Laser Stability Design Document

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Group 10

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1. Introduction

1.1 Problem and Solution Overview:

A label-free diagnostic tool used in medical area, infrared microscopy is based on the fact that molecular bonds in tissues and cells have a unique spectral signature in IR. However, the beam pointing could be affected by external factors like the drift of modules or vibration by sound. Because this technique requires a high level of sensibility, it is crucial to maintain the stability of the laser beam. Also, since various QCL(Quantum Cascade Lasers)'s would be used in the technique, they need to be aligned co-linearly with respect to each other.

By now the currently used method is a open-loop control with a look-up table for the QCL pointing. However, since this system cannot respond to the errors, the performance of the control system isn't very satisfying. A closed-loop feedback control system could be adopted to solve this problem. The position of the laser pointing could be obtained from a quadrant photodiode sensor passed to the processing unit. This sensor can generate a difference signal that can be used as the error signal in a PID controller. The microcontroller will then output a voltage to the servo drivers to correct the beam position.

1.2 Visual Aid

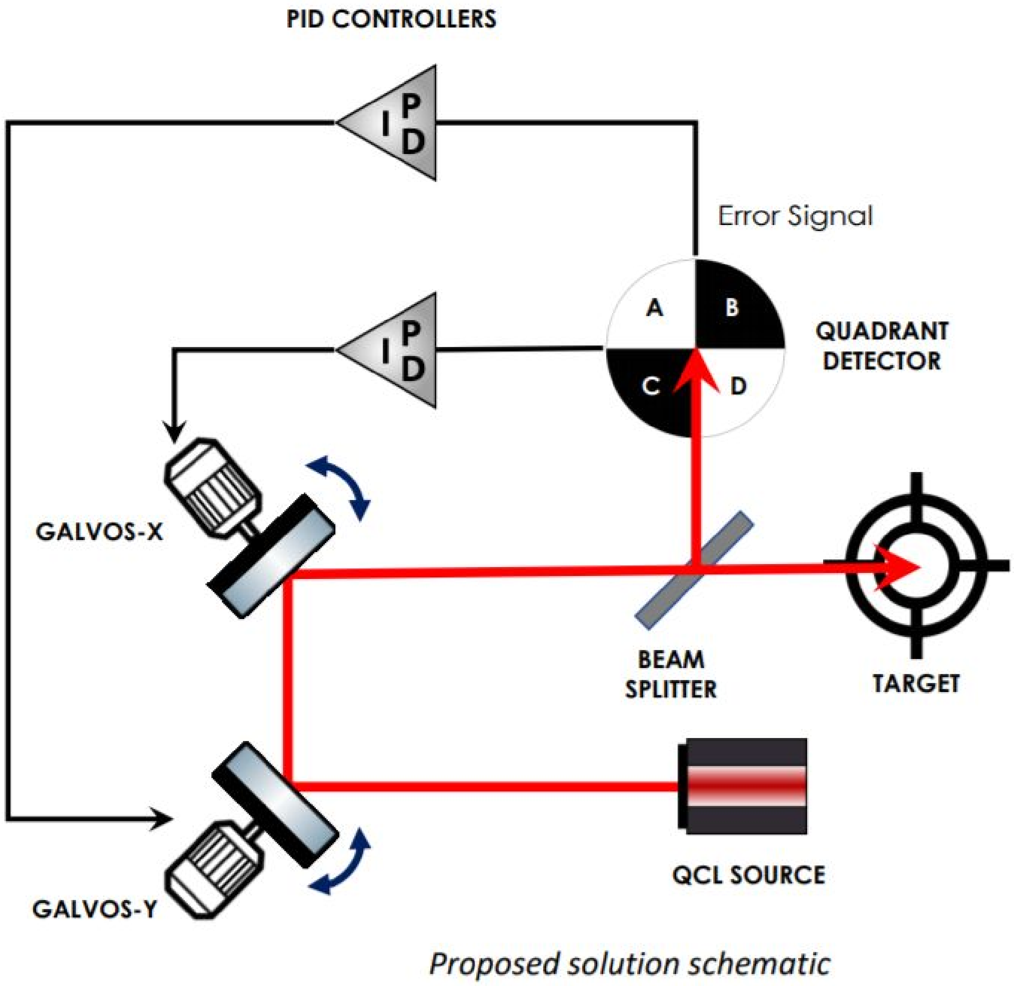

Figure 1. Proposed solution schematic [1]

- In Figure 1 (Y.Phal 3), the laser used for label-free diagnostic tool goes through a beam splitter, which separates the error signal from the one used for medical purposes. The output signal is then detected by a quadrant detector, which outputs X and Y value of the beam position. The PID control system then processes the output signal and compares with the theoretical value to compute error signal, and then generates instructions for the Galvos to adjust angle positions. The Laser beam can thus maintain relatively stable.

1.3 High-level requirements list:

1. The design should have high performance for the time response. The settle time requirement should be 100ms, where the system will stabilize before the next pulsed wave is generated.
2. For the accuracy, the maximum overshoot M_p should be 20% of the laser diameter (4mm), which is 0.8mm. The steady-state error should be less than 10% of the laser diameter, which is 0.4mm.

3. The design should have all sub-modules compatible with the I/O type of each other. The DAC output to the Galvo driver needs be -10V to +10V. All logic voltage should be united.

