D-MILE

Distance-Monitored Inkless Laser Engraver

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Motivation

Inkless Printers exist, but they use toner. Ink and Toner both can run out, and you need to pay outrageous prices to specific companies to buy compatible products to use your printer.

Printers have two states: on and off, it cannot ‘print’ less in some areas and more in others, those have to be defined on the document being printed.

Improve upon previous attempts at laser printing solutions by adding additional safety features and increase the precision and the scope of the printers capabilities.

Goals

Core Goals:

C1.0: D-MILE is safe to use and operate in a consumer environment.
C2.0: D-MILE has a high ease of use.
C3.0: D-MILE is economical.
C4.0: D-MILE has a high level of optical precision.
C5.0: D-MILE has a high level of motor control precision.
C6.0: D-MILE has an optical subsystem improving functionality.

Stretch Goals:

S1.0: D-MILE has an industry standard level of motor control.
S2.0: D-MILE has fully automated adaptability in x, y, and z.
S3.0: Switching between media or the thickness of media without manual adjustment needed.

Advanced Goals:

A1.0: D-MILE is capable of multi-media printing.
A2.0: D-MILE has multiple optical subsystems expanding functionality.
A3.0: D-MILE is capable of printing gradients onto more resilient media such as wood.
A4.0: D-MILE has an improved level of motor control precision.
A5.0: D-MILE has manual control over the z direction.
A6.0: D-MILE will have an improved level of precision.

Objectives

(C1.0) To achieve our primary objective of ensuring the D-MILE is safe for consumer use, we will take steps to minimize risks such as isolating the beam path of our laser and strictly adhering to rules and regulations pertaining to the operation of a laser as dictated by their class. To expand this concept, several subsystem options are expanded on in the paper.

(C2.0) To ensure the D-MILE is easy to use, we want to have the firmware used by the printer interact with user-friendly software that accepts common files that are readily available by most users, and to have a convenient means to transmit files to the D-MILE for printing.

(C3.0) Given that the project is entirely self-funded, the cost to produce the D-MILE needs to stay within budget without compromising any core goals.

(C4.0/A6.0) Our laser will have an optical system to support its function and create a specific spot size at a predetermined and convenient location.

(C5.0) Our system will have a series of motors to give access to moving the laser focus freely in x and y. (A5.0/S2.0) Resources allowing, this objective will expand into the z direction with or without constraint. (A4.0/S1.0) As well, we would like to increase the level of ambition regarding the DPI of our system.

(A1.0) As the current focus of the project is a single media of our choosing, we would like to expand this to more than just one. This does not mean users can print or engrave on anything, as such a behavior would compromise consumer safety should the user not have the requisite understanding of the effects a laser can have on different media.

(C6.0/A2.0) Written broadly, we will outline multiple optical subsystems to operate in tandem with the laser system, and would like to be able to include more than one of these subsystems, resources allowing.

(A3.0) Gradients could be produced by a Gaussian beam if we are able to quickly modulate the power delivered to the laser diode, or by controlling the beam path in time as well as x and y.

(S3.0) As materials change, it would be nice to be able to auto-adjust the material into the focus of the beam to ensure the precision of the laser is not affected. This process could even be adjusted and intertwined with the motor control to allow real-time changes of the z direction during printing.

Requirement Specifications

ID	Core Objective Requirements
C1.0	D-MILE complies with any and all safety requirements outlined
C2.0	Project will not exceed $1000.00
C3.0	Laser spot size will be at most 0.25” in diameter
C4.0	Motor Control will be, at minimum, 50-100 DPI
C5.0	System will not exceed 4ft x 4ft x 4ft in size, weight less than 100lbs, and use a standard USA Type A Power Cord
C6.0	At least one optical subsystem will function

ID	Advanced Objective Requirements
A1.0	D-MILE can etch onto A4 Paper and non-composite/treated wood media
A2.0	At least two optical subsystems will function
A3.0	Print methods include gradients available beyond strict simple contrast
A4.0	Motor Control will exceed 150 DPI
A5.0	The base of the print bed will be capable of moving in the z-direction ±5mm
A6.0	Laser Spot Size will be at or under ⅛” in diameter

ID	Stretch Objective Requirements
S1.0	Motor Control of 300 DPI or better
S2.0	Motor Control extends to the z-direction, allowing for variability in z to be factored into print maps
S3.0	The platform and laser will coordinate to auto-focus onto the material surface

Constraints

Lasers hurt eyes bad :(

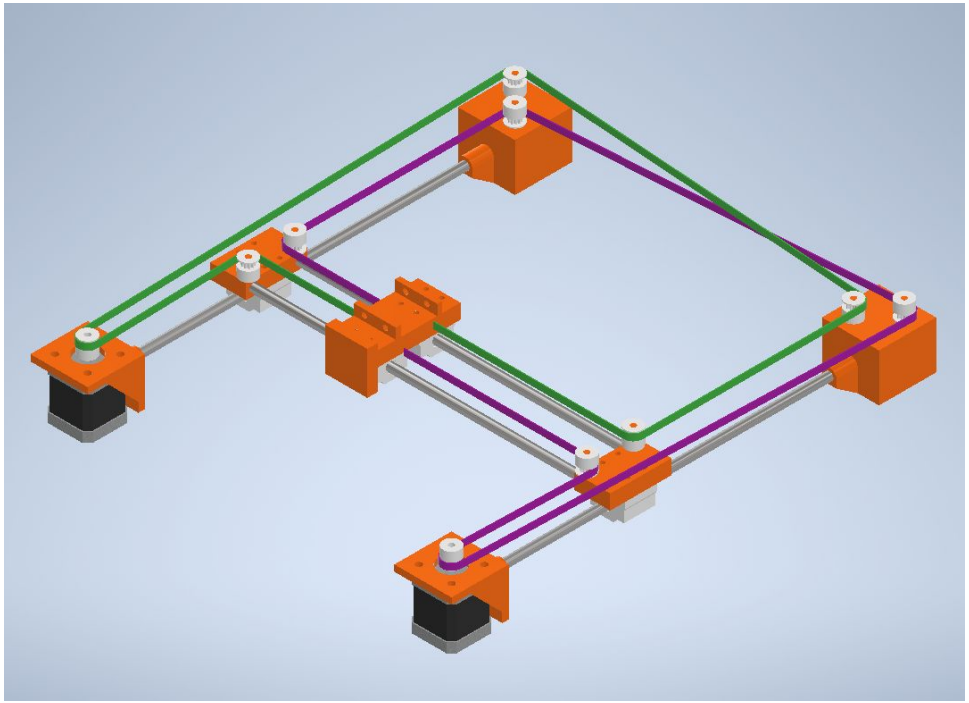
Environment

Electrical

Money

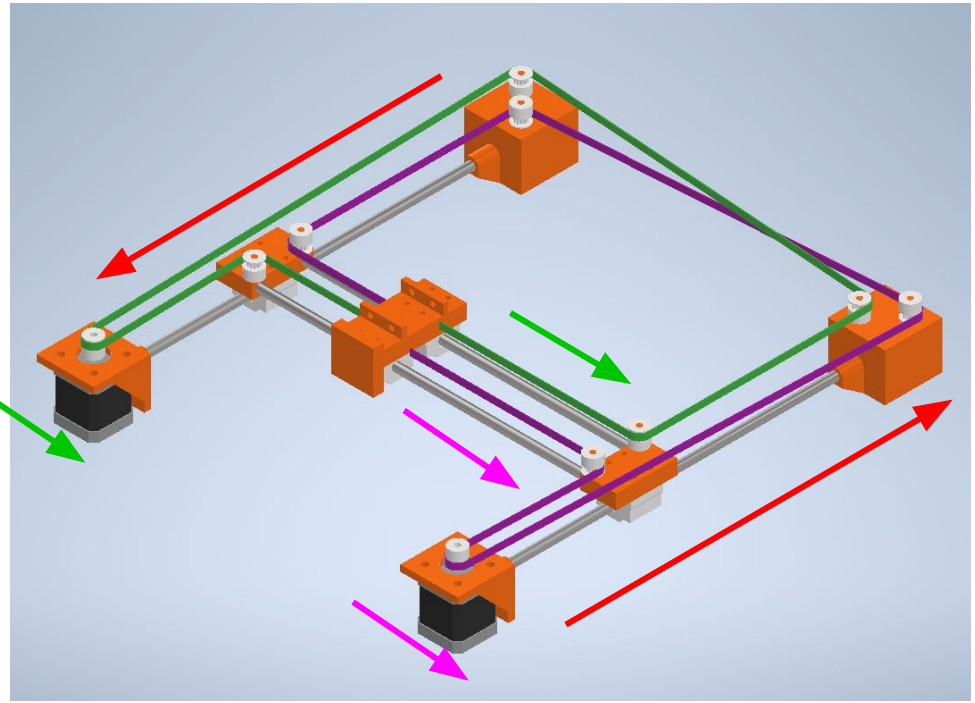
XY Gantry - Overall Design

- A belt system will be used to move the laser over the print area
- The gantry will be constructed with 3d printed parts and aluminum rods, gears, and linear bearings
- Corners will be mounted to the stationary frame for stability with printed parts or treated wood



XY Gantry - Function and Benefits

- Driving both motors in the same direction results in X axis movement
- Driving each motor in opposite directions results in Y axis movement
- Benefits:
  - Side-mounted motors reduces load weight
  - Simpler wiring
  - Cheaper construction than threaded rod design



