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ENGR 3010/3011
Mini-Project
1/14/2025

Introduction:

The goal of this project was to design and construct a circuit that utilizes a microphone to alter the brightness of an LED. The LED's intensity was intended to vary with the input we provided to the microphone. This design was achieved by manipulating values and orientation of the required components provided in the project statement. The key elements of the circuit are a second-order filter, an operational amplifier, and a current amplification element. Additionally, a speaker incorporated as an output option in place of the LED to provide an audio measure of the voltage gain. This report will outline the design process, challenges, results, and discussion involved in each stage of this project. Throughout this project, we aimed to reinforce circuit analysis concepts and gain experience in both circuit design and troubleshooting.

Design Process:

When we were assigned this project one of the first steps was setting up a schedule in the form of a Gantt chart, Figure 1.

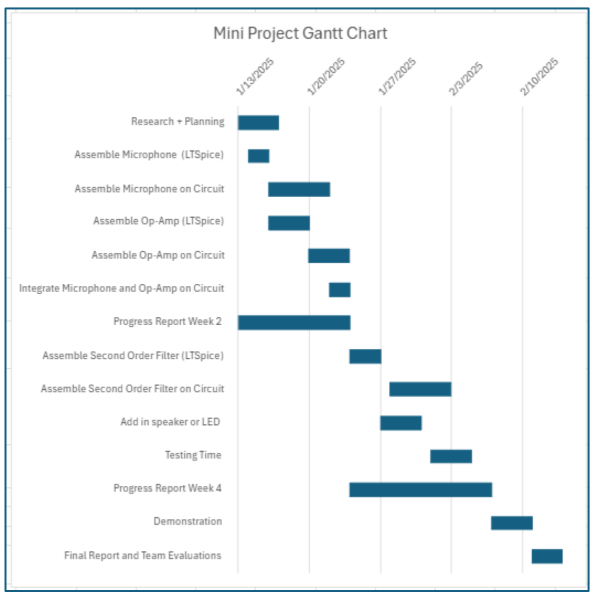


Figure 1: Gantt Chart

After some research and discussion, we decided to follow the schematic provided by the datasheet when setting up the microphone(Figure 2).The data sheet for the microphone showed a circuit diagram and a ratio for the values of capacitor and resistor needed. Before wiring up the microphone on the breadboard we used LTspice to construct our microphone. We settled on a desired power source of 5 volts, so using the ratio found from the datasheet, we were able to determine the corresponding resistor and capacitor values for the microphone. Our first attempt wiring the microphone with the values in Calculation 1 we were not able to get a working output. We resorted to trial and error until we produced a functioning sine wave output from the oscilloscope. Some of the methods we exhausted were replacing the microphone, checking oscilloscope set up, and changing component values. What we wanted to see on the oscilloscope was a sin wave with varying amplitude, frequency, and voltage outputs in response to the microphone's input. Figure 5 shows the microphone's sin wave output. Eventually we achieved a working microphone with the selected resistor and capacitor values in Table 1. This was a major step because the output values of voltage, current, and frequency would have a chain effect on the component values calculations for the rest of the circuit.

After we were confident in the microphone setup, the next step was the op-amp. The op-amp's purpose is to amplify the voltage enough to power the LED/Speaker at the end of the circuit. Just like the microphone we researched how to calculate the Gain, in Calculation 6 you can see our gain for the op-amp on its own and in Calculation 4 you can see the gain for the op-amp once it was placed in the circuit. We decided to focus on setting up an inverting op-amp. Again, using the oscilloscope to measure the input and output of the voltage to compare. Figure 3 depicts the voltage pre-op-amp and Figure 4 depicts the output voltage post-op-amp. We were able to achieve a voltage output greater than the voltage input. This was also a result of trial and error testing regarding resistor values and wiring orientation.

The next focus was on frequency. The goal was to create a 2nd order filter with a set cutoff frequency. This part of the project took the most time and was most challenging. There are many methods of creating a 2nd order filter. We began to experience decision fatigue regarding which methods to attempt. At this point in the project, constructing in LTspice was the most advantageous method. For example, Figure 13 is one of the first LTspice iterations we wired up in attempt to get a high pass filter working. To help us set up the component values for the filter we performed data collection of the frequency output of the microphone. We tried at least 5 different layouts of filters; some high pass, some low pass. The filter that worked for us in the end was an LC passive low pass filter, values in Table 1. Figure 15 is the full circuit layout that shows how the filter was constructed. At this point we had an LED hooked up to the output of the op-amp to test the filter. The oscilloscope was hooked up to the output of the op-amp before the LED to measure voltage and frequency. If we changed frequency into microphone, there should be a change in voltage output courtesy of the filter and op-amp. A helpful component in testing proved to be a phone app, Function Generator, that produced steady frequency noises to help us with the consistency of our inputs. We knew that our filter was low pass meaning the higher the frequency input, the lower the voltage output. Figures 9, 10, 11, and 12 demonstrate the input of various frequencies and the output voltages to prove our low pass filter success.

The final step was to include a current amplifier. Our research pointed towards using a transistor. The current amplifier was for the LED. Figure 7 shows the set-up of the transistor on our board. A transistor needs an external power source, so there was design discussion on what to use since our DC power supply was full. The result was a battery supplying the voltage to power the transistor. We were having a hard time getting the transistor to increase the current. Figure 6 displays the transistor output before the LED. Using the two DMMs we did find an increase by a very small amount shown in Figure 8.

