EEL 4914 – Group D

Automated Optical Setup

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Executive Summary

Our project was proposed by the Laser Plasma Laboratory (LPL) at the Center for Research and Education in Optics and Lasers (CREOL) here at the University of Central Florida (UCF). The project was to create an automated setup that involves the rotation of an optical element that the laser beam passes through. After passing through this optical element a sensor will measure the intensity of the laser beam. The purpose of wanting this process to be automated is for convenience, time, and accuracy. A computer is also able to do this faster and with a higher degree of accuracy then a human doing this by hand. Furthermore, making the whole process much simpler.

The basic setup for this project involves using a mount which contains two motors and a pivot point to rotate the object in the holder, whether it is a mirror or some other optical element. These two motors will be connected to a controller which is then connected to a computer along with a series of amplifiers coming from a light sensor that measures the intensity of the laser beam. The primary experiment this setup will be used for is called an Optical Parametric Oscillator (OPO) but will also be used for experiments such as Difference Frequency Generation (DFG). Some of these experiments may require the crystal be placed in an air seal camber or be confined to a small space via an optical cavity; therefore a mount with small motor was desired. The basics of the OPO experiment involves a laser firing into a crystal and, as long as the orientation of the crystal is descent, a new wavelength will be emitted from the crystal which will be longer in wavelength then the original beam. The orientation of this crystal will affect how strong the intensity of this new beam will be. A problem is that this intensity will be very small; therefore amplifiers are needed. All other equipment needed for this experiment is not the responsibility of this senior design group and there is no foreseen reason why any of these will prevent our project from working.

The complexity of the software involved in communicating with all of this equipment left us with the choice of purchasing most of the equipment. This included buying mounts with motors already attached since we have little interest in the mechanical design. All optical components were chosen by the people at CREOL working on this OPO experiment. Since we wanted to do some hardware design of an electronics board; a low noise amplifier was designed and assembled by us. This will amplify the signal from the light sensor and output to an analog to digital converter. A microcontroller will then read the conversion and send it to the computer via USB. The conversion will also be displayed on an LCD screen present on the PCB for easy viewing.

2.0 Project Description

2.1 Project Motivation and Goals

The project was motivated and inspired by the desire to aid UCF's laser department to better its tests. Currently, optical elements are manually tweaked through various mechanics that hold the optical elements in place. This method is unreliable and requires time to achieve a desired position which often changes, usually due to noise. If the time to achieve precise positions for the experiment is reduced, many experiments will be run in the same amount of time. This will undoubtedly improve the overall experiment. The primary goal of our project was to design a device that rotates an optical element accurately on various axes depending on the user's input. This reduces the possibilities of human errors in manually tweaking the mechanics.

The device has two primary features. The first feature was to have a friendly user interface to accept the two rotational angle inputs. One angle was responsible for rotating about the horizontal axis (Φ). The other angle was responsible for rotating about the vertical axis (Θ). These values were determined by a raster scan of the optical element in two ways. One way was to start at one of the limits and then scan the entire object. Another way is to choose a position that would seem to be the zero point and then make rectangular point scans until the true point is determined. With the scan, an algorithm calculated the ideal position and communicated to the motors with information on how far they need to move. This is the second feature which takes in information from the motors and light sensor. The motors relayed back their position and the light sensor relayed back the amplitude of detected laser beam. This light sensor is highly precise due to the short band of wavelengths produced from the test.

The goal was to have this device be able to scan and correct itself in real time without jumping too much or frying the motors. Even with a good algorithm the calculated coordinates could still be off; therefore a person, using the UI, will be able to increase and decrease the rotation of each axis by a desired amount. Algorithms were written to communicate with the motors on how to move, how quickly to move, and how long to move for. This algorithm was then be used for the automated adjusting the scanning procedure. An accurate feedback of the optical element's position is displayed to the user.

2.2 Objectives

This project was proposed in order to make Optical Parametric Oscillators (OPO) easier by automating much of the processes. Traditionally mounts for stabilizing optical elements had to be adjusted by hand. By connecting the motors on the mount to a computer to control them, and by having sensors setup to tell the computer which motor to move what distance and in which direction, will provide a great benefit. Not only does this allow for a reduced time orienting the mounts, but it will also allow for corrections in the orientation to be constantly updated while the OPO is running. Furthermore, a computer can make much more refined movement with a much higher degree of accuracy than a human turning a knob by hand.

Therefore our main objectives consisted of making OPO experiments more automated and allowing corrections to be made mid-experiment. We also amplify the signal of our light sensor that measures the intensity of the laser beam after it passes through the crystal and allow the user to manually adjust the mounts. In terms of efficiency, the controller for the motors was our limiting factor; therefore we maximized the adjustment speed of the motors to what the motor controller can handle. The code is able to run quickly enough so that the controller is not waiting for a command and the intensity value from the light sensor is received by the computer before the crystal mount has been moved to its next position. The refresh speed of the light sensor is faster than the speed of the controller; therefore they pose no problem in terms of efficiency and speed. Although the controller is connected by USB, it is still a serial connection; therefore when multiple motors need to moved, we thought the speed of each motor would decrease and priorities would be needed depending on the current situation/process the program is running, but locally we had no such issue

General Objectives:

- Automate the rotation of the crystal mount in the OPO experiment
- Allow corrections to be made mid-experiment
- Automated maximum power output scan feature
- Beam stabilization feature
- Provide software GUI

Hardware Objectives:

- Amplify light sensor signal by 10^6
- Amplifier exhibits low noise characteristic and high Signal to Noise Ratio, SNR
- Amplifier support RF signals up to 250kHz.
- Display amplifier data on LCD screen and send to computer
- Have a highly precise and steady voltage reference for an analog to digital converter
- Have a high degree of accuracy and reliability digitally measuring the Amplifier output
- Design a holder that fits in the mount and that can hold a cubed shaped crystal ranging in size from 3mm to 25mm on two of its sides

Software Objectives:

- Allow manual adjustment of the mounts
- Ability to adjust the motor speed and distance
- Have the processing of the data be faster than the motor movements
- Scan data is collected and stored before motors move to new position
- Ability to adjust the spacing between positions and the number of position for the precise scan process
- Set motor priorities based on the current situation
- Ability to find the position, from the scan, that provides the highest intensity while ignoring noise
- Updates to the GUI to be less than two seconds

2.3 Project Requirements and Specifications

Overall Scope- The block diagrams throughout this section shows how components are connected, what the components do, and which team member was responsible for each component. The names of the components are very general so that others can look at this and create a similar project but with their own design.

The block diagram in Figure 2.3-2 shows the general idea of how all the components, in the entire project, are connected to one another. The next block diagram, in Figure 2.3-3, shows how the algorithms in the main program receive and transfer data between the various components. Figure 2.3-4 shows a block diagram of all the components that make up the mount and how they each contribute to the function of the project. The final block diagram, in Figure 2.3-5, shows the process the data from the light sensor goes through before it is finally received by the computer. A legend for these block diagrams is shown in Figure 2.3-1.

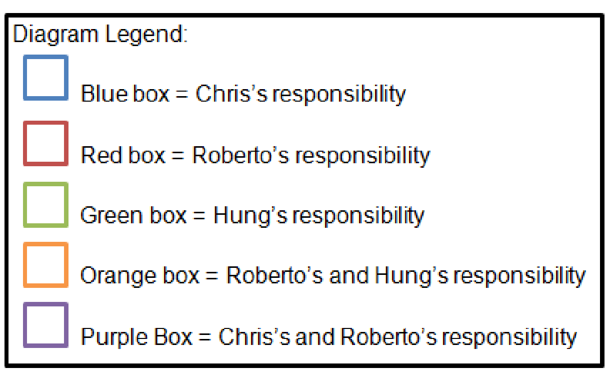


Figure 2.3-1 Block Diagram Legend

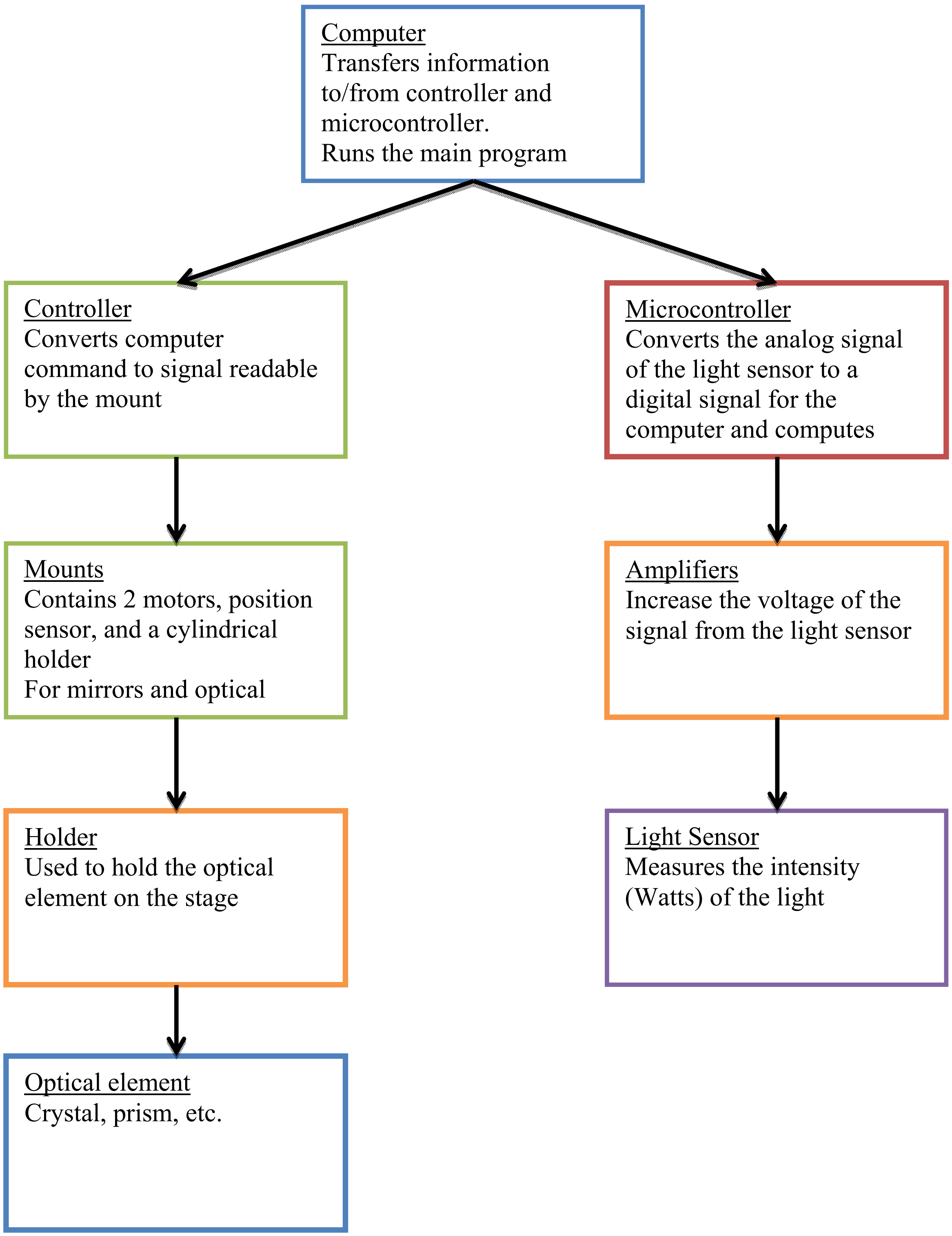


Figure 2.3-2 Block Diagram of the Whole Project

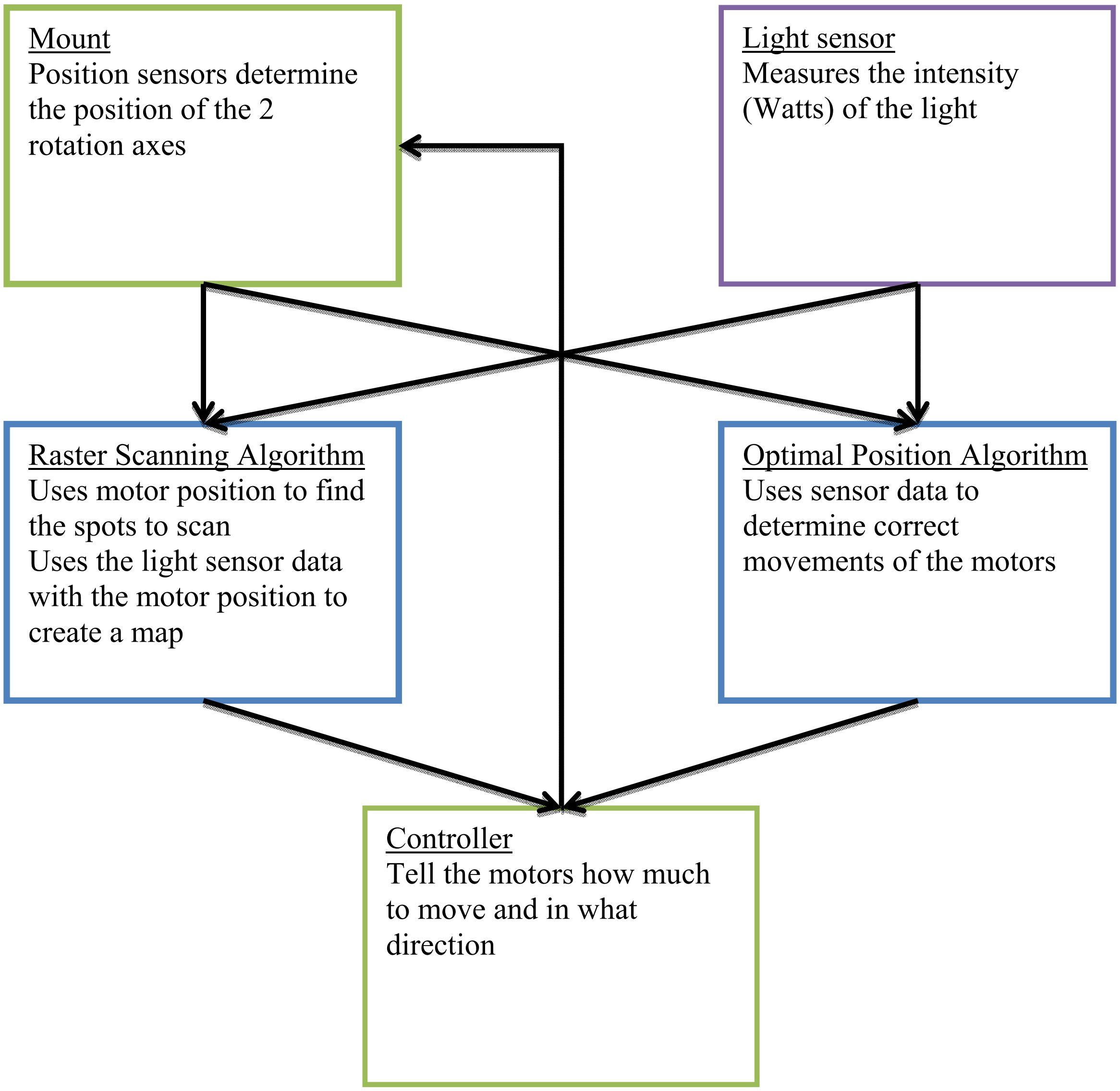


Figure 2.3-3 Block Diagram for the Algorithms

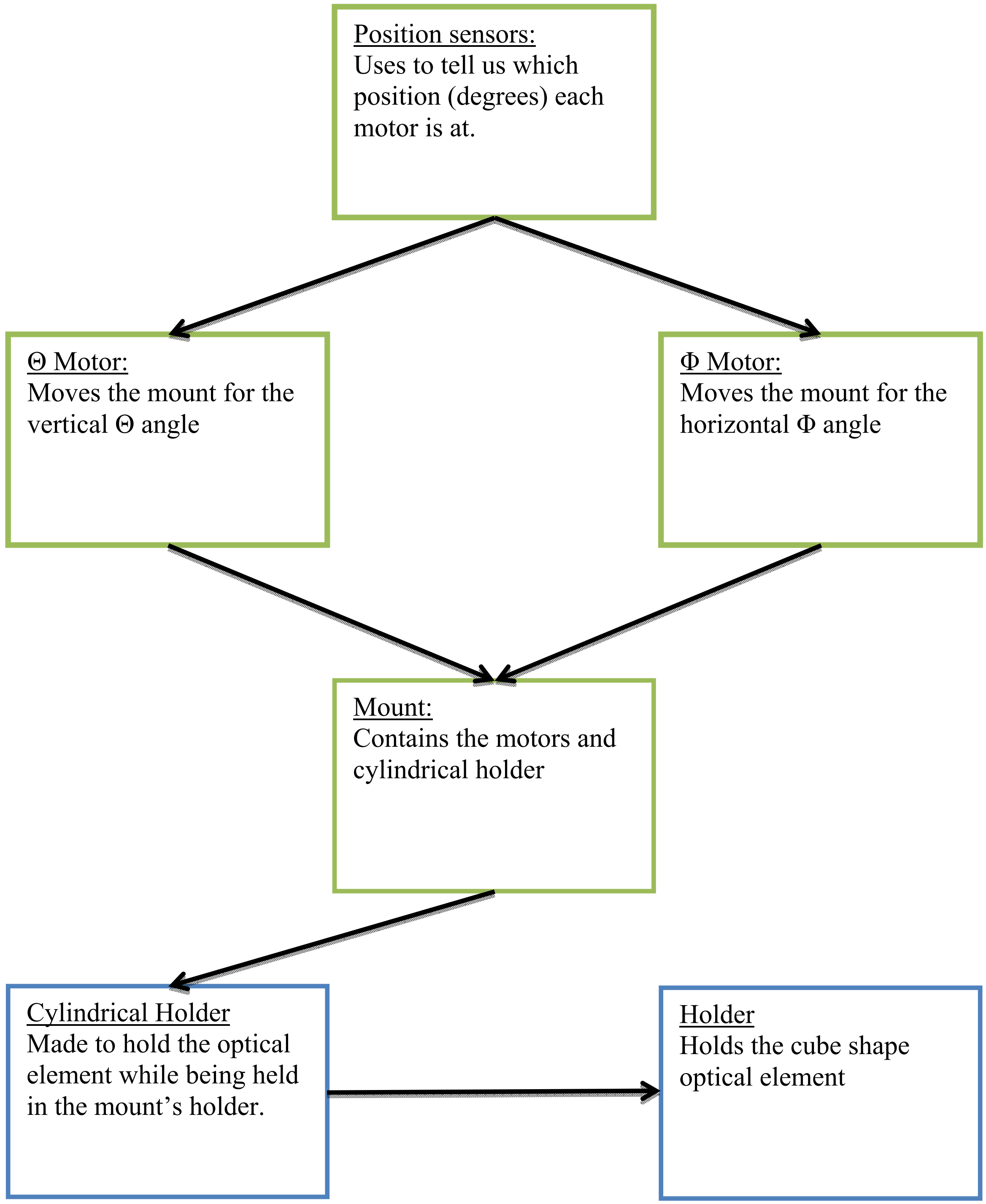


Figure 2.3-4 Block Diagram for the Mount

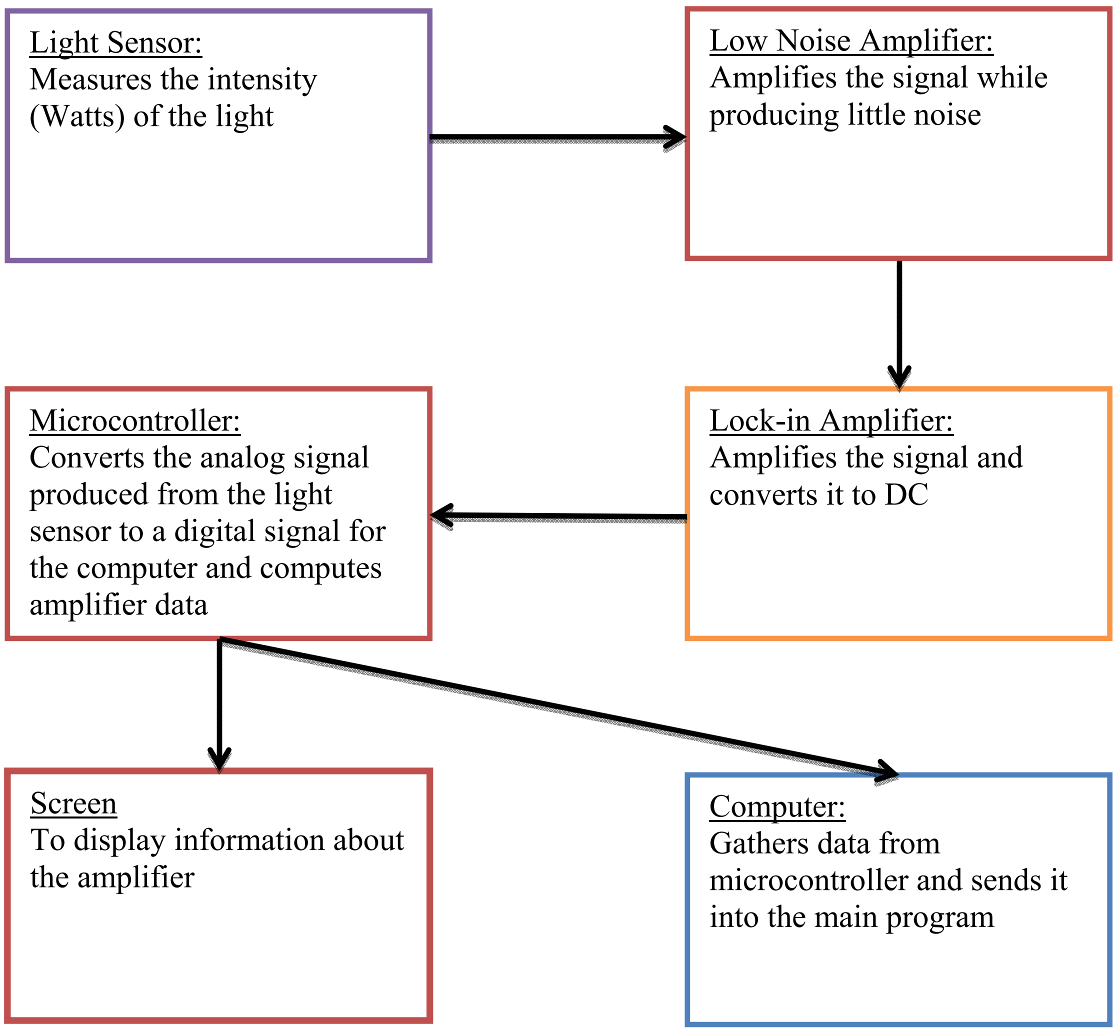
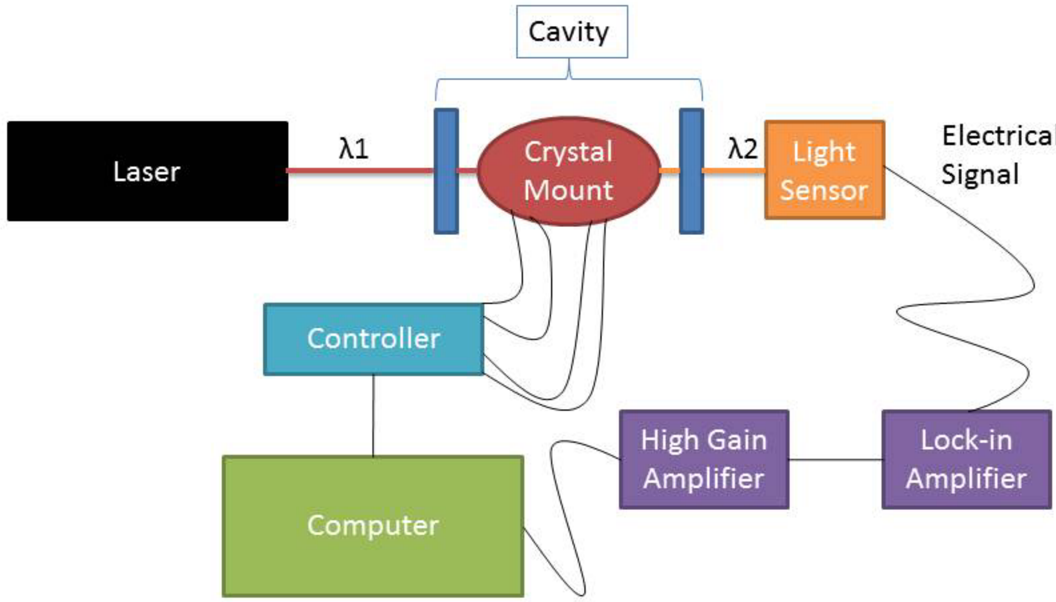


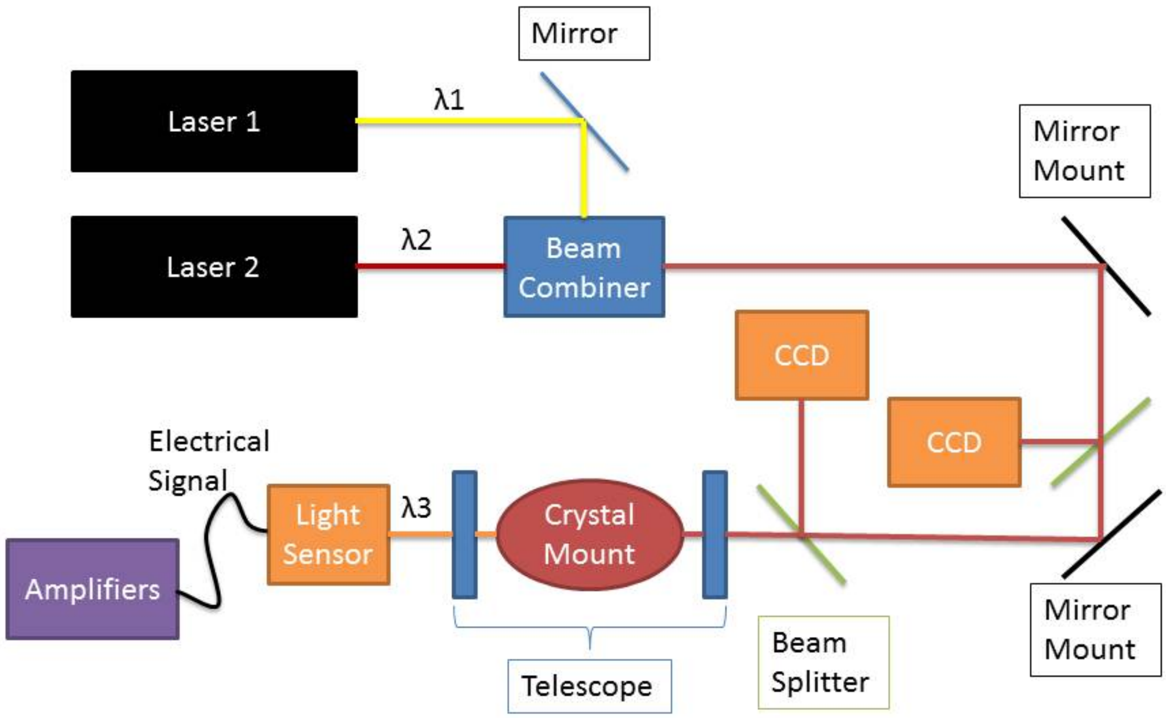
Figure 2.3-5 Block Diagram for Light Sensor to Computer Connections

Optical Parametric Oscillator (OPO)- This project is mainly for the use in Optical Parametric Oscillator experiments outlined in figure 2.3-6. The basics of the experiment are that a laser fires a beam into an optical cavity containing a mount that is holding a nonlinear crystal. This crystal mount contains a special holder that is made to hold varying sizes of crystals. When the beam passes through the crystal, a new wavelength is produced if it is oriented correctly. A light sensor then picks up the intensity of this wavelength which will be very weak. This weak signal will then need to be amplified before being sent to the computer. The light sensor has its own amplifier but a low noise amplifier and a lockin amplifier will also be used.



2.3-6 Optical Parametric Oscillator experiment setup

Difference Frequency Generation (DFG)- This project can also be used in experiments such as Difference Frequency Generation (DFG) outlined in figure 2.3-7. The basics of it are that two lasers, which produce different wavelengths, have their laser beams combined. This combined beam is reflected off two mirror mounts which are used to stabilize it with the help of CCD cameras to detect the position of the beam. The beam then travels through a telescope to culminate the beam. In between the two lenses that make up the telescope lies the crystal mount. This crystal mount is a similar mount to the mirror mounts with the big difference being that a special holder is put in place of the mirror. This holder is made to hold varying sizes of crystals. A third wavelength is produced after passing through this crystal if it is oriented correctly. A light sensor then picks up the intensity of this wavelength which will be very weak. This weak signal will then need to be amplified before being sent to the computer. The light sensor has its own amplifier but a low noise amplifier and a lockin amplifier will also be used. Not show in figure 2.3-6 are the mounts being connected to a controller responsible for converting the commands from the computer to a usable signal for the mounts. Also missing are the cameras, amplifier, and controller being connected to a computer which is running the program that controls the mounts.



2.3-7 Difference Frequency Generation experiment setup

Motorized Optical Mount-The mounts that we used for this project were motorized in order to automate the test processes for the lasers. This was essential and the main motive for this project. The motorized optical mounts are what will be used to adjust the mirrors and the crystal in order to alter the path of the laser to obtain the maximum output at the sensor. To achieve the maximum output, the mount must able to adjust the mirrors in various directions and angles.

A requirement was that the motorized mirror mounts be able to adjust the mirrors and crystal in two rotational directions of free space. Because of the nature of the laser tests, the motorized mirror mount had to be very accurate or the laser's point will not shine directly at the sensor to produce the maximum power output. To achieve this accuracy, the motor we chose were ultra-sensitive in making small incriminations. Another requirement we had, in terms of angle, was that the motorized mirror mounts should be able to rotate to the accuracy of less than a tenth of a degree. The limit of our motors steps ranged from about sixty five hundred to several million, depending on the step amplitude. The increase in amount of steps would increase the accuracy. Each revolution will include many steps in between. In addition, the motorize mirror mount will be connected to a controller which will send separate signals to each motor giving instructions on direction and distance. This controller will be communicating with the sensors to achieve further accuracy.

In addition to being accurate, the motorized mount had to be predictable in order to reduce wait time. Reducing wait time is essential because the motorized mirror mounts had to be able to keep pace with lasers up to 100Hz. Predictability would also allowed different algorithms to be implemented as the parameters are more predictable and less sophisticated. To obtain this predictability, non-resonant motor were used over ultrasonic motors. Ultrasonic motors introduce a lot of vibrations. These vibrations will be transferred to the mount and then to the mirrors. The laser beam reflecting from these mirrors would not be able stabilize to a single point to produce the max power output. Non-resonant motor eliminates most if not all vibrations and therefore are required.

Reproducibility is another characteristic that considered for our motorized mirror mounts. Reproducibility allowed our motors to be more reliable. This allowed the tests being performed by this project to be more consistent and therefore yield better results. To achieve repeatable absolute positioning, the amount of current and voltage introduced to the motor must be consistent and precise. One way to do this, and the way we chose, was to have precision electrical switches in the motor. Not only do these precision electrical switches allow the motorized mirror mounts achieve repeatable absolution positioning, but they also act as safety devices to prevent damage to the motors.

3.0 Research Related to Project Definition

3.1 Existing Similar Projects and Products

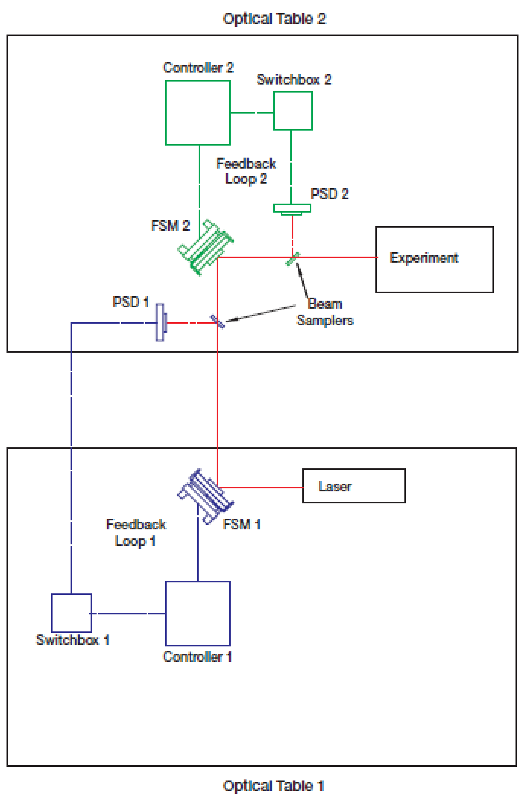
There are very few projects out there that are similar to this project, especially as a senior design project. However the scientific communities have had problems with manually adjusting various mirrors in laser experiments. This is largely due to the fact that it is inconvenient to adjust the mirrors while the experiment is running. In addition to being inconvenient, manually adjusting the mirrors often introduces many errors and the desired position might not be able to achievable. Because of these difficulties, the scientific communities have done similar projects to solve these problems.

A similar project to this would be an active controller for pointing of a multi-terawatt laser done at the Lund Laser Centre. The multi-terawatt laser that was used in the experiment was not stabilized due the introduction of various noises from surrounding sources. To stabilize the laser, motorized mirror mounts were used to adjust the mirrors so that it would readjust itself to eliminate the noise's effect on the experiment. The motorized mounts were connected to a stabilization system that was consisted of a controller with feed forward algorithm. The algorithm would receive signals from the sensors and make the necessary calculations needed. After which, the controller will send the necessary signals to the motorized mirror mounts to make the adjustments.

The active controller for the laser built by Lund Laser Centre has many similarities to our project. First, the beam stabilization system that was implemented is very close to the controller that will be used our design. The primary function of the controller that will be built in this project is to not only stabilize a beam, but it also auto adjusts the mirrors to achieve the most effective position of the mirror for maximum power output depending on the wavelength of the laser source. The motorized mirror mounts that will be utilized in our project must be quick enough to adjust with noise up to 100 Hz.

Another project found that was similar to our project was a National Instrument students design project. This project was named Development and Control of an Electron Beam Polarimeter. This project uses motorized mirror mounts to adjust the mirrors from a distance. This would ultimately alter the path of the laser beam to the position they want, consequently controlling the beam. To control the motorized mirror mounts, LabVIEW was used to interface between the computer and the mounts. This is similar to our project designs; however we may end up using C++ code to speed up processing time, thus leading to a signal produced by the controller quicker than if we were to use LabVIEW. Since our goal is to have the motorize mirror mounts auto adjusting itself to produce the max power at the sensor with noise up to 100 Hz, it is crucial that our processing time is fast enough for this adjustment.

Newport beam stabilization system - This system from Newport is the beam stabilizing mirrors with the controller. The housing for the mirrors is much larger than what we plan on using. However it does have replaceable mirrors, which is similar to what we want in our own design. The setup that this system advises to use involves beam samplers that split the beam at certain points in order to sample it and compensate for movement. The split off beam goes to a Position Sensing Detector (PSD) seen in Figure 3.1-1, which detects movement or oscillations in the beam, which then sends information to a Switchbox. The Switchbox passes information to the controller that in turn compensates for movement by moving the mirror. This can be done for one or more stabilizing mirrors. If need be, this setup can be cascaded over multiple controllers.



g 1. Active beam stabilization between two optical tables.

Figure 3.1-1 Pending permission from Newport; that of a suggested setup for a beam crossing a table

If the beam is required to cross experiment tables then two controllers would be needed. It also suggests positioning the beam splitters at equal distances from the first mirror in order to achieve the best results. The beam is kept at the center of the stabilizing mirrors in order to compensate for imperfections in the mirror. The Switchbox is used to control the gain over the signal from the PSDs so that it is a smaller gain when the beam crosses a greater distance while the gain is smaller when it's a shorter distance. This helps keep the beam from oscillating back and forth or moving too slow. The Switchbox provides switches to turn on internal or external gain for the signal from the PSDs. The Figure on the right shows the switchbox schematic that can be used so that gain for the PSDs can be controlled externally by the user using a potentiometer. For our own design, the external gain may not be favorable because reproducibility is an issue with researchers and potentiometers are notoriously difficult to get perfect once, let alone twice. We may add it as an extra feature simply because some may be more comfortable with knobs.

