Final Design Report

Project 29 – Mr. Ohm

Team Members:
Kyle Lambert
Cole O'Shaughnessy
Lindi Hang

Date	Revision	Release Notes
12/5/2022	01	Initial Release + Introduction
12/6/2022	02	Added Definition of Problem Section
12/7/2022	03	First Full Draft
12/9/2022	04	Added PAR, Noise, and Executive Summary
4/24/2023	05	Update analysis section, implement fixes from first draft
4/25/2023	06	Updated Intro + Problem to include new circuits, removed PAR, etc
4/26/2023	07	Added more to Design Process, Open Issues, and List of Expanses
4/27/2023	08	Second Full Draft

Table of Contents

1 Executive Summary

This project revolves around the improvement of the photodiode amplifier circuit, a part of the Light Direction Finding Sensor in the educational robot, Mr. Ohm. This circuit must be able to receive input from any classroom light, and output an amplified voltage based on the frequency of the flicker. There is currently a circuit that can do this, but not for any classroom light. The improvement proposed by the team, through the addition of a cascode amplification circuit, allows for the detection and use of a wider range of frequencies. The team also improved other circuits within the sensor, including the voltage controlled oscillator and quadrature DDS. These circuits, as well as the phase locked loop circuit, were manufactured and a few tested. More testing should be conducted in the future to determine the full function capabilities of the circuits and the extent of the improvements.

2 Introduction

The educational robot, Mr. Ohm, employs a variety of sensors to help teach students about computer science and electrical engineering. One of these sensors is a Fluorescent Light Direction Finder, which needs a photodiode amplifier to function properly. Photodiode amplifiers can have many different specifications including gain, bandwidth, voltage swing, and noise which determine how well it functions. This report will show that the changes made by Team 29 will cause a significant improvement in the performance of the photodiode amplifier as well as a few other circuits in Mr. Ohm.

This report will provide the background and importance of this robot, as well as the reason for improvement of the photodiode amplifier, voltage controlled oscillator, and Quad DDs. It will then discuss the key components of the amplifier and oscillator, and alternate ideas and designs that were taken into consideration. This report will also include analyses of the bandwidth and distances at which the circuit can detect lights to quantify the improvements. It will finish with a list of further actions which could be taken to better meet the client's needs, a summary of the project, and lessons learned throughout the process.

3 Definition of Problem

In the Fluorescent Light Direction Finding Sensor a photodiode detects light as an input and allows a certain amount of current to flow based on the light level. An amplifier is needed to increase the current from the photodiode. This photodiode amplifier must be able to take input from any classroom fluorescent light and output a voltage and frequency based on the frequency of the light. That output must also be compared to a range of frequencies created by the another set of circuits including the VCO, Quad DDS, and PLL. That range of frequencies must contain any possible frequency that could come from the amplifier.

3.1 Betterbots

One thing about Betterbots' Mr. Ohm that sets it apart from other educational robots is that it is made from discrete components. Rather than chips, its boards are made of discrete transistors, resistors, capacitors, etc. It is very important to the client that any changes to the robot must allow it to remain this way. The client was not specific at first about which part of the robot he wanted improved, nor how he wanted it improved. After some discussion, the client and team decided the light detection circuit was the correct place to start.

Once the team was assigned to work on the light detection circuit, the first subcircuit to work on was the photo diode amplifier. This circuit is used to find the flicker at which the florescent light is oscillating. The flicker occurs since fluorescent and LED lights use ballasts to change the frequency that comes from the power grid to change the current being delivered to the lighting element. The two improvement options considered were to increase the bandwidth or increase the gain. Since they are inversely proportional an increase in gain means a decrease in bandwidth. The second circuit given to improve was the voltage controlled oscillator. This circuit is used in conjunction with a microprocessor to search for frequencies of interest. The VCO has a few requirements, the first is that it needs to be 32 times faster than the highest frequency of interest since it feeds into another circuit. The VCO is used with the photodiode amplifier to indicate whether a particular frequency of interest is being detected.

3.2 Other Stakeholders

Outside of Betterbots, the other stakeholders in this project would be students and teachers of Computer Science and Electrical Engineering. The students would be in introductory classes in either High School or College. The use of discrete components is important to these stakeholders as it is one of the ways in which Mr. Ohm can be used to learn. Schematics of each circuit in the robot are available on the Betterbots website http://www.betterbots.com/). The student can observe how each component works within the circuit, along with how each circuit works within the sensor, and read about how it all works. The student programs the robot to do a task and can understand how his program is carried out by each part of the robot it affects.

A higher bandwidth in the photodiode amplifier is important to those using the robot because they would want it to sense any light rather than only those which flicker within a small range of frequencies. The sun may also pose an issue as many classrooms have windows and light from the sun would drown out most classroom lights. To combat this issue, a DC offset is needed in the photodiode amplifier to make sure the sunlight does not saturate the circuit.

Another way in which these improvements affect those using the robot is by allowing the robot to detect light from further away. The sensor should be able to receive light from 10 meters away and still detect the frequency. Increasing the gain and reducing the noise will allow a sensor to increase the range in which it can sense light. The increase in gain will allow it to use lower light levels, and a decrease in noise will allow it to detect the frequency more clearly.

The circuit must also be safe for use in a classroom. This means the board will not overheat or cause shorts which could lead to fires. It must also be safe to touch. No copper will be showing that has a high enough voltage or current to shock someone.

3.3 Scope and Specifications

The goal in improving the bandwidth is to allow the sensor to receive data from any classroom light. Through research, a desired range of frequencies was found. A team from the

Communications Engineering Lab at the Karlsruhe Institute of Technology determined that fluorescent lamps use a frequency of 100 Hz to several hundred kHz [1]. Using this information, the team decided the desired maximum value of the bandwidth would be at least 700 kHz. As there is a tradeoff between gain and bandwidth, the specification of the gain was that it would not drop below the original circuit's gain of 95 dB. There was also a requirement that the PD Amp must be able to detect lights 3 meters away and still output a usable signal.

An important specification for the VCO was also the bandwidth. It must have a much larger bandwidth than the PD Amp because of the 32 step multiplier in the DDS. For this specification, an average fluorescent light frequency of 200 kHz was used as a midpoint in the bandwidth. Multiplied by 32, that midpoint becomes about 6 MHz. The team decided the required VCO bandwidth is from 150 kHz to 10 MHz.

3.4 Customer Requirements

The following list displays other customer requirements discussed with the client.

Table 1: Customer Requirements

Rank	**Category**	**Requirement**
MED	Cost	Low cost to manufacture
MED	Functionality	Board size fits in the robot
HIGH		Board is made of discrete components
MED		Proper packaging is used
HIGH		Board can receive input from lights
HIGH		Increase bandwidth of PD Amplifier
MED		Increase gain of PD Amplifier
MED		Circuit can detect classroom lights
MED		Power Requirements
LOW	Environmental	Parts are sourced from facilities using sustainable manufacturing principles
MED	Human Factors and Safety	Board does not cause shorts which could lead to fires or overheating
LOW		Device is safe to touch

4 <u>Design Description</u>

4.1 Overview

The modified photo diode amplifier uses a photodiode as the sensor input to measure the frequency at which the florescent lights flicker at. The photodiode inputs to a cascode amplifier which consists of a common base amplifier and a differential amplifier. There are two feedback loops, the first is connected to the negative side of the differential pair and drives a common emitter amplifier, it is used to counteract the ambient light noise. The second feedback is connected to the output of the cascode amplifier and the output of the photo diode. Figure 1 shown below is the block diagram for the photodiode amplifier. The second circuit is the voltage controlled oscillator (VCO). The VCO is uses a diode bridge as an electronic switch with the integration of a Schmitt trigger. The resistor that connects power to the diode bridge and capacitor that is connected between the diode bridge and Schmitt trigger is used to set the rate at which the output of the VCO will remain low. The transistor and voltage input of the bottom of the diode bridge controls that rate at which the Schmitt trigger will remain in the high state, the components listed above are used to control the frequency. Figure 2 is the schematic for the VCO with key components labeled.

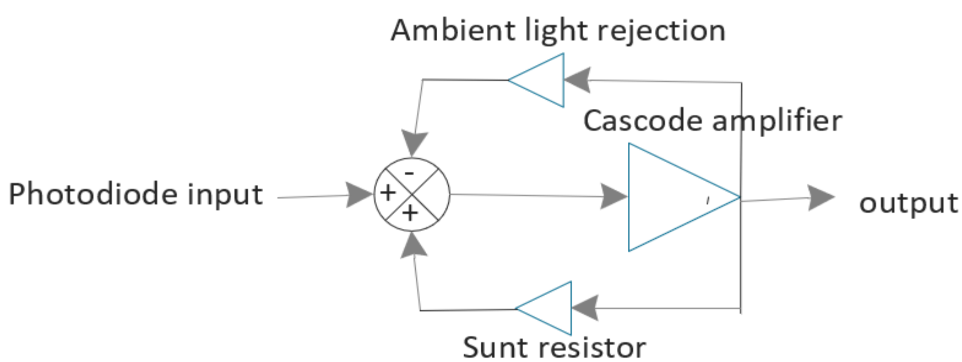


Figure 1. Block diagram of photodiode amplifier

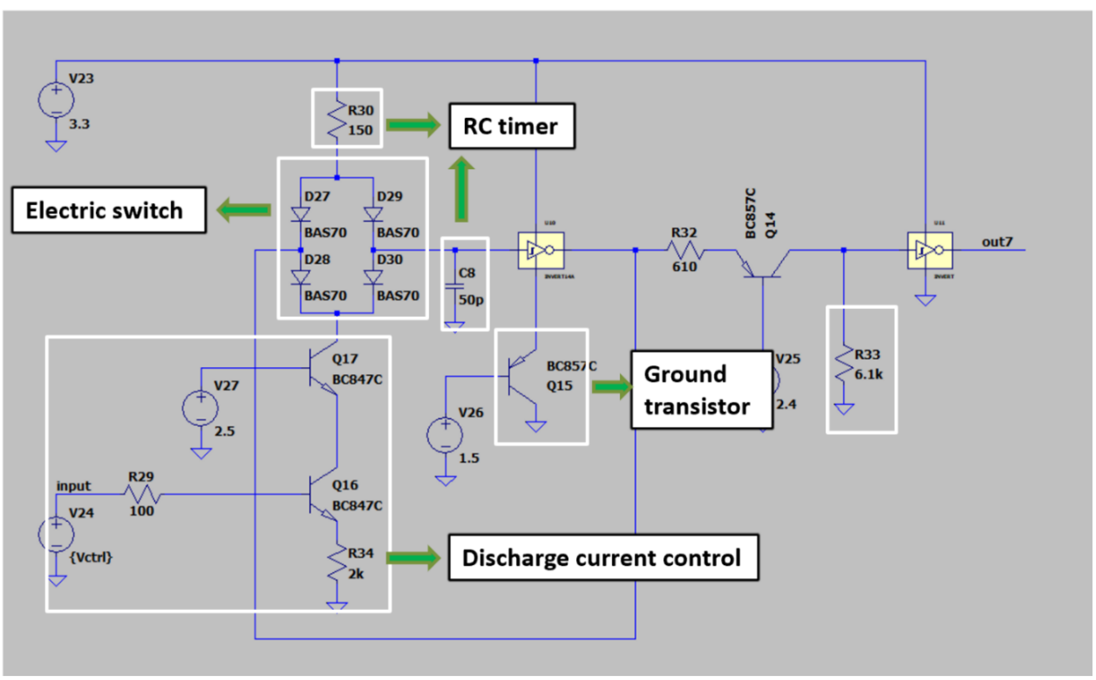


Figure 2. VCO Schematic with key components

4.2 Key Elements

4.2.1 Shunt Resistor

The shunt resistor provides stability in amplifier circuit by creating a constant gain for all frequencies within the pass band which is from 2kHz to 1MHz. Without the shunt resistor the gain is different as the frequency increases. Figure 3 shows the plot for gain with respect for frequency for the photo amplifier with and without the shunt resistor. Figure 4 indicates where the shunt resistor is placed in the circuit.

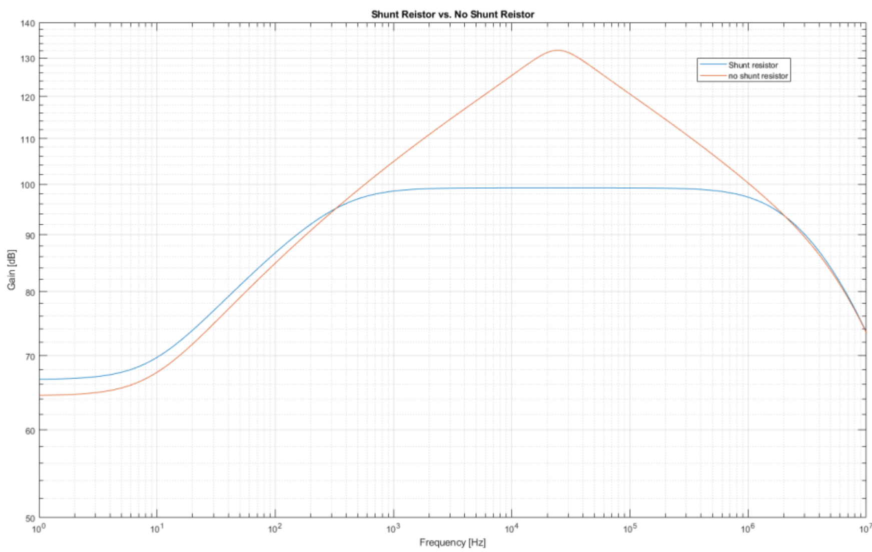


Figure 3. Comparison of gain with and without a shunt resistor

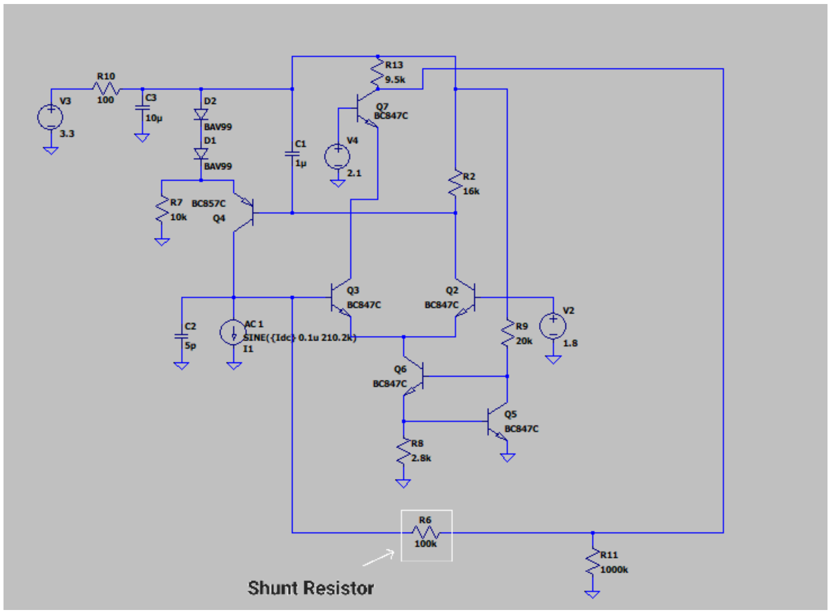


Figure 4. Shunt resistor location in circuit

4.2.2 Ambient Light Rejection

The ambient light rejection circuit consists of a common emitter amplifier and the negative output of the differential amplifier pair. Its use in the circuit is to remove the DC voltage that is produced by the photo diode so that only the alternating current is detected. It is also used to minimize the parasitic capacitance that is associated with the physical construction of the photodiode. Figure 5 indicates the location of the ambient light rejection circuitry.