Results:

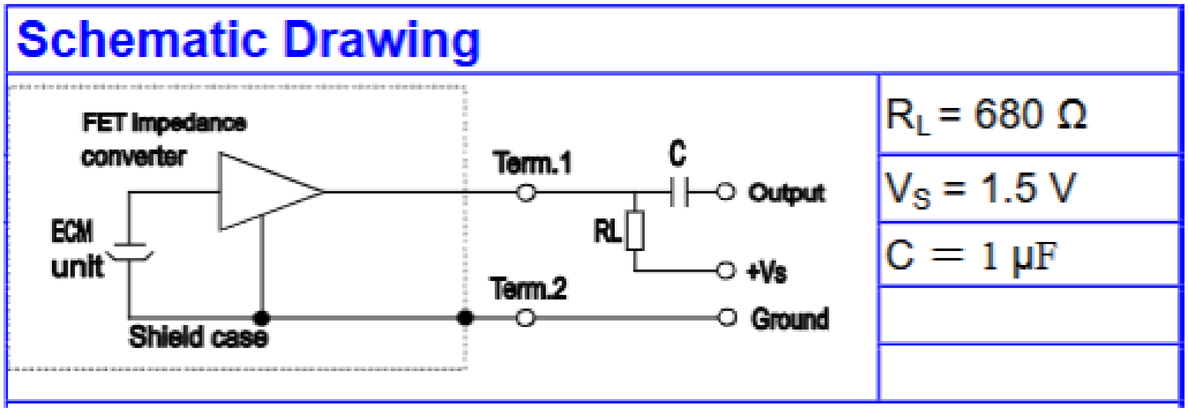


Figure 2: Microphone Datasheet Schematic

The datasheet above was provided in the project description. We used it to determine the values of the components accompanying microphone. We scaled the resistor and capacitor values to match the scale of our voltage source vs. the V_s provided.

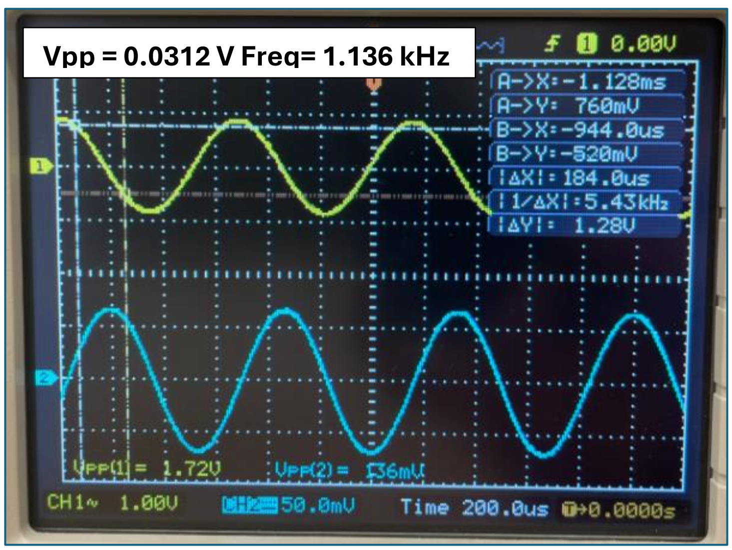


Figure 3: Pre-Assembly Microphone Output

This result was obtained by attaching the oscilloscope probe's tip to the node following the microphone and the probe's ground clip to our circuit's ground. We used the amplitude and frequency of this output to model our microphone as a sin wave in LT Spice. The yellow wave depicts the microphone output pre-op-amp and the blue wave depicts the microphone output post op-amp.

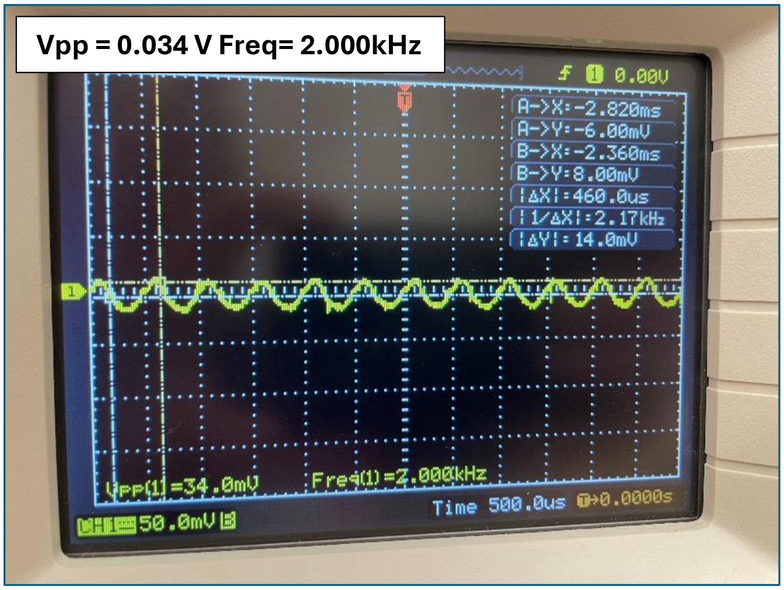


Figure 4: Pre Op Amp Output

This result was obtained by attaching the oscilloscope probe's tip to the first node of the circuit and the probe's ground clip to our circuit's ground. We used this output as a baseline to measure the impact of our operational amplifier in the circuit.