2. Design

2.1 Block Diagram

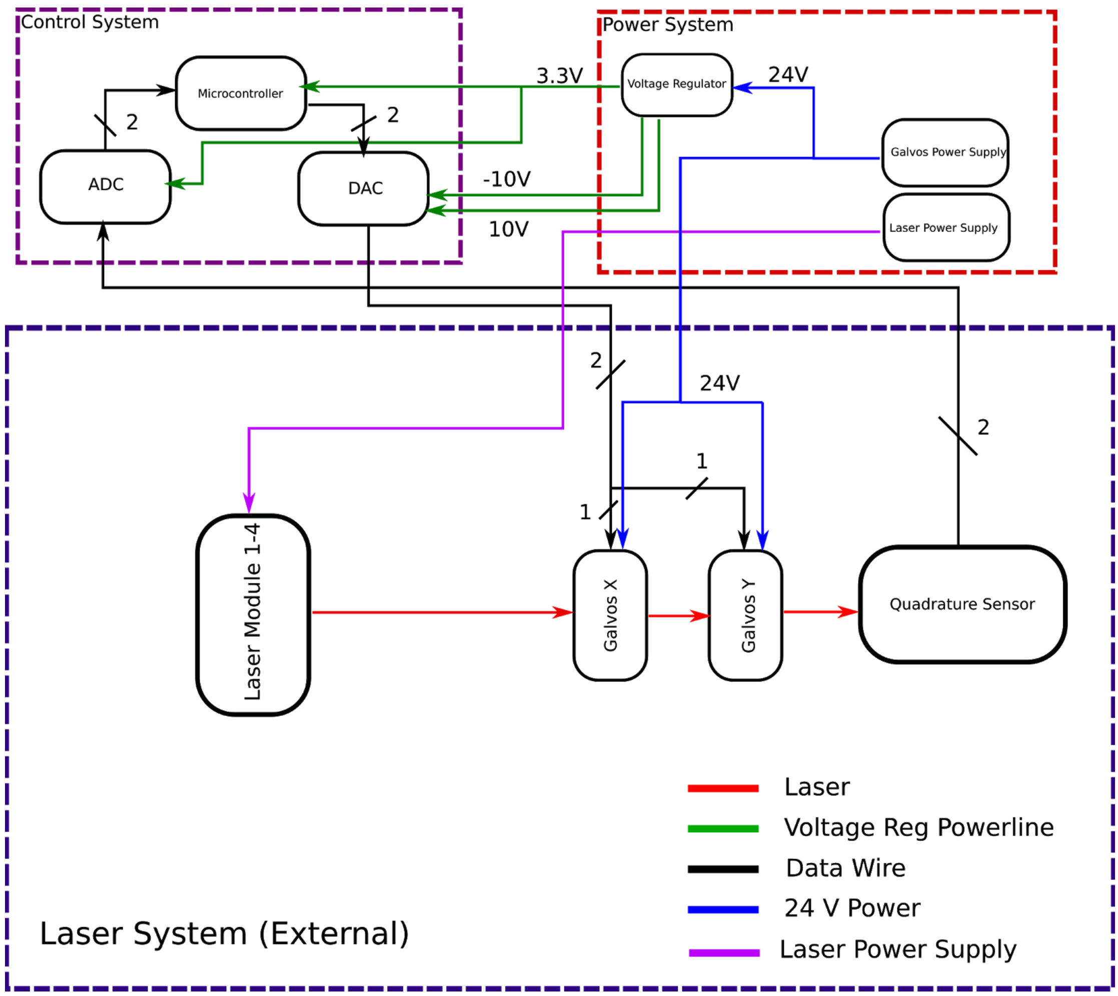

Figure 2. Block diagram

2.2 Physical Design:

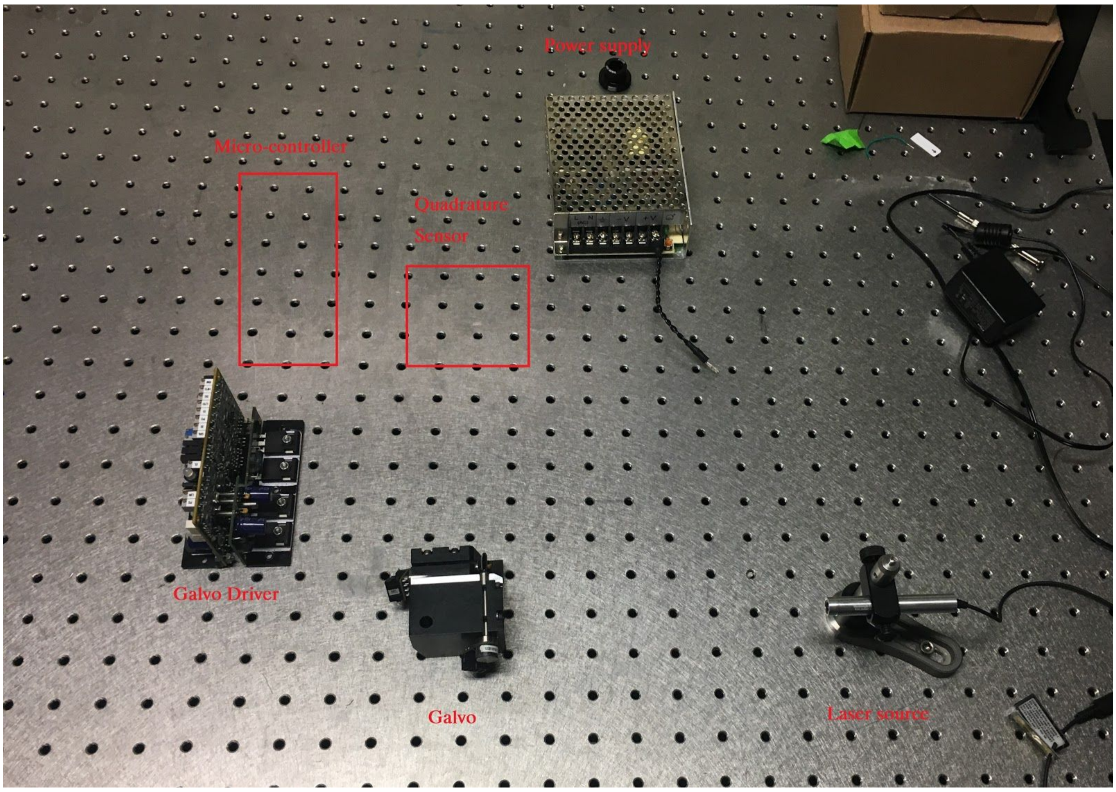

Figure 3. Physical diagram

In Figure 3, the main components are placed temporarily with unshipped parts indicated by the red squares.

2.3 Laser System

2.3.1 Laser Modules:

The laser within the system is an Infrared laser that sweeps from wavenumber 900 – 1800 cm^{-1}. The beam is not visible to the human eye, but the quadrant detector will still pick up the beams location. This beam drifts to various environmental factors such as thermal expansion, general small vibrations, and other factors.

Due to the sensor needed for infrared systems not arriving until after the course is over, we are making a testbed for our system shown in figure 3 above with a continuous laser. This laser is in the visible spectrum, so the sensor is easily available.

2.3.2 Quadrant Sensor:

This sensor has four separate elements that are equally spaced apart in the four corners. The following image is a visual of what the sensor looks like:

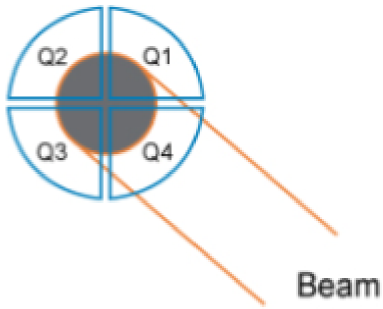

Fig 4. Quadrant Detector Mock-up Drawing[4]

Each of the quadrants outputs corresponding voltage value based on where the beam is hitting each of the elements. This creates four voltage measurements that can be used to determine the X and Y coordinates of the beam's position. However, OP-Amps are needed in order to amplify the signals that the quadrant detector outputs.

General Circuit Schematic:

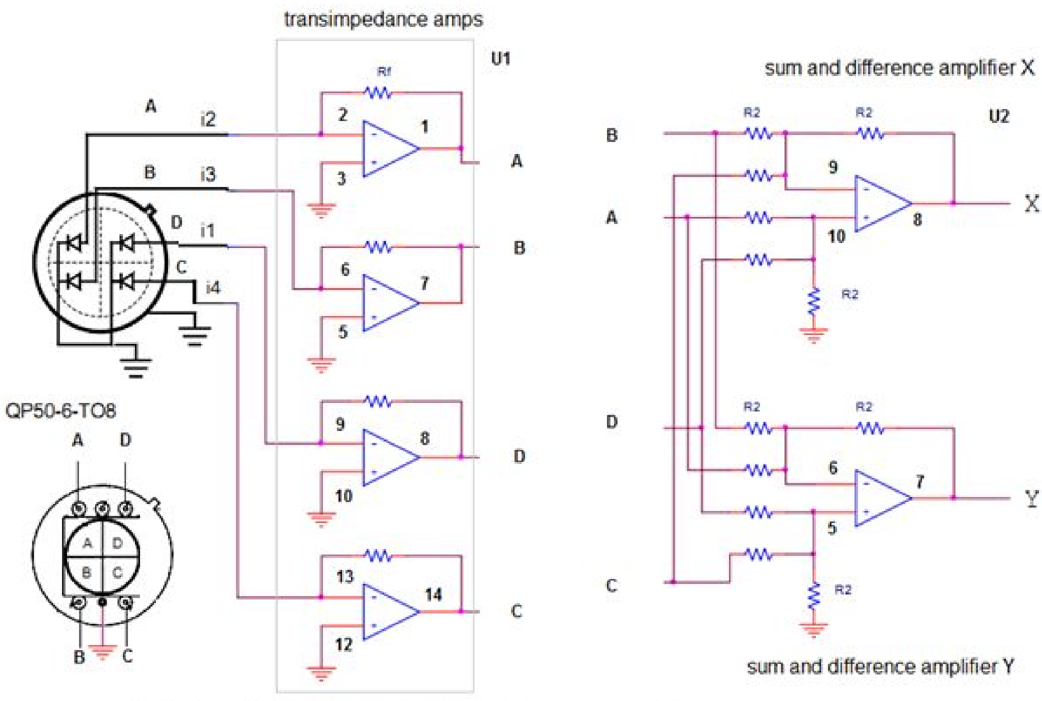

Figure 5. quadrant detector schematic [3]

Requirements and Verification:

Requirement	Verification
For Visible Lasers, must detect 500-565 nm. For IR lasers, must detect 5.7 - 12.8 μm wavelength	A. Shine Laser on Detector B. Check voltage of leads with multimeter C. Compare Voltage measurement to actual coordinate D. If it matches with +/- 5% then the laser is detected
Must have a rise time of less than 40 ns	A. Shine Laser on Detector B. Measure the output X labeled in Figure 5 using an oscilloscope. C. Measure the time difference between the spots where the voltage is 10% and 90% of the maximum. D. If the time difference calculated in C is less than 40 ns, then the requirement is met. E. Repeat A - D for the output labeled Y in Figure 5 using an oscilloscope.