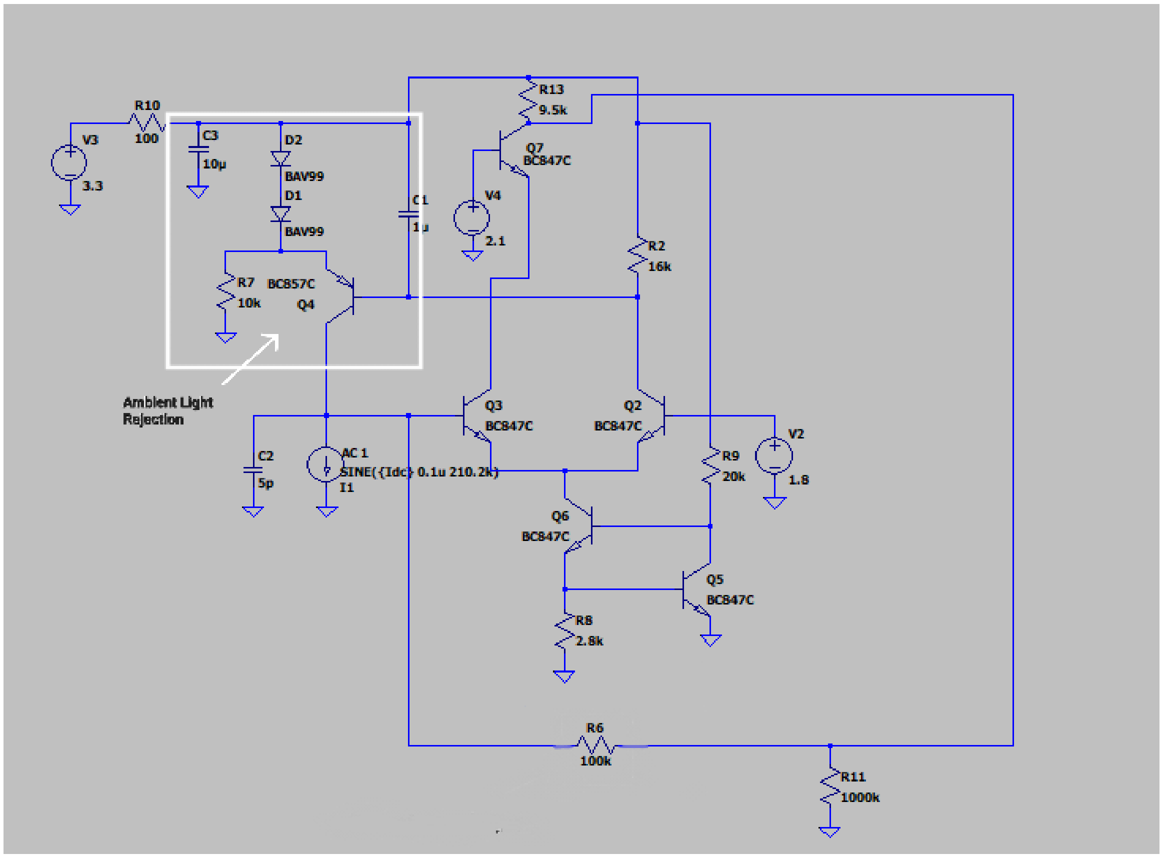


Figure 5. Ambient light rejection circuit

4.2.3 Cascode

The key change made to improve the bandwidth is changing the configuration of the output transistor, from a common emitter to a common base. The output transistor paired with the differential pair cause the amplifier to become a cascode type. The characteristics of the cascode is that this configuration allows for a large bandwidth, a relatively large gain, and can keep the voltage swing relatively large. The cascode allows for the larger band width since the common base is configured so that the parasitic capacitance known as the miller effect is eliminated. Figure 6 indicates the location of the cascode amplifier.

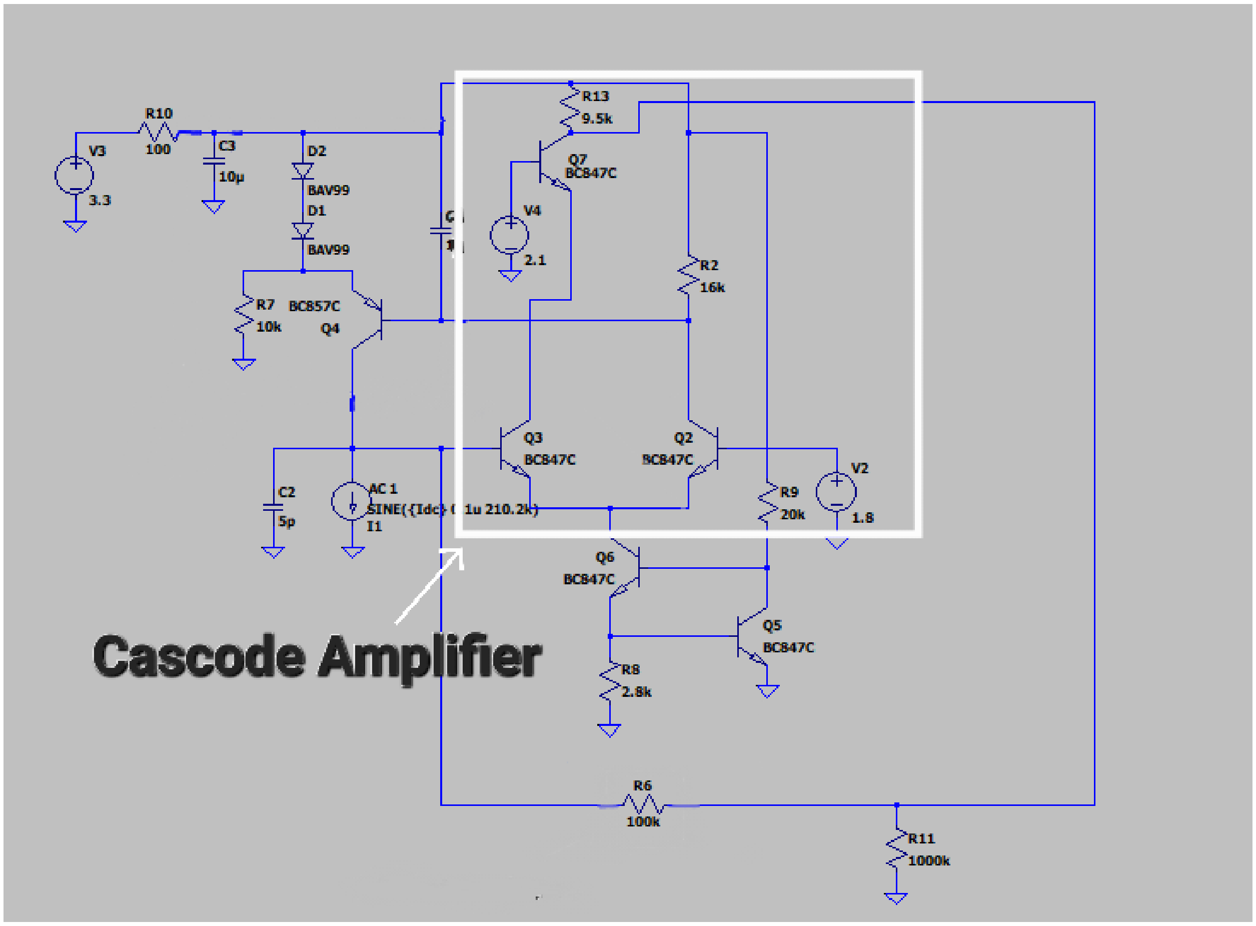


Figure 6. Cascode location in the amplifier circuit

4.3 Alternate Designs and Ideas

During simulation testing, other strategies and ideas were explored. Among these were the use of various transistors and shunt resistor values. As stated before, the resistance of the shunt resistor determines a level of constant gain. As its resistance increases, so does the constant gain, but at the expense of the bandwidth. Throughout the simulations the shunt resistor value was often changed but remained the same as the original in the improved circuit as the team felt it had the best balance.

Two different strategies were employed when searching for other transistors to test. The simulation software used, LTSpice, has many common small signal transistor models preloaded, which gave us a foundation to simulate and analyze the results. The other strategy was to find a transistor with a higher gain-bandwidth product and see if it would allow for a greater bandwidth without a loss in gain. The simulations, however, gave the opposite result. The only transistor which posed a possible improvement was the 2N3904, a transistor which is commonly used and even found (although at a different package size than the PCB) in the UVM labs. When simulated in the original circuit, this transistor gave a higher range for the bandwidth, however this was not the case when simulated in the improved design.

Working on the other circuits in the system the direct digital synthesizer (DDS) came into discussion, where the issue is that it requires eight stages to produce a sinusoidal wave with minimal harmonics. The idea that came up is to use switching capacitor filters and reduce the number of stages to four. This way the filter can move with the harmonic frequency which will better filter out the harmonics produced by the synthesizer. This also means that the VCO will not have to reach the lager frequencies that it will have to with its current design.

4.4 Design Process

The general design process used by the development team can be summed up with six steps:

1) Understanding the circuit

The team reads the description of the target circuit on betterbots.com, researches the concepts behind it, and meets with Mr. Walker to fill any gaps in the understanding of the circuit. Meeting with Mr. Walker was often the most useful action in this step as he has designed many of the circuits and can explain them with as much detail as needed.

2) Improving the circuit in simulation

The team, often with guidance from Mr. Walker, simulates the circuit on LTSpice. Different designs are experimented with, sometimes changing the schematic of the circuit, and sometimes just changing values of components.

3) Breadboarding the original circuit

To ensure the original circuit works outside a simulation, the team would often breadboard it and test it before manufacturing it. This, however, can be a time consuming step as it can take some time to gather the correct components, build the board, and troubleshoot it.

4) Manufacture the original circuit

The team uses EasyEDA to create the schematic, layout, and gerber files, which are sent to JLCPCB to be manufactured. It is important to send the layouts to the client for approval before submitting them to JLCPCB as components such as coupling capacitors may need to be added. Some important aspects of creating the PCBs are creating a ground plane, keeping components close to another, and labeling header pins. The board is then populated by the development team once the components and board are received. JLCPCB can populate the boards as well, however it increases the amount of time before the boards are received.

5) Manufacture the improved circuit

The team repeats the above process, but with the improved design. This step may be unnecessary if the only improvements to the circuit are changes in component values.

6) Testing and troubleshooting

With the original and improved circuit boards manufactured and populated, testing can begin. It is unlikely that the circuits will perform as expected the first time they are manufactured, especially if populated by the team. There are many areas in which mistakes can be made. It is valuable for the team to work with another and check each other's work to ensure fewer mistakes are made. Once the boards work as intended, measurements are made, and improvements are verified.

These steps do not necessarily need to be followed in that exact order as different steps may take varying amounts of time depending on the development team and the program they are in. It is important to reevaluate which steps are most important and require the most time and effort after each circuit is finished.

The prosses used to design the photodiode amplifier initial consisted of changing the value of the shunt resistor, this process resulted in a lower gain output, but the bandwidth did improve. The team found that the process did not produce optimal results, which led to implementing different transistors that have better bandwidth ratings, again this did not produce the desired effect. Following that other factors that affect the bandwidth were investigated, such as the input resistance of the second amplifier stage. The initial design had an emitter follower amplifier which has a low input resistance and drastically lowered the bandwidth. That is when the team started looking into different topologies and led to the discovery that a cascode amplifier has a large input resistance and a small capacitance. What this did was change it from a differential amplifier cascading into a follower emitter to a cascode amplifier topology.

They then settled on this topology and simulated it in LTSpice, where it proved to be a better option where it kept the gain and improved the bandwidth. The second step was to use a breadboard to build the circuit. The first issue was that a photoresistor was used, which had completely different properties than a photodiode. The build was thought to be a failure. Once a photodiode was implemented into the circuit and tested it, it worked as designed. Following the breadboard, the team created the PCB which was then populated. It was found that it worked to improve the bandwidth while keeping the same gain.

The design process for the VCO started out smoothly and became more difficult during the testing and troubleshooting phase. This was due to multiple reasons such as not spending enough time in the beginning to fully understand the circuit and a lack of communication and teamwork during the population of the board.

Improvements were made simply by changing the values of a few key components in the RC timer and discharge current control areas of the circuit. The team experimented with higher and lower values for each, recording the lowest and highest output frequencies for each change. Eventually, optimal values were found, and improvements were made. Given that the improvements were made purely in the values of components and not the design of the board, the same PCB layout could be used for both the original and improved circuits. This reduced the amount of time necessary for the manufacturing of the boards.

Difficulty came to the team once the first original board was populated and tested. It did not work as intended. Many ideas were explored, such as adjusting the ground voltage to the Schmitt trigger, the possibility of poor connections, and diodes facing the wrong direction. After much trial and error, as well as frustration to the team and client, it was found that the wrong ground transistor was used. After fixing this error, the VCO began to behave properly and the improved circuit could be populated.

