Project Documentation

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EEL 4914 - Senior Design I

CCLES

Computer Controlled
Laser Engraving System
Group 13

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1.0 Executive Summary

As a team of engineers, individual members want to put their engineering skills to practice as much as we want to learn and apply a new set of skills. Senior design gives us a chance for us to apply our previous knowledge while obtaining valuable skills. The Computer Controlled Laser Engraving System (CCLES) project is a two dimensional computer numerical controlled laser etching system. This project would be commonly seen in the manufacturing industry where a fine level of detail is required for pattern design. The project is broken down into to several subsystems that contribute to the overall production of the system. The first component is the frame. The frame is an important system of the project that encompasses the other subsystems. The microcontroller, laser, and power supply will be mounted onto the frame. The frame contains the motors that are used to move the mounted laser from coordinate to coordinate. The frame is an X-Y Plotter produced by MakeBlock that comes packaged with two stepper motors. The second component of the project is the microcontroller. The microcontroller is important for controlling the motors and the laser. The microcontroller will be able to do this by using two stepper motor drivers and a laser driver. The microcontroller will be able to send signals to these drivers to communicate what needs to be achieved by those components. The microcontroller being used for this project is the TM4C123GH6PM. The next component is the software. The software will be used to control when and what the physical components are communicating to each other. There are two programs that are being used to operate the project. The first program will be a graphical user interface that the user will be able to interact with. This program will allow the user to draw or upload an image that will be engraved by the project. The second program will run on the microcontroller. The graphical user interface will communicate information to this program that will be used to control the two stepper motors and laser. These program are custom and are designed with only the required functionality. The laser system will be capable of engraving several materials. Generally the type of laser and the main laser component of the chosen type can be replaced with little effort. Our system should at the very least create markings upon wood, plastic, glass, acrylic and paper as well as cut very thin pieces of wood and paper in order to produce our designs. The microcontroller will be able to control the power output of the laser as well as turn it on and off. The overall system will be powered by the AC mains which will be stepped down by a transformer and rectified using full rectifier diode bridge. The system will be protected from power surges by a metal oxide varistor Using Texas Instrument’s WEBENCH power architect tool a network of switching mode voltage regulators will be used to deliver the correct voltage and limit the current to the laser system, the microcontroller, and the two stepper motor drivers.

2.0 Project Description

2.1 Project Motivation

The CCLES project is a two dimensional computer numerical controlled laser etching system. This project would be commonly seen in the manufacturing industry where a fine level of detail is required for pattern design. The inspiration for this project is seen in the necessity for a quick and autonomous system with minimum user input. Post construction, this project should boast ease of use and low operating cost while producing products within a set standard of quality. In the manufacturing industry material waste, machinery cost/upkeep, and project lead times are major factors to determine the overall cost of production. This project should help elevate the production of material waste, increase the production time compared to a human worker. The main prohibiting factor is the initial cost of the machine and the training of a skilled operator to oversee it. With the simple interface that the end project will provide, no intense training will be required to operate this machine. This will help to reduce some of the training costs. For personal use, the benefits that a company receives will still apply. Thanks to the integration of computer software into the manufacturing process, the user will be able to visually see what the machine will produce, prior to actually committing material. This will give the benefit of working out design issues before sending it off to the machine, reducing the chance of wasting material.

Our group motivation for this project was to create a custom computer numerical controlled (CNC) machine for personal use. Most laser systems available for civilian use are very expensive, industrial sized, and impractical for personal use. The project started with the idea of a two dimensional moving apparatus with the ability to draw on a predefined surface. The original idea for this machine was to use a marker to draw on a piece of paper. After several group discussions, this idea evolved from using multiple pens with a device to change which pen was in use to the idea of using a laser to burn the surface of a material.

As a team of engineers, individual members want to put their engineering skills to practice as much as we want to learn and apply a new set of skills. Senior design gives us a chance for us to apply our previous knowledge while obtaining valuable skills. These skills are not only in a technical aspect, but in life skills. These skills include time management, group interaction, and project presentations. Our team consists of three computer engineers and one electrical engineer, so the difference in skill sets can be an advantage to our project. Having a computer engineer is an advantage for this project for designing the microcontroller and software needed. Having an electrical engineer is an advantage for this project for designing the power supply and laser.

2.2 Objectives

The goal for this project is to design and create a custom CNC machine. This machine would be able to burn a variety of materials with a design that the user selected. The user will be able to upload or draw an image to be etched. When the image is finalized, a series of events will take place to convert the image to real-world coordinates, transfer the coordinates to the machine, and etch the image on the material. The laser and motors will be controlled by the microcontroller to toggle them on or off. The project consists of the following objectives: High Degree of Precision, Custom Image Input, Variety of Materials, and Fast Response Time. The first objective of this project is to be able to obtain a high degree of precision and control when etching an image onto a material. This objective will be achieved by using a xy plotter with stepper motors to control the movement. By using a xy plotter to control the movement of the laser, it removes human error when etching the image onto the material. The second objective is for the software to be able to allow the user complete control of the image being etched. This objective will be achieved by designing and creating our own custom program. The program will present the user with a graphical user interface that will allow an image to be drawn or an image to be uploaded. The third objective of this project is to be able to use a variety of materials to be etched. This objective will be achieved by designing the laser with enough power to be able to etch different materials. This is done by designing a custom power supply for the project. The last objective is for the entire project to have a fast response time when being used. This objective will be achieved by optimizing the software algorithms that are being used during operation. The graphical user interface should have a fast response time when the user clicks a button or starts to draw an image. The driver controller should have optimized code to decrease the amount of time that it takes to etch the choose image.

2.3 Requirements Specifications

2.3.1 Frame

Initially there were no measurements that were drafted for the design which made generalizing motor movements extremely difficult. In conjunction, the lack of design made it difficult to take into consideration any space requirements for the laser. Since most of the other hardware is to be mounted on the frame it is important to have a clear and concise measurements that makes it possible to properly plan the layout of the system. Another goal that needed to be met was trying to minimize the cost of the supporting base that would be able to withstand the motions that were going to take place when the etcher was in operation. To help facilitate the conceptualization of the design the project was looked at from a top down approach where the first part to be looked at was the laser mounting apparatus. Once the size measurements were taken, two stepper motors were needed to control the bidirectional motion on the X and Y axis. On each of the axes a linear motion shaft joined together to install a laser mounted platform. The next concept that was needed was trying to figure out how much space was needed from the top of the apparatus where the laser is mounted and the bottom such that the laser is lifted off the ground. Four support pillar and joints were placed in such a way that when the laser etcher was in motion the stability of the frame stays intact.

When the laser is finished etching the final image that is being etched should resemble accurately of what was portrayed in the computer program. A topic that discussed was trying to vary the intensity of the laser etching. One option was to design the XY system to also be able to move in a Z direction. The alternative was to move the base of the system to lift and drop when needed. Both solutions were looked at when the mechanical design was taking place with extensive discussion. In the first option having the laser move in the Z direction when it was attached to the XY system would require an additional stepper motor to raise and lower laser. When looking at the XY system's motion there will be two stepper motors. One motor will control motion along the Y axis which will be fixed onto a square frame and have two shafts oriented horizontally. There will be attached gears to two timing belts where the gears will be driven vertically by the stepper motor. The motion on the X axis is the based off the same principle of the Y axis. This would add stability to prevent any stuttering or vibration of mechanical parts. One problem that would need to be addressed when the parts are purchased is trying to get the timing right by trial and error of the timing belts. If motion were take place in the Z axis, a servo motor would be used instead of a stepper motor. The Z servo motor would be installed on a carriage that would be attached onto the X axis that would be moving. The second option for the Z axis implementation is to instead of moving the laser mount move the base platform. This option was deemed too difficult for the scope of the project mainly due to the lack of experience of the team members. The other factor that discredited this approach was the amount of time to get the moving platform moving and synchronized with the rest of the project before the final project presentation. Another route that was considered was using the microcontroller and a laser driver or a potentiometer to vary the laser intensity. This would help eliminate some of the variables of complicated by removing considerations of object weights and the adjustment of mechanical parts. This would also remove the factor of having to move the laser apparatus which would eliminate the need of a stepper motor which cuts down on the power requirements as well as the budget on for the stepper motor.

The entire positioning system must be stable, highly accurate, and the positioning the laser must be without stuttering while maintaining smooth motions. After recommendation and understanding the time constraints of the project, it was highly advised to avoid trying to recreate the mechanical CNC system from scratch. It would be deemed as detrimental for trying to work out errors with prototyping, time, testing, and adding quite a bit more to the budget spending. With the experience the team has it would seem outside the scope of trying to complete the mechanical design upon the rest of the requirements for the etching in three months. The final decision to overcome the mechanical design was to buy a predesigned kit that would need to be assembled by the manufacture MakeBlock. The exact product that will be purchased will be the “XY-Plotter Robot Kit V2.0 (no electronic)” which includes the entire frame and stepper motors. There would still be the need to manually configure the motors, electrical setup, and the control system for the project specifications. The physical dimensions are 620mm x 620m x 140mm with an actual working area of 310mm x 390mm made of anodized aluminum which makes it light weight and durable.

2.3.2 Microcontroller

The microcontroller will be seen as the main driving force for controlling the location of where the laser will be moved to next. Due to the high dependence of this one component for motor controls it must have a high degree of accuracy and dependability. In addition the microcontroller will to have sufficient memory to load the program onto it as well as it should have the ability have a relatively high clock frequency so the execution time of the program should be near negligible compared to the waiting time for the laser to actually start etching onto the wood. Ideally the microcontroller should also possess enough pins on it to provide a means of input and outputs for any communications for other components in the project. The microcontroller at minimum should possess a JTAG interface for uploading the program and debugging, it should also have a ways of controlling the signal active levels utilizing a GPIO to enable and drive the stepper motor driver, and should be reliable in performance. The microcontroller should have a prevision to handle occurrences where if the voltage levels are outside of range some safety feature is enabled to help prevent damage to it. A huge benefit that would come from the size of the connection pins that would need to be mounted on a PCB in the case that a manual soldiering takes place. This leaves room to comfortably work with without having to worry contacts bleeding into each other causing problems when passing signals along the traces.