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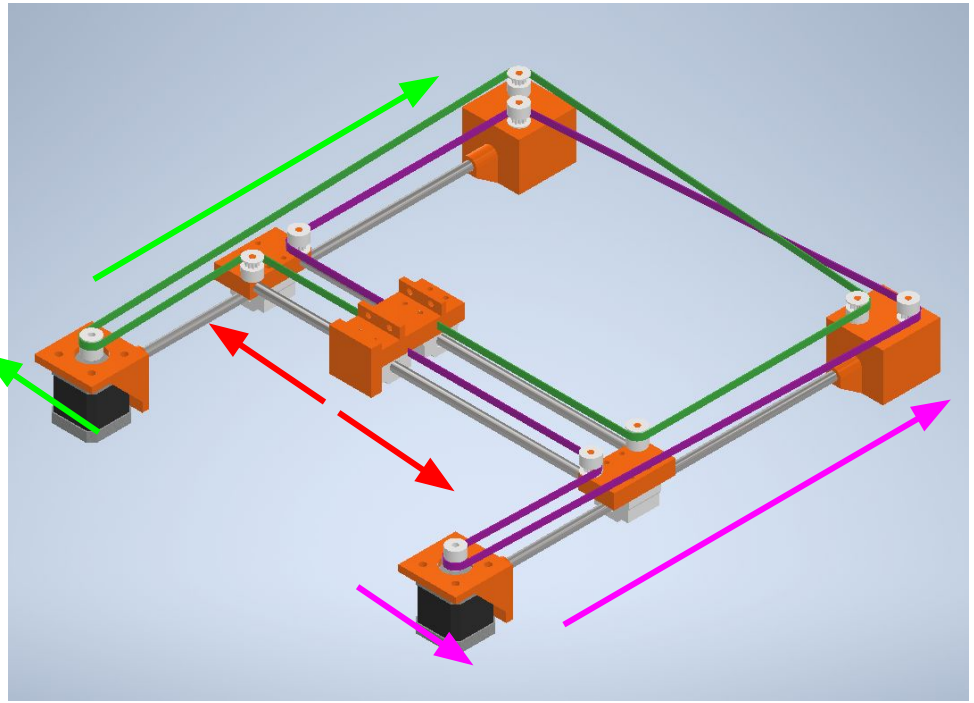
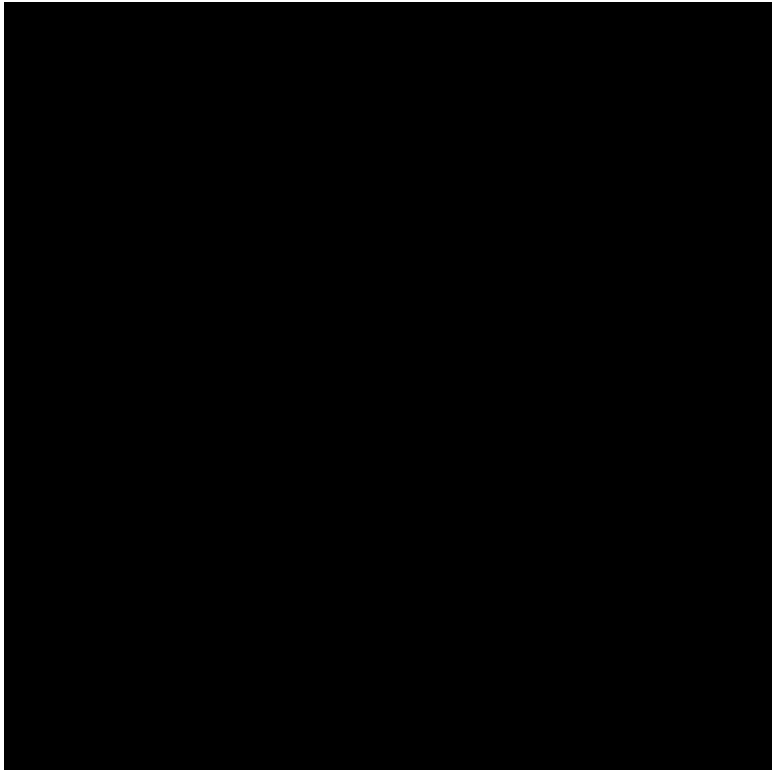
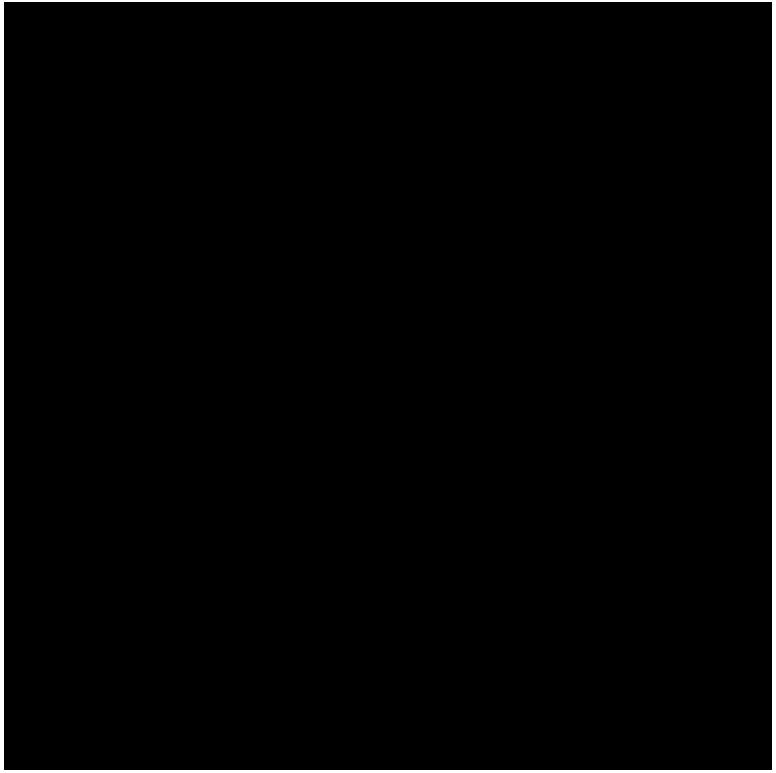


XY Gantry - Motor Adjustment

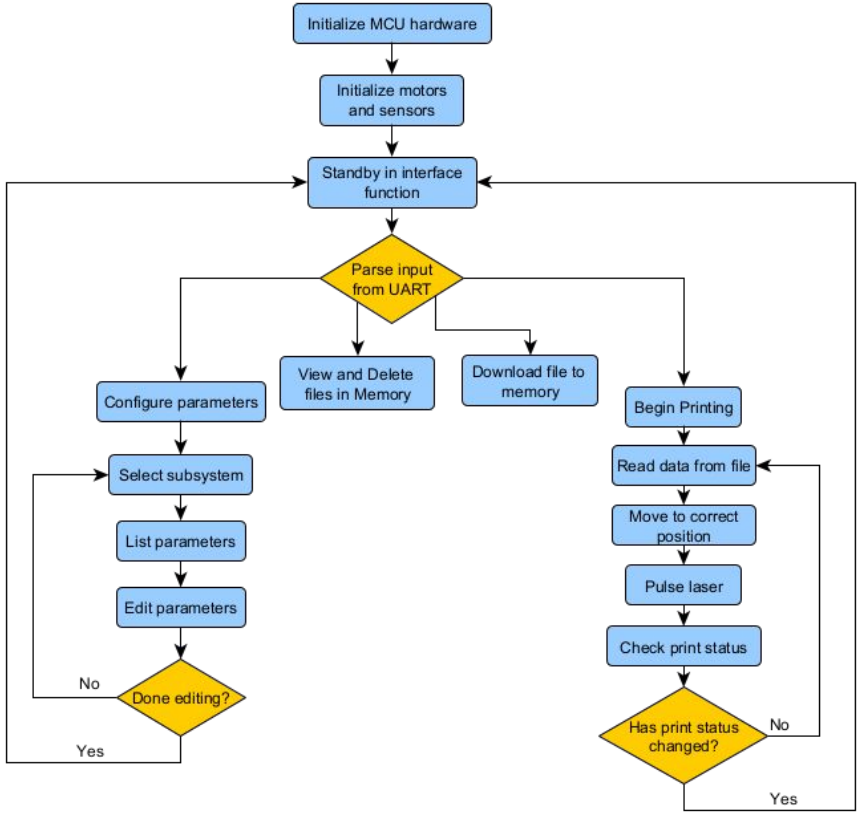




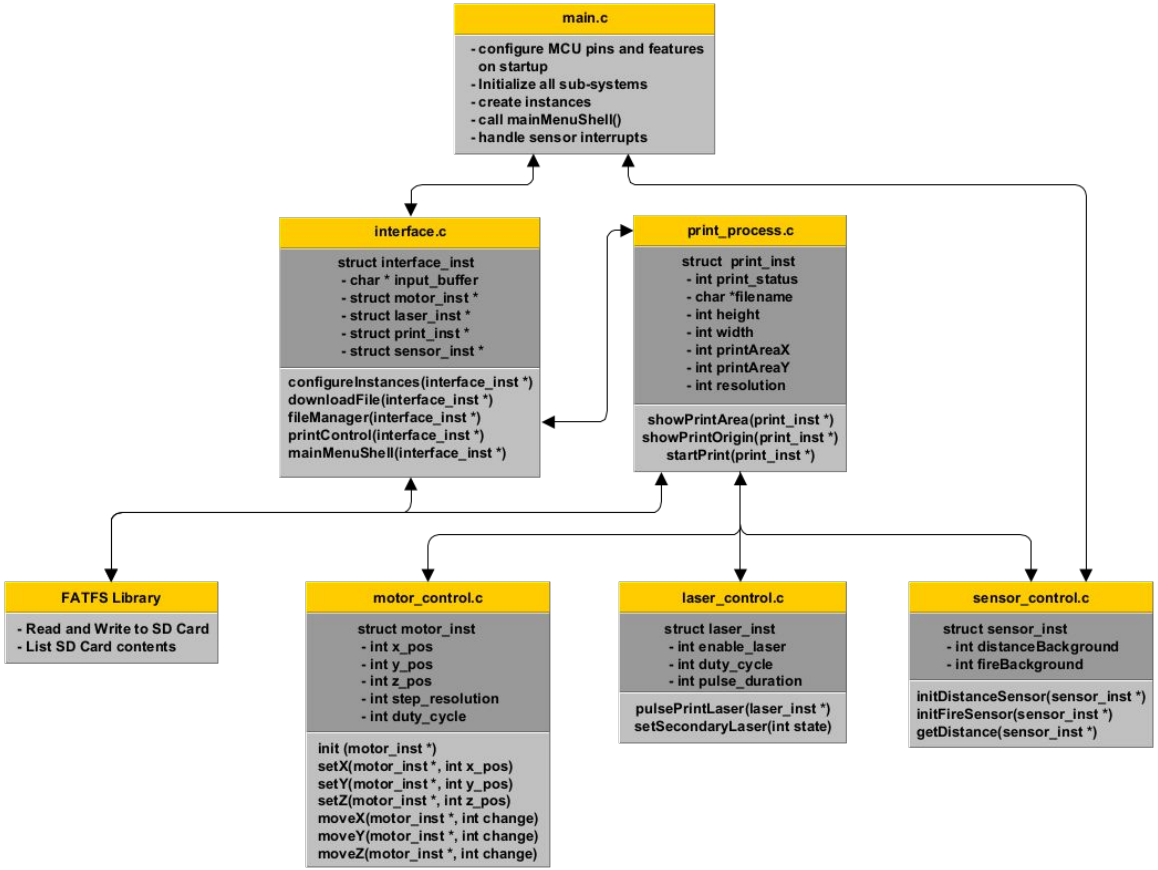
Z Axis

- The Z axis of the engraving area needs to be adjustable to account for different material heights
- This will be done with threaded rods, similar to common 3d printer designs
- Attempting to design a 3d printed threaded rod and nut to save cost and complexity