Reasons for Requirements:

There are two different lasers that the system will be tested on. The first is the visible continuous laser that will emit a green wavelength laser. Most quadrant detectors will only work with specific wavelengths, so two separate quadrant detectors will be used: one for the visible and one for the Infrared. The second laser is in the Infrared spectrum which isn't visible to the human eye.

The rise time for the laser is important in order for the pulsed laser to be picked up by the detector. Each pulse is only 40 ns long, so the sensor needs to act fast enough to pick it up to get an accurate reading.

PCB Circuit Schematic:

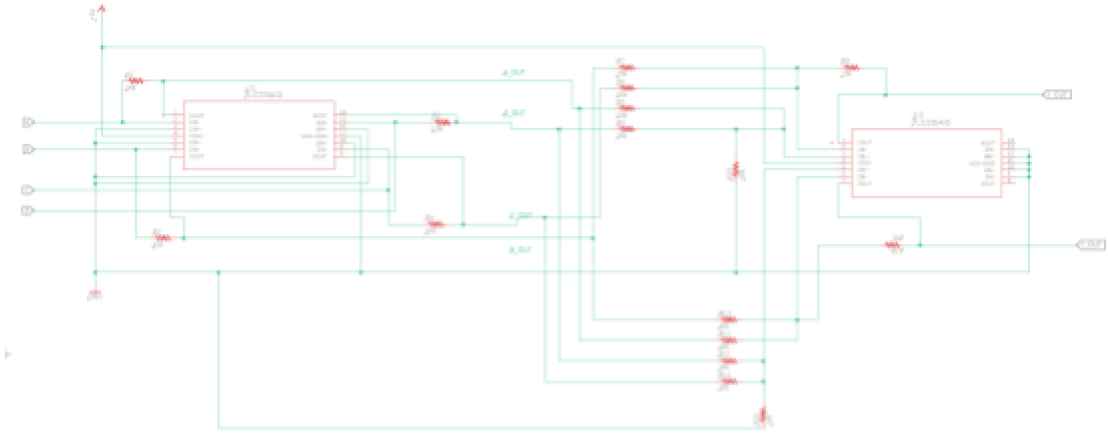

Fig 6 . Schematic with the OP-AMPS we intend to use

2.3.3 Galvanometer X and Y

The two galvos house mirrors that can be controlled similar to a servo system. The galvos are controlled through a provided galvos controller. The controller takes in an input from -10V to +10V which will change the angle of the corresponding galvos linearly (0.5V/Degree). The Galvos will be mounted to the table in a position such that the laser will make contact with both of the mirrors. The mount to our testing bed for the Galvos is shown below. The Galvos were already purchased by the research team, but a mount needed to be designed to mount the galvanometer to the test bed.

Galvanometer CAD Drawing:

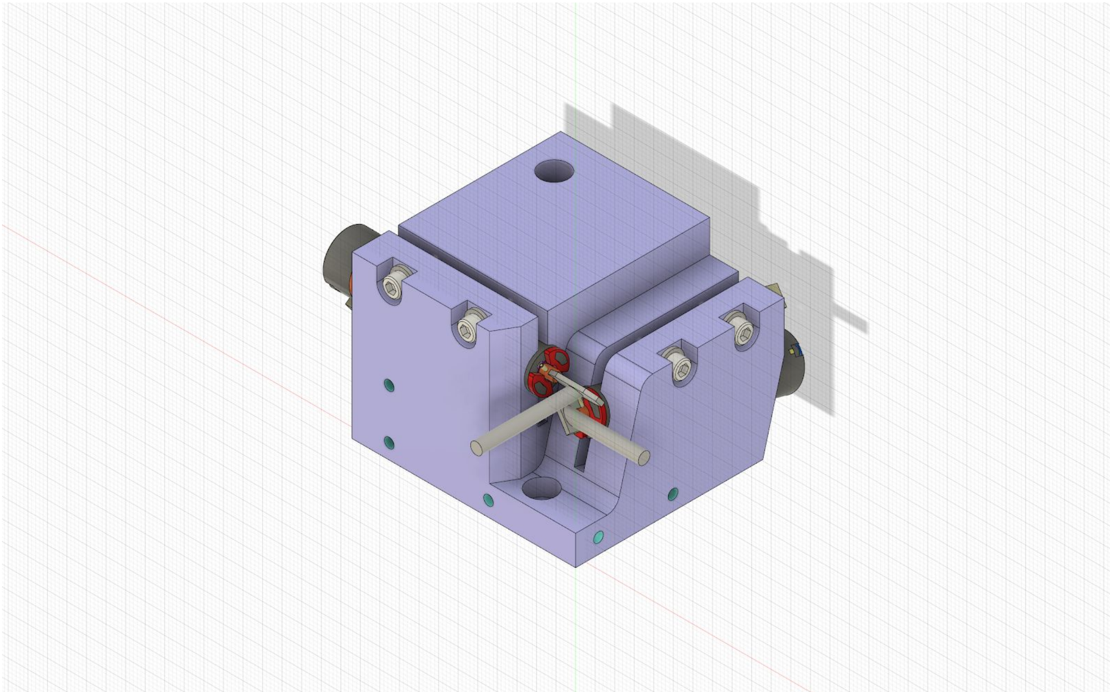

Figure 7 Galvanometer 3D module

Galvanometer Mount CAD Drawing:

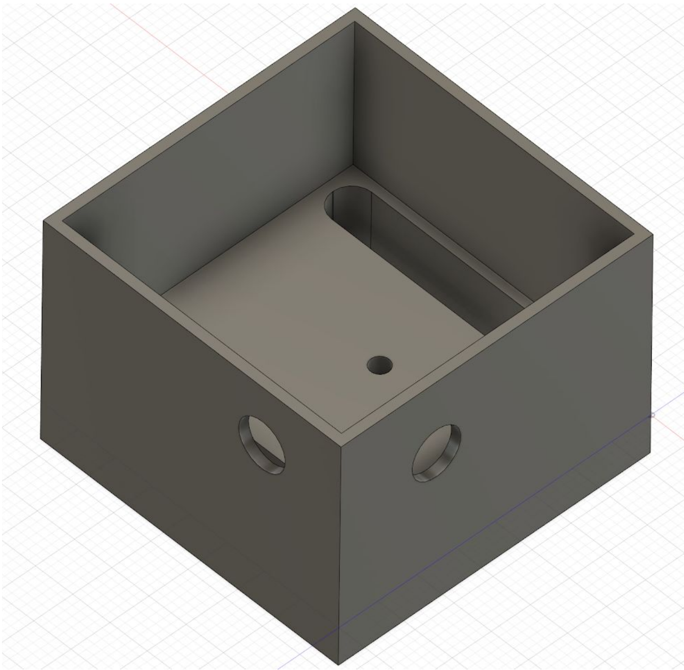

Figure 8 Galvanometer protection cage

Mirror Angle Calculations for Galvanometers:

This is a calculation for the final angle of the x axis based on the two mirrors present on the galvos. The first mirror is the only one that changes the x trajectory while the second mirror changes the y trajectory. As a result, a change in the x angle affects the actual trajectory twice as much as seen by the 2*Θx. The y angle is simpler in that only the top mirror affects the y trajectory and since it is the final mirror it affects the trajectory by Θy.