The Tiva C Series microcontroller (TM4C123GH6PM) was selected for this project. It is designed around a high-performance ARM Cortex-M based architecture. The Tiva C series architecture contains an 80 MHz Cotex-M with a 256 KB single-cycle flash memory. The microcontroller offers five main ways of communication which include Universal Asynchronous Receivers/Transmitters, Synchronous Serial Interface, Inter-Integrated-Circuit, Controller Area Network, and Universal Serial Bus. These functions can be toggled by changing the pin assignments found on the microcontroller with relative ease. The Cortex-M4 processor itself is a 32-bit ARM architecture. The main feature that made this part attractive was the fact that it has 64 configurable general pin input output which makes it very versatile for configuration. In addition, the TM4C123GH6PM is setup in such a way that most of the 64 pins have alternative functions already predefined. To enable the additional functionality it requires just a value to be modified in the special registers which will be read in utilizing the JTAG interface. The strength of the microcontroller begins to show when the alternative functionality has been toggled which the pin is now preconfigured with one or more communication options bundled in the TM4C123GH6PM. For this project the main way of communication will be done utilizing a USB where data will be sent from the computer and be read in through the special pins 43, 44, 45, and 46. The TM4C123GH6PM must be powered for each side utilizing a 3.3 V connection which enables the entire functionality of the microcontroller to be used.

2.3.3 Software

The specifications can be achieved by programming different methods or functions for the two programs. For the graphical user interface (GUI), the first specification is that the GUI should allow the user to edit the canvas to draw an image. The next specification is that the GUI should allow the user to remove anything that was previously edited on the canvas. The GUI should contain a button for the user to switch to the pen mode. The GUI should contain a button for the user to switch to the eraser mode. The GUI should contain a button that allows the user to start with a blank canvas. The GUI should contain a button that allows the user to upload an image from the computer to the program. The GUI should contain a button that allows the user to etch the image. The GUI should contain a button that allows the user to quit the program. The GUI should not allow the user to resize the window. The GUI should be able send data to the microcontroller. The GUI should be able to receive data from the microcontroller. The GUI should be able to convert the canvas to an image of a specified file format. The GUI should be able to convert the canvas to an array of integers. The GUI should be able to process the array of integers and determine where the user has drawn. The GUI should be able to handle an error code when it receives one from the microcontroller. The GUI should be able to transfer one set of coordinates to the microcontroller at a time. The GUI should send a finished signal to the microcontroller when it has finished transferring coordinates. The image size should be no larger than 310 pixels wide by 390 pixels high. The program should be able to support a variety of image formats. The GUI should accurately track the path of the cursor when the user is drawing or erasing. The GUI should have a response time less than 3 seconds on any action performed. The GUI should be able to etch the entire image in under 10 minutes. The GUI should be simple to use to a novice computer user. The GUI should take no more than 20 minutes to learn how to operate the program. The GUI should be able to run on Windows and Mac operating systems.

For the driver controller (DRC), the first specification is that the DRC should be stored on the microcontroller. The next specification is that the DRC should run without any user interaction. The DRC should be able to control both motor drivers for the xy plotter. The DRC should be able to control the laser driver. The DRC should be able to receive coordinates from the graphical user interface. The DRC should be able to transfer error codes to the graphical user interface. The DRC should be able to store the current position of the motors compared to the image array. The DRC should be able to convert the received coordinates to instructions for the motor drivers. The DRC should be to return the motors to the origin of the image when the finished command is received. The DRC program size should be less than 256 KB.

2.3.4 Laser

The specifications can be achieved by various types of lasers and the design could always be improved by simply replacing the laser module when necessary. Due to size restrictions and the budget of the project however we focus on specific applications and on certain materials which will be addressed in the laser types section. The laser module must be capable of burning wooden surfaces in order for the system to etch pieces of high thickness material and potentially cut pieces of smaller thickness of wood. Etching should be precise and avoid burning nearby areas of the surface to avoid blemishes and to maintain a clean design while the system functions. By achieving these specifications the system can be modified with minimum effort to etch and cut other materials such as paper, leather, and plastic with specific limitations of color due to wavelength interactions between the material and the laser. The output power required should not exceed 2.5 W and the system should be able to adjust the power output. Furthermore the system should be optically isolated to avoid causing eye damage to the user.

2.3.5 Power System

The power subsystem must be able to supply enough energy for the XY plotter stepper motors, the microcontroller, any LEDs and the laser module. The power system must be small enough to not hinder the transportability of the XY plotter and provide precise amounts of voltage and current with minimal heat dissipation and negligible ripple voltage. The current delivered to the microcontroller must be highly limited and it must remain constant to avoid damaging the hardware. The voltage for the laser module must remain constant and the current must be controllable for the laser module. The stepper motor will be controlled by the microcontroller driver circuit which will regulate power input appropriately to refine the function of the stepper motors. The supply must be able to provide the load required for the following components of the overall system in the following table.

Load	Voltage (V)	Max Current (A)	Quantity
Stepper Motor Drivers	12	1.9	2
Microcontroller	3.3	0.025	4
Laser Module	4.5	1.8	1

Table 2.3.5-1: System load requirements

2.4 Design Constraints

Economic

One of the crippling factors in this design, as with many things, is the economic feasibility of the project. Since the project has no funding other than the engineers working on it the design must be simple yet effective. By purchasing a frame rather than designing or commissioning one to our specific use the project becomes feasible and funds can be better allocated in the actual electrical hardware. The capabilities of the project must then be considered to produce a system within our resources. The idea for this project spawned from CNC in the industry and our design itself should be portable to accommodate many applications. Since this project uses a laser system the capabilities of the laser must be defined within our budget. The best compromise in this case is the engraving of non-metal materials. A difference in cost of laser systems that actually affect metal in a meaningful way is beyond what we can spare. Usually to work with metal gas based or YAG based lasers are necessary, the price of which could range well in the thousands. Therefore in our design we focus on engraving organic and non-metallic materials. Taking into consideration the other components of the design the microcontroller was obtained for free from the Texas Instrument lab for prototyping and a sample can be ordered for the final design. The stepper motors necessary for movement is included in the purchased frame and the drivers for the motors are within our resources to purchase. Taking all of these factors into consideration an effective system can be built based on our current fund expectations, any miscellaneous items such as LEDs and basic components for prototyping will be considered on a case by case basis and should be within our budget.

Environmental

Due to the scale of the project there are no evident effects on the surroundings. The ambient temperature of the design should not even cause any noticeable in an occupied room. The design will not produce any waste from operating. The energy consumption of the system will be considered when designing the power distribution system to maintain high efficiency without sacrificing the specifications for the project. Depending on the material being engraved fumes may be released but since the objective is wood there are no noticeable drawbacks.

Manufacturability

Manufacturability refers to the system's ability to be produced efficiently. The entirety of this system relies on proven, tried and tested technology. The main improvement if budget was not an issue would be a custom frame, but disregarding that parameter the project is quite easy to create. The biggest issue is the printed circuit boards being soldered together which if the budget allows can be done to order or with the aid of a metcal station. Due to the power source coming from the AC mains the project could also be easily upgraded without affecting its ability to be built, all that would be required is the appropriate voltage regulator for whatever load is added, provided it is within reason.

Sustainability

Sustainability addresses how the system will perform when casually operating for any length of time. It is critical that the device can operate uninterrupted in order to complete whatever design is being processed by the operator. This is the primary reason batteries are not ideal in this scenario instead opted to use the AC mains. All the subsystems require constant, precise voltage and current. The voltage regulators are also chosen with relatively high efficiency to avoid any damage the system may face due to overheating and increased ambient temperature. The laser system in this case requires special consideration. Due to the laser diode's nature it will be the highest temperature component; as a result its internal resistance will decrease and draw out more current, drastically reducing its life expectancy. The voltage and current regulation for the laser diode must therefore be designed to be reliable and deliver a precise current.

Health and Safety

This is the most critical topic when considering the system's design. There are several dangers that must be taken into consideration for this project, namely the laser system and the power distribution system. The laser required to meet our specifications is considered a class IV laser as discussed in the standards. Due to the high power output of the laser it can blind instantly if misused. The wavelength used for our project does not provide an easily seen laser but due to the power output the diffusion spot will be large. Direct eye contact will result in immediate blindness, human reflex will not be sufficient to mitigate the power output of the laser. Skin damage due to the laser is also possible, cause burns. Furthermore looking at the diffusion spot will also cause considerable damage to eyesight and therefore the system must be optically isolate when in operation and inoperable otherwise in order to bring the laser down to a class I laser. Next the power system poses a great risk for electrical shocks and electrocution. The transformer will be stepping down the 120 V AC mains to 24 to 36 V and carry at least 2 amps out, a dangerous amount for humans. The voltage regulators will continue to step down the voltage but most current paths will be between 1.5 A and 2 A which is still a dangerous amount. The electrical system therefore must be covered in heavy duty insulated enclosure to ensure it is isolated from the operator.

3.0 Project Management

3.1 Milestones

In order for the project to move as smoothly as possible there must be an established schedule with hard cut off dates to determine if the group is following behind on pace. The table shown in figure 3.1-1 illustrates the goals and dates for the spring 2015 semester.

Date	**Goal**
3/17-4/30	Each member should have developed a base understanding of assigned section with notes to be presented to the group with findings.
4/2	A first round discussion will be held to share results of research as well as start establishing what dependencies each subsystem and how they should be handled.
4/10	By this date each member should have 10 pages written down from their research giving the group total page count to 40. Another discussion will be held on trying to generalize a resolution of subsystem dependencies.
4/16	Logic developed for how the systems should be finalized or near finalized. Development dependencies should be fully understood and should be getting resolved.
4/17	By this date each member should have 10 pages written down from their research giving the group total page count to 80.
4/17-4/30	Parts that are known to be used in the project will be purchased at this time to have ready by the beginning of the next semester. The prices will be marked under budget.
4/24	By this date each member should have 10 pages written down from their research giving the group total page count to 120. All system dependencies should be resolved and documented.
4/25-4/30	The group will go over the documents and do any revisions that are seen as necessary as well as beginning the finalization of design and documentation.
4/30	Final documentation submission is due.

