Team Final Report

Build a BetterBot Education Robot

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ENEE 4850 Interdisciplinary Design Project

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Executive Summary

This report presents the design project undertaken by the Better Bots team to improve the Direction Light Finding subsystem on the Mr. Ohm robot. The project focused on enhancing three circuit portions: the photodiode amplifier, multiplexer, and preamplifier. The report provides details of the design, improvements, and testing results for each circuit component.

For the photodiode amplifier, the team replaced the original circuit with a common base amplifier, increased the bias current , and added a second common-emitter amplifier to improve the bandwidth and reduce noise. Simulation results showed significant improvements in bandwidth and noise performance compared to the original circuit. Testing of the improved circuit confirmed its effectiveness in amplifying the signal from the photodiode.

The multiplexer component aimed to switch between signals from the photodiode amplifier. The team proposed cost-saving measures by replacing some MOSFET with transistors. Simulations demonstrated improved signal leakage when using transistors instead of MOSFETs. However, due to ordering issues, PCB implementation of the improved circuit was not completed.

Preamplifier is responsible for scaling the output of the multiplexer, and was left unmodified due to time constraints. Simulations and testing of the original circuit revealed satisfactory performance within the specified frequency range.

This report will also cover how the components fit into the subsystem. Ethics and safety will also be discussed on how it applies to the project along with the specifications that the team strived to reach. A manual and troubleshooting section will also be available so that those who choose to test the project at a later date will have the information to assist in the endeavor.

Introduction

This report encompasses all parts of the design project for the Better Bots team for the improvements on the three circuit portions on the Direction Light Finding subsystem on the Mr. Ohm robot. First the design, improvements, and testing results will be discussed for the photodiode, multiplexer, and preamplifier. From there the safety and ethics for the implementation of the circuits will be applied. After that, the specifications for the project, that were decided earlier in the design process, will be determined whether each of those verifications were met and if they were not met it will be explained why that could not be done. A step by step walkthrough will be provided with a troubleshooting guide. This will allow others to use and implement the circuit without issue. The conclusion of the process and recommendations for improvement are added at the end.

Photodiode Amplifier

The purpose of photodiode amplifier was to make improvement to the original circuit the which is the bandwidth and the noise, the feedback circuit in the better boot website was replaced with a common base amplifier the current bias was increased through it which reduced the input impedance, the gain was lower in the common base version than the feedback version and a second common-Emitter amplifier was added to increase the gain.

Simulation of original circuit

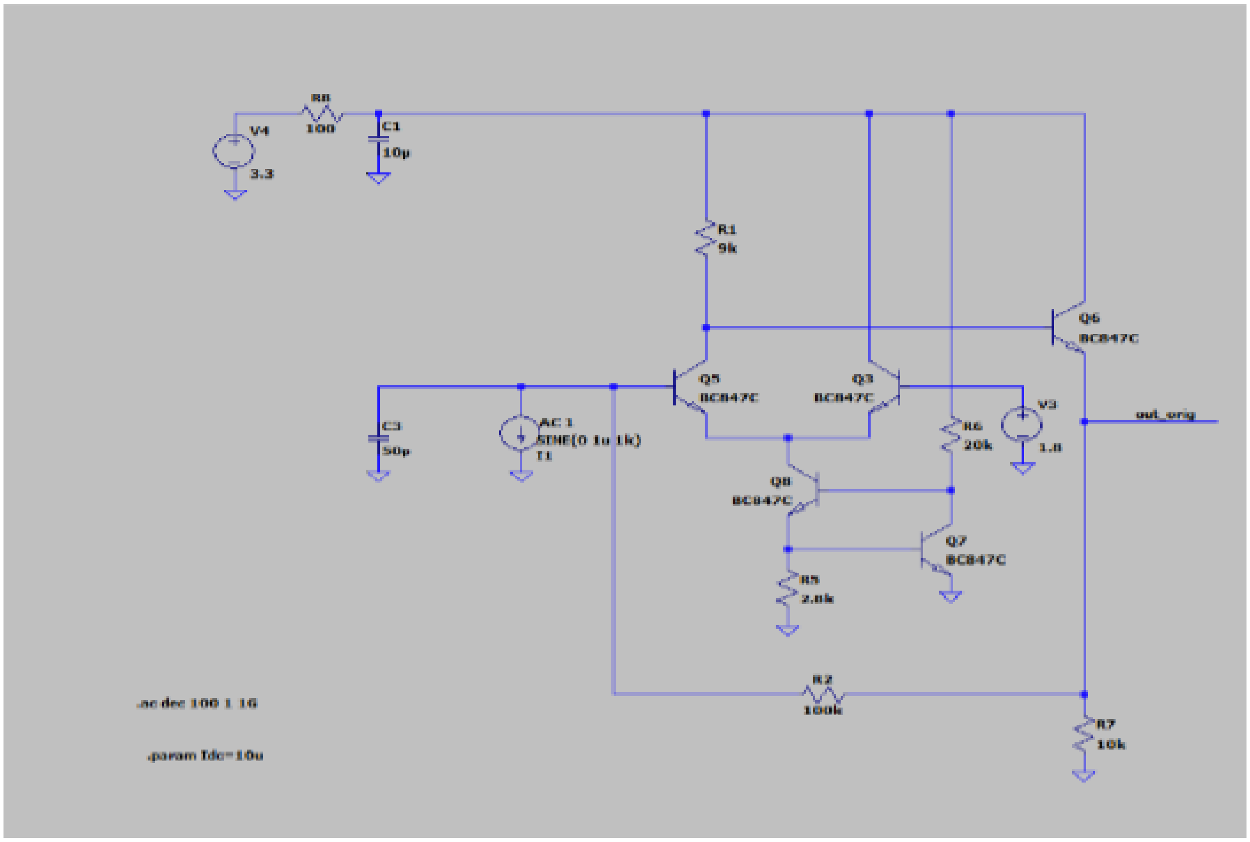

Figure 1: Original Circuit

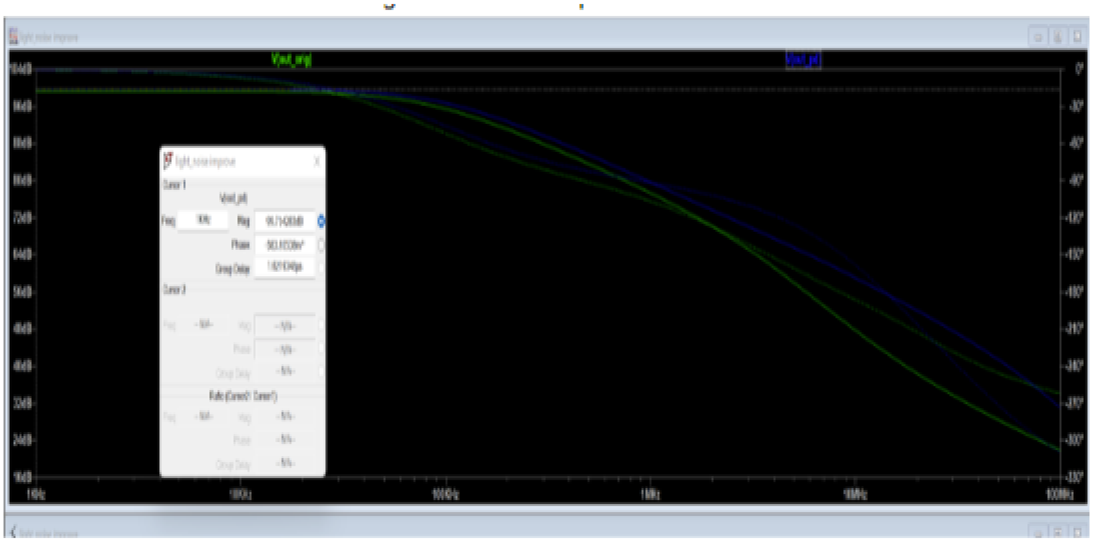

Figure 2: Bandwidth for the Original and the new Circuit

MultiSim

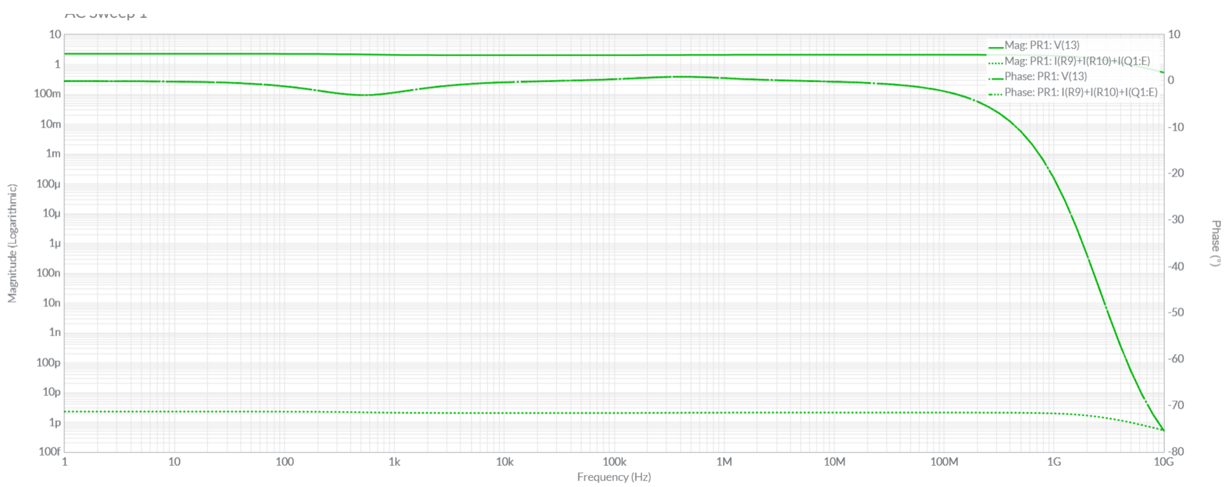

Figure 3 : Multisim Simulation of the Unmodified PD Amp

From working with Multisim and comparing to the LTSpice output of the circuit when the circuits are identical the two softwares are interchangeable when simulating. This graph shows an output of the PD Amp modeled in Multisim and the output plotted. When compared to the LTSpice plot of the same circuit the two graphs are identical.