Optics in Motion is also going to soon be offering a Beam stabilizer that is an attachment to a mirror controller box that is already present. This is a great option for our own project so that we do not have to directly develop the controller logic and circuitry. This product is a card like PCB that inputs the current position from two FSMs, and one PSD, it then outputs the optimal signals to the controller box to move the FSMs to compensate for the movement of the beam. This product also includes potentiometers to adjust the mirrors manually to get the beam onto the detector in order for it to start stabilizing the beam. The stabilizer card also includes a port to connect to a PC so that if the beam is not on the PSD it can scan the mirrors field until it places the beam on the PSD. The ability to talk to a computer is a key feature in our project because a computer will be telling the microcontroller where the optimal placement of the crystal will be for maximum attenuation. While the controller can do the scanning all by itself, the computer receives the power output from the laser at each position and records it. This will be recorded onto a 2D map of the mirror positions and will localize the point of maximum power. This position for maximum power will be sent to our controller which will then calculate how to move the piezo mount to the position.

3.2 Relevant Technologies

Motorized Mirror Mounts- There are many relevant technologies to our project as it is a huge problem in the optics scientific community. The first relevant technology related to our project is the motorized mirror mounts. Motorized mounts are often used in various laser experiments that require great precision, stabilization, and control of the laser beam. It provides a way to alter the experiment's parameters such as the angle of reflection of the laser beam from the mirror. This can be done to stabilize the laser beam from surrounding noise or simply just to adjust the mirror's position to a desired one without having to interfere with the ongoing experiment. There are many different types of motorize mirror mounts with various specifications.

One of the most important specifications is how accurate the mount can be. Usually accuracy is determined by the smallest degree of change that motorized mirror mount can perform. The smaller the change, the more accurate the mount can be because it is more precise. This is especially important to our project because it is designed to support various tests that often require that the laser beam travel far distances the length of a full scale lab room. As the length increases, the slightest error will be magnified. If the length is far enough, the error will be very noticeable. Many motorized mounts use the step motor for its design. With greater precision and accuracy, there are more steps in between each revolution. However, there are other motors that use the squiggle motor. These squiggle motors use ultrasonic vibrations to rotate and translate the screw inside the motor, which in turns cause the movement of the mirror. Both of these motors can provide the needed accuracy.

Another important specification that varies between different motorized mirror mounts is the speed at which the motorized mirror mount can change. This is usually measured by degree per second or millimeter per second. It is important that this specification of the motorize mount is capable of supporting 100 Hz changes since our project is required to stabilize noise up to 100 Hz. It is desirable to have faster speed of the motorized mirror mount than it is required considering the computation time for the computer to execute an algorithm.

Light Sensors-Light sensor is another relevant technology for our project. There are several forms of light sensors that can be picked from for our project. The first form a light sensor can take is in the form of a component. With this form, the output signal of the light sensor will be likely fed to other components. The output signal from the light sensor is usually in the form of a current. The second form that a light sensor can take is in the form of a chip. Based on various data sheets, the output signal from light sensors that are chip is usually in the form of current as well. In addition, it has been compared that both have similar inputs and outputs. It is worth to mention that light sensors on chips can be easily integrated on circuit boards for compacted space. The last form a light sensor can take is as a stand-alone device that has just power inputs and a signal output as the connection.

Usually when a light sensor that is in the form of a device, it takes on extra features as well. One of the extra features the device can take upon is temperature control. This is needed for sensing an extreme light source, such as a laser source, that might provide enough heat to destroy the electronics inside the device if it didn't have temperature control. Another feature that the device can take is amplification features. With sensitive and weak signals, usually low noise amplifiers are added near the sensor to amplify the incoming signal. These amplifiers introduce very low noise while increasing the strength of the weak signal.

Light sensors can be used for numerous applications. It is a key component in our design to achieve the best crystal orientation that would produce the maximum power output. The most important specification for light sensors is the spectral response. Most of the light sensors sold in the field have a spectral response of range of around 500 to 600 nanometers.

Optics in Motion information - The Optics in Motion site offered an outline of the different technologies for laser beam stabilization as well as some helpful information. Piezo mirrors use crystals and ceramics to move quickly by varying the voltage across sections of the material. They have the advantage of pushing forcefully over a small range, as well as having high bandwidth and high accuracy. Piezo driven screw mirrors are also used, which use a piezo to drive a fine pitch screw thread actuator giving the result fine movement. They are not that great for actively stabilizing a beam because they make a loud audible noise and have a short lifetime. Repetitive motion causes it to stop working because of the way it works. It has a maximum speed of 40μm per second limiting its stability applications to slow movement like thermal drift, not at all useful for our application against vibrations and turbulence. Actuator motor driven mirrors have slow speeds. These are the mechanically driven mounts that have ac or dc driven servo motors that have a high chance of breaking over time from the repetitive movement that they undergo. Galvometric scanning mirrors rotate a mirror about a single axis mounted on shaft which may connect directly to a stepper motor. Some have built in position sensors much like piezo mirror mounts. This class of mirrors in impractical for our application because it would require two mirrors just to function as a single regular mirror as well as not being nearly as accurate as some of the other forms of mounts. Voice coil mirrors use two axis mirrors with flexure suspension in a push/pull configuration. These usually have magnets mounted to the moving mirror piece and the voice coils on the fixed base, allowing for better heat sinking of coils, eliminating the problems with moving wire connections. This results in an infinite life mirror limited by the electrical component lifetimes.

Figure 3.2-1 shows two options for Position Sensing Detectors (PSD) that are viable candidates for beam stabilization; these are lateral effect and quad cell. Lateral effect cells are linear across the entire cell and don't take into account the beam size in terms of volts/beam position. Quad cells only measure the position when the beam is split up into the quadrants of the cell so that if the beam is fully within one quadrant, the output will saturate. The size of the beam will affect the quad cells, and quad cells have a tendency to drift from the center position with aging. Quad cells do have lower capacitance and lower noise compared to lateral effect cells. Depending on the size of their linear region, they may be a viable candidate for our project as well as the linear effect cells.

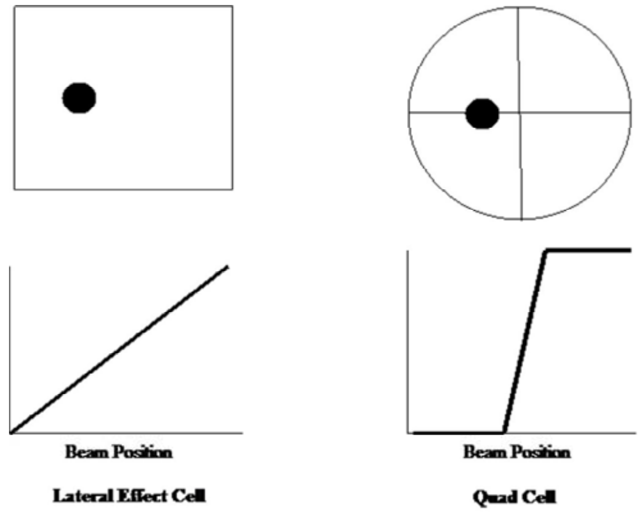


Figure 3.2–1 Reprinted with permission from Optics in Motion; shows the difference between output of Lateral Effect cells and Quad cells

The figure 3.2–2 suggests placing the PSDs at the same distance from the next mirror. The distance the beam travels from Fast Steering Mirror 1 (FSM1) through Beam Splitter 1 to the cell is the same as the distance from FSM1 to FSM2. This allows for simple correction and minimal error. As we are not the ones experimenting with this product, we cannot possibly suggest limiting our project to such a simple layout. One specific experiment that was mentioned was stabilizing a beam that would be crossing a large distance. It would therefore not be possible to place the cells at the same distance they must travel. Another suggestion is to use lenses in front of the PSD detectors in order to focus the beam and minimize error, but this is up to the discretion of the experimenter. If extra accuracy is needed in our project we will experiment with it and include it as part of our design.

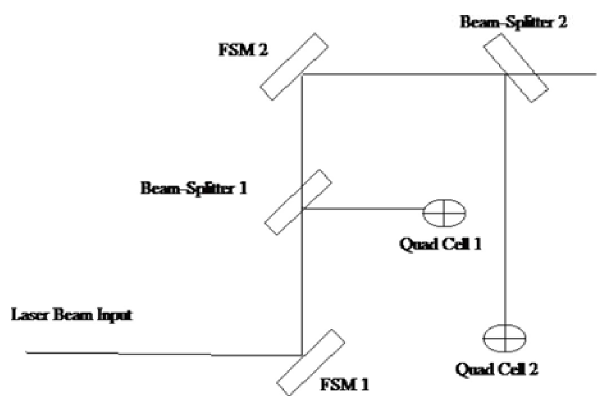


Figure 3.1–2Reprinted with permission from Optics in Motion; shows best setup for Quad cell light sensors

Stellaris information - The Stellaris comes with 4 possible clock speeds that can be used for this project. The Internal Oscillator (IOSC) is capable of 12 MHz with a standard inaccuracy of 30%. The Main Oscillator (MOSC) can use a different crystal to change the oscillating frequency; these can range from 1MHz to 8.192MHz. An alternate Internal Oscillator is can go at 30kHz with a 50% inaccuracy which is intended for deep sleep modes. Because our project does not need an accurate frequency to be maintained I believe we can use the IOSC to maximize the clock speed. If more accuracy is needed, we can always add a crystal to the Stellaris.

An Analog to Digital Converter (ADC) will probably be used for this project. An ADC peripheral will convert continuous analog voltage to a discrete number. The Stellaris ADC module has 10 bit conversion resolution and supports 4 input channels. This can sample at 500,000 samples/second giving us the rate that we need to compensate for high vibrations. This ADC also includes a hardware averaging of 64 samples to improve our accuracy which is definitely something we should look into. Power for the analog circuitry is separate from the digital power.

Arduino information - The Atmega328 offers a much higher frequency of oscillation, 20MHz than the LM3S8962. The Atmega328 is also much easier to work with because of its available 32 pin DIP packaging. This microcontroller also features a 10 bit A/D converter from 6 channels. This microcontroller also offers an ADC Noise Reduction Mode that will turn off the CPU when the SLEEP instruction is given to minimize noise and take higher resolution measurements. Once the conversion is done, a signal is sent to the CPU to turn back on. While the LM3S8962 and the Atmega328 have more or less the same features, the Atmega seems to be more popular and much easier to work with. It is open source, making it very easy to obtain schematics and code examples for it. It’s simple design would make debugging much faster than working with 100 pins.

3.3 Key Components

To achieve the specifications for our project, various components are needed to be acquired and design. Below are the key components needed for our project.

Compact Piezo Driven Optical Mount - The first thing we will need is a motorized mirror mount. Below in Figure 3.3-1 is a diagram of a general motorized mirror mount that will be required for our project. The circumference in the middle will be used to hold the mirror for stabilization and a holder for cube shaped optical elements. Different mounts have difference circumference designed to hold various mirror size. It is desirable that the circumference for our motorized mirror mount will be 1 inch in radius.

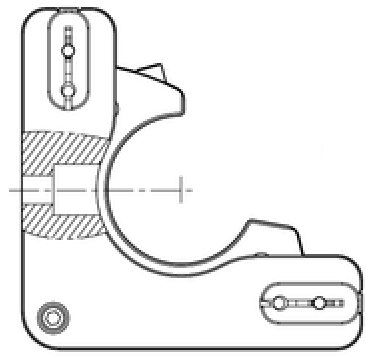


Figure 3.3-1 Front view of the motorized piezo mount

From the diagram, there are two motors located at the bottom right corner and the upper left corner. From the majority of motorized mirror mounts, these motors can be varied between the step motor and the squiggle motor. The motors are used to adjust the mirror's orientation. Instead of manually turning the screw at the pivot point, the motors will turn the screw instead. Because the motors are responsible for the adjustments, it is very important in determining many aspects of the motorized mirror mount.

The first aspect would be the accuracy and precision the motorized mirror mount can be. As there are more steps in each revolution, the more accurate the motorized mirror mount can become. In addition to being accurate, the motor also is important in determining the speed at which the mirror moves and changes its orientation. This is usually measured using degrees per second.

From the motor, it is wired to a 4-pin DIN connector. Of the four pins, two of the pin will be used for signal ground connections. The other two pins will be carrying two signals, one on each pin. The signals that they will be carrying are luminance and chrominance. These 4-pin DIN connectors will be connected to a controller that will ultimately be responsible for the controlling of the motor.

Amplifier - The main purpose of amplifiers is to manipulate a signal. Usually it is used to increase the strength of weak signals for processing. It can also be used to invert the polarities of different signals using the inverting configuration. In addition, it can be used to sum various signals together to produce a single signal. In our project, many amplifiers will be needed to increase the strength of the signal produced by our light sensor. Since the light sensor we will be using produces a current, the amplifier we will need is most likely a transimpedence amplifier.

A transimpedence amplifiers main purpose is to convert a current source and produce a voltage signal. A typical transimpedence amplifier can be built using one operational amplifier. The input current source will be connected to the negative terminal of the operational amplifier. A resistor will be connected from the output terminal to the negative input terminal. The positive terminal of the operational amplifier will be grounded. For the + and – Vcc terminal, it will be connected to a power supply of our choice. This power supply value will be determined once we have determined the range of output signal. Theoretically, the Vcc will determine the limit of our signal at the output terminal. It is important that our Vcc power supply be higher than the desired output signal.

The resistor that is connected from the output terminal of the operational amplifier to the negative input terminal determines the gain of the amplified signal. It is desirable that the gain for our amplifier be around one million. With one operational amplifier, the gain is very high. We will need to use several amplifiers to achieve the desired total gain. With the mentioned schematic, the output signal will have inverse polarity. To correct this, another amplifier will be utilized to correct the polarity. The operational amplifier we will need is the inverse operational amplifier. Like the transimpedence, the inverse operational amplifier has a very similar schematic. There will be a negative feedback from the output terminal to the negative input terminal. The negative input terminal will also have a resistor connected to it and the input source. The positive terminal will be grounded as well. The total gain will be negative of the ratio between the negative feedback resistor and the input resistor.

Camera - The camera will be one of the key components in the stabilization feature in this project. When determining which camera will fulfill our project needs, we need to examine the specs of various types of cameras. In our case, the camera will be used for providing real time feedback video to the computer. The image is not required to be in high resolution, since a laser beam can be easily picked up. With this specification, we can eliminate expensive cameras as they are not needed to perform the required task. In addition, it is ideal that the camera is USB compatible to interface with the computer.

After looking at various cameras, we have decided that a webcam with a high frames per second (fps) value would be our best option. The webcam has many advantages over other video capturing devices. The first advantage is the price. When compared to camcorders, the webcam can be much cheaper. The prices may vary depending on the specification, but they are usually around $60 while camcorders can be well over $100. The second advantage the webcam has is that it comes with a standard USB connector. This is very ideal for our situation as it is exactly what we want in order to interface with the computer. The last advantage the webcam has over other video capturing devices is that it's very compact, which is ideal for experimental areas where space can be an issue. The webcams usually comes with a stances built in as well.

Ideally, the webcam will provide video stream to the computer. We will use LabVIEW to analyze the differentiation between the laser beam's point and the desired position from this stream. For best stabilization, it is important that our webcam has a high enough FPS. It is very common that webcams have around 15-30 fps; however ours need to be upwards of 60 fps.

Arduino notes - The ADC uses the AVcc as the supply voltage pin; AVcc must not differ more than 0.3v from Vcc. The input range is 0 – Vcc Volts. Internal voltages of 1.1v or AVcc are provided on the chip. By default the reference is 5v on Arduino boards, 1.1v in the Atmega328. The external reference voltage will be used as the peak voltage for the analog conversion and can range from 0-5v on the Atmega. The reference voltage needs to be set to “External” using the “AnalogReference()” command so that the internal voltage reference and the AREF pin do not get shorted together and damage the microcontroller. The reference voltage should be decoupled at the AREF pin by a capacitor to reduce noise which is especially important to remove in this application where we may be working with very fine movements. Data from a conversion is first red from the ADCL register and then the ADCH register in that order unless it is told to justify the data in another manner.

A conversion is started by disabling the Power Reduction ADC bit, PRADC by writing a zero to it and then a one to the ADC Start Conversion bit, ADSC. A normal conversion takes 13 ADC clock cycles, the first conversion after the ADC switch is turned on takes 25 ADC clock cycles. It takes 100 microseconds to read from the analog input so that makes the maximum sampling rate 10,000 samples/second. At the coding level, a conversion is made by using the “AnalogRead(pin)” command. The 10 bit conversion offers 1024 units of accuracy offering resolution in the millivolts range.

3.4 Possible Architectures and Related Diagrams

There are several architectures to implement our design. The diagram below, Figure 3.4-1 portrays the architecture for our stabilization feature that will be implemented in our design. First, a laser beam will be split using a beam splitter after reflecting off a mirror. The split beam signal will be fed to the video camera. This can be done by having the beam shine directly on the video camera’s lens. The image signal will be fed to the computer through the use of a USB connector and port. The computer will then analyze and processes the image using LabVIEW.

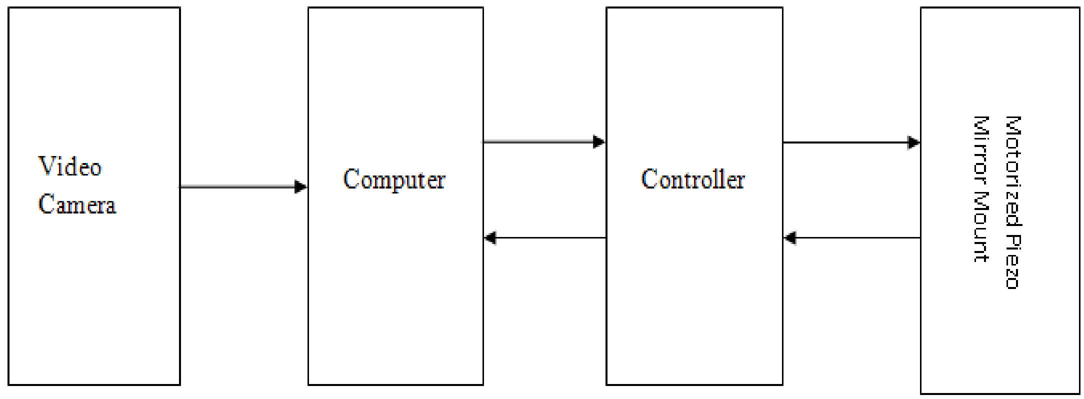


Figure 3.4-1 Block diagram of possible beam stabilization system.

LabVIEW was chosen to interface between the computer and the video camera because it can easily be done. The program will then analyze the picture provided from the video camera. The current laser point will be compared with the desired stabilized location. This can be set by the user through LabVIEW or it can be set to be at the center of the lens by default. The differentiation between the current beam location and the desired location will be monitored constantly. LabVIEW will be programmed to minimize that differentiation by sending signals to the controller which will ultimately adjust the position of the mirrors to change the laser beam's position.

The connection between the controller and the computer will be supported by USB cable and port as well. The controller will have several DIN female input ports to support at least three or more motorized mirror mounts. The controller will mainly be used as a way to control the various mirror mounts. The controller can be powered by a separate power supply or it can be powered through the use of USB port. Since the controller will be communicating with the computer, the USB port will be used for both communication and powering of the controller. The communication will be a bilateral type communication. The controller will be providing useful information such as the current position of the mirror mounts.
The motorized mirror mounts will have a bilateral connection as well using 4 pins DIN connectors. There will be communications with the controller to provide the current position of the mirrors. Another communication will be from the controller to the motorized mirror mounts. The controller will provide the currents needed to operate the mount. The duration of the current will be varied depending on how long the mount is needed to operate. This will be calculated by the computer.

An alternative architecture can be found below in the Figure 3.4-2 The architecture is very similar to the previous architecture. However, as noticed, the controller that use to interface between the computer and the motorized mirror mounts is gone. This architecture design will decrease the time needed to adjust the mirrors, which will ultimately be able to stabilize the beam at higher frequencies. However, it is very difficult to implement this architecture due to the fact that the computer does not support many 4 pin DIN connectors.

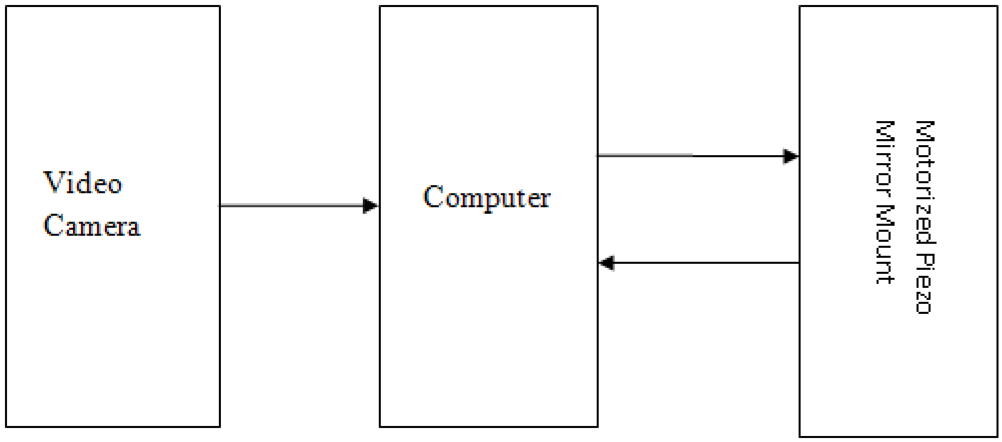


Figure 3.4-2 Alternative block diagram of the structure for beam stabilization system.

Atmega code block diagram - This Figure 3.4-3 shows the flowchart that the code for the Atmega328 follows. The code written in the Arduino IDE using their coding C-like language. This is done because all the low level coding for timing is already done that handles the proper timing for i2c and other such signals. The first step in the code is to initialize all variables and communication lines that need to be initialized. The display is cleared using its clear all command, the display is then initialized as per sudo code given in datasheet of the LCD. A signal is then sent to the computer so that LabVIEW can know that the microcontroller is on, working and has been initialized. The next step is to begin reading data from the ADC through the i2c protocol; prior to the conversion being read, the reference voltage will be read through the Atmega using the built in ADC. The i2c protocol limits the ADC to a maximum of 10 samples per second. The input voltage to the NAU7802 is then calculated based off its internal gain, the reference voltage and the digital conversion given through the i2c link. The final step is to output the final conversions to the USB port for LabVIEW to read, the same information will be output to the LCD screen, as well as the gain through the low noise amplifier. The cycle will then repeat with the reading of the next conversion from the NAU7802. The sample rate will be kept the same so that the computer/LabVIEW can have as many samples as physically possible. There are far faster ADCs, but the precise level at which the signal is being converted slows down the processing and sample speeds.

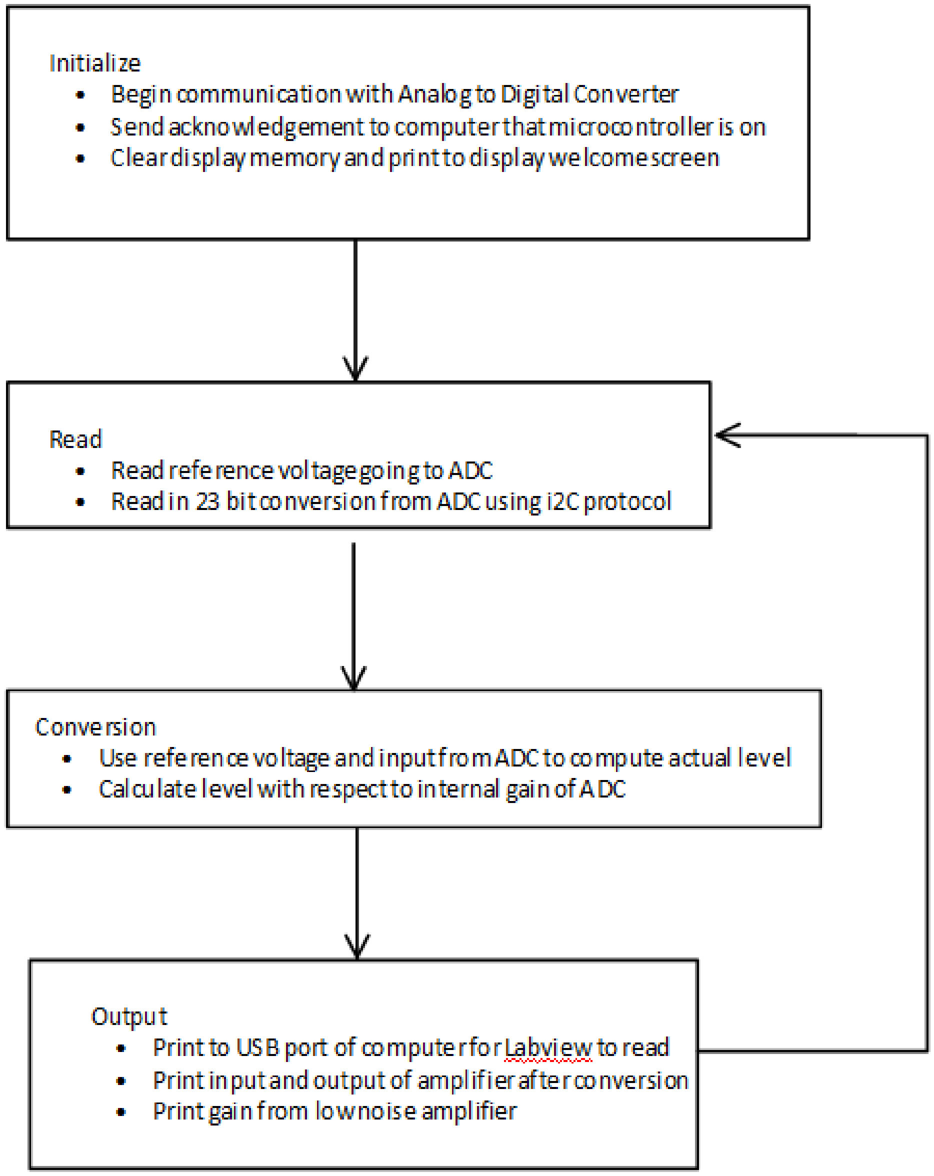


Figure 3.4–3 Flow of code written for Atmega328

4.0 Project Hardware and Software Design Details

4.1 Initial Design Architectures and Related Diagrams

USB to UART IC - This figure is slightly edited from the datasheet to the FT232R, reprinted with permission from FTDI chip and is a simple schematic to communicate with a microcontroller, seen in Figure 4.1-1. The FT232R was chosen as the choice IC to convert the USB computer interface to the UART interface for the Atmega328. This support IC was selected because of its ease of use due to how much is already integrated onto the chip: the EEPROM, the clock circuit and USB resistors. This IC requires very little support circuitry, and along with its SMT package, will take up very little room on a PCB. The capacitors are for noise reduction and the Ferrite bead is in series to remove EMI noise coming from the FT232R to the computer. This diagram already shows how the Atmega328 can get power from the USB port on the computer, however our circuit will be slightly different to include a low pass filter before reaching the Atmeg328. The drivers for this IC can be downloaded from http://www.ftdichip.com/FTDrivers.htm and should be downloaded prior to connecting to the FT232R chip. The FTDI chip drivers are fully compatible with any operating system that has come after windows 98.

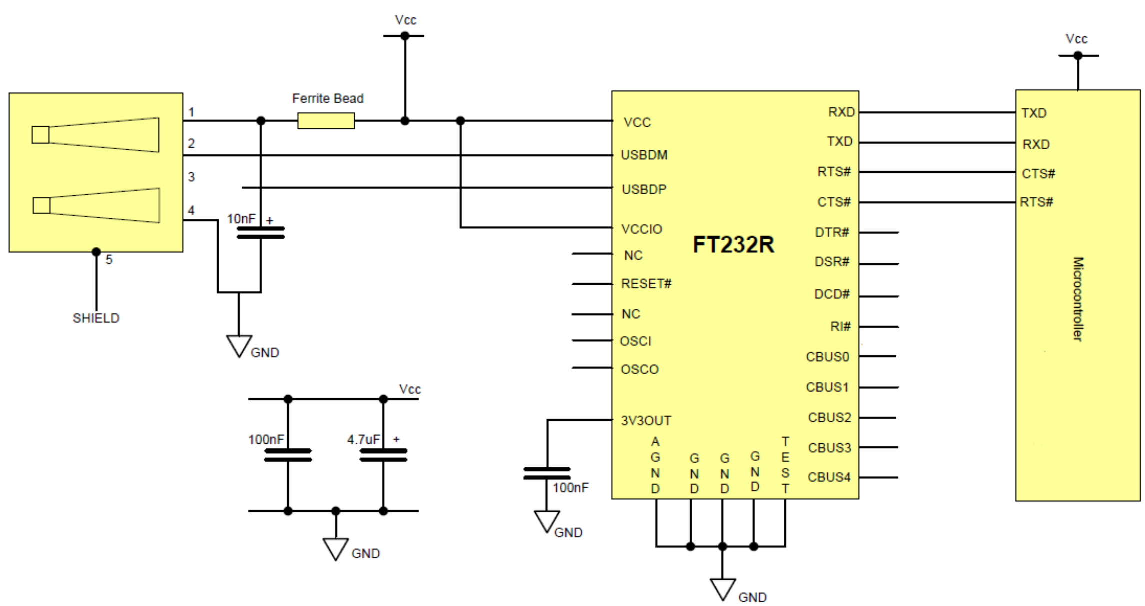


Figure 4.1–1 Reprinted with permission from FTDChip showing the typical connections to a FT232R chip when connected with a Microcontroller

LEDs - There will be two LEDs connected to the FT232R at the CBUS0 and CBUS1 pins in order to visually see communication with the computer and

Atmega328. Because these two LEDs will be lighting up a lot, it would be preferred that they are of low light output because the primary area where this will be used is in a dark room with little to no light. Therefore a LED of bright white light would be irritating and painful. For the sake of the user, two low light LEDs will be selected for this application. The first will be a red LED for transmission because the FT232R will be transmitting more than it will be receiving, thus a low wavelength should be used. This red LED was also selected because of its low light output, 2.5 milliCandela, low current consumption, and low forward voltage required. The second LED should be a different color than the first in order to distinguish between the two. To distinguish the two, the color green was selected because it is different from red, and not as bright as blue and white LEDs. This green LED will have a 2.2v forward voltage, and a rating of 12 milliCandela that will be dialed down by selecting the appropriate resistor in series to lower its brightness. There will be another LED that will be used as an indicator that the Microcontroller is on. As it will be on for the time whole time the device is active, it is plain that a low wavelength should be used. This is why another red LED was selected. Its forward voltage will be 2v and have a rating of 45 milliCandela that can be restricted if the higher light output is deemed too bright in low light. This LED may also be used as an indication of a reset.

24 bit Analog to Digital Converter - The Nuvoton NAU7802 offers 24 bit analog to digital conversion, an onboard oscillator and a programmable low noise amplifier. The low noise amplifier will come in handy to amplify the output signal from the beam intensity detector so that the converter can recognize the low signal that will be in the nanoWatts range. The input signal may be internally amplified by up 128 times. This IC also features an i2C operation which will allow it to communicate with the Atmega328 via 2 pins and have two more pins for power and ground, for a total of 4 pins to the Atmega. The i2C protocol allows for multiple devices to be connected in parallel, “Daisy chain,” and communicate over the same two lines. Because the i2C pins on the Atmega328 are also the analog input pins, the onboard Analog to Digital converter cannot be used in conjunction with this IC at the two pins being used for communication. The number of pins on the NAU7802 allows for up to two signals to be converted, so that any more than two signals will require another Nuvoton NAU7802 to be connected in parallel.

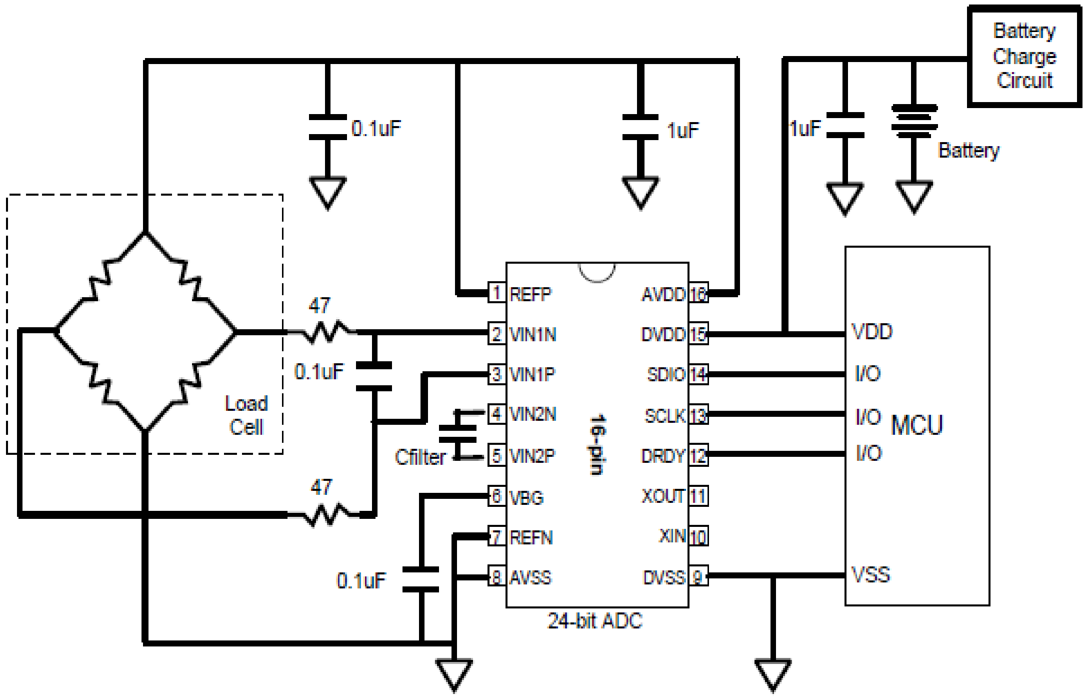


Figure 4.1–2 Typical connection of the NAU7802 with a microcontroller used as a guide to connecting with the Atmega328

LCD for user - This figure is reprinted with permission from Newhaven Display International. This figure shows how the digital output pins from a microcontroller should be interfaced a few of the pins to the LCD board in order to write characters to the display. Characters are written to their location in RAM using an address given in the datasheet followed by the character that you wish for. This display is simple because it also includes commands to clear out the whole display or turn it off. This display module was chosen over many 7 segment displays because we wanted more freedom with what was being displayed in case we decided to include something else to display. With the included backlighting, it is perfect for the dark rooms of the rooms dedicated for optics. This is also one of the few displays that includes a built in character map because of the integrated driver built into this unit. The price difference between purchasing an integrated display such as this and designing your own is negligible if not better.

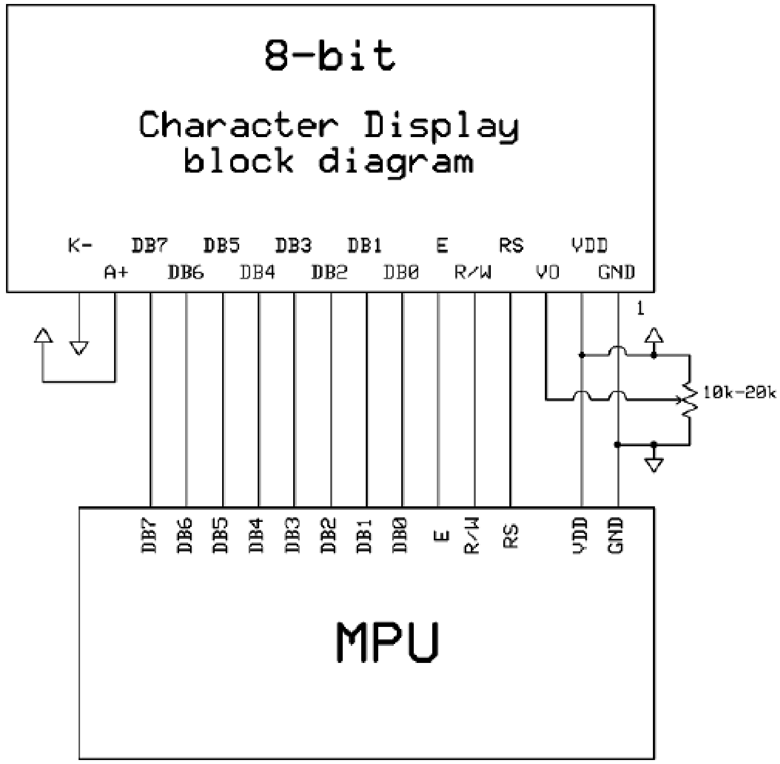


Figure 4.1–3 Reprinted with permission from New Haven Display, typical connection with a microcontroller used to help design schematic

Oscillating crystal - Crystal selection for the Atmega328 is based off of our needs in this project. The Atmega is needed to send data to the computer, display on a screen and input data from the Analog to Digital converter. These functions are not difficult in themselves but combined may require some computation time. It is not known yet exactly how many computations will be required of the Atmega and as such, we do not want to limit it to a lower frequency of oscillation. Because the Atmega can handle up to 20 MHz oscillation it would be nice to use this extra speed for this project. The rest of the circuitry does not need to be changed or altered if a prototype is first made with the 16MHz Arduino board. The difficulty arises when the bootloader must be burned to the Atmega 328, because the Arduino Company does not provide one to be compatible with the 20MHz frequency. The Arduino code will have some timing discrepancies when working with the 20MHz, as well as having difficulty communicating with the computer. Any delay functions are based off the 16MHz and will be inaccurate for the 20MHz frequency. There may be further complications from using the 20MHz frequency that may make it difficult to debug, so a 16MHz speed will be used because of the amount of documentation and the easy to find IDE already provided by the Arduino Company that works well with that frequency.