Figure 3.1-1

In the summer of 2015 the group will move onto the construction phase of the project where a separate schedule is going to be required. Figure 3.1-2 illustrates the project goals and deadlines.

Date	Goal
5/18-5/22	First week of Senior design begins. Assembly of the frame should start to take place during this week.
5/27	Finalization of any purchases should be made before this date to ensure they will be available for use.
5/22-6/9	Construction of each subsystem should be taking place. A running log should also be generated if any problems arise and need to be resolved will be made as needed.
6/9-6/16	Each subsystem should be tested independently from one another.
6/16-6/30	Problems should be debugged at this point in time to help minimize problems before the subsystems begin to be integrated into each other.
6/30-7/14	All independent systems should be debugged and each component should be ready to be integrated into one another. A running log should also be generated if any problems arise and need to be resolved will be made as needed.
7/14-7/28	Problems should be debugged and resolved at this point in time as the project nears finalization.
5/18-8/6	A user manual of how to operate the project will be made as the project progresses.
8/3-8/6	The final week of senior design 2. Assume that all work would be completed by this week.

Figure 3.1-2

3.2 Group Management

Although the entire team will be working on the project simultaneously, in order to distribute the workload evenly and efficiently each member will be placed in charge of a particular subsystem. The team will have biweekly meetings at minimum that may be increased in frequency if it seems to be necessary. The objectives of the meetings will cover research that have been done on an individual level and also serve as a measurement of progression. Additionally design concepts will be discussed to see what is most feasible and analyze how subsystems will interact with each other as designs become more defined. The following two figures illustrate the subsystem break down. The figures will illustrate which members are in charge of each subsystem. The member in charge of that subsystem is responsible for the completion and quality of the section. The team members are Jose Rivera, Juan Pumarol, Han Ly, and Brandon Workman. In the following figures (Fig 3.2-1 and Fig 3.2-2) the hardware is broken down into different subsystems. Han Ly will be in charge of the subsystems XY Plotter, Stepper Motors, and Motor Drivers. Juan Pumarol will be in charge of the subsystems Laser, Laser Driver, and DC Power Supply. Jose Rivera will be in charge of the subsystem Microcontroller. Brandon Workman will be in charge of Graphical User Interface and Driver Controller. Each member will be helping the others with their subsystems, but the group member in charge needs to make sure that the work is completed. The reason each member needs to help with the other subsystems to some degree is because each of the subsystems interact with each other to some degree. This reasoning is to make sure that the correct power is supplied to the microcontroller, or that the microcontroller sends the correct signals to the laser or motors.

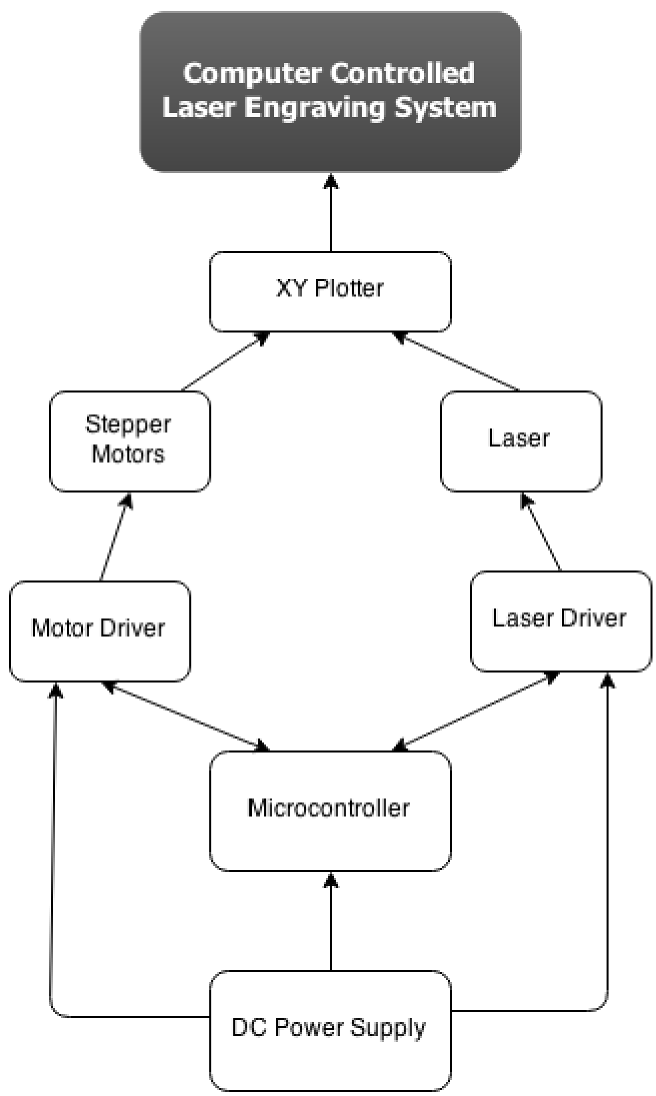


Figure 3.2-1: Hardware Block Diagram

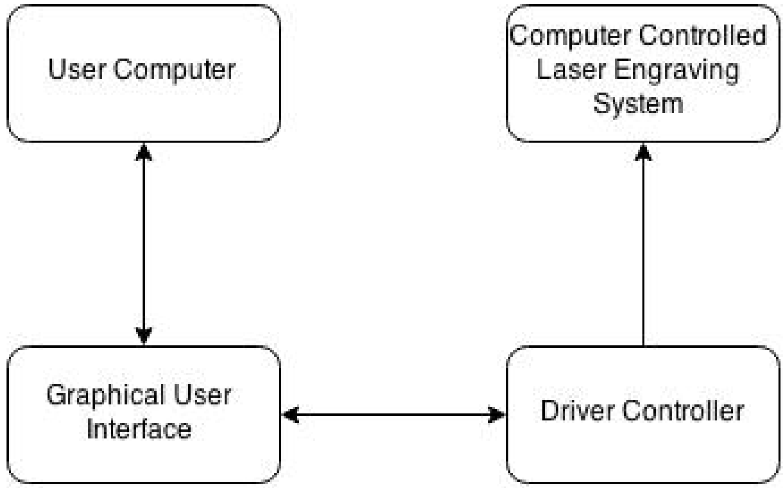


Figure 3.2-2: Software Block Diagram

3.3 Budget and Finance

Table 3.3-1 is the initial budget plan with the initial cost limitations. This table shows the budget we are willing to spend for each section of the project.

Item	**Cost**
Frame	$150.00
Power Supply	$60.00
Laser	$150.00
Microcontroller	$50.00
Motors	$120.00
LEDs	$10.00
Misc.	$50.00
Total	$590.00

Table 3.3-1 Initial Cost

Table 3.3-2 is the calculated cost for each component after the design has been completed for the laser. The total cost was under the projected cost, and can therefore use the extra spending elsewhere.

Item	Cost
2W 445nm M140 Blue Diode	$45.00
AixiZ aluminum mount and heat sink for 12mm modules	$3.50
AixiZ 12 X 30mm laser module blanks 10 pack	$20.00
3 pack 12 X 30mm Copper 5.6mm laser diode mount blank module	$17.50
Total	$86.00

Table 3.3-2 Laser Cost

Table 3.3-3 is the calculated cost for each component after the design has been complete for power supply. The total cost was under the projected cost, and can therefore use the extra spending elsewhere.

Item	Cost
TPS54531	$3.97
TPS54332	$1.69
TPS53915	$4.76
TPS61232	$2.67
Transformer	$15.00
Power Regulation	$28.98
Total	$57.07

Table 3.3-3 Power Supply Cost

Table 3.3-4 is the calculated cost for each component after the design has been completed for the microcontroller. The total cost was under the projected cost, and can therefore use the extra spending elsewhere.

Item	Cost
TM4C123GH6PM	$11.42
Pin Headers	$5.55
Motor Drivers	$39.98
Total	$56.95

Table 3.3-4 Microcontroller Cost

Table 3.3-5 is the calculated total for each of the components. Since the motors come with the frame, the cost for the XY Plotter at $210.00 is lower than the initial cost for both combined of $270.00. The power supply cost of $57.07 is lower than the initial cost of $60.00. The laser cost of $86.00 is lower than the initial cost of $150.00. The microcontroller cost of $56.95 is higher than the initial cost of $50.00, we can use funds from the other sections for this. Since the total cost of $417.01 is lower than the initial budget of $590.00, this will allow for $172.99 to be used for miscellaneous parts or for broken parts.

Item	Cost
Frame	$209.99
Power Supply	$57.07
Laser	$86.00
Microcontroller	$56.95
Motors	$0.00
LEDs	$7.00
Total	$417.01

Table 3.3-5 Final Cost

4.0 Research

4.1 Frame

An XY system has the ability to move in a two-dimensional region. There are many different configurations to achieve this goal. There are two different types of systems that can be implemented. The first type is an XY system that only moves in a two-dimensional plane. The second system is an XYZ system that can move in a three-dimensional plane. These systems can be used to provide precise horizontal or vertical motion for the basis of industrial machinery. The first example of an XY system is an XY Stage. As you can see if figure 4.1-1, the XY Stage is composed of two separate sections making up a total of three plates. For this setup, the two moving plates are on the top and the stationary plate is on the bottom. The material would be placed on top of the surface. The three surfaces are generally separated by ball bearing or rollers. The stepper motors would be used to slide one of the top two surfaces. This system has the benefit of a small amount of moving parts to control the table and the laser would be mounted in a fixed position over the XY Stage. This will help benefit from the possibility of a mechanical error occurring while the system is in use. A downside to using this system is that the material would have to be placed directly onto the surface of the machine. Depending on the type of material, the stage would need to be sturdy enough to support the weight without interfering with normal operation. The heavier the material, the more power that would be required for the motors to be able to move the surface. The XY Stage would also need some sort of system to attach the object to the stage during use. If the material was allowed to slip on the surface, error would be introduced into the process. This would decrease the accuracy of the final image when the process is complete. Over time, use of the XY stage will degrade the quality of the ball baring or the rollers. These will eventually need to be replaced. If they are not replaced the quality of the final product will degrade as well. The XY Stage can be redesigned to have the ability to move in the z direction. This would add the benefit of controlling how close the laser is to the material during operation. Due to the lack of knowledge in mechanical engineering, this design option is not viable.