Testing of original circuit

The original circuit were tested and the figures below show the result of the testing

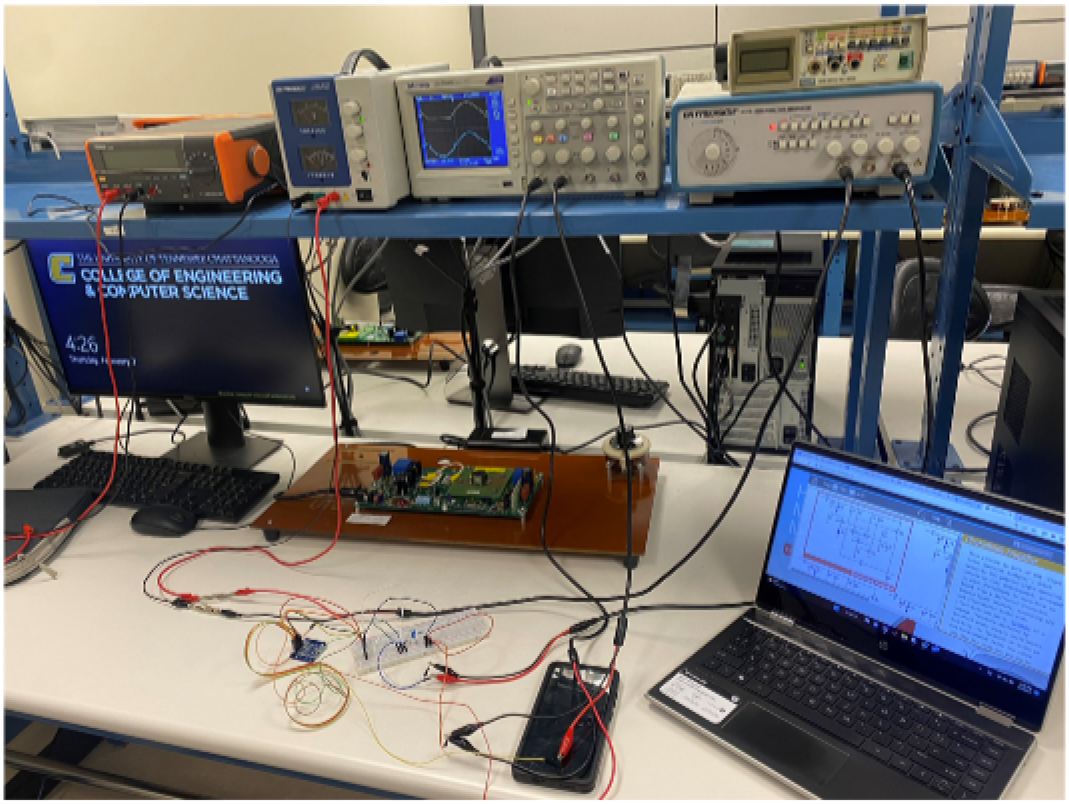

Figure 4: testing setup

	Frequenc	Amplitude	Db
2	2 KHz	1.2	1.5836249
3	4 KHz	1.36	2.6707782
4	6 KHz	1.44	3.1672498
5	8 KHz	1.44	3.1672498
6	10 KHz	1.6	4.0823997
7	12 KHz	1.6	4.0823997
8	14 KHz	1.92	5.6660246
9	16 * 10^3		
10	18 KHz	1.52	3.6368718
11	20 KHz	1.36	2.6707782
12	40 KHZ	1.36	2.6707782
13	60 KHz	1.36	2.6707782
14	80 KHZ	1.36	2.6707782
15	100 KHz	1.68	4.5061856
16	120 KHz	1.68	4.5061856
17	140 KHz	1.68	4.5061856
18	160 KHz	1.68	4.5061856
19	180 KHz	1.68	4.5061856
20	200 KHz	1.6	4.0823997
21	400 KHz	1.28	2.1441994
22	600 KHz	1.28	2.1441994
23	800 KHz	1.2	1.5836249
24	1 MHz	1.2	1.5836249
25	1.2 MHz	1.2	1.5836249
26	1.4 MHz	1.2	1.5836249
27	1.6 MHz	1.2	1.5836249
28	1.8 MHz	1.2	1.5836249
29	2 MHZ	1.6	4.0823997

