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PHYS 219, Section L1B

Final Lab: Experiment 9 – Electrocardiogram

Abstract:
The low level (~ 5 mV) electrical impulses of the heart is measured using electrodes attached to the body and then amplified by a factor of 100 using an instrumental amplifier. The instrumental amplifier has a large common mode rejection ratio which allows only the differential voltage to be amplified so that the heart waveform can be seen on an oscilloscope.

Introduction:
The human heart is triggered by electrical impulses which can be detected by placing electrodes in strategic places on the skin. The electrical impulses make a waveform which can be displayed on an oscilloscope. However, the electrical impulses are generally very low, around 5 mV, and needs to be amplified before the waveform can be clearly seen on the oscilloscope. Using a standard operational amplifier, such as the LM741, will not work in this case because the body is generally held at a significant common-mode voltage on the order of several volts, which is much larger than the AC voltage of the heart wave form. Using the OpAmp amplifies both the common-mode and the electric waveform by a very large amount and we just see the voltage go back and forth between positive and negative rail. Applying the + and – electrodes to the + and – inputs of an OpAmp configured with negative feedback will also not work because the waveform is much smaller (~ 5mV) than the common-voltage. The input impedance of such a circuit will be too small for the current carried through the electrodes.We must, therefore, construct a an instrumental amplifier which rejects the common-mode shared by both the positive and negative electrodes and only amplifies the differential signal.

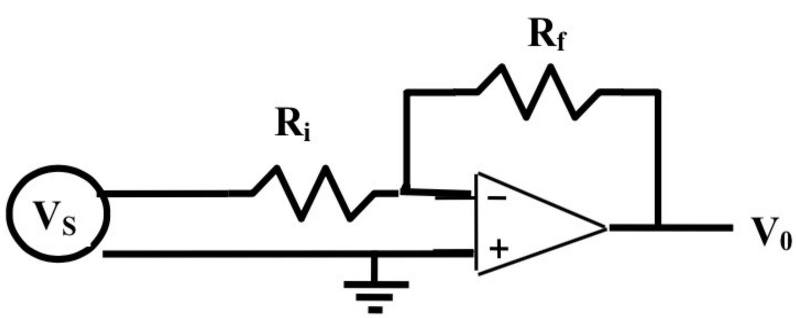

Figure 1. Attempt with the Inverting Amplifier

In order to test the instrumental amplifier, we must first build a square wave generator that produces square waves of a comparable amplitude and frequency as that of the human heart. We can use two Schmitt trigger inverter (MC54/74HC14A) which have a hysteresis in the input triggering characteristic to do this.

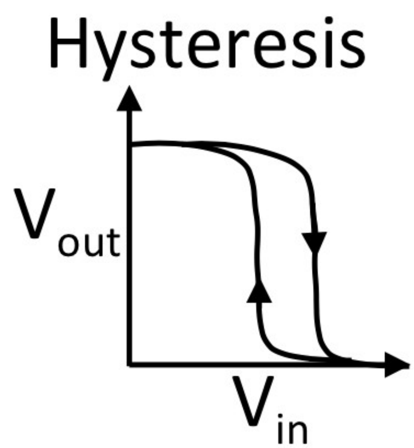

Figure 2. Hysteresis of the Schmitt trigger inverters.

This characteristic allows the following circuit to output square waves.

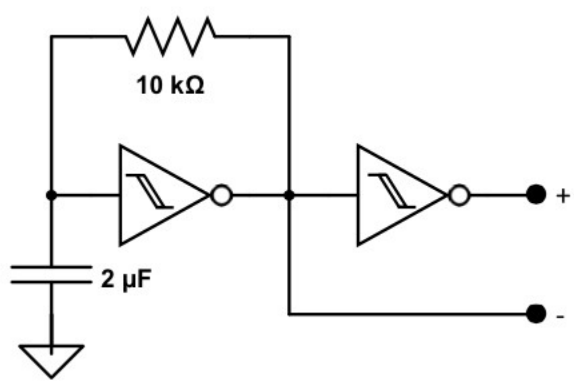

Figure 3. Square wave generator.

This is because the output of the first inverter will not change until the input drops below, or rises above the threshold voltage, at which time, the output changes abruptly. The resistor and capacitor combination allows the voltage change to be slower so that this test circuit more closely imitates the heart.