Firmware Design - Program Flow



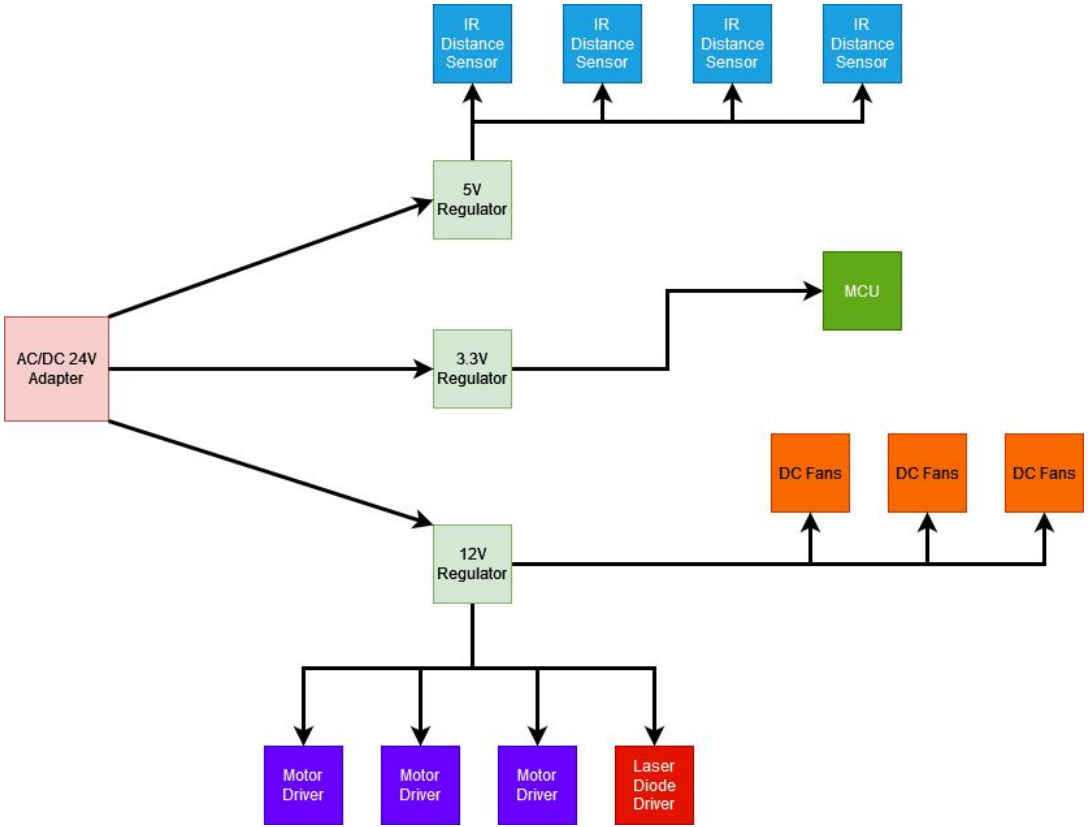
Firmware Design - Structure



Firmware Design - Remaining Tasks

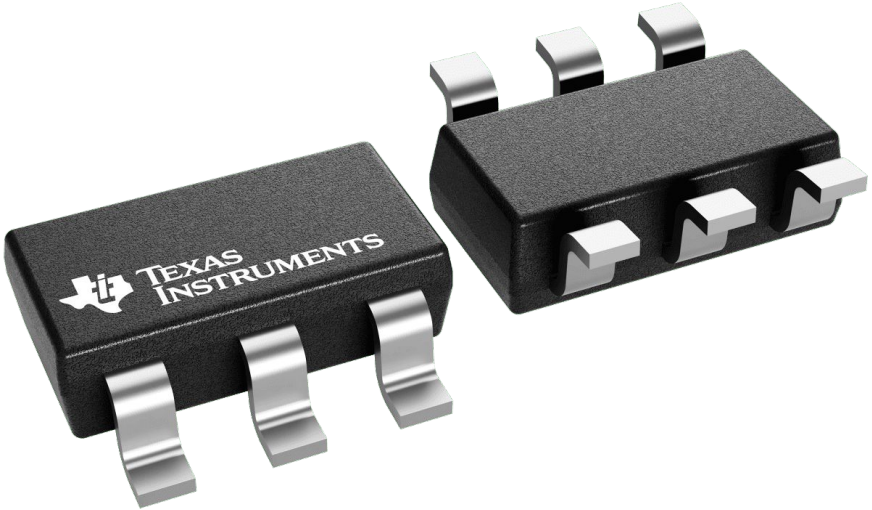
- Integrate components together
- Test integrated firmware with hardware prototype
- Create UI frontend software to automate communication over USB

Power Regulation Flow Chart

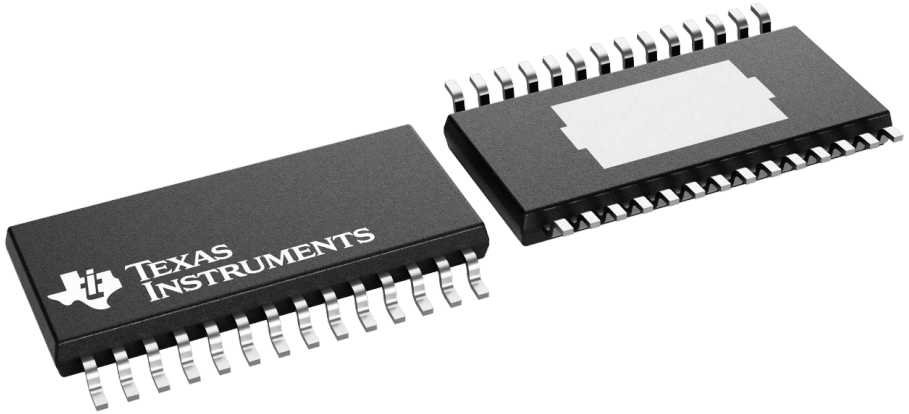


PCB Parts - LMR51420

- The LMR5140 is a switching buck regulator that will allow us to step down input voltage to whatever is necessary
- Adjustable regulator, allowing us to use this same chip for multiple voltages on our PCB (3.3V, 5V, and 12V)



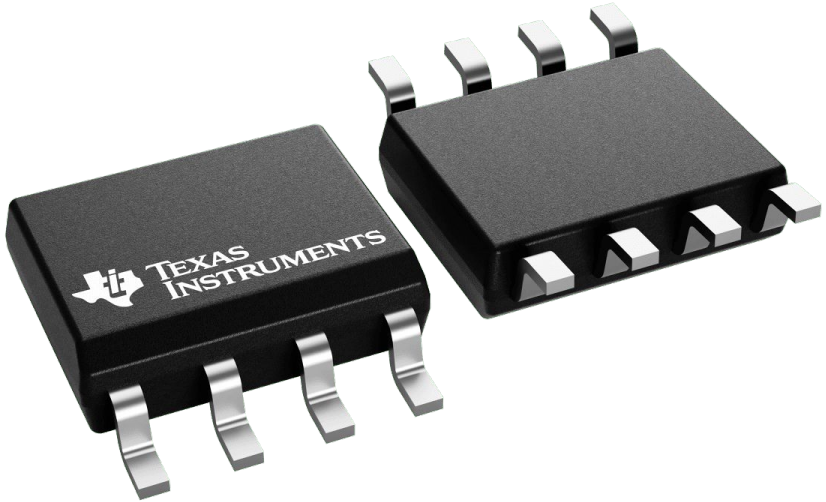
PCB Parts - DRV8825



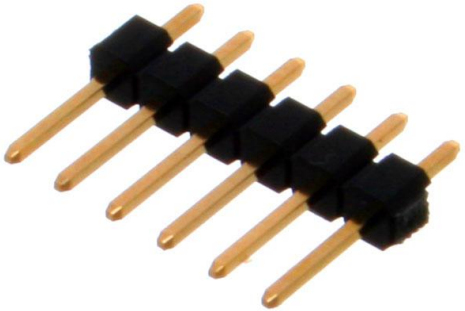
- The DRV8825 motor controller will allow us to to control our bipolar stepper motors with microcontroller inputs
- 3 needed for each motor