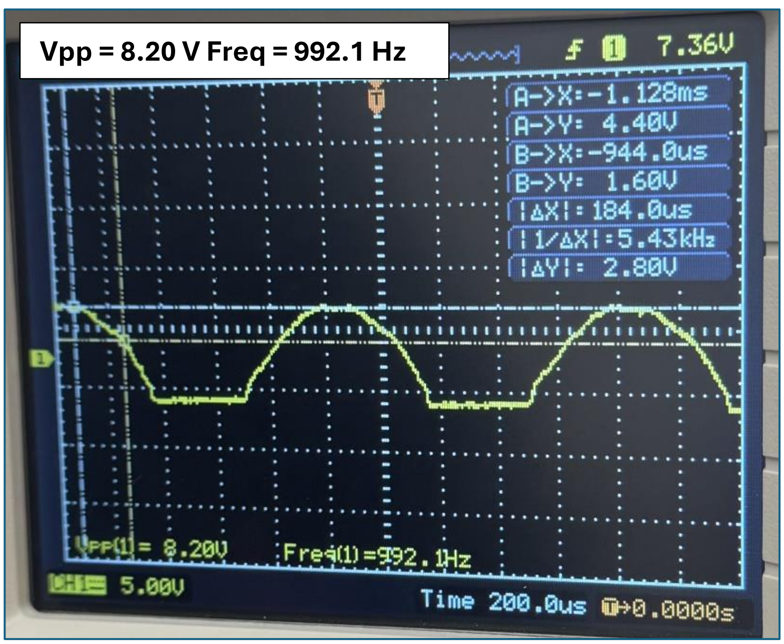


Figure 5: Post Op Amp Output

This result was obtained by attaching the oscilloscope probe's tip to the node following the op-amp and the probe's ground clip to our circuit's ground. We compared this output to the baseline to measure the impact of our op-amp in our circuit and found that the op-amp significantly increased voltage from 34 mV to 8.2 V.

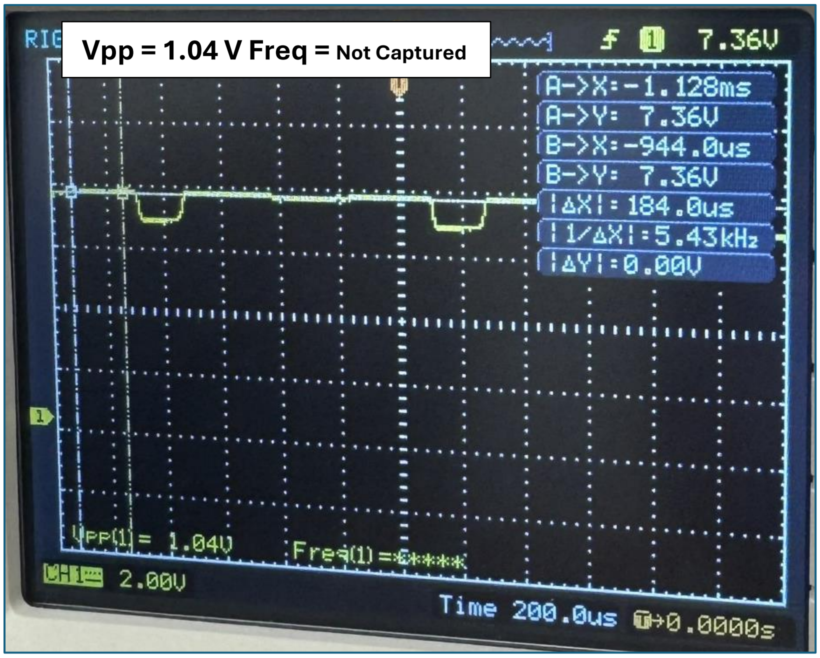


Figure 6: Post Transistor Output

This result was obtained by attaching the oscilloscope probe's tip to the node following the transistor and the probe's ground clip to our circuit's ground. This resulted in a slight increase in voltage from 34 mV to 1.04 V.

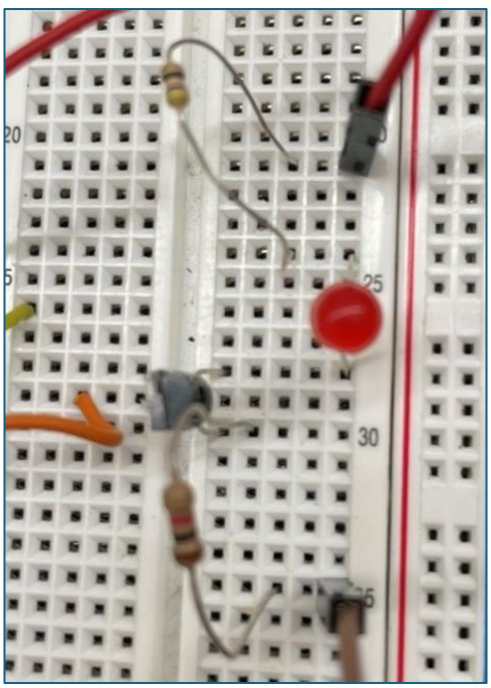


Figure 7: Transistor Assembly

Assistance from the instructor was used to set up the current amplification component of the circuit.