5 <u>Design Evaluation</u>

5.1 Photodiode Amplifier Bandwidth

This analysis tests the bandwidth specification of the photodiode amplifier. The specification is shown below:

- The PD Amp shall have a lower cutoff frequency of 3 kHz
- The PD Amp shall have a higher cutoff frequency of 700 kHz

The bandwidth requirement was the most important requirement to meet, since the purpose of this circuit is to distinguish between the different flickering frequency of florescent and led lights. From previous research it the frequency of the flicker is from 60Hz to 1MHz [1]. The two factors that affect the bandwidth of the amplifier circuit are the inherent capacitance of transistors coupled with the input resistance of a cascading amplifier stages. With this a lower value capacitance would increase the bandwidth, or a lower input larger input resistance will increase the bandwidth. This led to adding a common base amplifier to the output of the differential pair, which turned the amplifier into a cascode configuration. The cascode is known for removing the miller capacitance and having a large input resistance. Both factors improved the bandwidth, which can be seen when comparing the results of the two circuits.

To test the bandwidth of the PD amplifier, the PD amplifier received a light input from a led that is connected to a function generator, and a box covers the whole assembly to remove the overhead light interference. The function generators frequency is increased from 10Hz until the output of the PD amplifier is less than 3mV.

5.1.1 Test Procedure

1. Connect a 3.3V power supply to the pd amplifier.
2. Place a white led into a bread board with a 10kΩ resistor.
3. Connect the function generator to the led circuit.
4. Apply a 1.2V dc offset to the, set the peak to peak voltage to 9V
5. Set the frequency to 10Hz.
6. Attach a set of oscilloscope probes to the output of the PD amplifier.
7. Cover the setup to block out the overhead lights.
8. Increase the frequency of the function generator until a sine wave output can be seen of the oscilloscope that matches the frequency of the function generator.
9. Take the frequency and amplitude of the output signal.
10. Increase the frequency logarithmically and measure the frequency and amplitude of the output.

11. Repeat step 10 until the max amplitude is found then divide the max amplitude by the square root of 2 and continue until that amplitude is found, record the frequency at which that amplitude occurs.

5.1.2 Pass Criteria

To pass the lower frequency cutoff needs to be 3kHz or less and the upper cutoff frequency needs to be 700kHz or greater.

5.1.3 Results

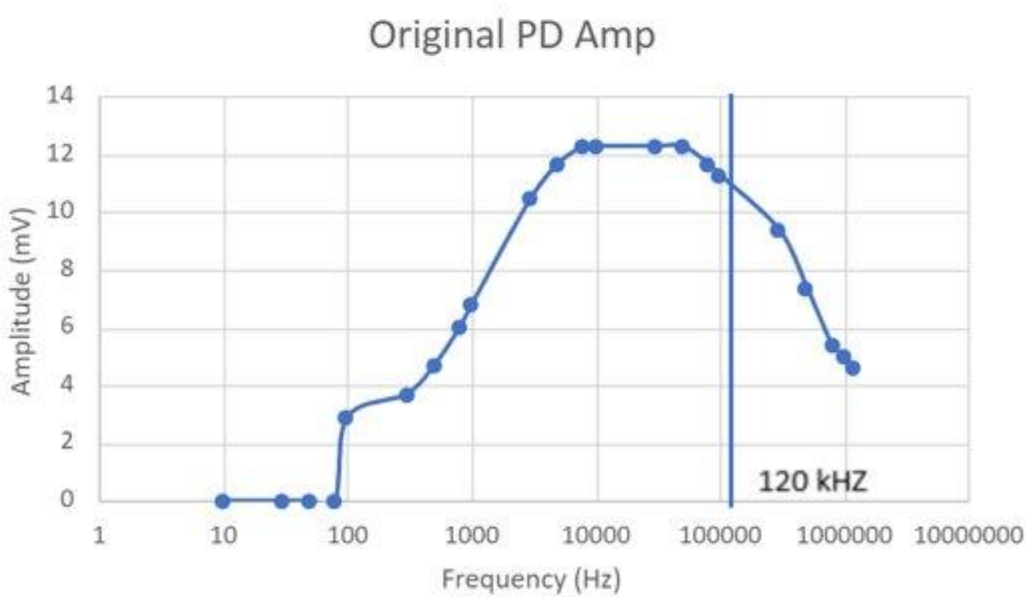


Figure 7. Original photodiode amplifier bandwidth

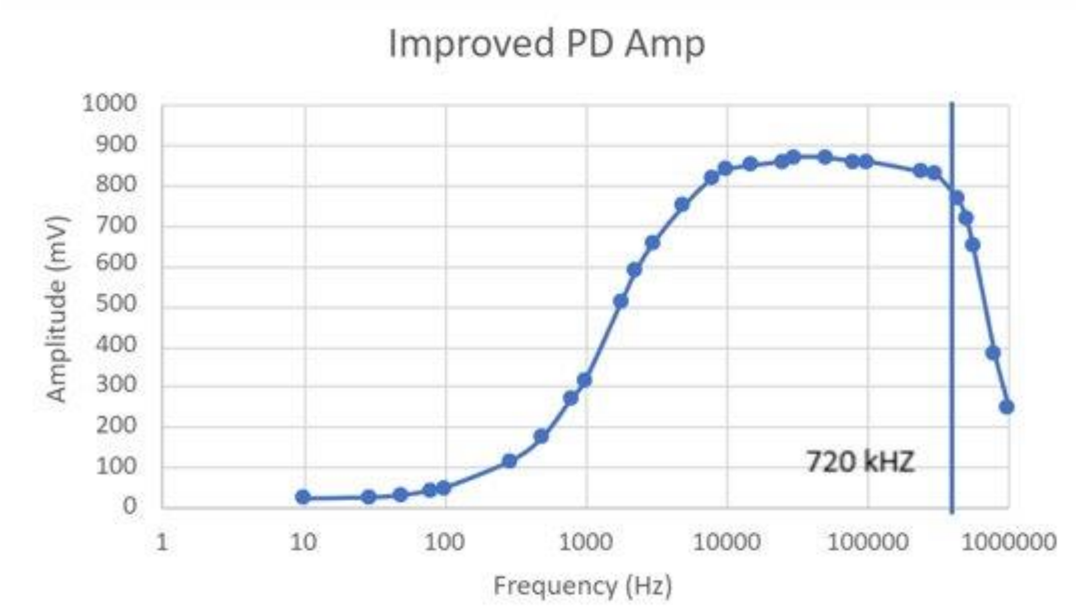


Figure 8. Improved photodiode amplifier bandwidth

Figure 7 shows the bandwidth for the original photodiode amplifier where the lower cutoff frequency is 2kHz, and the upper cutoff frequency is at 120kHz. Figure 8 shows the improved photodiode amplifier bandwidth, with a lower cutoff frequency at 2.5kHz and an upper cutoff frequency of 720kHz. The amplitude of the graphs are different due to the test setup using different led at slightly different distances, but that is not an important factor in this analysis. The comparison of the two graphs indicates that the improved photodiode amplifier design improves the bandwidth which means that more frequency of light flicker can be analyzed by the circuit.

5.2 VCO Bandwidth

This analysis uses LTspice to determine the range of frequencies that can be output by the Voltage Controlled Oscillator. The program applies different control voltages to the input and detects the frequencies that are output. The highest and lowest are recorded. The specification being analyzed is that the improved VCO bandwidth shall have a lower frequency of 150kHZ and an upper frequency of 10MHz.

5.2.1 Analysis

The following circuit is analyzed (Figure 9).

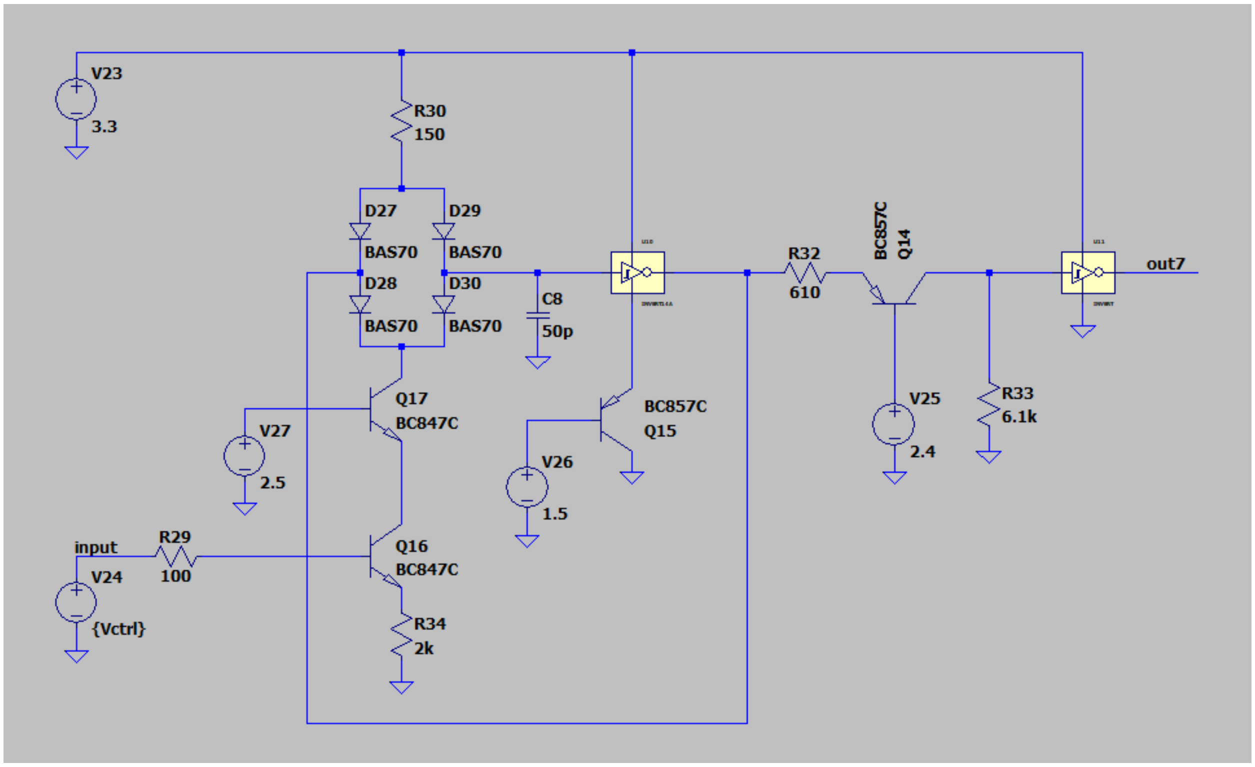


Figure 9. Schematic of the Improved VCO in LTspice

The following graph (Figure 10) shows the highest frequency (blue) and the lowest frequency (green) output by the range of voltages shown in the initial conditions. The voltages are applied to "{Vctrl}" and measurements are taken at "out7" (Figure 9).

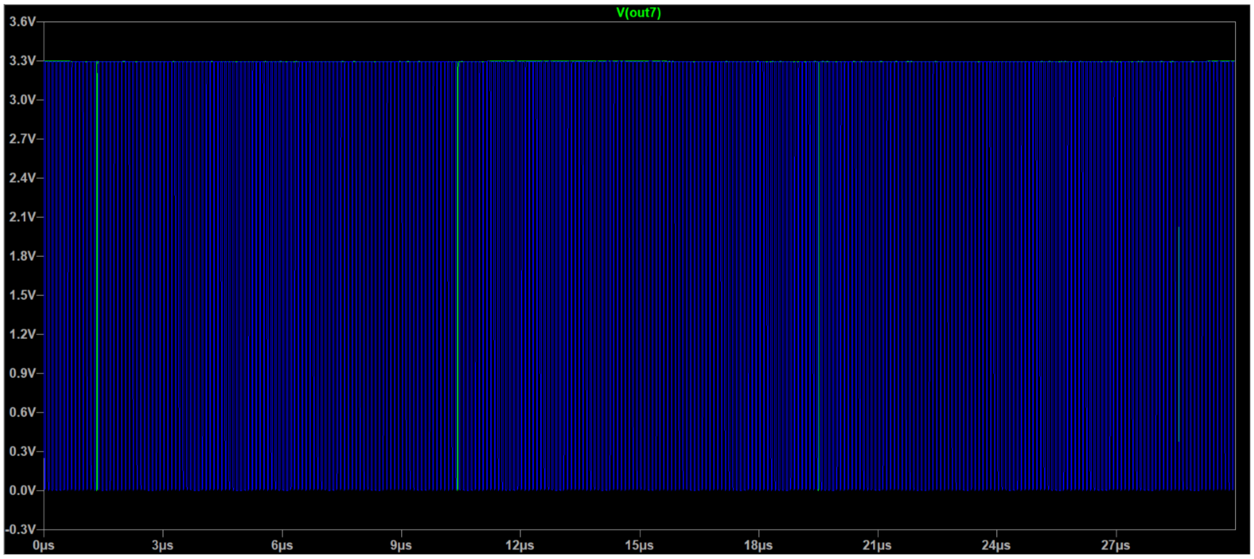


Figure 10. VCO Frequencies

5.2.2 Pass Criteria

The original VCO design had a bandwidth of about 3.12MHz, centered on 1.6MHz. To pass, the new design must have a bandwidth about twice that size and be centered on a value close to the average signal that will be output. The value being used as the average flicker of a lightbulb is 200KHz. This is multiplied by 32 (a step needed for the DDS, the following circuit in the sensor) to result in a center of around 6MHz.

From this information, the team determined that the passing criteria of the VCO is

- Lower Limit: 150KHz
- Upper Limit: 10MHz

5.2.3 Results

The results from the analysis are shown in Figure 11.

```
Measurement: out7_freq
  step      1/out7_period
     1      110092
     2      1.03309e+007
```

Figure 11. Simulated Frequencies

Judging from these results. The pass criteria are met.

Lower Limit: 110KHz < 150KHz
Lower Limit: 10.3MHz > 10MHz

5.3 Distance Analysis

This analysis tests two specifications of the photodiode amplifier:

1. The photodiode amplifier can detect classroom lights 3 meters away and output a usable signal.
2. The photodiode will output an accurate frequency regardless of its distance from the light (up to 3 m).

5.3.1 Test Procedure

Set Up

1. Connect power supply to power and ground pins of circuit.
2. Connect oscilloscope test probe to output and ground pins.
3. Turn on the oscilloscope and power supply.
4. Set power to 3.3 V.

5. Set oscilloscope to measure frequency and peak to peak amplitude. Ensure probe is set to 10x.
6. Turn on power supply output and make sure frequency and amplitude are detected in oscilloscope.
7. Turn off power supply output and begin the test procedure.

Test Procedure

1. Measure the desired distance from the light and secure photodiode amplifier there. The first distance in this test is 1 m, followed by 1.5, 2, 2.5, and 2.69 m. 2.69 m is the furthest the circuit could be moved from direct light.
2. Turn on power supply output.
3. Use scaling and trigger knobs on the oscilloscope to obtain the wave output from the circuit.
4. Record frequency and amplitude displayed on the oscilloscope.
5. Dim lights by 1 setting and record the new frequency. The lights used to conduct this test are dimmed with buttons. Pressing a button once changes the light by one setting.
6. Repeat step 5 three more times and return light to original brightness.
7. Turn off power supply output to circuit.
8. Repeat steps 1-7 for each desired distance.