PCB Parts - LM393B

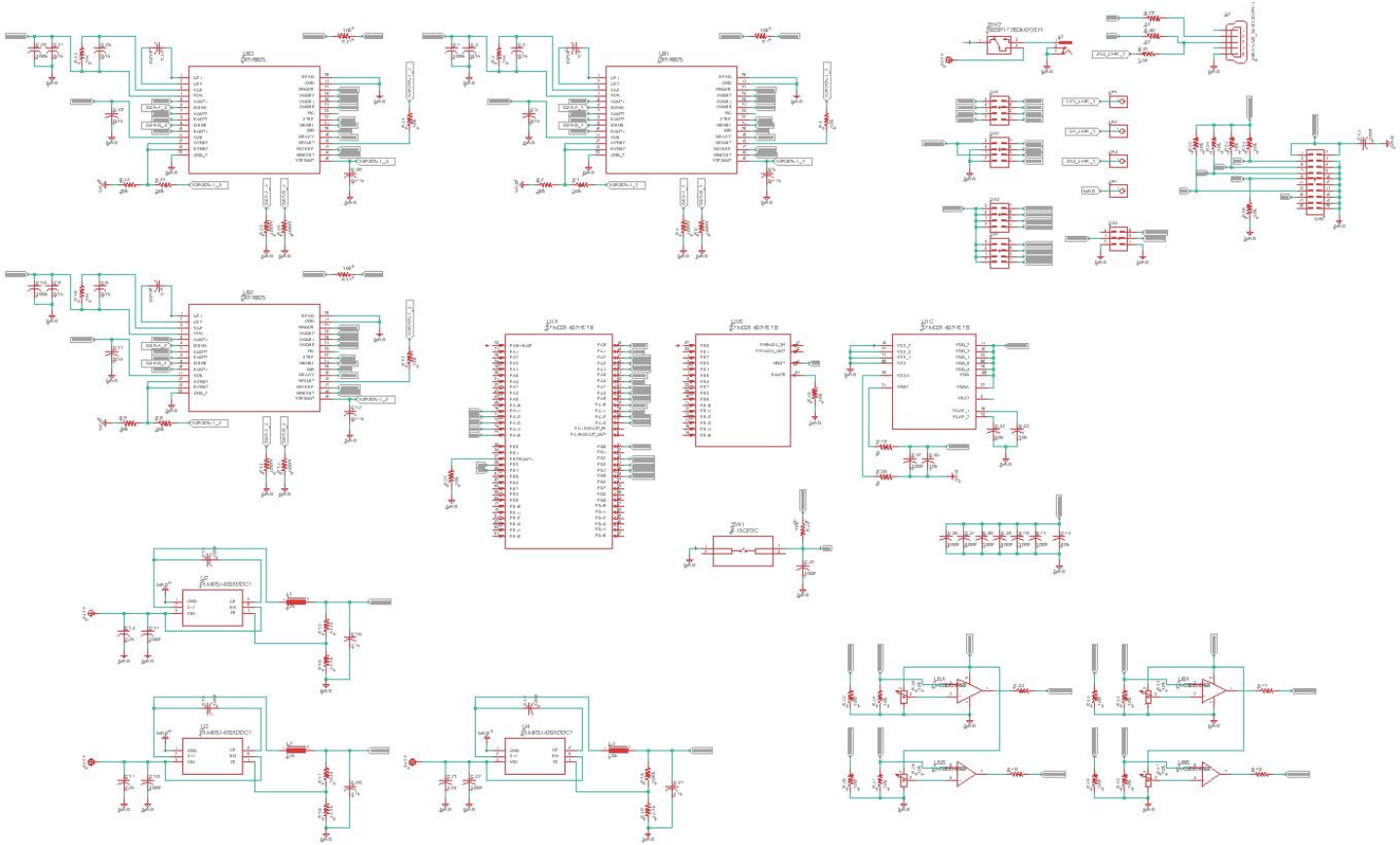
- The LM393B is a simple Op-Amp that will be used in our distance sensing circuit to allow our microcontroller to read its analog voltage output
- 4 distance sensors are in our design, so 2 of these chips are required



PCB Parts - Other

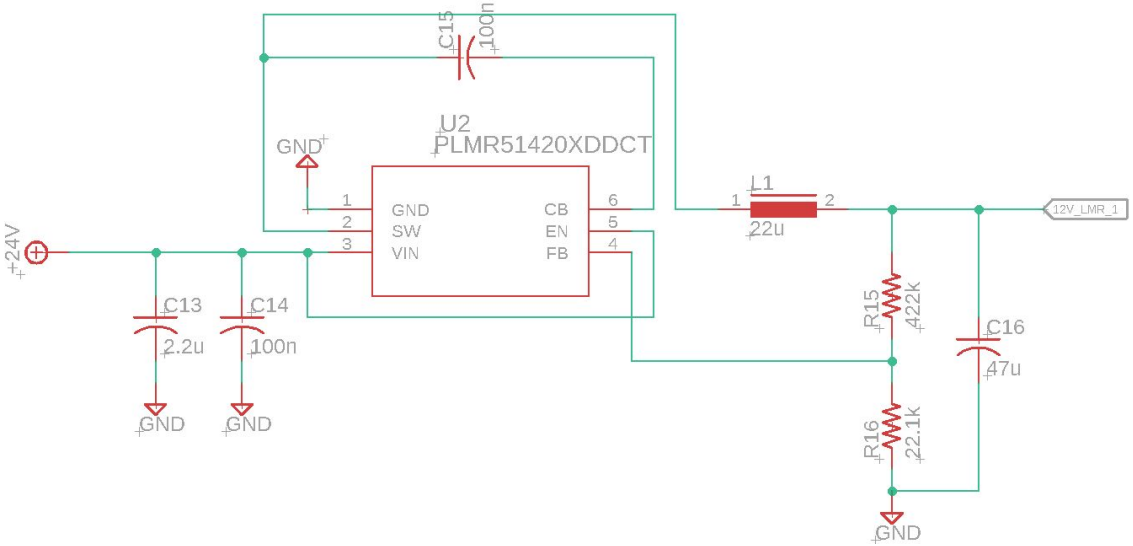


PCB Schematic

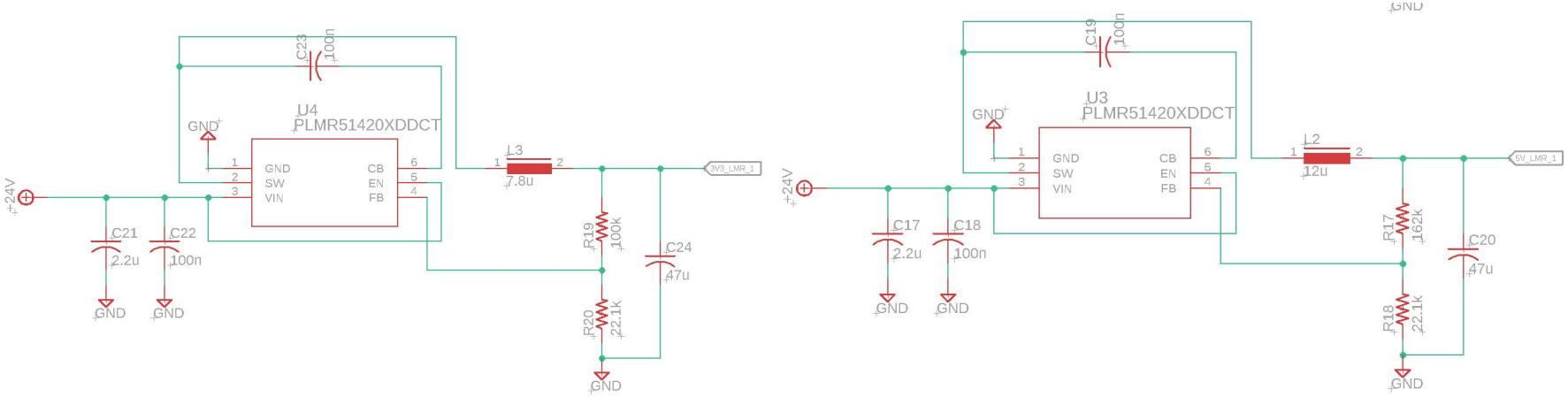


Power Regulation Schematics - 12V

- LMR51420 regulator allows a 4.5V-36V input range and adjustable output
- Resistor and inductance values chosen with the aid of WEBENCH Power Designer

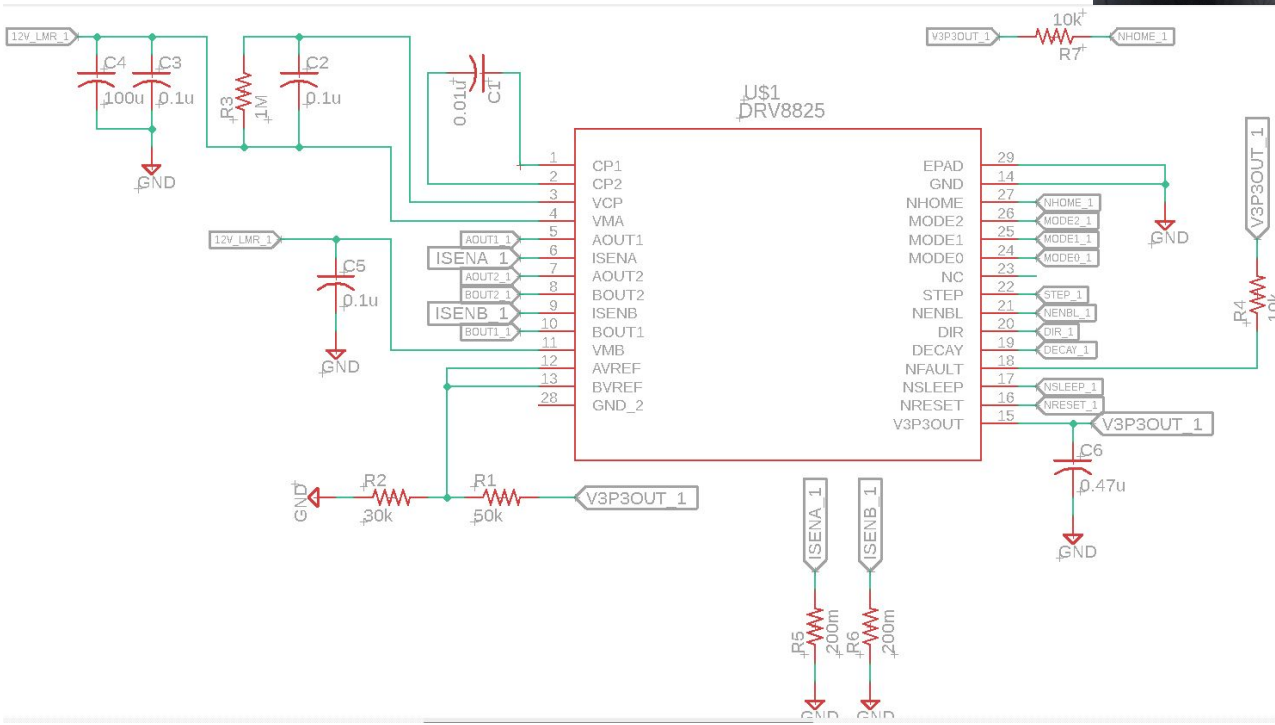


Power Regulation Schematics- 3.3V and 5V



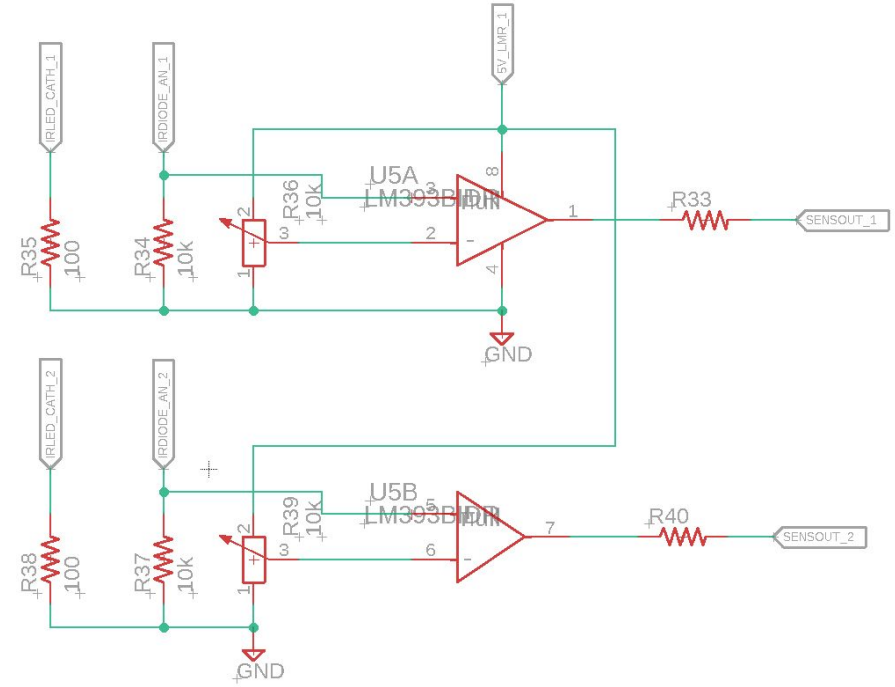
Motor Driver Schematic - DRV8825

- The datasheet provides the schematic for typical application of the DRV8825, which is used here