The instrumental amplifier is constructed with a LM 124N chip by connecting the amplifiers like so:

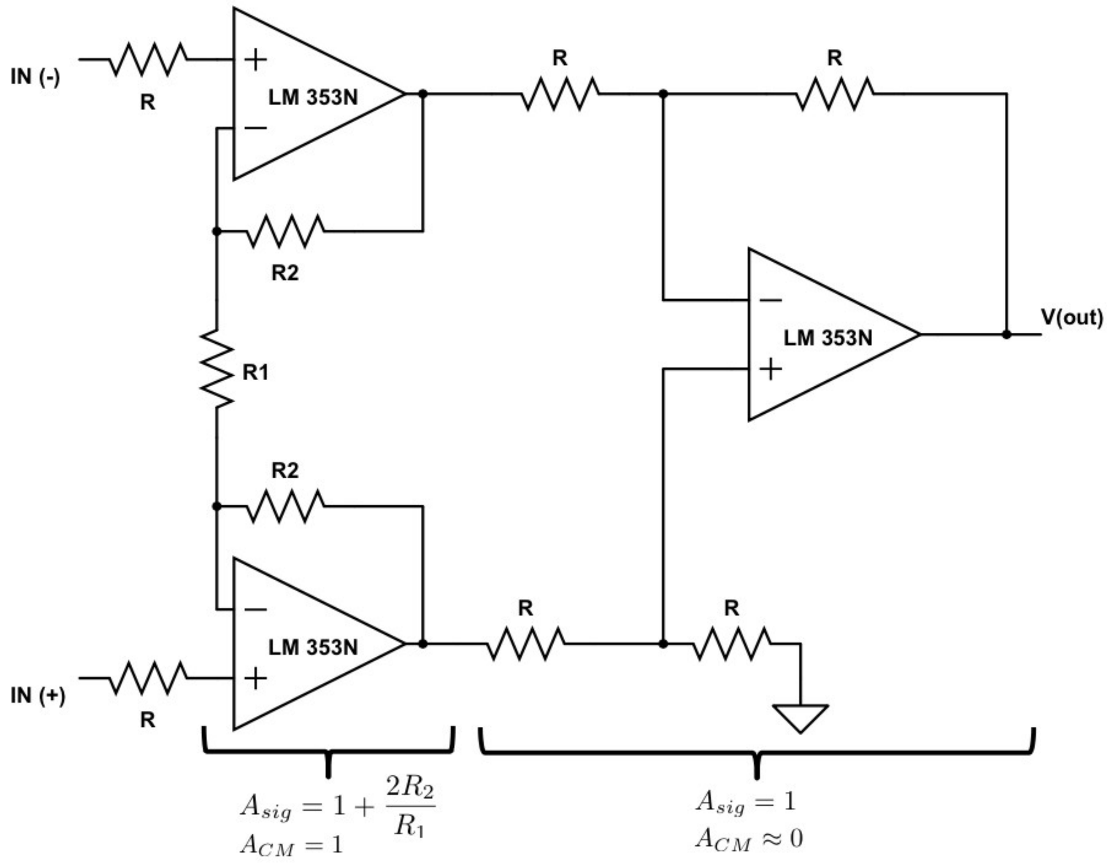

Figure 4. The preliminary instrumental amplifier. The common-mode (CM) is rejected while the differential signal (Asig) is outputted.

Finally, for practical and safety reasons, we also wish to power all of our circuits using a 9V battery instead of the power from the breadboard sources. To do this, we must split the battery voltage to power the inverter chip with about 4.5V and use the full 9V to power the amplifiers. A simple voltage splitter can be constructed like this:

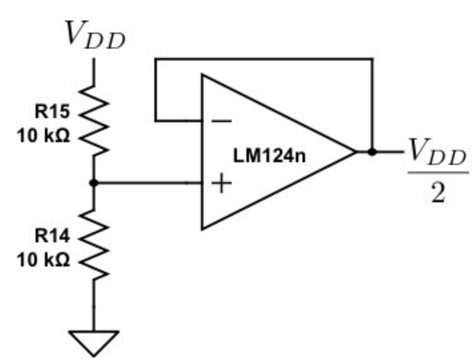

Figure 5. A voltage splitter.