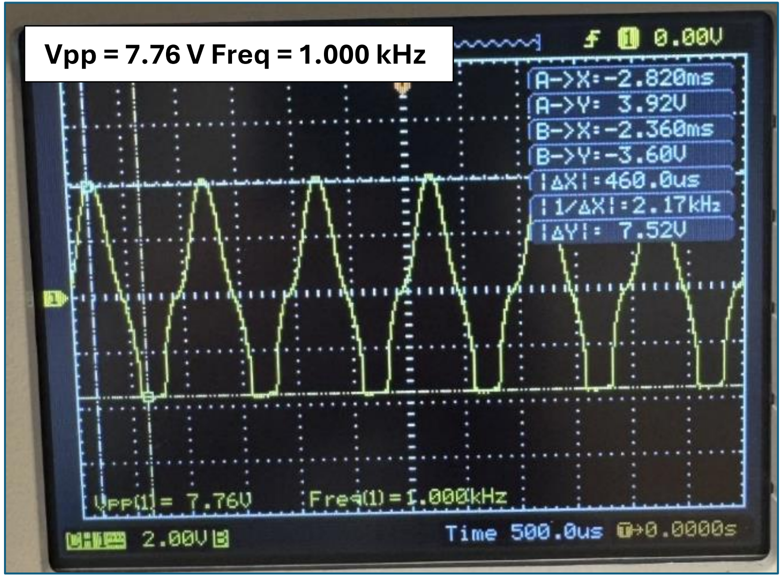
Figure 8: Post Transistor Output

Current pre-transistor was obtained by placing the multimeter between the power supply and the transistor's collector. Current post-transistor was obtained by placing the multimeter between the transistor's emitter and the load, R3 in Figure 15. The transistor amplified the current by 1.25 A.

Table 1: Circuit Component Values

Component	Value
Mic. Resistor	6,690 Ω
Mic. Capacitor	0.000003194 F
Filter Inductor	0.001 H
Filter Capacitor	0.000001001 F
Op. Amp. Feedback Resistor	356,400 Ω
Op. Amp. Input Resistor	1,068 Ω
Transistor Collector Resistor	46.2 Ω
Transistor Emitter Resistor	985 Ω

These values were determined through a combination of sources 1-4, calculations 1 and 2, and trial and error.



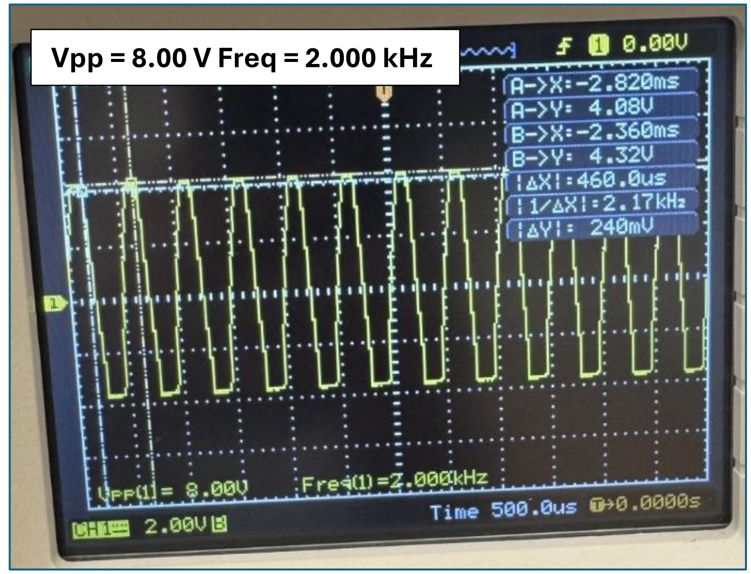


Figure 9: 1 kHz Frequency Voltage Output

Figure 10: 2 kHz Frequency Voltage Output

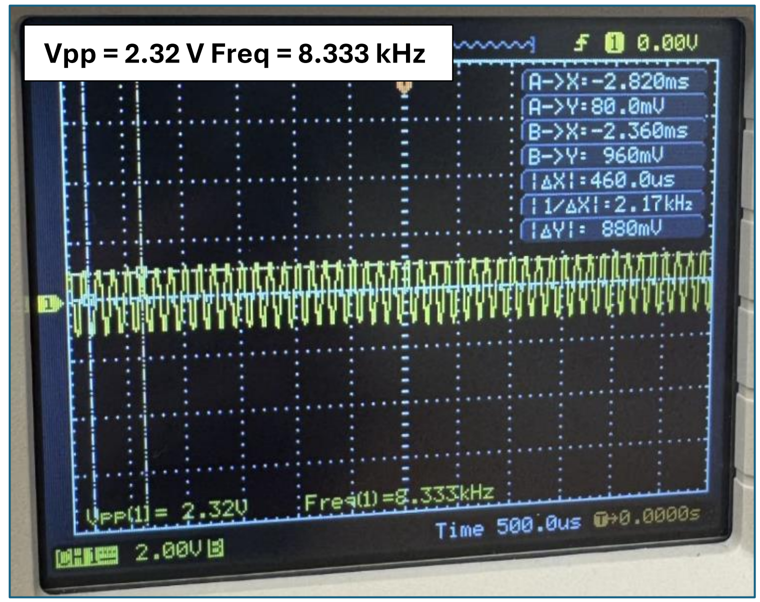


Figure 11: 4 kHz Frequency Voltage Output

Figure 12: 8 kHz Frequency Voltage Output

Figures 7-10 were captured by attaching the oscilloscope probe's tip to the node before the LED and the probe's ground clip to our circuit's ground. This data proves our filter is low-pass and successfully lets lower frequencies through while attenuating frequencies higher than the cutoff frequency.