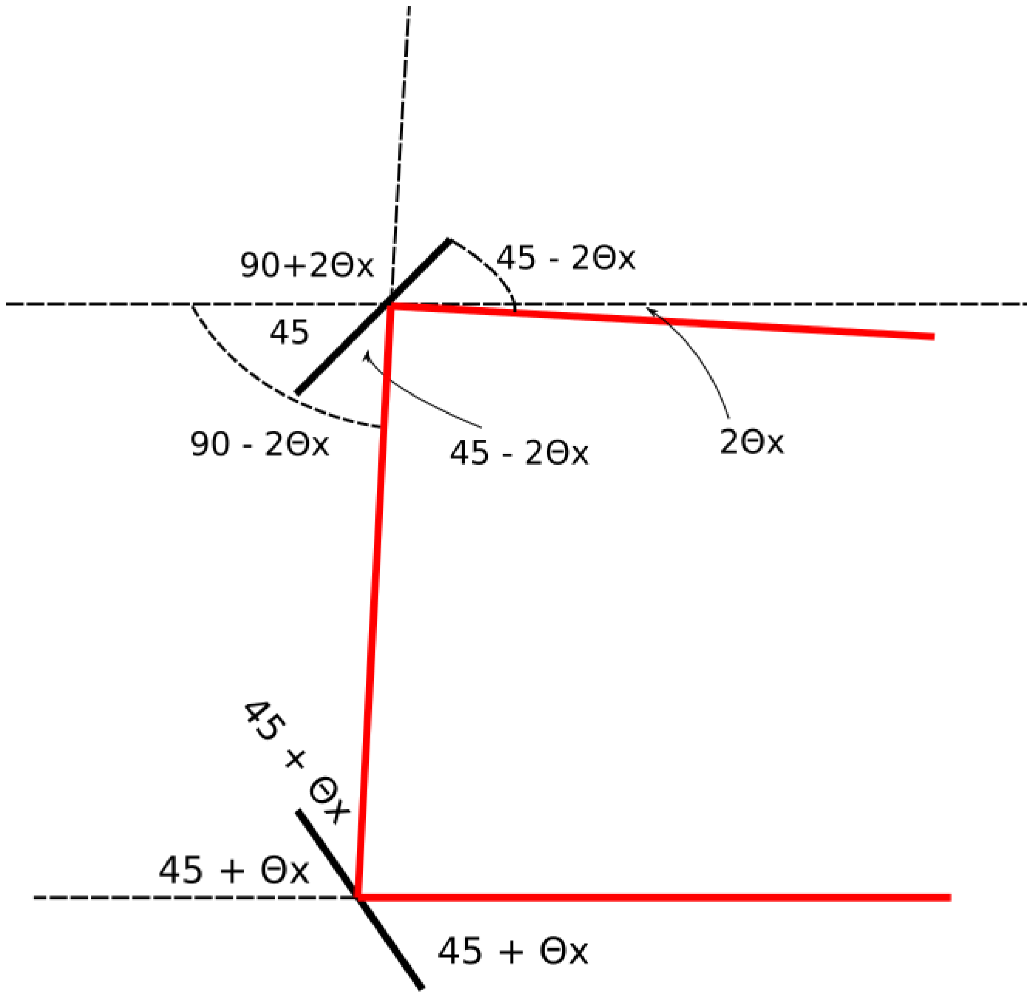

Fig 9. Galvanometer Laser Reflection Calculations for X trajectory

2.4 Control System

The control system has three main steps: read analog signal for position of the laser, determine correcting voltage, and then output corresponding correcting voltage to the Galvos controller. Each of these steps are accomplished through the interaction between the ADC system, microcontroller, and DAC system.

2.4.1 Microcontroller

This will take in the X and Y coordinate signal that was read from the ADC and use it to determine the error of the laser position. The laser position should ideally be located at the coordinate (0,0), so the error signal give the difference between the actual coordinate and the expected (0,0) coordinate. This will then be used as the PID controller's error signal. Using both how the error changes overtime and the current error, the system will determine the appropriate correction voltage it should apply to change the mirror angles to correct the mirror's position. We will be using a LAUNCHXL-F28379D launchpad due to the complexity of the microcontroller.

Inputs:

- Outputs from the Quadrant Sensor. These outputs are listed as X and Y on the quadrant detector schematic. These correspond to two voltage signals that will be read by the ADC

Outputs:

- Two from the DAC that will output the correction voltage to the galvos controller
- Output to clear the peak detection circuit

Requirements and Verification:

Requirement	Verification
ADC within the microcontroller can read the 2.5V signal for the 12-bit ADC mode	A. Send a 2.5V constant voltage from a power supply to the ADC input B. Store the value within the microcontroller that was read from the ADC C. Verify the ADC reads within +/- 5% of the output of the power supply
DAC within the microcontroller can output a consistent 2.5V constant	A. Set the DAC to output 2.5V within the microcontroller (corresponding to 12-bit representation of 2730) B. Using a multimeter measure the output of the DAC. C. Verify that voltage is 2.5V +/- 5% and stabilizes around that value within +/- 1%

Reasons for Requirements:

The accuracy of the ADC and the DAC in the microcontroller are crucial to the function of the control system. The ADC needs to be accurate so a specific voltage reading from the Quadrant Detector will always be associated with a specific laser position. The DAC needs to output a constant voltage in order to not cause the beam to move. Small amounts of noise can drastically change the position of the laser at its target.

Microcontroller Schematic:

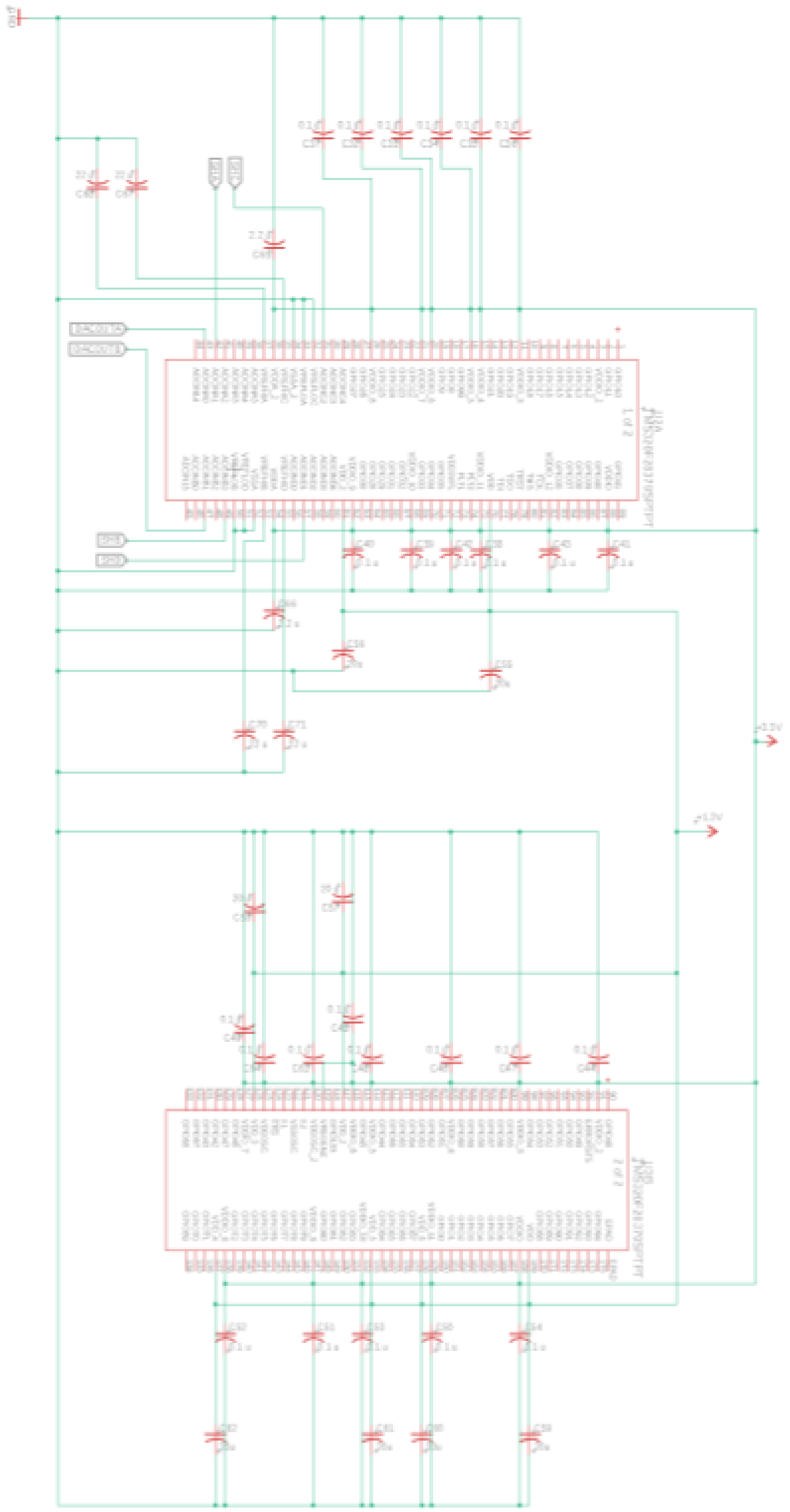

Fig 10. MCU Schematic

Program Flowchart:

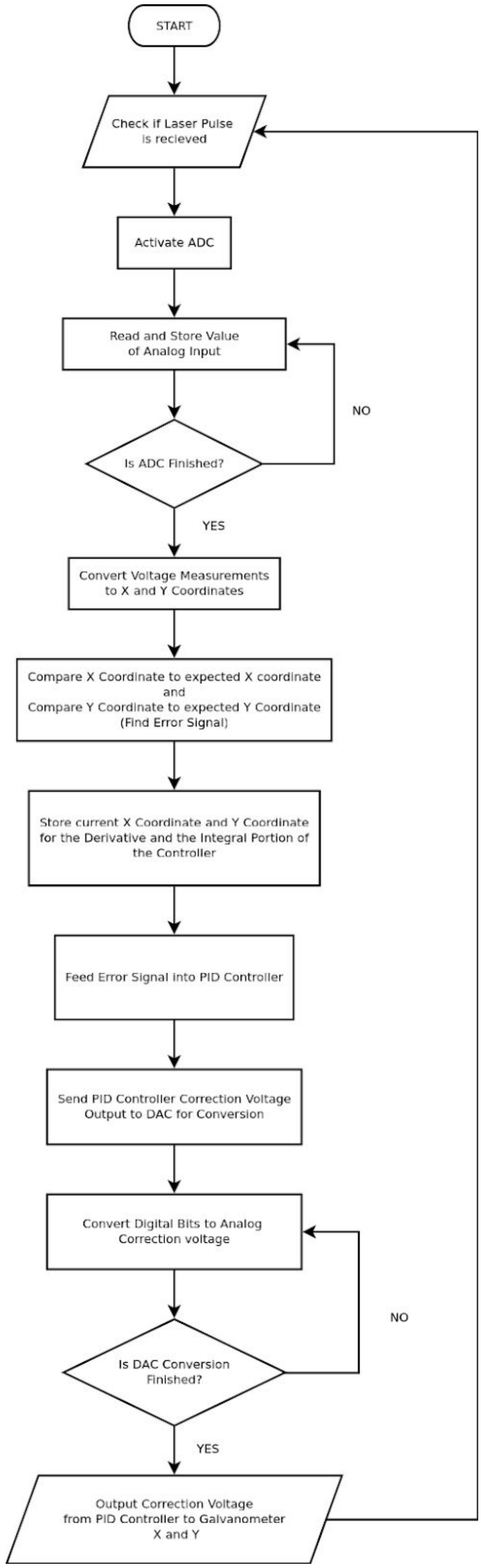

Figure 11 Microcontroller Program workflow

2.4.2 DAC System

The DAC itself is a part of the microcontroller. This 12-bit DAC can output a value between 0.3 and 3.3 V based on what bits the microcontroller assigns it. This output from the microcontroller then is scaled to -10 to 10V by the OP amp seen in figure 11. The output from the OP-AMP is fed into the Galvanometer controller to change the angle of the mirror.

<u>DAC System General Schematic and Simulation:</u>

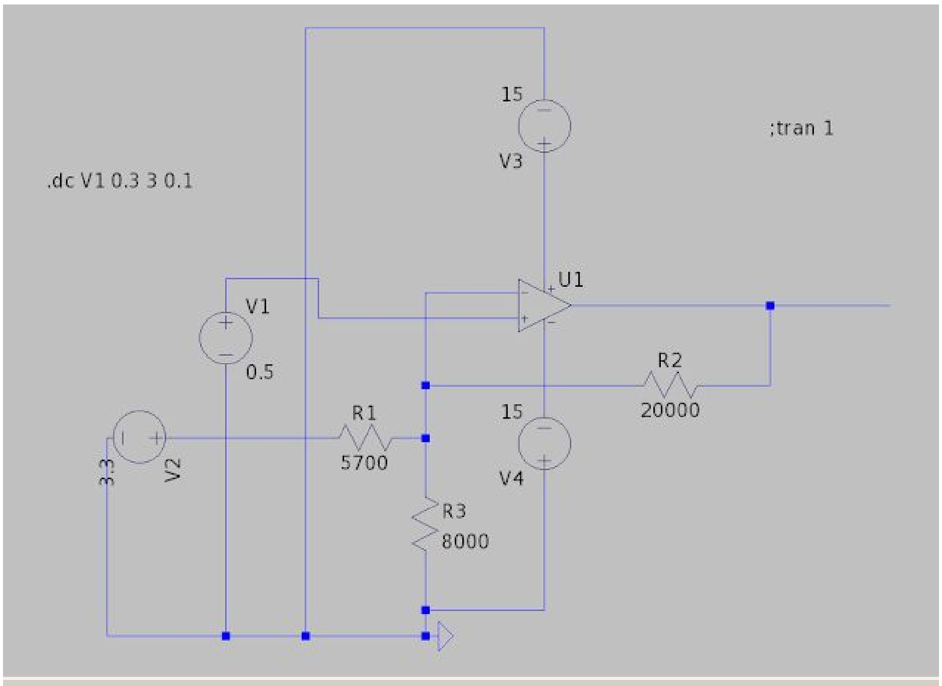

Figure 12 DAC OP-AMP Scaling Schematic

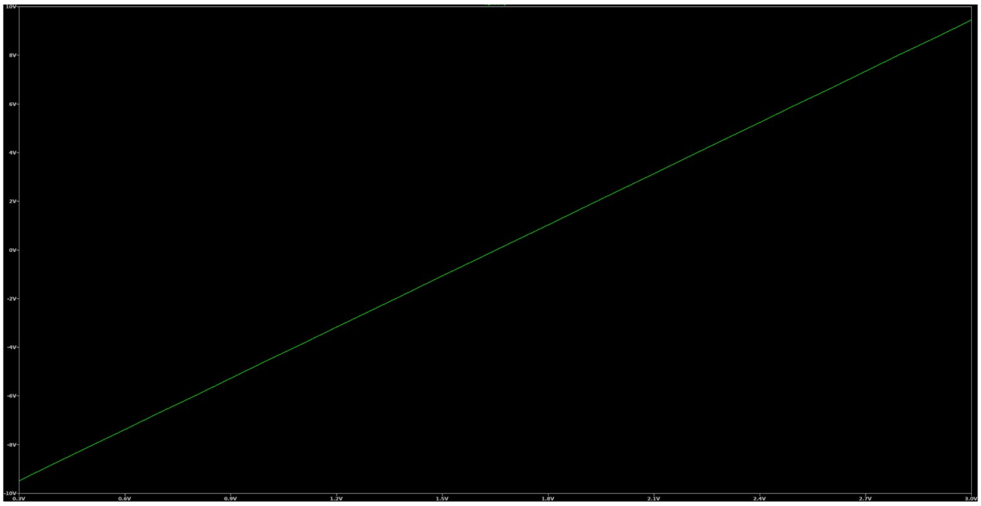

Figure 13 DAC OP AMP Scaling schematic simulation result

DAC System PCB Schematic:

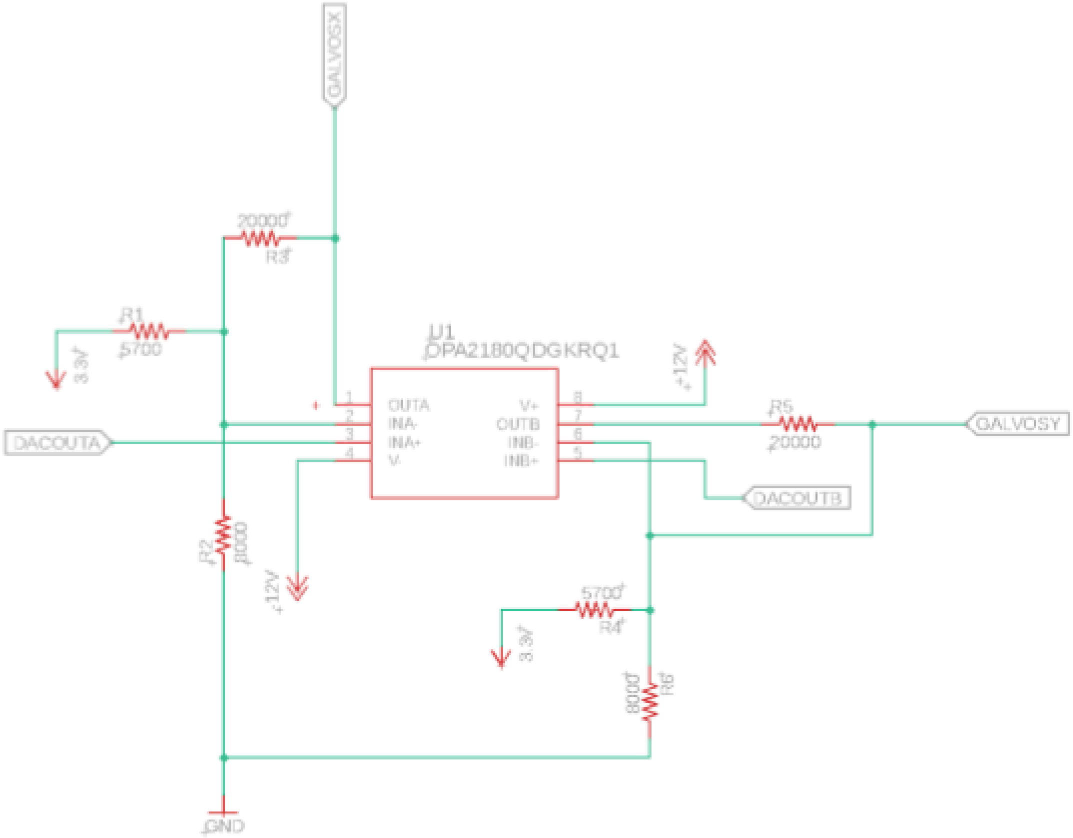

Fig 14. DAC PCB schematic

Requirements and Verification Table:

Requirement	Verification
Can output -10 - +10 V and remain steady within +/- 5% of value	A. Send a 3V constant voltage through the DAC system B. Measure the output of the DAC System C. Check to see if the output is within 5% of 10V D. Send a 0.3V constant voltage through the DAC system E. Measure the output of the DAC System F. Check to see if the output is within 5% of -10V G. If C and F are true, then this passes
Can drive the galvanometers through its output	A. Set a specific DAC output through the microcontroller B. Measure the angle of the mirror to see if the corresponding voltage outputs the correct angle

Reasons for Requirements:

The DAC needs to output -10V to +10V since the galvos controller requires a -10 to 10V output. The output of the DAC circuit needs to remain steady due to small changes affecting the angle of the mirrors.

2.4.3 ADC System

This is comprised of two main components: the ADC itself housed within the microcontroller and the peak detection circuit. The peak detection portion is used for phase 2 of the project which is integrating it into a pulsed laser system. The ADC needs to read the output of the quadrant detector which is fine for the continuous laser since there is no time restraint to read the quadrant detector. However for the pulsed laser, the quadrant detectors output will also be a pulse and the ADC within the microcontroller is not fast enough to sample that 40ns pulse. As a result, a peak detection circuit is used to hold the maximum value that is read from the quadrant detector. This allows the ADC enough time to read the value. Once the value is fully read, it will clear the peak detection so that it can obtain a reading again.

ADC Circuit Schematic:

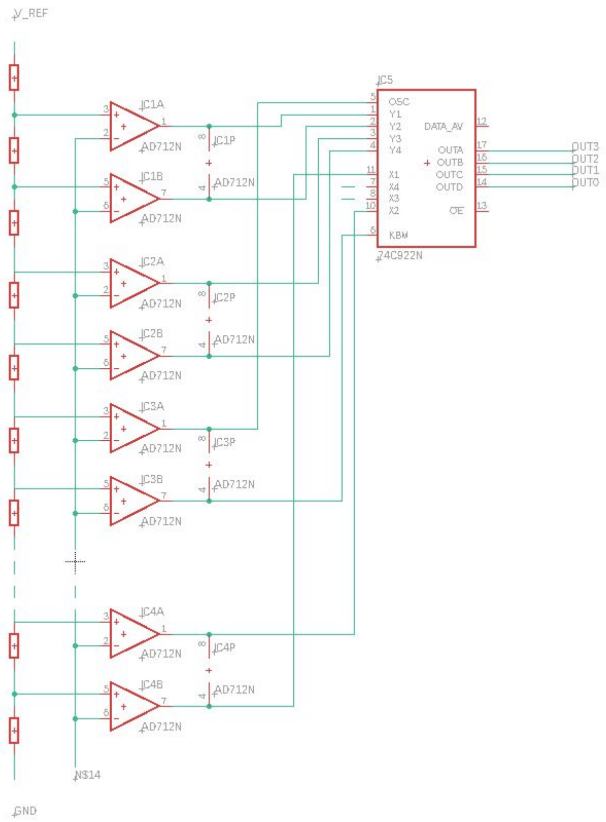

Figure 15 ADC schematic(already on the microcontroller)