5.3.2 Pass Criteria

To pass this test, the results must stay within multiple bounds:

1. All recorded frequencies at the same light intensities must be within 2% of another.
2. Output amplitude at 3 m must be usable.

For an output amplitude to be usable, it must be larger than the sum of the amplitude with no input, the noise from the oscilloscope, and the noise from the circuit.

The amplitude with no input was found by simply covering the photodiode amplifier and recording the amplitude. It was found to be 24 mV. The noise from the oscilloscope was determined to be 4.7 mV. The noise from the circuit can be calculated by 195nV/sqrt(frequency). This noise is so small it is negligible in this situation. Therefore, for an output amplitude to be usable, it must be over 28.7 mV.

5.3.3 Results

Table 2. Test Data

	Frequency (kHz)						Amplitude (mV)
Distance							@127 Hz
1	107	112	117	122	128		285
1.5	106	112	117	122	127		169
2	107	112	117	122	127		133
2.5	107	112	116	122	127		96
2.69	107	112	117	123	127		84

Table 2 displays the frequency detected at each light intensity, along with the amplitude at each distance. It can be clearly seen that as the largest difference between frequencies at each light intensity is 1 kHz, the difference is never greater than 2%. This shows that within this distance, the circuit gives consistent data. The amplitudes also remained well over 28.7 mV.
The only issue with this test is that the circuit could not be conducted at 3 m or more. To show that the circuit will have a usable output at 3 m, a graph was constructed (Figure 12).

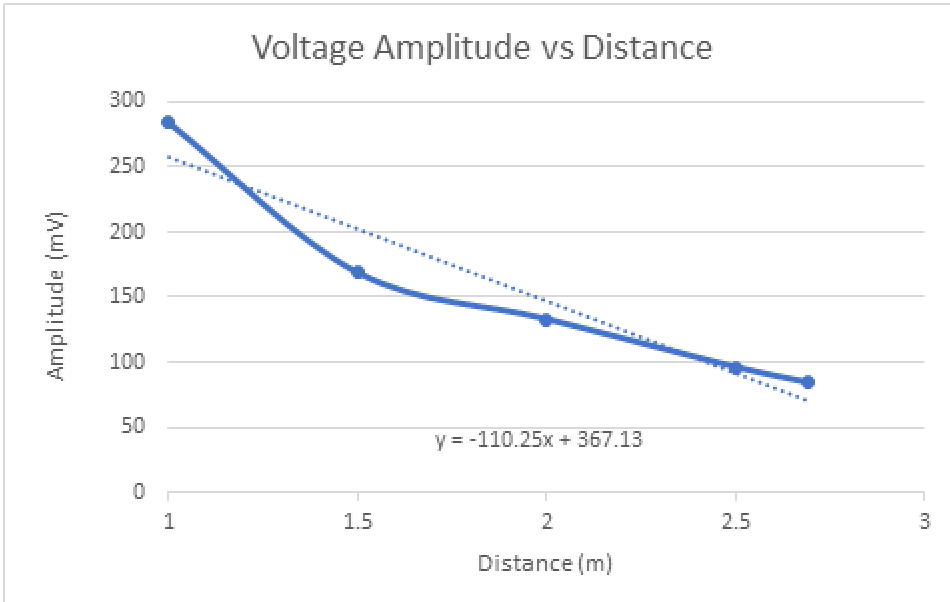


Figure 12. Voltage Amplitude vs Distance from Light

This graph shows the amplitude at each distance from the light. A linear trend line is displayed to estimate the amplitude at 3 m. A linear trendline was used because it will underestimate the output at 3 m. Using the formula for the trendline, the output amplitude at 3 m will be 36.38 mV, which is over 28.7 mV, passing the test.

5.4 Engineering Specifications

The circuit designs passed 100% of the engineering specifications. These include those covered in the analyses above, as well as the price to manufacture the board, the size of the board, the sustainability of the components, and more.

Engineering Specifications					**Results**			
ID	**Relative Weight**	**Engineering Specification**	**Units**	**Notes**	**Verification Method**	**Verification Result**	**Verification Status (Pass/Fail/Not Verified)**	**Notes**
10	8%	PD Amp shall not cost more than $20 to manufacture	$		Engineering Analysis	$10.71	**Pass**	
20	6%	Area of board shall be 0.875 square inches with a width of atleast 0.507in	Inch		Inspection	A = 0.859 in, w = 0.788 in	**Pass**	

30	12%	Componet packages shall be SOT 32, 603, and SOT 363			Inspection		**Pass**	
40	21%	Lights shall be detected within 3 meters	m		Test		**Pass**	
50	14%	The light sensing circuit shall have an upper frequency of 700kHz and a lower frequency of 3kHz	Hz		Test	720 kHz	**Pass**	
60	7%	Gain shall remains above 95 dB	dB		Test	95 dB	**Pass**	
70	1%	Board shall consumes less than 1.65 W	W		Test	5.148 mW	**Pass**	
80	4%	100% of parts shall be Complient with RoHS			Inspection		**Pass**	
90	4%	The DDS shall reduce the harmonic frequency by 10dB compared to the fundamental frequency	dB		Engineering Analysis	Harmonics are 21dB lower than fundemental frequency	**Pass**	
100	8%	The VCO bandwidth shall have a lower frequency of 150kHZ and an upper frequency of 10MHz	Hz		Engineering Analysis	LL: 110 kHz UL: 10.3 MHz	**Pass**	
110	3%	Components shall not reach 45 °C at operating power	degrees C		Engineering Analysis	BAV99 :2.145°+ambient BC847C: 1.50°+ambient BC857C: 2.68°+ambient 0603: 0.27°+ambient	**Pass**	
120	3%	There shall be no exposed copper with a voltage over 60 V	V		Inspection		**Pass**	
130	8%	Current shall not reach .1 A	A		Test		**Pass**	
140								
Total	**100%**					**Relative Pass %**	**100%**	

6 Project Reflection

6.1 Retrospective

Throughout the year, the team used a SCRUM style of project management and meeting. This means the team works in sprints that last three weeks. The goal of each sprint is to have a physical increment, showing the progress made in the project during that sprint. Each time the team meets, they start with a scrum huddle, where they discuss the work each member has completed and what they need to complete before the end of the sprint. At the end of the sprint, the team would review what was able to be completed, and then plan the next sprint based on this knowledge. This style benefited the team because it allowed them to observe what work could be done during a sprint and what steps slow down the process the most. One example of this was the ordering process. The ordering process could take almost the length of an entire sprint. If the team was to hope to complete a PCB board for a sprint, orders would have to be placed either on the first day of the sprint or even before the sprint. Using this information, the team could make an assumption as to whether or not it is worth it to attempt to complete a board as the sprint increment, or if they should focus on the improvement or testing of a board instead. The ordering process would still be done during that sprint, but the board would not be completed until the next sprint. This, however, shows the weakness of the SCRUM style for this team. A three week sprint was too short to be effective as it was near impossible for a board to be manufactured during this time. With the acceptance that the board could not be the sprint's increment, focus would shift elsewhere in the project and the board would be delayed more.

After each sprint, the team reflected on what worked well within the team, what needed work, and what the team could change to make it function better. The most useful of these was the decision to switch to a hybrid meeting model. The team met on Mondays, Wednesdays, and Fridays. This change meant that on Mondays and Wednesdays, the team would meet online to talk about what work had been done since last meeting and what needs to be done before the next. The team could discuss hurdles and difficulties in each member's independent work as well as where they are finding success. These meetings would generally be quick before the team went back to working independently. On Fridays, the team would come together in a lab to test the circuits that had been worked on during the week. This model of meeting allowed the team to know what to expect from each meeting. Instead of meeting each day and spending time trying to figure out what the meeting would entail, the team could come to the meetings focused and prepared.

6.2 Open Issues and Recommended Actions

Below is a list of issues and concerns of the circuits. Each issue has at least one recommended action in the list below this one. The list is organized from most important to least important.

6.2.1 Open Issues

i. Lack of physical testing on VCO, DDS, and PLL circuits
ii. Lights may be further than 3 m away from sensor
iii. Circuits have not been connected

6.2.2 Recommended Actions

The following recommended actions directly relate to the open issue that shares its number.

i. More testing shall be conducted on VCO, DDS, and PLL circuits.
ii. Another gain stage should be added to the PD Amp to increase the distance at which it can detect lights.
iii. The completed circuits shall be connected to another and tested to ensure their compatibility.

6.2.3 Satisfaction

Throughout the year, both the client and development team were happy with the progress, manufacturing, and improvement of the circuits. At first, the team became frustrated as delays in manufacturing slowed down the process. They felt as though more circuits could have been manufactured had these delays been quelled. In the second semester, the client began to share that feeling. Overall, the development team and client are happy that most of the circuits could be improved, all the boards were manufactured, and half of them could be tested.

6.3 Budget

The total budget for this project is $500, the total cost of the project is $285.35 and there is $214.65 remaining. The circuit components cost $131.75 and the PCB board cost $153.6. This project successfully controlled the budget. The way to control the budget is to analyze the minimum value of electronic components required for each board among others. When ordering a new board, analyze whether there are enough electronic components available. Since some boards are soldered with leftovers such as resistors and capacitors, use all electronic components as fully as possible. In this way we can better control the budget. The list of all expenses has been attached in the next section. On the list of expenses section, the shipping cost will be covered by the UVM seed program. (Note: The actual cost is the total cost of this project.)

6.4 Lessons Learned

The first lesson learned from this project is communication, specifically communicating expectations of all team members, especially when it comes to who will work on what aspect of the project and when the expected completion time is. Since the team did not do this, it led to many late nights editing the work so that it would be acceptable for turn in, along with delaying the project since the team was required to send the printed circuit boards out to be manufactured. The best advice is to have teams start a plan at the beginning that sets up expectations for all members and when assignments should be submitted to the team for review.

The second lesson is to have an eye for detail, especially when it comes to critical components of the design. Where the team went wrong is that some of our boards were sent out with incorrect component layout, which led to many hours trying to fix the problem delaying the testing and asking for help from other individuals. The best advice for future students is to have a second pair of eyes look over the design before it is sent out to be manufactured.

7 **References**

[1]

M. Hauske and F. K. Jondral, "Characterization of wireless optical indoor channels," in *2010 Photonics Global Conference*, Orchard, Singapore: IEEE, 2010, pp. 1–5. doi: 10.1109/PGC.2010.5705968.

[2]

http://www.betterbots.com/ (Accessed Apr. 25, 2023).

[3]

G. E. Schmidt, "Photodiode amplifier," CA2580297C, Jan. 03, 2012 Accessed: Apr. 25, 2023. [Online]. Available: https://patents.google.com/patent/CA2580297C/en?q=(photodiode+amplifier)

