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# BMEN 2320 Final Project Report

## 1. Objective:

The objective of this project was to design a photoplethysmogram (PPG) using the TCRT5000 optical sensor. A photoplethysmogram is a non-invasive optical technique that measures blood volume changes of the blood vessels in the epidermal layer. Since the changes in blood volume are synchronous to the heartbeat, the PPG signal can also be used to calculate the heart rate and monitor cardiac activity in a clinical setting. Using the same PPG circuit, additional clinical applications can measure blood oxygen saturation, respiration, monitor autonomic function, and detect peripheral vascular disease (Allen, 2007). The circuit in the PPG is also found in wearable technology to track an individual's heart rate while exercising.

An improvement that could be made when designing the circuit for this project, would be to use a wider range of cutoff frequency for the passive low pass filter. Setting the cutoff frequency to around 60Hz instead of 1.59 Hz would allow for better visualization of the PPG waveform signal. Another improvement that could be made is to change the high-pass and low-pass passive filters into active filters. This would eliminate two resistors on the breadboard, amplify the filtered output, and minimize the loading effect.

## 2. Design decisions and simulation results:

To design the photoplethysmogram circuit, a photometer called the TCRT5000 reflective optical sensor was used to produce and measure the strength of infrared light. An advantage of using this component is that it includes both an infrared emitter and phototransistor in a compact package, making it useful for circuits with limited space. Additionally, compared to its transmissive counterpart, having the detector on the same side as the transmitter allows for materials of different shapes to be applied to the sensor. Since the reflective sensor uses infrared light that cannot be seen with the human eye, a test circuit from Google images was utilized to check the sensor as seen in Figure 1. Small modifications were made to the test circuit to comply with the available components in the provided parts kit. These modifications include resistor changes to 3.3k ohms and 220 ohms respectively and an additional Analog ground connection from the myDAQ to the negative rail on the breadboard. A screenshot of the test PPG waveform from the in-person lab oscilloscope, as seen in Figure 2, was taken to compare the waveform signals after the filters and amplifier were applied. The same test was conducted using the myDAQ, as seen in Figure 3, just in case the final circuit measurements were done at home instead of in the lab. The latter was also approved during office hours.

After the TCRT500 was approved, the waveform needed to be filtered and amplified to reduce the noise. The filters used for this circuit included a passive high-pass filter and a passive low-pass filter. These filters were used in the previous lab on filters conducted last semester in BMEN 2210. For the design aspect, the high pass filter was placed before the amplifier to reduce some of the noise before the current signal reaches the amplifier to avoid amplifying the noise. The low-pass filter was added after the amplifier to clean up the signal and reduce any residual noise from the amplified signal. Justifications and calculations for the cutoff frequencies are mentioned in the circuit build section of this report.

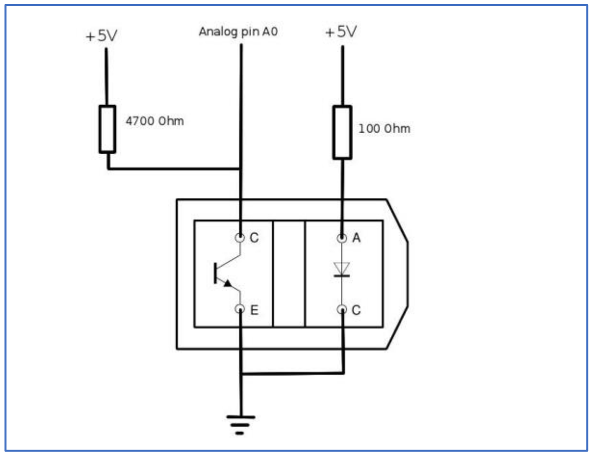
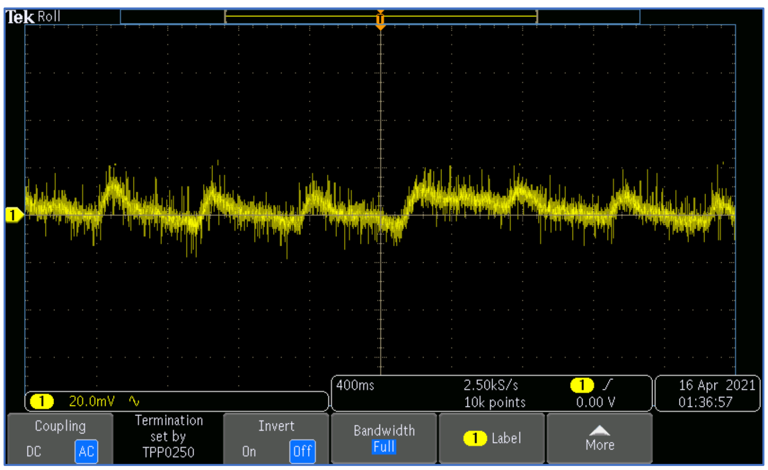