Voltage regulation - The first place that voltage regulation may be needed is to power the integrated circuits in the circuit. This includes but is not limited to the

Atmega328, the NAU7802, the FT232R, and the screen. The standard for USB power is 5V, while current depends on the USB version that the computer has and can range from 500mA to 900mA. For this reason, current will try to be minimized. If extra power is needed, a power supply may need to be designed or purchased. For this purpose a voltage regulator would be needed apart from the input DC supply. The ON Semiconductor MC33269D was chosen for regulating the voltage from the DC power supply because it has a simple configuration with only 3 leads. It is also very common and has been used in conjunction with the Atmega328 for many applications and has extensive documentation on their usage together. The output of the MC33269D is fixed at 5V but will drop with temperature and current consumption. If current consumption can be kept to a minimum, an external supply may be avoided in order to minimize wires and a need for an outlet near the experiment.

The second place that a voltage regulator may be needed is for the Analog reference voltage for the NAU7802, the 24 bit Analog to Digital converter. This reference voltage would ideally be kept at the perfect voltage at all times to keep accuracy as high as possible. This ideal voltage would be impossible to have even with a voltage regulator, but an attempt must be made for maximum accuracy. The lowest voltage regulator found is the Analog Devices ADR130 which is a high precision, low reference voltage that can output 500mV with 0.35% accuracy. It’s able to get this accuracy because of an internal temperature drift curve that modifies its output voltage. The ADR130 is able to input a voltage range from 2 – 8v and output 0.5v; this is set up in the range of the USB supply voltage. From the 500mV output, a precision of 59.6nV would be possible with 23 effective bits of precision. If further precision is needed past the easily available 56.7nV, the reference voltage may be further divided to a lower voltage. The NAU7802 accepts a reference voltage as low as 0.1V, bringing the precision to 11.92nV which is the absolute minimum precision available from the NAU7802 unless the internal amplifier is used. The lower 0.1V reference voltage would be possible by using a voltage divider on the output and connecting a Unity Buffer Amplifier to keep the load off the resistors keeping them at a constant stable temperature. If the input is 1nV, the NAU7802 can amplify it by 128 times to 128nV. This would be within the range of the precision available from the 0.1V reference voltage. The precision needed to accurately measure the input signal is dependent on the lowest voltage that could possibly be input. If the second input voltage is above the AV_{ref}, a second ADR130 and NAU7802 will be needed.

The third voltage regulation that will be needed is to the power supply for the LCD screen. This screen has a total of 3 pins where a 3.3 supply voltage is needed. The first pin, V_{dd}, is for the power supply of the internal logic which only consumes roughly 1.5mA, or 2.5mA maximum. The supply voltage for the contrast for the LCD screen needs to be kept at approximately 3 volts, but for this a potentiometer can be used to tune the contrast to the desired amount as in the suggested wiring diagram given in the datasheet. The power supply for the LED backlight also requires 3.3v and pulls approximately 20mA. Typically the LCD will pull 21.5mA of current. For this purpose the L78L33C from STMicroelectronics was selected because of its low power dissipation. The L78L33C has a typical dropout voltage of 1.7V and can supply up to 100mA which is more than enough for LCD screen to work off. This is a typical 3 pin regulator with a V_{in}, ground, and V_{out}. The only supportive elements needed for it are two capacitors, one for the input, and one for output. A 0.33uF is recommended for the input pin and a 0.1uF is recommended for the output pin to help eliminate noise on those pins.

Op Amp for voltage buffer - Typically a high precision voltage reference IC is purchased for Analog to Digital conversion reference. This is done to safeguard against voltage drift and imperfections for a simple voltage divider resistive circuit. A 0.1V reference voltage could not be found as of writing this so a 0.5V reference voltage IC will be used as described in another section. To get to the lowest reference voltage that the NAU7802 can use, 0.1V, a simple voltage divider resistive circuit may be used because of the stable reference voltage provided by the ADR130. In order to provide further stability to the voltage reference, a Unity gain amplifier will be used as a buffer. The first Op Amp that was selected as a candidate is the Texas Instrument LF353. It is capable of operating at 5V, and has matched JFET inputs, keeping input bias current to roughly 50pA. It comes in an 8 SOIC package and has two Op Amps integrated on the chip. The second Op Amp that was researched is the STMicroelectronics TS27IDT which is a general purpose CMOS Op Amp that can use the 5V supply voltage from the USB port. The CMOS gates in it keep the input bias current to a minimum, roughly 1pA. They have extremely high input impedance so that it does not alter the current and thus the input voltage is kept stable. This is the major advantage over the LF353 Op Amp; it keeps the input voltage stable through a large temperature range. The STMicroelectronics TS27IDT was selected over an adjustable Op Amp with an offset pin because of its stability over a broad temperature range and because of its low input current. If the output is found wanting in precision, an Op Amp with an offset pin can be found to calibrate.
The right port that is seen in Figure 4.1-4 is the USB female type B port that was selected as part of the initial design for the Atmega subsystem. The power line should have a bypass capacitor in order to dampen any change in the voltage and current. There will be a ferrite bead after the bypass capacitor to block any noise coming from the FT232R IC that may disturb the USB port of the computer. After these simple steps have been taken, the 5V supply may be used as the supply voltage for all of the ICs with little to no alterations which is shown in Figure 4.1-4 as the symbol for a power rail; this supply will be the power supply for all the devices on the PCB which will include any and all integrated circuits as well as voltage regulators. Below the USB port there can be seen a LED that will light up when the circuitry is receiving power making it easy to when it’s not connected or is not receiving power for some reason or another. Pin 17 of the FT232R chip needs to be decoupled to ground in order to keep noise out of the internal 3.3V supply. Pin 20 of the FT232R is power to the core circuitry while pin

4 is power to the UART interface that will be driving the voltage of the signals. There will be two LEDs, as shown in Figure 4.1 – 5, that will light up when transmitting and receiving data from the Atmega328. These are not connected directly to the TXD and RXD lines, but to pins specifically for the purpose of driving LEDs.

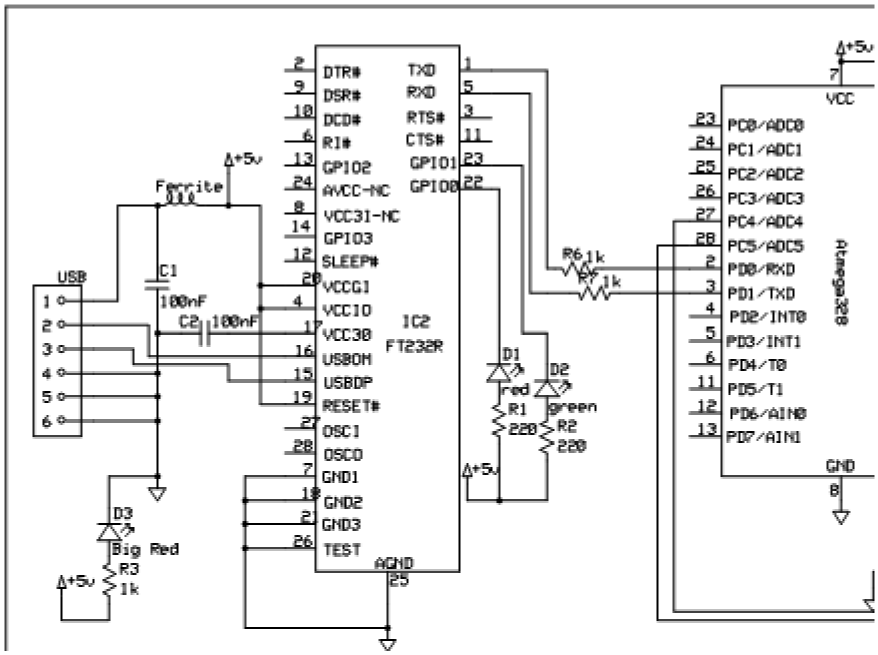


Figure 4.1–4 Right half of the initial schematic for the Atmega subsystem

The TXD and RXD lines of the FT232R are connected to the opposite lines on the Atmega328 so that the TXD of the FT232R is connected to the RXD, pin 2, of the Atmega as seen in Figure 4.1-4. The resistors in series keep the current low so it does not damage the ICs. The Atmega328 needs an external connection to the 5V power rail to the Reset pin 1 which is best seen in Figure 4.1-5; this includes a resistor for the voltage to drop across when the switch is pressed to reset the Atmega, preventing a short between the power supply and ground. Another external power line is needed for AVcc which is the power to the Analog to Digital Converter that must be powered even if the ADC is not used; a bypass capacitor ensures low noise on the ADC power supply. Pins 27 and 28 of the Atmega328 are used to interface with the 24 bit ADC, the NAU7802, where pin 27 is the actual data line and pin 28 is for outputting the clock to synchronize communication. Pin 14 will be used to communicate to the Atmega when a conversion has completed which is signaled at the Data ready pin, Drdy pin 12, of the NAU7802; this connection can be seen in Figure 4.1-5. Pins 9 and 10 of the Atmega are used to input the frequency from the oscillating crystal/capacitor network that is a capacitor connected to an end of the crystal and then to ground.

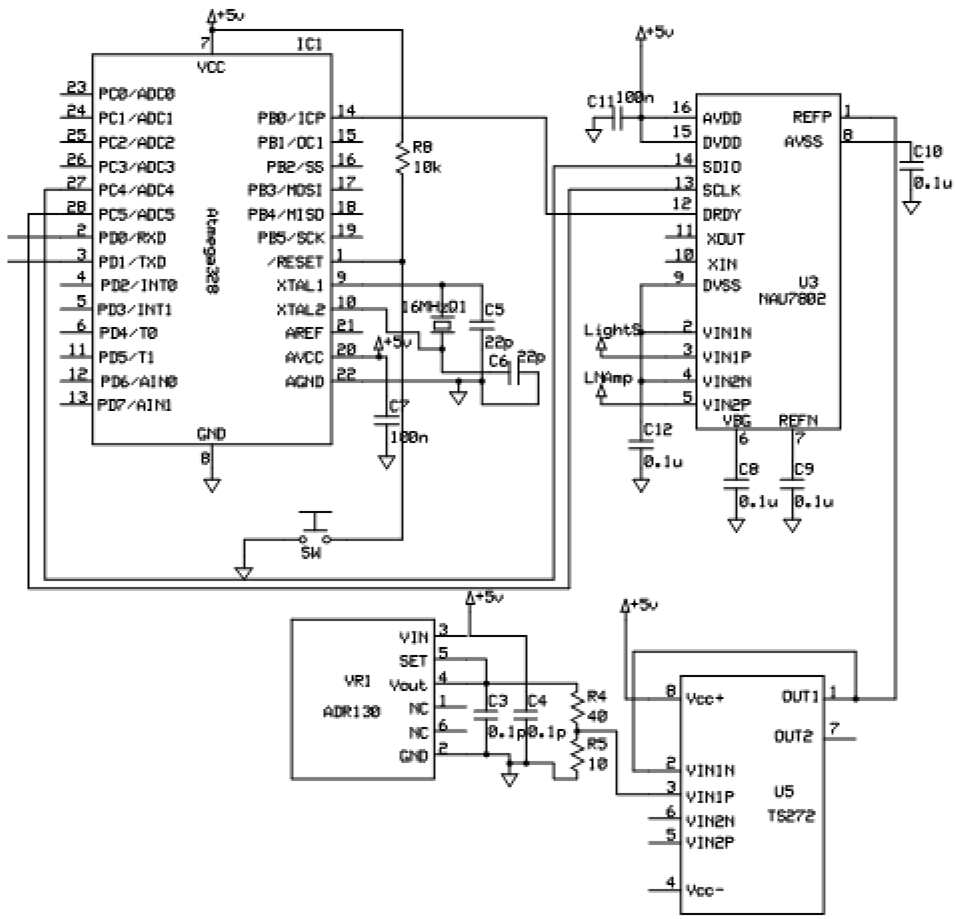


Figure 4.1-5 Right half of the initial design of the Atmega subsystem

Power and ground to the ADC NAU7802 are received through pin 15 and pin 9 respectively for digital logic components, and pins 16 and 9 for analog components. Research into 24 bit ADCs has shown that they are extremely prone to errors due to fluctuation in the analog power supplies. No matter how well the circuitry within the NAU7802 is designed, a change in the analog supply will show through the converted results because of how susceptible ADCs of this precision are to noise and any high frequency signals that are nearby. In order to minimize this error, the power supply pins will have capacitors to keep these voltages from fluctuating; these can be seen in Figure 4.1-5. The Refn pin, pin 7, provides the reference to the low voltage, and Refp, pin 1, provides the high voltage. For this project, the Refp pin will be input from a circuit to supply the 0.1V that is closest to what we expect to be receiving; while Refn will be pulled to ground through a low pass filter in order to avoid any noise. Pins DVSS, VIN1N, and VIN2N will be pulled to ground through a low pass filter so that the ADC has a stable ground to reference against. Pin VIN1P will be used as the first analog input from the Light detector. This signal will then go through a low noise amplifier; this output will then be read by the second analog input pin, VIN2P.

Amplifier System - The amplifier is crucial for this project because it was used to amplify the weak RF signal produced by the MCT Detector. The amplifier was designed to achieve a very high gain of about 10^6. To achieve this gain, several amplifier configurations were used. The two most popular configuration are the inverting operational amplifier and the non-inverting operational. After consideration, it was decided that the inverting operational amplifier configuration was to be used due to the ease of parts acquisition. One possible design architectures can be to have various inverting operational amplifiers to be connected in series. The block diagram in Figure 4.1-6 describes the general layout of the connection. The Amplifier system consisted of six inverting operational amplifiers with a gain of ten. When it was connected in series, the gain was multiplied each time as the signal passes through the operational amplifier. With this configuration, we were able to achieve our desired gain of 10^6.

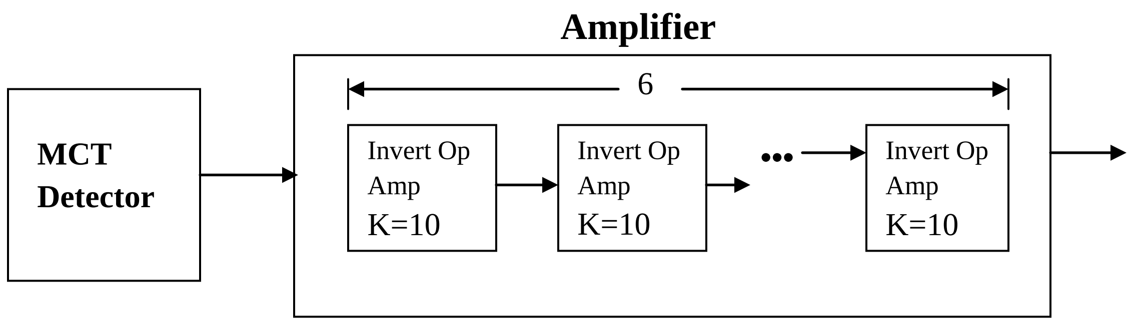


Figure 4.1-6: Initial block diagram of the amplifier design.

Operational Amplifiers - The operational amplifier chosen for this design was the TLC2201CP from Texas Instrument. After consideration between the performances versus the cost, it had been decided that the TLC2201CP supports our needs and the cost is manageable as well. The TLC2201CP gain bandwidth goes up to frequencies as high as about 250kHz. The gain starts to decline as higher frequency components are introduced. The TLC2201CP operational amplifier produces very low noise at the output which prevents major distortions of our already weak signal. There are many factors that cause an amplifier to produce noise and the CMRR, Common Mode Rejection Ratio, is on one factor that helps determine the noise produce by the operational amplifier. The TLC2201CP CMRR in dB versus frequency can be found in Figure 4.1-7. According to Figure 4.1-7, the CMRR is very high, at about more than 100 dB, for low frequency signals of less than 1kHz. As the input signal exhibits higher frequency components, the CMRR starts to drop almost linearly per decade Hertz.

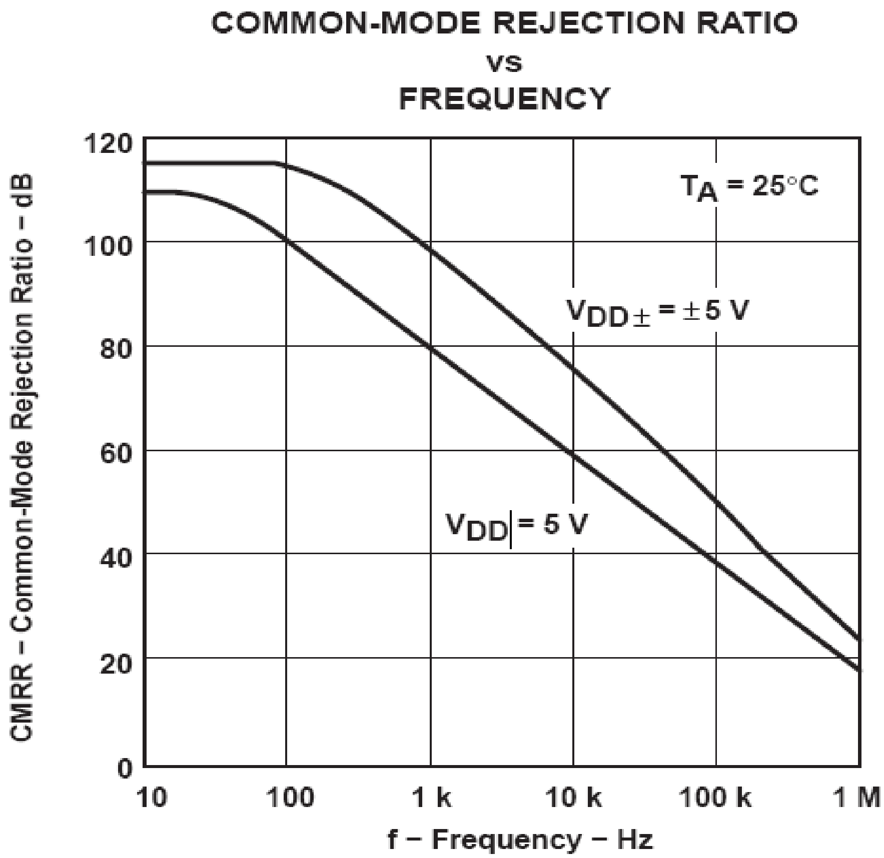


Figure 4.1-7 CMRR in dB vs. Frequency graph for TLC2201CP
Reprinted with permission from Texas Instrument

Overall Amplifier Design - Using the structure layout found in the Figure 4.1-6, a schematic was designed for the amplifier system. The amplifier system schematic can be found in Figure 4.1-8. In the schematic design, TLC2201CP operational amplifiers are used. The input signal comes from the MCT detector's output through the edge mount SMA connector. From there the signal is fed through a 1kΩ resistor connected to the negative input terminal of the operational amplifier. The 10kΩ resistor was connected from the negative input terminal of the operational amplifier to the output. The positive input terminal of the operational amplifier was grounded (GND). The output of the first operational amplifier was connected to another inverting operation amplifier with the gain of 10, like the first operational amplifier's configuration. Currently, the design does not contain any filter in between each output to reduce unwanted noise. However, in the future filters can be added into the design to reduce noise in between each output.

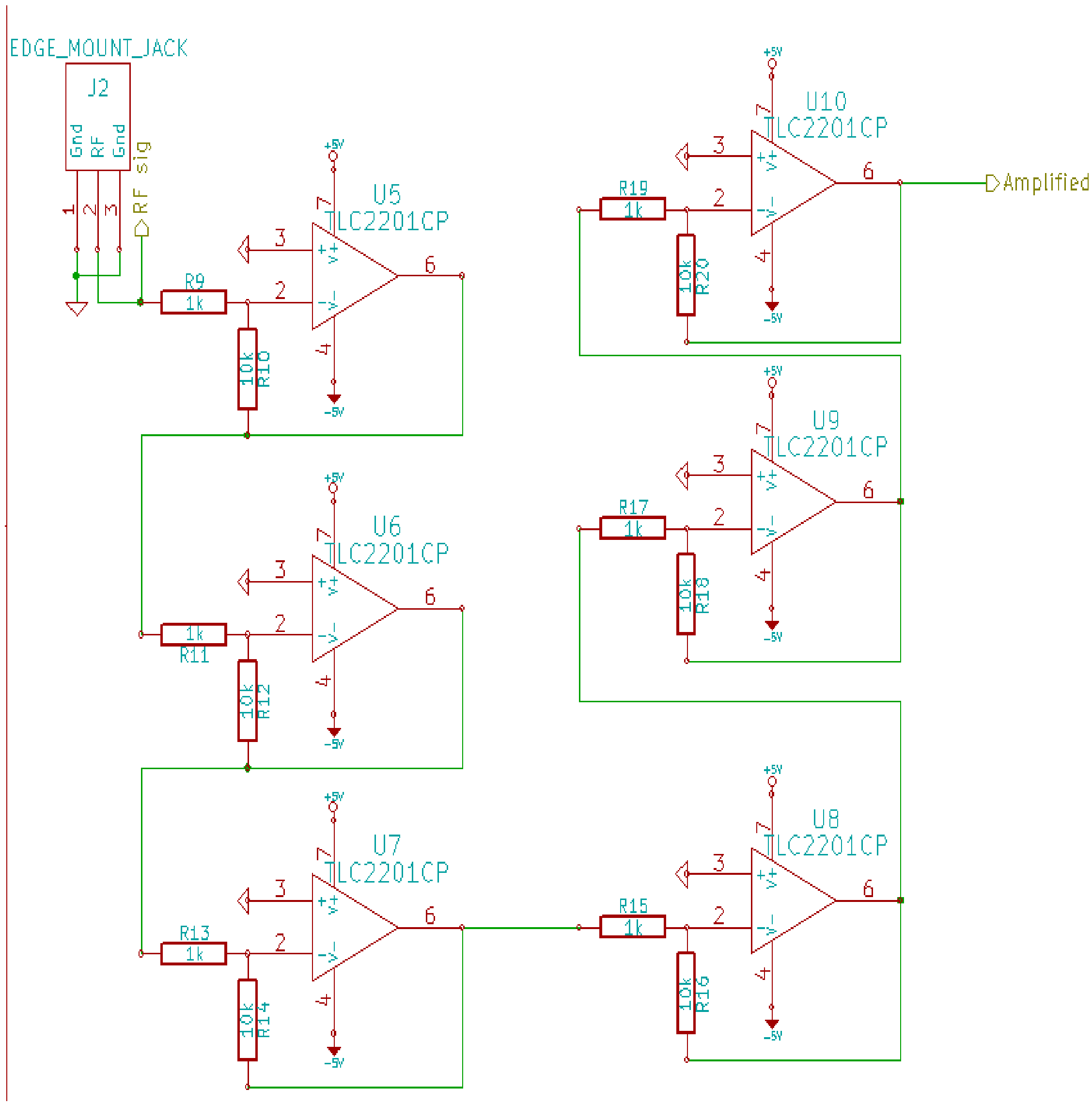


Figure 4.1-8 Schematic of amplifier

4.2 Microcontroller with computer subsystem

From the initial schematic done in ExpressPCB, the final design was done in KiCad, an open source schematic and PCB layout software. This schematic is very similar to the initial design where the communication with the computer is through a USB type B port which is shaped in the likeness of the port in Figure 4.2–1. This female port that was selected has two connectors that will also be soldered to the PCB but is merely for grounding the port and for mechanical stability to easily plug and unplug the USB cable without movement or bending of the port pins. From this USB connection, there is a 5v power supply coming from the computer that will be utilized. This power supply will connect to a 100nF capacitor that is used for its reactance; this purpose of the capacitor requires that it be speedy so a ceramic capacitor will be ideal over an electrolytic capacitor which is much slower to respond in terms of time. The capacitor and 5v supply from the USB port will be tied to a ferrite bead that acts to isolate noise coming from the FT232R chip. This will cancel out any fluctuations in the power supply caused by a change in the load somewhere in the rest of the system. There will still be a red LED connected to the power supply that is used to indicate that power is being received to the USB port. The two data lines of the USB port will be connected to the FT232R chip that handles all the USB protocol and the UART to the Atmega328. The FT232R is used to communicate between the computer and the Atmega328, this chip can be seen in Figure 4.2-1. Power is supplied to pins 4, 20, and 19 of the FT232R; the last pin being the reset pin that remains high and is never pulled low. The ground pins of the FT232R are pins 7, 18, 21, and 25 which are all pulled to ground using a ground plane on the back of the PCB. Pins 17 and 26 of the FT232R are also pulled to ground, where pin 17 is decoupled from ground using a 100nF capacitor. Pin 26, test, needs to be pulled to ground because a high pin will put the chip into test mode and will appear to be failing. Pins 1 and 5 are the transmission and receiver lines respectively and are connected to the opposite set of pins on the Atmega328. A 1k resistor is placed in series between the transmission line of the FT232R and the receiving pin on the Atmega to keep current low on the lines; the same is done on the receiving to transmission line. An LED will be connected to pins 22 and 23 respectively and will also have a resistor connected to keep the power supply from sinking too much current into the LEDs. Transmission will be green and receiving will be red. The crystal/capacitor network can also be seen in figure 4.2–1, which is connected to pins 9 and 10 of the Atmega328 that are used for the input of the desired clock frequency. The acceptable capacitor values are in the range of 10pF to 30pF, so the 22pF selected are appropriate. Figure 4.2-1 also shows the reset push button that will be connected to the reset pin of the Atmega328. This will have a 10k resistor in series with the button to keep the power supply from shorting when the button is pressed.

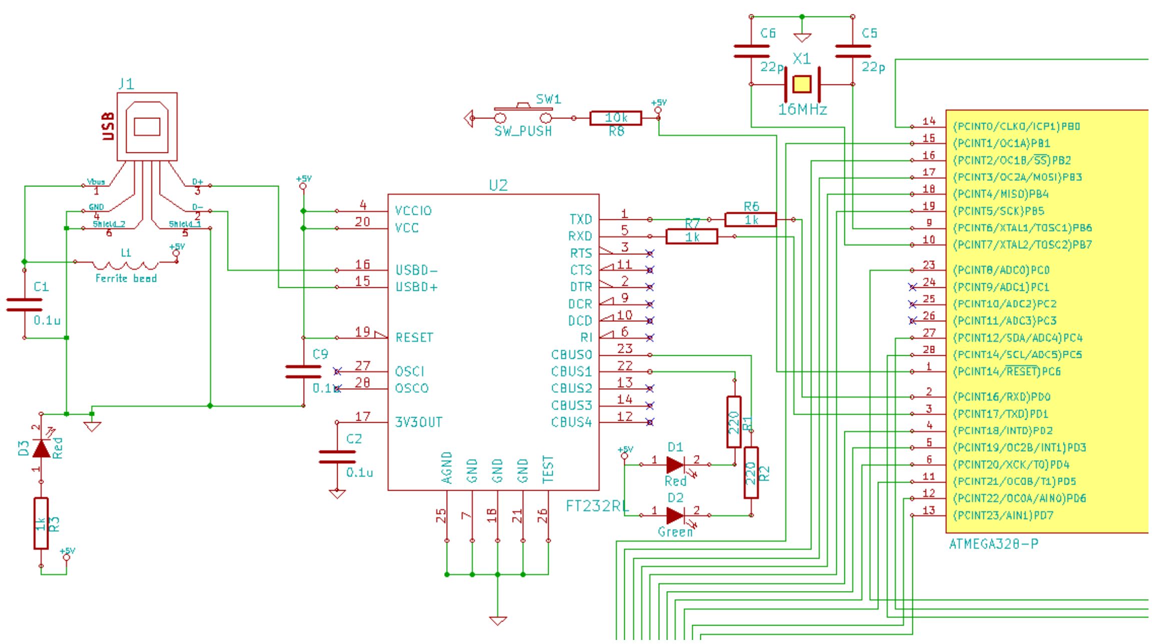


Figure 4.2–1 USB communication and 5v power supply

Power to the Atmega328 is received at pins 7 and 20 for the digital and analog power sections. This power will also have a 0.1uF bypass capacitor. The ARef pin, 21, will remain unconnected despite utilizing the Atmegas built in ADC because the internal 1.1v reference voltage will be used instead. The main supply of information to the Atmega328 will be from the 24 bit Analog to Digital Converter that has been selected which is the NAU7802. In figure 4.2 – 2 it can be seen that it will be connected to the 5v power supply at pins 15 and 16. It will have a single bypass capacitor at those pins to provide reactance and short any high frequency oscillations from the power supply. A ground reference is provided to pins 2 and 4 which are the negative conversion pins of the NAU7802. Ground reference is also provided to pins 9, 8 and 7. Pins 2 and 5 are seen in Figure 4.2–2 to be connected to signals off the page called RF sig and Amplified respectively. These two signals are being sent from the Low Noise Amplifier subsystem that is located on a second page of the schematic. RF sig corresponds to the signal directly coming from the light sensor that is also the input of the Low Noise Amp. The Amplified signal is therefore the output of the Low Noise Amp after it has gone through the gaining loops. These two signals will be converted into a 23 bit representation of the voltage at certain sampling times. The NAU7802 will be sending samples to the Atmega328 at 10 samples per second, or 5 samples per signal; this is accomplished through the I2C interface that can also be seen in figure 4.2–2. The I2C interface with the Atmega328 is comprised of two lines and one optional connection which indicates a conversion is complete at the DRDY pin 12. Pin 13, SCLK, of the NAU7802 is used to get the clock at which communication will be taking place; this is received from pin 28 of the Atmega. The actual data is transferred from pin 14 of the NAU7802 to pin 27 of the Atmega. Although two of the ADC pins on the Atmega328 are being used for the I2C interface, one of the ADC pins will be used to track the positive reference voltage being supplied to the NAU7802 at pin 1. It has been verified in the datasheet for the Atmega328 that this will not produce any noise at the pin being used for analog to digital conversion.

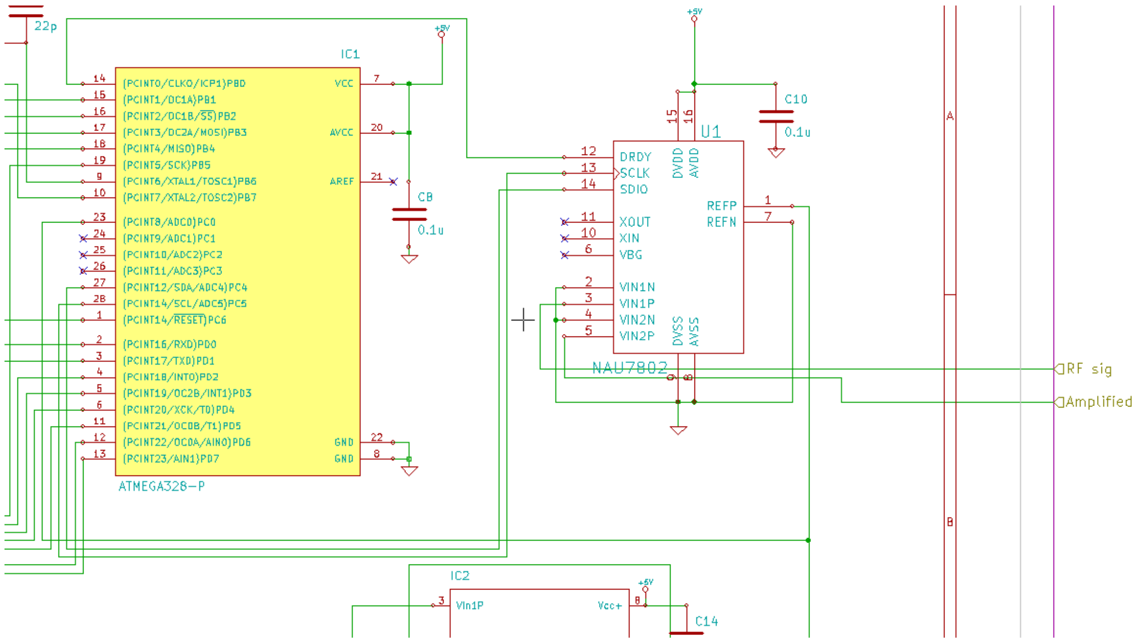


Figure 4.2–2 Connection between Atmega 328 and 24 bit ADC

The positive voltage reference being supplied to the NAU7802, pin 1, in figure 4.2 – 2 is being supplied by the ICs in figure 4.2 – 3. The first step in producing the 0.1v for reference voltage is to use the high precision, low voltage reference that was selected, the ADR130. This will receive power at 5v and will have two capacitors, one 10uF, to stabilize the supply voltage in case of large voltage dips, and a 0.1uF to stabilize higher frequency oscillations. The ADR130 will output 0.5v when its Set and Vout pins are connected together; this voltage will be stabilized with two capacitors, a 0.1uF and a 1uF ceramic capacitor. This will voltage will drive a voltage divider that will output the required 0.1v that is required for the low voltage conversions that will be made. The TS272 Op Amp will serve as a unity gain buffer between the NAU7802 and the reference voltage. This buffer will help keep the reference voltage stable by keeping the load constant so that only temperature will be what causes any change in voltage. The TS272 will get power from the 5v power supply at pin 8 and will have 0.1uF bypass capacitor. Although the TS272 is a dual op amp, only one will be used. This means that pin 6 will be tied to ground and pin 5, the second positive input, will be remain unconnected.

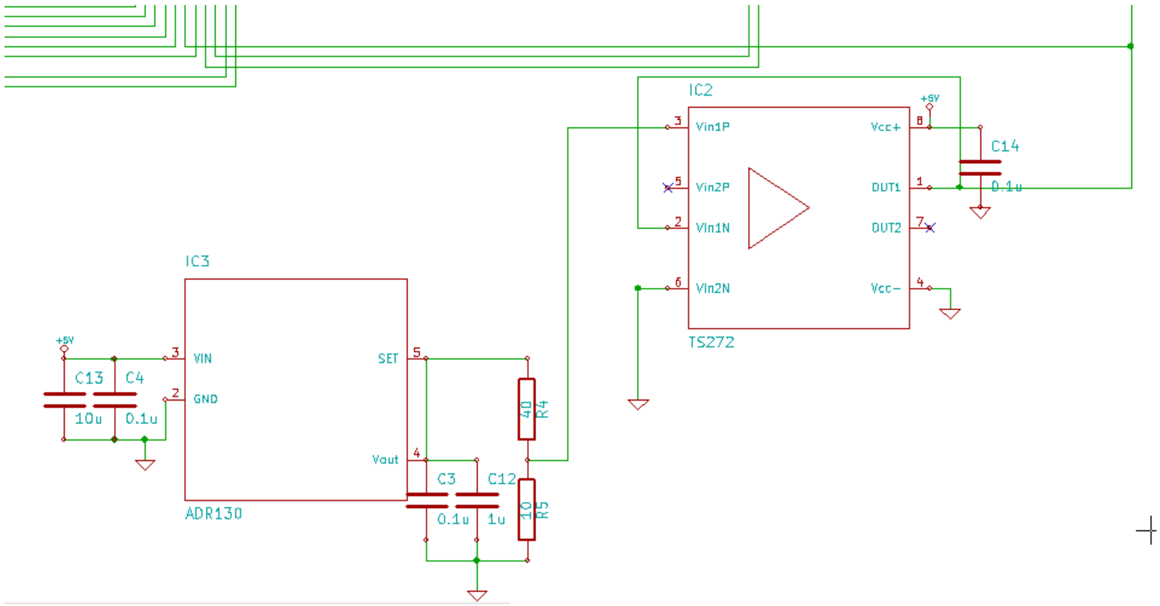


Figure 4.2–3 Voltage reference for 24 bit ADC

The final aspect of the subsystem is the LCD display that will be connected with the Atmega328 and display information in order to quickly view the measurements as well as the current gain from the low noise amplifier. The LCD will first need a 3.3v power supply that will be provided by the L78L33C, which will input the 5v from the USB and output the necessary 3.3v to drive the LCD logic and LED backlight. The L78L33C will need one support capacitor to regulate the input and another to regulate the output. This 3.3v power is supplied Pin 2 and 15 of the LCD screen. A large potentiometer will be connected to the 3.3v as well to power pin 3 of the LCD which controls the contrast of the screen.
Pin 4 of the LCD controls whether a command or data is being sent to it, this will be connected to pin 15 of the Atmega328. Pin 5 of the LCD controls the reading and writing, this will be connected with pin 16 of the Atmega. Pin 6 is the operation enable signal which will be connected to pin 17 of the Atmega. Pins 7 through 14 of the LCD are data bus lines that supply the command, address, or character data. All the information for the command codes, addresses and the character map are supplied on the datasheet, these will be coded and included as part of the code being uploaded to the Atmega. There was not an array of 8 pins in sequence available on the Atmega so the data pins are connected to the remainder of the digital pins, 4–6, 11–13, 18 and 19 that were not part of the analog to digital converter pins. All connections to the LCD screen can be seen in their PCB form in figure 4.2–5, as well as being an accurate representation of the space each component will take up on the final PCB layout.