Figure 5: Collected data

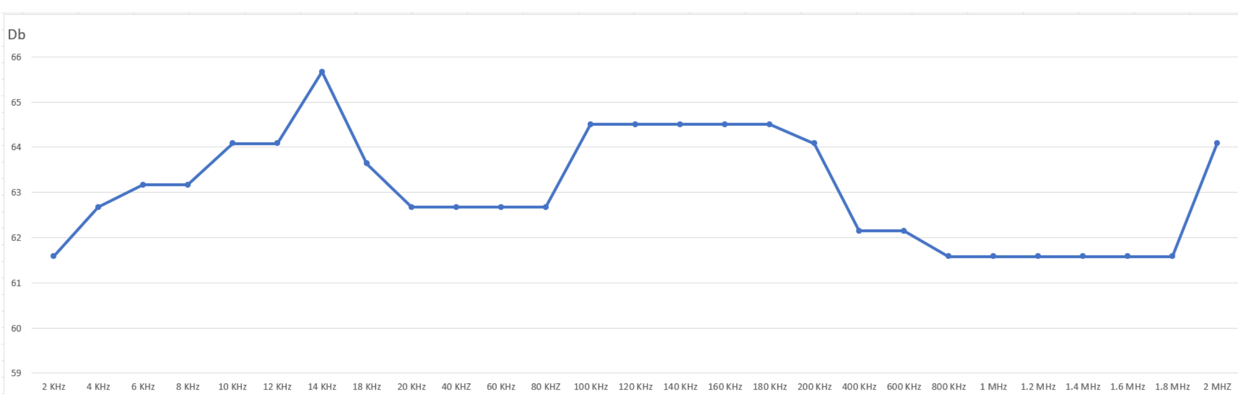

Figure 6: Data collection graph

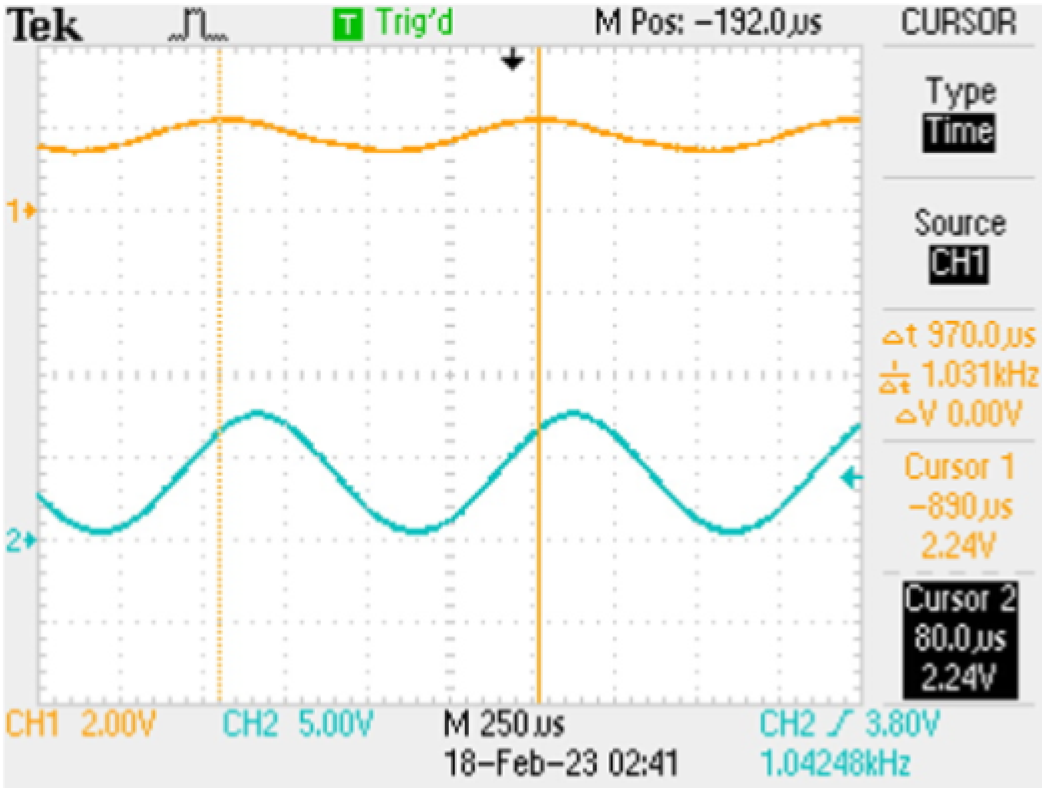

Figure 7: frequency at 1kHz

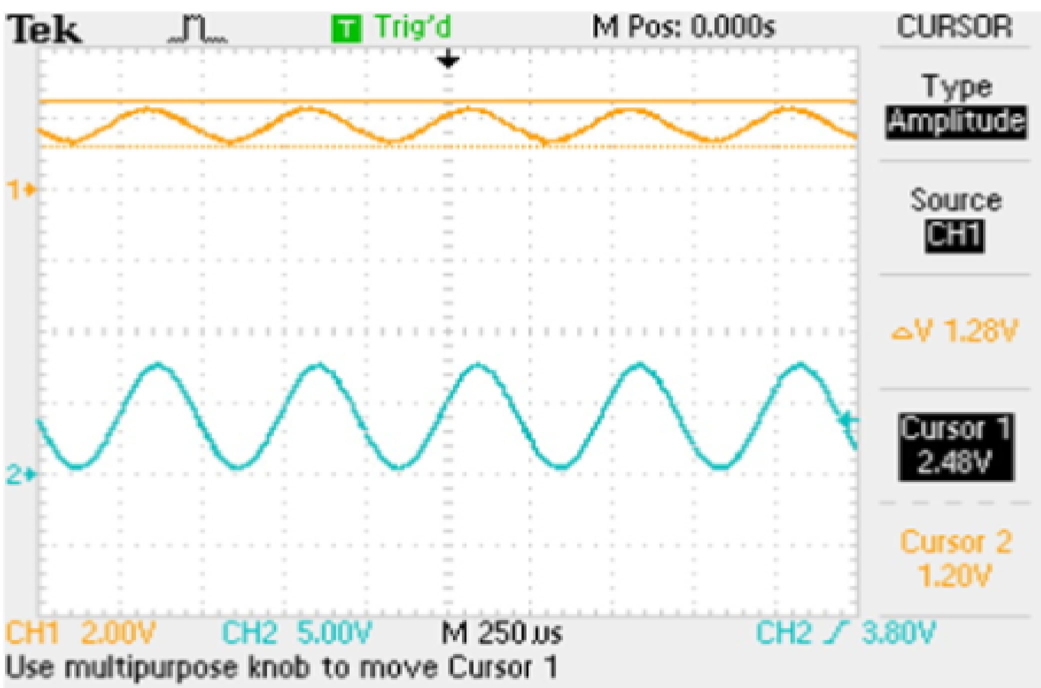

Figure 8: frequency at 2kHz

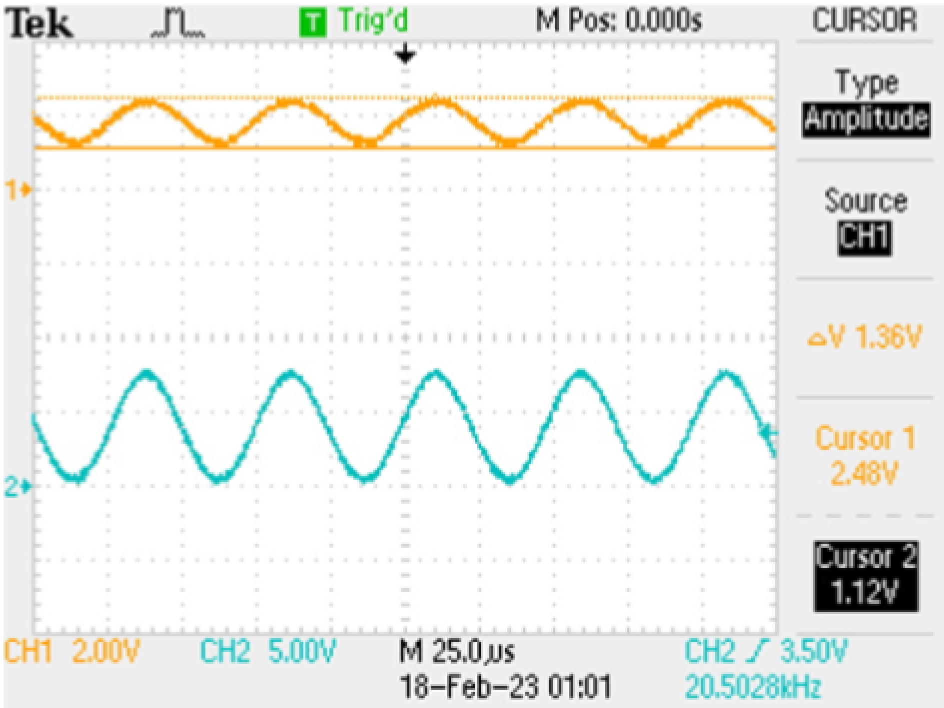

Figure 9: frequency at 20kHz

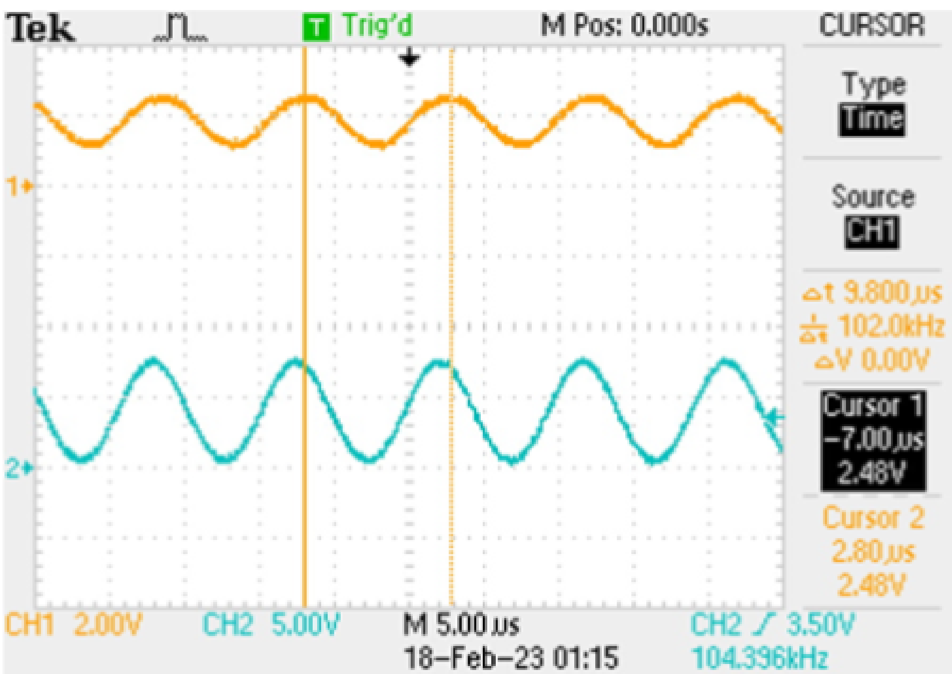

Figure 10: frequency at100kHz

Simulation of improved Circuit

The main goal of the Photodiode was to make some improvements to the original circuit which was replaced by a common base amplifier and compare the improvements with the original circuit which is the inoise and the bandwidth figure below shows the bandwidth and inoise for the new circuit

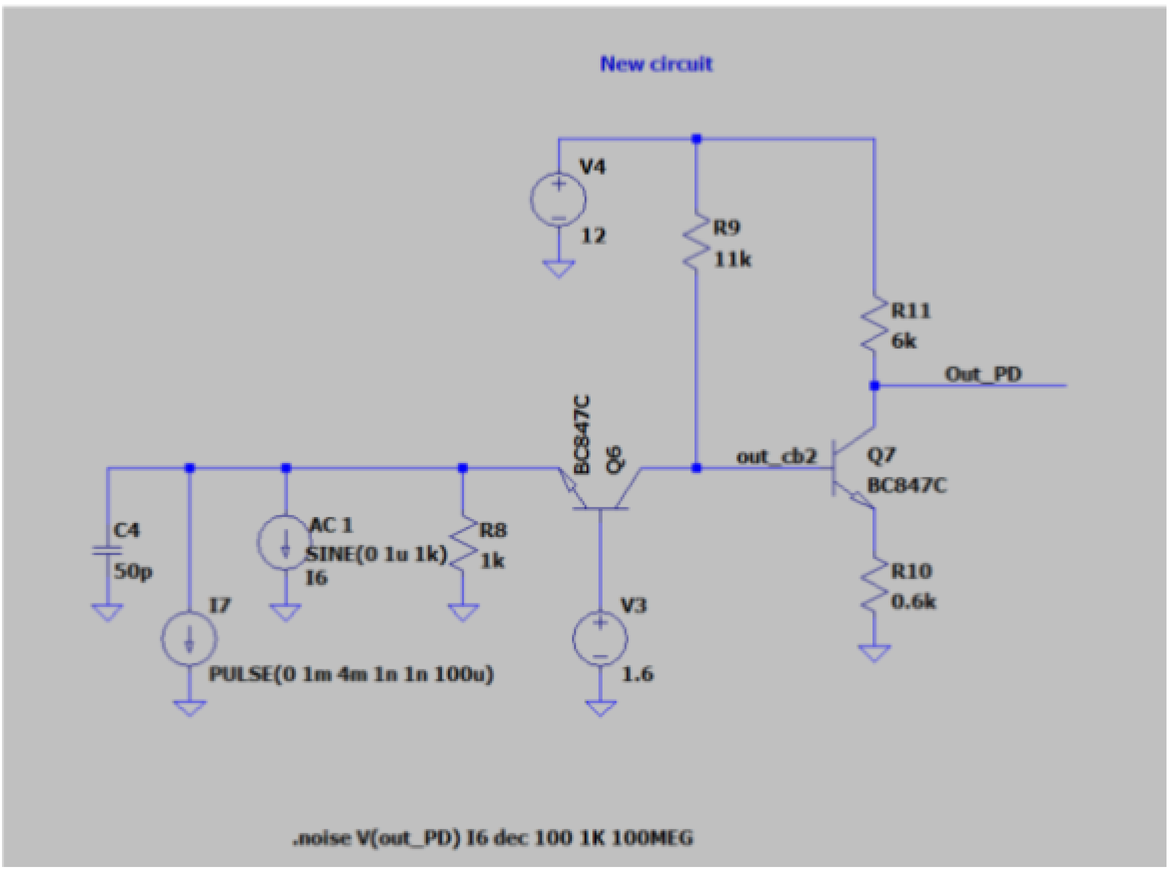

Figure 11: new circuit

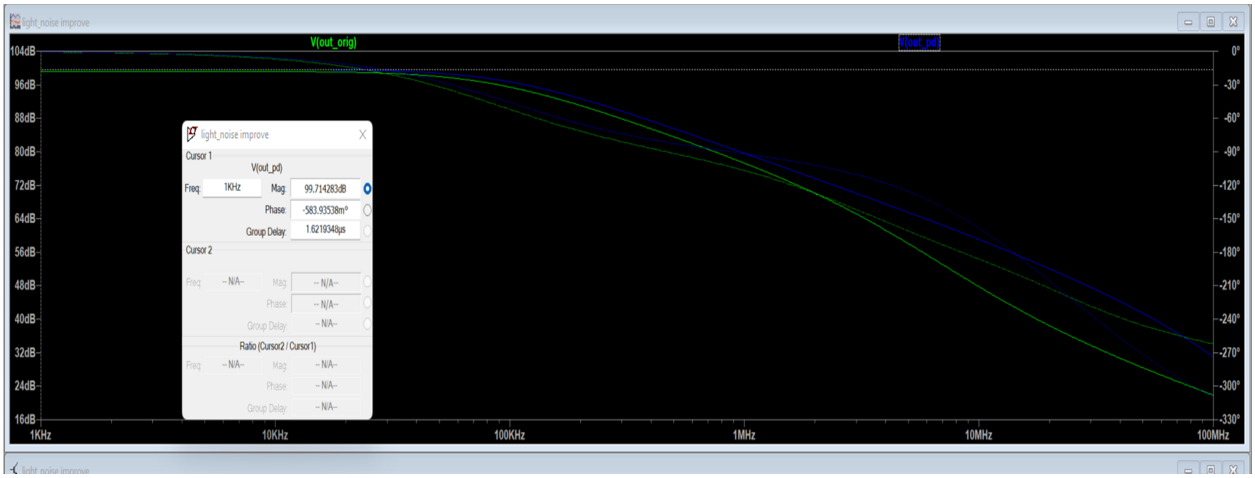

Figure 12: Bandwidth for new Circuit

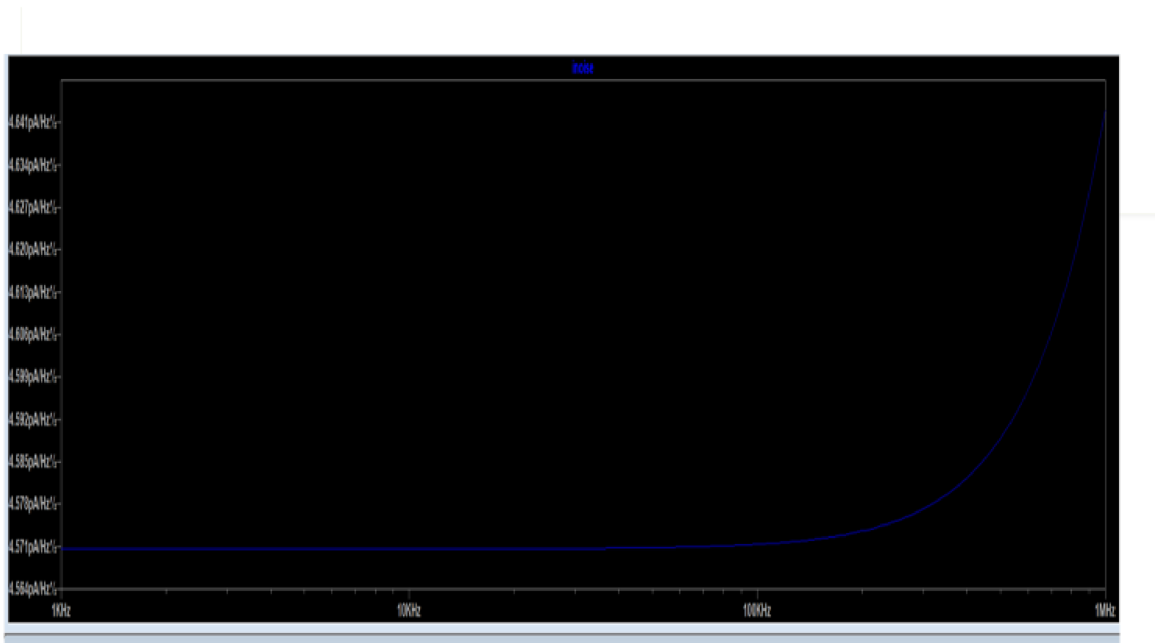

Figure 13: Inoise for the new circuit

From the figure above we can see the bandwidth and inoise improvement for the circuit. The common base version versus the feedback version and a second common-Emitter amplifier was added to increase the gain. To design a transistor amplifier and the gain of it is the resistor collector divided by the emitter resistors which is R11/R10 = 6k/0.6k =10k.