*Figure 1: TCRT5000 test circuit from Google images.*



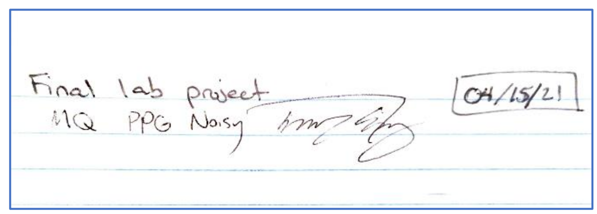




*Figure 2: Noisy PPG waveform as a result of testing only the TRCT5000 using the circuit diagram above using the oscilloscope in the lab.*

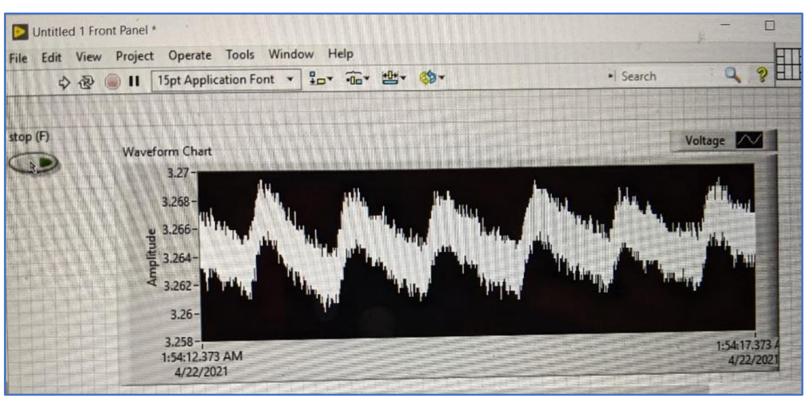
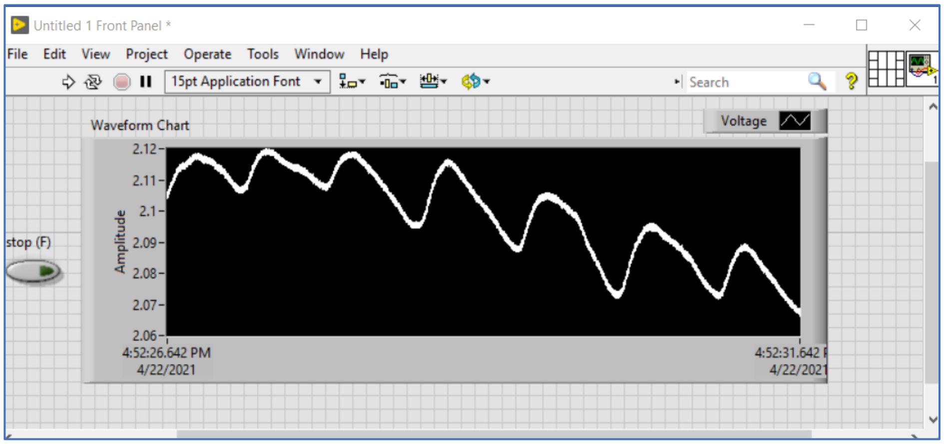



*Figure 3: Noisy PPG waveform as a result of testing only the TCRT5000 using the circuit diagram above using the myDAQ. (Double checked during office hours)*