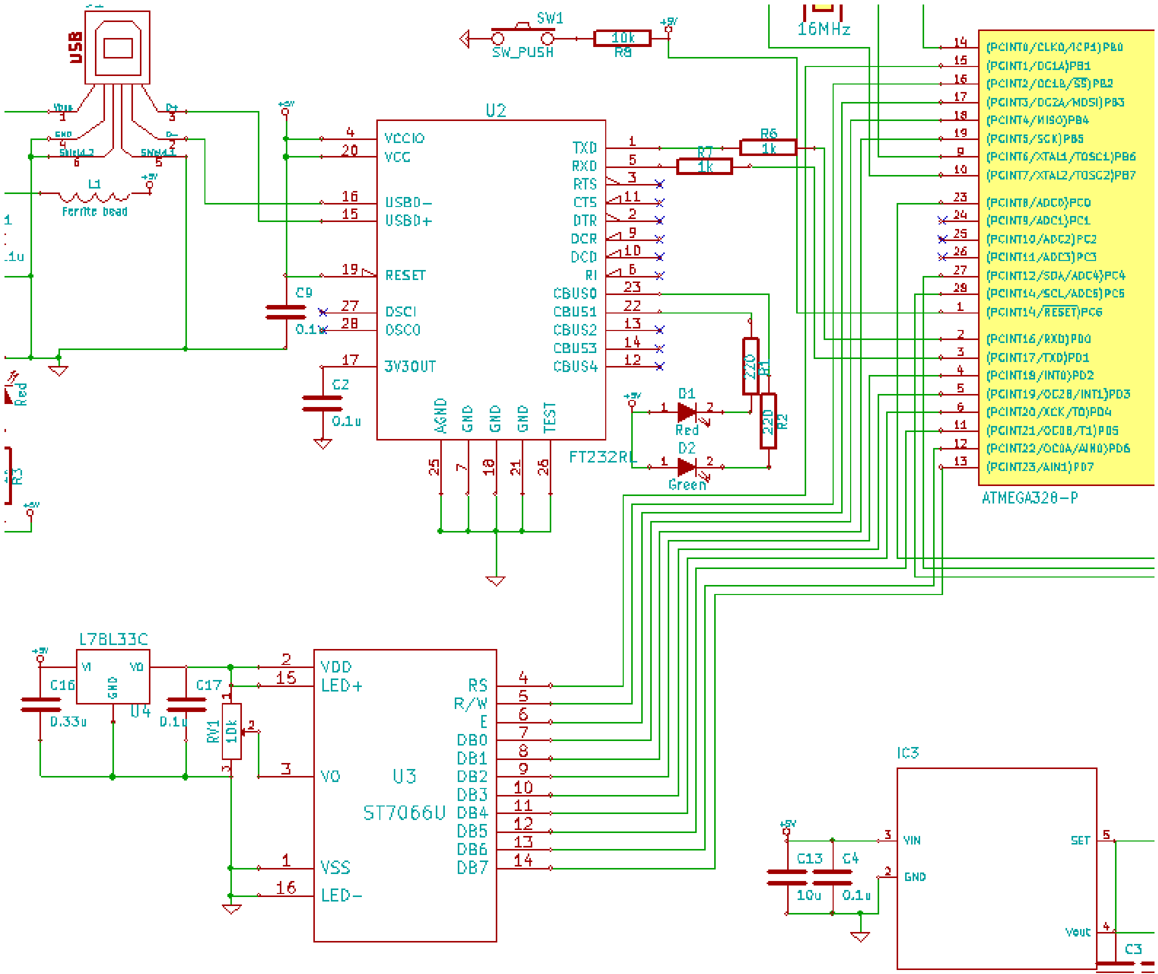


Figure 4.2–4 Final section of schematic showing voltage supply to LCD and connection with Atmega328

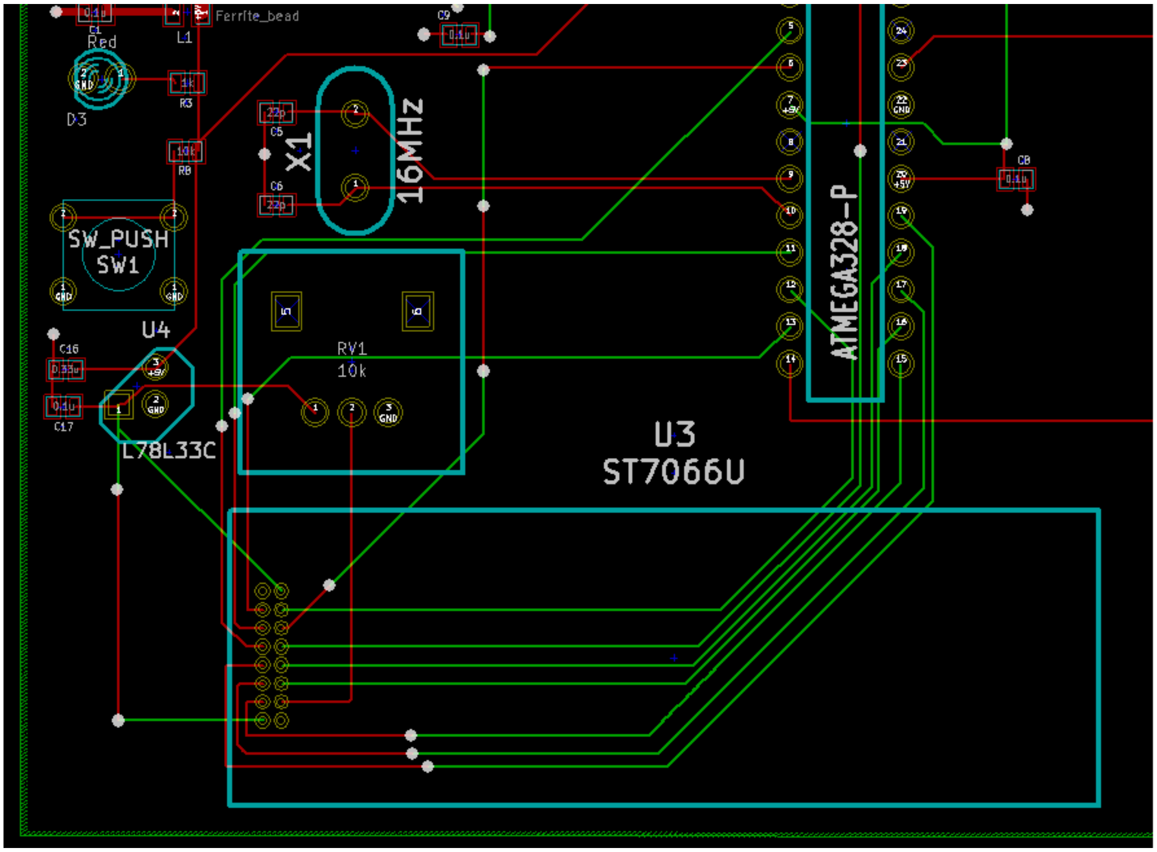


Figure 4.2–5 LCD screen footprint and supportive voltage regulator with potentiometer for screen contrast

For the USB to UART IC, the FT232R, the 28-SSOP packaging will work for this application. It has a small footprint of 5.3mm width and 10.2mm height, this can be seen in figure 4.2-6. The leads have a pitch of 0.65mm. This package does not have an exposed pad making it easier to solder onto the PCB board by hand. The FT232R does not need to be programmed and handles all the USB protocol. This means that it simply needs to be soldered where it needs to go without having to worry about programming it after it's placed. When compared with the 32-QFN package that is offered, which is 5mm by 5mm, not much space is saved with the QFN package and is more difficult to solder because the leads are underneath the package. The QFN package also has an exposed pad that complicates soldering onto a PCB board on top of the extra difficulty of 4 more pins.

In conjunction with the USB to UART IC, there will be a USB port to use to connect the Atmega328 with a computer. There are many choices when it comes to the USB port as there is standard type A and B connectors, along with a mini and micro version of each of those. The Arduino development board uses the type B connector commonly used on printers, while the type A is the connector on all computers. The only benefit for the mini and micro versions is the small footprint that is essential to portable electronics. For our application the reduction in size is negligible and may even make it inconvenient if its original cable is lost. Cables for the smaller USB types can sometimes be difficult to find. The type A female port has a width of 13.1mm and length of 14.1mm; while the type B female is 16.5mm long by 12.1mm wide. Type A connectors are by far the most common ports, but type A to A cables are nonstandard making them difficult to find in a store. Both types provide a large port to stay securely connected. Type B is what will be used for convenience and because of its common use, this connector's size and footprint can be seen in figure 4.2-6.

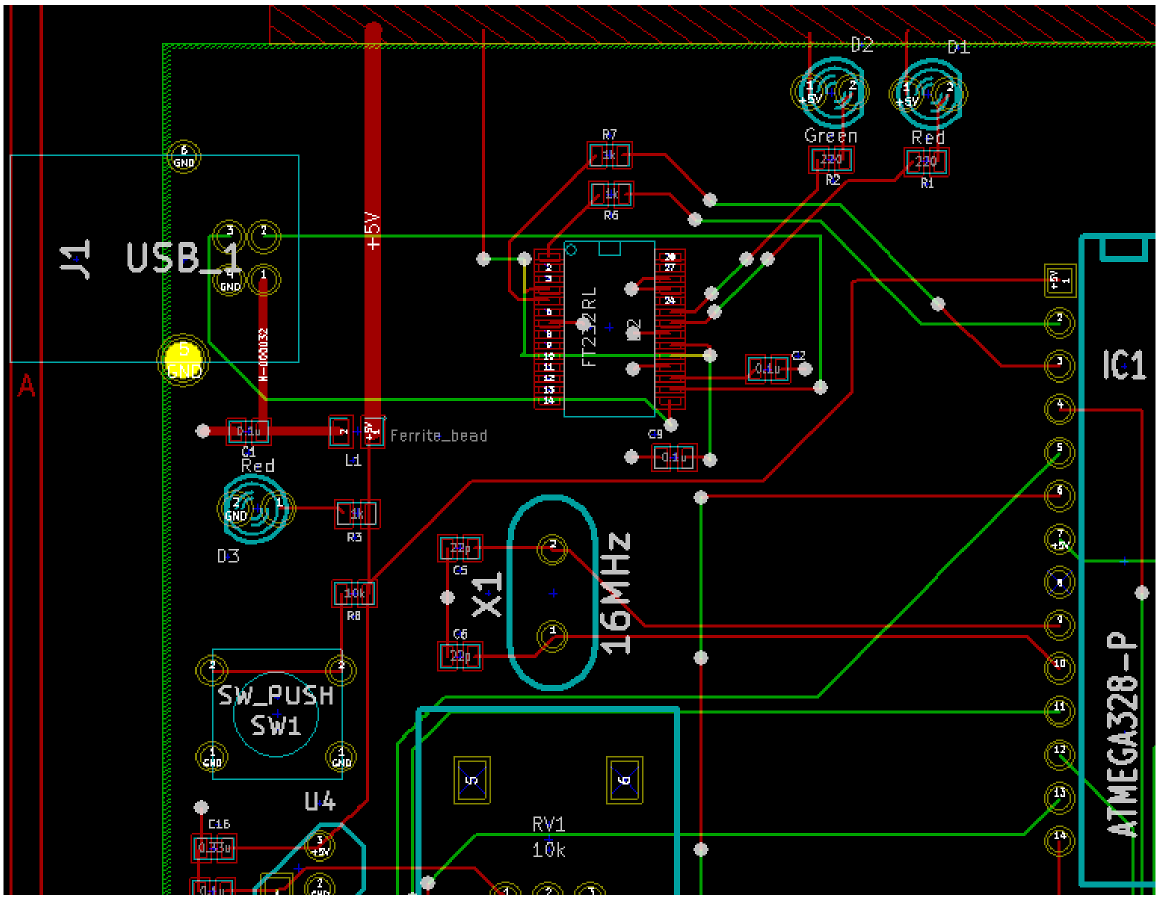


Figure 4.2–6 Communication footprints with USB port and FT232RL chip, and supportive elements to Atmega328

The Atmega328 was chosen because it contains all the features we need as well as being extremely popular, so extensive documentation is available for many projects. It comes in a 28-DIP, 32-TQFP, and 32-VFQFN packaging. The 28-DIP is what we will be using for this project because it is much easier to bootload with an Arduino development board as a DIP. A VFQFN or a TQFP would first have to be soldered to a PCB and then programmed with pins on the PCB board. A DIP also has the advantage of being easy to prototype with the Arduino board with its built in IC socket. A large package will have the advantage of making it less susceptible to heating and static discharge. The 28 DIP selected for the final design and can be seen in figure 4.2–7 on the right.

The Nuvoton NAU7802 Analog to Digital Converter (ADC) comes in a 16-DIP as well as a 16-SOP. While a DIP is much easier to work with, the SOP has a smaller footprint. The SOP is 10mm long and 4mm wide; while the 16-DIP is 19mm long and 6.5mm wide. The IC does not require any programming making it alright to use the SOP. The package will not be under heavy strain from input voltage so heat will not be a problem. In the end, using the 16-SOP will save space on the PCB board. Upon further research of using a 24 bit ADC, there has been difficulty in achieving the desired 23 effective bits of resolution using the datasheet configurations of all ADCs. Because this part of the circuit may require more testing and modifications, the 16-DIP package will be bought to make prototyping easy on a breadboard, this footprint can be seen on the final PCB design in figure 4.2-7.

The Reference voltage regulator is an integral part to providing a stable voltage reference for the NAU7802. This package is very small however and does not need to be programmed and will not require rigorous testing. In order to conserve space, a small package will be purchased for the ADR130**.** The 6-TSOT seems to be the smallest form that the Voltage reference comes in and is therefore the one that we will be using for this project, this footprint is in figure 4.2–7 towards the top. In conjunction with the Reference voltage ADR130, an Op Amp will be used to buffer the voltage from a voltage divider after the ADR130. This Op Amp will be a simple unity gain configuration and will not need as extensive prototyping and testing as the NAU7802 ADC. The TS27IDT that was selected to be the Op Amp of choice for this step comes in 3 different packages: DIP8, SO8 and TSSOP 8. The DIP8 is about 10.9mm by 6.5 mm. The SO8 package is estimated to be about 5mm by 3.9mm. The last package, the TSSOP8, is about 3mm by 4.4mm. For the purposes of saving board space, the SO8 will be used for the TS27IDT because a footprint is readily available for this package and it is still much smaller than the DIP8, the SO8 package is in figure 4.2–7 as part of the final PCB layout. The library and coding for the LCD screen will need to be written before the PCB is finalized and ordered. In order to supply the voltage and current for the screen, the L78L33C voltage regulator from STMicroelectronics will be used to prototype and test the LCD screen and code. In order to easily test and prototype, the TO-92 was selected for purchase for the L78L33C voltage regulator, which is simply a 3 pronged through hole package. This will also provide more surface area for heat dissipation due to the high voltage dissipation needed to reduce the voltage to the necessary 3.3v. The footprint for this package can be seen in figure 4.2–5 to the left of the large square potentiometer.

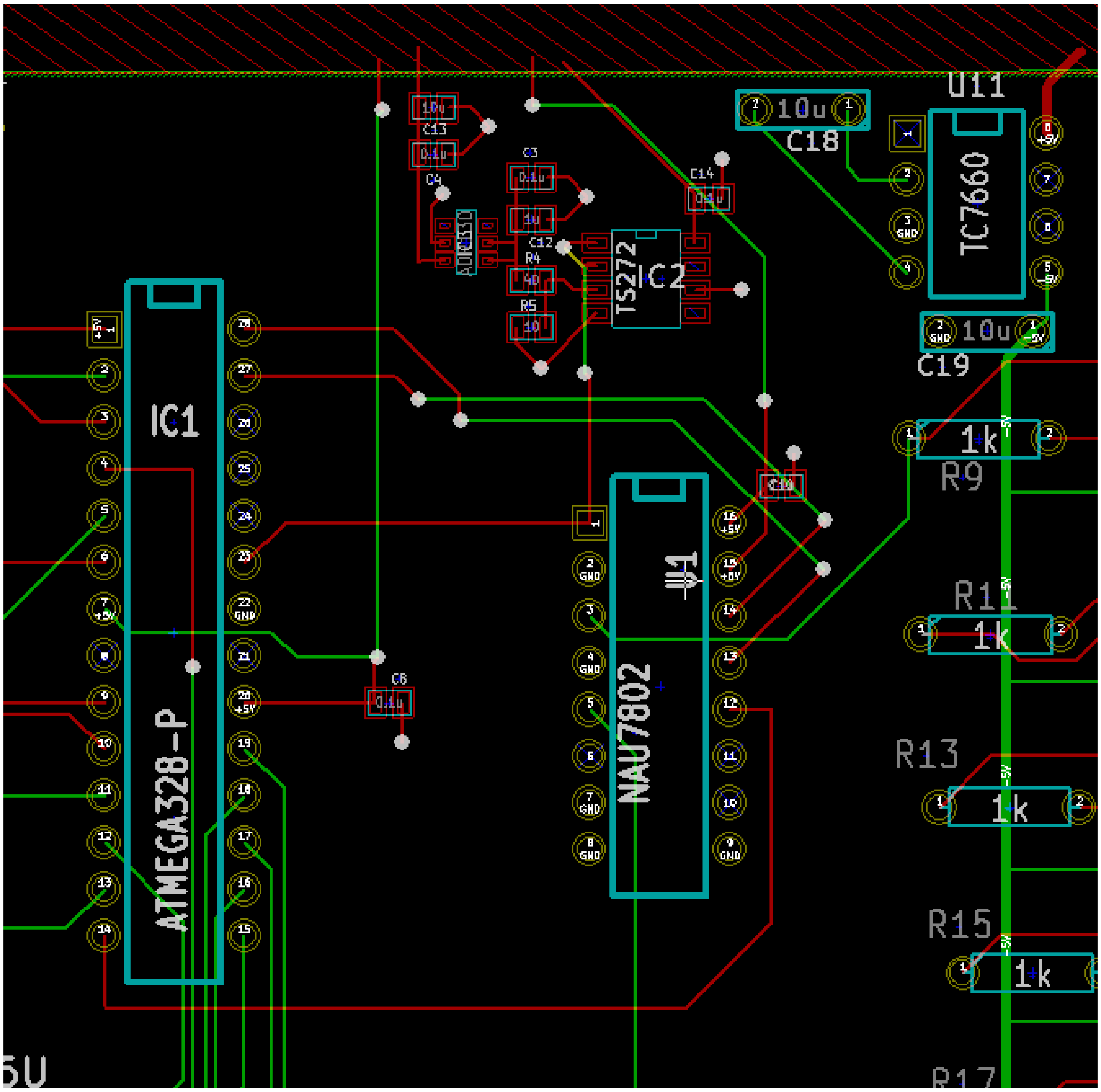


Figure 4.2-7 24 bit ADC and reference voltage circuitry above it

4.3 Microcontroller with Light Intensity Sensor Subsystem

The crystal mount used to hold the crystal inside a mirror mount will be of a thin metal construction. This will be made from steel to provide durability and a rigid stable structure. The general shape of it will be of a thin circle that has been extruded. To make this, a strip of half an inch from a thin sheet of steel will be cut. It will be formed into a circle to fit into the motor mount's holding area; a set of four holes will be drilled in opposite side of the circle. The holes will serve to hold screws which will be tightened to hold the crystal in place. The overall structure for the light sensor and microcontroller subsystem is composed of three components. The first component is the MCT detector, which is a light sensor. The MCT detector is expected to produce an analog signal that will be connected to a low noise amplifier system. After the signal is amplified to a desired gain, the output will be connected to a microcontroller. The signal will get sampled for computational analysis. The block diagram for the overlook structure of this subsystem can be found in Figure 4.3-1.

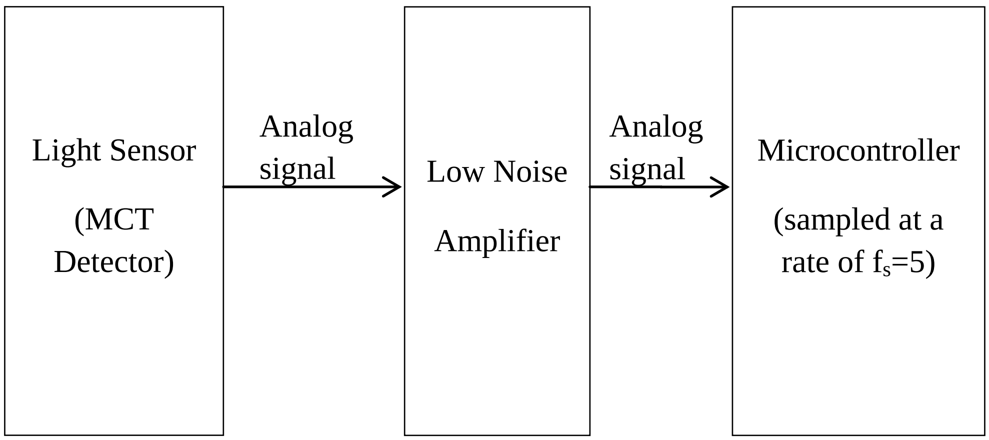


Figure 4.3-1 Structural diagram of subsystem.

The light sensor that we used for this project was the MCT detector. The acronym MCT stands for the material used to make the semiconductor contained within the device, which are: mercury, cadmium, and telluride. MCT detectors were chosen over normal light sensors because the wavelengths needed to be detected are low intensity infrared coming from the crystal. The MCT detectors have a very high level of sensitivity compared to normal light sensors.

Naturally the signal detected by the sensor was very weak. The MCT detector device we used recognizes this and therefore it also has a low-noise amplifier from within. This amplifier will intensify the weak signal for processing while introduces little noise to the signal. The output of the MCT detector will be in the form of a SMA connector. A SMA Cable was then used to feed the signal to other amplifiers in order to achieve the correct signal strength for processing. SMA cable was chosen over normal wires because our signal is very weak and the SMA Cable would protect and preserve the signal from outside noises much better than the standard wire.

In preparation to setup up the MCT detector, the schematic setup in Figure 4.3-2, located below, was used. The schematic found in the figure below consists of two operational amplifiers. The first amplifier is a non-inverting amplifier with a gain of 3. The gain can be calculated using the following equation: $K_{total} = 1 + R_2/R_1$. The values of 10kΩ and 5KΩ resistors were chosen because it provided a ratio of two, which we needed to get K_{total} to equal three. With a power supply of 5VDC input connected to the positive input terminal of the non-inverting amplifier, labeled U1, would produce an output of 15VDC. Since the MCT detector that we used required 5VDC and 15VDC to operate, that part of the schematic took care of the 15VDC input required. For the 5VDC input, we can feed it directly from the

5VDC power supply used for the non-inverting amplifier or we can feed it through a buffer, labeled U2, as can be seen in the figure. It is important to note that the amplifiers we used are rail-to-rail operational amplifiers. The advantage of using this schematic is instead of using two DC power supplies for the MCT detector, we can reduce the amount into one, the 5VDC power supply. As seen from the multi-meters in figure 4.3-2, the output is that of which we want for the MCT. If we decide to use the same ±VCC to power both operational amplifiers, then the operational amplifier that requires the higher VCC will be determining the ±VCC for both. In this case, our ±VCC should be greater than 15V. This can come from the controller and computer subsystem's power supply.

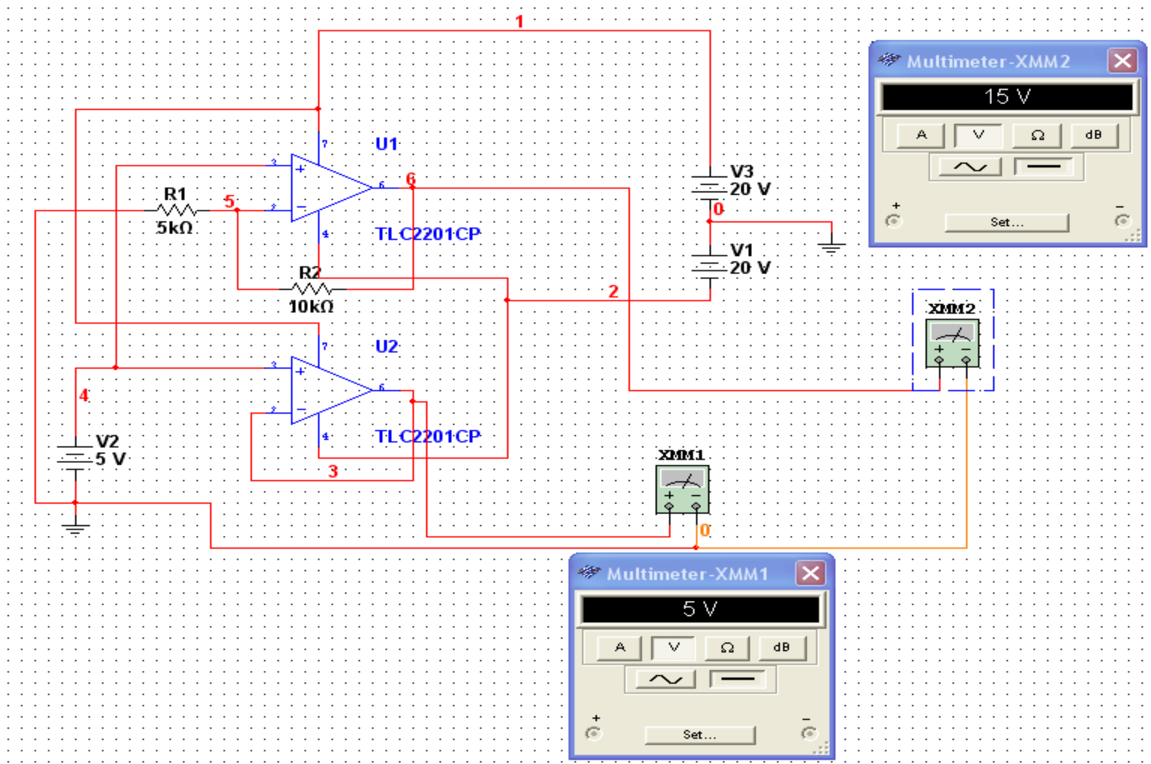


Figure 4.3-2 Power supply schematic for MCT detector.

To set up the MCT detector, we use the connections found in the Figure 4.3-3. The connection is fairly simple since there are only three inputs. This simplicity was an advantage considering the space environment of the lab's set up. The 15VDC and 5VDC produced by the two previous amplifiers was connected to appropriate ports. The ground was connected to the universal ground used for other devices.

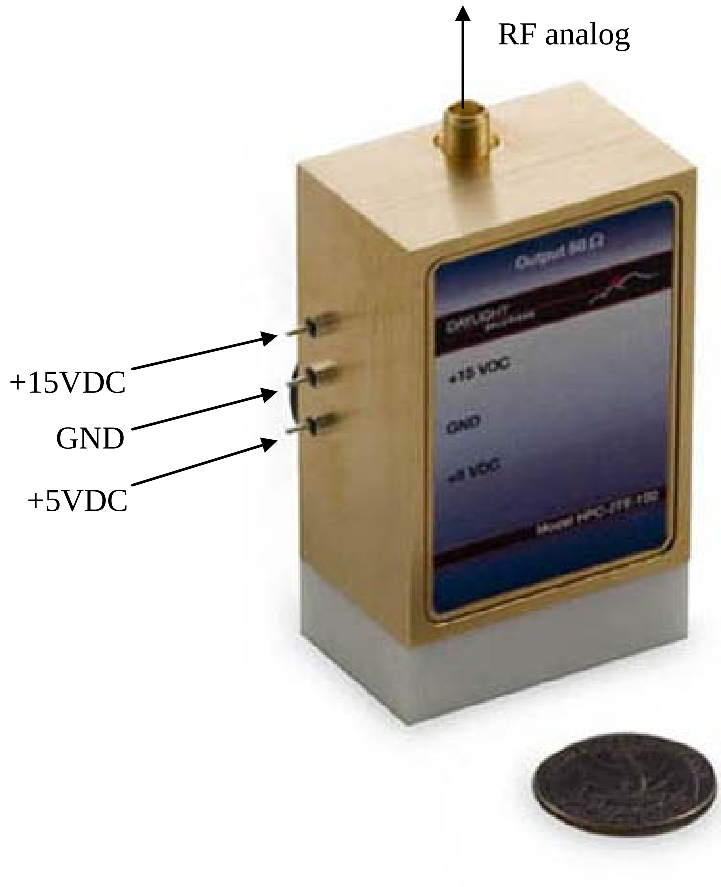
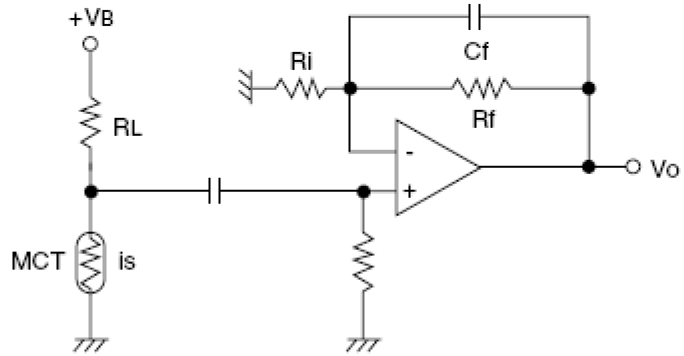


Figure 4.3-3 Diagram MCT Detector input/output.

The inside of the MCT detector, it is composed of the circuit schematic found in Figure 4.3-4. As seen from the schematic, the infrared light will come into contact with the MCT detector. The detector will produce a current that would go towards the positive input of the internal of the operational amplifier. This current varied based upon the intensity of the light. At the positive input of the operational amplifier, a Rd resistor is added. Ideally, all of the current produced by the detector will travel across the Rd resistor since 0 current is supposed to enter the positive input terminal of the operational amplifier. The voltage at the positive input terminal of the operational amplifier would be determined by $-I_{detector}$ x Rd. Rd can be adjusted for a desired voltage range at the positive input terminal. With the configuration, it is determined to be a non-inverting amplifier. The gain is 1+(Rf/Ri), where Rf is the resistor across the negative feedback and Ri is the resistor at the negative input terminal of the operational amplifier. A power supply with low noise and ripple will be used for Vb. This corresponds to the +5VDC in the Figure 4.3-3. Several capacitors are used in this circuit to filter positive noise. The cut off frequency, f_c, can be calculated with the following equation:

$$fc = \frac{1}{2\pi CfRf}$$



$$Vo = -\, is \cdot Rd \cdot \left(1 + \frac{Rf}{Ri}\right) \quad \left(\begin{array}{l} \text{is: SIGNAL CURRENT} \\ \text{Rd: DARK RESISTANCE} \end{array}\right)$$

Figure 4.3-4 MCT Detector Schematic

It is predicted that the output signal from the MCT detector will be in the nano-volt (nV) range. However, our project's specification requires that the signal to be in the milli-volt range (mV). In order to achieve this, the signal in the SMA Cable will be connected to a series of low-noise amplifiers. For the connection to occur, a female SMA connector mount used for printed circuit boards will be soldered onto the circuit board containing the amplifier to connect with the male SMA cable. The reason this mount was chosen because it can support signal frequencies up to 18GHz. That range is enough to support the bandwidth of our signal. The PCB will most likely have four holes at the desired mounting location.

Based on the specifications mentioned earlier, our total gain K_{total}, must be 1 x10-^{6}. We will be using the equation Ktotal = K_1 * K_2*…K_n to determine the desired gain our amplifier will need. Since the gain desired is so high, several amplifiers will need to be implemented and connected in series. At this stage, it is unclear on what the range of frequencies produced by the MCT detector we will be interested since the specification on the detector only hinted of Radio Frequencies, from 3KHz-300GHz.It was found out that operational amplifier have different gain bandwidths and so by picking which operational amplifier used in the design will ultimately decide which frequency components the amplifier supports.

The schematic of the 10^6 gain amplifier system is found in Figure 4.3-5. It is composed up of six individual amplifiers connected in series. The operational amplifier model chosen for these amplifiers are the TLC2201CP. These operation amplifiers produce very little noise, which means it is capable of preserving the original signal. With this decision, the amplifier will support frequencies up to 100kHz. As the input signal frequency components are higher, the total gain will drop. With a 5 nano-volts signal, the gain is still sufficient enough to have milli-volts at the output up to 250kHz.

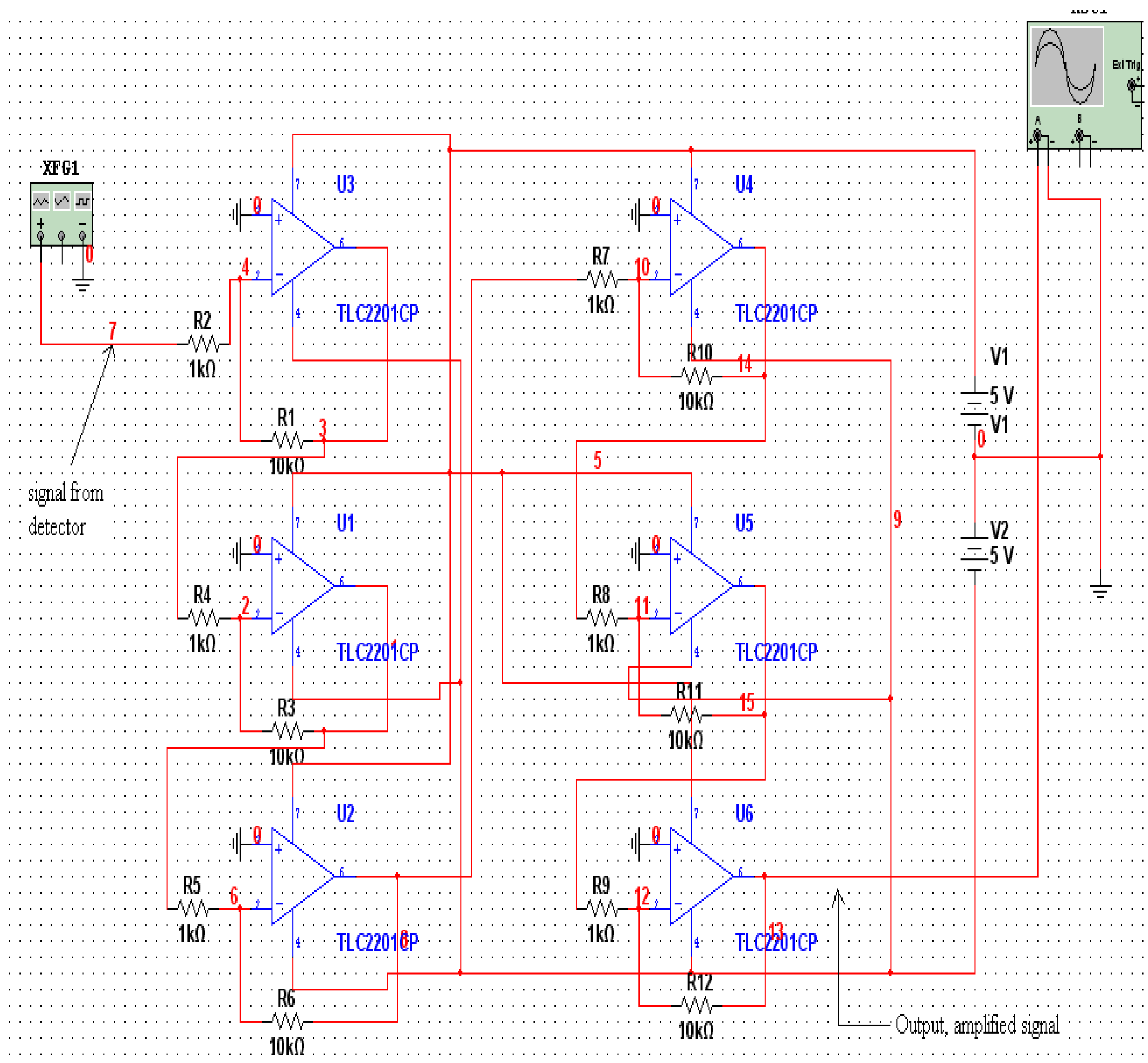


Figure 4.3-5 Amplifier schematic

In addition to the gain bandwidth, the Common Mode Rejection Ratio (CMRR) is very important to our amplifier. With low CMRR, the output signal of the operational amplifier will include noise. Since we are dealing with very weak signals, it is ideal that our CMRR is high. The TLC2201CP operational amplifier CMRR graph can be found in Figure 4.3.2-2. From the chart, this operational amplifier has very high CMRR when dealing with signals with frequency components less than 1kHz. As the frequency components increases, the CMRR starts to drop, almost linearly. At about 100kHz, the CMRR drops to 50dB.