Testing the new circuit

The improved circuit was tested and the figure below shows the result of the test: The decibel range obtained after performing a frequency sweep on the photodiode PCB. The function generator's maximum output is 2 MHz, hence the range of the sweep was 50 Hz to 2 MHz. The transistors in the photodiode started to become saturated as the frequency hit 100 kHz.

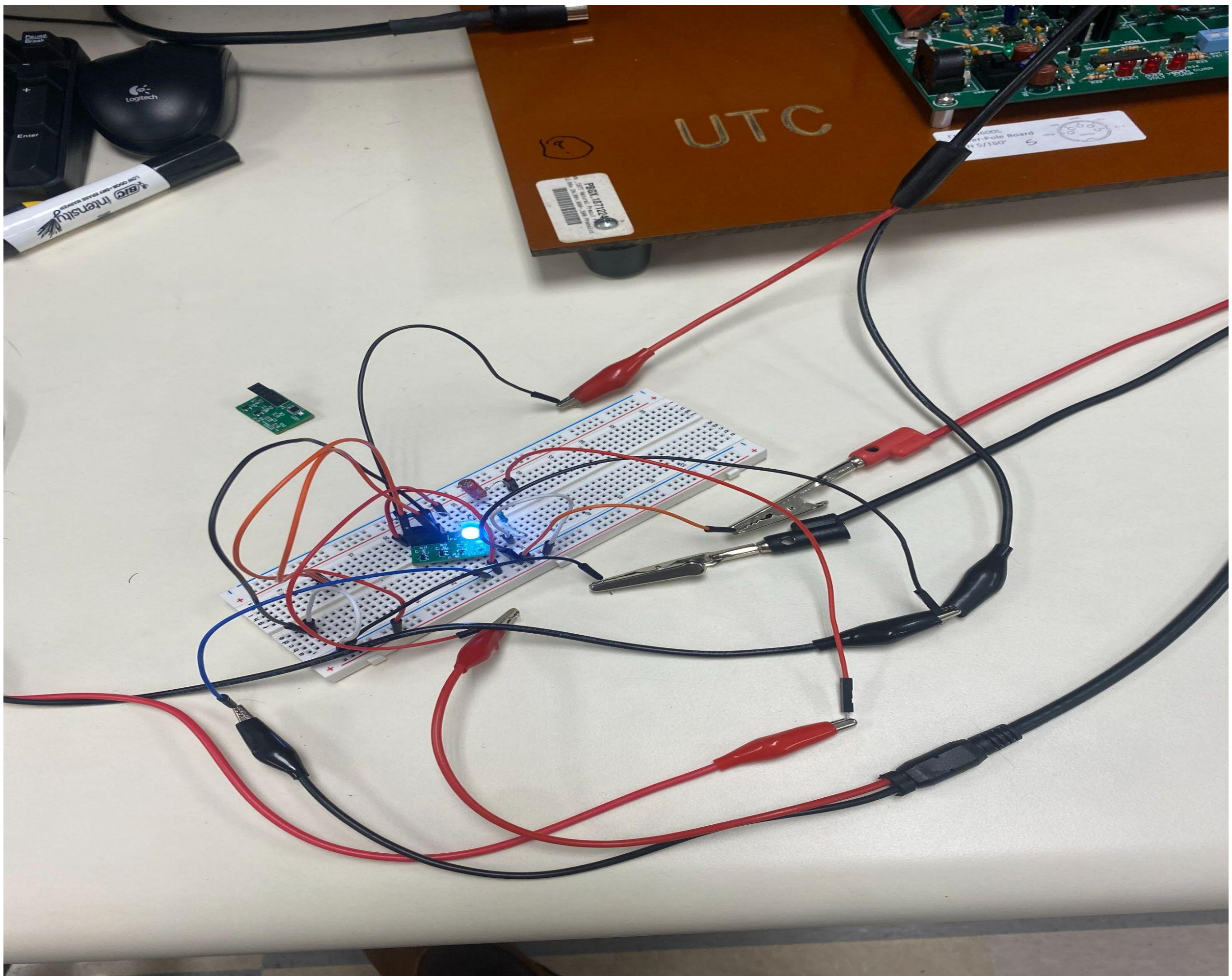

Figure 14: testing setup

Frequency	Amplitude	DB
50 HZ	26.0 mv	61.58362492
100 HZ	22..0 mv	62.67077817
300 HZ	43.2 mv	63.16724984
500 HZ	40.0 mv	63.16724984
1 KHZ	52.0 mv	64.08239965
1.5 KHZ	60.0 mv	64.08239965
2 KHZ	140.0 mv	65.66602457
3 KHZ	140.0 mv	63.63687176
5 KHZ	188.0 mv	62.67077817
7.5 KHZ	194.0 mv	62.67077817
10 KHZ	204.0 mv	62.67077817
20 KHZ	216.0 mv	62.67077817
50 KHZ	224.0 mv	64.50618563
75 KHz	244.0 mv	64.50618563
100 KHZ	257.0 mv	64.50618563
200 KHZ	268.0 mv	64.50618563
300 KHZ	282.0 mv	64.50618563
500 KHZ	306.0 mv	64.08239965
750 KHZ	318.0 mv	62.14419939
1 Mg	328.0 mv	62.14419939
2 Mg	343.0 mv	61.58362492

Figure 15: Collected data

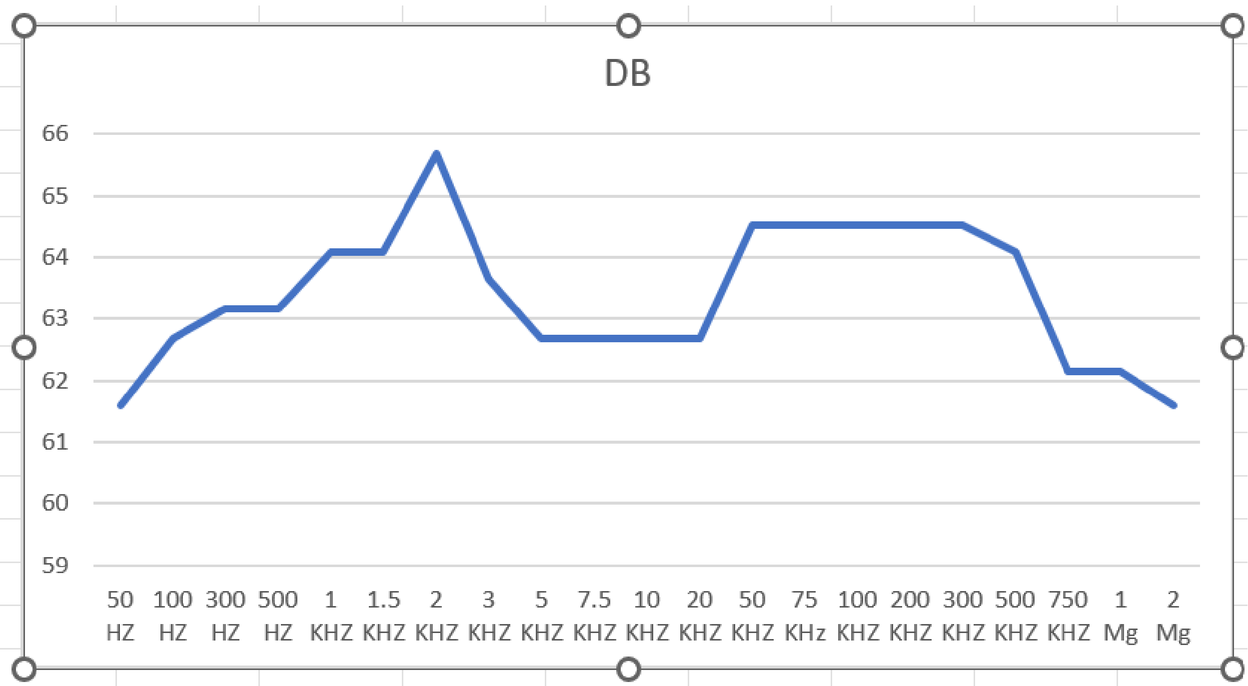

Figure 16: Data collection graph

Multiplexer

Purpose of this component here The purpose of the multiplexer is to switch between signals coming from the photodiode amplifiers. The multiplexer is connected to the outputs of the photodiode amplifiers. Based on whether the input signal is high or low the multiplexer can switch the incoming signals of the photodiodes. This is done with a combination of transistors and mosfets. The goal for this particular component was for monetary benefit. This will be accomplished by replacing one or some of the mosfets with transistors. The simulations comparing the difference will be shown as well as the various pricing for components.

Simulation of original circuit

The original LTSpice file can be found on the Better Bots website. Once downloaded, it's important to look at the circuit and understand what is going on before it is run. Looking at figure seventeen, it can be seen that the circuit has multiple mosfets which can be costly. This is why the team wanted to improve the circuit by replacing one with a transistor.