The two resistors of equal resistance splits the voltage in half between them (this can seen with a simple application of Kirchhoff's loop laws). The amplifier is with negative feedback does not change the output voltage, but does lower the input impedance that would otherwise be very high because of the 10 kΩ resistors.

The final version of the instrumental amplifier looks like this (the diodes are added in as safety precautions in case the oscilloscope suffers from a power surge and something catastrophic happens, the diodes should short out the circuit and return the voltage to the ground):

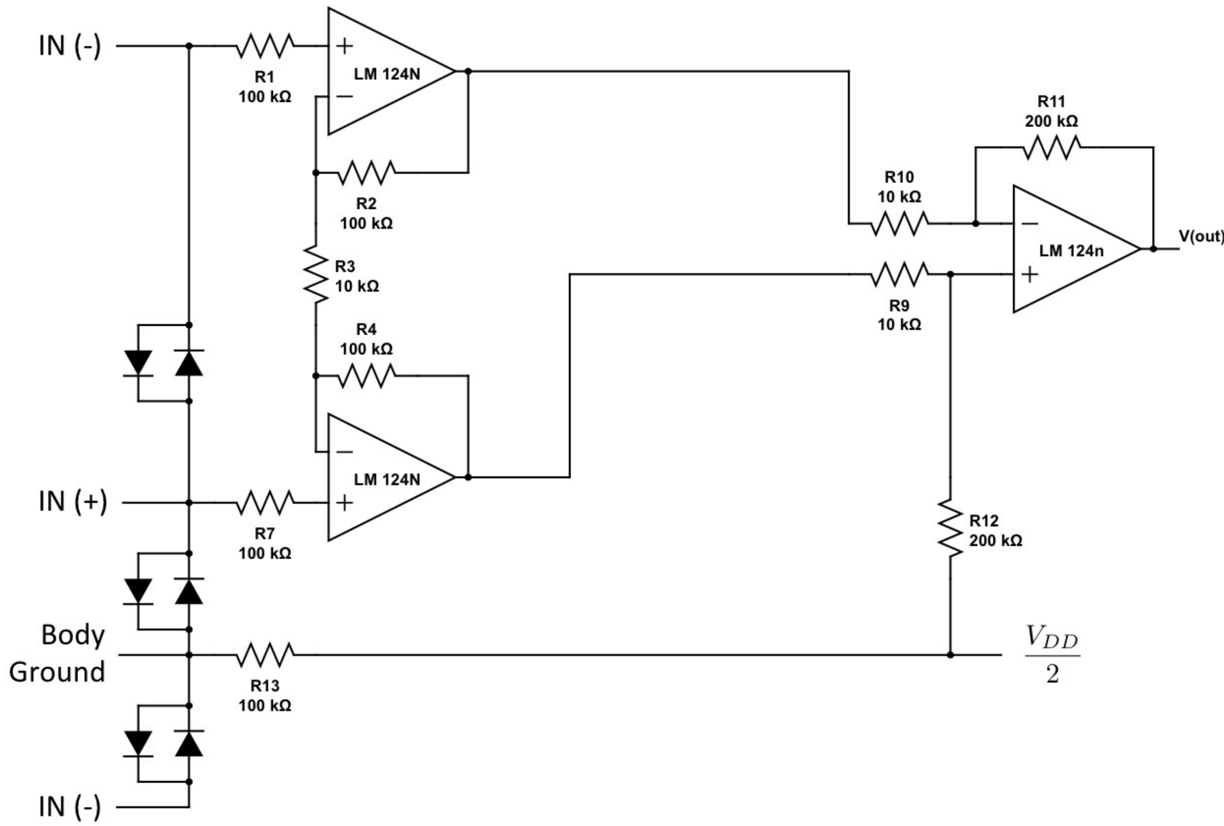

Figure 6. The final instrumental amplifier

The body ground is added so that the circuit ground is the same as the circuit ground and the diodes are added to prevent large currents to flow in either direction, thereby preventing any injuries. Note that the body ground, which is VDD/2, is also the oscilloscope ground.

Experimental Methods:

1. First, we tested the hysteresis of the Schmitt inverters (MC54/74HC14A). We powered the Schmitt trigger inverter with the DC power supply on the bench. Pin 14 (Vcc) is attached to 5V while pin 7 (Ground) is attached to the breadboard ground.