The following equation can be used to calculate the CMRR:

$$CMRR = \frac{Av}{Acm} \;\; or \;\; 20\log\left(\frac{Av}{Acm}\right) dB \quad (1)$$

Where Av is the differential gain and Acm is the common-mode gain. To calculate the differential gain and the common-mode gain, the following equations are used:

$$Av = \frac{Vo}{(V+) - (V-)} \quad (2)$$

$$Acm = \frac{Vo}{Vcm} \quad (3)$$

From the equations above, Vo represents the voltage at the output of the operational amplifier. V+ and V- represent the voltage at the + and – terminal of the operational amplifier respectively. Vcm is usually the voltage common to both V+ and V-. As seen from the equations, the Av and Acm are affected by the input voltage at the terminal. This will ultimately affect the CMRR and noise of the output signal.

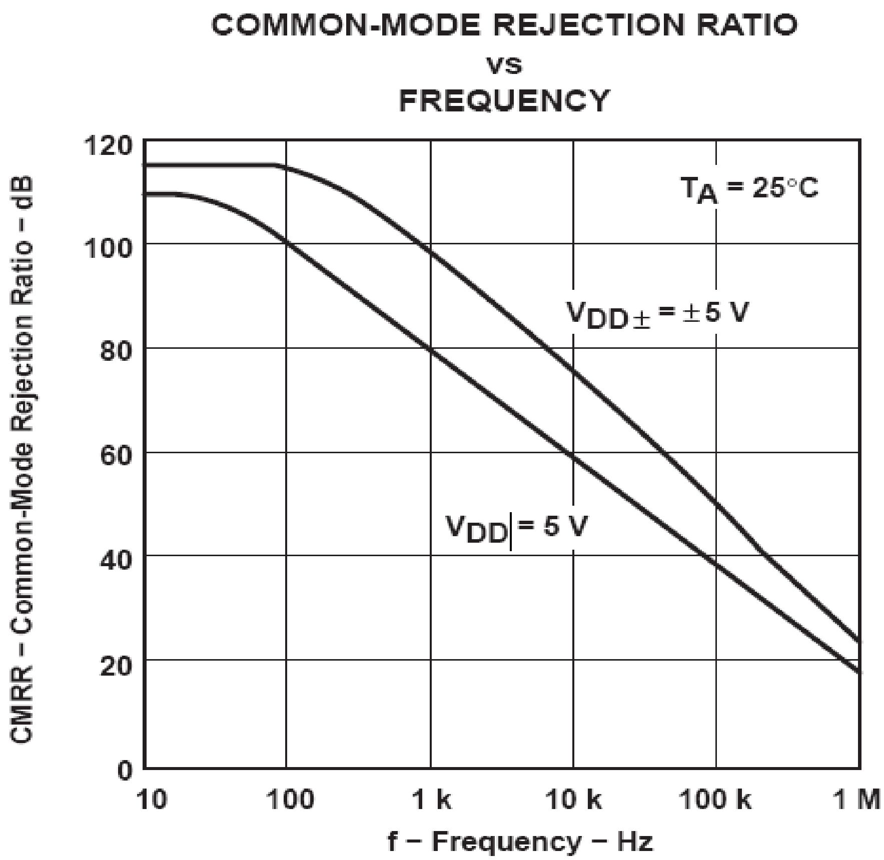


Figure 4.3-6 CMRR in dB vs. Frequency Plot of TLC2201CP

In designing the amplifier, simulations were done to reinstate and support the schematic design. A screen shot of the simulation can be found on Figure 4.3-7. In the figure to the left, displays the input signal from the function generator. In application to our project, this will be the signal received from the MCT detector. A sine wave of amplitude 10 nano-volts peak with frequency component of 250kHz were used to verify that the design supports high frequency components. An oscilloscope was placed at the output of the last operation amplifier and was measured to be about 1 milli-volts. This is the ideal range we would like our signal to be amplified.

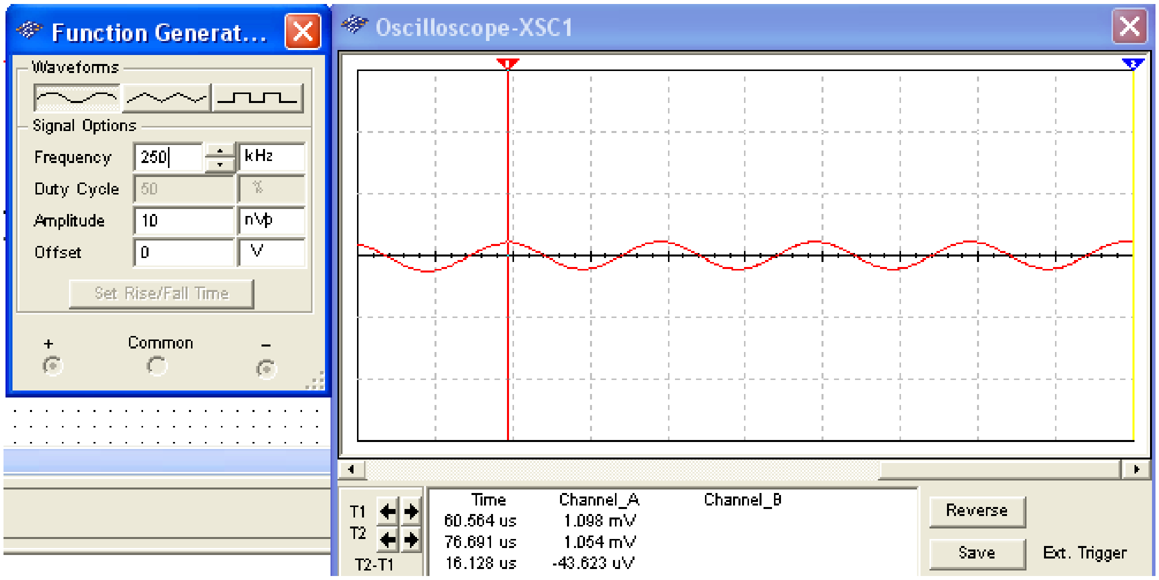


Figure 4.3-7 Simulation result of amplifier with input signal at 250kHz.

The same simulation was run at lower frequency components. The result can be found in Figure 4.3-8. The signal used this time has the same waveform and amplitude as the previous simulation. However the frequency component was changed from 250kHz to 250Hz as seen in the figure above. The output measured at the output terminal of the operational amplifier by an oscilloscope reads to be about 20 milli-volts. Comparing this result with the simulation results of the 250kHz signal, it clear that our gain is higher in our low frequency simulation. However, measurements met our desired goal of having our signal amplified from nano-volts to milli-volts.

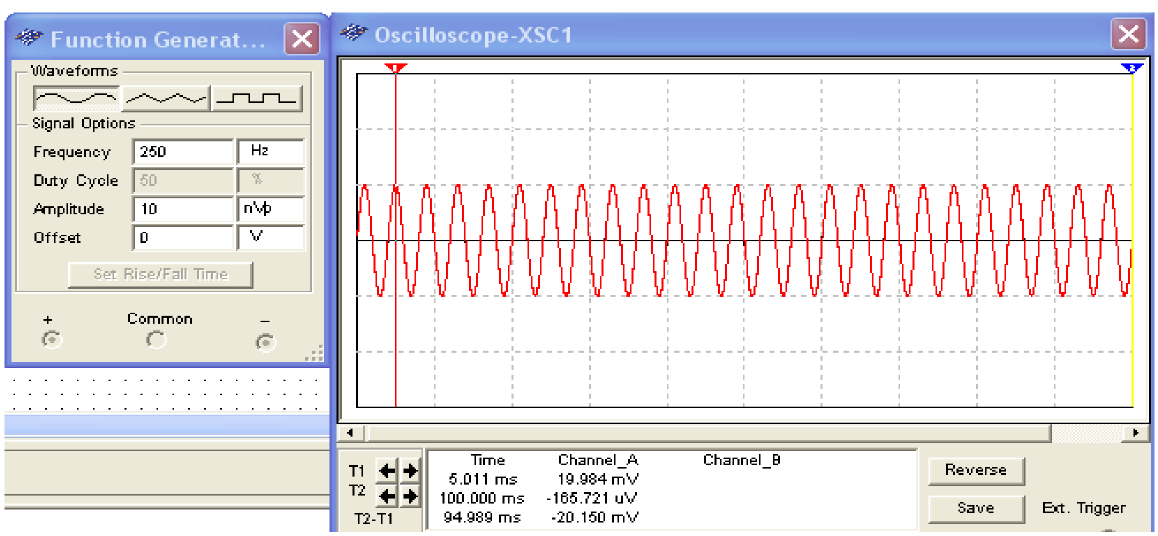


Figure 4.3-8: Simulation result of amplifier with input signal at 250Hz.

After the schematic was simulated to understand its behavioral response, the schematic was transferred over to KiCad, a program to develop PCBs. The schematic created in KiCad can be found in Figure 4.3-9. The schematic is very similar to the previous schematic. However, this schematic includes the SMA connector at the input. The operational amplifiers used will be the TLC2201CP.As an individual circuit, we need a power supply to power the Vcc for the operational amplifiers. However, it has been planned that this circuit will be combined with the microcontroller's PCB. The final circuit will have its +5V Vcc power supply provided through USB from the microcontroller.

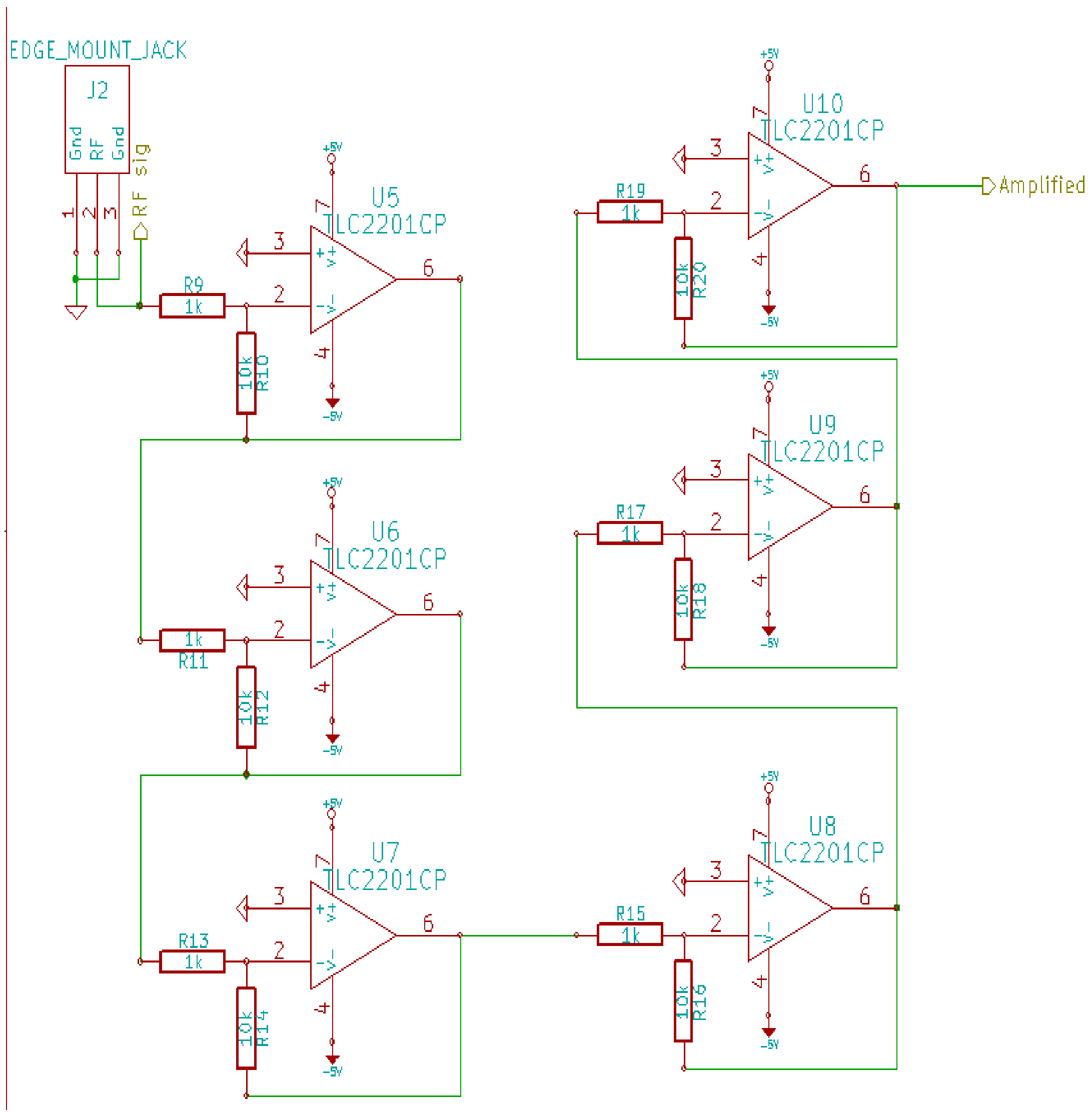


Figure 4.3-9 Complete schematic for amplifier system.

The +5Vcc is expected to be provided from the USB port. However, the signal will be inverted at the output of the first operational amplifier and therefore the amplifier requires a -5V at the –Vcc terminal of the operational amplifier as well.

To provide the -5V to power the –Vcc terminal, we use a VDC to VDC converter device modeled TC7660. The schematic in KiCad of the TC7660 configuration can be found in the Figure 4.3.3-2. The +5VDC from the USB port will be junction and connected to pin 8 of the TC7660. Pin 5 of the TC7660 will produce -5VDC and is connected to the –Vcc terminal of the TLC2201CP operational amplifiers. The voltage at the output of TC7660 will experience some oscillation due to the imperfect conversion. The 10µF capacitor will be attacked from the Vout pint to GND to stabilize the output. The capacitor serves as a filter to higher frequency oscillations.

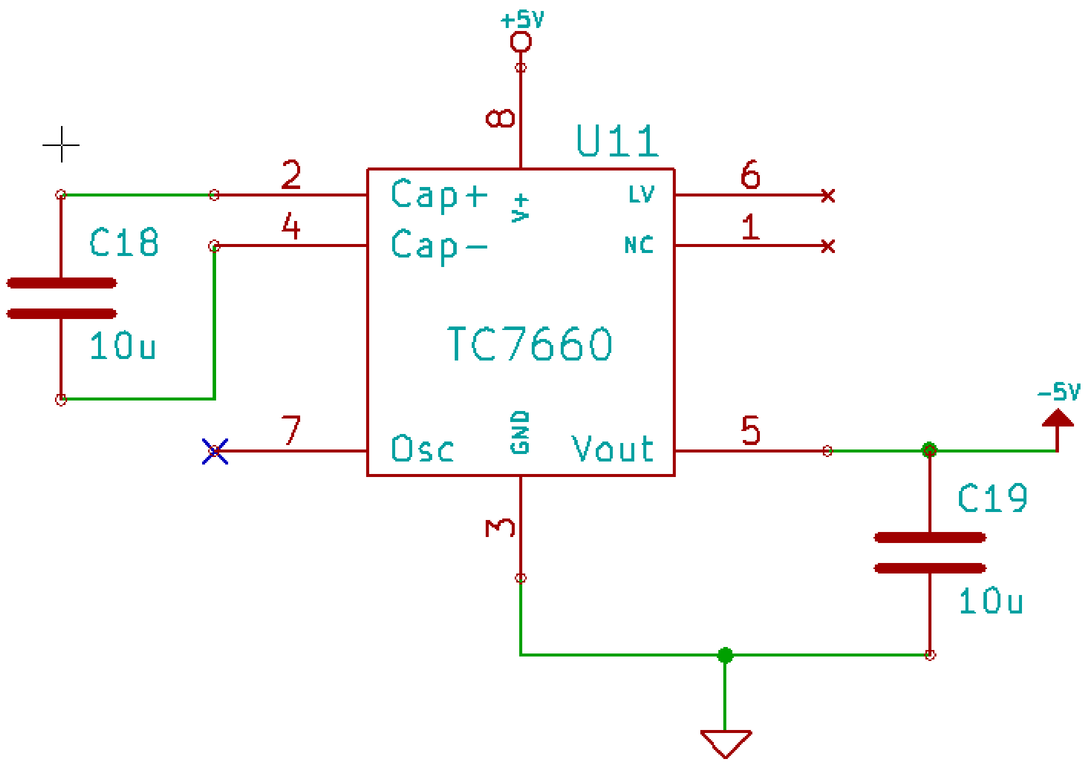


Figure 4.3-10 TC7660 voltage converter configuration schematic.

After the schematic was done, the PCB was designed. This can be found in Figure 4.3-11. In this figure, the lines seen are traces of the various components and their connections. The red traces in the figure indicate the routes for the top layer of the PCB. These will be for surface mount components such as the operational amplifier. The green traces in the figure indicate the routes for the bottom layer of the PCB. This will be for through-hole components like the resistors used in the design.

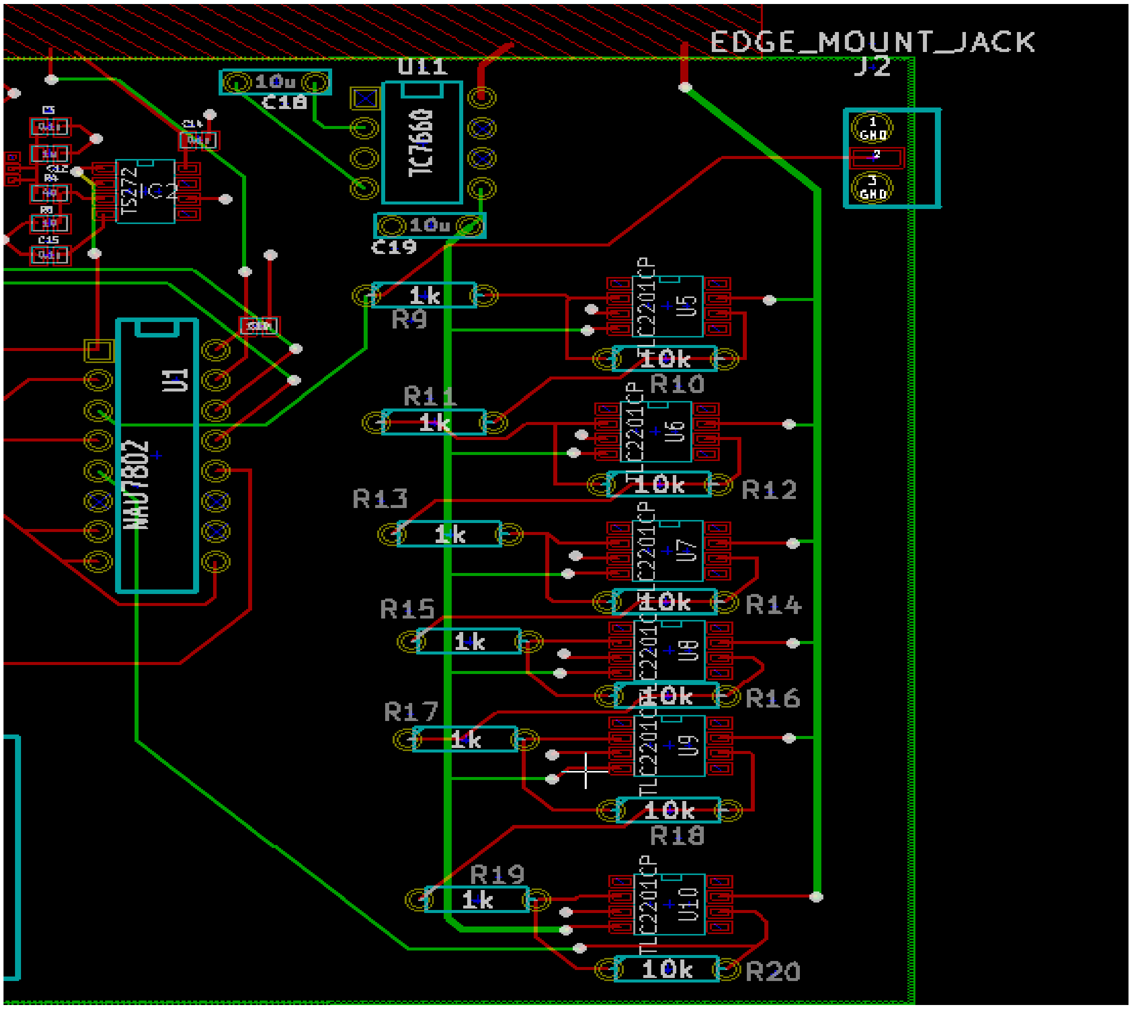


Figure 4.3-11 Portion of PCB showing the amplifier system.

The design uses six operational amplifiers as well as six 1kΩ and 10kΩ resistors. Inverting amplifier connections were used, however the output signal's polarity is not inverted due to the even amount of inverting amplifiers used. Inverting amplifiers were used due to the ease of evening the gain for each of the operational amplifiers. Since the gain across the operational amplifiers are the same, the ratio of the resistors must be the same from the equation $K=-(R2/R1)$. It was picked so that the same two resistor's nominal values could be used for each operational amplifier so that the components are bundled. Because they are bundled, acquiring the components will be much easier than if they weren't. The 5Vcc required to power the operational amplifiers will be produced through the USB hub from the microcontroller.

After the desired gain of the signal is achieved, the signal will be connected to the Atmega328 microcontroller subsystem. It was decided that the amplifier will be included on the microcontroller's PCB, so the connection will be an internal trace. This will prevent a lot of noise that might affect the signal if the connection were to be externally. The Atmega328 subsystem will be connected to the computer to further analyze the signal. Most of the analysis will be simple, since the objective is to check for the strongest signal. This can be done in the LabVIEW program.

4.4 Software Design

The main part of our project is to create a program for rotating the optical crystal, as seen in the class diagram (Figure 4.4-1), minus the parts about stabilizing mirrors. Rotation of the crystal involves being able to manually move the motor mounts to a desired position. The more complex component is a raster scan of the crystal.

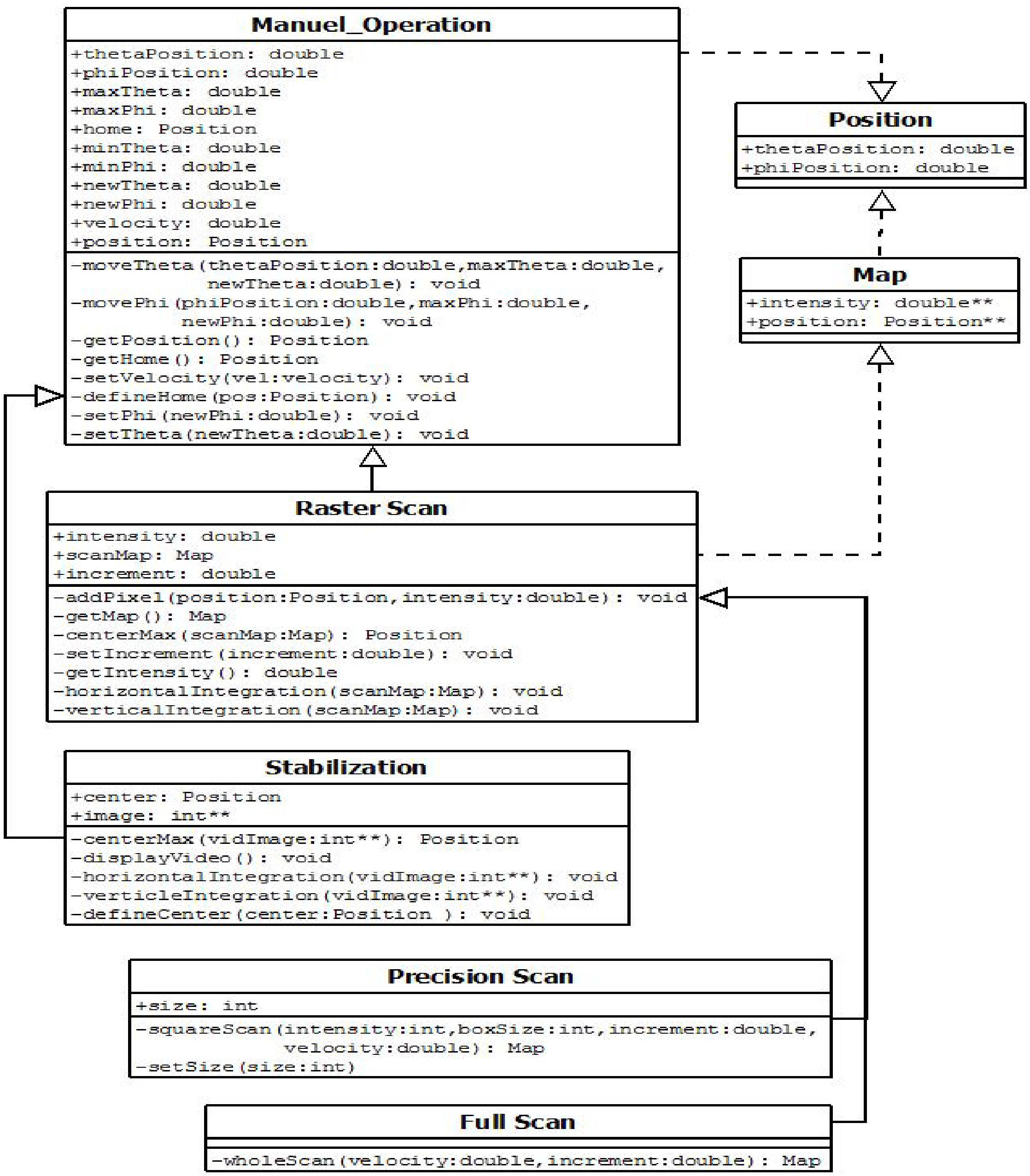


Figure 4.4-1 Class diagram of entire program

Two different raster scans were needed. The first had to do a full scan to narrow down the correct orientation and the second was a precise scan where we scanned a smaller area with smaller increments until we hone down an orientation that is off by only a marginal amount. Classes for a position and map were made. The position class contained degrees of the two motors in the mount (theta and phi). The map class represented a grayscale image and is used for the data from the cameras used for the beam stabilization and it's used for determining the correct orientation of the crystal. This latter map was made based on position information and intensity value from the light sensor.

Raster Scan- The raster scan incorporates the essence of the program and project. As previously mentioned, it is very difficult to orientate the crystal by hand. Therefore, this setup and program accomplish just that. A scan is performed to find the intensity value at several positions and the position with the highest intensity, which also has surrounding high intensities as to avoid noise, was made the new optimal position. First a scan of the entire range of motor movements was made to greatly narrow down where this desired position may be. The user then uses the manual operation program to move to where it looks like the desired position will be near, based on the displayed map, or the program will decides position on its own and moves there when the scan is complete. When this position is set, the precise scan is then used to make smaller and smaller rectangles, based on parameters set by the user. The user will also set how much the increments will be. The first time this scan runs, the user should pick a large scan size and increment size and each new scan should decrease both of those amounts until the correct position is eventually set. Figure 4.4-2 shows just how complex this part of the program is and how the precise requires more data and functions.

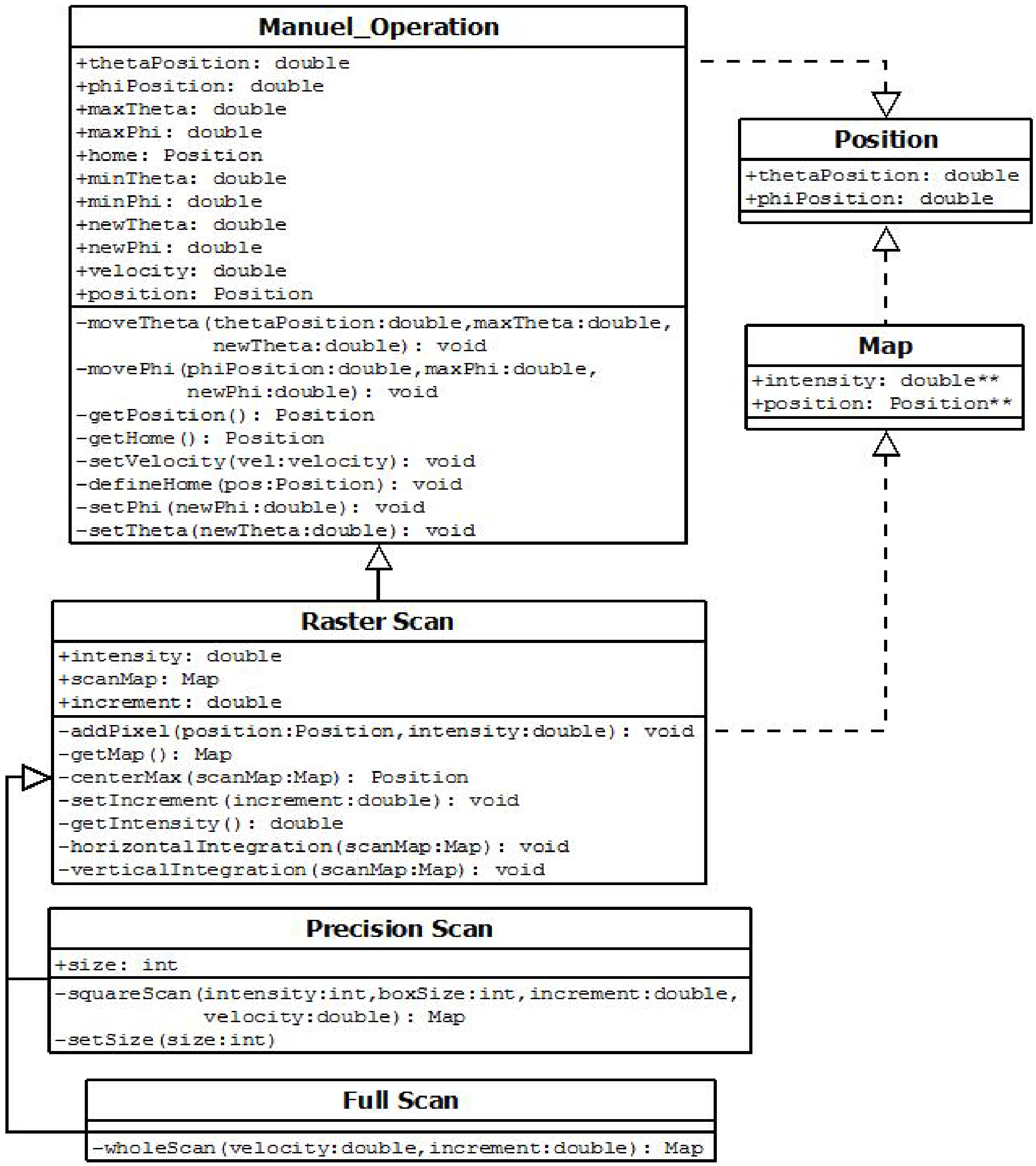


Figure 4.4-2 Class diagram for the raster scans

Full Scan-The full scan is used to scan as much as the mount will be able to move, from one extreme to the other. It creates a map, represented as a grayscale image. This image is made based on the degree measurements of the motors (theta and phi) to represent the x and y components that make up the number of pixels and the intensity value of the light sensor to determine the value of each pixel. With the creation of this map, a function to determine the position of highest intensity based on surrounding pixels runs and the motors then move to that position. By observation of this map, the user is able to change this position. Various sources of noise could make it difficult for the program to choose between multiple possible positions. This scan should be the first part of the program to run in order to greatly narrow down the possible orientations the crystal may need to be at.

Precise Scan-Once some idea of where the correct orientation should be and the user is currently at that orientation then this part of the program should run. After several runs, the optimal orientation of the crystal is achieved. After each run the user should decreased the size of the scan, which must be an odd number, and/or the size of the increments. We would have liked to make the shape of the scan, or at least give the option, to make the scan shape a circle, but this was low on our priorities and did not make it into the final code. The increments are the degrees amounts that the motors will move for each pixel. Therefore, both of these values determine the total size of the scan.

Program Overview-The use case diagram, as seen in Figure 4.4-3, shows how the user, mirror mount (in the case of a DFG experiment), and crystal mount interact with the program. The user has the possibility to at first choose between editing parameters for the various functions, using the current parameters and move one of the three mounts, or start one of the scans. The mirror mount and crystal mount are both responsible for actually causing the movement. Either scan that is chosen causes the mounts to move and the light sensor to collect data which then creates a map with this data.

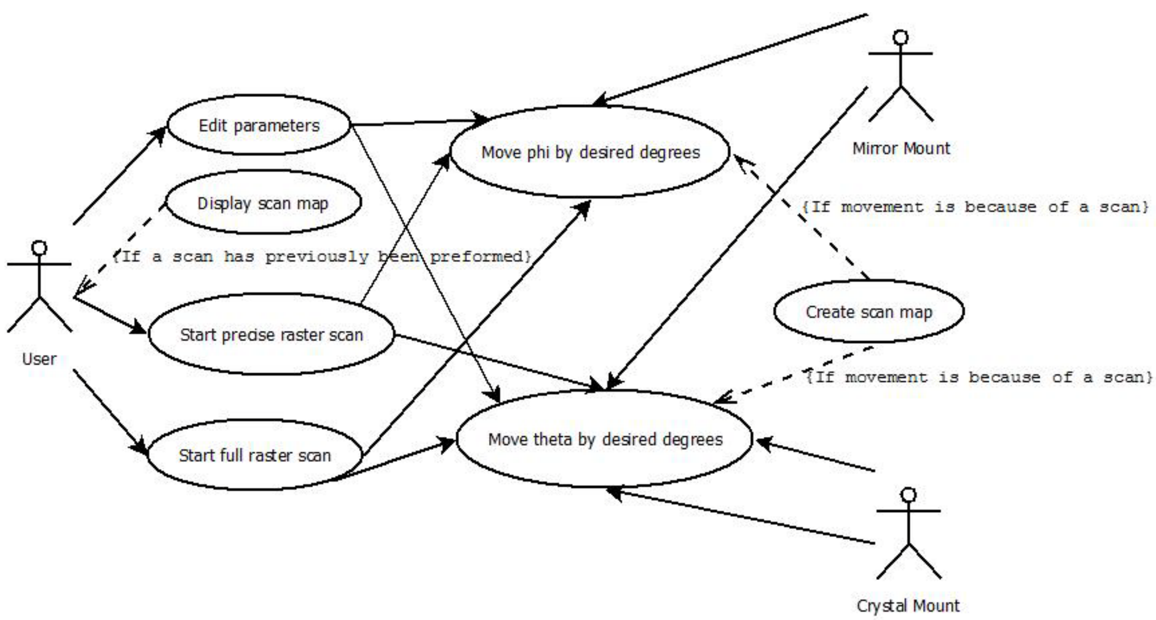


Figure 4.4-3 Use case diagram

To better explain this process the activity diagram in Figure 4.4-5 was made. This shows the basics of all the possible ways a user can interact with the software, the order in which they would interact with each part, and the choices they could make to do certain tasks. The activities are broken down into the three main parts that have been discussed through this section; these being beam stabilization, manual movement, and raster scanning. The first of these activities that the user needs to do when running the program for DFG experiments is to check the display for the beam stabilization to make sure that there is a reading and that the reading tells us the beam is hitting the center of the camera. If there is no reading then the range of rotation of the mirror is not able to point the laser beam onto its target. Therefore the setup needs to be adjusted by hand to make it possible for the beam to hit its target. This may need to be done for both mirror mounts. Other problems for lack of stabilization could be the optical setup responsible for combining the two laser beams into a single beam. This is something the user will have to check that is not part of our project.