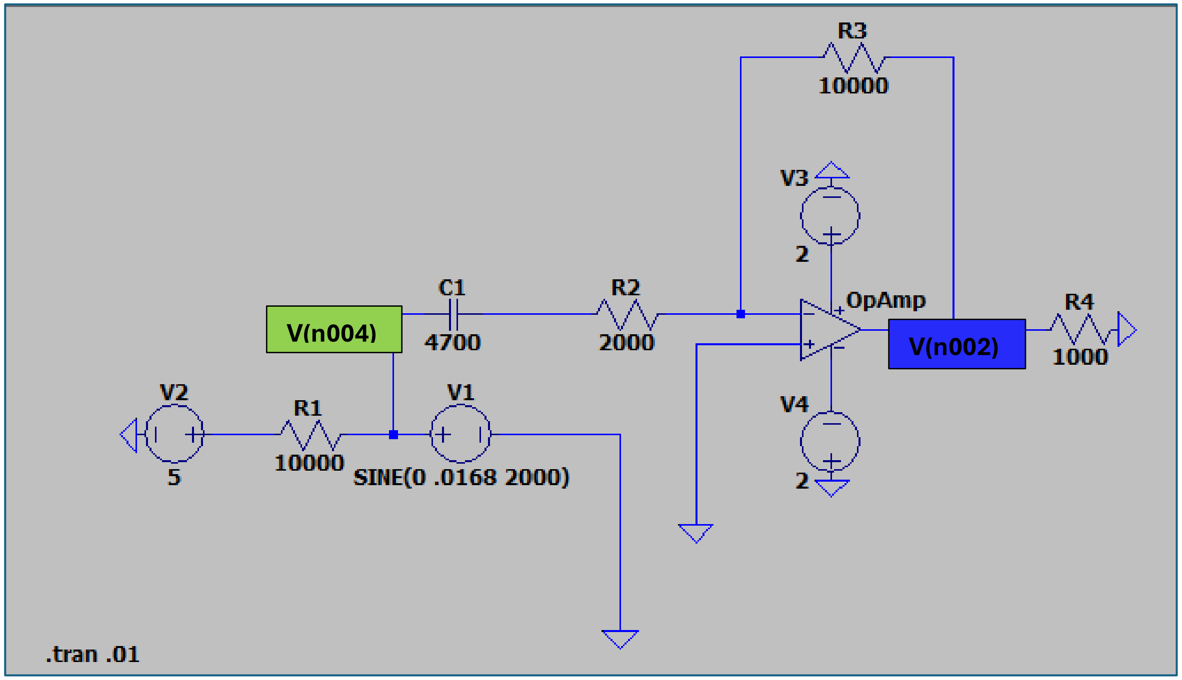


Figure 13: High Pass Second Order Circuit

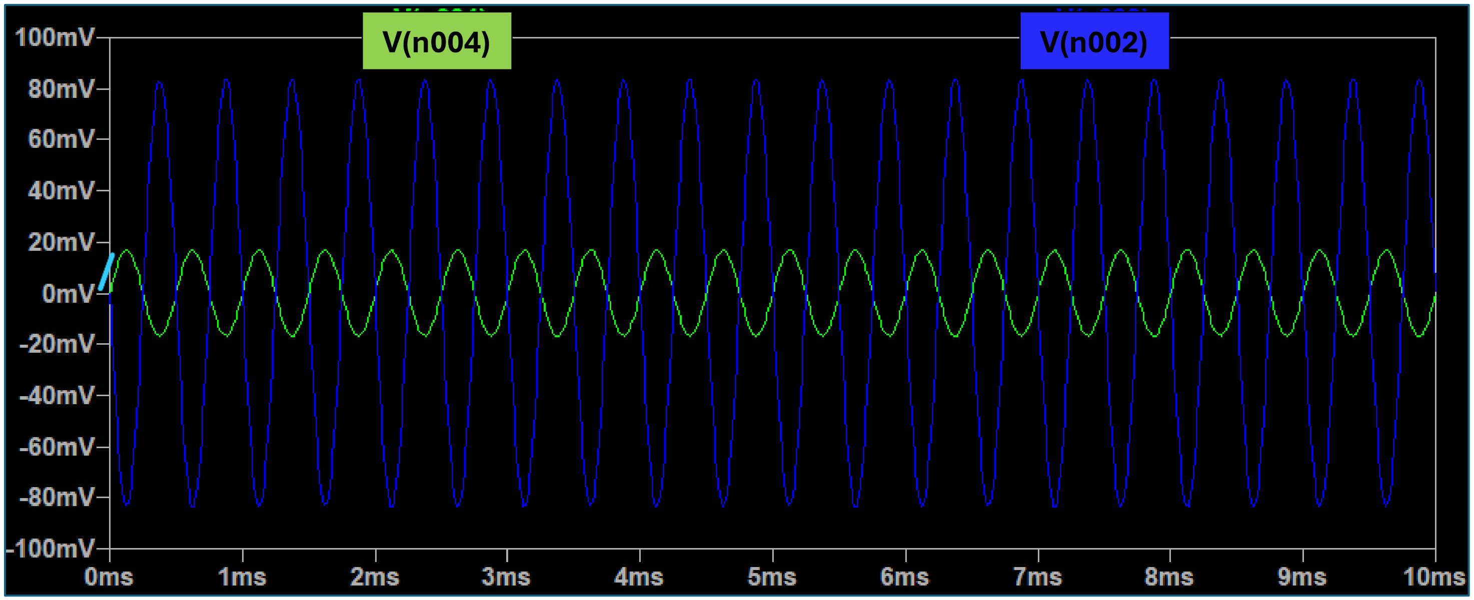


Figure 14: High Pass Second Order Circuit

This circuit diagram in Figure 13 was constructed in LTSpice using Source 3 to confirm component values for a 2nd order high pass filter. The output in Figure 14 shows an inverted and amplified sin wave, but the output did not vary with frequency input changes. Although this design was successful in LTSpice, we were not able to accomplish successful implementation on the board.