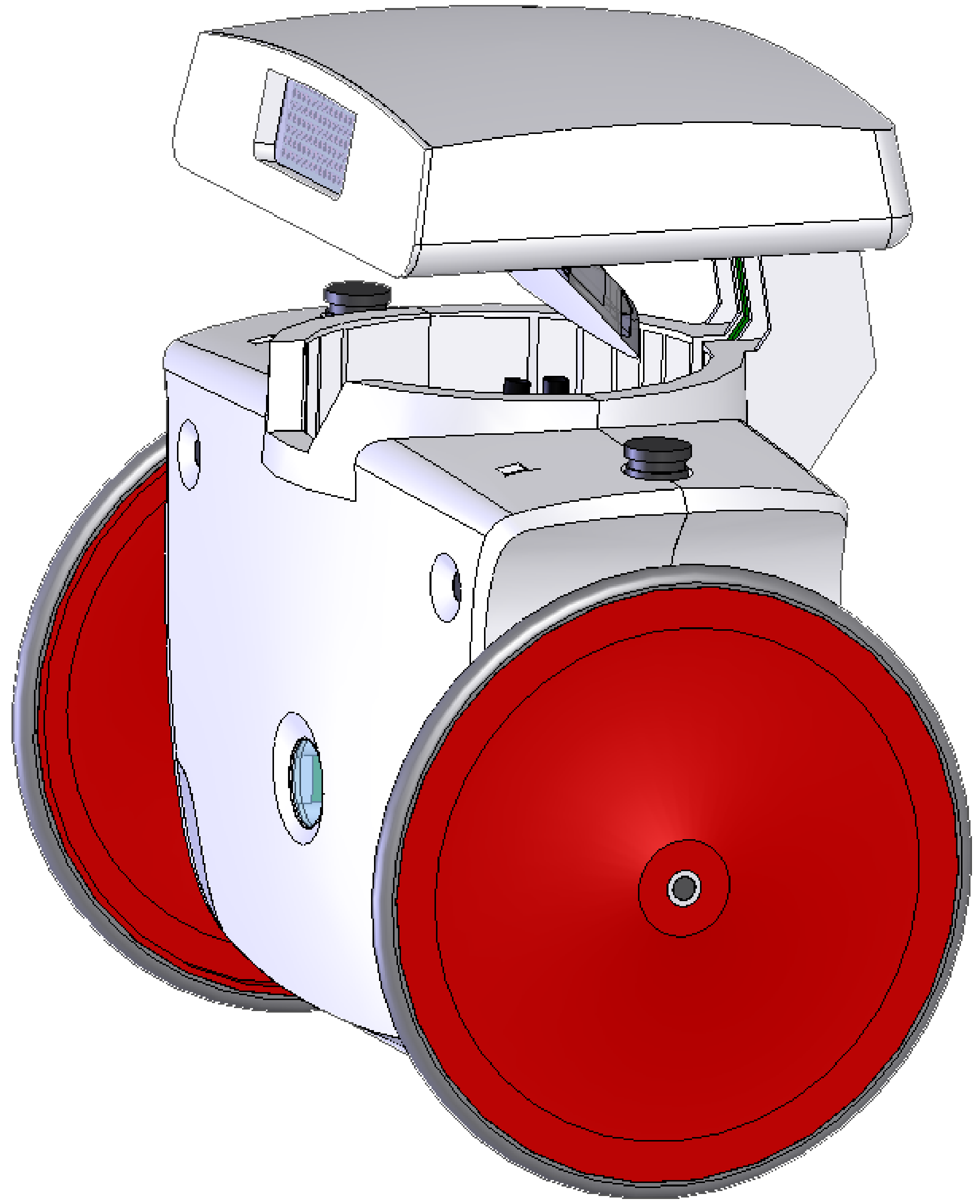
8 List of Expanses

Order ID	Vendor	Catalog Number	Quantity	Unit Price	COST
2698	Mouser	963-JMK107ABJ106MA-T	20	$0.05	$0.92
2699	Mouser	755-SDR03EZPF1000	20	$0.13	$2.54
2700	Mouser	755-SDR03EZPF1000	20	$0.13	$2.54
2702	Mouser	583-BAV99	20	$0.18	$3.66
2703	Mouser	963-EMK107B7105KAHT	20	$0.04	$0.86
2704	Mouser	755-SFR03EZPF9101	20	$0.10	$1.96
2705	Mouser	755-SFR03EZPF1602	20	$0.10	$1.96
2706	Mouser	71-CRCW060320K0FKEAC	20	$0.04	$0.72
2707	Mouser	621-BC847C-7-F	20	$0.19	$3.84
2708	Mouser	755-SFR03EZPF1002	20	$0.12	$2.50
2709	Mouser	621-BC857CW-7-F	20	$0.19	$3.84
2710	Mouser	755-SFR03EZPF1102	20	$0.10	$1.96
2711	Mouser	863-SBC847BDW1T1G	20	$0.35	$7.06
2712	Mouser	652-CR0603FX-1332ELF	20	$0.03	$0.60
2713	Mouser	652-CR0603FX-1332ELF	20	$0.03	$0.60
2714	Digi-Key	475-2659-2-ND	10	$0.73	$7.30
2715	Mouser	80-C603C104K5RAC3121	20	$0.09	$1.84
2716	Mouser	652-CR0603FX-2801ELF	20	$0.03	$0.66
2717	Mouser	667-ERJ-3EKF1003V	20	$0.05	$0.98
2814	Mouser	963-JMK107ABJ106MA-T	10	$0.05	$0.46
2815	Mouser	963-JMK107ABJ106MA-T	10	$0.05	$0.46
2816	Mouser	963-EMK107B7105KAHT	10	$0.04	$0.43
2817	Mouser	963-EMK107B7105KAHT	10	$0.04	$0.43
2818	Mouser	80-C603C104K5RAC3121	10	$0.09	$0.92
2819	Mouser	583-BAV99	10	$0.18	$1.83
2832	Digi-Key	475-2659-2-ND	10	$0.73	$7.31
2833	Mouser	621-BC847C-7-F	10	$0.19	$1.92
2834	Mouser	621-BC857CW-7-F	10	$0.19	$1.92
2835	Mouser	863-SBC847BDW1T1G	10	$0.35	$3.53
2836	Mouser	755-SDR03EZPF1000	10	$0.13	$1.27
2837	Mouser	755-SFR03EZPF1002	10	$0.12	$1.25
2838	Mouser	755-SFR03EZPF1002	10	$0.12	$1.25
2839	Mouser	652-CR0603FX-9531ELF	10	$0.03	$0.34
2842	Mouser	652-CR0603FX-9531ELF	10	$0.03	$0.34
2843	Mouser	755-SFR03EZPF1602	10	$0.10	$0.98

2844	Mouser	652-CR0603FX-2801ELF	10	$0.03	$0.33
2845	Mouser	71-CRCW060320K0FKEAC	10	$0.04	$0.36
2846	Mouser	667-ERJ-3EKF1003V	10	$0.05	$0.49
2847	Mouser	755-SDR03EZPJ105	10	$0.10	$0.98
2848	Mouser	652-CR0603FX-7501ELF	10	$0.02	$0.17
2849	Mouser	652-CR0603FX-1332ELF	10	$0.03	$0.30
2850	Mouser	755-SFR03EZPF1102	10	$0.10	$0.98
2851	Mouser	963-EMK107B7105KAHT	10	$0.04	$0.43
2852	Mouser	963-HMK107SD101KA-T	10	$0.28	$2.78
2853	Mouser	963-EMK107B7105KAHT	10	$0.04	$0.43
2854	Mouser	78-BAS40-02V-G3-08	10	$0.25	$2.46
2855	Mouser	621-BC847C-7-F	10	$0.19	$1.92
2856	Mouser	755-SFR03EZPJ621	10	$0.10	$0.98
2857	Mouser	755-SFR03EZPJ621	10	$0.10	$0.98
2858	Mouser	652-CR0603FX-6651ELF	10	$0.03	$0.33
2859	Mouser	652-CR0603FX-2102ELF	10	$0.03	$0.33
2860	Mouser	755-SFR03EZPJ302	10	$0.08	$0.75
2861	Mouser	755-SFR03EZPF1102	10	$0.10	$0.98
2862	Mouser	755-SFR03EZPF9101	10	$0.10	$0.98
2863	Mouser	652-CR0603FX-8251ELF	10	$0.03	$0.32
2864	Mouser	755-SFR03EZPJ223	10	$0.08	$0.75
2865	Mouser	755-SFR03EZPF6201	10	$0.10	$0.98
2866	Mouser	771-74LVC1G14GW-Q100	5	$0.37	$1.85
3272	Mouser	603-CC0603JRNP9BN500	10	$0.07	$0.74
3273	Mouser	755-SFR03EZPJ151	10	$0.08	$0.75
3274	Mouser	755-SFR03EZPF2001	10	$0.12	$1.25
3383	Mouser	963-JMK107ABJ106MA-T	10	$0.04	$0.44
3384	Mouser	810-C1608JB1E155K08B	10	$0.10	$1.01
3385	Mouser	810-CGA5L1X7R1E685KC	10	$0.41	$4.10
3386	Mouser	810-C1608X7R1H334K	10	$0.10	$1.01
3387	Mouser	595-SN74LVC74ADBR	5	$0.48	$2.41
3388	Mouser	621-74LVC04AT14-13	5	$0.38	$1.91
3389	Mouser	621-74LVC273AT20-13	5	$0.57	$2.86
3390	Mouser	603-RP0603BRD071K5L	10	$0.29	$2.87
3391	Mouser	594-MCT0603MD4990DP5	10	$0.27	$2.72
3392	Mouser	603-AC0603FR-131KL	10	$0.02	$0.22
3393	Mouser	603-RC0603FR-07100RL	10	$0.02	$0.18
3394	Mouser	71-CRCW0603768RFKEAC	10	$0.04	$0.39
3395	Mouser	652-CR0603FX-1132ELF	10	$0.03	$0.33

3396	Mouser	603-RP0603BRE072KL	10	$0.28	$2.79
3397	Mouser	603-RC0603FR-13140RL	10	$0.02	$0.25
3398	Mouser	652-CR0603FX-5622ELF	10	$0.02	$0.18
3399	Mouser	71-CRCW0603-13.3K-E3	10	$0.04	$0.42
3400	Mouser	71-CRCW0603-13.3K-E3	6	$0.04	$0.25
3401	Mouser	603-RP0603BRD0720KL	10	$0.29	$2.87
3402	Mouser	80-C0603C162F4HAUTO	10	$0.24	$2.45
3403	Digi-Key	1727-7319-2-ND	10	$0.17	$1.73
3404	Digi-Key	1727-7319-2-ND	10	$0.17	$1.73
3405	Digi-Key	BC847B-7FDITR-ND	10	$0.18	$1.85
3406	Digi-Key	1727-1139-2-ND	10	$0.13	$1.28
Total cost of components					$131.75
PCB Cost					
Order	Vendor	Catalog	Quantity	Cost	
2867	JLCPCB	W202301272058861	1	$41.80	
2972	JLCPCB	Y51-3459112A	1	$41.80	
3324	JLCPCB	Y63-3459112A	1	$70.00	
Total cost of PCB				$153.60	

Team 29 - Betterbots Mr. Ohm Improved Circuitry



Kyle Lambert
Cole O'Shaughnessy
Lindi Hang

College of Engineering and Mathematical Sciences
University of Vermont

April 20, 2022

The UNIVERSITY of VERMONT

Client

Daniel Walker

CEO Betterbots

BETTERBOTS :)

Mentor

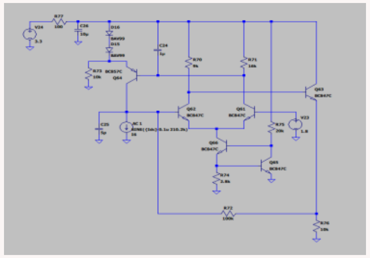
Dr. James Kay

Professor of Electrical Engineering, UVM

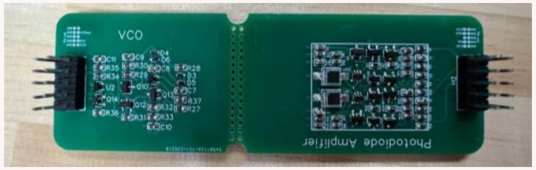
The University of Vermont

ELECTRICAL ENGINEERING

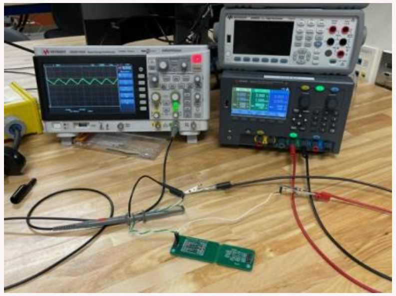
This presentation focuses on our team's work on improving, manufacturing, and testing circuits in the educational robot, Mr. Ohm.