Once the beam is stabilized and traveling throughout the whole setup then the user needs to check all of the parameters that can be edited which affect some of the main functions. These main functions are the manual movement of the mounts and the raster scans. The part of the program for manual movement of the mounts allows you to move either rotational axis (theta and phi) or one can be set to move while the other is fixed. The distance and speed of these axes would have been determined when the user was editing the parameters. If the user wishes, they can rotate the crystal mount themselves using the manual movement commands but it is recommended that they run through the raster scans first to save time.

The part of the program responsible for the raster scans is further divided into two categories: full and precise. The first time running the program, the user would most likely choose to do a full scan and thereafter choose the precise scan. Both of these functions control the rotational axes of the crystal mount like the manual movement did. The full raster scan however has no parameters to set. It simply scans over the max range of the rotation of the mount. The precise scan, on the other hand, allows you set the size (the number of spots to scan) and the increment (the space between each scanned spot). As the mount moves for each scan, it will collect intensity values from the light sensor and add it to the scan map. When the scan is completed, the scan map will be displayed to the user and the crystal mount will move to calculated position of highest intensity.

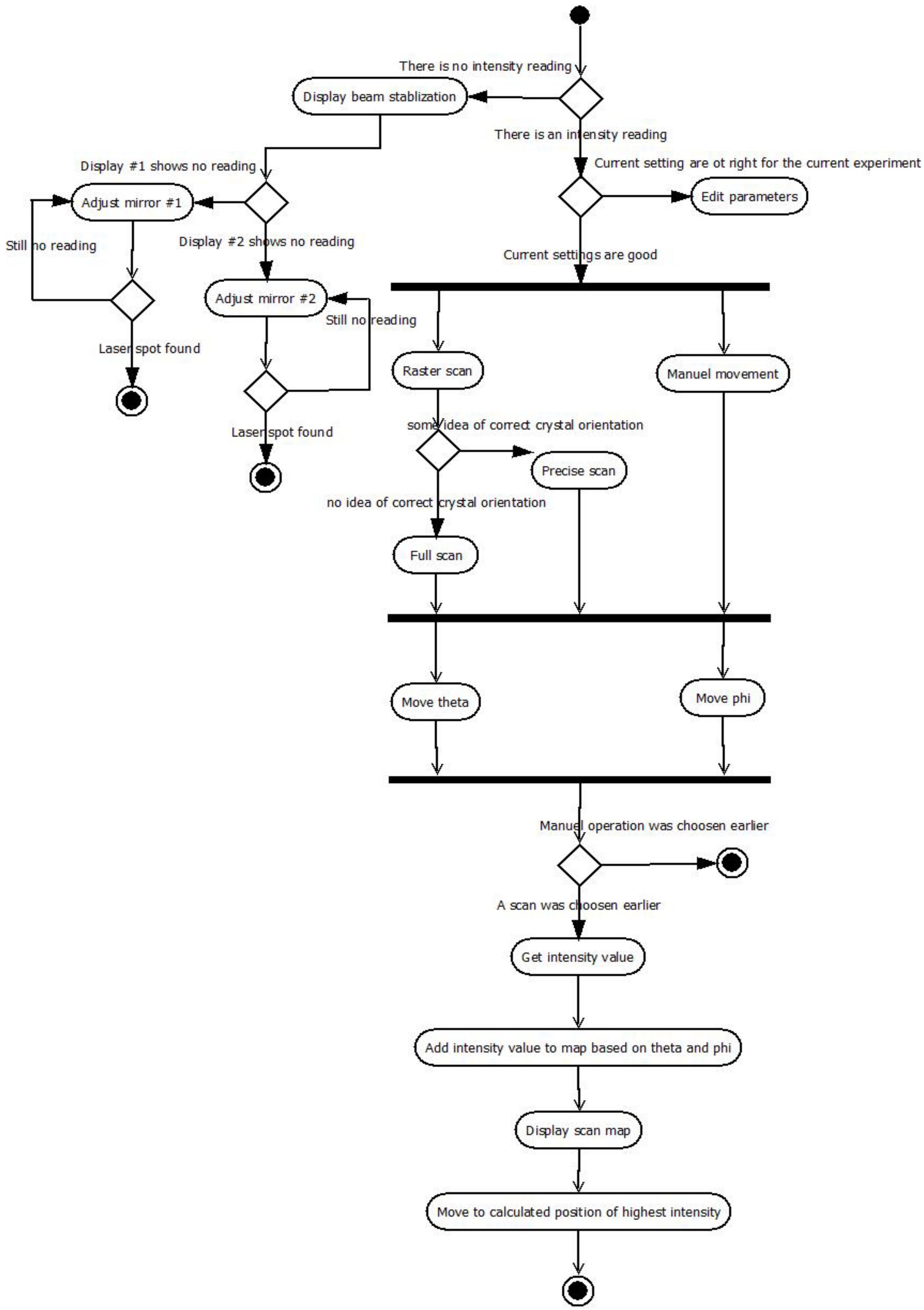


Figure 4.4-4 Activity diagram

5.0 Design Summary of Hardware and Software

5.1 Hardware summary

MCT Detector - The outline structure of the light sensor and computer subsystem breaks down into three components. The first component is be the MCT detector as seen in Figure 5.1-1. The MCT detector produces a weak signal at the output terminal. Since the signal is very weak, in the nano-volts range, it is fed into the amplifier to increase the signal strength. After the signal is strong enough, in the milli-volts, it is fed into the microcontroller for sampling.

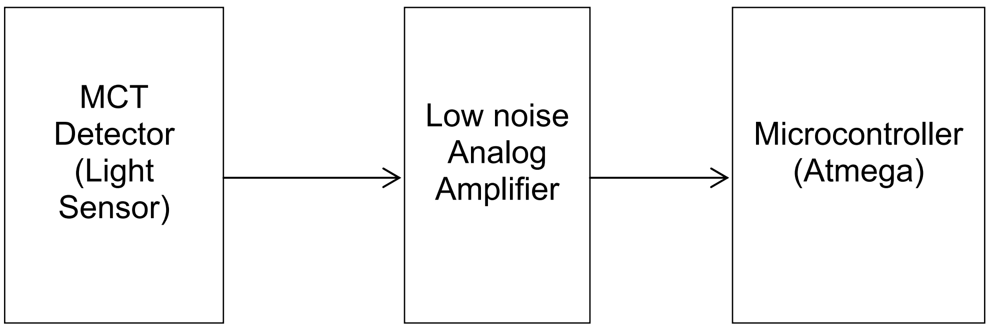


Figure 5.1-1 Structural diagram of light sensor and microcontroller subsystem.

The basic function of the MCT detector is to detect the intensity of wavelengths whose spectrum is outside of the visible light spectrum, in the infrared (IR) region. The output of the MCT detector may be an analog voltage signal with RF frequencies through a SMA connector. Depending on the light intensity shine on the detector, the voltage signal will be varied respectively. This exact relationship can be found in the circuit diagram of Figure 5.1-2. From the equation of Vo, it can be seen that the output voltage is directly proportional to the MCT photo detector's produced current, I_s.

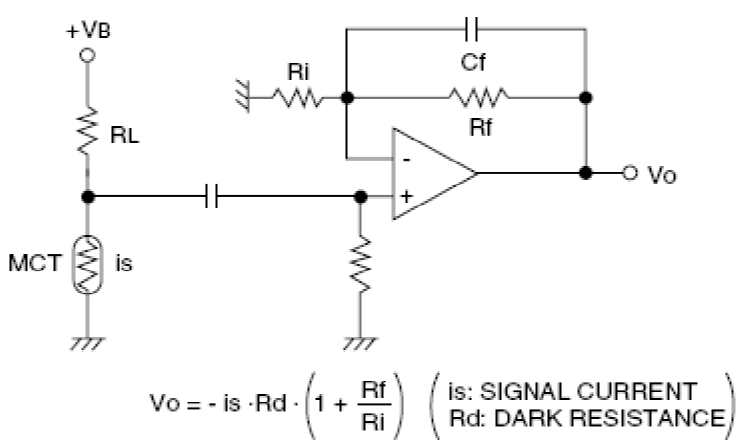


Figure 5.1-2 MCT detector schematic.

The MCT detector requires a +5 VDC power supply input to power the Thermal Electric Cooler, TEC, of the detector. Another +15VDC is required for the RF section of the detector. It is ideal that the power supply used for the RF section have low noise to reduce noise added to the output signal, which is already weak.

Amplifier - The voltage signal from the detector is then transferred to the amplifier using a male to male coaxial cable. There is a female SMA edge connector mount at the edge of the amplifier's PCB. The SMA edge connector alone can support frequencies up to 18GHz and have a 50Ω impedance. Once the connection has been made, the signal can go through a series of six amplifiers connected in series to get the appropriate gain needed. The amplifier circuit schematic can be found in Figure 5.1-3.

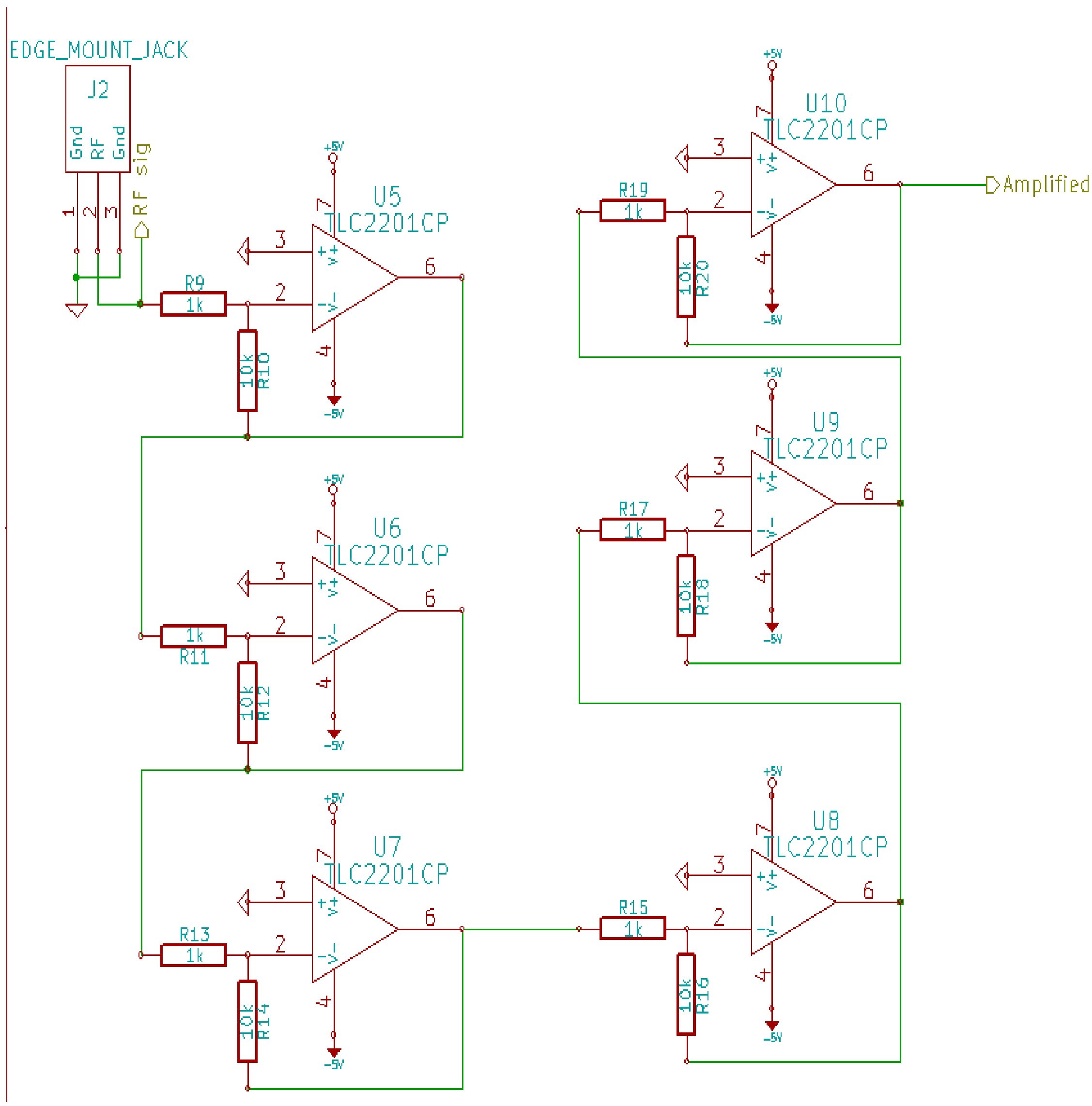


Figure 5.1-3 Amplifier schematic

In Figure 5.1-3, the first component named US2 is representing the female SMA edge mount connector. The analog RF signal can go through an amplifier with a gain of 6. This output signal will be used as the input for the next amplifier. At the output of that amplifier, the signal will be about 36 times the original signal coming from the MCT detector. At the final output of the 6^{th} and final amplifier, the signal will be about 6^6 times the original signal from the MCT detector.

Since we are dealing with relatively very weak signals, noise was considered to be very important when designing the overall amplifier system. The operational amplifiers that were used produce very low noise at the output. They are Texas Instrument's operational amplifier model# TLC2201CP.The TLC2201CP has a rail to rail output. The Common Mode Rejection Ratio, CMRR, for this operational amplifier is about 90dB. Compared to other operational amplifiers, the CMRR is relatively high. The amplifier also has a very good voltage gain as well at about 110 dB.

There are several factors that can affect the amplifier's overall performance in this design. The first factor is the frequency components the input signal exhibits. The TLC2201CP amplifier's gain bandwidth is able to support signal with frequencies as high as 250 kHz. For signals whose frequency components exceed 250kHz, the gain starts to decrease and the total gain of 6^6 will not stand. This was found through various simulations done in Multisim. In addition, the numbers used for calculating the gain in this design were nominal values. The resistors that were used in the design have a 5% tolerance. This 5% tolerance will yield in a gain of $6^6 \pm 2332$ in extreme cases.

5VDC to -5VDC Conversion - The Vcc used to power the Amplifier is shared from the USB port's power supply on the PCB with the Atmega microcontroller. There is a split power plane in order to have an Analog and Digital power plane. This keeps the area handling the signal separate from the digital area such as the USB, Atmega microcontroller, as well as the ADC. However the USB port only provides a +5VDC and the -5VDC comes from the TC7660. This device's schematic set up can be found in Figure 5.1-4. From the figure, the power source from the USB port is connected to pin 8, input to the TC7660. The -5VDC produced by the TC7660 is output to pin 5. This voltage signal will not be a perfect VDC because it has inherited some oscillations. In the schematic, the 10µF capacitor was added to filter the higher frequencies.

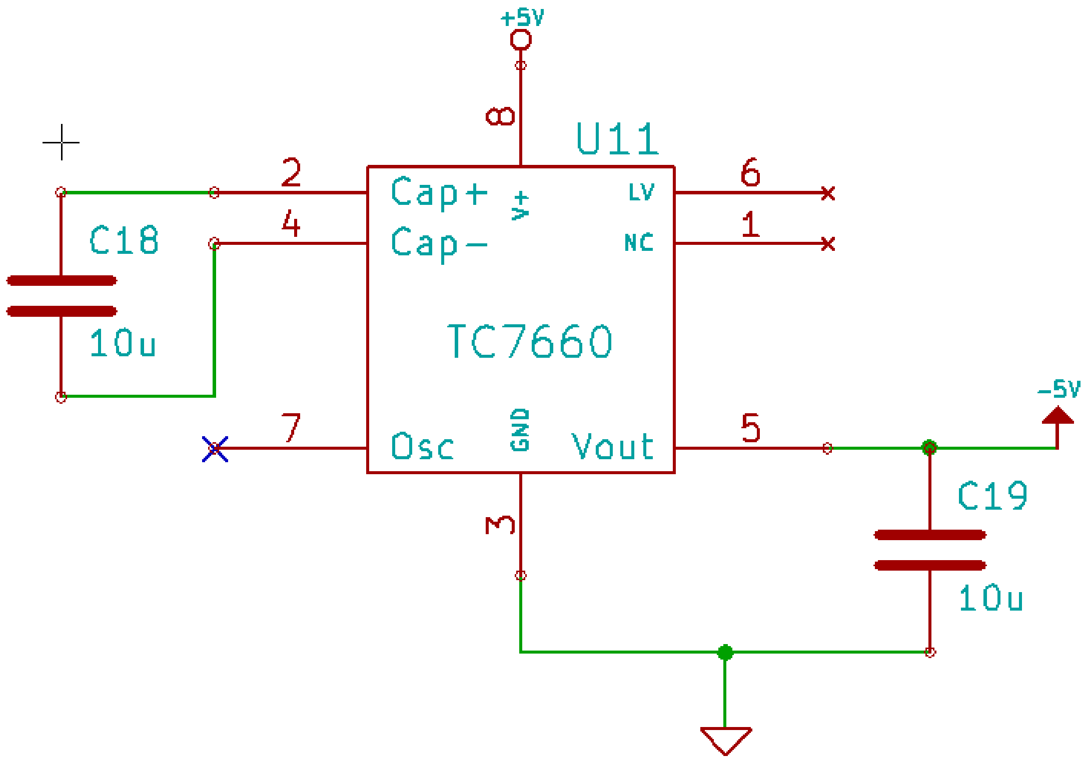


Figure 5.1-4 -5DVC voltage converter.

After the signal has been amplified, the output signal is connected to the 24 bit Analog to Digital Converter. The ADC samples the incoming analog signal and passes this data collected to the Atmega328 through the standard I2C protocol. The 24 bit ADC has a 0.1V reference that is then split into 23 effective bits of resolution, if they can be achieved through noise reduction, giving it an 11.92nV accuracy. The input to the Amplifier is also input to the ADC to compare the gain if it is possible to measure the low voltage. The Atmega computes the final value in Volts based off the conversion, it then displays on an LCD located on the PCB the most recent measurement. The Atmega328 also communicates with the FT232R chip to send the same measurement to the computer via USB. This integer data is then recorded by LabVIEW in a matrix for analysis.

5.2 Design Summary of Software

The basic function of the software, as seen in Figure 5.2-1, is the take in the position of the motors, get the intensity value of the light hitting the light sensor, get the position of the light hitting the cameras(in the case of DFG experiments), and use that data to move the motors to their correct position. However the process involved in determining that position is much more complicated. First of all there are two cameras and six motors, adding up to nine pieces of data to take in. Luckily, this is grouped into three separate parts with each part containing two motors and either the light sensor or one of the cameras. Also the OPO only deals with one of these sets of data.

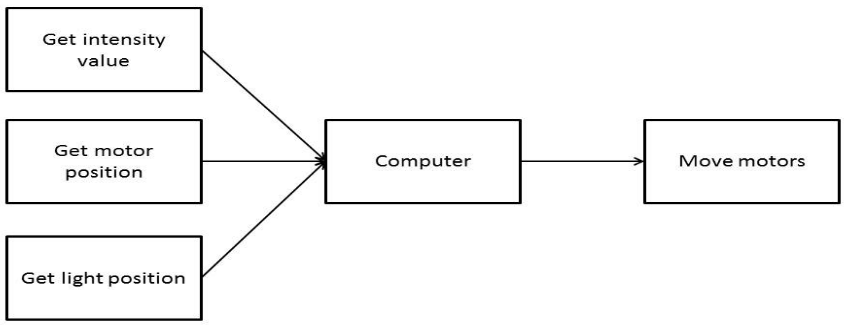
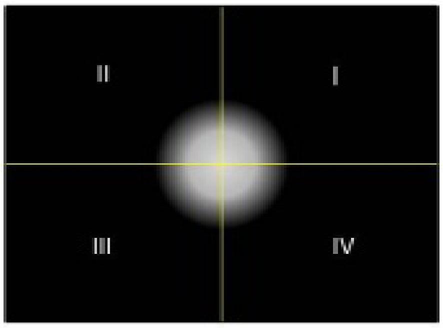
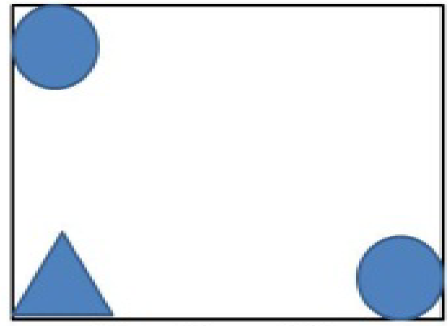


Figure 5.2-1 Software relation to hardware

The first part of the program that runs for DFG experiments is used to stabilize the laser beam; therefore this involves data of position of the four motors attached to the mirror mount and the two cameras. The cameras display a grayscale image that are able to tell us where the beam is hitting the camera, as seen in Figure 5.2-2. If the beam is not hitting the middle of the camera then the program takes in the position data of the motors and adjusts it until the beam is finally centered. Looking back at Figure 5.2-2, if the laser spot is in quadrant I or II then the theta will move in the positive direction. If the spot is in quadrant III or IV, theta will move in the negative direction. The phi motor will move in the positive direction if the spot is in quadrant I or IV and in the negative direction if in quadrant II or III. In the mount representation image above, the motors moving in a positive direction causes their perspective corner to come towards the viewer. Therefore the top left motor will adjust the theta rotation and the bottom right motor will adjust the phi rotation.



Camera Image



Mount Representation:
- Circle = Motors
- Triangle = Pivot Point

Figure 5.2-2

The final part of the program which collects data from the remaining two motors and the light sensor is also the largest part of the program. As seen in Figure 5.2-3 the crystal is affected by the rotation and the laser beam is affected by that rotation where the light sensor picks up that change. The light sensor then sends the intensity of the laser beam, as units of power, to the computer. The motors are used to rotate a crystal until it is at the orientation which produces the highest intensity. Each measurement of the intensity also has the position of the two motors linked to that data.

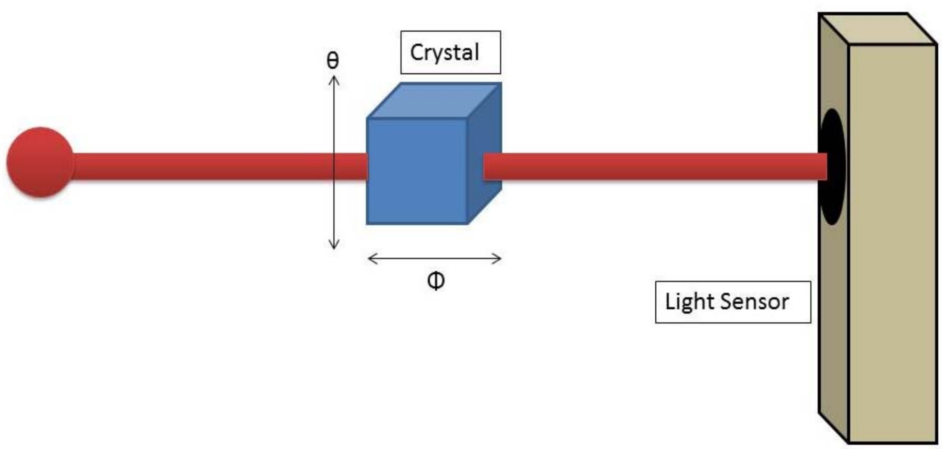


Figure 5.2-3 Laser, crystal, and light sensor interaction

Since the value of this intensity is unknown, we must first scan over the entire rotational range. While we do this, we record the intensity value and position which is then represented as a grayscale image where each position acts as a pixel. From there we have greatly narrowed down the possible rotational position and the program decides on a position where the intensity output was greatest. This decision is also based on the intensity output of the surrounding positions. The user also has the ability to choose a new center position based on the image representing the scanned area. In order to increase the precision we do a rectangle shaped scan around that center position. We do this several times, while decreasing the range in degrees of rotation, until the user is satisfied with the output intensity.

Center: $(0^{o},0^{o})$

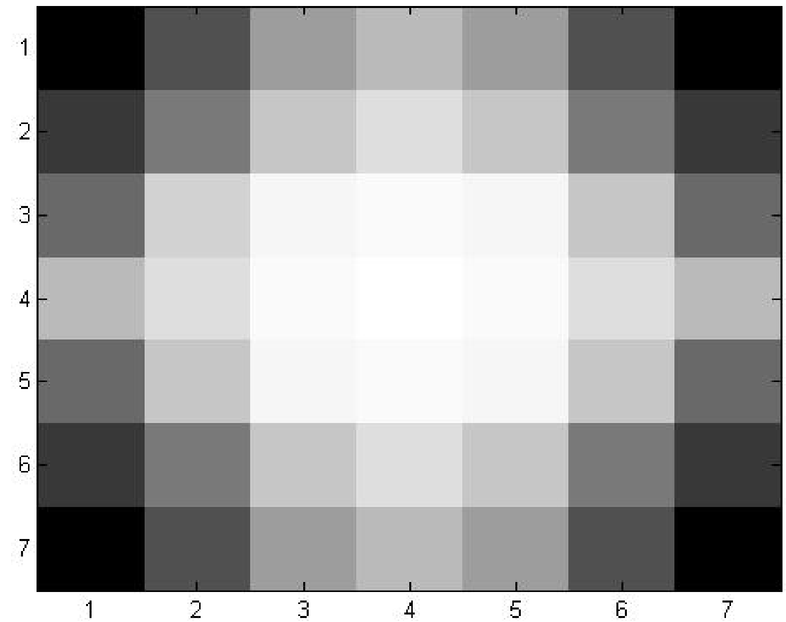


Figure 5.2-4 Scan Map Example

56 $-0.3^{o},0.3^{o}$	120 $-0.2^{o},0.3^{o}$	180 $-0.1^{o},0.3^{o}$	200 $0^{o},0.3^{o}$	180 $0.1^{o},0.3^{o}$	120 $0.2^{o},0.3^{o}$	56 $0.3^{o},0.3^{o}$
100 $-0.3^{o},0.2^{o}$	150 $-0.2^{o},0.2^{o}$	210 $-0.1^{o},0.2^{o}$	230 $0^{o},0.2^{o}$	210 $0.1^{o},0.2^{o}$	150 $0.2^{o},0.2^{o}$	100 $0.3^{o},0.2^{o}$
140 $-0.3^{o},0.1^{o}$	220 $-0.2^{o},0.1^{o}$	247 $-0.1^{o},0.1^{o}$	250 $0^{o},0.1^{o}$	247 $0.1^{o},0.1^{o}$	210 $0.2^{o},0.1^{o}$	140 $0.3^{o},0.1^{o}$
200 $-0.3^{o},0^{o}$	230 $-0.2^{o},0^{o}$	250 $-0.1^{o},0^{o}$	256 $0^{o},0^{o}$	250 $0.1^{o},0^{o}$	230 $0.2^{o},0^{o}$	200 $0.3^{o},0^{o}$
140 $-0.3^{o},-0.1^{o}$	210 $-0.2^{o},-0.1^{o}$	247 $-0.1^{o},-0.1^{o}$	250 $0^{o},-0.1^{o}$	247 $0.1^{o},-0.1^{o}$	210 $0.2^{o},-0.1^{o}$	140 $0.3^{o},-0.1^{o}$
100 $-0.3^{o},-0.2^{o}$	150 $-0.2^{o},-0.2^{o}$	210 $-0.1^{o},-0.2^{o}$	230 $0^{o},-0.2^{o}$	210 $0.1^{o},-0.2^{o}$	150 $0.2^{o},-0.2^{o}$	100 $0.3^{o},-0.2^{o}$
56 $-0.3^{o},-0.3^{o}$	120 $-0.2^{o},-0.3^{o}$	180 $-0.1^{o},-0.3^{o}$	200 $0^{o},-0.3^{o}$	180 $0.1^{o},-0.3^{o}$	120 $0.2^{o},-0.3^{o}$	56 $0.3^{o},-0.3^{o}$

Table 5.2-1 Matrix of Scan Data

Shown in Figure 5.2-4 is a grayscale image of what the data, from a scan, might show and in Table 5.2-1 that we have a matrix of the data that the image represents. The pixel location is a representation of the degree position where each position in this example image is in increments of 0.1^{o} and the shade of the pixels is a representation of the intensity value measured at that position. This intensity value is an 8-bit number so 255 is white, 0 is black, and everything else is a shade of gray.

6.0 Project Acquisition and Bill of Material

6.1 Parts Acquisition and Bill of Material

MCT Light Detector - There are several vendors that provide the MCT Detector used in our project. We decided to acquire our MCT detector from Daylight Solutions. One of the advantages that this detector has over other detector is a built in low noise amplifier. The detector cost around $6,300 and had about 4 weeks of lead-time.

Operational Amplifier - The operational amplifiers used in our design are the TLC2201CP from Texas Instrument; our design requires eight of them. Since we need 8 of them, the total cost was around $47.80 for the op amps, but a few more were ordered in case they were burnt out during testing. This is coming from Digikey because purchasing directly from TI has a high lead time.

Resistors - It was decided that our resistors be ordered through Digi-Key vendor because most of our other parts can be ordered from them. By doing this, it would reduce our shipping cost. For all of our resistors we designed surface mount pads because they are much easier to solder than through hole and reduced the size of the board. Surface mount is also much cheaper than through hole. Through hole resisters were obviously used for prototyping but the end design uses all surface mount, mostly the 804 package.

SMA Connector - For our SMA board edge connector, we also went with Digi-Key to save shipping cost. The connector is type female and is capable of 18GHz maximum frequency and has 50Ω impedance. The 50Ω impedance seems to be the standard for most SMA connectors. In terms of frequency, the cable could support our signal easily. The price for the SMA connector was $4.86 per unit.

Motorize Piezo Mirror Mounts/Controllers - We have chosen to buy our optic parts from Newport. We got model AG-M100L at the price of $732.00 each. We also got the compact piezo motor controller modeled AG-UC8. This controller is at the price of $419.00. The sum for these two items was $1151.00, before tax.

Bill of Materials- Table 6.1-1 is the bill of materials encompassing the specific parts that are needed to put together the PCB. On the left side is the Passive components labeled by their reference number in the schematic. The passive components have two sections that have been placed next to each other to save space. The Active components are listed on the right and are also listed by their reference in the schematic. The actual package of some components may change as we prototype and test certain parts of the project.

Passive						Active	
C1	0.1u	**CP6**	.1u	**R17**	5k	**IC1**	ATMEGA328-P
C2	0.1u	**CP7**	.1u	**R18**	1k	**IC2**	ADR130
C3	0.1u	**CP8**	.1u	**R21**	1.5k	**Q1**	IRLML6244
C4	0.1u	**CP9**	.1u	**R22**	1.5k	**Q2**	IRLML6244
C5	22p	**CP10**	.1u	**R24**	1k	**Q3**	IRLML6244
C6	22p	**CP11**	.1u	**R26**	1k	**Q4**	IRLML6244
C7	680p	**CP12**	.1u	**R27**	5k	**Q5**	IRLML6244
C8	0.1u	**CP13**	.1u	**R28**	5k	**Q6**	IRLML6244
C9	0.1u	**CP14**	.1u	**R29**	5k	**U1**	NAU7802
C10	0.1u	**CP15**	.1u	**R30**	1k	**U2**	FT232RL
C11	0.1u	**CP16**	.1u	**R31**	200	**U3**	ST7066U
C12	1u	**R1**	1k	**R32**	200	**U4**	TC7660
C13	10u	**R2**	1k	**RV1**	10k	**U5**	PCF8574
C14	0.1u	**R3**	1k	**SW1**	SW_PUSH	**U6**	TLC2201CP
C17	0.1u	**R4**	1k	**X1**	16MHz	**U7**	TLC2201CP
C18	10u	**R5**	250	**D1**	Red	**U8**	TLC2201CP
C19	10u	**R6**	1k	**D2**	Green	**U9**	TLC2201CP
C20	.1u	**R7**	1k	**D3**	Green	**U10**	TLC2201CP
C21	.1u	**R8**	10k	**J1**	USB_1	**U12**	TLC2201CP
C22	.1u	**R9**	1k	**J2**	EDGE_MOUNT_JACK	**U13**	TLC2201CP
CP1	.1u	**R10**	1k	**L1**	Ferrite bead	**U14**	TLC2201CP
CP2	.1u	**R11**	1k				
CP3	.1u	**R12**	1k				
CP4	.1u	**R15**	5k				
CP5	.1u	**R16**	5k				

Table 6.1–1All parts that were soldered onto the PCB

6.2 PCB vendors and Assembly

PCBExpress - This PCB fabricator has an easy to use schematic capture program that is integrated with the PCB layout software. Experience using this proprietary software has shown that it is very easy to work with and simple to understand. Once the PCB layout has been made on the PCBExpress software package, it can only be used to purchase a board from them. This is because no other company accepts PCB layout files from the PCBExpress software package. Although they may save in the same file type as other PCB software, no other PCB software can even open it. It is, however, very simple and intuitive; however the pricing for the actual PCB vendor is average. The price is very good for the turnaround time, which is about a 3–4 days, and the price is excellent when compared to other United States fabricators. The smallest cheapest service offered is $51 plus shipping, however this includes 3 copies of a 3.8 by 2.5 inch board that has traces on two sides. The step above, standard, charges at $62 plus 0.70 cents *per* square inch of board and additional shipping fees; this standard board also has traces on two sides. Roughly estimating our board size, a single 25 square inch board would cost $79.50 plus shipping. This service is reasonable when compared to the exorbitant prices of other fabricators in the country. This would be a great service if time was of the essence and money was not a factor or if the size of the board was small enough that the price makes it at the same price as the others.(Standard Service)

BatchPCB - This fabrication service is essentially what it sounds like, many PCB designs are accumulated through SparkFun and compiled into a large order. It is then ordered from china where it is sent back to SparkFun and they handle cutting and shipping to each individual person. Because it takes a long while to fill up a batch and panelize it and then go through with the rest of the process, the turnaround is typically 3 – 4 weeks. The time can be expedited by using USPS priority mail which will of course cost more as opposed to First class mail. Pricing is calculated by starting with a $10 setup fee, and $2.5 per square inch for a double layered board, or $8 per square inch for 4 layered boards. A single 25 square inch board would cost $72.5 plus shipping and would only be 2 layered, so that traces would only be on a single side.(BatchPCB)

Advanced Circuits - This company, Advanced Circuits, is based in the USA and has one of the fastest turnaround times because of that, about one week. They offer a student price of $33 per board for a 2 layer prototype with no minimum order. This is a full spec board with two sided traces, a solder mask to help with soldering and a silk layer to identify where parts go. There is no minimum size but the maximum size is 60 square inches. There is also a four layer deal for students that is similar to the two layered board but also has a power and ground layer. This four layered board goes for $66 with a max size of 30 square inches. In order to be able to buy these PCBs at that price with no minimum amounts, the promo code “Student” should be put in and a shipping address to the University should be used. We purchased two four layer boards for a total of $132 before tax and shipping. They had a week lead time plush shipping time, so it took about two weeks to receive using ground shipping. (Student Program, 2012)

Olimex - Olimex offers a few choices for PCB fabrication that begins with a choice of Single sided traces or double sided traces. A standard size is 6.3 x 3.9 inches while the larger size is 12.6 x 7.8 inches which is four times the area of the standard size. This company also allows for free panelizing of PCB layouts; meaning that they will accept one file that really has more than one PCB which is outlined with a graphic square with different connections. They will then take these multiple layouts and perforate them at the lines where they are joined so they can easily be snapped off. Many other places do not recommend putting multiple layouts on a single board because they do not perforate them for you. These other fabricators will make the PCB as a single board and you must cut the board into their respective pieces with a hacksaw and protective mask. Our project involves a microcontroller and several surface mount devices which require two sided traces even when placement is optimized. For this reason the double sided PCBs are the only ones we should be looking at for this project and the smallest size for this company will cost around $39 to make plus shipping. This option will also take some time to arrive because it comes from Europe so time must also be taken into account. (PCB COST)

Self Etching - The processes of etching a PCB can be somewhat difficult for single sided PCBs, but this difficulty is augmented when vias are involved on a two sided etching. The difficulty with vias is that the layout of the board must be perfectly aligned on both sides so that the via holes match up and actually function as they should. Another difficulty with vias is that they have the each be hand soldered through with a piece of copper wire. This will leave pieces of solder sticking out of the PCB making it look unprofessional as well as being somewhat time consuming to solder if there are many vias. The nub of solder sticking it also makes it impossible to place a via underneath an IC that is surface mounted. The process that allows for double sided boards is to use copper clad boards and to transfer a laser printed image of the circuit onto the PCB using an clothing iron. The image is printed on a high gloss paper such as magazine paper and then melted to the copper board. It is then etched with ferric chloride to remove excess copper and leave you with the desired traces. The toner is then removed from the board using acetone. The price for this process is computed by selecting the desired board size that is double sided and then the desired size of acetone and ferric chloride containers. No other special equipment is required besides a laser printer, which is readily available to us, and a drill/dremel. All the containers can be easily found as any simple plastic container will do. A dremel is also used to cut the board to size and sand all edges off. The speed at which one can prototype makes self-etching attractive despite the difficulties involved. The only thing that would slow turnaround time would be when more chemicals need to be ordered. (DIY double sided board etching, 2010)

Table 6.2-1 is a list of PCB fabricators with their respective PCB prices. The first two vendor prices are calculated based on the input size of board; while the last four prices are static. The Self etching price is calculated by selecting appropriate amounts of the chemicals needed and selecting a two sided copper clad board. However, a few boards can be made with the chemical sizes selected for the pricing. The Advanced Circuits fabricator seems to be the clear winner with the lowest price board, fast turnaround time, and comes with the solder mask and silk layer. If the order can be shipped to the University, this will be the fabricator of choice. Through the course of researching fabrication costs, it was noticed that all fabricators agreed on gerber files made from Eagle as the standard except for PCBExpress which uses its proprietary software instead and is what was being originally used. This forced us to switch to a schematic and PCB layout software that was compatible with the other fabricators. For this purpose, KiCad was selected because it is an opensource schematic capture and PCB layout software that does not limit the user in any way. Although KiCad has a smaller initial library, footprints are easier to make and multiple sheets for a schematic are simple to make and integrate.