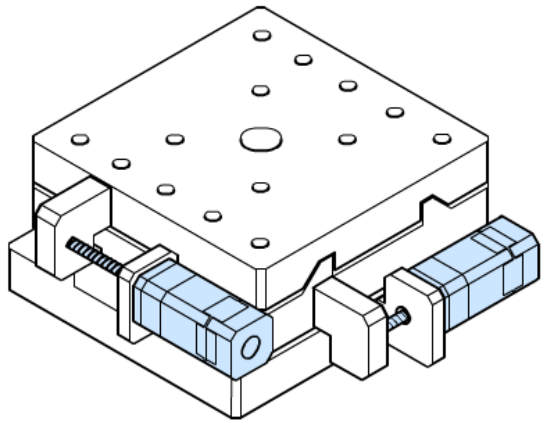


Figure 4.1-1 XY Stage

When automated equipment is designed, various factors must be taken into consideration. This includes the production line layout, installation environment, ease of maintenance, configuration of electrical wiring, control system, and so on. This means many man-hours are needed to select the motor and other mechanical components. From this process parts lists, drawings, operating manuals, and such can be generated. The XY stage in figure 4.1-1 has a custom design for the stepper motors is uses. These stepper motors were converted into linear actuators. In the figure 4.6-2 below is a compact linear actuator that was designed by Oriental Motor. This Linear actuator features a stepper motor integrated with a ball screw. This model is ideal for pushing and pulling small loads or for fine-tuning applications. This stepper motor actuator has various advantages over the hydraulic and pneumatic actuators. The first feature is the linear actuator is very stable when operated, even at low speeds, and offers smooth acceleration and deceleration. The motion of the linear actuator can be programmed with multiple stopping points. This can be helpful when multiple stopping points are known beforehand and can be selected at the same time. Due to using a stepper motor, adjustment of the position and speed can be modified easily by changes the data. Changing the setup to another settings is as easy as changing the previous data stored.

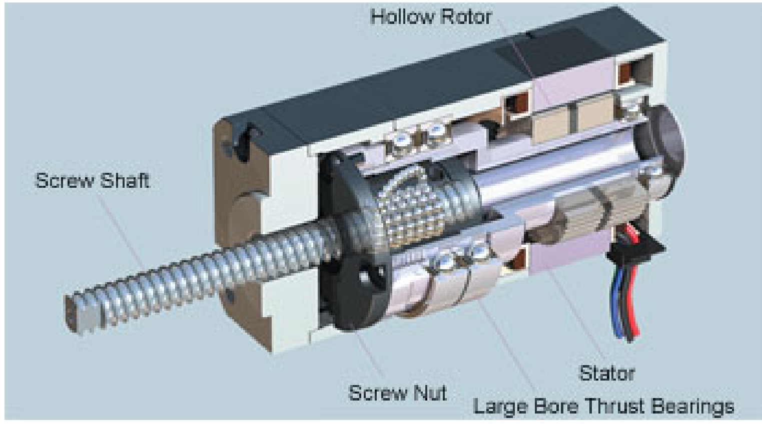


Figure 4.1-2 Compact Linear Actuators and its driver.

Velmex offers various XY positioning devices. They have a history of specialized positioning equipment that offer high precision control. This equipment can often been seen in scientific and industrial applications. Shown below in figure 4.1-3 is an example of a few of their products that were taken into consideration for XY system alternatives. When two of the same devices are combined together, an XY system that can move in a two-dimensional plane can be created.

Figure 4.1-3

Velmex offers series MAXY4000 and MAXY6000 as a few of their motorized XY stages assembled with motor driven UniSlides. The standard tables include a motor mounting plate, coupling, lead screws, large base, and a top plate. These XY stages are predesigned by Velmex and are viable for use in more projects. This design allows the buyer to select their own motor, limit switches and control unit. Some general features that are provided by Velmex motorized stages are large top work surface area, precise and smooth travel with a low profile, and plugin compatibility with UniSlide motor controls. The assembled XY stage can have up to 2", 3", 5", 6", or 9" of travel. Figure 4.1-4 is an image of a typical XY stage offered by Velmex.

Figure 4.1-4

Despite the advantages the XY stages offered by Velmex, it has some constraints that need to be observed. Suppose a group used the MAXY4000 and the maximum load capacity was accurate. As the weight of the load increases, the sturdier XY stage and base need to be to support the load weight. The CCLES project requires the project to be mobile, and due to this the Velmex XY stage would not be a good choice. The XY stage would be too large and heavy to be mobile and easily be transported. The Velmex XY stage would need to be mounted in place in order to support the weight of the maximum load capacity. In table 4.1-5 is an example list of the size and load capacity of a few XY stages from Velmex series.

Model Number	**Travel**	**Height**	**Load Capacity**	**Working Area**
MAXY4006W1-S4	2" x 2"	4.13"	60 lbs.	12 1/2" x 12 1/2"
MAXY4009W1-S4	5" x 5"	4.13"	25 lbs.	18 1/2" x 18 1/2"
MAXY6009W1-S6	3" x 3"	5.47"	100 lbs.	17 " x 17 "
MAXY6012W1-S6	6" x 6"	5.47"	60 lbs.	25 " x 23"
MAXY6015W1-S6	9" x 9"	5.47"	30 lbs.	29" x 29"

Table 4.1-5

4.2 Microcontroller

Atmel ATmega640

This microcontroller is an 8-bit Atmel high performance microcontroller. It utilizes a RISC based Architecture with 135 instructions of which most are single clock cycle execution. It has a 16 MHz clock cycle with 32 eight bit general purpose working registers. The ATmega640 is IEEE standard 1149.1 compliant with their JTAG interface. This allows programming onto the 256kB flash memory. There are many peripheral features that the Atmel ATmega640 possesses. The peripheral features include two eight bit counters/timers or four 16 bit counters/timers. It has real time counters with a separate dedicated oscillator. Four eight bit PWM channels or six/twelve PWM channels with a programmable resolution of two to sixteen bits. 8/16 channel ten bit ADC. It also contains four programmable serial USART. It contains support for a master/slave SPI serial interface.

The power configuration for the ATmega640 pins are as follows: VIN is the input voltage the Arduino board is expecting from an external power source. There is a 5V regulator on the board that can be supplied with either a 5V USB connector or DC power between 7-12 volts. An IOREF is used as the voltage reference which the microcontroller operations. This helps select the power source or enable voltages on the outputs.

SAM3X

The SAM3X microcontroller uses a Thumb – 2 instruction set architecture. It can run up to 84 MHz. It contains two blocks of 256 kB flash memory bringing up the total flash memory available for programming to 512 kB. The microcontroller also has 100 kB SRAM with dual banks. The peripheral features include 4 USARTs that are ISO7816 certified and one UART. There are 2 TWI I^2C compatible configurations. Also it contains up to 6 Serial Peripheral Interface (SPI) busses can used at once. In addition it can support up to eight-channel 16-bit PWM controller with complementary output. It has the capability of utilizing an Ethernet MAC with a dedicated DMA or 2 CAN controllers for communication to the microcontroller.

The power configuration for the SAM3X pins are as follows: VIN is the input voltage the Arduino board is expecting from an external power source. There is a 5V regulator on the board that can be supplied with either a 5V USB connector or DC power between 7-12 volts. An IOREF is used as the voltage reference which the microcontroller operations. This helps select the power source or enable voltages on the outputs.

ATmega 48PA

The ATmega 48P is a lower power 8-bit microcontroller. It utilizes and advanced RISC architecture with 131 instructions most of which are single cycle execution. It has 32 eight bit general purpose registers with a throughput of 20 MHz. ATmega 48P has 32 kB of flash memory with 2kB of SRAM. The peripheral features include two eight bit counters/timers or one 16 bit counters/timers. It has real time counters with a separate dedicated oscillator. It also contains six PWM channels. The controller has 8 to 6 channel ten bit ADC depending on configuration. It also contains one programmable serial USART. It contains support for a master/slave SPI serial interface.

The power configuration for the ATmega48 PA pins are as follows: VIN is the input voltage the Arduino board is expecting from an external power source. There is a 5V regulator on the board that can be supplied with either a 5V USB connector or DC power between 7-12 volts. An IOREF is used as the voltage reference which the microcontroller operations. This helps select the power source or enable voltages on the outputs.

ATmega32U4

The ATmega32U4 is an 8-bit Atmel high performance microcontroller. It utilizes a RISC based Architecture with 135 instructions of which most are single clock cycle execution. It has a 16 MHz clock cycle with 32 eight bit general purpose working registers. The ATmega640 is IEEE standard 1149.1 compliant with their JTAG interface. This allows programming onto the 32kB flash memory. There are many peripheral features that the Atmel ATmega32U4 possesses. There is two 16 bit timer/counter for normal use and one 10 bit high speed timer/counter. It also contains four PWM channels with a programmable resolution of 2 to 16 bits for normal operation while having six PWM channels for high speed operations with a programmable resolution of 2 to 11 bits. It contains twelve channel of 10 bit ADC. There is programmable serial USART with. It can also support for a master/slave SPI serial interface.

The power configuration for the ATmega32U4 pins are as follows: VIN is the input voltage the Arduino board is expecting from an external power source. There is a 5V regulator on the board that can be supplied with either a 5V USB connector or DC power between 7-12 volts. An IOREF is used as the voltage reference which the microcontroller operations. This helps select the power source or enable voltages on the outputs.

MSP430G2553

The team members of this project have had previous experience utilizing the MSP430g2553 in two previous courses. The MSP430g2553 microcontroller itself has a frequency of 16 MHz clock speed. The microcontroller has 16 kB of flash memory with 512B of SRAM. It has 24 general pin inputs/outputs (GPIO) that can be configured to one either Inter-Integrated Circuit Interface (I^2C), one Serial Peripheral Interface (SPI), or one Universal Asynchronous Receivers/Transmitters (UART). It has a 16-bit RISC architecture with 62.5ns instruction cycle time. In order to power the MSP430fg1618 the V_{CC} pins should receive 3.3 V.