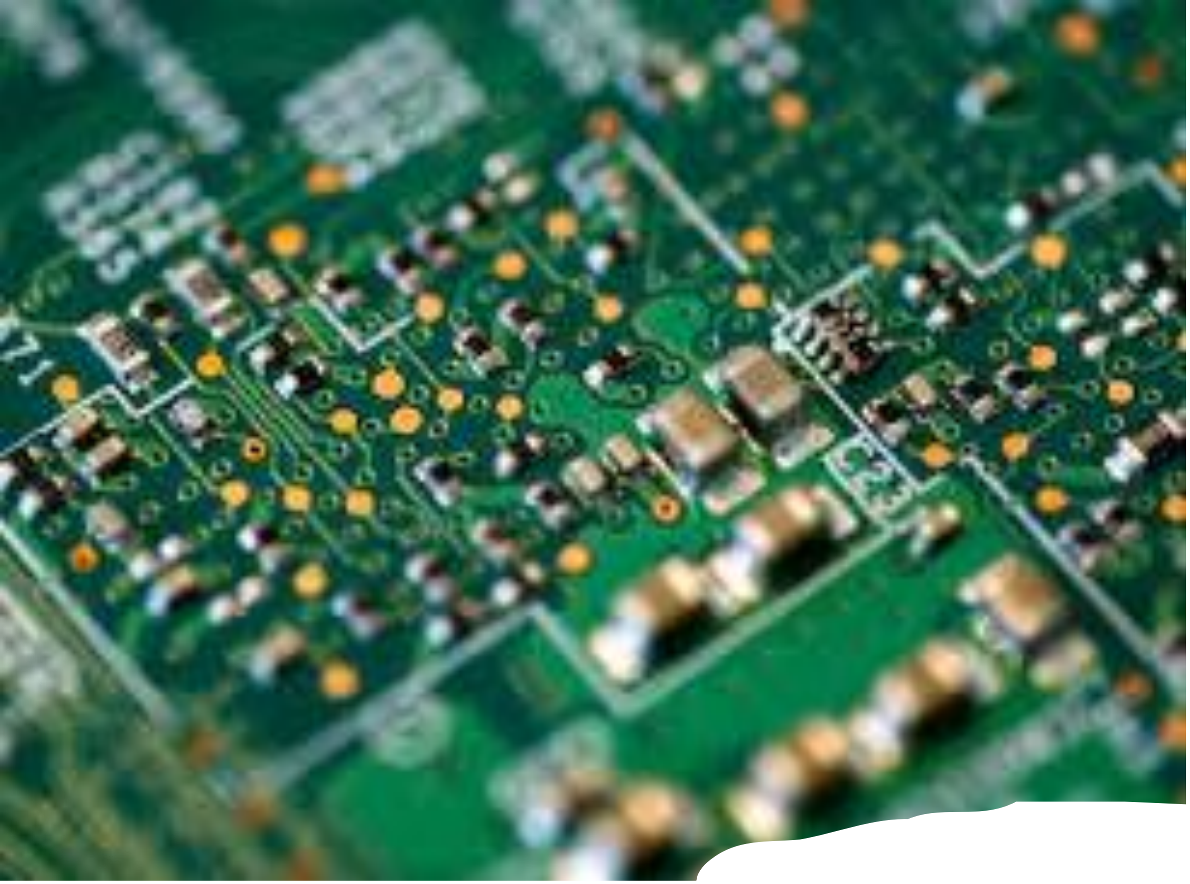
Problem

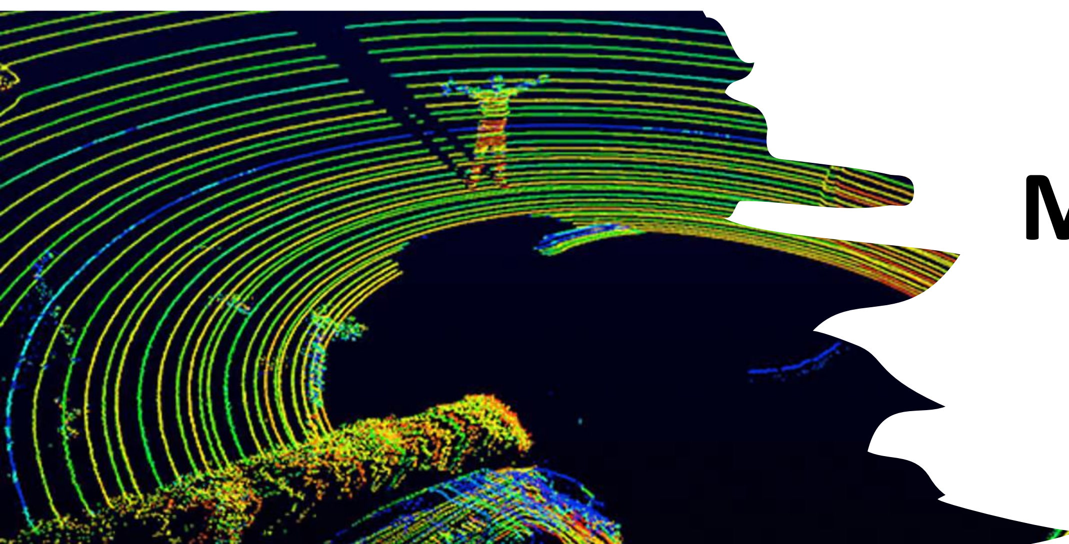


Designs



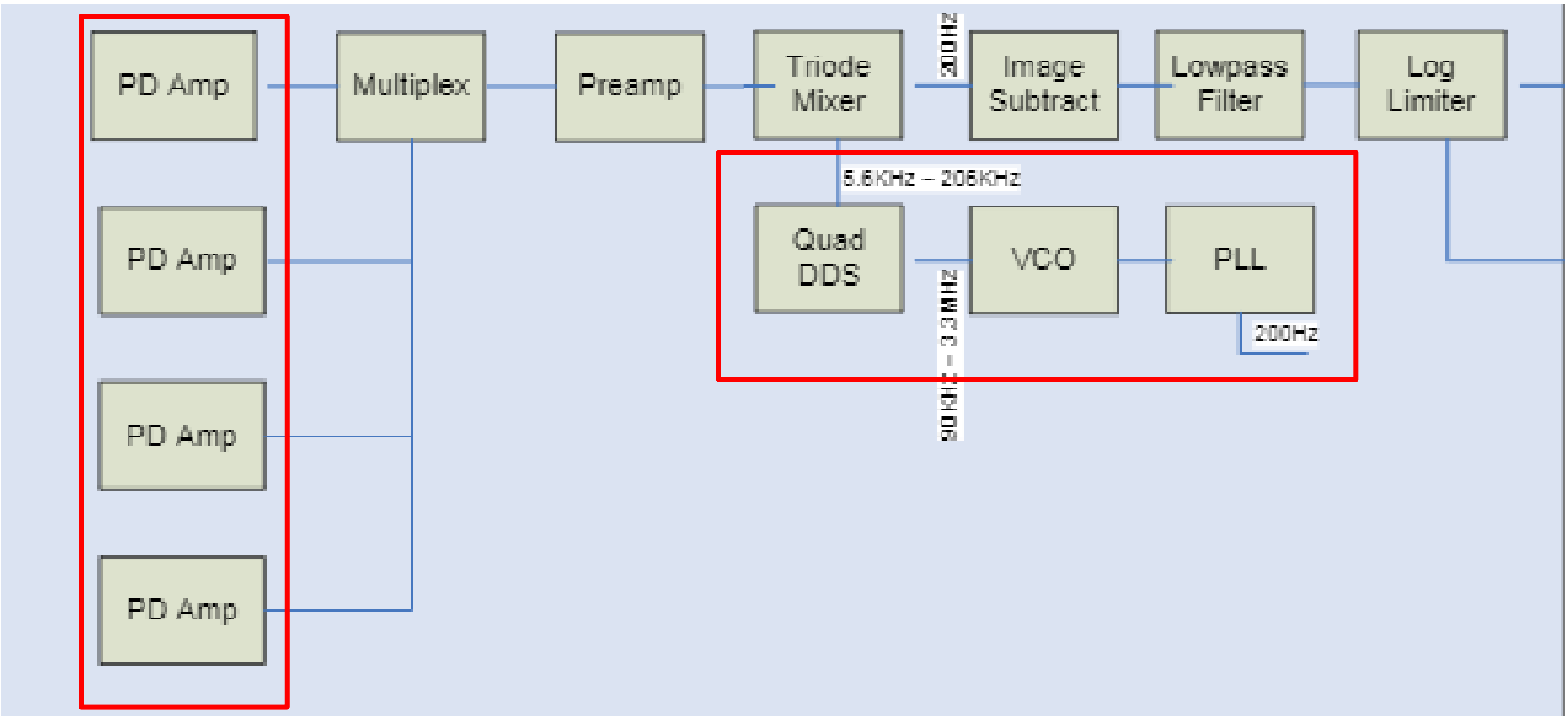
Testing





Mr. Ohm

Fluorescent Light Direction Finding Sensor

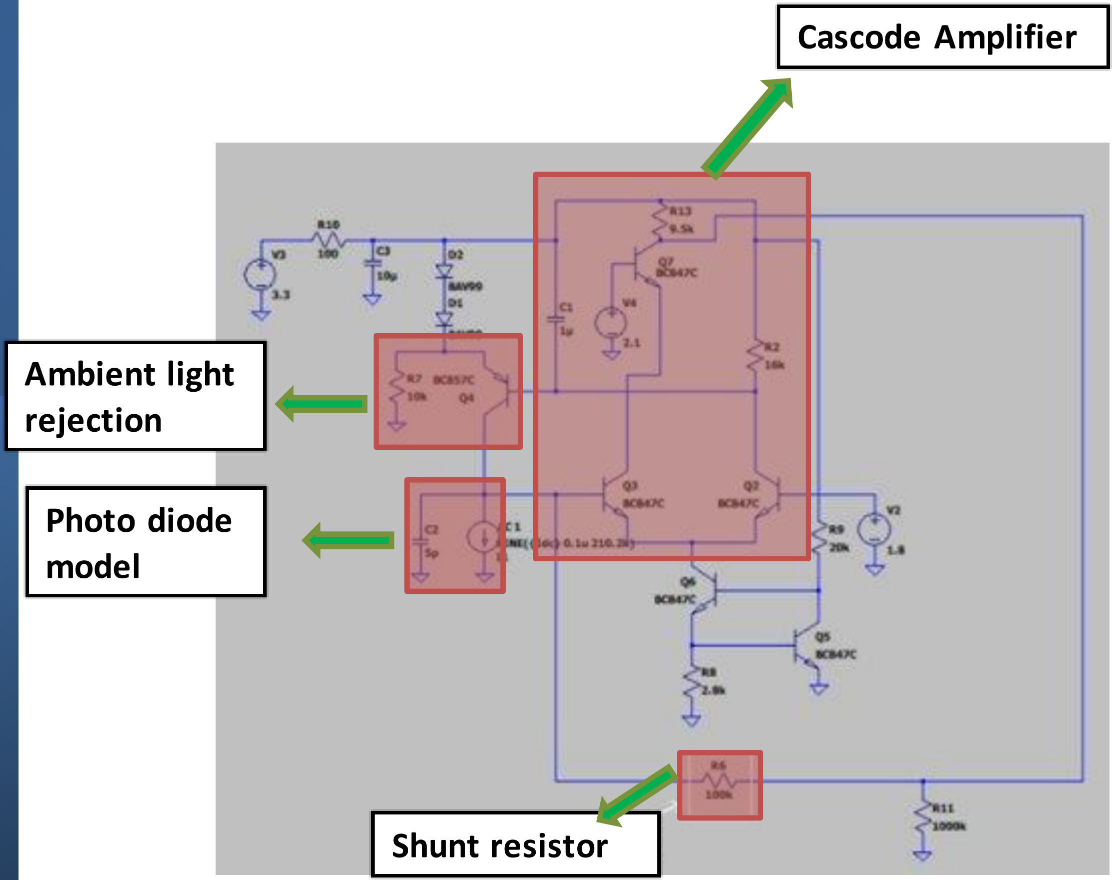


The Problem

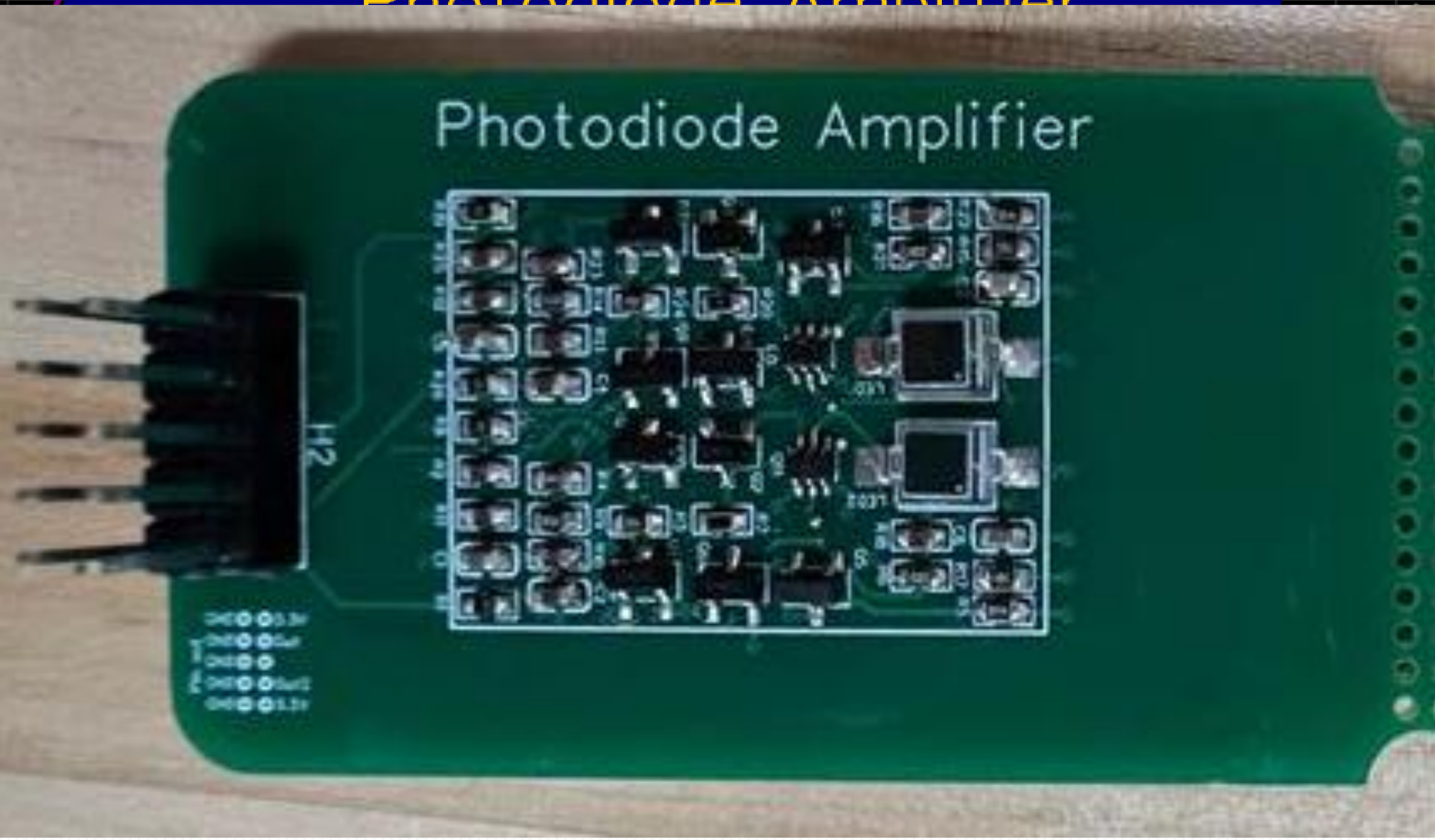
Bandwidth	**Over 700 kHz**
Gain	**Remains above 95 dB**
Distance	**Usable output 3 m away**