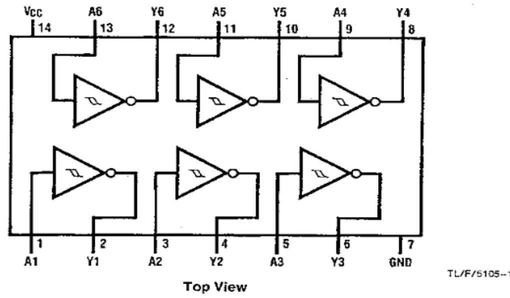

Figure 7. The Schmitt Inverter

The input voltage and the output voltage are tracked on channel 1 and channel 2, respectively, on the oscilloscope. Using the voltage changer on the breadboard circuit, we found that the output drops to 0V when the input is at 2.60V and the output rises to 5V when the input is at 1.56V. This confirms the hysteresis property of the inverter.

2. Next, we built the square wave generator described in the introduction and shown in figure 3. We used Schmitt inverters (MC54/74HC14A) powered by the DC power supply. We then observed the resulting square waves on the oscilloscope.

3. Now that we are sure the oscilloscope is working, we built the voltage dividers as shown in figure 5. This is put right next to the square wave generator as the output of the inverter will be powering the generator.

4. We now attached the 9V battery to the voltage divider, using diodes to make sure the current flows in the right direction, thereby not frying our inverter chip. We then power the inverter chip with 9V (Vdd) at pin 14 (Vcc) and about 4.5V (Vdd/2) at pin 7 (the ground). This is to simulate the common mode of the heart wave form. We verify the square waves are being generated with an offset on the oscilloscope. Then, to simulate the amplitude of the heart waveforms, we used resistors to drop the voltage to about 5mV.

5. Next, we build the preliminary instrumental amplifier as shown in figure 4. The amplifier is powered by full voltage of the battery. Since Vdd/2 is ground, this means that its is powered by -4.5V and 4.5V. We verify that it works as intended by inputting the square waves and observing the amplified square waves with the oscilloscope.

6. Then, we add in the diodes and the body ground as safety precautions, in case the oscilloscope suffers from a power surge and something catastrophic happens, the diodes should short out the circuit and return the voltage to ground. This is the final version of the instrumental amplifier and we should now be able to see our heart waveforms. We make sure that it can in fact amplify the square waves.

7. We attached the electrodes to me (Jack Hong) as shown below.

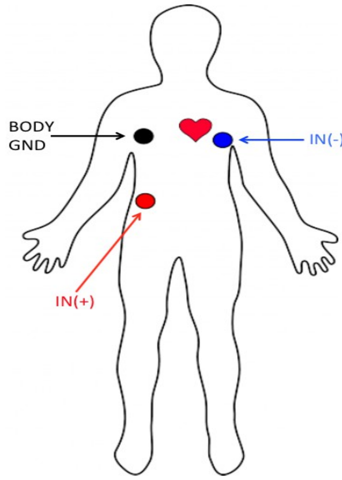

Figure 8. Electrode placements on the body

To verify that the electrodes are properly attached and working, we connect them to a given, commercially prepared heart wave monitor and observe its output on an oscilloscope.

8. Now that we know everything is working, we attach the electrode wires into our instrumental amplifier and view the output on the oscilloscope.