MSP430fg4618

The team members of this project have had previous experience utilizing the MSP430fg4618 in the computer systems laboratory. The MSP430fg4618 microcontroller itself has a frequency of 8 MHz clock speed. The microcontroller has 116 kB of flash memory with 8kB of SRAM. It has 80 general pin inputs/outputs (GPIO) that can be configured to one either Inter-Integrated Circuit Interface (I^2C), one Serial Peripheral Interface (SPI), one Universal Asynchronous Receivers/Transmitters (UART), or three channel internal Direct Memory Access (DMA). It has a 16-bit RISC architecture with 125ns instruction cycle time. In order to power the MSP430fg1618 the V_{CC} pins should receive 3.3 V.

TM4C123GH6PM

The Tiva TM4C123GH6PM manufactured by Texas Instruments. The key features listed by Texas Instruments are its 80 MHz clock with 256 KB of flash memory. Additionally it also has the ability to mount one USB 2.0 port which allows programs to be loaded onto the controller memory to be executed. An additional eight UARTs (Universal Asynchronous Receiver/Transmitter) are also available to use with speeds up to 5 Mbps with normal speeds and can go to an upward of 10 Mbps. In addition to the multiple communications that is supports it offers 32 KB of SRAM. The architecture of the TM4C123GH6Pm is ARM which great at maintaining quick execution speed compared a CISC based architecture.

Comparisons

Initially the team wanted to try experimenting with different controllers that we have had previous experience with. Many controllers were looked at from the Arduino site and the microcontroller of choice they used was from ATmega. While browsing over the selection of controllers it became somewhat apparent that most of the selections from the site were either too small FLASH memory which would be a problem when it came to programming this application. In addition the interfacing of communication seemed somewhat limited compared to the Texas Instruments selections. For this reason the selection choices switched from Arduino to Texas Instruments product line. Another predominate reason for the switch was the familiarity of the IDE that would be used in order to programming onto the microcontroller. The first products to be looked at were microcontrollers that the members had previous experiences with. Looking at this the group realized that the functionality of previous microcontrollers were somewhat lacking the necessities that were predefined in the project requirements. The group considered using the TM4C123GH6PM microcontroller after a recommendation was made by one of the staff inside the Texas Instruments Innovation Labs. After spending a conservable amount of time with researching the TM4C123GH6PM it seemed to be the right selection for this project as it allows multiple communication protocols, large storage on its FLASH memory, and most importantly a familiarity of experience with working with previous Texas Instruments microcontrollers. Using this microcontroller allows programs to be quickly written in Code Composer Studio which was developed by Texas Instruments. This a very powerful tool which makes writing programs for Texas Instruments microcontrollers straight forward because it provides most libraries to interface between the IDE and the hardware.

4.3 Software

Research for the software development of this project was done in three different areas. The first area of research was trying to decide which programming languages would be best for the programs being developed. Since we are developing two different programs, there could possibly be two different languages that could be used. The second area of research was trying to decide which programming development environment would best fit the projects needs based on the chosen programming languages. This was an important choice due to different environments having different benefits. The area of research as don't in algorithm analysis. This section was important for trying to decide how the motors were going to function when the image was beginning processed.

4.3.1 Programming Languages

There was a wide selection of programming languages that were evaluated when choosing what to use to develop the software for this project. There are two different program that need to be developed, so a possible two different languages need to be selected. The first program that needs to be developed is the user interface. This program will be used as a canvas for the user to draw and save an image. For this reason, only high level programming languages were evaluated for selection. This program should also be cross platform so that a user will be able to use the software on almost any computer. The first language that was looked into was C#. Visual Studios is the recommended integrated development environment to use to develop with C# when wanting to create a user interface. To create a user interface, the programmer first needs to create a new Windows Form to add components to. After the Windows Form is created, it is as easy as dragging and dropping the components onto the frame. The programmer has a list of available buttons, text fields, labels, etc. on the side of the Visual Studios window. The programmer will be able to see what the user interface looks like as they are creating it, instead of having to compile and run the code. This saves time when trying to develop the software. This language was not chosen though due to the fact it is not a very well-known language to us. Only a few of our members have programmed in C#. Those that have developed with C# have only done a few simple programs on their spare time. Due to Visual Studios being a Windows Operating System based programming environment, it may be hard to keep the program compatible with other platforms. The next language that was evaluated for selection was C++. The recommended integrated development environment for C++ is Qt. To get started creating a user interface using Qt, the programmer first creates a widget. After the widget is created, the programmer can simple drag and drop the components onto the widget frame. Using Qt and C++ to develop the user interface will allow the program to be cross platform and run on almost any computer. This programming language was not chosen due the group members having very little knowledge in C++. The last programming languages that was evaluated for selection was Java. The recommended integrated development environment for Java was Eclipse. Java was chosen as the language to be used due to a couple of factors. The first factor is that three out of four group members have done Java programming for two or more years prior to this project. Since the majority of the group members have done sufficient work with Java, it helps during development. The group members will be able to ask each other for help while programming if they need help. This helps since the group members do not have to learn a whole new language to develop what is needed and requires little research to get started. The second factor as to why Java was chosen is because it is cross platform. This will allow us to develop a user interface that a user can execute on any computer.

The second program that needs to be developed is the driver for the x-y plotter and laser. This program will run on a microcontroller and will not need to be cross platform. There will be no user interface for this program and will run in the background. For these reasons a different set of programming languages were evaluated when deciding what to program with. The first language that was evaluated was the appropriate assembly language for the chosen microcontroller. This was the first language evaluated because assembly language is the primary language our group has used to program on microcontrollers. At least three of the four group members are proficient enough in the language in order to be able to start the software development with little to no prior research. This helps in the programming process when a group member is stuck and needs help. Another reason this program was evaluated was because it allowed for complete control of the microcontroller. We would be able to tell what registers or how the input output pins acted easily. The reason this language was not chosen was due to it being too low level for our software design. The next language that was evaluated was G programming language or G-code for short. G-code is a popular language when picking a numerical control programming language. G-code is a popular language for interfacing with a computerized machine tool. It is a popular tool for cutting machines. G-code allows the programmer to easily tell the machine tool where to move, how fast to move, and what path to take to get to the designated destination. This makes designing the software easy. There are two reasons we chose not to use the programming language. The first language is because none of the group members has any knowledge of G-code. In order to start programming in this language, each group member would need to do plenty of research into the language just to start programming with it. This time can be put to a better use. The second reason for not choosing this language was because we decided to design our own microcontroller. Due to this we decided it would be easier to use a different language instead of trying to figure out how to interface the two together. The last language that was evaluated to be used for the second program was C programming language. This is the language that was chosen to design the second program. There are three factors that contribute to this language being chosen. The first factor is because at least three of the four group members have proficient knowledge in this programming language. It will be easy for the group members to assist each other during development if a group member runs into an obstacle while programming. Since the majority of the group members has proficient knowledge of C programming language, it will require little to no previous research in order to start development for this software. The second factor this language was chosen is because at least two of the four group members have moderate knowledge of programming and running a C language program on a microcontroller prior to this project. This will help when designing the initial software design. The final factor this language was chosen is because we are designing our own microcontroller. This will allow us to import the libraries as needed to be compatible with our microcontroller. We will be able to have similar control over the microcontroller as we would if we were programming in assembly.

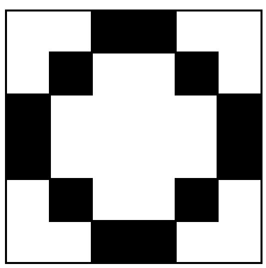
4.3.2 Programming Environments

After deciding what programming languages were going to be used to design our two software programs, we needed to decide what programming environments were going to be used. First we needed to decide what programming environment was going to be used to create the software for the user interface. Since we are programming this software with Java, we need to pick an appropriate integrated development environment (IDE). There were a few environments that were reviewed for use. The IDE that was evaluated first was NetBeans. NetBeans is a programming environment used for Java developed in Java. The environment is cross platform and allows each member in the group to choose which operating system they choose to work on, while maintaining a similar working environment. By keeping a similar working environment, group members are able to help each other out if a problem arises. This will help save time when dealing with possible errors in the program or trying to solve compilation errors. Another benefit the NetBeans offers is a built in graphical user interface builder. This will be very helpful when trying to design the user interface the user will be sing to draw an image. By using NetBeans all users will be able to use the same tool without having possible errors or version mismatch when installing a third party plugin for the IDE. The reason this IDE was not chosen was because it was not the environment the majority of the group was used to programming in. The alternative IDE that was evaluated was Eclipse. Eclipse is another programming environment that was developed using Java and all it to be used on which ever operating system the group member decides to use. This IDE will also allow each member to work in a similar environment regardless of what computer they are on. An added benefit Eclipse has over NetBeans is that Eclipse compiles the programmer's code as they type. This allows the programmer to quickly fix an errors in the program without having to wait for the IDE to compile it and report the error. A problem with Eclipse is that it does not have its own graphical user interface builder. A good thing on the other hand is that Eclipse is an open source IDE and allows other programmers to design and release compatible plugins. This allows us to download and install a plugin to help build a user interface. This IDE was chosen for our programming environment because it is the most familiar IDE. Our group members will be able to start programming without having trouble learning the user interface of the IDE. Being familiar with the IDE outweighs the potential problems we may have installing the plugin to help create graphical user interfaces.