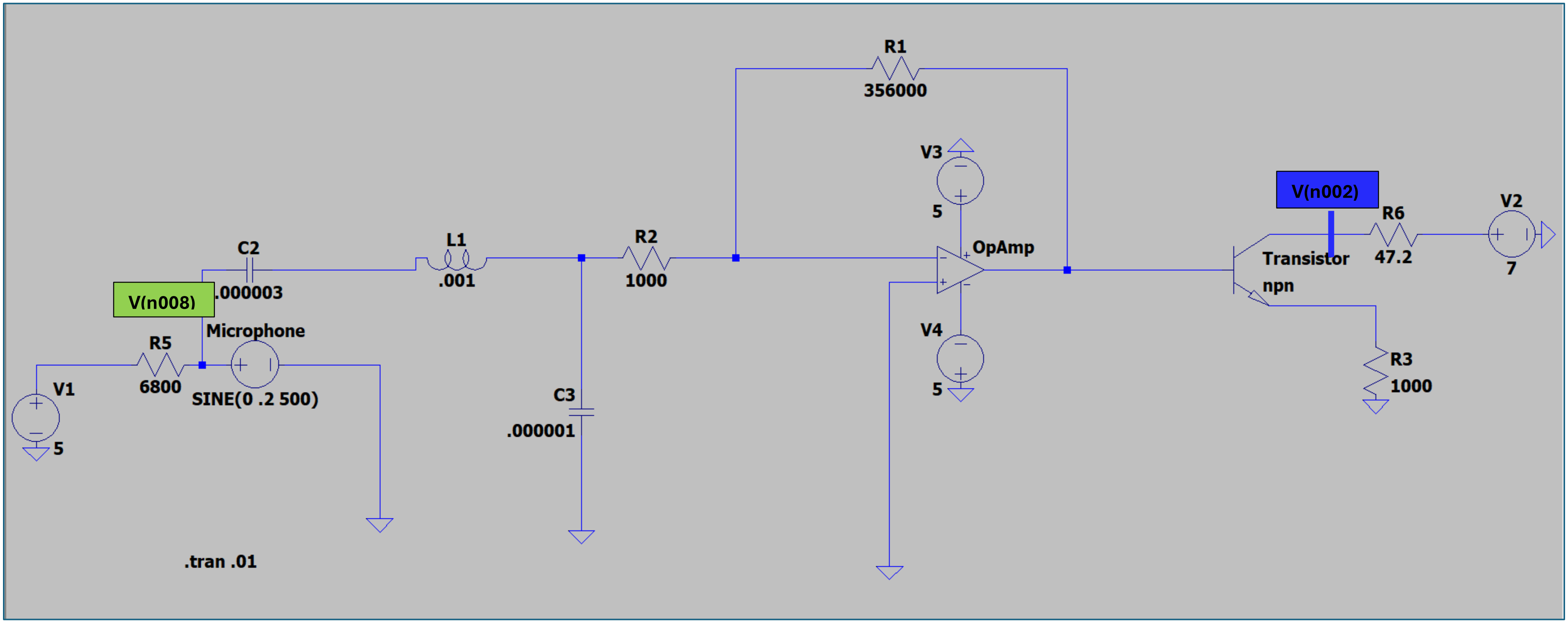


Figure 15: Low Pass Second Order Circuit

This circuit diagram in Figure 15 was constructed in LTSpice using Source 4 to confirm component values for a 2nd order low pass passive filter. This is an electronic representation of the orientation of our chosen circuit components.