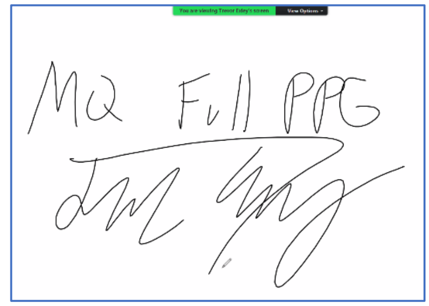



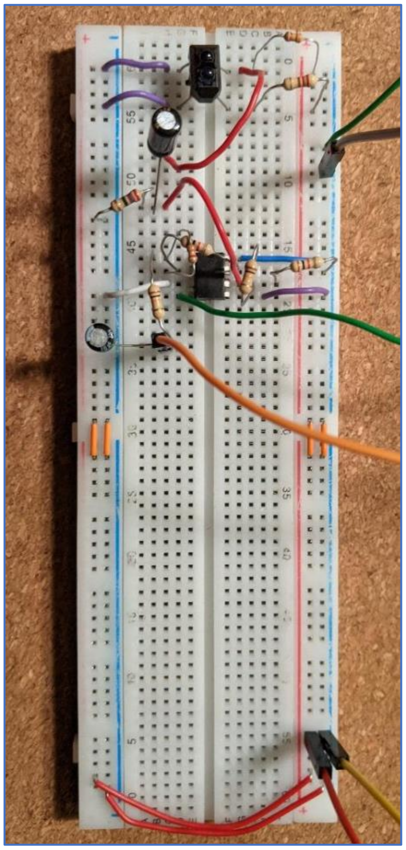
*Figure 4: PPG waveform with the TCRT5000, filters, and amplifier*.

**3. Circuit build:**

The first component placed on the breadboard is the TCRT5000, as seen in the full circuit photo labeled Figure 5. A 3.3k-ohm resistor was connected in series with the collector of the phototransistor. While a 220-ohm resistor was connected in series with the anode of the photodiode. Both the cathode and emitter were wired to the ground rail of the breadboard. Once the infrared light was emitted by the photodiode, the light reflected through the finger and fluctuated with the pulse of the blood flow. This caused a change in light intensity which was then detected by the phototransistor. A wire connected in series with the collector functioned as the output and carried the current signal from the phototransistor into the rest of the circuit. The power source used for this circuit was the 5V DC power supply in the in-person lab, and the 5V digital power supply from the myDAQ when the circuit was tested at home. Both were connected to the power rail of the breadboard to power the entire circuit.

After the current passed through the phototransistor, it entered the passive high-pass filter. The passive low-pass filter was added after the amplifiers. The cutoff frequencies used for the passive filters in this circuit ranged between .5Hz and 1.67Hz to reflect the average heart rate of 60 and 100 beats per minute. The calculation for each cutoff frequency is displayed in Figure 6, along with the heartbeat to frequency conversion. Additionally, the cutoff frequency for the high pass filter was set below the calculated frequency of 60 beats per minute to attenuate the magnitude of the undesirable lower frequencies, keeping only the frequencies of interest. The high pass filter was then connected to two sequential inverting operational amplifiers. The first inverting op-amp was to significantly amplify the voltage signal of the PPG waveform, while the second amplifier was placed with a lower gain to invert the waveform back to a positive voltage output. To amplify the signal, the gain for the first amplifier was set to 10 and the gain of the second amplifier was set to 3.3, as seen in the calculations in Figure 7. The resistor values for the inverting op-amp were established on a trial-and-error basis until the signal on the LABVIEW waveform chart displayed a visible PPG waveform. Originally, both gains were set to 2, however, it was not enough to amplify the signal.

Finally, the integrated circuit that could be implemented into this design would be the 7404 IC as a NOT gate buffer. This would be done by adding the output from the low-pass filter into two sequential NOT gates, allowing this IC to function as a buffer by lowering the output impedance. Figure 8 shows how this component would connect to the rest of the verified circuit. However, the integrated circuit was not evaluated using LABVIEW and is only mentioned in this report for theoretical purposes. From the output pin of the integrated circuit is where the final output would have been measured to produce the PPG waveform in LABVIEW. The other input pins would be either connected to power or ground.



Components listed in order:

TCRT5000:
Cathode/Emitter= Ground
Anode/Collector= Power via resistor
Output= Collector to capacitor of the high-pass filter.