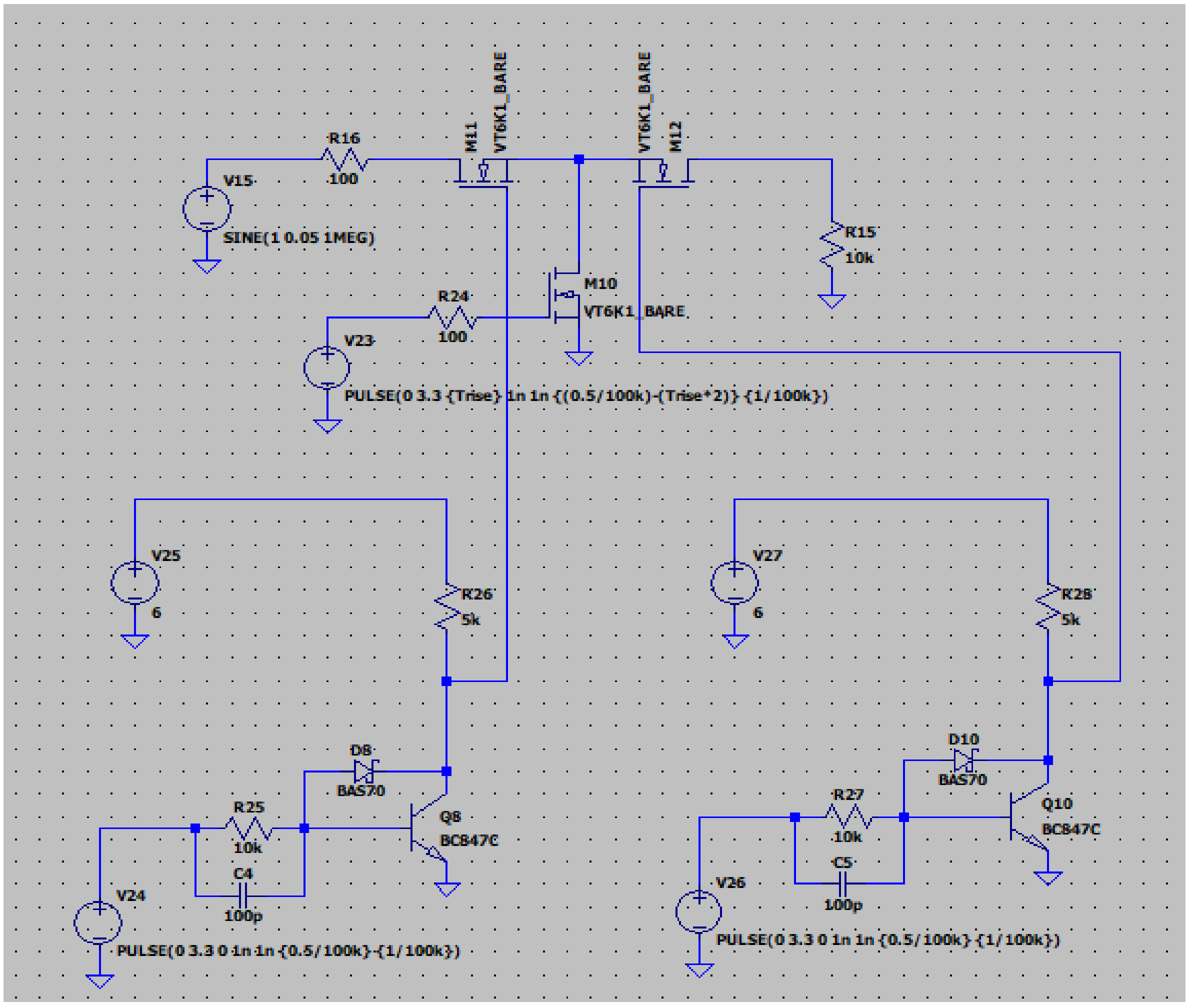

Figure 17: LTSpice of the Circuit

The first test on the multiplexer was to see the switching speed and running the circuit it can be seen that the switching speed was appropriate at less than six microseconds. This can be seen in figure eighteen. Continuing to look at the same graph it is important to note that there is some signal leakage in the original circuit. This could be due to extra capacitance within the circuit or the type of diode that is being used.

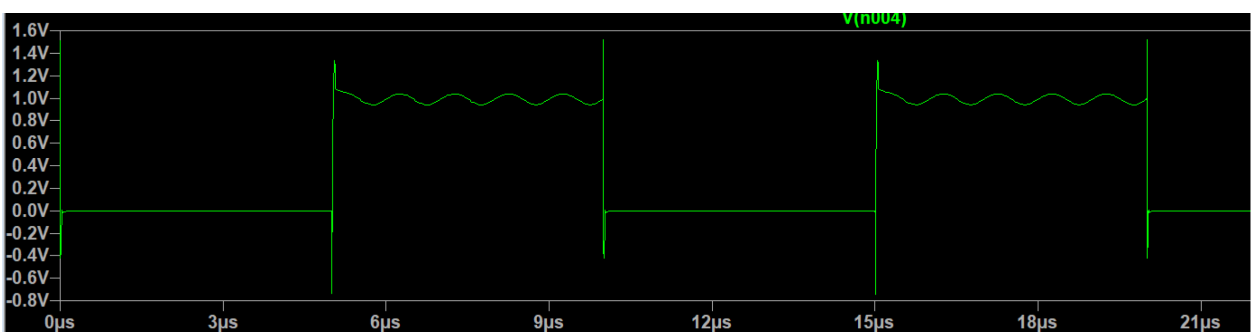

Figure 18: Waveform of Original Multiplexer

MultiSim

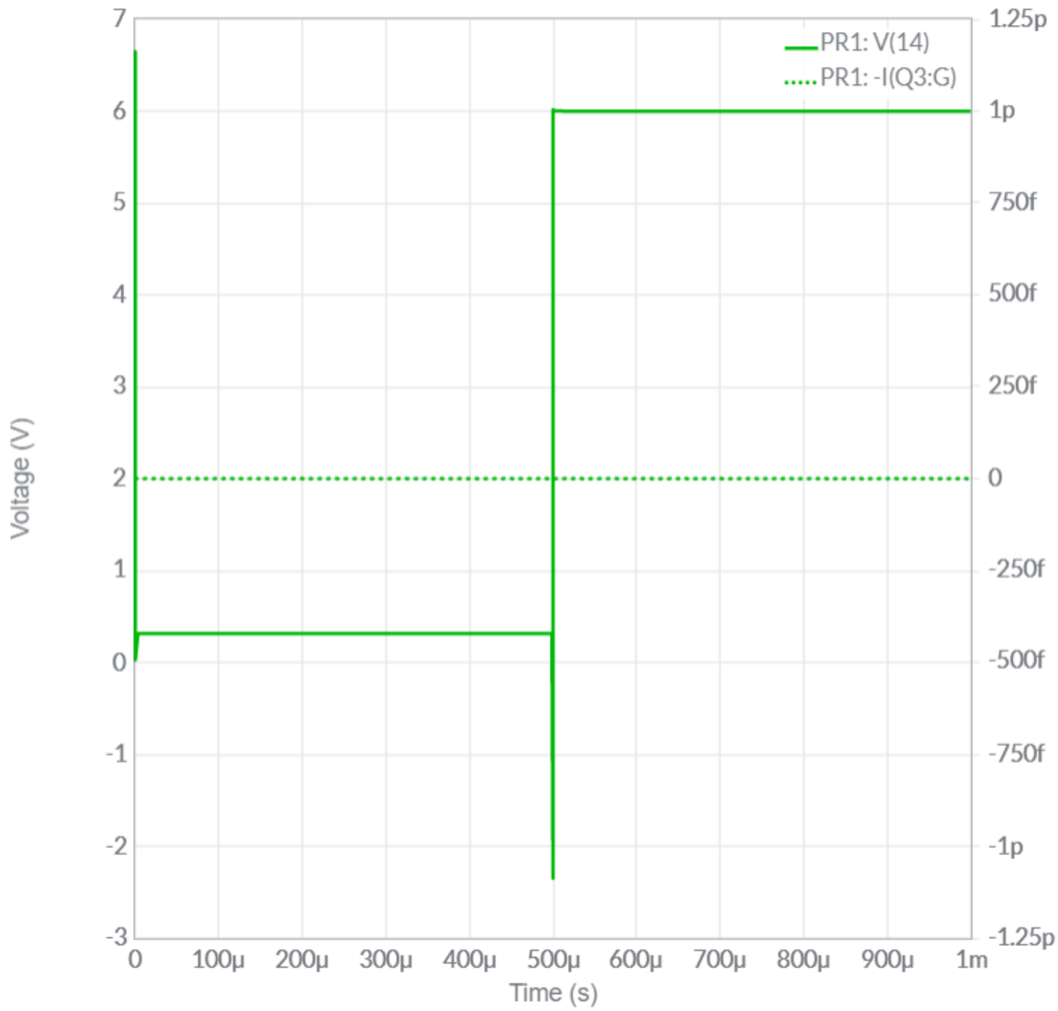

Figure 19 : Multisim Simulation of the Unmodified Multiplexer

When working with the unmodified multiplexer in Multisim and comparing its output to that of the circuit modeled in LTSpice the two plots are identical when compared across the same scale. The biggest difference between the graphs between the two softwares is that Multisim's grapher does not have the same capabilities or scaling as the one in LTSpice.

Simulation of improved Circuit

The important objective of the multiplexer improvement was to lower the cost of the circuit by replacing the mosfet on the shunt side with a transistor. The original cost of the mosfet seen on the original circuit was about $0.42 per unit whereas the chosen transistor was $0.30 per unit [4]. When that is replaced the signal leakage is slightly improved as shown in the figure below.