Enter size in sq. inch	10
PCBExpress	69
BatchPCB	35
Olimex 6.3 x 3.9 inch, 24.5 sq in	39
Advanced Circuits Max 60 sq in	33
Self etching 4 inch x 6 inch	37.22

Table 6.2 – 1 Comparing PCB fabrication prices after input of approximate board size

Assembly – While it may be easier to simply pay some company to assemble our PCB, our layout is not sufficiently difficult to warrant paying the cost of a professional assembly. This is especially so because the packages that were selected do not require any special techniques in order to mount onto the PCB. For all surface mounted parts a simple reflow oven will work such as the one found in the Senior Design lab. The cost of assembly via reflow oven will amount to the cost of paying someone to operate the reflow oven and mount the parts for us. Another option is to become certified in the use of the reflow oven in order to assemble the PCB ourselves. Two other options exist that are more difficult but may be used if we find ourselves in a pinch. The surface mounted components can also be soldered by hand using a soldering iron which requires an excellent iron and a steady hand. Surface mounting with a soldering iron also requires the use of the correct flux which is applied to the PCB where the component will be soldered. This flux can come as a liquid but for surface mounting, it is best to use a no clean paste made specifically for surface mounting. This flux is wicks heat to the pads and also serves to hold the component in place. To do surface mounting with a soldering iron a temperature steady iron is best. These are typically rated for 50 watts or more and have temperature control to get the correct temperature at the tip of the iron. If a lower wattage soldering iron is used, it may result in cold joints or a burnt IC when the tip is too hot; to avoid this, a high watt soldering iron should be purchased that has feedback from the tip and is temperature controlled. A soldering station like this can cost anywhere from $48.99 for the Aoyue 937 to several thousand dollars for a Weller station. On the cheap end of the spectrum is also a SMD station that includes a solder iron as well as a hot air pencil that is made by Kendal for $72.90. Hot air pencils are another option for surface mounting but are a bit more difficult to use. The difficulty with hot air pencils is that the temperature at the PCB is never the same as the temperature coming out of the pencil because of ambient cooling. A temperature probe or an infrared thermometer is used in conjunction with the hot air pencil to get the appropriate heating to properly melt the solder and attach it to the SMD. The hot air method would likely be used in case an IC needs replacing because it is difficult to get all the leads of an IC to stay melted and then remove the IC, using a soldering iron. To replace a single IC, using a reflow oven is not a viable option either because some other chips may be damaged in the processes of replacing a single IC. It is also very difficult to use a desolder braid or a solder sucker to remove solder from any SMD because even a small bit of solder can keep the component stuck in place. An alternative to buying the large solder station to desolder surface mounted ICs is to use the ChipQuik surface mount removal kit which costs $10.99 on amazon. This removal kit uses a low temperature melting solder which is melted onto all the leads of the IC and will stay melted long enough for all the leads to melt and remove the IC. This option is best if only the solder iron is purchased and an IC needs to be replaced in the future, this kit can be ordered in conjunction with the replacement parts. There are some desolder sockets that are specifically made to fit around the IC and heat up all the leads at the same time using the soldering iron, but these are special fits that must be purchased for each type of packaging. These are worth purchasing when many of the same packages are going to be desoldered because it can be quickly done without waiting for the area to heat up with air or apply solder to all the leads.

In order to get a feel for the size of the PCB components and amount of space taken up, a 3D version of the layout was rendered in KiCad, seen in figure 6.2 – 1. The USB B connector can be seen on the left side of the PCB as the large block. A 3D rendering of the LCD was not made as there was insufficient time to model it, however the outline and footprint can be seen at the bottom. Mounting holes are yet to be placed on the PCB layout because a final case has yet to be selected due to the PCB will not be ordered until all the prototypes have been made and are confirmed to work.

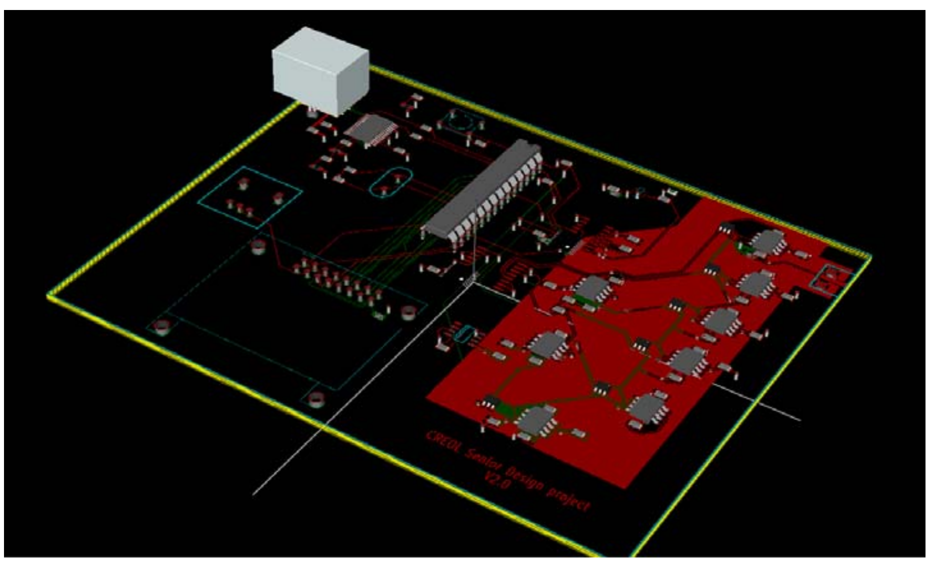


Figure 6.2–1 3D representation of most of the components and PCB layout.

6.3 User Interface Prototypes

For this project there was originally going to be three different User Interfaces (UI's) with two of them being displayed at a time on separate monitors. When the primary experiment changed to an OPO then we switched to just a single displayed at a time with a total of two UI's. These three UI's were for the mirror stabilization (which had been removed), the full raster scan, and the precise raster scan. Each of these has ways to manually move their respective motors. The goal here was to have a very clean graphical user interface (GUI) but performance came before quality; therefore, very basic UI's were made first which consist of simple input and display boxes and buttons, as seen in Figure 6.3-1a, and will be able to perform all necessary functions. Figure 6.3-1b shows a few examples of more advanced UI elements, a few of which were incorporated. The basic GUI elements shown include a display, input (vertical line is a cursor), and a button respectively. The more advanced GUI elements shown include input that can be set using arrow buttons, a switch, and a meter that could be used as a display of information or contain a drag-able cursor for inputting information.

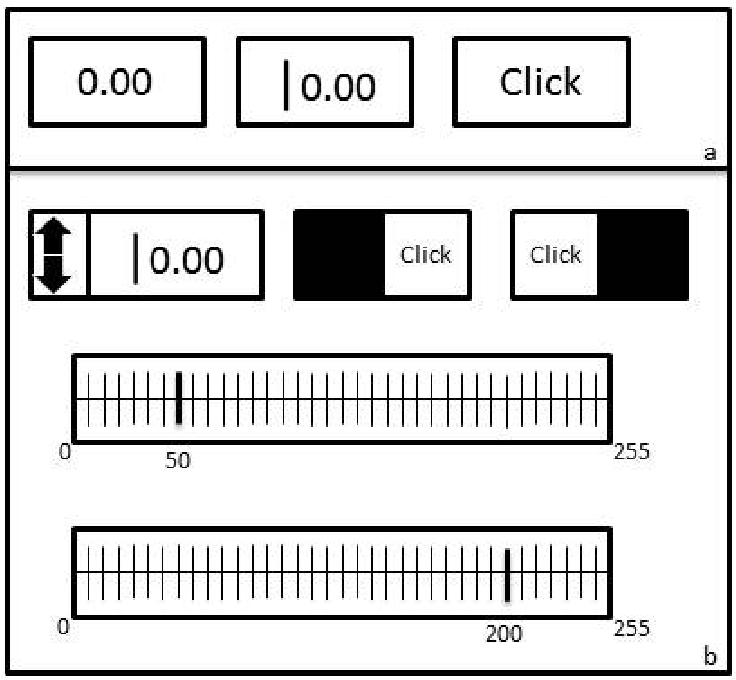


Figure 6.3-1 (a) very basic and (b) more advanced GUI elements

Mirror Stabilization- In Figure 6.3-2, we have our original mockup of what we would have liked the GUI that controls the mirror stabilization to look like. The start and stop buttons are for starting and stopping the process of beam stabilization. The four directional arrows control the movement of the motors per mount. The up and down arrows move theta in the positive and negative direction by the distance inputted in the box labeled “Theta Distance” and the left and right arrows move phi in the positive and negative direction by the distance inputted in the box labeled “Phi Distance”. An added feature would be to allow the user to click and hold one of the arrows to enter a job mode where the motor will keep moving, defined by the parameter velocity, in that direction until the hold is released. Below this, labeled “Motor Parameters and Information”, is the area which contains various displays, inputs, and buttons relating to the motors. For example, velocity, current position, home position, define home button, and distance to movement limits. Further down we have displays for the two cameras and their video feeds. These will have a crosshair indicating the position the user has chosen as the center. By default this value will be the center of the image. The user will be able to click anywhere on the video feed to set a new center position. Located to the right of the video feed will be graphs of the vertical and horizontal integrations of the video feed and to the left, labeled “Camera Adjustments and Information”, will lay various controls and displays, for each camera, similar to the “Motor Parameters and Information” section. This section will include items such as gain, exposure time, turn on/off the camera, and run/stop filter. Turing on and off the camera and filter may be needed if the computer can’t handle all of the processing.

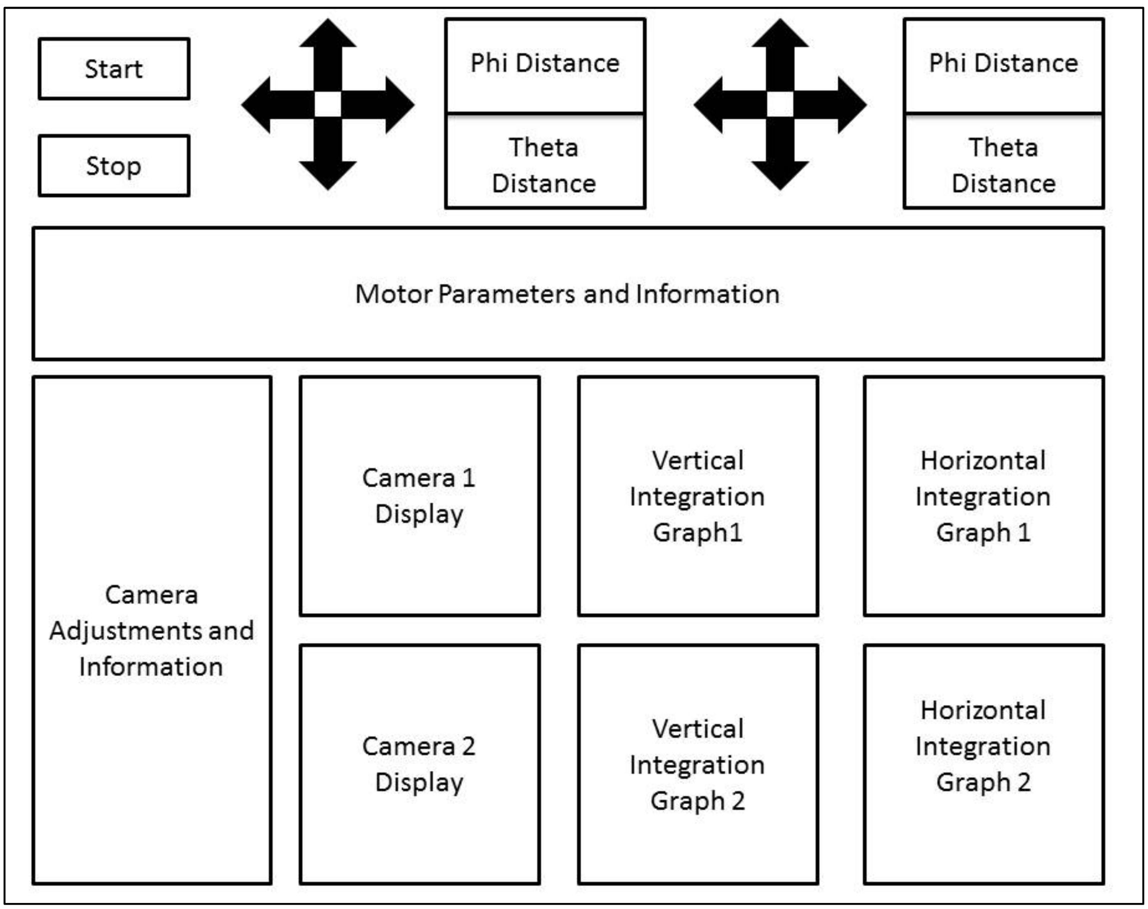


Figure 6.3-2 Mirror Stabilization GUI

Full Raster Scan- The GUI for the full raster scan contains fewer elements than the other two GUI’s but this is due to the limited customization of this scan. As see in Figure 6.3-3, this early prototype GUI is similar to the mirror stabilization GUI but there are some key differences. At the top there is a button marked “Full Scan”. This tells the user which scan mode they are currently in and if the user presses that button then it will switch to the precise raster scan GUI which will be mentioned in the next section. Like in the mirror stabilization GUI the motor can be controlled from here but this time there is only one motor to control. Also there are start and stop buttons to start and stop the scan. The bottom portion of the GUI is where things are different. The left most section allows the user to edit parameters and view other information related to the scanning process. Some of these parameters and displayed information include iteration distance, velocity, and detected intensity. To the right of section is where the scan map will be displayed once as scan has been completed. Hopefully the scan map display will be populated with information while the scan is in process. Another feature of this display will be the switching between grayscale image representation and matrix representation when the display is clicked on or a switch next to it is clicked. The last part of this GUI includes the vertical and horizontal integration graphs. Unlike with the mirror stabilization GUI which had integrations of the video feed from the camera, these will be integrations of the scan map based on the intensity value. The integration graphs will be useful for determining the position of highest intensity which the motors will move to after the scan is completed.

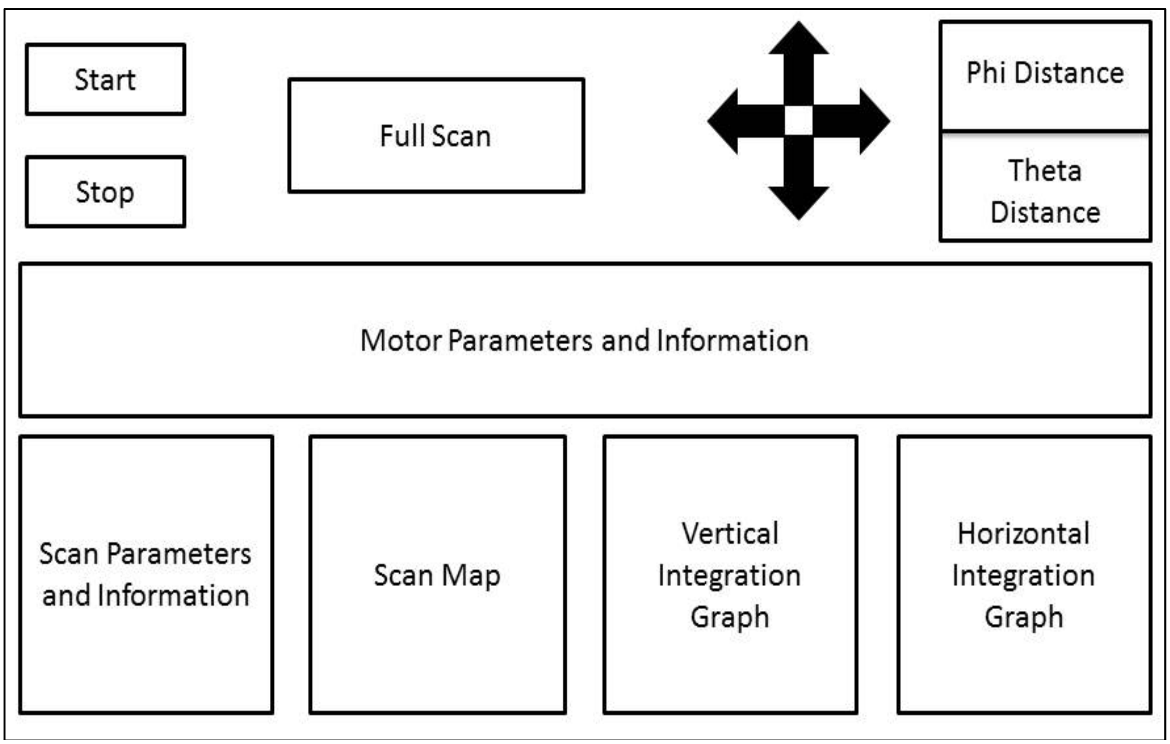


Figure 6.3-3 Prototype Full Raster Scan GUI

When got started coding, the GUI was constantly changing and the final product is shown in Figure 6.3-4. We added controls to select the COM for the amplifier and a control to alter the amount of amplification. Several indicators had to be removed because the way the functions in the Newport motor control worked. These indicators were of little use and therefore give you less information but overall leaves you with a cleaner GUI. Some nice GUI elements are the arrow buttons and intensity meter which gives the user more information in a more condensed area. We also removed some controls which we expected to be useful such as a velocity control. The scan needs to move as quickly as possible and later on a job mode was added, making these features obsolete for manual movements also. Lastly, a switch control to go between the two scan modes could not be accomplished in LabVIEW without the look of the GUI. Therefore this was substituted for a simple tab control.

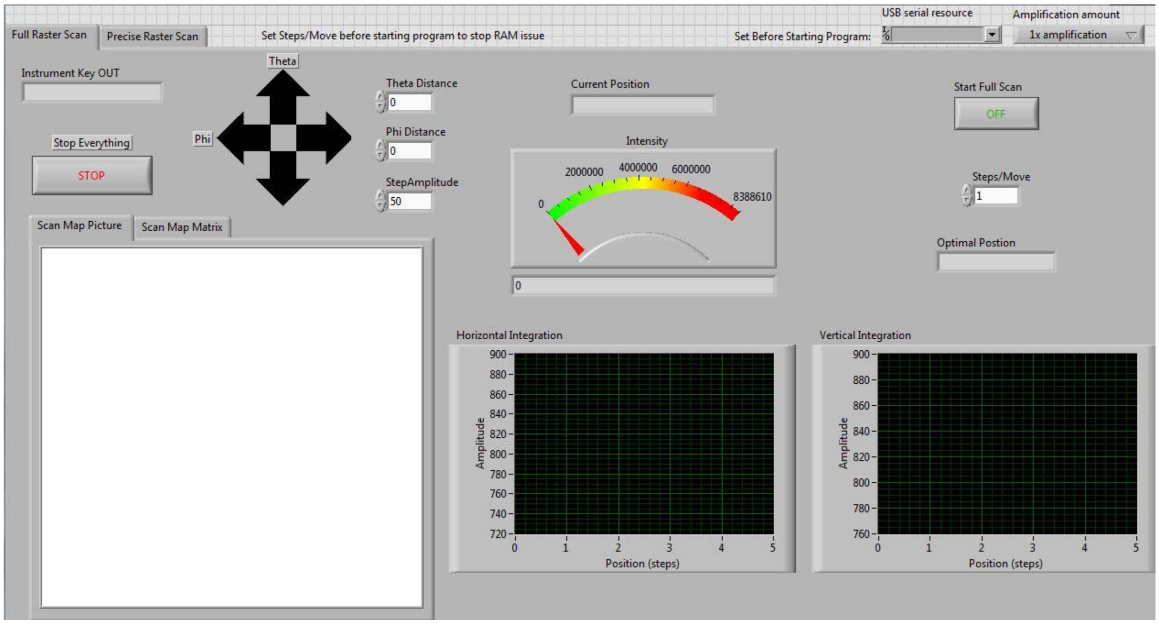


Figure 6.3-4 Full Raster Scan GUI

Precise Raster Scan- Since the precise raster scan is very similar to the full raster scan process, the layout of the prototype GUI ended up being mostly the same (figure 6.3-5). The final precise scan GUI ended up being even more similar to the final full scan GUI as seen in Figure 6.3-6. The precise raster scan needed to have more parameters causing that section to increase in size. The extra parameters in this scan were to involve the scan size of the various scan shapes. The useful scan shapes to include were a square, rectangle, or circle. A circle was scrapped because of time and the rectangular was sufficient. The square has a single value for its size which has to be an odd number and represents the number of spaces from the current position to scan by a separation of the iteration distance. The rectangle shape scan has a value for the length and for the width. In other words, the number of positions to scan for each motor. The circle shape scan would have had a value for the radius. All of these values representing the number of steps from the current position. From this larger sized section, we planned on saving space by moving the integration graphs to a top bottom formation from a left right formation. When all was done we found that the scan map and graphs required a good amount of room so they were placed on the bottom, all next to each other. The scan parameter did not require much extra space and there was plenty surrounding the area of the full scan parameters leading us to have both in the same spot. Also, not shown are error indicators displayed below what is shown so that it is out of side and non-distracting to the user but still easy to get to.

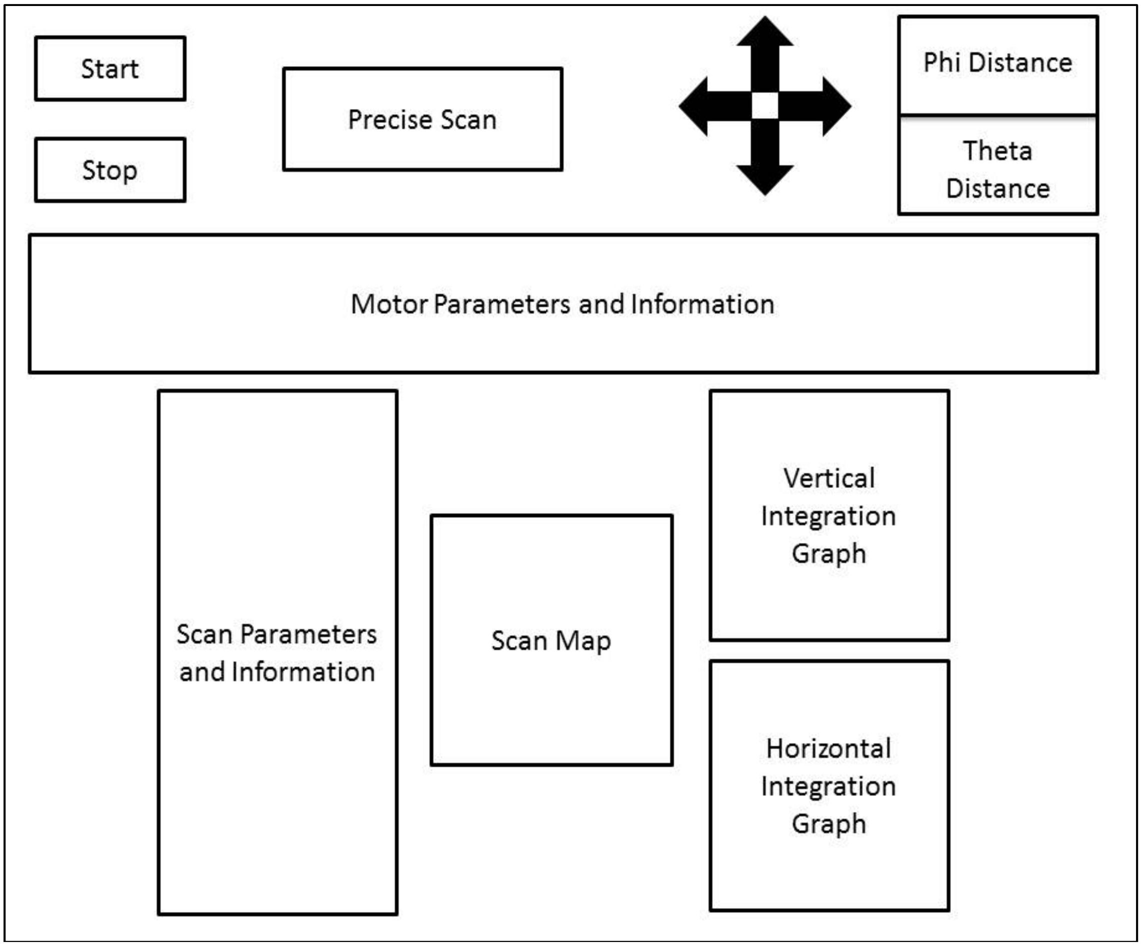


Figure 6.3-5 Prototype Precise Raster Scan GUI

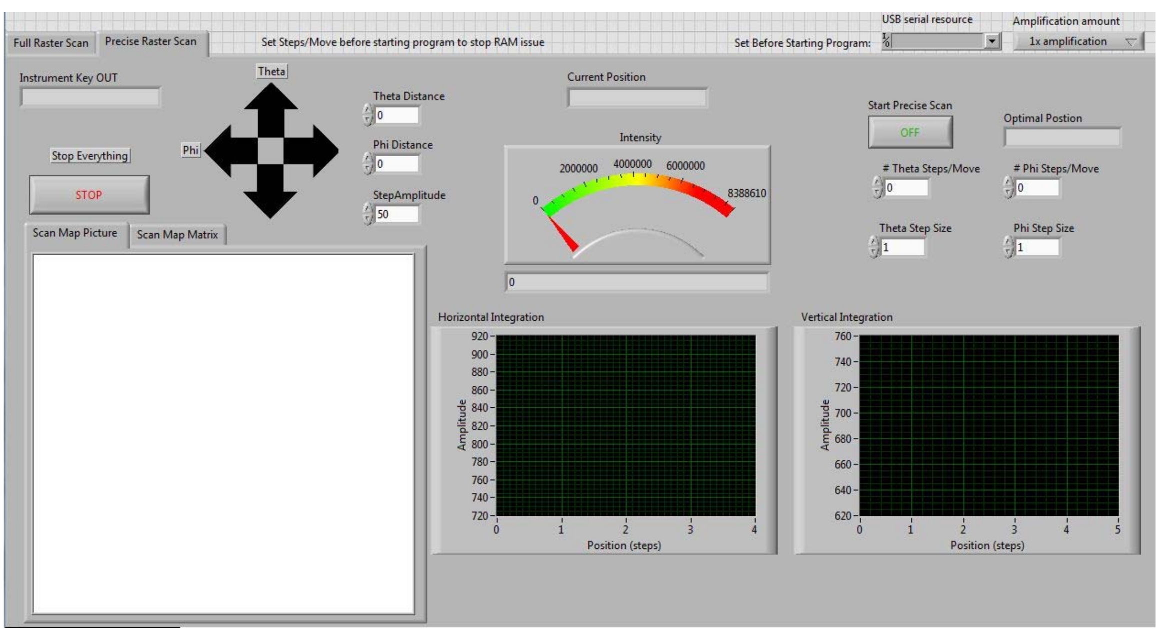


Figure 6.3-6 Precise Raster Scan GUI

7.0 Project Prototype Testing

7.1 Hardware Test Environment

Computer with Light Intensity Subsystem - The environment used to test this system was in one of the LPL labs. Part of the OPO must be set up in order to test all of the hardware in this subsystem. In Figure 7.1-1 is the setup of the OPO experiment, in which the project was design to accommodate. After the laser, depicted as a red line it went through a crystal that was held by the motorized crystal mount. The light at the output of the crystal was then captured by the MCT detector.

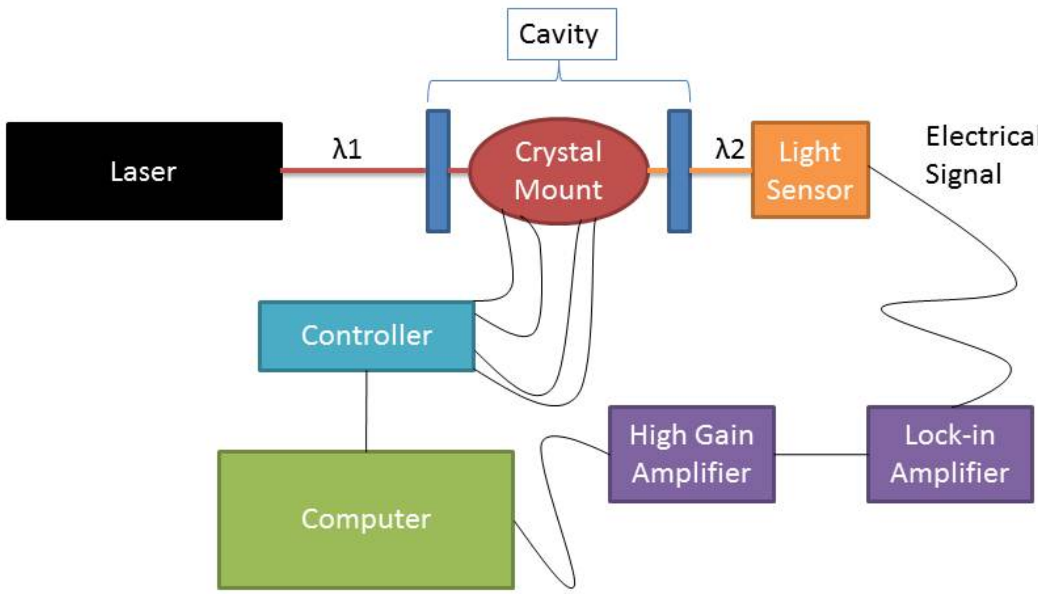


Figure 7.1-1 OPO experiment set up.

Before the signal can be analyzed by the computer, the signal must be amplified which is represented by the amplifier boxes in the diagram. Although it is not depicted in the diagram, the amplified signal from the amplifier was fed to the Atmega microcontroller so it can sample the signal. The now sampled signal was transmitted and analyzed by a computer connected through USB port.

For signal debugging purposes, electrical equipment such as the oscilloscope, a power supply, and a function generator was needed to test the amplifier. The oscilloscope was very important in tracking the signal as it goes through various electronics. For example, if we do not see the signal appearing on LabVIEW in the computer, we probed for the signal at various points in the system to debug the faulty parts. This helped to find incomplete solder on certain pins. The oscilloscope was also to analyze the noise added to the signal by the system. This can be done by probing the input as well as the output and comparing the two. Often times these noises added by the system can mislead the data used for the analysis leading it to be incorrect.

In addition to the oscilloscope, the power supply and the function generator would be needed to test various components. The power supply can test aspects such as the ±Vcc powering the operational amplifiers. In the case of the MCT detector, it also requires a 5VDC and a 15 VDC input. To test this device, we would need to use the power supply to provide the requirements. The function generator can be used to generate a certain input signal that we would like to test. This was primarily used in the place of the MCT detector if it didn't work properly in order to test the remaining parts of the subsystem. The 24 bit analog to digital converter used in the microcontroller subsystem is prone to switching noise, but our testing showed the design is stable enough for getting accurate measurements.

7.2 Hardware Specific Testing

MCT Detector - The purpose of the MCT detector is to produce a voltage signal dependent upon the light intensity it is detecting. To test the MCT detector, a laser source was used to provide the MCT detector with a known intensity of light to set a relative point. Measurements were taken at the output terminal of the detector and recorded. The laser source's intensity was then increased and a measurement reading at the output again took place. The increment served as a "sweep". After all of the data was collected, it was compared and analyzed. If the intensity of the source feeding to the MCT detector increased, the measurements should reflect the increasing characteristic. To be cautious, a decreasing sweep was also done to further test the MCT detector. Measurements taken using an oscilloscope as the signal had various frequency components associated with it.

5 VDC to -5VDC Converter - The amplifier design was placed on the same PCB as the Arduino microcontroller. The amplifier requires a voltage source of +5VDC and -5VDC at the Vcc terminals in order to operate properly. However, there was only one power supply source of +5VDC through the USB port. The TC7660 was used to convert the +5VDC to -5VDC. The output of TC7660 exhibited oscillations at 10 kHz that could impact our output signal. To test the distortion, we had a +5VDC power supply source connected to pin 8 of the TC7660 produce a -5VDC at pin 5 and connect that to the –VCC input of the operational amplifier on a bread board. We powered the +VCC input using the same +5VDC power connected to pin 8 of the TC7660. A function generator was used to generate a signal at the negative terminal of the inverting operational amplifier configuration. We then monitored the amplifier's output signal and input signal using an oscilloscope.

If the behavioral waveform's shape at the input and output are what we had expected then it is concluded that the conversion was a success and may be used to power the operational amplifier. However if the signal is not like what is expected, then distortion is experienced.

Amplifier - There were two stages of testing the amplifier. The first stage tested the amplifier as a stand-alone component. In this case, a function generator was used to generate a known signal into the input of the amplifier. The oscilloscope measured the output terminal of the amplifier. There are various important aspects we needed to consider for this test. The first is the gain of the amplifier. To calculate the gain, channel 1 of the oscilloscope measured the input signal and channel 2 of the oscilloscope will measure the output. Using the oscilloscope, we measured a point on each of the signal simultaneously. The two values were then analyzed by the equation Gain = Vout / Vin. This was repeated for ten points or more. The average was then taken of the Gain data collected using a spread sheet. This gain was compared against the desired design gain.

The second aspect we need to test with our amplifier is the frequencies it supports and at which frequency is the threshold. To do this, we can do a frequency sweep using the function generator. We can start at 1 Hz and increase the weight by 10 times at lower frequencies and reduce the weight at higher frequencies. An example of these sweep are as follows: 1 Hz, 10 Hz, 100 Hz, 1 kHz, 10 kHz, 20 kHz, 40 kHz, and onwards. Again we had channel 1 of the oscilloscope measuring the input signal and channel 2 of the oscilloscope measuring the output of the signal. The measurement points of the input and output of the signal were recorded for analysis. The gain of the amplifier at each frequency components was calculated using the equation mentioned earlier. The gain was expected to drop according to the Gain Bandwidth plot found in the TLC2201CP data sheet.

The third aspect we tested our amplifier was for the noise generated by the amplifier system. The TLC2201CP are very low noise amplifiers. However, since the signals that we are working with are very weak, we needed to test and make sure that the low noise being generated did not affect our signal. To test for noise, the function generator was set to generate a very weak signal. The signal can be in the micro-volts or milli-volts range. The output was measured, analyzed, and compared with the input signal. We tested for large discrepancies of the signal’s waveform at the output and the input.

The second stage of testing the amplifier is to connect it with the MCT detector. In this stage of testing, we looked at various parameters. A light source shone on the MCT detector. The first parameter we looked for is to check if the two can communicate with each other. The output of the amplifier was measured for a signal. If there is a signal at the output in the range of milli-volts, then we know that both are working as intended. Again, we did a sweep of different intensities to make sure the amplifier is able to support range of light intensities used for the experiment. Once all of the tests had been past, we moved onto test the Atmega.