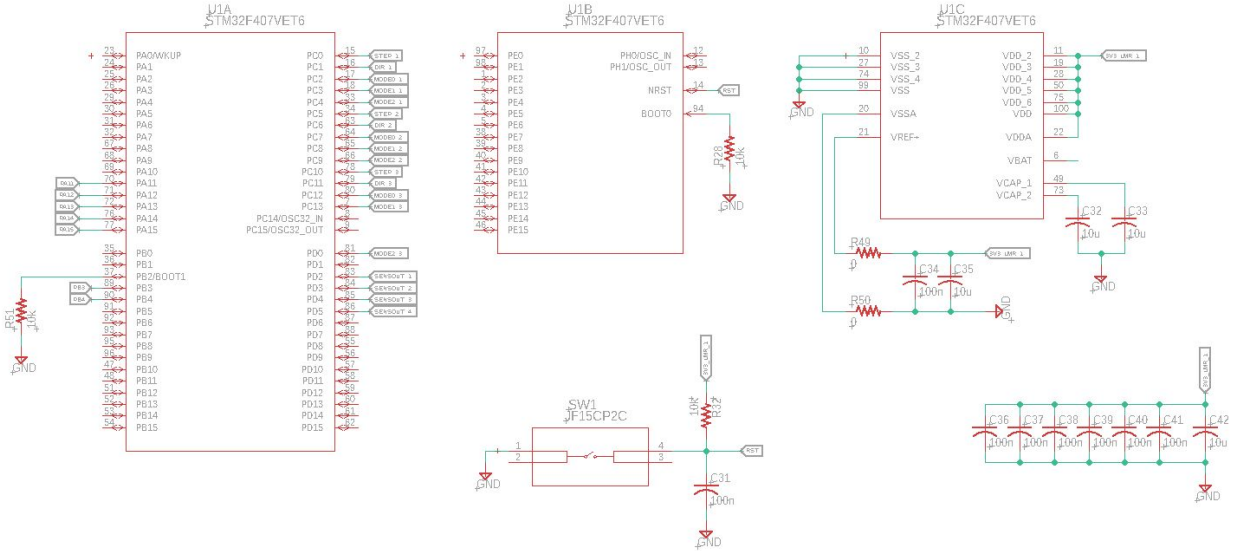
Distance Sensor Schematic - LM393

- The IR LED and IR Photodiode used in the sensor will be mounted on the chassis and connected to the PCB with wires
- The output will be an analog value that will be read by the microcontroller to determine distance



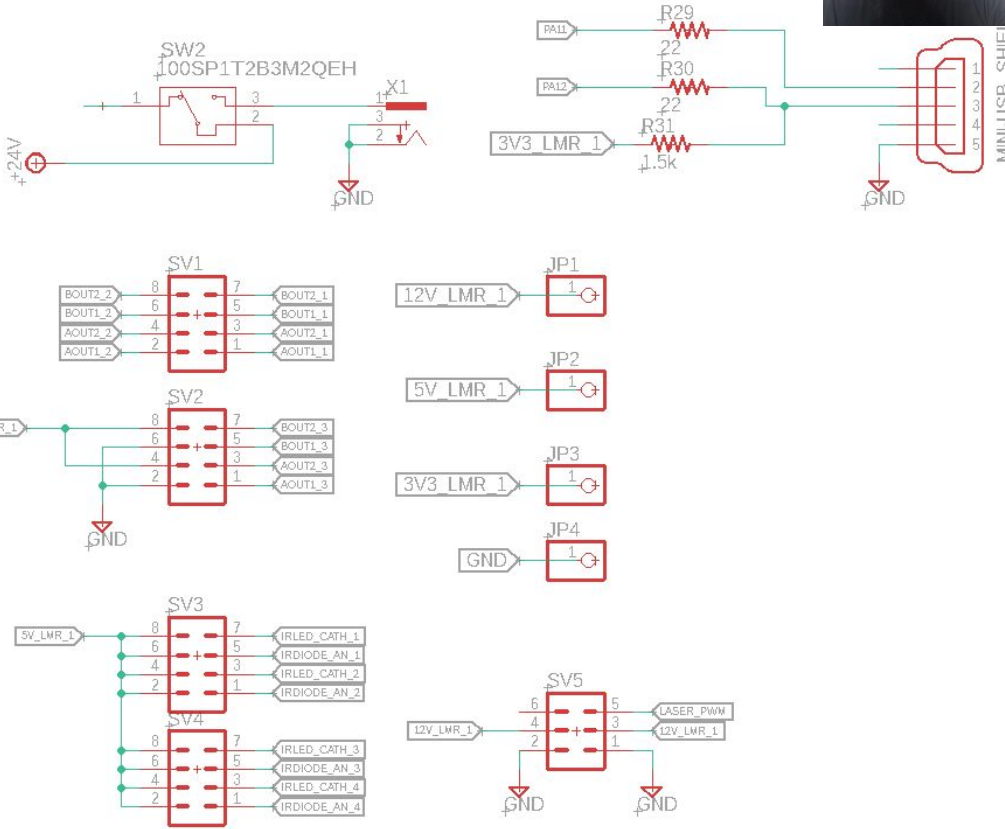
Microcontroller Schematic

- The STM32F407VET6 has 100 total pins
- Powered with 3.3V
- Tactile switch to reset microcontroller



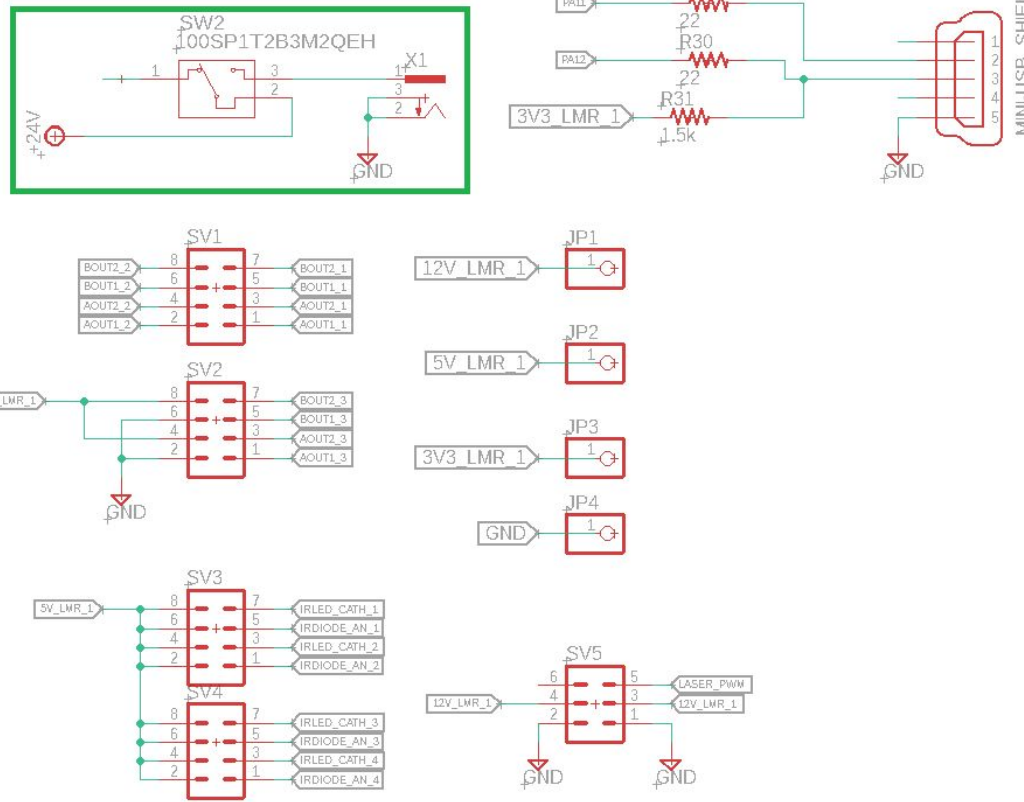
External Connections

- Several external connections from the main PCB are required for our engraver to function