There are a few potential integrated development environments (IDE) when developing in C language for the second program. The IDE we evaluated first was DevC++. The programming environment DevC++ uses the GNU Compiler Collection to compile and run C language programs. It is a very good IDE to use but has a downside, it does not receive updates and is not maintained. Due to this, some features may not work to their full potential. Since it is not maintained it may also be missing features that other IDEs may have that can be useful. There are two reason why this IDE was not chosen. This first reason is that it is not maintained. The second reason is because the majority of the group members prefer to use other IDEs over DevC++. An alternative IDE that is preferred over DevC++ is CodeBlocks. CodeBlocks also uses the GNU Compiler Collection to compile and run C language programs. CodeBlocks is consistently maintained and preferred amongst our group members. Since the majority of the group members have used this IDE it will help avoid problems when trying to learn the interface of a new software. A small downside to using CodeBlocks to develop a program for the microcontroller is interfacing it with the microcontroller. It is not a straight forward process and can result in some errors. Due to this CodeBlocks was not chosen for use. The last IDE to be evaluated was Code Composer Studios. Code Composer Studios is an IDE that's combines the advantages of the Eclipse software framework with enhanced embedded debugging. Code Composer Studios supports a broad range of TI's embedded processors making it easy to interface the program with the microcontroller. This allows the IDE to easily transfer the program from the workspace to the microcontroller. Another feature is that the IDE comes prepackaged with the correct libraries for our microcontroller. The libraries will be made easily available without having to find and download them for another IDE. This will help ensure that the program is loaded and stored correctly. This is why Code Composer Studios was chosen over DevC++ and CodeBlocks.

4.3.3 Program Algorithms

There are four methods that can be implemented to control the movement of the laser. Let's take Figure 4.3.3-1 as an example image that was submitted by the user to etch onto a given material. The first image (Fig. 4.3.3-1a) will represent an image a user submitted to be etch. The second image (Fig. 4.3.3-1b) will represent the image after it is converted to an array of integers. A value of one in the array would stand for black, while a value of zero would stand for white. The columns will be represented by the letter 'j' and the rows will be represented by the letter 'k'. The indices will start at zero and go to five.



A

0	0	1	1	0	0
0	1	0	0	1	0
1	0	0	0	0	1
1	0	0	0	0	1
0	1	0	0	1	0
0	0	1	1	0	0

B

Figure 4.3.3-1: Example Image

The first method for moving the laser is the most basic and easiest to implement. The program will move the laser to each corresponding element in the 2-d array, regardless of whether or not the value is one or zero. The program would start by incrementing 'j' from zero to five, moving the laser to each corresponding location above the material. After 'j' reached the value of five, the program would reset 'j' back to zero and increment 'k' by one. At this point the motors would move the laser back to the beginning of the current row and then move down to the next row. The process would be completed when the last row was finished. When the program does find a one, it will turn on the laser long enough to burn a spot on the material. The second method is a small optimization of the first method. This method would still move the laser to each spot of the array one by one. It would start by incrementing 'j' from zero to five, moving the laser to each corresponding location above the material. This time the program would immediately increment ‘k’ by one, and move the laser down one row. After this, the value ‘j’ would work backwards decrementing from five to zero, moving the laser the each time. This optimization would improve on the speed on the printing as well and the energy used overall. This is due to the motors not wasting time or energy resetting the laser back to the beginning of each row when it reached the end of the row. The third method is another optimization that can be used on the second method. This method will not be moving the laser to each element of the array unless it has a value of one. Internally the program will still iterate through the array the same as the second method, but will only move the laser when necessary. The program will have to do a couple extra calculations to determine where the motors will have to move the laser. These calculations will be small and not impact the speed of the etching. There will be an increase in time due to not having to move the laser to every element of the array. This will also decrease the amount of energy being used to etch the image. The last method is an alternate method to the previous methods discussed. This method would implement the Breadth First Search (BFS) algorithm. The laser would start in the middle of the 2-d array and work outwards looking for values of one. The program would find the nearest value of one and then move the laser to the corresponding spot. This method could improve on the time and energy used to etch the image. Method three will be used to control the motors and laser as it seemed the best approach for our design.

4.4 Laser

Using a laser to engrave wood is quite a popular project among the DIY community. The amounts of way to create a laser to meet our specifications are several since it is a tried and true endeavor. The majority of enthusiasts generally rely on gas based lasers, YAG based configurations, and laser diodes. YAG lasers are generally of much smaller wavelength and are widely used for working with metal due to the absorption at those wavelengths. Gas based lasers are particularly popular for wood, plastic, glass, paper and generally any organic material due to the wavelength being higher by design+. Given our budget however the YAG and gas based mediums are ambitious and would prove a challenge to integrate to our system due to the size and weight involved. Before focusing on the type of laser a standard for the necessary power output must be stablished. Most wavelengths are capable of working with wood to an acceptable degree, and at least 1 W of power output is sufficient to cause visible markings on wood. The power necessary to fulfill the project’s specifications can therefore be potentially done with a single laser diode. Depending on the laser diode specifically chosen cutting could be possible feature that could be added. A single laser diode may not be able to cut wood that’s very thick but a knife edge array of high power diode could potentially provide an efficient cutter module. This would incur more costs due to the requirement of using multiple diodes at once, which are the most expensive part of the physical laser module itself. Aside from meeting specification requirements safety is a critical part of the laser module. According to standards the best way to create a safe product in this case would be to drop the classification of the laser diode from class IV to class I. The drop in classification must be achieved by designing an optical isolation module for the laser. The laser's originating point and the diffusion spot must be completely covered by material that will not reach to the power output of the laser diode. Furthermore without this material covering the laser function of the system's engraving action should be impossible. Therefore the isolation unit will act as a "switch" which will complete the circuit and allow for the microcontroller to execute commands to engrave. Once a complete system is designed etching should be possible on acrylic, basal, and oak and cutting to some limited thickness.

4.5 Power System

Designing a power supply system is critical to maintain optimal operating values while maintaining high efficiency. If the voltage from the AC mains is used it must be stepped down without drawing to much current. To this end the transformer has to step down the 120 V to at least 36 V and at most 24 V. Any lower and the current required would be much higher, to that end the system warrant and increased cost in voltage regulators because they must be designed to handle current that high as well as wires that can handle that current. Higher current generally implies a higher safety risk to human operators and would warrant more protective countermeasures to ensure safe handling. With the appropriate turn ratio determined the signal will have to be rectified and using Texas Instrument's WEBENCH power architect tool the parts to create the network that will regulate the loads will be designed

4.6 Motor

4.6.1 Introduction

The project is a medium scaled laser etching system, with the size of a typical multipurpose home printer. The positioning system relies on the movement configuration which is comprised of the motors and motor controllers. The functional requirements state that the laser etching system should be able to cut or burn with a high degree of accuracy and precision. It should be able to maintain this level of precision while working as efficient as possible. There are a variety of motors that can be used for this project to achieve the specified goal.

The motor needs to be light weight yet powerful enough to provide a consistent rate of power for detailed etching. There are a variety of motors that can be chosen from.

4.6.2 Types of Motors

The primary power source this project is alternating current from the utility mains. Based on this constraint, gas or other supplements of power for a motor are disregarded. This is the reason an electric motor was chosen to power the XY system. The electric motor will convert electric energy into kinetic energy. This is achieved using the magnetic field generated from the current going through a coil to move the metal object. By reversing the process and converting kinetic energy to electric energy an electric generator is formed. Certain applications use specialized electric motors to operate in motoring mode, generating mode, and braking mode. Each of these modes have a different interaction between the transfer of electric energy to kinetic energy and the transfer of kinetic energy back to electric energy. There are two different types of electric motors that are either power by direct current (DC) or alternating current (AC). DC motors can be powered from batteries, rectifiers, or other similar systems. AC motors can be powered from the power grid, inverters, and generators. Electric motors can be classified further into subcategories based on electric power source type, internal hardware configuration, application, type of motion output, and specialty base types. To choose the best motor to best fit the need of the project, the different types of motors need to be analyzed for a better understanding.

4.6.2.1 DC Motors

Direct current (DC) motors were the first type of electric motor to be invented. As the name suggest, DC motors use direct current to generate mechanical energy and power. The electric current is sent through a coil to create a magnetic field to produce rotary motion. DC motors have a voltage induced rotating armature winding and a stationary armature field frame winding that acts as a permanent magnet. However, DC power systems are not very common outside the field of engineering. Due to this the power source might be any DC source from batteries to an AC to DC converter. The AC to DC converter can accomplish this with a linear regulator to keep the DC voltage constant. Using AC to DC converter, the voltage is able to be shifted from low to high or high to low. In a DC motor, the supply voltage V and current I is fed into the input ports and the mechanical output are torque T and rotational speed ω. The DC motor can then be used in many applications from miniature helicopters to parts of an automobiles. DC motors can be categorized into two subcategories of brushed and brushless DC motors.

Brushed DC Motor

The operation of any Brush DC Motor is based on electromagnetism. The first DC motors used brushes to transfer current to the other side of the motor. The brush is named so because it first resembled a broom-like shape. The little metal fibers rubbed against a rotating part of the motor to keep constant contact. A brush DC Motor consists of two pieces: the stator which includes the housing, permanent magnets, and brushes, and the rotor piece consisting of an output shaft, windings, and commutators. The brush DC Motor stator is stationary, while the rotor rotates with respect to the brush DC Motor stator. Brushed DC motor does not required a controller to switch current in the motor windings, but instead the commutation of the windings from the brushed DC motor is done mechanically. When voltage is applied to the brushed DC rotor winding, the polarity of winding and stator magnet is misaligned, the brush DC motor rotated until it is almost align with stator magnet. When the alignment is happening, the brushed come in contact with the commutator. A reversed current resulted causing the winding and brush DC motor stator magnet to misalign again. Repeating the process is what keeps brush DC motor rotating.

The brush DC motor generates torque from Lorentz force directly from DC power supplied to the motor using internal communication, stationary magnets (which can be either electromagnets or permanent magnet), and rotating electrical magnet. Brush DC motor has a few advantages such as it has a low initial cost, high reliability, simple speed control using level of voltage to control, and high starting torque (a powerful start) as mention above. Limitation of brush DC motors are the limiting rotation speed due to friction and sparks create from brushes. This can overheat the device and wear the brush out. On a side note, the spark can also cause radio frequency interference. If brush DC motor was used at high intensity, the maintaining cost to replace brushes and worn-out parts would be higher, thus decrease life-span. Brush DC motor is less reliable in control at the lowest speed. While physically larger than other type of motor, brush DC motor produce equivalent torque. Brush DC motor is vulnerable to dust, which can decrease performance.