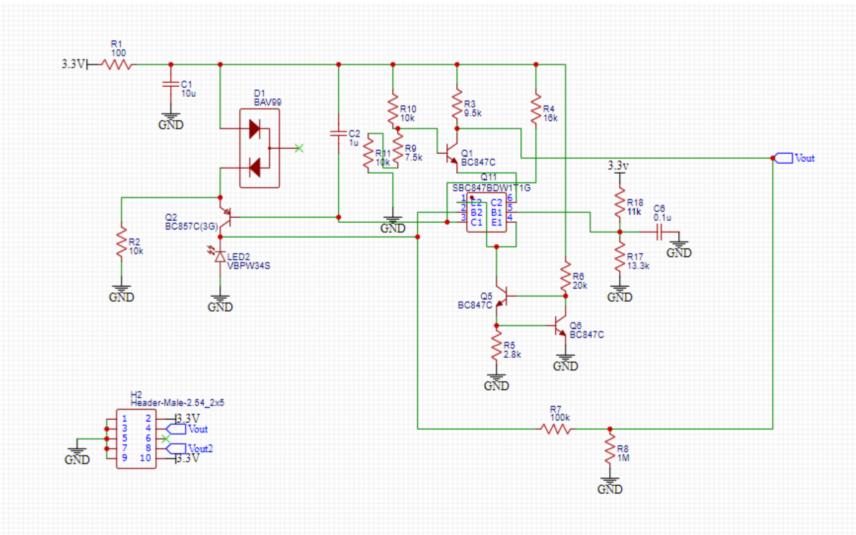
The Designs

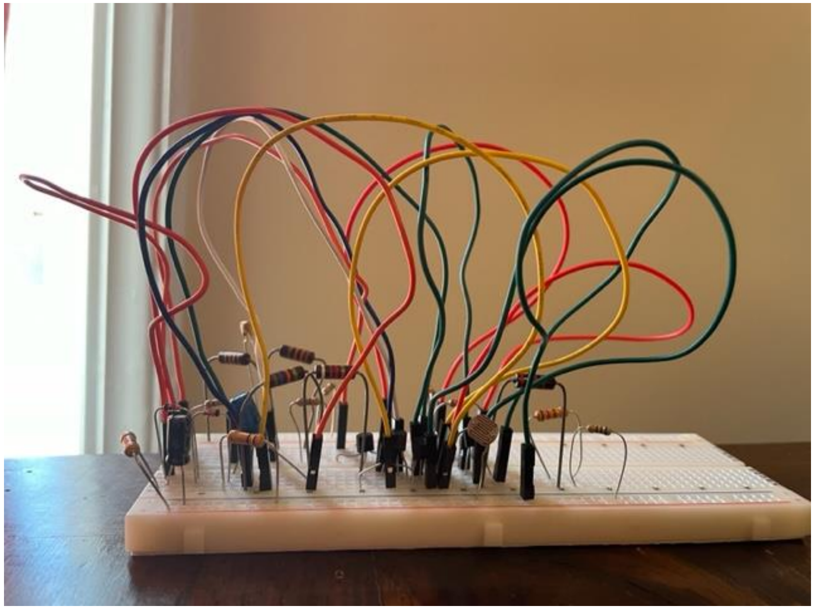
Photodiode Amplifier

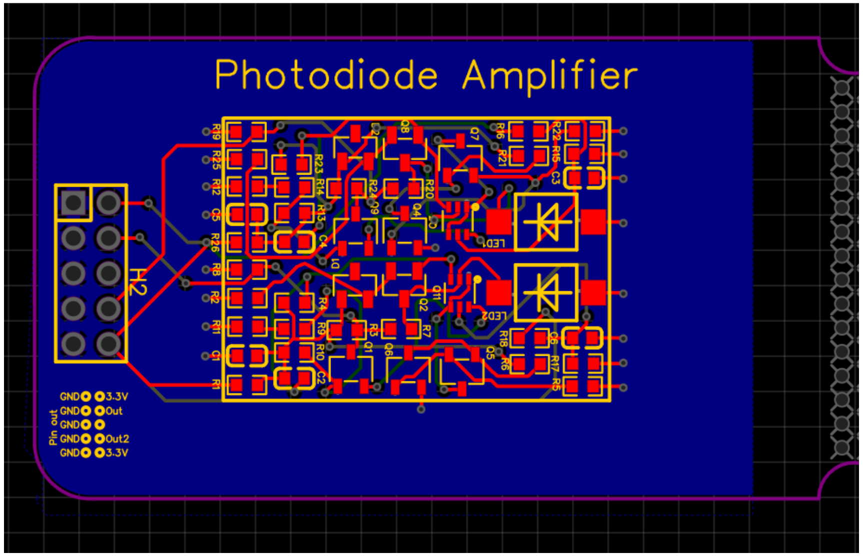


Photodiode Amplifier



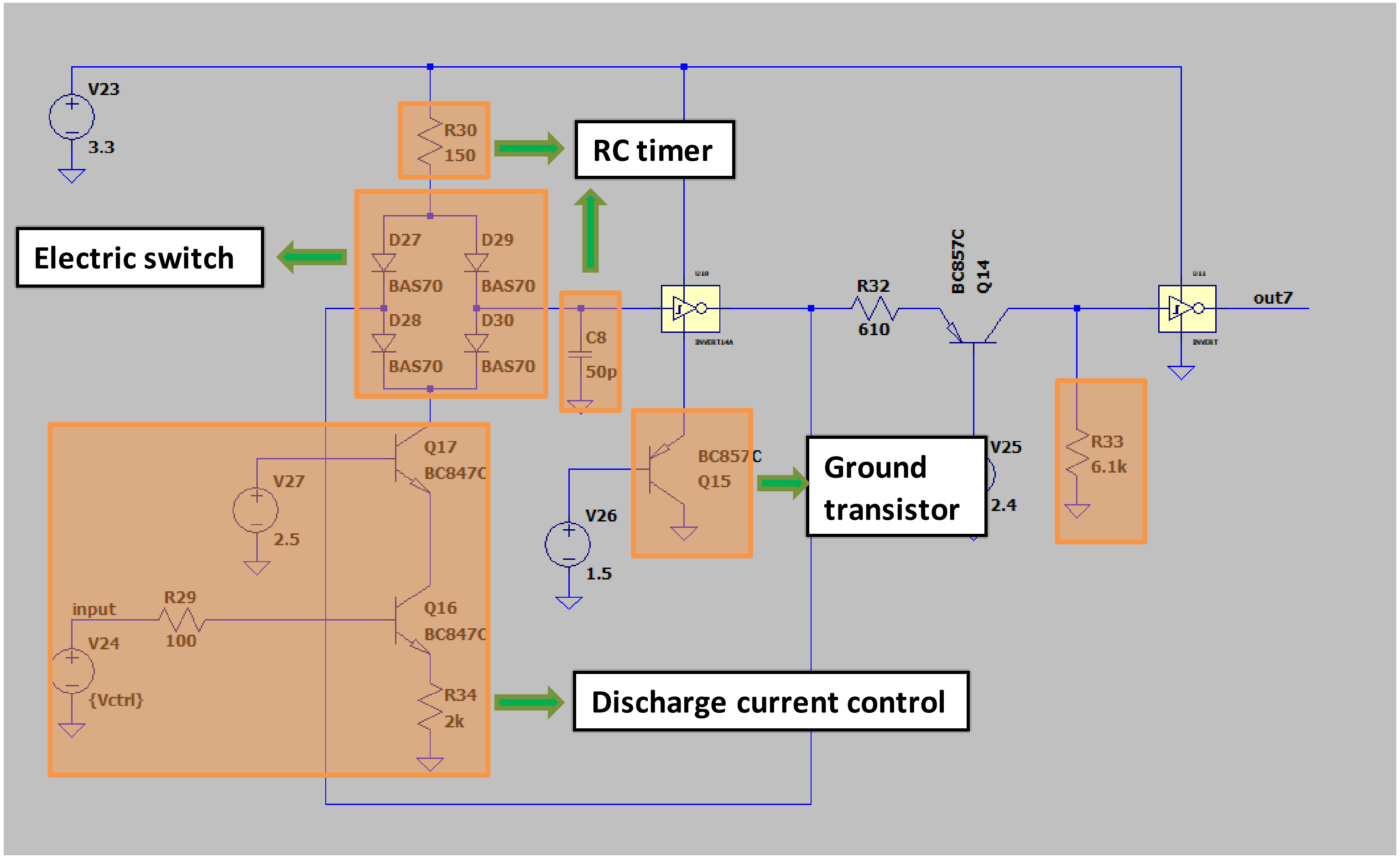

3.3V
R1 100
C1 10u
GND
D1 BAV99
C2 1u
R10 10k
R11 10k
R9 7.5k
R3 9.8k
Q1 BC847C
R4 16k
Q11 SBC847BDW1T1G
Vout
3.3v
R18 11k
C6 0.1u
R17 13.3k
Q2 BC857C(3G)
R2 10k
LED2 VBPW34S
R6 20k
Q5 BC847C
Q6 BC847C
R5 2.8k
H2 Header-Male-2.54_2x5
Vout2
R7 100k
R8 1M



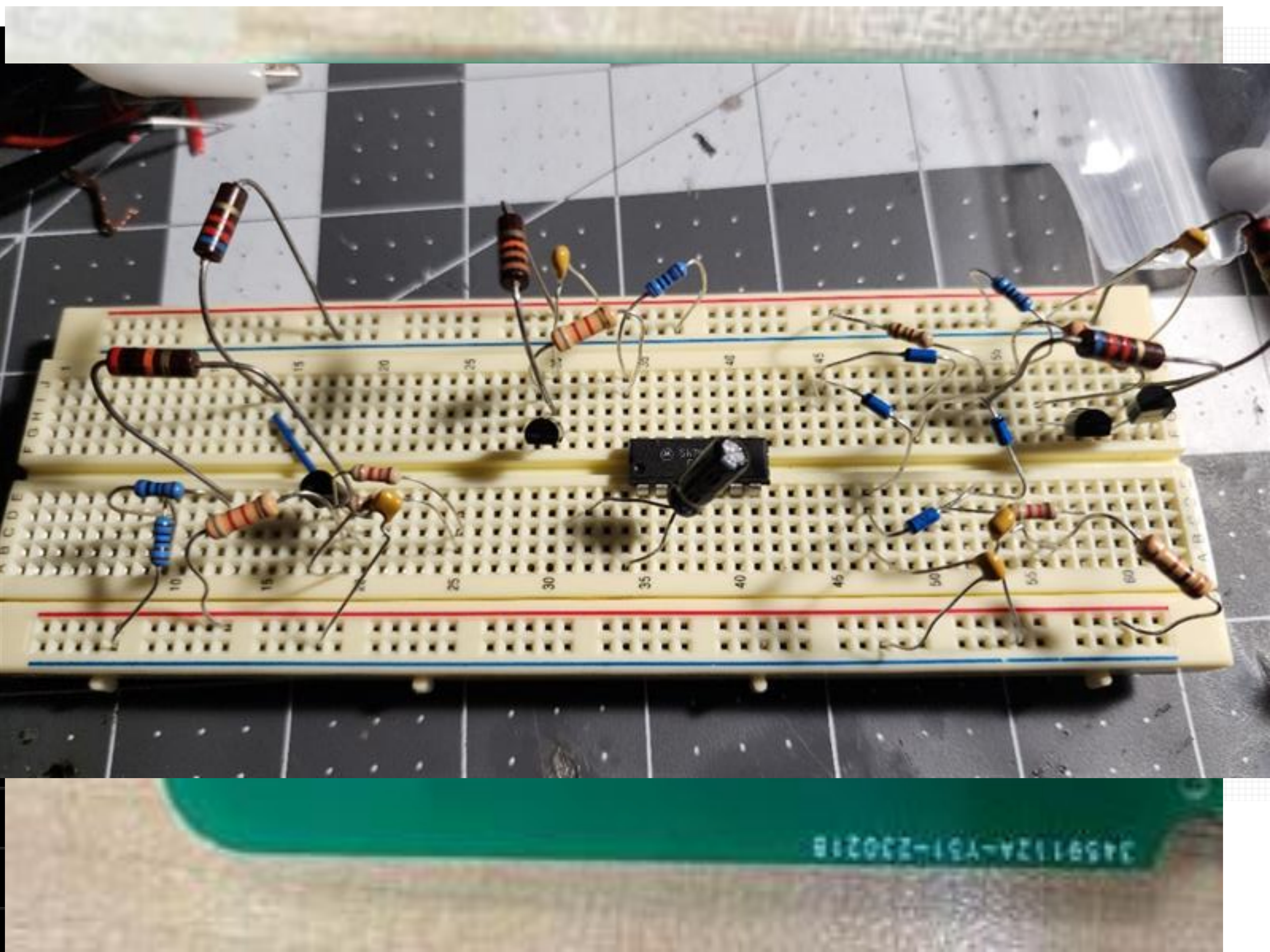

Photodiode Amplifier
H2
Pin out
GND 3.3V
GND Out
GND
GND Out2
GND 3.3V

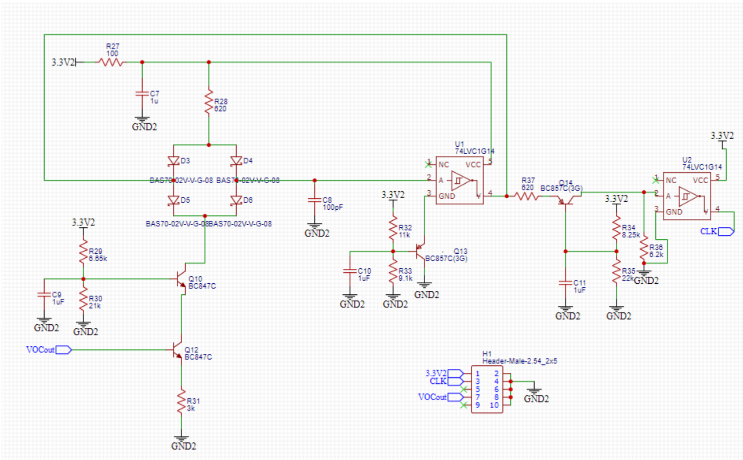

Photodiode Amplifier
H2

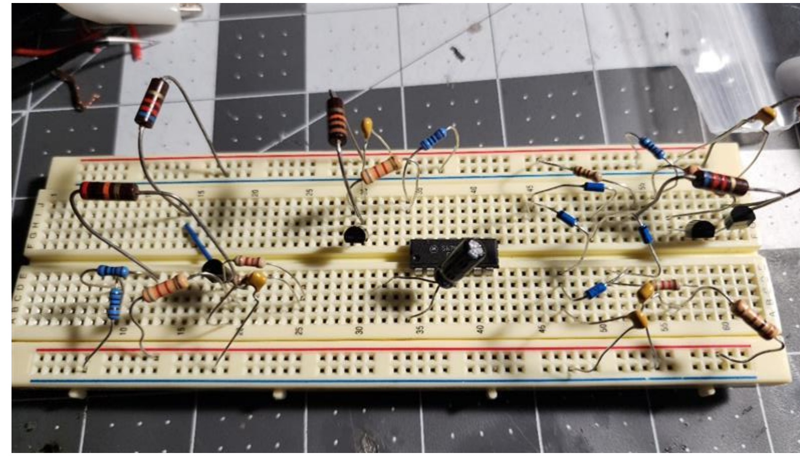
VCO

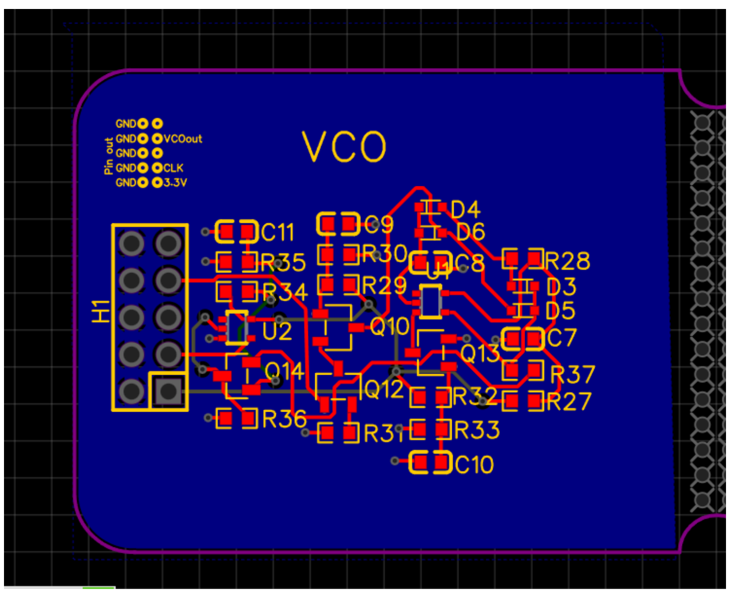


V23
3.3
R30
150
RC timer
Electric switch
D27
D29
BAS70
BAS70
D28
D30
BAS70
BAS70
C8
50p
R32
610
BC857C
Q14
out7
Q17
BC847C
V27
2.5
BC857C
Q15
Ground transistor
V25
2.4
R33
6.1k
V26
1.5
input
R29
100
V24
{Vctrl}
Q16
BC847C
R34
2k
Discharge current control