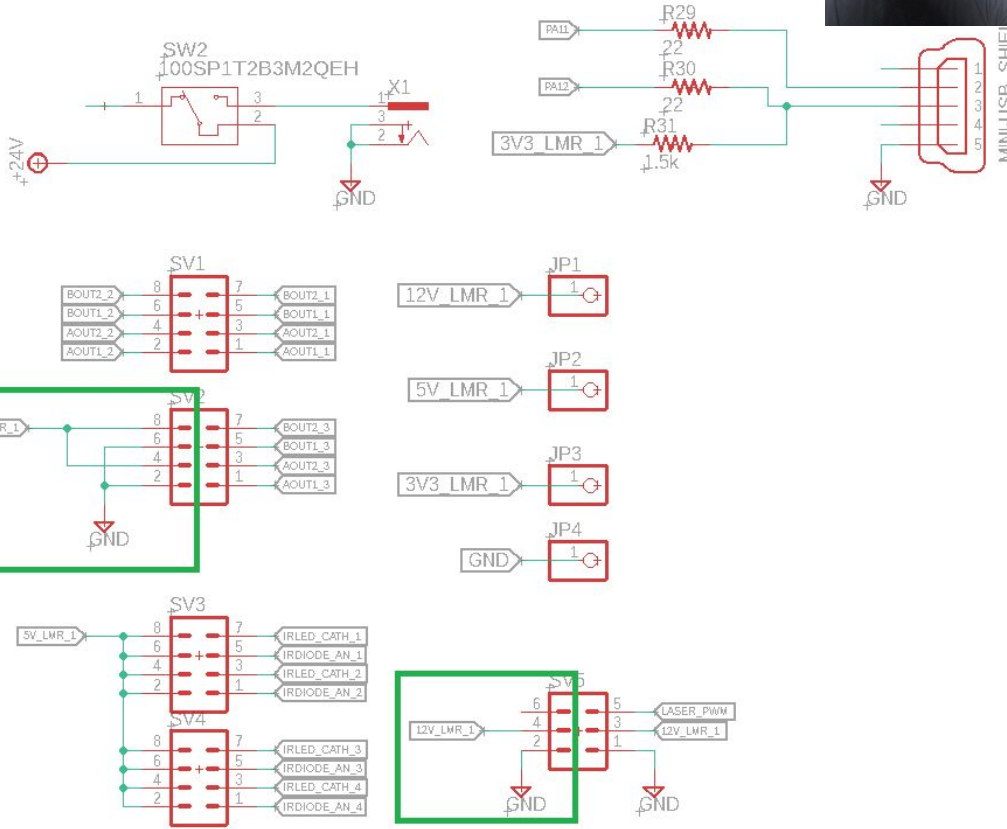
External Connections - AC/DC 24V Adapter Jack

- Power source for all the regulators will come from 24VDC from an external adapter
- A master switch will be used in series to control all the power to the PCB



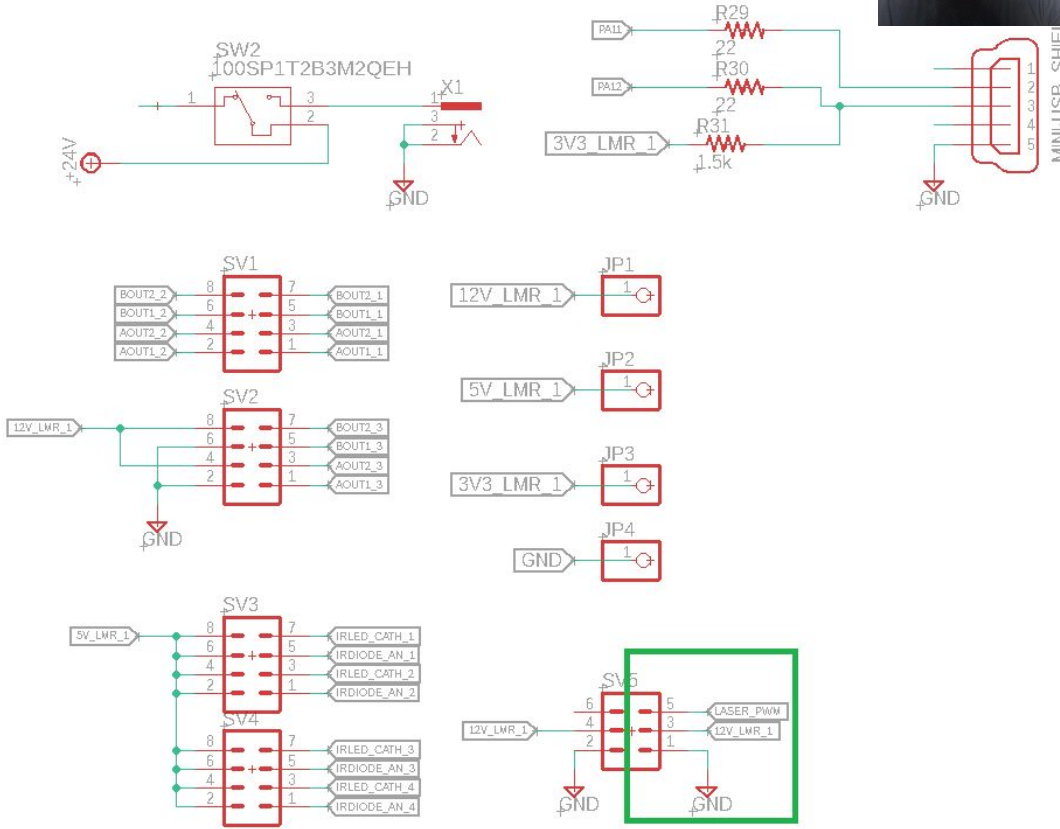
External Connections - DC Fans

- Pin headers will be used to give power to the cooling fans
- Two fans are for cooling the PCB and one will be attached to the laser diode driver



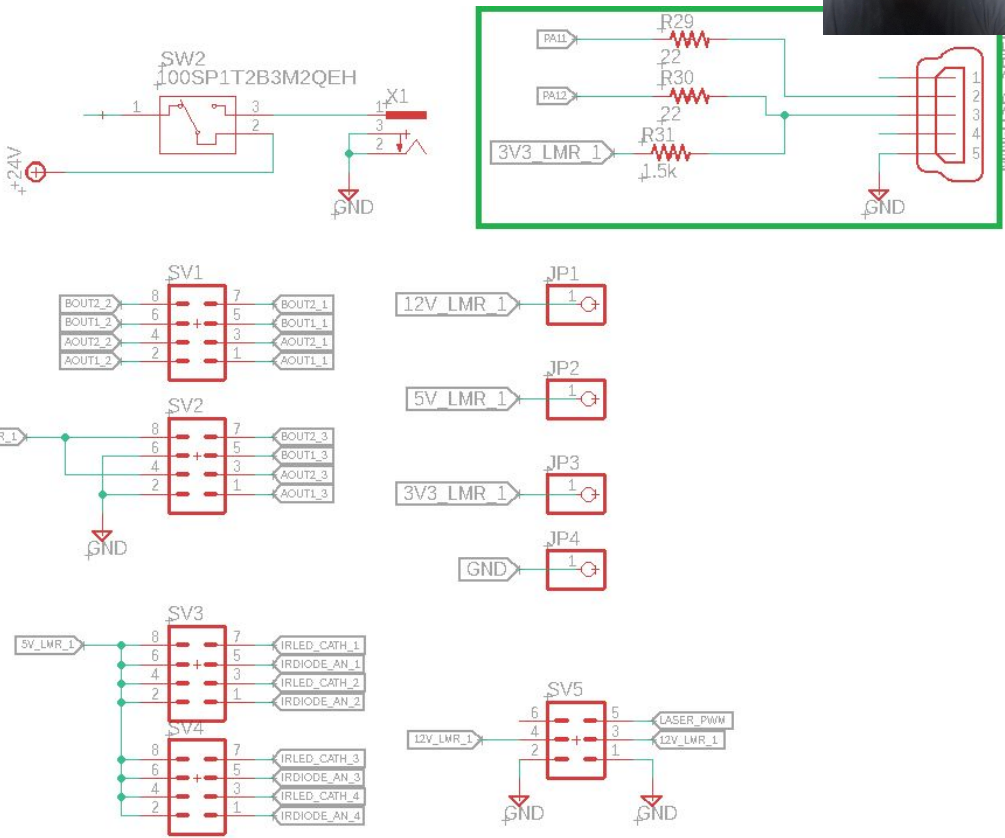
External Connections - Laser Diode Pins

- The laser diode has two pins for power and ground and, and one pin for PWM signal from the microcontroller