Atmega and Computer - The testing of communication between the amplifier and the Atmega as well as the computer and Atmega was done in one test. The main objective of this test is to confirm the communication between the Amplifier, Atmega, and computer is working properly. The amplifier was connected to the Atmega and the Atmega to the computer. The input test signal at the amplifier's input terminal came from the function generator or the MCT detector that had passed its test earlier. It was best that we use the function generator to produce the test signal as we know what the waveform looked like. On the computer, we check for value readings of the signal through a COM port terminal. These values analyzed with the input signal values to make sure that the values are from the signal and not noise. The NAU7802 is expected to sample at least 10 samples per second, so we counted the number of samples per second to make sure we were getting the maximum number of samples. The second part of integration was getting LabVIEW to receive the conversions which was tricky since it tried to install a driver for a mouse instead of just the FTD chip driver. We had to disable the mouse part of the driver, leaving the USB ft232 driver active. We simply had to use a COM Via to integrate with LabVIEW.

Analog to Digital Converter- This piece of the microcontroller subsystem was tested on its own because of the precision that is needed for this measuring. The difficulty that has come with it is that using the schematic given in the datasheet, people have reported 19 bits of usable resolution as opposed to the theoretical 23 effective bits of resolution. Some recommendations that have been come across have been included in the initial design of that part of the circuit to maximize the initial set of effective bits. This includes having capacitors at the power supplies of the IC to remove noise or supply current as bypass capacitors. Further testing was needed to see the amount of noise that is present on the power lines, but the capacitors and the Computer power supply were enough to regulate the power. Another item on the list to check was to see if the NAU7802 is more accurate when only a single input line is being used or if it is just as accurate with both lines being used for input. The single line accuracy was tested with a decoupling capacitor across the second positive and negative input pins to remove internal noise. A final suggestion for Analog to digital converters is to keep the IC as far away as possible from any sort of noise caused by power, switching, and oscillations from crystals or microcontrollers. This can be most costly on a PCB which is costly per square inch. The NAU7802 was kept marginally away from components and a split power and ground plane helped filter out switching digital noise.

Atmega328 – the Atmega needed to have the bootloader burned into it through the Arduino development board. This did not need to be purchased because one member already has one. The Atmega328 that we purchased was connected to it and burned as per manufacture instructions. For all prototyping the Arduino development board was used because it was more likely to work as expected. The development board was used to write the code needed to display on the LCD screen, communicate with the NAU7802 and communicate with the computer. After the coding was completed and tested, the Atmega328 that is purchased had the bootloader burned in. Then it replaced the one located on the Arduino IC socket, finally code was uploaded to it. There was a problem that we ran into burning the bootloader as it did not recognize the 328-PU chip, so some modifications to the programmer were necessary to recognize the chip and burn it.

Whole System Test - After testing each individual parts of the subsystem, the whole system was tested. The objective of this test was to see if the Hardware subsystem is capable of performing to specification. The specification was to have the subsystem be able to scan the various orientations of the crystal and search for the orientation that yields the maximum power output.

To test, we scanned various orientations of the crystal. Each yielded data of the power output at that specific orientation. After a good amount of various orientations had been scanned, we checked to see if the final orientation produced the maximum power output compared to other orientations. This analysis was done by checking the data collected in the computer.

7.3 Software Test Environment

Programming Language Choice- The chosen programming language for this project is G, using LabVIEW from National Instruments. Most experiments at the Center for Research and Education in Optics and Lasers (CREOL) use LabVIEW mostly because of its ease of use. LabVIEW uses a graphical programming language and allows for parallel execution which will be useful for the many motors and sensors. LabVIEW also contains something called MathScript which was considered to be useful for creating functions that don't exist but the graphical language was easy enough to use. MathScript is text based instead of graphical and is MATLAB code inside a box with inputs and outputs which all the group members at CREOL are familiar with.

Testing Environment- An open optics table in one of the labs at CREOL was used to setup the experiment by the graduate students at CREOL. These tables are extremely flat, rigid, reduce vibrations, and contain a grid of threaded holes to fasten down equipment. Most of the software testing couldn't have started until the amplifier had first been tested; therefore, artificial data in a spread sheet was created to simulate the scan data. This artificial data is also useful for testing extreme cases. The motor mounts and controller were lent to us during our work so that testing for the movement of the motors could be tested. Luckily, the only piece of hardware that delayed testing was the light sensor since it had to be kept in the optics table. We were also lucky that this data could easily be replicated since it is just an amplitude modulation analog signal. The other pieces of hardware required no modification by us.

All experiment tables already had a computer setup for use and plenty of screws to fasten down components that require it. CREOL is already in possession of several server licenses for both LabVIEW and MATLAB which were already installed on the computer. Two monitors are usually also setup to make monitoring data and controlling instruments easier to do in the case of the original OPO experiment we were working on. With two monitors, this would have allowed for both the UI for the mirror mounts and for the crystal mount to be up and monitored at the same time. Since optical setup takes a great amount of time with their need for alignment; only the one setup was made and tested on our own computer. Logs for the test cases, mentioned in the next section, were made to keep count and help organize potential problem/errors, which became very useful for this team oriented project. For some important data sets, the mathematics were checked by MATLAB or by hand, and when possible, compared to results of similar experiments.

7.4 Software Specific Testing

The first step in designing software is to gather the requirements and based on those requirements, choose or create a test cycle. We have chosen a test cycle that is similar to the waterfall with prototyping model but with just a few modifications. These modifications include the two way direction of the model seen in Figure 7.4-1 and only prototyping for the UI. An evolutionary prototyping approach was used. Therefore we were able to make a functional UI first and with our left over time make it simpler to use. Since half of the project's time is spent in design, a design prototype is not needed but a UI prototype allowed a greater chance of success at the final stage, acceptance testing. Also, our requirements are not changing much, or at least only requirements were removed not added; playing strength to the waterfall model. The main drawback of the waterfall model is the time it takes to get a final product. Since we had a very specific deadline and we didn't need any smaller form of the product ready soon, this drawback did not concern us. Other benefits of this test cycle model included reliability, flexibility, easy of understanding, and provided a high level view of the development process.

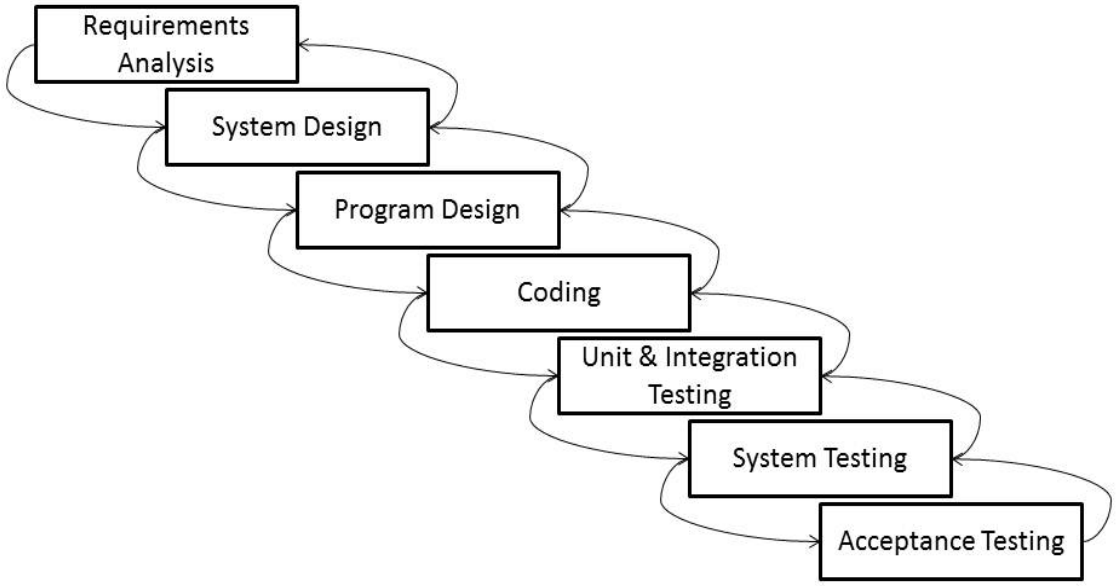


Figure 7.4-1 Software Test Cycle

This model is reliable because it contains unit testing. So we are testing every little function first. Then with integration testing we test more and more of the pieces/functions together. When we finally got to testing the program as a whole, we had to make very few changes to get it completely working. The flexibility in the model comes from the two way direction of it. For example, if something doesn't work in an integration test, then we can look back at its units and then go back to coding to fix the error. If an error occurs during system testing we can even revert all the functions back to original system design coding. Compared to most test cycle models, the waterfall model shows the most detail, making it easier for the client to understand how this development process will work unlike an agile method of development. The waterfall model shows high level processes that other models, like the operational specific model, don't. The operational specific model mostly consists of requirements analysis, repeatedly executing and revise operational specifications, testing, and then delivering the product.

Among these previously mentioned reasons for not using other models, the following are reasons why they were not chosen. The V model is very similar to the waterfall model but any error in testing is assumed to be a cause of bad design when, in our case, more likely due to bad coding. Operational specification model is also similar but spends a lot of time in revise the requirements. It also suspects that you will satisfy that requirement before revise the rest. Since we are verifying all the requirements before coding begins, this model does not work for us. The transformational model was not chosen mainly for the lack of a high level view. Since we don't need a partially working program soon, the phase development model is not ideal. However, when the requirements are fulfilled, small phases of extra features will be implemented if time permits. The spiral model is more ideal for a project that will take a long time, has a constrained budget, and has greater risks to health, security, etc. An agile method such as extreme programming could get the project done quicker and takes advantage of the client being onsite but usually requires a large team. Agile methods also make it difficult to optimize a fully functional product or change the underlining architecture. For a project that doesn't require much of a plan and has constantly changing requirements, an agile method would be more suited.

Test Cycle Block Descriptions - The requirements for the software are as follow: the ability to gather data from the various sensors, the ability to communicate properly with the controller, the ability to move the motors, the ability to detect where the laser beam is hitting the camera (was removed with the switch of experiments), the ability to move the correct motors to make the desired corrective movements, the ability to generate an image like representation of scan data, the ability to identify the position of max intensity, the ability to move to a desired position, the ability to complete the two forms of raster scans that are to be implemented, and to display all functions and data in an easy to use manner. System design involves how everything, hardware and software, are working together. Since the program is running on a local computer where all the hardware is connected to, the difficulty of design is minimal. The program will however be stored on an already setup server in a section only accessible by Laser and Plasma Laboratory (LPL) members. The program design is how the program is going to be written and organized. This explained in section 6.3 (Final Coding Plan) through the use of class diagrams, activity diagrams, and other UML diagrams. Coding will be defined as the process of actually writing the code for the program. Unit and Integration could be broken up into two separate blocks. Unit testing was done first for all functions. If the function failed or got an error, we looked back at the code for problems. If none arise then that meant there was a flaw in the program design which would need to be addressed. Once all unit testing was done then those units were integrated into larger components. These components continued to be integrated as they pass their testing until all components are integrated into the full program; this is when system testing would be done. Because of the unit and integration testing, less time was spent in system testing. Throughout these test we used destructive testing which is where we tried to create scenarios that will break the program. The graphical UI will help in limiting the type of data that can be entered. With the approval of all the team members, approval testing will start for the customers, LPL students and faculty who will be using this project. At first, we did not let them see the code, just use the software. We then move on to allowing them to see the code and use destructive testing. Normally the waterfall model has one more block called "Operation and Maintenance". We excluded this block since we will no longer be working on the program once the semester is over. All maintenance will have to be handled by the customer.

Test Cases - Each test case is divided up into three sections. Information about the test being conducted, the activities invoked during the test, and the expected results of the test.

Information
Test to make sure that commands that are sent to the controller move the correct motor, the correct direction, the correct distance.

Activities
1. One at a time, send the command to each of the six motors individually to make them move.
2. Check that correct motor moved by the correct distance, in the correct direction.
3. Test range in movement from smallest measured to end to end of movement and several values in between.
4. Check that correct distance was moved
5. Test opposite direction and same distances for each motor.
6. Check that the direction changed and the correct distance was still moved.
7. Do above test for motor pairs moving simultaneously (motors that are connected to the same mount).
8. Do steps 1-6 for motors belonging to the mirror mounts, all moving simultaneously.
9. Do steps 1-6 for all motors moving simultaneously.

Results
When making the commands to send to the motors, the tester knows what should happen and simply checks that the physical movements match the coded command. This will require calibers to measure the small distances.

Information
Test to make sure the home functions operate as they should.

Activities
1. Move motors on crystal mount.
2. Send command for them to return to home. (these motors don't need a virtual home)
3. Check to see if they returned to correct position.
4. Define home for all motors at random positions covering the maximum ranges.
5. Move all the motors to random positions covering max ranges of movement.
6. Send command to return to home position.
7. Check to see if all motors returned to their respective home positions.

Results
When setting home positions, measurements need to be taken for the later check when the motors should return back to this position.

Information

Test the light and positions sensors for accuracy.

Activities

1. Shine laser into our light sensor.
2. Check measured value.
3. Shine laser into power meter.
4. Compare measured values.
5. Move all motors to various positions ranging from all limits of movement.
6. Physically measure positions and change in positions.

Results

The intensity value, as measured from the light sensor and power meter, needs to be accurate within the error range of the power meter to pass this test. The position sensors need to be accurate to within $0.1^{o}$of the physically measured values.

Information

Full scan test to make sure data from the light sensor and position sensors are grouped together and put into a represented map. Also checks that the center position is correctly chosen most of the time and the motors move to that position.

Activities

1. Scan a single position.
2. Check to see if intensity data and position data are grouped together into a cell.
3. Check grayscale image representation for correct shade of gray.
4. Scan while only changing degrees of phi.
5. Check if the right intensities are matched with the right positions and the image has the correct shade of gray.
6. Scan while only changing degrees of theta.
7. Check if the right intensities are matched with the right positions and the image has the correct shade of gray.
8. Scan in both directions (full function).
9. Check that motors move to both of their limits.
10. Check if the right intensities are matched with the right positions and the image has the correct shade of gray.

Results

For the single position test, the UI will show the intensity and position for comparison. In order to check the matching of position and intensity, several pairs will be checked but not all because of time restraints. This check will require moving to the position that belongs to our test sample and reading the intensity measured. Checking the grayscale value involves uploading the image into MATLAB and comparing the sample pixels with the matrix of the image.

Information

Precise scan test that performs similarly to the full scan test but also checks iteration movement distance, scan size, and scan shape.

Activities

1. Attempt 3x3 scan.
2. Observe position reading of where intensity data was taken.
3. Check to see if all the positions are the same number of degrees apart.
4. Check results for a 3x3 image.
5. Repeat above steps but with varying iteration step values and scan sizes, ranging from the smallest iteration to twenty times that value and a scan size of 3 to 59.

Results

Reading the position and intensity data will first be with calibers and a power meter. When that is verified to be accurate, the display data will be used.

8.0 Prototype Modifications

8.1 Amplifier Modifications

When the MCT light detector has arrived at CREOL, several new characteristics was known about the sensor. This triggered modifications to the original amplifier design in order to integrate it with the MCT detector. The first major change made to the amplifier is the overall maximum gain it supports. Since the signal from the MCT light detector is much stronger than previously suspected, the gain was changed from 10^6 to 6^6 using the non-inverting configuration. This was the first major change from our original specification. In addition, the signal coming from the MCT detector varied in intensity. To address this, we included a variable gain ability to our amplifier using N-MOSFETs as switches. The new block diagram for this change can be summarized and seen in Figure 8.1-1.

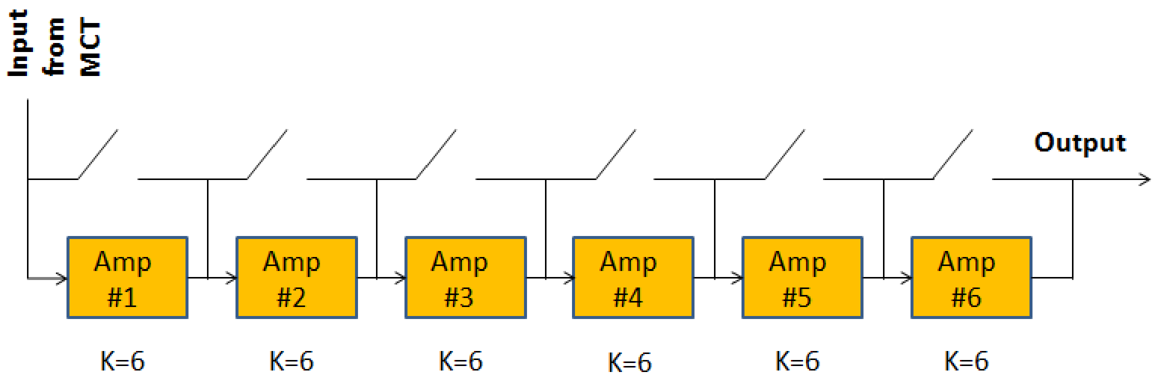


Figure 8.1-1 Final block diagram of the amplifier design.

To accomplish the new gain, the resistor value of 10kΩ was changed to 5kΩ. From the equation for non-inverting operational amplifiers, K = (1 + R2/R1), changing R2 to 5kΩ while keeping R1 1kΩ, we achieved 6 gain.

Using the structure layout found in the Figure 8.1-1, a schematic was designed for the amplifier system. The amplifier system schematic can be found in Figure 8.1-2. In the schematic design, TLC2201CP operational amplifiers are used. The input signal comes from the MCT detector's output through the edge mount SMA connector. From there the signal is fed to the positive input terminal of the operation amplifier as well as the Drain pin of the N-channel MOSFET. The 5kΩ resistor was connected from the negative input terminal of the operational amplifier to the output. There was a 1kΩ resistor connected to ground (GND) on one node and the other node was connected to the negative input terminal of the op-amp. The output of the first operational amplifier was then connected to three other pins. The first pin was at the input of another non-inverting operation amplifier with the gain of 6. The second connection was then made to the Source of the first N-channel MOSFET. Finally, the third connection was connected to the Drain pin of the next n-channel MOSFET. This configuration allows the N-channel MOSFET to be used as switches to allow the signal to bypass the operational amplifiers or forced to travel through. The configuration was then repeated to have 6 non-inverting op-amps with switches for each one. Each of the gate pins from the N-channel MOSFETs was then connected to the I/O pins on the PCF8574. The final output from the last op-amp was connected to an non-inverting unity gain op-amp filtering system. The filter was designed to filter any noise higher than 16 kHz.

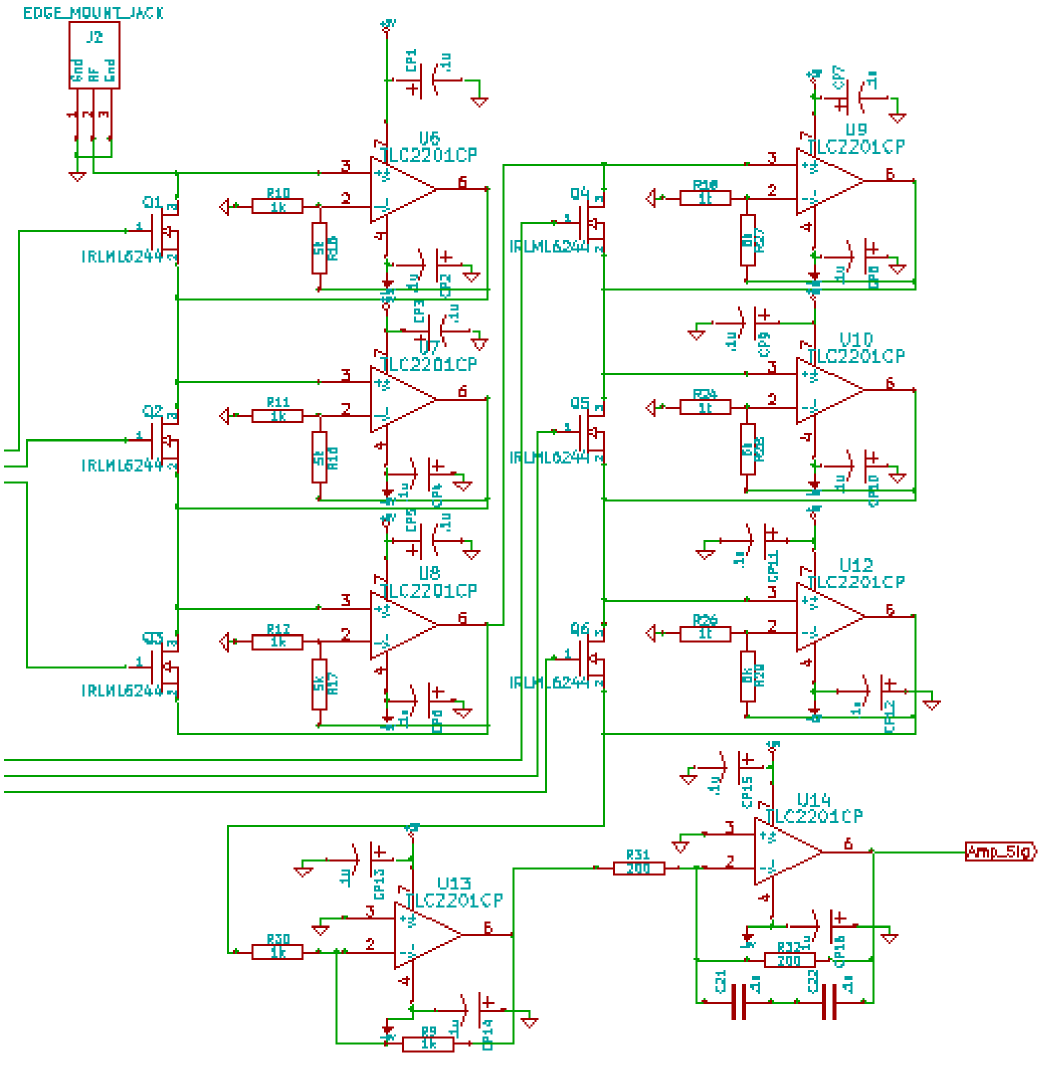


Figure 8.1-2 Schematic of modified amplifier

Simulations were done in LTSPICE to simulate the bypass ability of the amplifier as well as the variable gain. A schematic similar to the schematic depicted in Figure 8.1-2 was assembled in LTSPICE. A function generator was used to generate a small signal of 6 milli-volt sinusoidal wave of 100 Hz as the input signal. Below in Figure 8.1-3 is a simulation of the amplifier during bypass mode.

By having all of the gate input of the MOSFET be set to 5V, we can achieve bypass mode. As seen in the figure, there were some noise introduced in the original signal. However it was determined that the noise will not interfere with our objective.

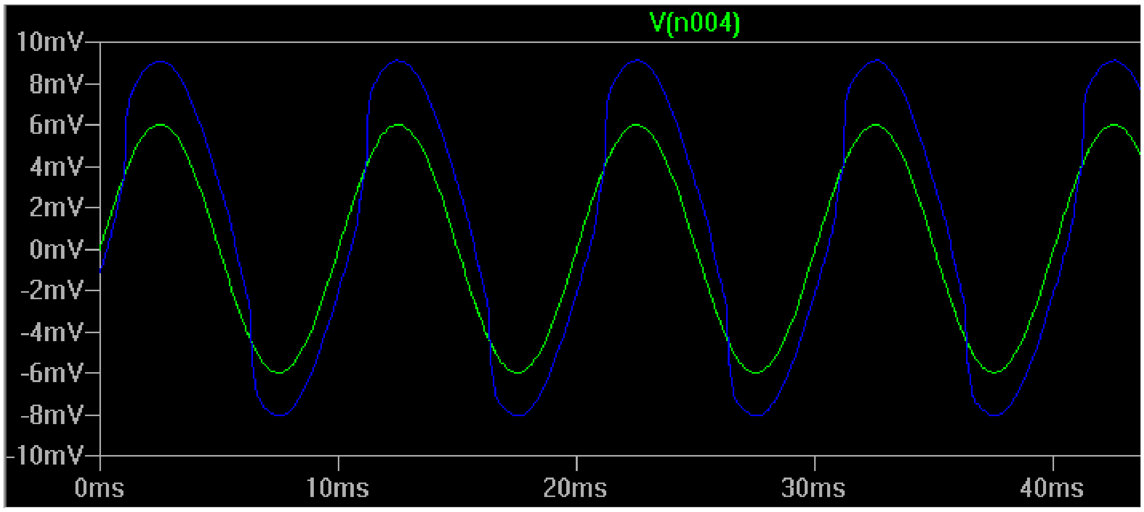


Figure 8.1-3 Amplifier bypass mode simulation

With the same schematic, the variable gain feature was simulated. The simulation result can be found in Figure 8.1-4. The simulation shown is for a gain of 6. To achieve this gain, the initial 5 MOSFET gate input was set to 5 V while the last MOSFET gate input was set to 0 V. The signal will be amplified during the last amplifier. The green signal appearing in the simulation is the original signal that was also used in the above simulation. Considering there were noise introduced before being amplified, the correct amplification was achieved. Although there were some noise introduced, it does not interfered with our objective during prototype because this is constant and applied to all signals.

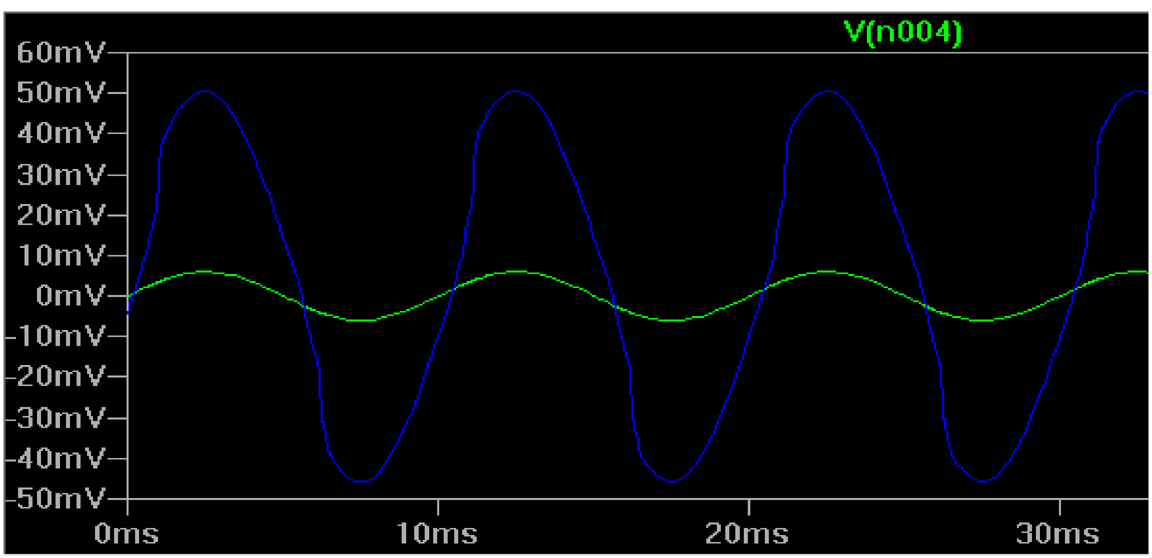


Figure 8.1-4 Amplifier in variable gain, 6, mode simulation

Once the PCB was ordered and integrated with the MCT light sensor, it was found out that the n-channel MOSFETs used in the previous configuration created a loop connecting the output and the input. This created an infinite gain on the signal. An alternative route was chosen in order to finish the project. The internal amplifier of the analog to digital converter (ADC) was used instead. The ADC can be programmed to have the gain increased by a factor of 2, with a maximum of 128. This gain can be chosen from the drop down menu of the Automated Optical Setup program's graphic user interface (GUI). Although the maximum gain is only 128, it was suitable for the project since the input signal from the MCT light detector was much stronger than previously expected.

Several test were ran to be sure that the amplifier was integrated with the microcontroller properly. The results for the new design can be seen in Table 8.1-1 below. To set up the test, a test signal of about 10 mill-volts was used as an input to the edge mount jack using a DC power supply. A DMM was used to monitor the input signal. The serial monitor screen was then opened to monitor the output data sent to the AOS software through USB port. The AOS GUI was also opened to select the various optional gain applied to the signal. After each gain was selected, the data was read from the serial monitor to verify that the output signal was close to the theoretical value.

Input (mV)	Selected Gain	Output (mV)
10.00	1	10.40
10.10	2	22.02
10.12	4	42.25
10.00	8	83.12
9.95	16	164.23
10.07	32	330.24
10.04	64	655.16
9.99	128	1340.46

Table 8.1-1 Amplifier test result data

From the results above, it was noticed that there are small discrepancies between the theoretical values versus the recorded values. However, these discrepancies were most likely due to the small noise introduced within the whole system. It was determined based on several dry runs that the small discrepancies did not prevent the AOS from achieving the desired orientation of the crystal since the MCT detector produced little to no signal when the crystal has not reached its correct orientation.

9.0 Administrative Content

9.1 Milestone Discussion

Project Timeline -The table found in Figure 9.1-1 is a timeline of how our time will be distributed amongst the various phases. In the figure, the vertical axis represents various phases that need to be done chronologically. The horizontal axis represents the time we have to complete all of the phases. There are seven phases in all, but we will only be able to complete the first three after the first semester. The three phases we will be able to complete this semester are: Research, Design, and Preliminary Documentation. The first 3 phases are crucial to our project as they provide us with a foundation for our project.

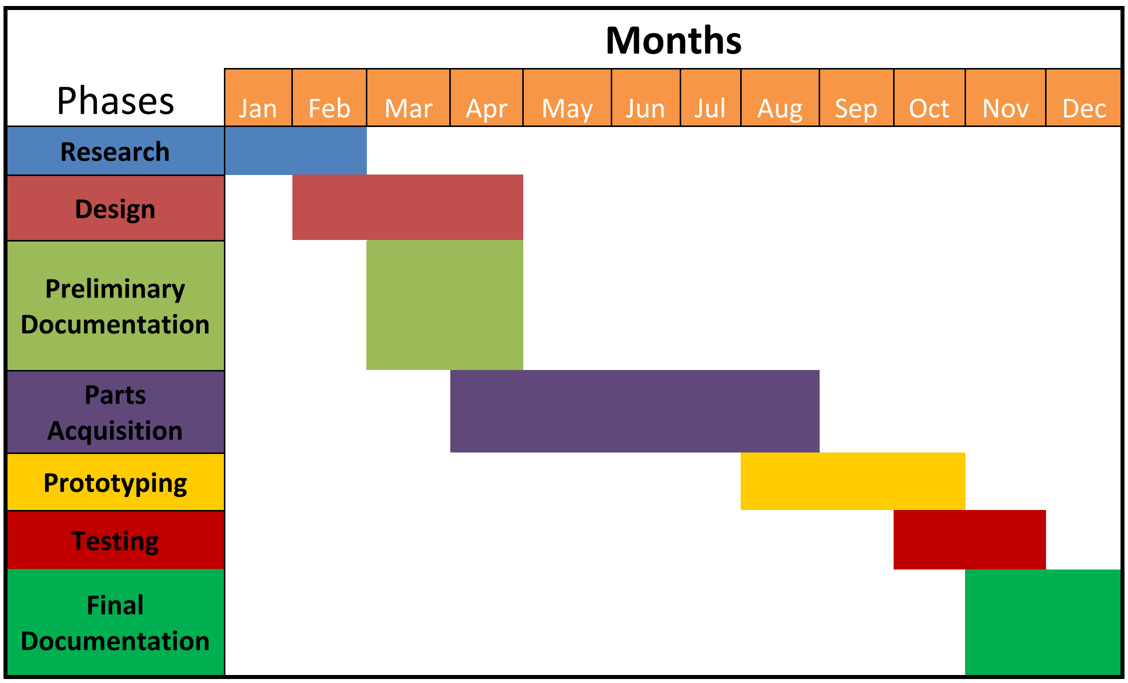


Figure 9.1-1 Project Timeline

The first phase is research, which was done after we had decided on which project we will work on as a team. Initially, each individual group member had different project in mind that they would like to do. However, it was later converged to the sponsored project by CREOL. Once the project has been decided, the next two months was used as research on relevant technologies as well as possible design architectures to be used. This phase was used to gather a body of knowledge about our project.

Once the knowledge had been gathered, the design process was started. From Figure 9.1-1, it can be seen that both the research and the design process occurred simultaneously. It occurred simultaneously because further knowledge is needed to be developed as design difficulties began to appear and the initial design needs to be changed. The design phase would most likely require the most amount of time and therefore it was given three months to complete.

The first documentation to be turned in is the preliminary documentation. This is a big milestone for us as we submit a copy of all of our accumulative work associated to the project after the first semester is completed. Two months has been set aside for us to prepare the document. During that time, we spent in writing of the document, proofreading of the document for any mistakes, formatting the document, printing, and binding the document.

The remaining four phases, with the exception of one was continued in the Fall semester. The phase that was a continuation from Spring into Summer and Fall was the Parts Acquisition as sample request for components required some time to acquire. Prototyping was done in the first three months at the beginning of the semester. During the prototyping, test of individual hardware and software components were ran simultaneously and the devices were verified to work properly. A final test was ran for the subsystems and whole system once the prototype has been assembled. Two months was set aside for testing of components as well as the whole system. During the testing period, we gathered the results to include it in the final document that is to be turned in December. This document included any changes made to our initial design as well as the test results. We had set aside two months to prepare the document.

The project was completed. The Conference Paper was done, submitted, and sent out to the review committee before the final presentation. The initial Critical Design Review presentation was presented to the class and to the review committee at the final presentation. The project objectives were met at the final project's demonstration for the judges review.

9.2 Budget and Finance Discussion

The core project was sponsored by the department of CREOL at the University of Central Florida. The sponsored project idea was submitted and was advised that the project didn’t have enough hardware design to meet the senior design requirements. Due to such circumstances, additional features were added to the sponsored project to meet the senior design requirements. Due to the situations stated, our project was financed by both parties, the CREOL department and the senior design group at the initial stage. This was later changed as the project developed.

The CREOL department paid for the total cost in this project. Some of the components the CREOL department paid and provided for are: the motorized piezo mirror mounts and the controller of the motorized mirror mounts. In addition, the CREOL department also provided us with access to software needed for this project like LabVIEW. The components related to the additional features of the design was paid for by CREOL as well.

10.0 Appendices

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Don Henderson opticsinmotion@yahoo.com

to Roberto

Roberto,

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Don Henderson, Partner
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Arduino

Open-source hardware shares much of the principles and approach of free and open-source software. In particular, we believe that people should be able to study our hardware to understand how it works, make changes to it, and share those changes. To facilitate this, we release all of the original design files (Eagle CAD) for the Arduino hardware. These files are licensed under a Creative Commons Attribution Share-Alike license, which allows for both personal and commercial derivative works, as long as they credit Arduino and release their designs under the same license.

The Arduino software is also open-source. The source code for the Java environment is released under the GPL and the C/C++ microcontroller libraries are under the LGPL.

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www.ftdichip.com

www.imagineeringezine.com

Dimagineering@aol.com

Duy-Hung Pham,

OK, you have my permission. Let me know what your project is.

Dave Johnson

In a message dated 3/24/2012 2:22:20 P.M. Central Daylight Time, p.duy-hung@knights.ucf.edu writes:
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Fax: 847-844-8796

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http://www.newhavendisplay.com/index.php?main_page=product_info&cPath=2_83&products_id=5161
I'd like to talk about some of its features and use the schematic for connecting it to an 8 bit microcontroller that is on page 4 of the datasheet.

Sincerely,
Roberto Borja

Daylight Solutions

From:**Chris Armacost** (carmacost@daylightsolutions.com)
Sent: Mon 4/16/12 8:45 PM
To: Duy-Hung Pham (p.duy-hung@knights.ucf.edu)
Hi Duy-Hung,
That is fine.
Thanks,
Chris
From: Duy-Hung Pham [mailto:p.duy-hung@knights.ucf.edu]
Sent: Monday, April 16, 2012 1:44 PM
To: Chris Armacost
Subject: RE: Amplified MCT Detector
Hi Chris,

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We would like to ask permission from Daylight Solution to reprint the MCT

detector picture as well as information provided in the manual for our design documentation. All credits will be given to Day light Solution.

Thanks,
Duy-Hung Pham

Texas Instruments

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Nancy
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Subject: [TI.com Website Feedback] Permission to reprint for student project
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Email: p.duy-hung@knights.ucf.edu
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Message:
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I would like permission to reprint figures, information or products as part of my research paper. All credit would go to your company. All I need is an email confirming I am allowed to reprint this information and I will attach this confirmation as part of my paper as well.
Thank you,
Duy-Hung Pham

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