High-pass filter:
Capacitor=.1uF
Resistor= 2.7M Ω

IC LM358:
Pin 1= Output of op-amp2/Input of low-pass filter
Pin 2= Input from op-amp1
Pin 3= Ground (op-amp2)
Pin 4= -5V on myDAQ
Pin 5= Ground (op-amp1)
Pin 6= Input from high-pass filter (op-amp1)
Pin 7=Output from op-amp 1
Pin 8= VCC

Low-pass filter:
Capacitor= 10uF
Resistor= 1kΩ

*Figure 5: Full circuit with the TCRT5000 optical sensor, passive high-pass filter, two inverting amplifiers, and a passive low-pass filter.*

Cutoff Frequency for passive high-pass filter:

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

$$.59Hz = \frac{1}{2\pi * R * .1\mu F}$$

$$R = 2.7M\ \Omega$$

Cutoff Frequency for passive low-pass filter:

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

$$1.67Hz = \frac{1}{2\pi * R * 10\mu F}$$

$$R = 10k\ \Omega$$

Heartbeat to Frequency:

60 to 100bpm
1bpm=1/60Hz
60bpm=1Hz
100bpm=1.67Hz

*Figure 6: Calculated cutoff frequencies for the passive high-pass and low-pass filter, along with the heartbeat to frequency conversion.*

Gain of the first inverting op-amp:

$$Gain = \frac{R2}{R1}$$

$$Gain = \frac{10k\ \Omega}{1k\Omega}$$

= 10

Gain of the second inverting op-amp:

$$Gain = \frac{R2}{R1}$$

$$Gain = \frac{3.3k\ \Omega}{1k\Omega}$$

= 3.3

*Figure 7: Calculations for the gain of each inverting op-amp in this circuit.*

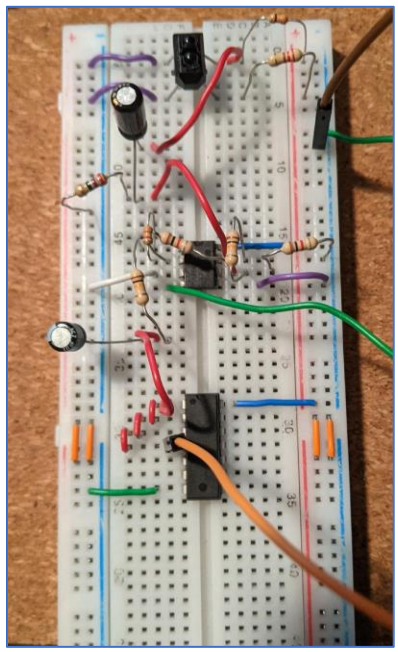


*Figure 8: Full circuit with the integrated 7404 IC as a NOT gate buffer.*

**4. Conclusion:**

After reviewing my circuit, there are a couple of improvements that I would have preferred to make. The first being to change the cutoff frequency of the passive low-pass filter to a range closer to 60Hz. Another improvement I would have liked to make is changing both passive filters to active filters to make the PPG waveform cleaner. Also, changing the NOT gate buffer into a voltage follower would avoid the gate delay. Regarding issues that I encountered, there were a couple of software issues that were not able to be resolved on my computer. To solve this, I borrowed my sibling's computer and was able to download the software. Another issue that I ran into was missing the diastolic portion of the PPG waveform. This may have been due to the limited range of the low-pass filter, or the sensor sensitivity to the applied pressure that was not able to read the entire waveform. After attempting different gains for the inverting op-amps, I was unable to precisely replicate the PPG waveform example that was given in the project instructions. On the other hand, I was still able to observe a waveform as the final output of this circuit.

Overall, this project helped to solidify my understanding of all the concepts that have been not only taught during this semester but also previous concepts that were taught last semester as well. Specific concept theories that helped me understand this project includes passive filters, operational amplifiers, and logic gates. This project also helped me understand how to take a design concept and utilize a physical breadboard to further develop that concept.

**5. References**:


1) Allen J., *Photoplethysmography and its application in clinical physiological measurement*. Physiol Meas. 2007 Mar;28(3): R1-39. doi: 10.1088/0967-3334/28/3/R01. Epub 2007 Feb 20. PMID: 17322588.

2) LM358 Datasheet: ONSemiconductor, “Single Supply Dual Operational Amplifiers”, Type: LM358. Rev. 22, July 2019. https://www.onsemi.com/pdf/datasheet/lm358-d.pdf

3) 7404 Datasheet: STMicroelectronics Electronic Components, “7404 Datasheet TRIPLE VOLTAGE REGULATOR”, Type: 7404, Rev. Dec. 1992. https://datasheet4u.com/datasheetpdf/STMicroelectronics/7404/pdf.php?id=248136