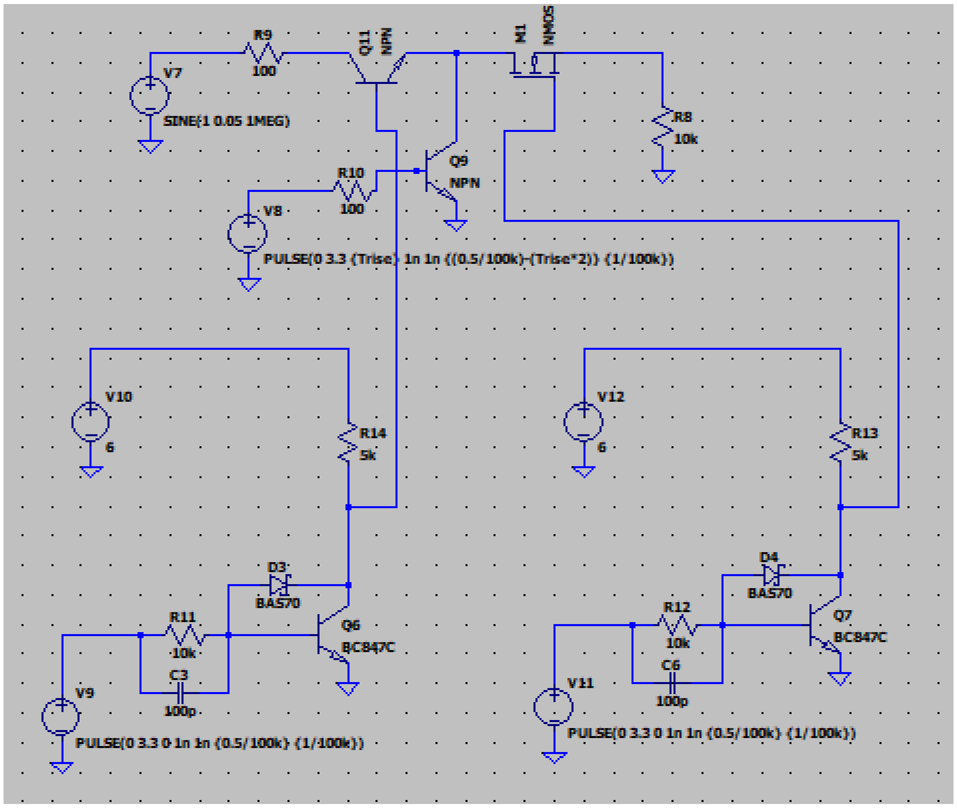

Figure 20: Improved LTSpice

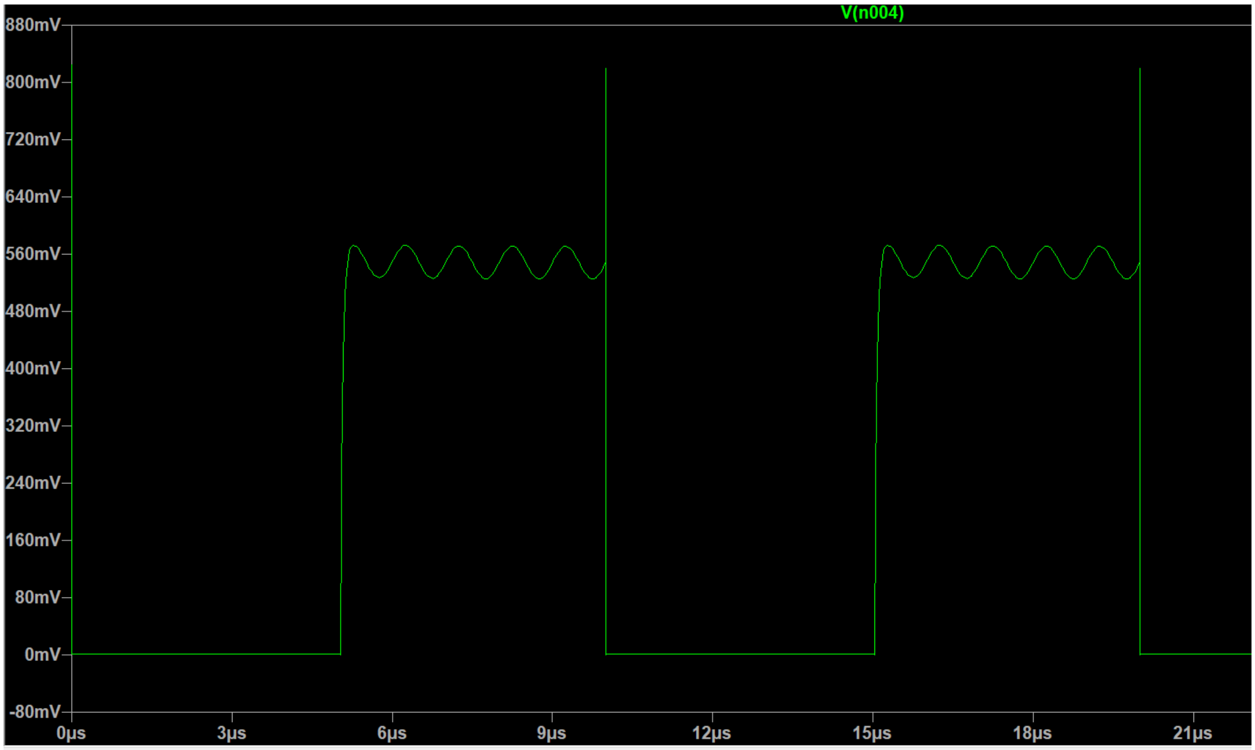

Figure 21: Output of Improved Circuit

New circuit

The new circuit as seen in figure twenty is improved as the client requested. Due to ordering issues the Multiplexer. The PCB order could not be complete but the gerber file along with the other associated files were created. Based on this, there are only simulation results that were discussed in the section prior.

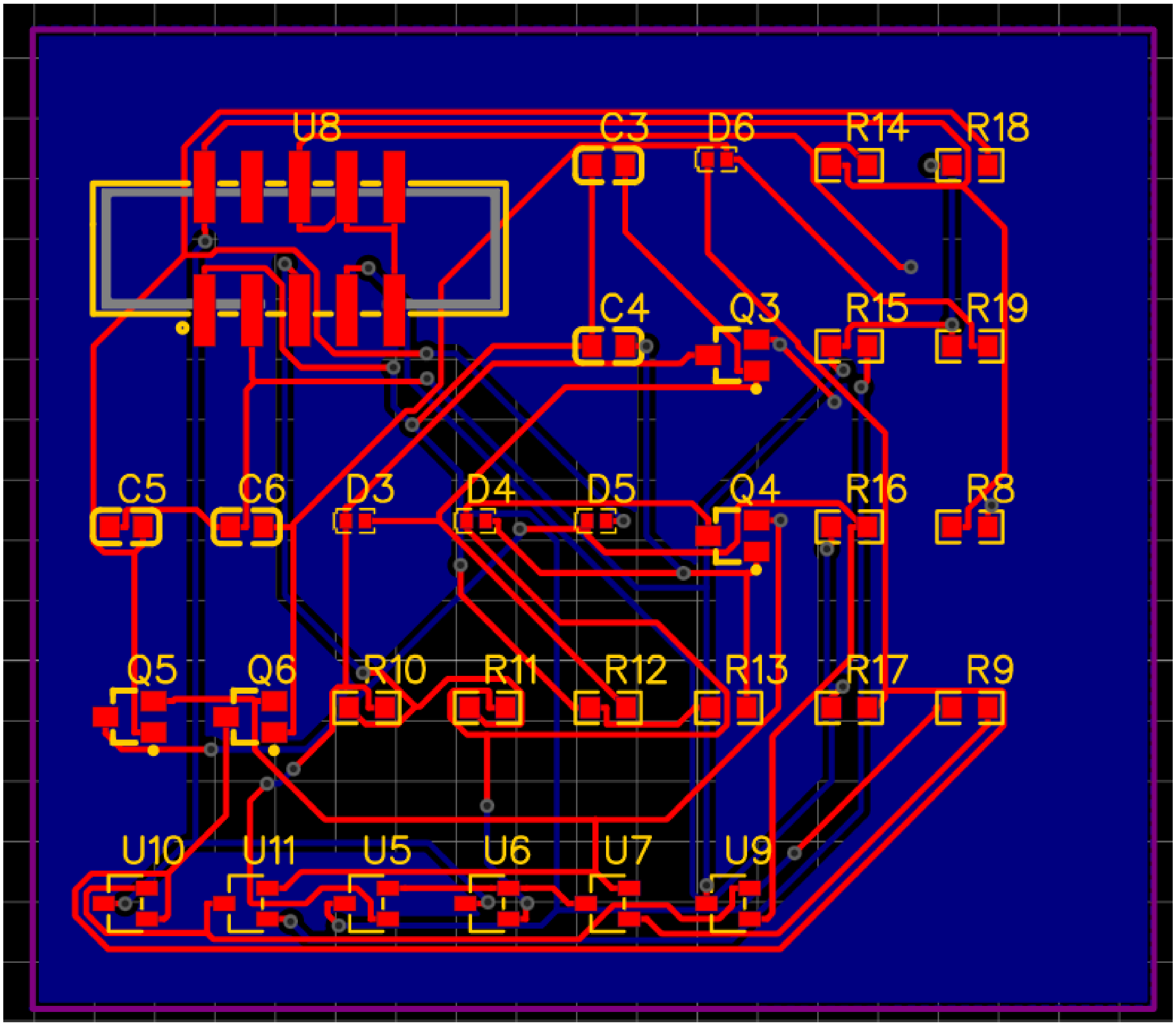

Figure 22: PCB of Circuit

Preamplifier

The preamplifier is connected to the output of the multiplexer. The purpose of the preamplifier is to take the output of the multiplexer and scale it to a detectable level without degrading the signal and introducing more noise into the output. The preamp was left unmodified due to time constraints and so only the original circuit simulations are shown below and will be the primary focus of any analysis of this component.

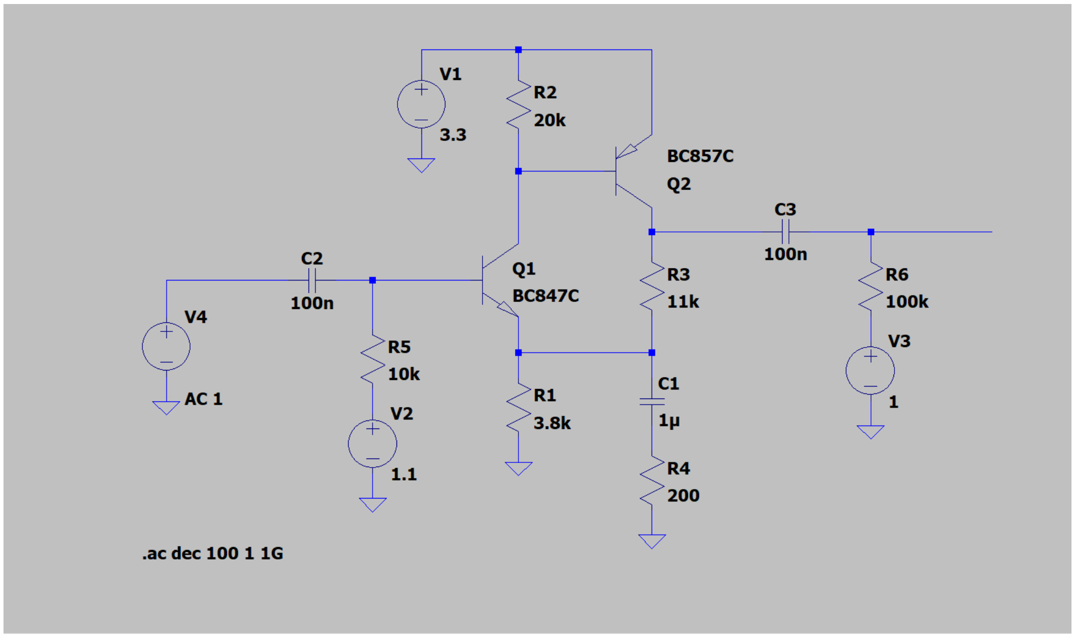

Figure 23 : LTSpice Simulation of the Unmodified Preamp

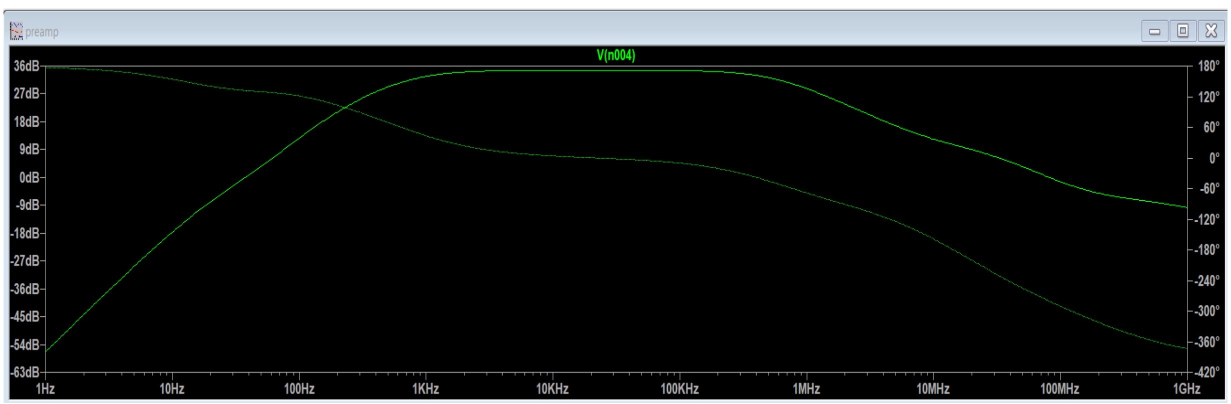

Figure 24 : Simulation Result from LTSpice

The figure above shows the results from LTSpice when an AC Sweep was performed on the circuit. It is comparable to the figure below which shows the Multisim simulation. When comparing the two they are only comparable up to 1 MHz, after that the Multisim limitations are reached and the two plots are no longer similar enough to be comparable.