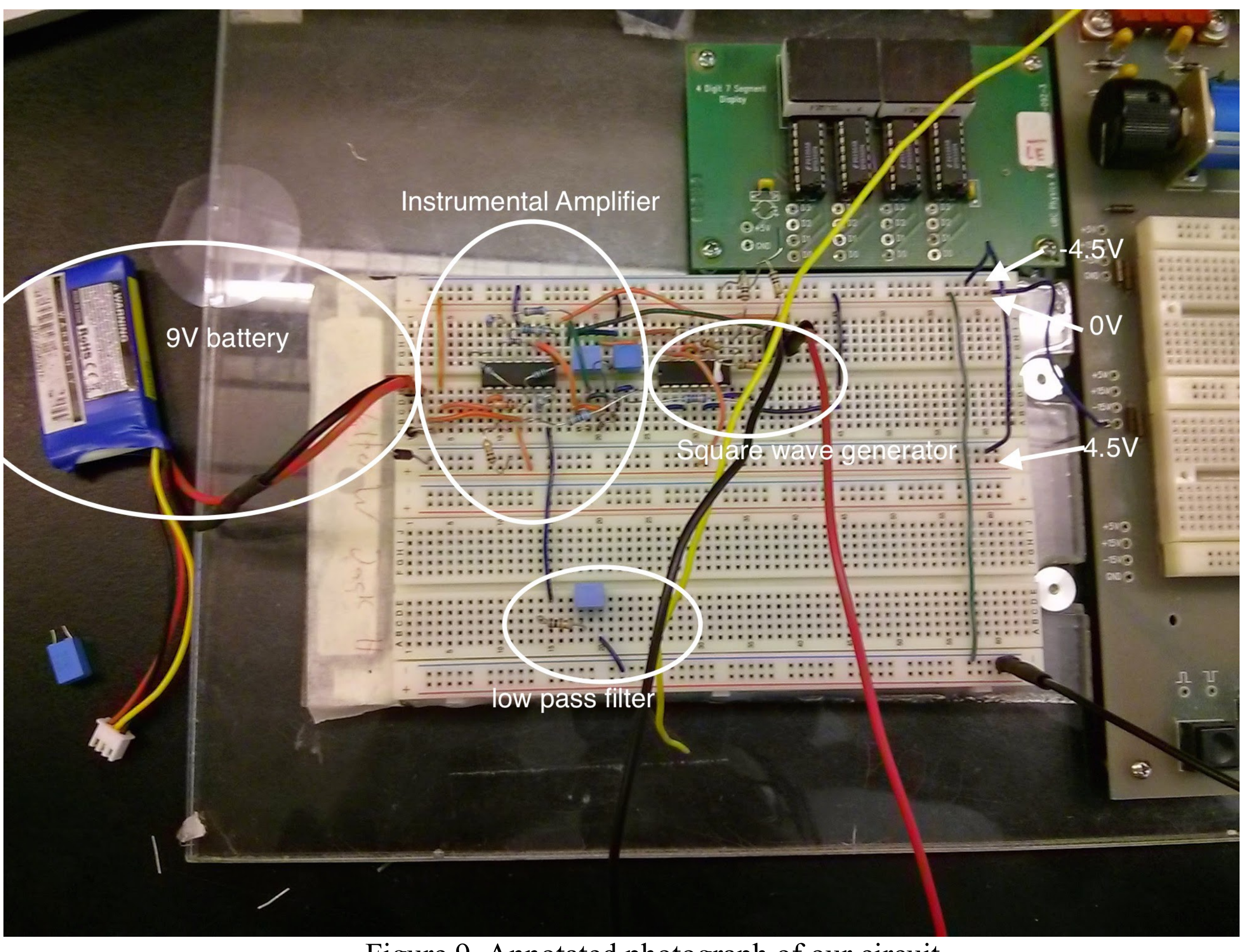

Figure 9. Annotated photograph of our circuit.

Results/Discussion:

The instrumental amplifier we built was capable of rejecting virtually all of the common mode and amplified the square wave signal from approximately 5mV peak-to-peak to about 3V peak-to-peak. This is approximately a 600 times amplification. There is also no offset, which means that the common mode is virtually entirely rejected by the instrumental amplifier. (Recall that the inverter is powered by 4.5V for ground and 9V for Vcc, which means there should be an offset of about 4.5V)

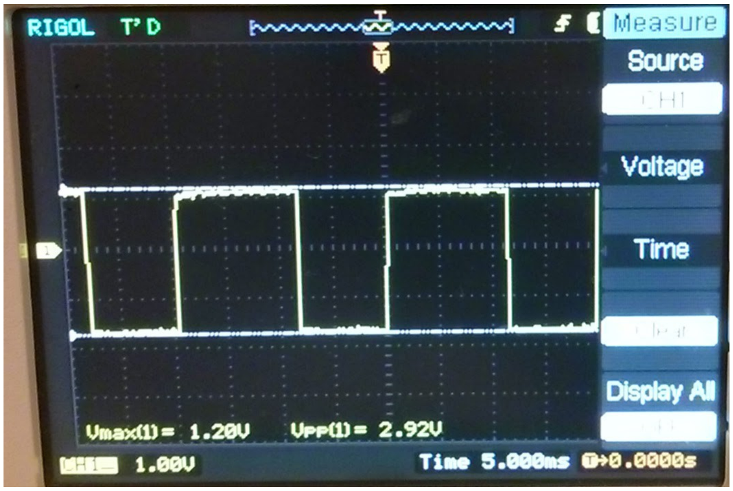

Figure 10. The amplified square waves. Note that Vpp is approximately 3V, a 600 times amplification.

