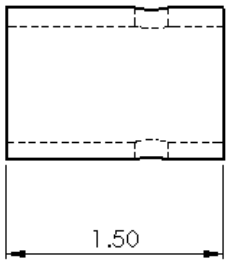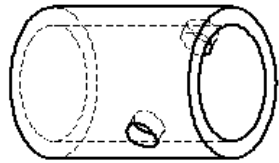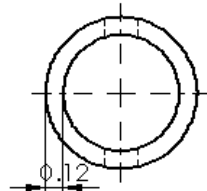
C   CAD Drawings

1.50

Ø.12

0.50

Ø0.23

Ø1.04

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
ONE PLACE DECIMAL   ±.1
TWO PLACE DECIMAL   ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY   USED ON

APPLICATION

	NAME	DATE
DRAWN	CEF	11-18-2015
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Worcester Polytechnic Institute

TITLE:

Tube

SIZE: A   DWG. NO.   tube   REV: A

SCALE: 1:1   WEIGHT: SHEET 1 OF 1

16

Dimensions shown: Ø0.23, Ø0.16, Ø0.12, 0.63

				NAME	DATE	
		DRAWN	CEF	11-18-2015		Worcester Polytechnic Institute
		CHECKED			TITLE:	
		ENG APPR.				
		MFG APPR.				sleeve
		Q.A.				
		COMMENTS:				

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: 1°
ONE PLACE DECIMAL   ±.1
TWO PLACE DECIMAL   ±.01
THREE PLACE DECIMAL ±.005

INTERPRET GEOMETRIC
TOLERANCING PER: ASME Y14.5

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY   USED ON

APPLICATION

SIZE A   DWG. NO. sleeve   REV A

SCALE: 5:1   WEIGHT: SHEET 1 OF 1

17