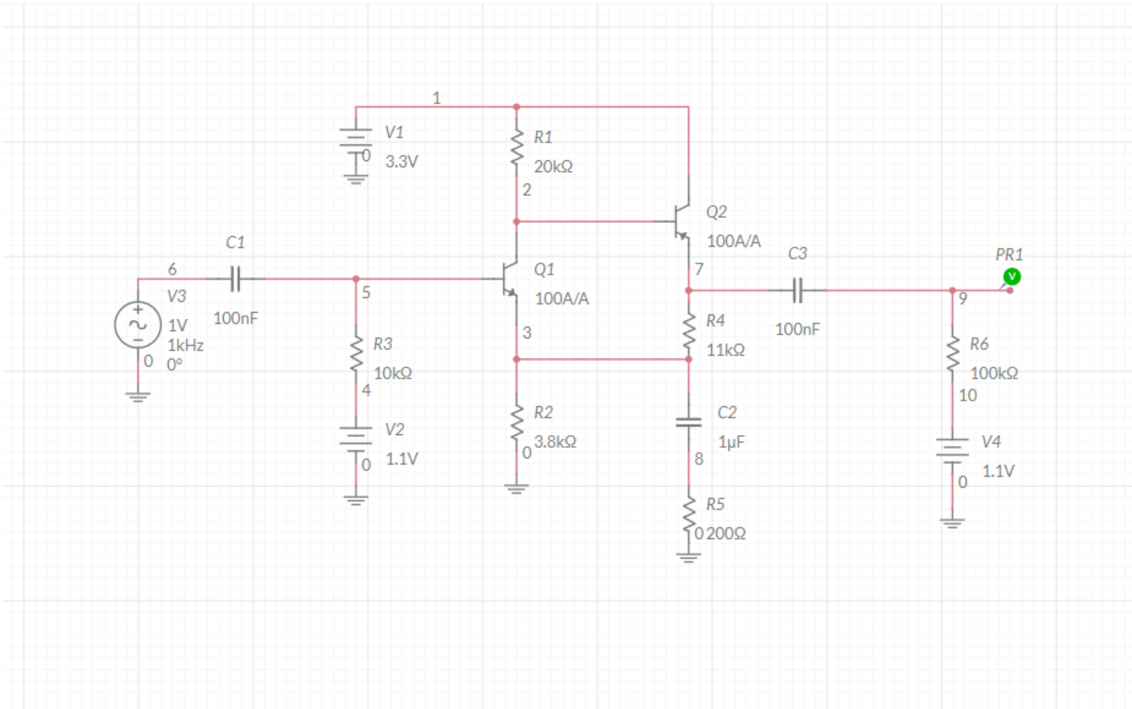

Figure 25 : Simulation of the Unmodified Preamp

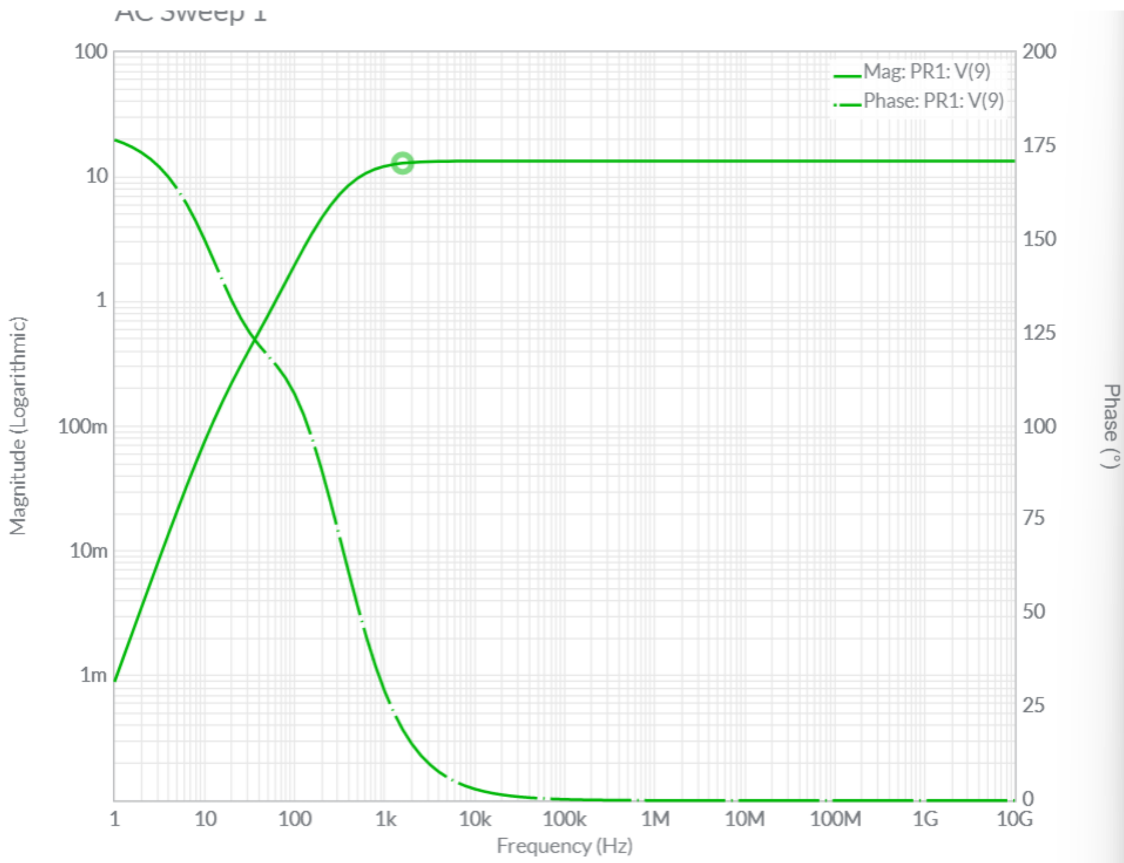

Figure 26 : Simulation Results from Multisim

Testing of original circuit

The two figures shown below merely show what the circuit setup looks like when all the inputs and measuring devices are connected to the device. The second figure shows a closer look as to what the PCB itself looks like.

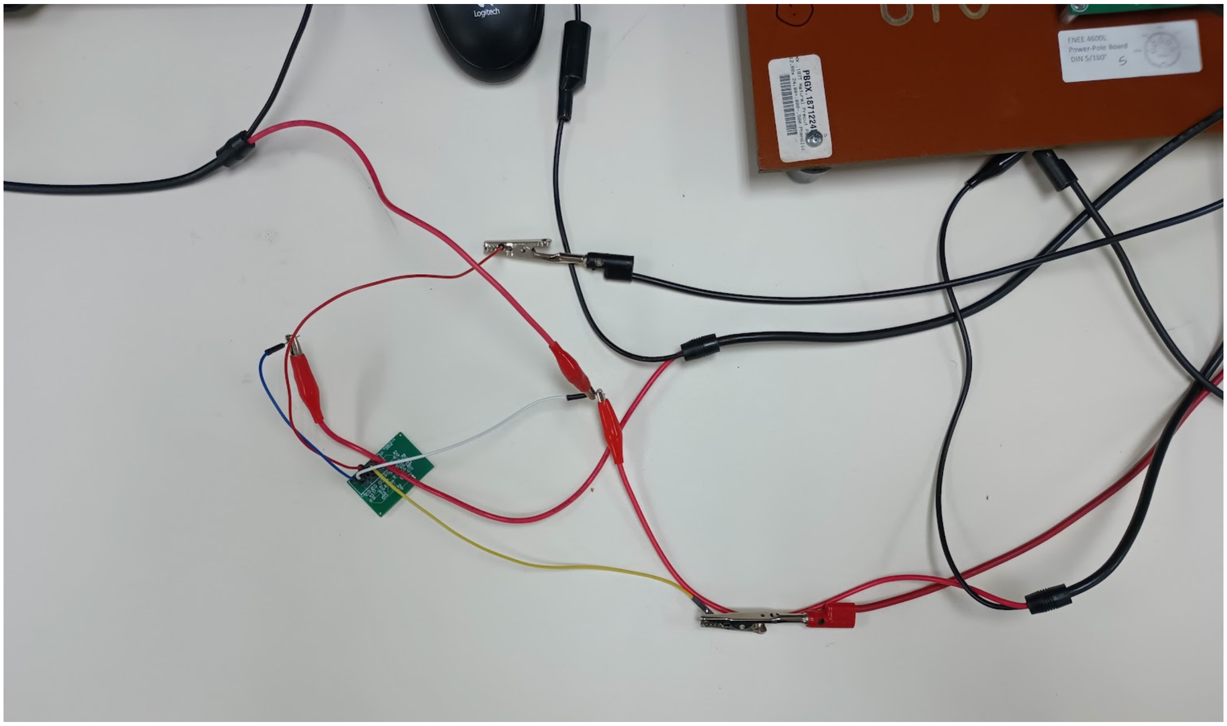

Figure 27 : Testing of the Preamp Circuit

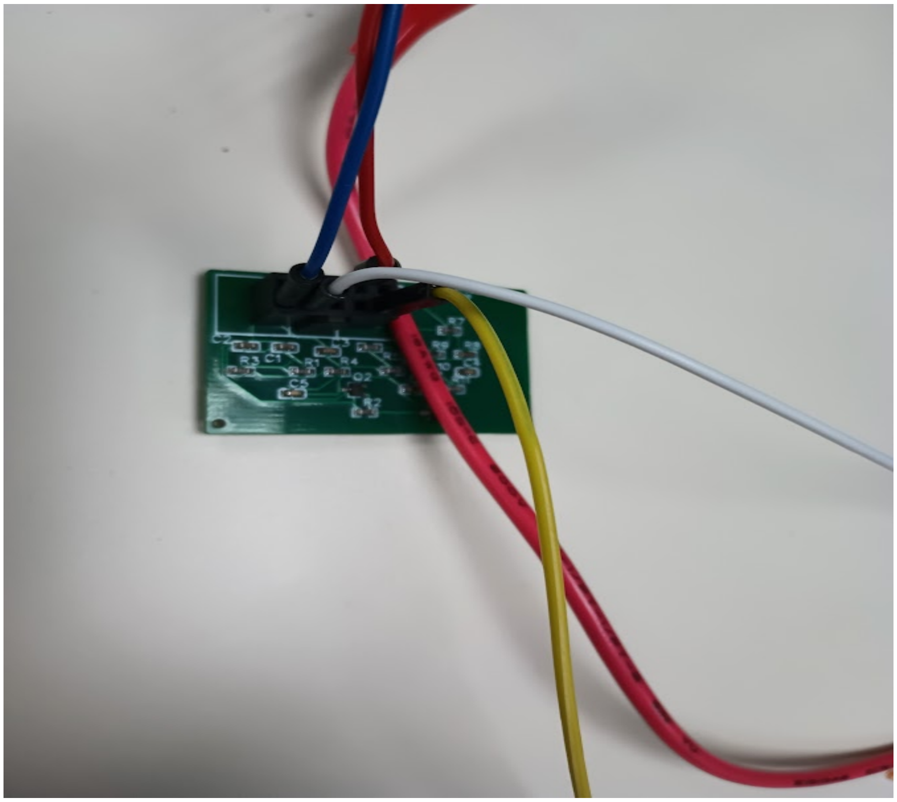

Figure 28 : Close up of Preamplifier Circuit

Results and discussion

The figure below shows the resulting decibel range from doing a frequency sweep on the preamplifier PCB. The sweep took place from 50 Hz to 2 MHz as the function generator has a maximum output of 2 MHz. When the frequency reached 100 kHz the preamplifier began to saturate and from that frequency on the output decibels began to decrease.