Interestingly, and rather unfortunately, although we made sure that the instrumental amplifier works, and that the electrodes work, we could not get a discernible wave form on our oscilloscope for several hours. In order to cut down on the noise, we swapped out several components for better versions of the same thing. The brownish coloured resistors were replaced with the smaller, less noisy blue ones and the diodes were also replaced for better versions. We also tried putting the components closer together and using shorter wires. In addition, we also used the output of a pulse oximeter (which is at the same rhythm as my heart) to trigger the oscilloscope for a cleaner image. This resulted is a pretty good image:

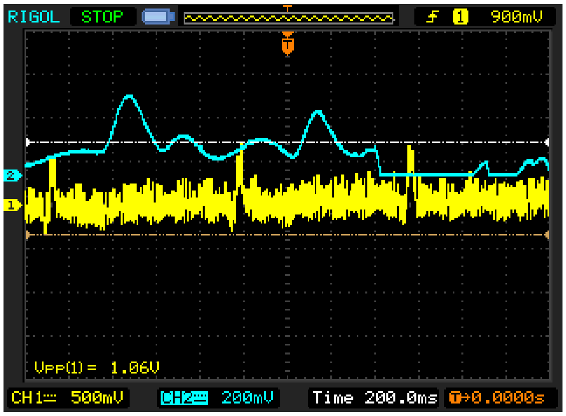

Figure 11. The yellow line is my heart waveform. The blue line is the output of a pulse oximeter, used to trigger the oscilloscope.

Note that Vpp in the amplified signal is about 1V, and since the instrumental amplifies about 600 times, the original signal is about 1V/600 = 1.67mV.

Finally, we also used a simple low pass filter to further clean up the signal.

- Cut off/break around 160Hz
- $f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$ -> want this to equal ~160 $\frac{1}{2\pi \cdot 160} = RC \approx 0.001$ $R = \frac{1}{1000C}$ -> use C = 1 microfarad -> $\frac{1}{1000 * 10^{-6}} = 1000\,Ohm$

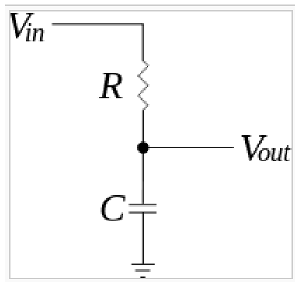

Figure 12. A simple low pass filter. R = 1 kΩ; C = 1 microfarad

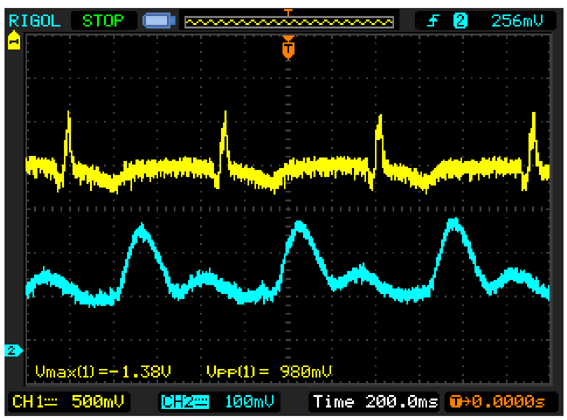

Figure 13. The heart waveform shown on the oscilloscope. The signal is passed though a low pass filter. Once again, the blue signal is used as the trigger.

Conclusions:

An instrumental amplifier rejects the common mode of a signal and amplifies the differential signal. This allows the heart wave form to be detected and seen on an oscilloscope. Shorter wires, better components and a low pass filter help to clean up a noisy signal. The electrical pulses of the heart as detected on the surface of the chest is about 1.67mV.

All the information and sources used in this lab is from the PHYS 219 Experiment #9 lab instructions written by Prof. David Jones.