Brushless DC Motor

This type of motor is also known as electronically commutated motors (ECM). Brushless DC motors are similar to AC synchronous motors. The rotor part of a brushless motor is often a permanent magnet synchronous motor. Problems that were encountered in brushed DC motors are solved in brushless DC motor. The brush is replaced by an external electric switch which is synchronized to the position of the motor (it will reverse polarity as needed to keep the motor shaft spinning in one direction). Brushless DC motor has two primary parts; which are the rotor and stator. Other important components of the motor are the stator winding and rotor magnet. There are two types of brushless DC motors, with unique advantages and drawbacks. Below is figure of two basic brushless DC motor designs: inner rotor and outer rotor.

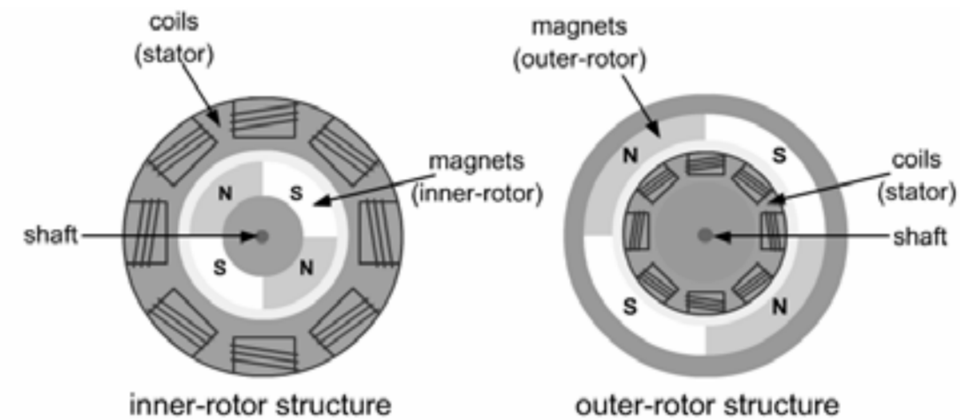


Figure 4.6.2.1-1 Design of Brushless DC Motors

In the outer rotor design, the coil arranged inside and the magnet that is to be rotated is arranged on the outside. The stator magnets surround the rotor winding and act as an insulator, reducing the rate of heat dissipation from the motor. The advantage of an outer rotor brushless DC motor is minimizing cogging torque, offer high rotor inertia thus slower acceleration which can positively affect system performance. Some examples are computer disk drives and cooling fans. Outer rotor designs are axially shorter than inner rotor designs for the same performance level.

For the inner rotor design, the stator windings surround the magnet rotors. The winding are affixed to the motor’s casing. Inner rotor structure has features that are also advantageous such as high heat dissipation efficiency compared to the outer rotor structure. The inner rotors have a small moment of inertia of the rotating shaft. However creating a large number of coils inside the stator is much more difficult than winding coils outside rotors. Due to this, inner rotor type motors are usually used for application that require a compact and high output motor with superior dynamic traits. The following table summarizes the comparison between brushed DC and brushless DC motor.

Feature	Brushed	Brushless
Commutation	Mechanical	Electronical
Maintenance	High	Low
Electrical Noise	High	Low
Lifespan	High	Low
Speed/Torque	Moderately Flat	Flat
Efficiency	Medium	High
Size	Large (due to commutator and difficulty removing heat	Varies and smaller
Speed range	Limits speed due to commutator	Rotate at high speed
Audible noise	Louder at high speed due to brushes	Low
Drive complexity	Simple and low cost	Complex and expensive
Control Requirements	Optional	Always need

Table 4.6.2.1-2

DC motors can be divided into further classes based on the electrical component of the armature winding and field winding, i.e. magnetic sources. There are separately excited, self-excited, and permanent magnets subcategories. In a separately excited DC motor, the field winding is independent of the armature winding. As the name suggested, the separate-field motor has its field and armature winding connected to a separate power supply. Controlling speed in a wide range is possible by separately controlling the current for both windings

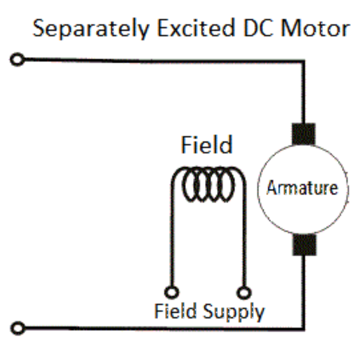


Figure 4.6.2.1-3 Typical Circuit of Separately Excited DC motor

Permanent-magnet DC motors have the performance advantages over direct-current, excited, synchronous types, and have become predominant in fractional horsepower applications. With smaller and lighter size, permanent magnet motor types have be proven to be more efficient and reliable than other electric motors. Permanent magnet DC motor make up of an armature winding like the usual motor but does not contain the field winding. The permanent magnets are fixed on the stator to produce the magnetic flux field. Advantages of permanent magnet are that it does not need to control the field of excitement. Thus another advantage is that no input power was consumed for excitation, proving the efficiency of this type of DC motor. Only the permanent magnet fixed to stator, the field coil, was not needed, so the size of motor was reduced. Less power consumed to creating excitation lead to cheaper and economical for partial kW applications.

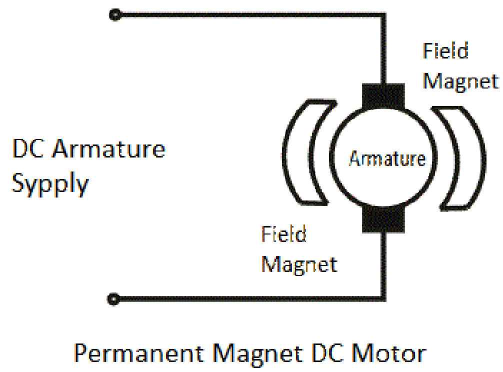


Figure 4.6.2.1-4 Typical Circuit of a Permanent Magnet DC motor

Within the self-excited subcategory, the DC motor distinguishes itself in the way it connects to the circuit. There are three types of connections: Shunt excited, series excited, and compound excited. Each of the connection types have special speed/torque characteristic appropriate for different loading torque profiles.

A shunt DC motor connects the armature and field windings in parallel or shunt with a common DC power supply. Shunt DC motors have good speed controlling even as the weight load varies, although it does not have the starting torque of a series DC motors. Typically, shunt DC motors are used for industrial, adjustable speed application, machine tool, positioning system, winding and unwinding machines and tensioners. Below is circuit of shunt DC motor.

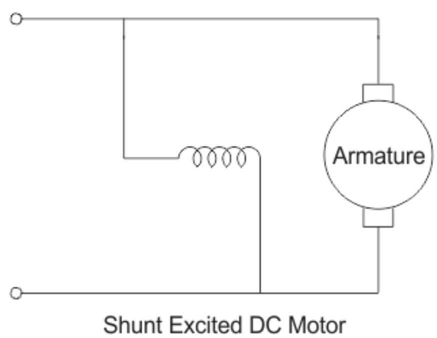


Figure 4.6.2.1-5 Typical Shunt Connection.

A series DC motor connects the armature and field winding series with common DC power supply. Series DC motor has very high starting torque and used for starting high inertia loads, like trains and elevators. Series motors are usually damaged by over speeding, because no mechanical load lead to low current and therefore the armature must turn faster to produce sufficient counter EMF to balance the supply voltage. Series DC motor can also use an alternating current, this has another name called "universal motor". The armature voltage and the field direction reverse at the same time and the torque continues to be produced in the same direction. Universal motors are lighter than induction motor while outputting the same rate of mechanical works. Series motor is useful for handheld power tools whether it is operated by a DC power source such as a battery or an AC source from power grid. Below is the circuit of series DC motor.

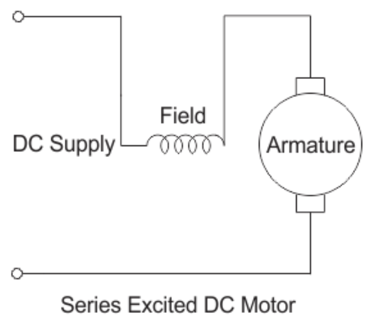


Figure 4.6.2.1-6 Typical Series Connection

A compound DC motor connects the armature and field windings in a shunt and a series combination to give it characteristics of both a shunt and a series DC motor. This type is fairly useful when both high starting torque and capability to control speed is needed. The compound DC motor can be connected in two ways: either cumulatively or differentially. Cumulative compound motors connect the series field to aid the shunt field, which provides higher starting torque but the tradeoff is less speed regulation. Differential compound DC motors have good speed regulation and are typically operated at constant speed.

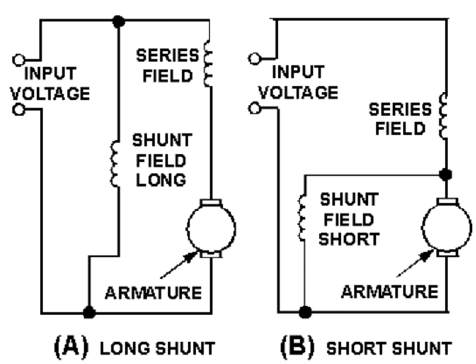


Figure 4.6.2.1-7 Typical (A) Long Shunt and (B) Short Shunt Connections

In the previous discussion, we explored through the main categories of DC motors, in which help us recognized few advantages of DC motors over AC motors. The first advantage is speed control over a wide range above and below the rated speed. This can be achieved in DC shunt motors by methods such as armature control method and field control method. This is one of the main applications in which DC motors are widely used in fine speed applications. Another advantage is a high starting torque of DC series motors are termed as best suited drives for electrical traction applications used for driving heavy loads in starting conditions. DC series motors will have a staring torque extremely high compared to normal operating torque. The next advantage is a quick starting, stopping, reversing and acceleration. The last advantage is a constant torque drives over a range of given speed.

Before considering using DC motors for our project, we need to take a look into the disadvantages of DC motors. Any disadvantage that put our project in jeopardy is clearly a reason to not use DC motor. One disadvantage is a high initial cost. Another disadvantage is a high maintenance cost of commutator and brush gear. The last disadvantage is that the brush DC motor creates sparks, and is therefore not safe to operate near explosive and hazard conditions.