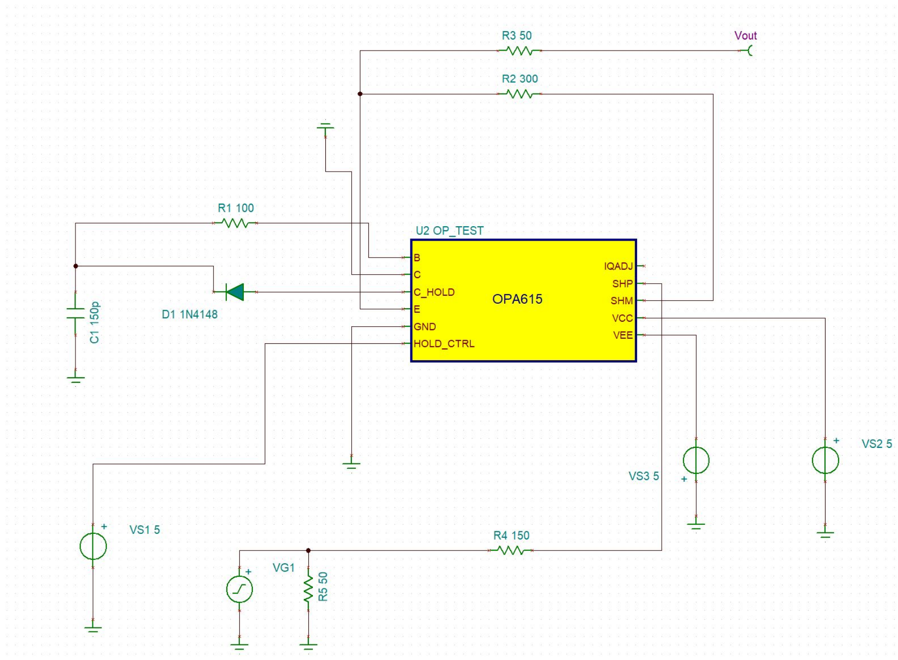

Figure 16 ADC Peak Detection Schematic

Verification Table:

Requirement	Verification
Can recognize a 40ns pulse and read the analog value	A. Output a 40 ns 1V square pulse from a function generator B. Measure the voltage of the ADC System output. C. If the output of the ADC system is 1V +/- 5% the system passes
The read measurement remains stable overtime such that the voltage for a particular position will not vary	A. Output a 40 ns 1V square pulse with period of 1 microsecond B. Store the first 10 pulses within the microcontroller E. Compare results to each other. If the values are within +/- 1% of each other then pass

Reasons for Requirements:

The laser system that the professor is using has pulses that last 40ns. The ADC system needs to be able to recognize that pulse fast enough so that the data can be acquired accurately

The measurement from the ADC system needs to remain consistent, so an accurate position of the laser can be obtained from the ADC system.

2.5 Power System

2.5.1 Galvos Power Supply

The galvos power supply is a 24 V, 4.5A Power supply that is used to power the galvanometers. This will also be used as the input into the voltage regulator. The +10 and -10V will come from the Galvos Controller which has an output of that.

2.5.2 Voltage Regulator

The voltage regulators will supply +3.3V, +1.2V to the microcontroller and ADC systems. This adjustable regulator requires only 2 external resistors (370Ω and 10Ω) to set the output voltage. It also includes current and thermal overload protection. overload protection remains functional even if the adjust terminal is disconnected.

Circuit Schematic:

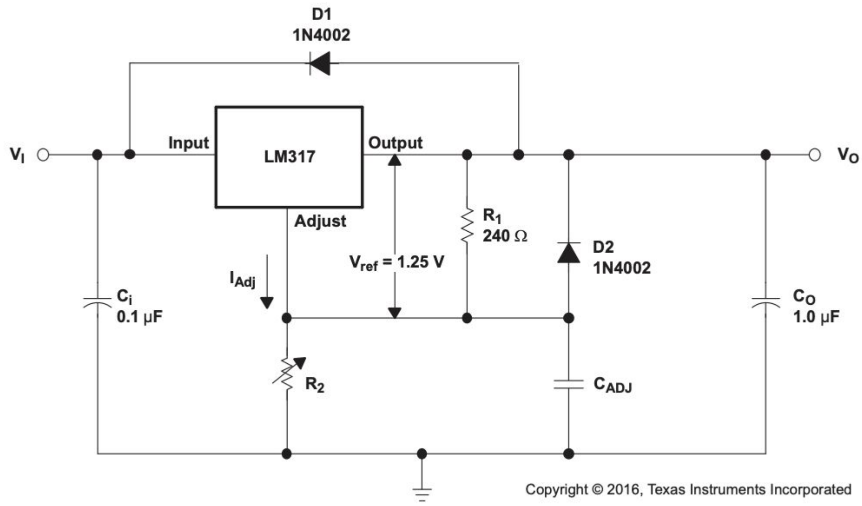

Figure 17: Voltage Regulator Circuit Schematic[9]

Requirements and Verification Table:

Requirement	Verification
The voltage regulator supplies 3.3V and 1.2V +/- 5% to the microcontroller from a 24V source	A. Power the voltage regulators using the power source B. Measure the output voltage of the voltage regulators using a multimeter C. Verify that the output voltage is within 3.3V and 1.2V
Maintain a temperature below 125° C with each of the regulators	A. Power the voltage regulators using the power supply B. Using a temperature probe, measure the temperature of the regulators C. Verify that the regulators maintain a temperature below 125° C

Reasons for Requirements:
The voltage regulator needs to supply 3.3V and 1.2V in order for the microcontroller to function properly and in order for the system to remain stable, the temperature of the regulator must be below 125° C

2.5.3 Laser Power Supply

This supplies power to the laser system. Due to the risk of damaging laser, the control system will not be powered off of this power supply

2.6 Tolerance Analysis

One of the main components of this project is to integrate it into a pulsed laser system that will have pulses that are 40ns in total length. The time dimension is illustrated in the following figure:

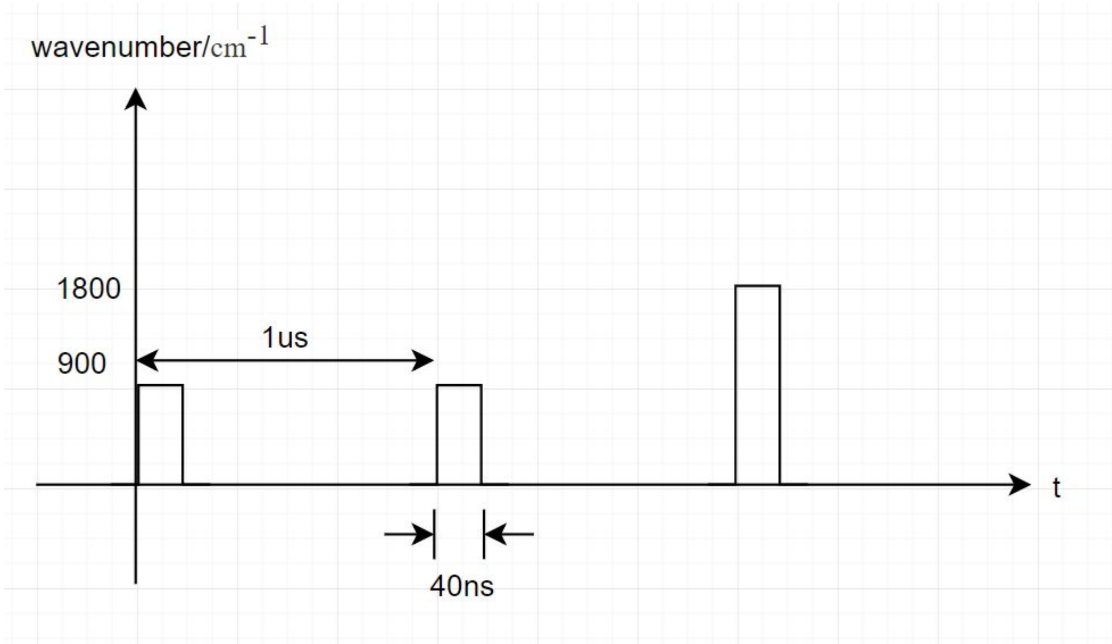

Figure 18: timing of the pulsed wave

where several pulses are generated before switching the wavelength value.

As a result, the system needs to be able to detect those fast laser pulses. There are two ways to solve this problem. The first is to have a high speed ADC that could detect 40ns pulses. This would require a minimum 50 MSPS sample rate to capture the 20Mhz wave and even then it would more than likely only be able to collect one point on the curve which is not ideal. Higher MSPS sample rate ADCs are expensive. The other way to do this is to have a peak detection circuit that would hold the max value that is read from the quadrature sensor. This is a cheaper option.