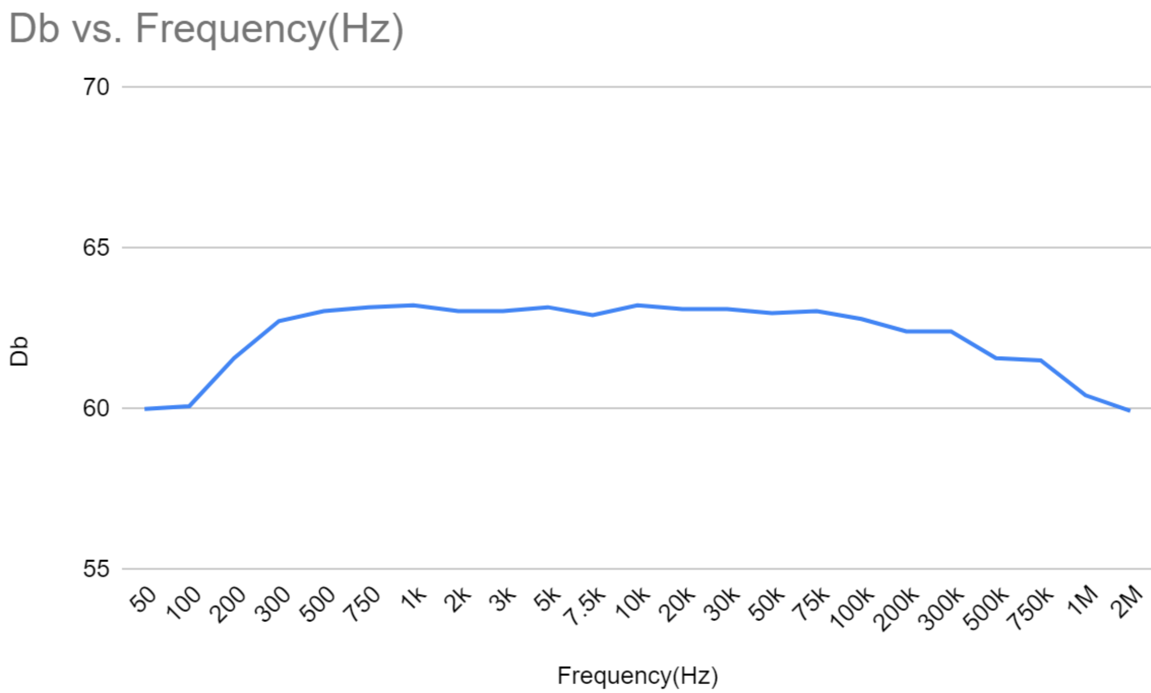

Figure 29 : Testing Results of the Preamp PCB

All these subcomponents will fit linearly within the system. First will be the photodiode that measures the light then filters out that noise. From there the amplifier will choose one of the outputs from the four photodiodes and send it to the preamplifier. The preamplifier will take the signal and amplify it to send to the rest system.

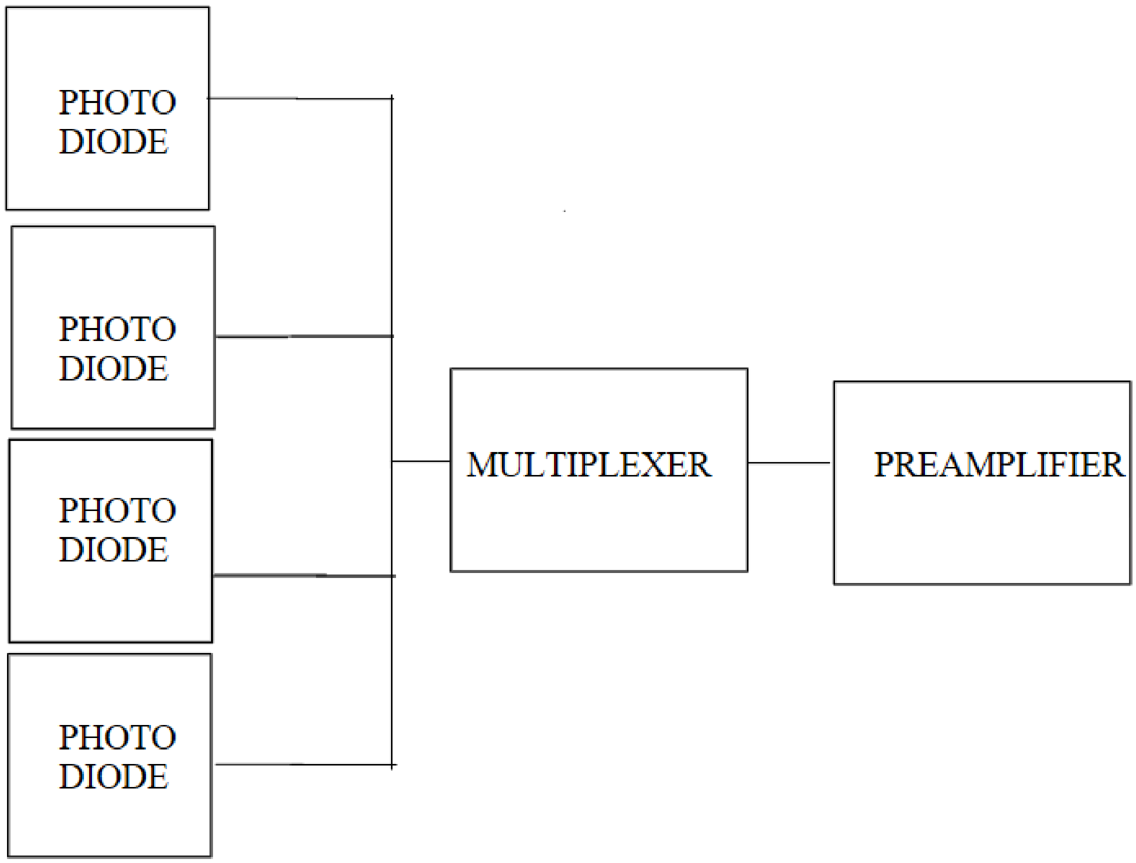

Figure 30: Flow of the System

Ethics and Safety

The ethic that the team focused on was to protect public interest. This can be applied to the project since the overall robot is meant to teach school children once it is built. In order to keep this ethic in mind, the team strived to improve the circuit within the codes and standards in relation to the IEEE standards. The standards that were referenced were IEEE SA - IEEE 2089-2021 and IEEE SA - IEEE 2700-2017.

As mentioned above, the overall robot will be in schools with children. As this is the main focus of the final product safety should be considered a vital part of the design. For this project the team focused on keeping our components safe to be used and worked with by others.

When the team was working on their components safety was always in the forefront and kept in mind for the team members working on the project and for the users who could be using the final product that the components would make up.

Engineering Specs Verification

The specifications for this design will be broken down per circuit. The first one that can be discussed will be the photodiode amplifier. The first specification was to simulate the original circuit in LTSpice and MultiSim. The circuit was simulated in both simulations. It can be seen in multiple figures per each component section. The team did not do a PCB design of the original circuit this was due to time constraints, but there was a PCB design and build of the improved circuit. The next specification was seeing an improvement of five to twenty percent bandwidth improvement. The can be verified based on testing results as seen in the previous design portion of the report. The final verification for the photodiode is a noticeable improvement in the noise. This was verified as well in the testing portion which can be seen in figure 13.

The next circuit was the multiplexer. Like the photodiode, the first specification was to simulate the in LTSpice and in MultiSim. This can be verified in figures 17 and 19. The next specification for the multiplexer was to create the original circuit as a PCB and test it. These cannot be verified, because the team did not do this. Instead, the team improved the circuit by replacing a mosfet with a bipolar transistor. This made the circuit more affordable to produce. This improvement was specified by the client after the original specifications were created which is why the PCB creation and testing for the original circuit cannot be verified but can be verified for the improved circuit. The final specification was to test the PCB which was accomplished.

The final circuit with specifications was the preamplifier circuit. The first specification is the same as the others which was to be simulated in LTSpice and MultiSim and was verified by figures 24 and 26. Then the next specification is PCB design of the original circuit which was completed and can be seen in figure 28. The specification of a design of an improved preamplifier was not completed. This is due to time restraints and for future teams more work can be done so that team and client can stay on the same goals within the time frame. The original preamplifier circuit did test with good results.

The original overall specification of this circuit was to determine if the image subtraction circuit was needed in the subsystem. This was not accomplished. If a future team chooses to do a similar project, the design and goals need to be agreed on early on. Then the schedule and goals need to be stuck to throughout the project. If some goals need to be adapted it needs a meeting for both teams to review and discuss whether it is applicable within time constraints.

Manual for End Users, Engineers, and Operators

To turn each PCB on, reference the matching PCB file that was supplied with this report. The file should have a schematic that has each pin on the PCB labeled. The power supply voltage should match the schematic. Then connect the correct input pin to the red wire from the power supply. The black wire from the power supply should be connected to its respective ground pin on the PCB. The output pin will need to be connected to the oscilloscope. The oscilloscope will show the output of the circuit. For the PD amp the circuit needs some type of light forced on the circuit such as ambient light or a flashlight. To see the difference. The preamplifier will just show a larger waveform than what you originally started with.
https://www.youtube.com/watch?v=RuEWUjL0gnc

Troubleshooting Guide

There can be multiple reasons to have errors while setting up these circuits, but luckily they are included in this section of the report. One of the biggest issues on this project is making sure the connections with the cables are secure. This means that the user needs to check that the wires that are inserted into the PCB header are secure. Then from those wires to the equipment, such as the oscilloscope and power source, need to be securely connected as well.

If the amplitude of the waveforms are coming out a little off check the attenuation of the probe. This can affect certain measured values when looking at the oscilloscope. The attenuation used in the testing process was 10x.

As long as these two main things are checked the testing should go smoothly. These two issues were the biggest hurdles that the team faced when testing the circuits. It tends to be small issues that make testing difficult.

Conclusion and Recommendations

In conclusion, the team accomplished the specifications that were set for them as well adapting as needed to better accomplish the needs of the client. The team was able to stick to the specified standards that apply to the project along with learning new software to learn and improve the circuits they were given. Not only did the team manage to demonstrate this knowledge in a classroom setting, but at the Technology Symposium as well. The team managed to get second place in their section.

The recommendation for whomever takes this project next would be to review their notes from analog class and read up on important concepts for power electronics. This knowledge will assist in understanding the needs for this project as well as how to move forward. A clear understanding of this knowledge improves the circuit.

References

[1] *Betterbots.com*, https://www.betterbots.com/.

[2] "IEEE SA - IEEE 2089-2021." *IEEE Standards Association*, standards.ieee.org/ieee/2089/7633/. Accessed 16 Nov. 2022.

[3] "IEEE SA - IEEE 2700-2017." *SA Main Site*, standards.ieee.org/ieee/2700/6770/. Accessed 16 Nov. 2022.

[4] "MSD1819A-RT1G: Digi-Key Electronics." *Digikey*, https://www.digikey.com/en/products/detail/onsemi/MSD1819A-RT1G/1482625.