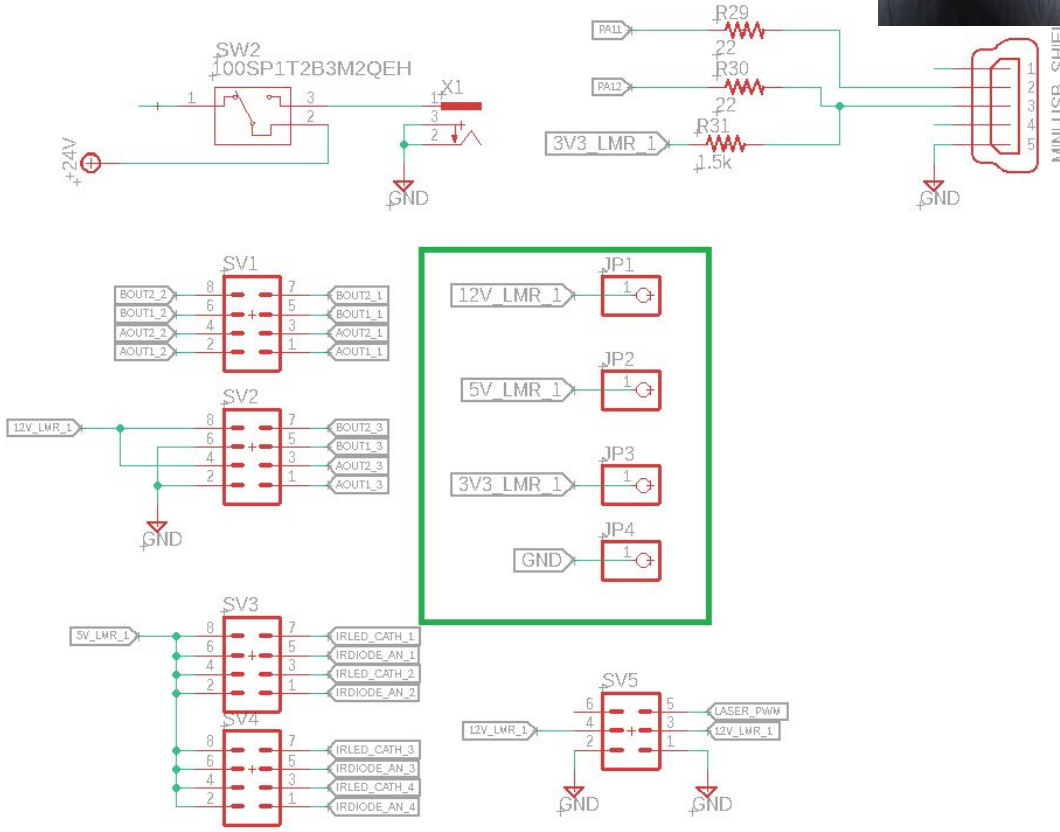
External Connections - Mini USB

- A mini-USB connector to communicate with the microcontroller



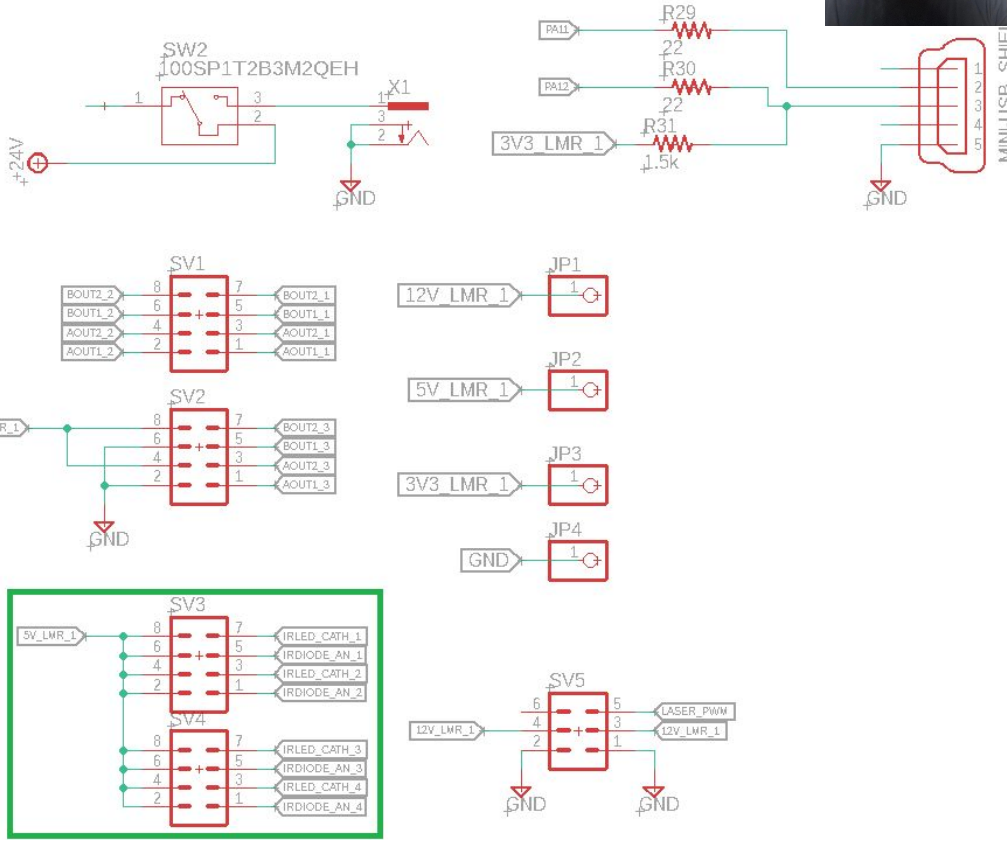
External Connections - Regulator Pins

- These pins are each connected to an output of one of the three regulators and ground
- They exist only for testing and troubleshooting purposes



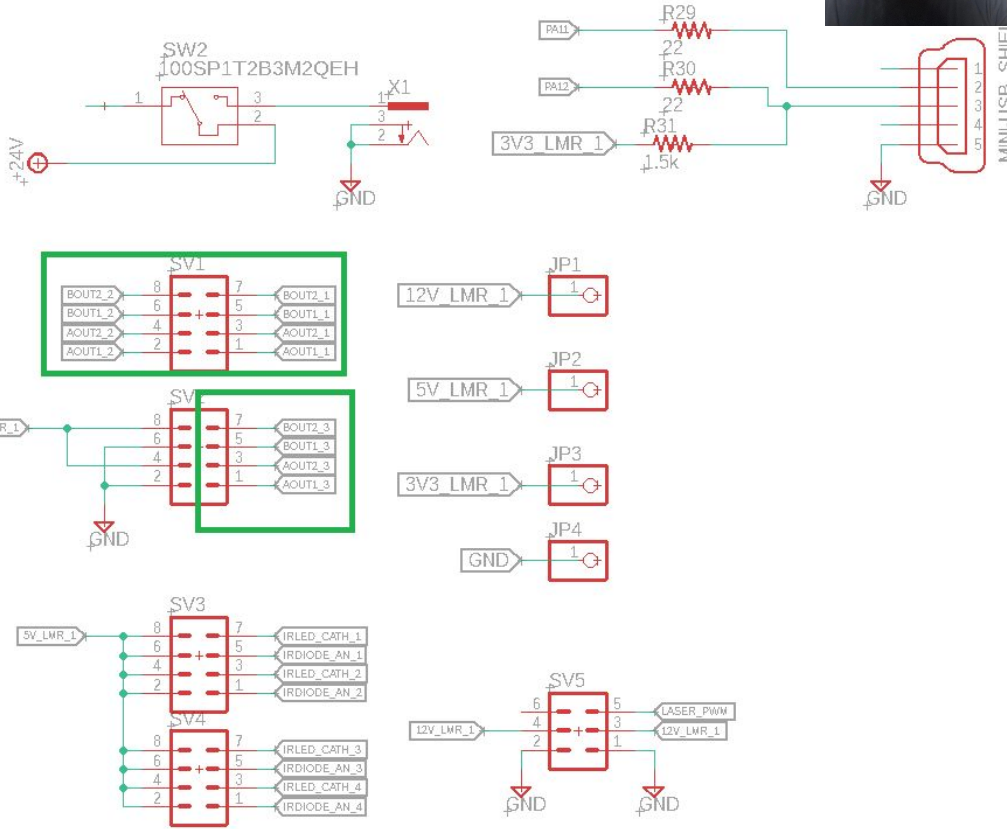
External Connections - Distance Sensor Diodes and LEDs

- The IR LEDs and IR Photodiodes need to be mounted on the chassis
- Through cables and pin headers they will be connected to the sensor circuits



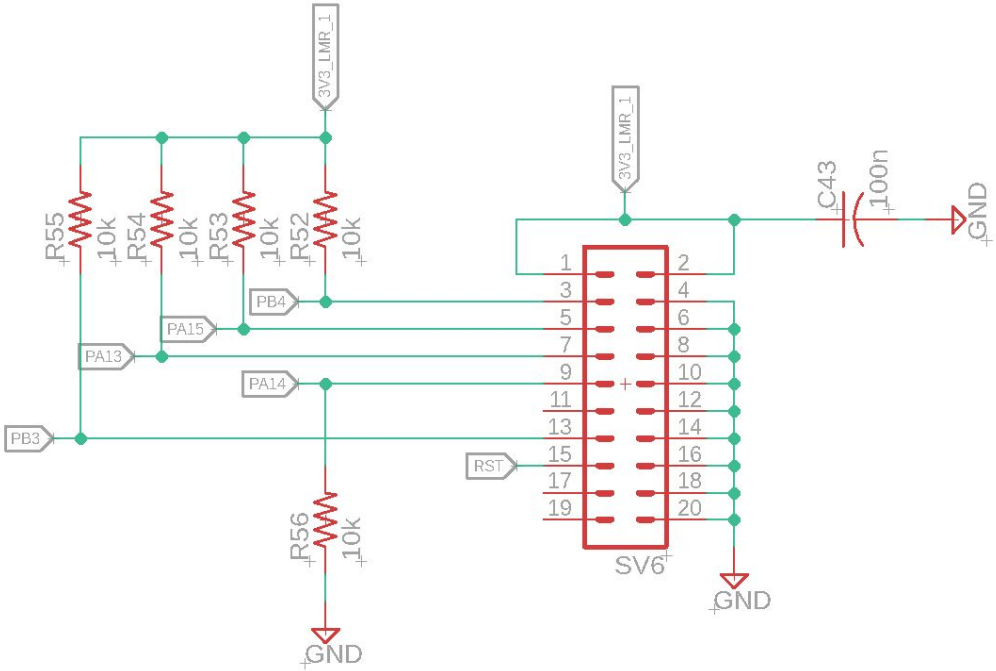
External Connections - Stepper Motor

- Each stepper motor requires four pin connections to each motor driver
- 12 pins are needed for three stepper motors, one for each X, Y, and Z axis of movement



External Connections - JTAG 20-Pin Header

- The JTAG header is necessary for programming the microcontroller, using 5 different pin connections to the controller



Laser

With attached specifications, the laser is capable of etching safely (without causing fires) onto:

- Paper
- Cardstock
- Wood (Excluding Composites)

Laser is compact and lightweight, with inbuilt screws for mounting to the mechanical gantry.

Progress Report: 80%
Remaining Tasks: Needs to be mounted

Fig. ##-##. Laser used in Optical Engraving Process

Specifications:
Dimensions: 3.3cm x 3.3cm x 10cm
Turn on Conditions: 50% Duty Cycle, $5V_{PP}$ Amplification, 0.5 Watts Input Power, 405 nm Wavelength, 237 mW Output Power

Class 3R Laser
Safety Goggles must be worn at all times during operation.

Laser - Optical Design

Laser light will be focused to an ideal spot at a distance 140mm away from the laser. The acceptable spot size range[1] will extend closer to the laser by ##mm.

The focusing is accomplished by two identical plano-convex lenses made of N-BK7 glass, positioned at their focal length (38.1mm) away from the laser.

Lens: Newport KPX046 Uncoated Lenses

[1]: Until the beam spot size diverges from ideal by a factor of √2

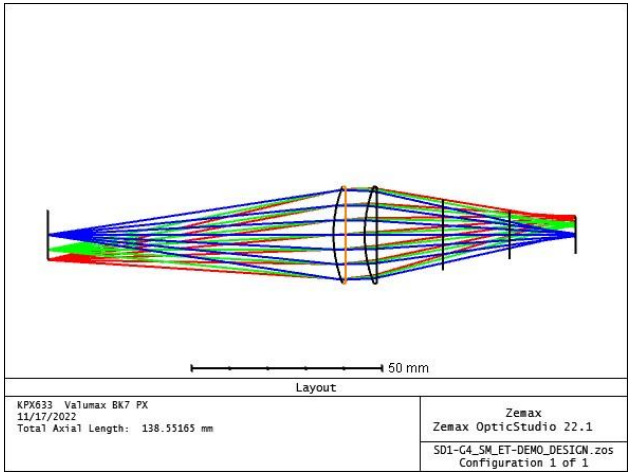
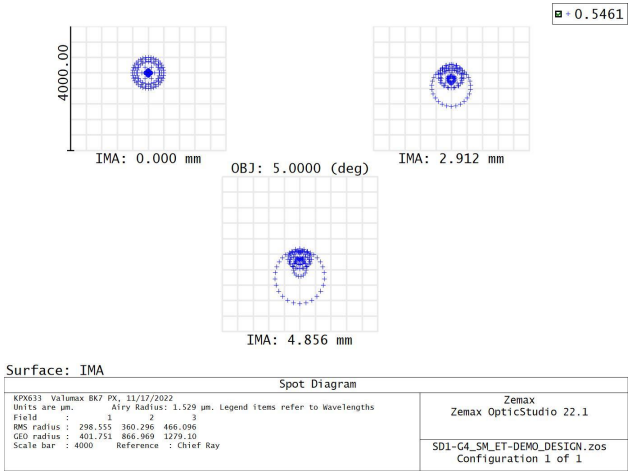


Fig. ##.##. (Above) Total Optical Design in Zemax, (Below) Spot Size Diagram for on and off axis rays at various points along the path length.