The Texas Instruments OP615 is a DC restoration chip that is able to detect these short pulses because according to the data sheet it has a pulse response of less than 10ns with 20Mhz frequency signal.

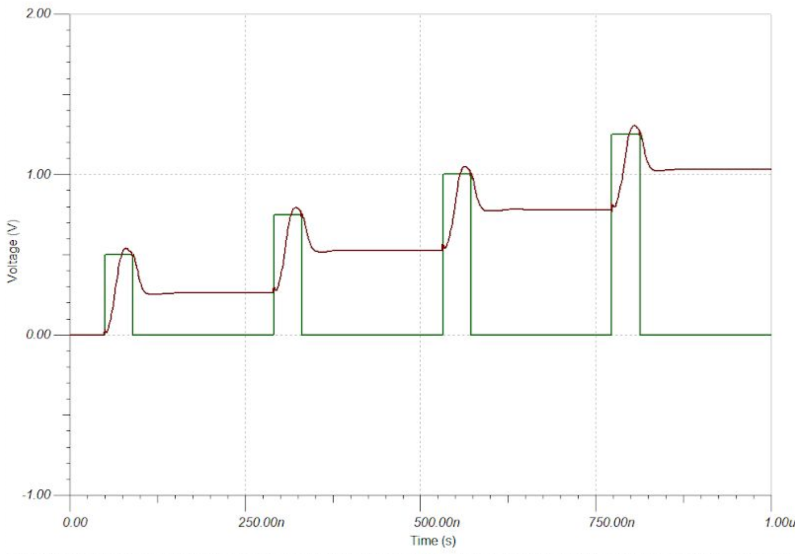

Fig 18. Simulation of detecting varying 40ns pulses

This chip is able to hold the value to allow for the slower 3.3 MSPS 12-bit mode ADC within the microcontroller to read the analog voltage value. Despite the steady state not matching the actual output value, the steady state output allows the input into the ADC to be consistent as it is read.

Once overall system must read and output a control voltage within 1ms of the pulses. This is easily doable with the microcontroller since the pulse can be read within 1 µs according to the TMS320F2837xD datasheet[5]. This gives the microcontroller ample time to determine a voltage to output and allows it to read each pulse within the 1 µs period.

3. Costs and Schedule

3.1 Cost Table

For the labor costs we will consider the average entry level Electrical Engineer salary at \$33/hr with each of us working 12 hours per week for the 12 weeks of the design and development phase of the project:

$$\$33 * 3\ people * 12\ hours * 12\ weeks = \$14256$$

Part Name	Description	Manufacturer	Quantity	Unit Cost($)	Total Cost($)
OPA2180-Q1	OP Amp for DAC	Texas Instruments	1	1.24	1.24
TLC2264ID	OP Amp for Quadrant Detector	Texas Instruments	2	2.40	4.80
TLC2264ID	Op Amp for Quadrant	Texas Instruments	2	1.01	2.02
QP50-6-TO8	Quadrant Detector	First Sensor	1	118.64	118.64
TMS320F28379SPTPT	Microcontroller	Texas Instruments	1	18.52	18.52
Molex #02-08-2004	Molex Connector	Molex	25	0.038	0.95
Molex #15-24-4048	Molex Housing	Molex	4	0.35	1.4
LAUNCHXL-F28379D	Microcontroller Test Board	Texas Instruments	1	33.79	33.79
OPA615ID	DC Restoration	Texas Instruments	1	6.34	6.34
1N4148	Diode	ON semicondutor	5	0.10	0.50
LM317	Voltage Regulator	ON semiconductor	2	1.58	3.16
Total					191.36

Grand Total: $14448.36

3.2 Schedule

Time (the week start date)	Task	Responsibility
9/30	Stage 1: prototype of continuous visible laser build	All
	PID control design	Sean
	component communication	Ruomu
	bench test and performance measure	Hao
10/7	Test and modify the stage 1 prototype; Decision on components for pulsed wave stability control	All
	Performance analysis and debug	Hao
	pick components for the stage 2; decide hardware configuration	Ruomu
	finalize PCB design for stage 2	Sean
10/14	Test and modify the stage 1 prototype; Early-Bird PCB order	All
	PCB order and communication with ECE store; finalized PCB design	Sean
	bench preparation to simulate pulsed laser; modular debug	Ruomu
	modular test for stage 2 before components are shipped	Hao
10/21	Stage 2: change the system to work with pulsed laser	All

	control mechanism test and debug	Sean
	modular I/O test on breadboard	Ruomu
	soldering	Hao
10/28	Test and modify the stage 2 prototype; debugging the board	All
	change sensor to measure pulsed high-freq laser	Sean
	pull trigger signal from QCL source for the adc when pulse is active	Ruomu
	modular I/O test and debug for internal signals	Hao
11/4	Debug and troubleshooting: find issues	All
	software test on the control system	Sean
	hardware test with simulated test signals	Ruomu & Hao
11/11	Debug and troubleshooting: solutions and substitutions	All
	Sensor and ADC acquisition	Sean & Ruomu
	DAC and Galvo drivers	Hao
	microcontroller	Sean & Ruomu
11/18-25	Mock demo and last modify	All
	Fix existing issues and final test	Hao & Ruomu
	Demo and presentation material preparation	Ruomu

	Demo design	Sean
12/2	Demo and presentation: Finalize the project, work together for presentation material like slides and test case .etc	All
12/9	presentation, poster and final paper。 Members work together for report materials	All

4. Ethics and Safety

This project belongs to a research group which is working a developing FTIR and QCL instrumentation for infrared spectroscopic imaging[6]. As a relatively important part of their entire model, IEEE Code of Ethics #10[2] is applied here, to help and assist their laser pointing stability from an active feedback controller.

Laser safety is a main part in our laboratory, according to IEEE Code of Ethics #9[2], additional training is required to ensure our eligibility working in this specific laboratory. When working in the lab, it is suggest not wearing expose large amount of skin, when the laser is turned on, safety goggles with corresponding spectrum are required at all time. We also need to be aware that there is no possible reflective medium along the path of any model in the lab, in case of unexpected reflected laser point to any lab personal.

If we successfully accomplish our task, reaches the ultimate goal of this project, IEEE Code of Ethic #5[2] fits here. As we improve the performance of the model, the closed loop feedback system will adjust the beam and make it stable. we hope this project can have a support on the diagnostic tool as mentioned above, and eventually put on a clinical application if possible.

References

[1] Yamuna Phal, (27 August, 2019), “Proposed solution schematic”, [online] Available at: https://courses.engr.illinois.edu/ece445/lectures/FA_2019_Lectures/Pitches/Pitch_ECE-445.pdf [Accessed 12, Sep, 2019,]

[2] Ieee.org. (2019). IEEE Code of Ethics. [online] Available at: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed 16 Sep. 2019].

[3] D. Marett, “Conspiracy of Light,” *welcome.html*, 2012. [Online]. Available: http://www.conspiracyoflight.com/Quadrant/Quadrant.html. [Accessed: 02-Oct-2019].

[4]https://www.thorlabs.com/Images/GuideImages/4400_PSDMounted_10.jpg. (2019). [image].

[5] Texas Instruments, “TMS320F2837xD Dual-Core Delfino™ Microcontrollers,” TMS320F2837xD Datasheet, Aug. 2014 [Revised Nov. 2018].

[6] Pearson, P. (2019). [online] Available at: https://chemimage.illinois.edu/Yamuna-Phal.html [Accessed 17 Sep. 2019].

[7] Texas Instruments “Width Bandwidth, DC Restoration Circuit,” OPA615 Datasheet, Feb. 2004, [Revised Sept 2009].

[9]Texas Instruments “LM317 3-Terminal Adjustable Regulator” LM317 Datasheet, Sept. 1997, [Revised Sept 2016]