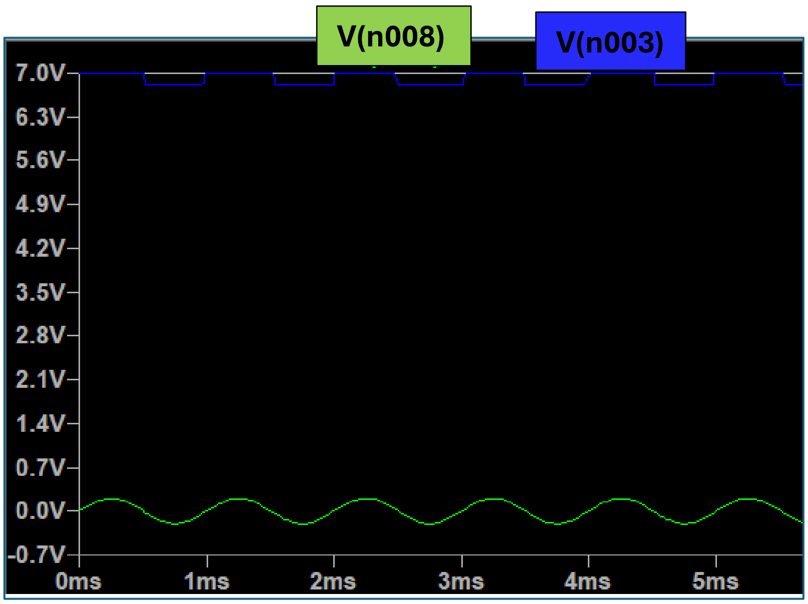


Figure 16: Low Pass Output @ Low f

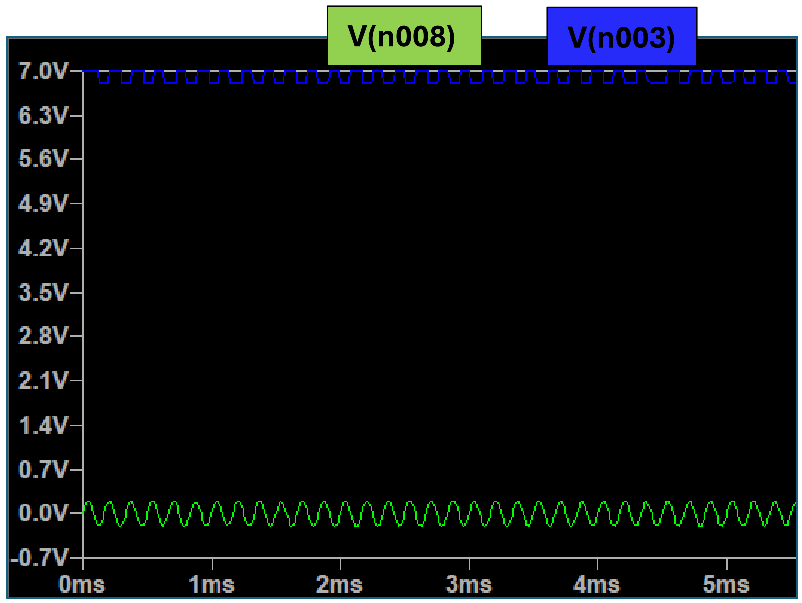


Figure 17: Low Pass Output @ Low f

Figures 16 and 17 represent the LT Spice output at a frequency below the intended cutoff, 500 Hz, and a frequency above the intended cutoff, 6 kHz. These outputs did not match the function of our filter incorporated into our circuit board.

https://youtube.com/shorts/oeDeUKM9iCE?si=6Osn0tygjxcGtWP9

Figure 19: Low Pass Passive Filter Output

In this video you can see the voltage output increasing when Halen switches from the whistle to the lower pitched noise. This video provides proof of the low pass filter attenuating the high frequency input and allowing the low-frequency component to pass through.

https://www.youtube.com/shorts/OYtthoSsb9s?feature=share

Figure 20: Low Pass Passive Filter Speaker Output

This video depicts the speaker working in our latest circuit update. The filter has the same function as in Figure 19, it is depicted through the speaker rather than voltage output this time.

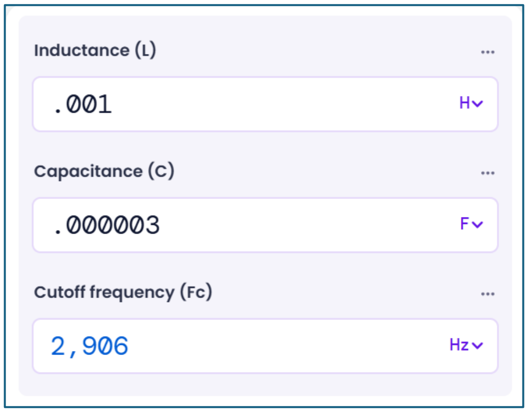
Calculations:

Calculation 1: Microphone C/R Theoretical Required Value

If Vs = 5V, scale other values by factor of 5V/1.5V = 3.33

=>R_L = 680Ω * 3.33 = 2.27kΩ   => C = 1μF * 3.33 = 3.3μF

Calculation 2: Frequency Cutoff for Low Pass LC Filter via Source 1



The formula to calculate the LC low-pass filter's cutoff frequency is:

$$f_c = \frac{1}{2\pi\sqrt{LC}}$$

where:

- f_c — The **cutoff frequency** of the LC filter circuit;
- L — The **inductance** of the inductor; and
- C — The **capacitance** of the capacitor.

Calculation 3: Post-Assembly Theoretical Operational Amplifier Gain

Gain Factor = R_F / R_i = 356,400 / 1,068 = 333.71

Calculation 4: Post-Assembly Observed Operational Amplifier Gain

Gain Factor = Vout / Vin = 8.2V / 0.034V = 241.18

Calculation 5: Post-Assembly Gain Percent Error

((333.71 – 241.18) / 333.71) * 100 = 27.73%

Calculation 6: Pre-Assembly Operational Amplifier Gain

$$Theoretical\ Gain = \frac{R_{feedback}}{R_{in}} = \frac{19.71}{1.46} = 13.5$$

$$Actual\ Gain = \frac{V_{out}}{V_{in}} = \frac{1.72}{.136} = 12.6$$

Calculation 7: Pre-Assembly Gain Percent Error

((13.5 – 12.6) /13.5) * 100 = 6.7%

Calculation 8: Theoretical Current Amplification Through Transistor

B= Ic/Ib

B= 600ma/5.15

B= 116.504 mA

Calculation 9: Actual Current Amplification Through Transistor

B= 6.4/5.15

B= 1.243 mA

Calculation 10: Transistor Amplification Percent Error

% error = ((1.243-116.5)/116.5)*100

%error = 98.93%

Discussion:

The first component of the circuit, responsible for acting as a sinusoidal voltage source when audio is detected, is a microphone. Assembling the microphone as listed in the data sheet (Figure 2) required the inclusion of a resistor and capacitor. The value of these components was determined by Calculation 1 using the data sheet as reference. The only limitation that arose during the implementation of the microphone was with the resistor, which was theoretically calculated to need to be about 2.2kΩ. During testing, however, we found that the microphone would not produce a sinusoidal wave form, like what is expected in Figure 5, with a resistor of the recommended value. Through trial and error, we found that the microphone would only function as expected with a resistor value of around 6.8kΩ (Table 1), but this was only discovered after the assembly of other components such as the filter.