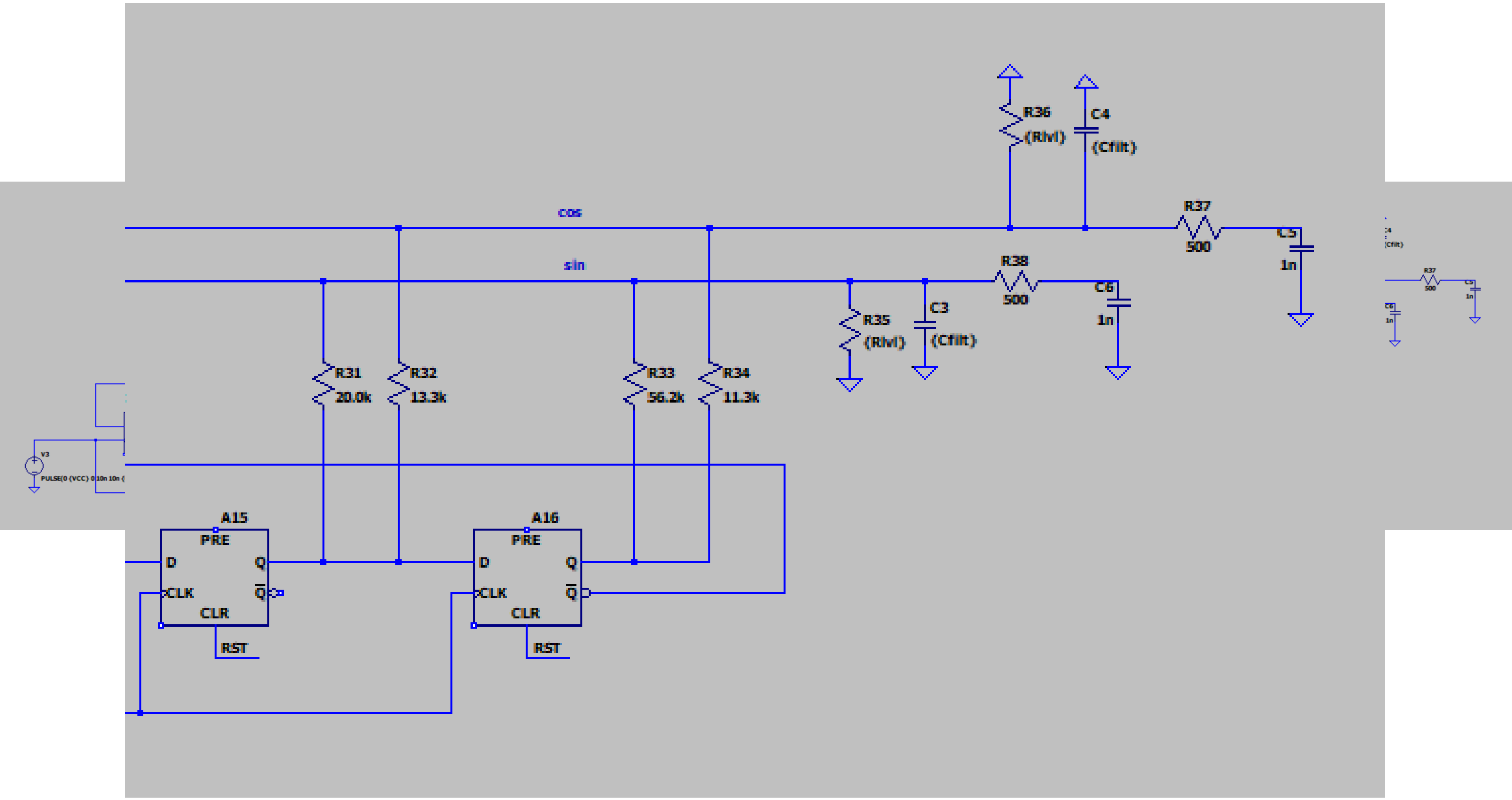




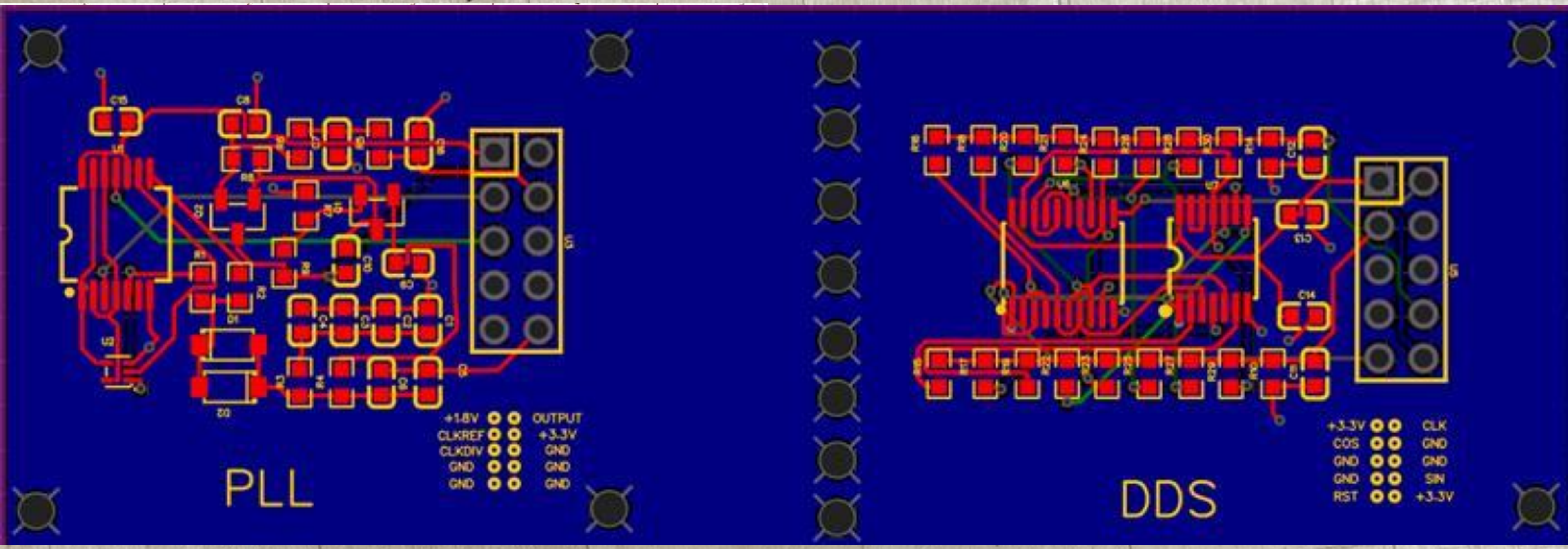

VCO
GND
VCOout
CLK
3.3V
Pin out
H1
C11
R35
R34
U2
Q14
R36
C9
R30
R29
Q10
Q12
R31
D4
D6
C8
U1
Q13
R32
R33
C10
R28
D3
D5
C7
R37
R27


VCO
C11
R35
R34
U2
Q14
R36
C9
R30
R29
Q10
Q12
R31
D4
D6
C8
Q13
R32
R33
C10
R28
D3
D5
C7
R37
R27

DDS



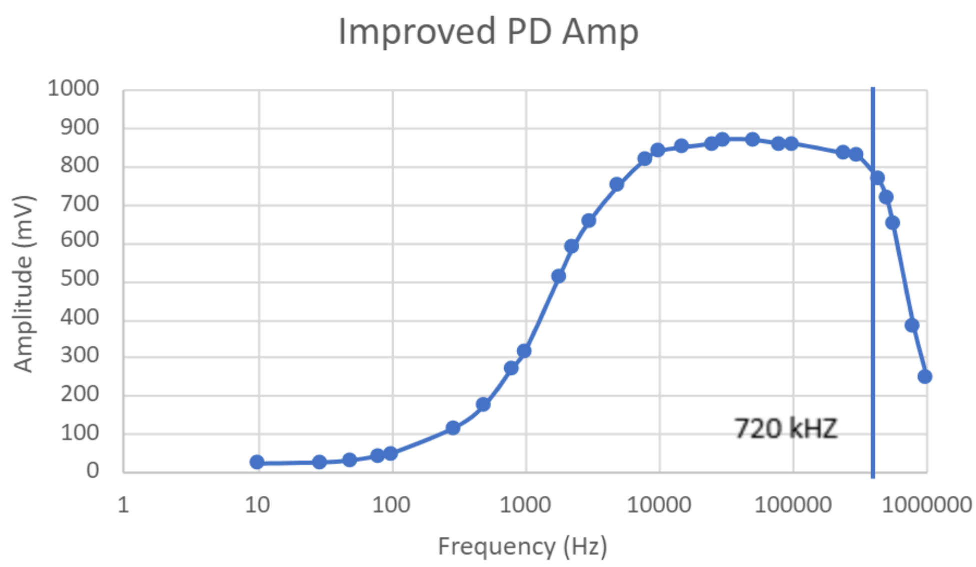
cos
sin
R36
{Rlvl}
C4
{Cfilt}
R37
500
C5
1n
R38
500
C6
1n
R35
{Rlvl}
C3
{Cfilt}
R31
20.0k
R32
13.3k
R33
56.2k
R34
11.3k
A15
PRE
D
Q
CLK
CLR
RST
A16
PRE
D
Q
CLK
CLR
RST

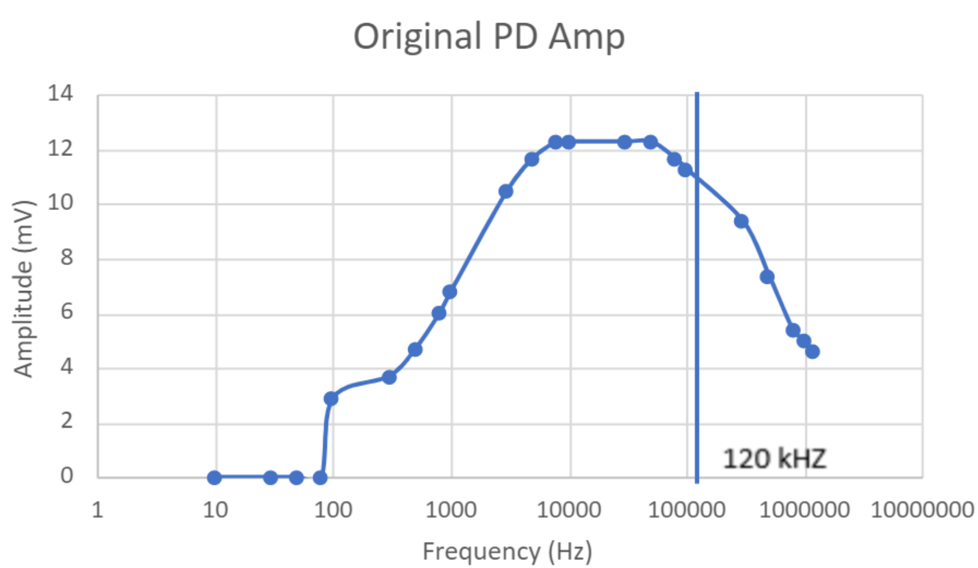


+1.8V
OUTPUT
CLKREF
+3.3V
CLKDIV
GND
GND
GND
GND
GND
PLL
+3.3V
CLK
COS
GND
GND
GND
GND
SIN
RST
+3.3V
DDS

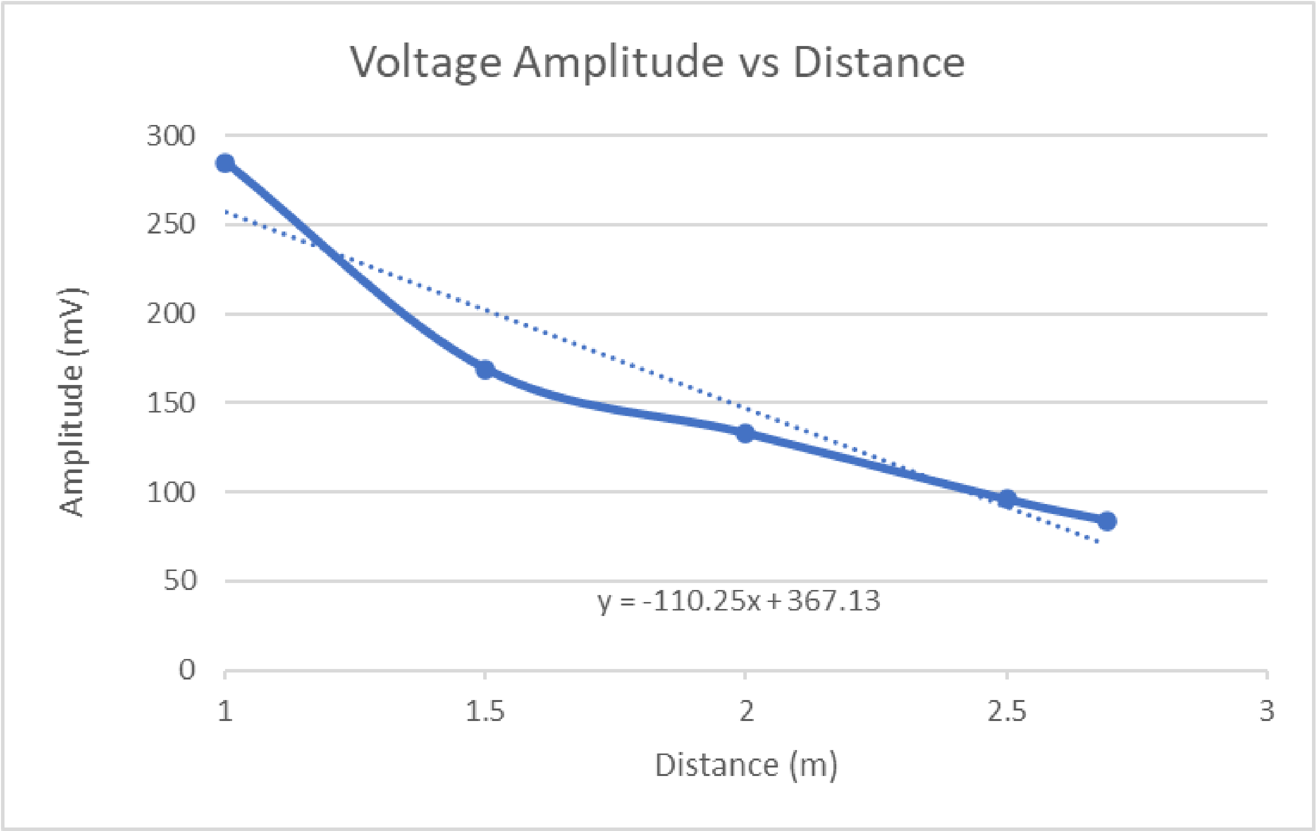
Testing

Bandwidth Analysis





Distance → Testing



VCO Bandwidth
Beat the Target!

	Lower Limit	Upper Limit	Difference
Original VCO	59 kHz	3.18 MHz	3.12 MHz
Target	150 kHz	10 MHz	9.85 MHz
Improved VCO	110 kHz	10.3 MHz	10.2 MHz

We met 100% of our specifications!

But here's where we struggled

And what we recommend

Project Summary

Stayed Under Budget!

	Price
PCB	$104.8
Components	$67.67
Previous costs	$74.03
Shipping	$112.35
Overall	$358.85/$500

Communication and Time Management

Positives and Negatives

Team communication

Attention to detail