Laser - Focusing Lenses

Common Questions:

Why not make a custom lens?

Pros: Light is focused more effectively, shorter optical track length, less aberration

Cons: Incredibly high price tag, potentially high delivery time

Why use only two lenses?

Pros: Two lenses make the system simple and cost effective while increasing the degrees of freedom during design

Cons: A reduction in potential solutions to aberration problems and limitations on focusing

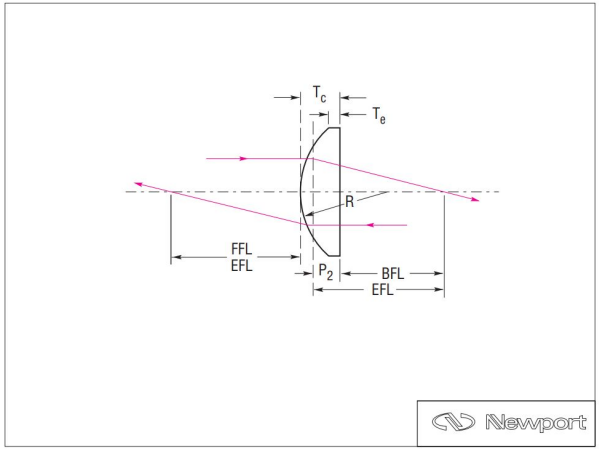


Fig. ##-##, KPX046 diagram and schematic according to Newport Website

Laser - Prototyping

When designing the mount, the primary objectives were:

- Minimizing complexity for quicker, more efficient prints
- Keep costs low, and make assembly quick and easy

Add Image of Laser + Lens System, with or without the 3D Printed Mount

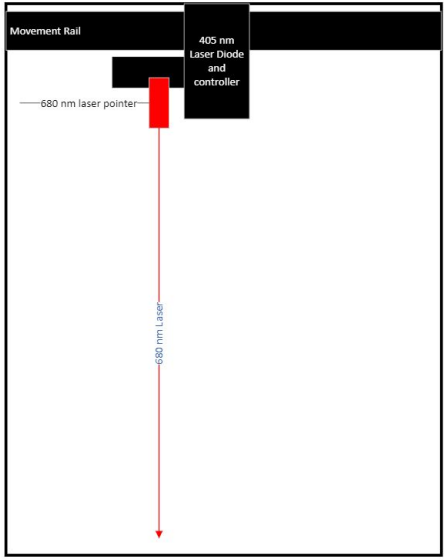
The design was made in solidworks, shown below:

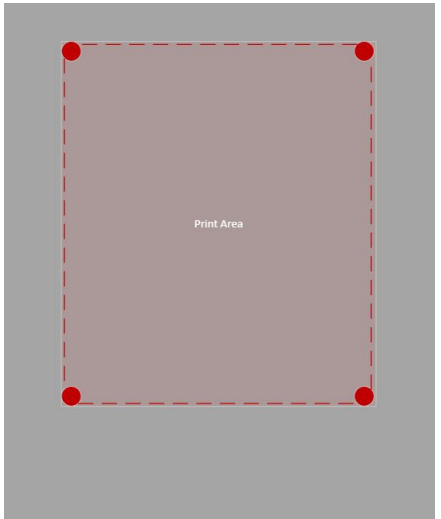
Bottom Half of Mount

Top Half of Mount

Laser Print Area

- This is a relatively simple feature.
- When you turn the printer on it will give you an option to view the printing area onto the material you are printing.
- The purpose of this system would just be used for telling the user where the edge of the print is with a visible laser.

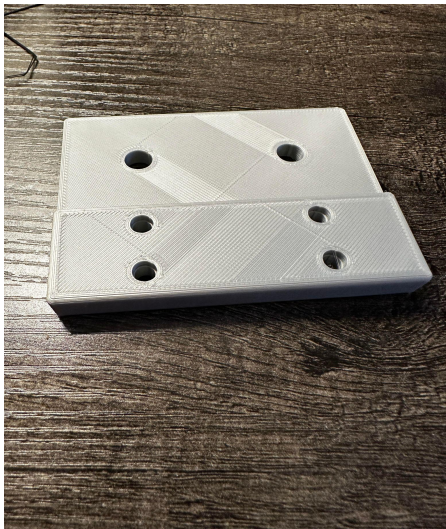




Distance Sensing and Fire Detection

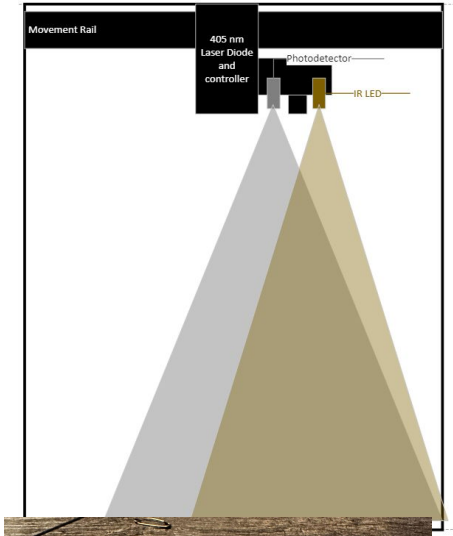
- These are two secondary optical components
- They will both make sure of the same electrical circuits
- Same fundamental concept

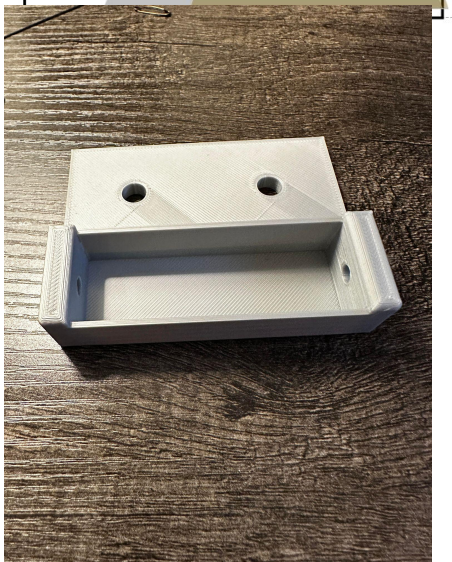
- Components used in working prototypes:
  - 5 mm IR Emitter
  - 5 mm IR Receiver



Distance Sensor

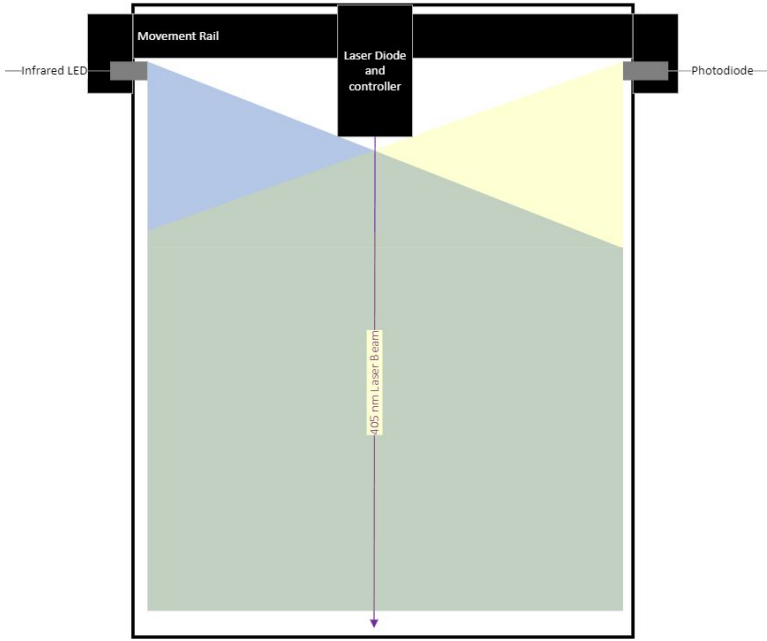
- Mounted on the top the top of the system
- Works more as distance avoidance
- Will make use of a reflective flat material
  - Require user to place a reflective material on top of the print material
  - The reflective material height will be accounted for in the measurement





Fire Detection System

- Same circuit as the distance sensor
- LED and Photodiode will not be able to sense the other
- When smoke/fumes present light is scattered
- Photodiode to detects intensity
- Fire Detection System is tripped
- Causes system to stop lasing
- Waits to see if its just fumes or actual smoke



Budget

	Material	Unit Cost	Quantity	Total Cost
Optical	405nm Laser	$50	1	$50
Optical	Laser Mount	$20	1	$20
Optical	LEDs	$10	1	$10
Optical	Photodetectors	$10	1	$10
Optical	Lenses	$40	2	$80
Optical	Beam Combiner	$150	1	$150
Optical	650nm Laser	$10	1	$10
Optical	Warning Labels	$5	1	$5
Comp.	Microcontroller / microprocessor	$30	1	$30
Electric.	Stepper Motors	$15	3	$45
Electric.	AC Adapter Power Supply	$20	1	$20
Electric.	Motor Controllers	$4	2	$8
Electric.	Custom PCB	$20	1	$20
Electric.	Misc. PCB Components	$20	1	$20
Electric.	Display	$20	1	$20
Electric.	DC Fans	$5	3	$15
Mech.	Aluminum Rails	$10	10	$100
Mech.	3D Printer Filament	$20	1	$20
Mech.	Paper	$4	1	$4
Mech.	Wood	$50	1	$50
Mech.	Misc.	$30	1	$30
Total Cost Estimate:				**$717**

Work Distribution

	Laser	Distance Sensor	Fire Detection	Firmware	Power	PCBs	Mechanical Gantry
Sean	++	+++	+++				+++
Ethan	+++	+	++				+
Ifran		++			+++	+++	
Franklin				+++	+	+	+++

Progress Report

Laser		80%
Print Area		40%
Distance Sensor		60%
Fire Detection		60%
Power		60%
PCBs		80%
Firmware		60%
Mechanical		40%
Overall		60%