The second circuit component in the circuit is a second order, passive, low-pass filter. This was the last circuit element we implemented because we considered creating an active filter for a majority of the project, but we ultimately decided against it after unsuccessful testing. Through the equation used in Calculation 2, we were able to set our filter to have a cutoff frequency of 2.9kHz. This seemed a good choice because circuit elements of those required values were readily available and it would not dampen any input a person gave to the microphone. Instead, it would only dampen sound waves produced by a function generator as seen in Figures 9 & 12. The inclusion of the filter had one unexpected side effect, which was a significantly decreased sensitivity of our microphone. Instead of being able to light the LED from a distance of a few feet, someone would need to make noise within a few inches after the filter was added.

The output of the filter leads directly into an inverting operational amplifier. The purpose of this circuit element is to amplify and output the voltage supplied to the input. The amount in which the voltage is amplified, known as gain, is determined by the ratio of the feedback to input resistors used when assembling. In our operational amplifier we used a 356,400Ω feedback resistor and 1068Ω input resistor (Table 1), giving us a theoretical gain of 333.71 (Calculation 3). The voltages measured before and after the operation amplifier shown in Figures 4 & 5 showed an observed gain of 241.18 (Calculation 4). Therefore, giving a percent error of roughly 27% below the theoretical (Calculation 5). One potential source for this error is likely the amplifier itself, because as observed prior to assembly in Figure 3 and Calculation 6 & 7, there was a gain percent error of about 7% without any other circuit elements. Another source for this error could be negative interactions between the other complex circuit elements such as the microphone assembly.

After the voltage has been amplified, the final circuit element that needs to be included before lighting the LED is a current amplifier. The current amplifier that is included in the final circuit utilizes a transistor, 9V battery, and resistors assembled as shown in Figure 7. Current is amplified when enough voltage is supplied to the base leg of the transistor to allow current to flow from the battery through the other legs. Significant issues arose when implementing this circuit element that were due to incorrect wiring and placement of the battery terminals. These issues were resolved by reviewing content learned in previous semesters and receiving in-person assistance. Once wired correctly, the resistor values chosen for the collector and emitter legs (Table 1) were determined through trial and error. The most important factor that influenced the function of this component was not having too large of a resistor on the collector leg or else the

LED would struggle to light. Overall, little success was found in this circuit element performing its function since we only saw a current amplification from 5.15mA to 6.4mA (Figure 8).

Furthermore, this current amplification gain was far below what we expected to see given the values of our battery source (Calculation 8 & 9) giving us a percent error of 98.93% (Calculation 10).

Through the process of assembling all the aforementioned circuit elements to form an optical transmitter, all learning objectives were met. In order to implement the microphone, operational amplifier, and current amplifier, we had to read datasheets to determine correct resistor/capacitor values, pin placement, and voltage thresholds, respectively. Much of the second learning objective was also met through the reading of the datasheets, as well as external research. Any remaining arrangement issues were resolved through trial and error. Meeting the third learning objective was more difficult for the group than the first two due to our lack of experience with LTSpice. We were never able to observe our fully assembled circuit functioning as intended in LTSpice, however, the program proved extremely valuable in testing potential designs for our first iterations such as what's seen in Figure 13. After the first functional design had been created in LTSpice, the assembly required as part of the fourth learning objective began. This was an iterative process, but the final product was successful and demonstratable. Finally, the team has reached a point where we can all comfortably meet the fifth learning objective because of our individual contributions and clear communication. Without the effective communication and initiative of each member, the creation of all successful circuit components would not have been possible.

As a team, a lot of additional valuable information related to electrical systems was learned through this project. For example, prior to this project, we were not particularly familiar with the function and assembly of all the different types of filters. Likewise, we had very little comfortability with the assembly of operational amplifiers. Not only did this project serve as an opportunity to improve our skills at assembling these circuit components, but we also became able to draw connections between the physical assembly of these complex elements and how they appear on a schematic.

Conclusion:

The team was able to create a functional optical transmitter through the inclusion of a microphone, a 2nd order, low-pass, passive filter, an operational amplifier, and a current amplifier. All components were researched in depth to assign appropriate values to and have been proven to perform the function they were intended to through intensive testing and analysis. The final product can be used to light an LED or produce sound out of a speaker at varying intensities based on the input to the microphone, therefore accomplishing the primary goal of the project. Throughout the process, we were able to meet all learning objectives and gain comfortability with various electrical components that are essential to common electrical systems. All team members also showed a lot of growth in was in the use and value of LTSpice. Finally, we were able to practice and improve upon our communicative abilities as well as our ability to assimilate and provide value to a team.

References:

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