4.6.2.2 AC Motors

An AC motor is an electric motor driven by an alternating current (AC). An common AC motor consists of two basic parts, an outside stator having coils supplied with alternating current to produce a rotating magnetic field and an inside rotor attached to the output shaft that is given a torque by the rotating field. AC motors are roughly classified into synchronous and induction motors. Both type of motor have the rotating speed determined by the rotating magnetic field. In AC motor, rotating magnetic field occurred by applying three phase, two phase or multiple phase alternating current to the stator winding rotates at speed based on the frequency of the multiphase alternating current. AC motor divided into classes based on the method of rotations.

Induction motor replied on difference in speed between stator rotating magnetic field and the rotor shaft speed called slip to induce rotor current, therefore induction can also be called asynchronous motor because the rotor always turn at lower speed than then field. Asynchronous AC motor have the biggest advantage of being simple. Rotor is the only moving part the motor, thus make them quite, longer lifespan and more economically compare DC motors (commutator and brushes). Speed of the induction motor depend on the frequency of alternating current that drives it, the speed remain constant unless there is pulse wide modulation in the motor driver that controlling speed while other motor having an easier task regulating speed. One more drawback that the induction motor can only be drive by alternating current because it need changing magnetic field. Another biggest reason that steer the group away from the induction motor is its weight. Due to it winding coils, the motor is heavy and bulky. Thus the group decided to not use this type of motor for this project.

Synchronous AC motor are constant speed electric motor, the speed of the shaft rotor is synchronized with the frequency of the supply alternating current. Therefore the synchronous motor will either run at synchronous speed or not run at all, changing supply frequency meaning changing speed. The synchronous motor is not self-starting motor, it needs external force apply to bring it closer and synchronized speeds. Synchronous motor can majorly improve system power factor through the ability of synchronous speed and run parallel with induction motors. Although synchronous motor need external force to bring it to synchronized, this motor's speed remain constant irrespective of the load it's driving. Many disadvantage of synchronous motor are zero starting torque because it need external force to start. If and when the load became over capacity, the motor will not slow down, but instead it will come to halt. Synchronous motors are limited to application that required frequent starting and high starting torque, such as positioning system that need in the project.

Advantages of AC motors make it very popular in current technology application. Such as low cost and light weight, high power factor, and reliable operation. Unfortunately, of all type of AC motors that could be viable to the project, each motor type have a disadvantage that could dismiss specifications of the project. Induction AC motor, synchronous motor have disadvantages in speed when performance in positioning system, due to low starting torque and zero starting torque respectively. The complexity of regulating speed in synchronous motor will be a strain in the designing of power system because synchronous motor need DC power source to start and AC power source to operate. AC motors summed up to poor position control and the inability to operate at low speed. Thus it is a terrible motor choice for the laser etching system.

Electric motor differentiate themselves base on power source, winding technique and connection, and lately, based specific requirement. Below is a block diagram that summarized most of the main motor types.

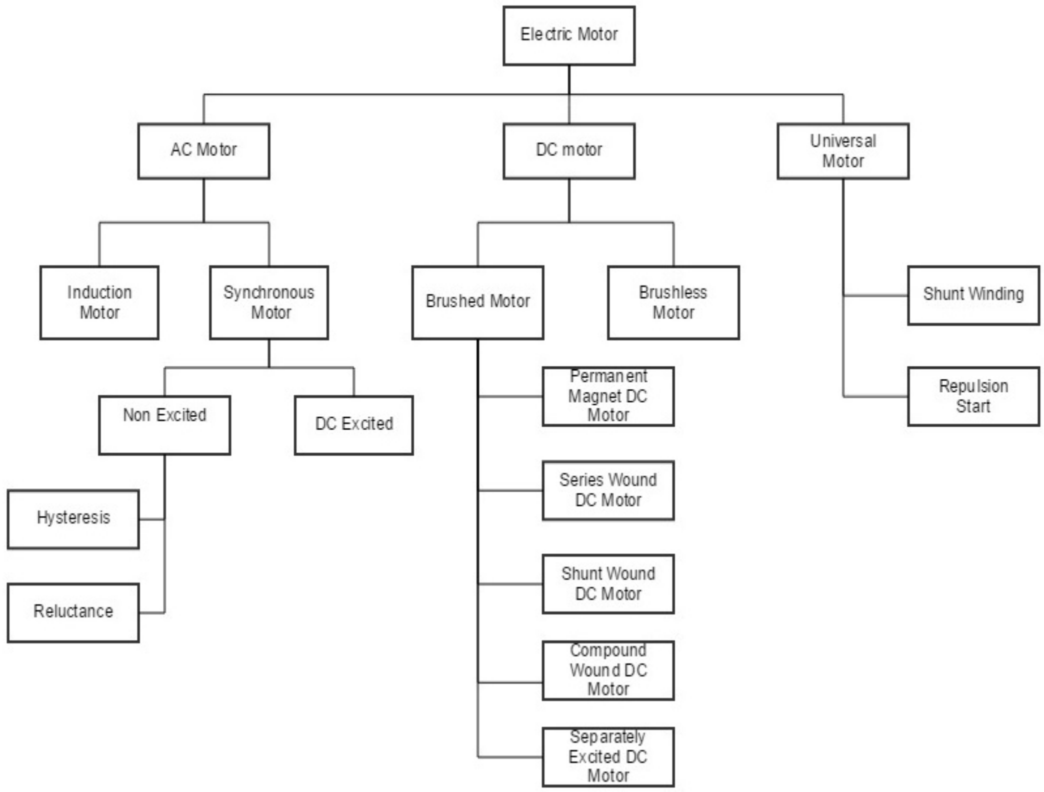


Figure 4.6.2.2-1 Type of Motors

4.6.2.3 Specialized DC Motor

Base on the information above, DC motor rise over AC motor for medium scaled project. This section will be focus on specialized DC motor, small size motor that use for mobile and personal project. To pick the best type of motor for the laser etching system: the group need to have a more insight look of mobile motor, specifically at stepper motor and servo motor. Considering between two types of compact motors can be tedious task because of many important factor such as cost considerations, torque, speed, acceleration, and drive complexity.

Stepper Motor

A stepper motor is a digital version of electric motor or brushless DC electric motor that divides a full rotation into a number of equal steps by converting electrical pulse into specific rotational movement. Each electrical pulse move the rotor shaft a step. Which is a representation of the rotation of the output shaft caused by each step, measured in degrees, typically 1.8° for 200 steps of 360°. These motors are commonly used in measurement and control applications. To operate a stepper motor, a driver is required. The accuracy and precision of the motor will based off the complexity of driver. Stepper motor‘s position does not need feedback sensor because the motor driver can command the rotor to move to any of the divided step, as long as scaling calculation is done precisely. This type of configuration is called open loop. Controlling a stepper motor requires a stepper drive and a controller. The controller unit, usually a microcontroller generate step pulses and direction signal that go into the drivers. The stepper driver interpret these signal and drive the motors. There are three type of stepper motors: permanent magnet, variable reluctant, and hybrid.

The permanent-magnet (PM) stepper motor operates on the reaction between a permanent-magnet rotor and an electromagnetic field. The permanent magnet pole pairs is key to stepping resolution. The resolution of rotor rotation can be improved (smaller step angles) in permanent magnet rotor by either increasing the number of pole pair on the rotor. To increase step resolution, additional phases (stator winding) might be used. An important characteristic of the PM stepper motor is that it can maintain the holding torque indefinitely when the rotor is stopped. When no power is applied to the windings, a small magnetic force is developed between the permanent magnet and the stator. This magnetic force is called a residual, or detent torque.

Variable-reluctance (VR) Stepper Motors is nonmagnetic rotor and made of soft iron. When stator coils is energized, the teeth on the iron rotor will aligned with the stator pole. With torque generated through the phenomenon of magnetic reluctance. The rotor experiences a torque and moves the rotor in line with the energized coils. Continuous clockwise motion is achieved by sequentially energizing and de-energizing windings around the stator. To increase step resolution, add more teeth on geared rotor.

Hybrid stepper motor borrowed characteristic of both permanent magnet and variable reluctant motors. The rotor not only have teeth but also magnetized. Hybrid stepper motors provide excellent performance in areas of torque, speed, and step resolution (step angle range from 0.9^o to 5^o). Typically, step angles for a hybrid stepper motor range from 200 to 400 steps per revolution. Biggest drawback for hybrid is its cost, thus the hybrid motor is mostly used for high end positioning applications.

Characteristics	Permanent Magnet	Variable Reluctance	Hybrid
Cost	Cheapest	Moderate	Most expensive
Design	Moderately complex	Simple	Complex
Step Resolution	30º – 3º	1.8º - smaller	0.9º - smaller
Noise	Quite	Noisy	Quite
Stepping Mode	Full, half, microstepping	Typically full step	Full, half, microstepping

Table 4.6.2.3-1

Step motors are excellent for positioning applications. If sized properly for the application, a step motor will never miss a step. And because they don't need positional feedback, they are very cost effective. Despite advantages, every motors have its drawbacks. The table below carefully listed and compare advantages and disadvantages.

Advantages	Disadvantages
Low cost	Rough performance at low speed unless microstepping
Open loop capability	No feedback to detect missed steps
Excellent holding torque	Consume current regardless of load
Good torque at low speed	Torque decrease with speed
Rugged design	Limited size from small to medium
Precise for positioning control	Low output power for size and weight
No tuning	Noisy
	Need different drivers for accuracies

Table 4.6.2.3-2

Servo Motors

Contrast to stepper motor, servo motors are closed-loop control system. A servomotor is a rotary actuator that has capability to control angular position precisely, as well as speed and acceleration. In closed loop control system, the encoder of some kind helps the motor achieved the desired states of position, speed, acceleration. Servo motor is general type of DC motor, what special about it is the closed loop control system. Depends on what kind of closed loop system, the servo motor may need tuning. Tuning is the process of making a motor respond in a desirable way. Tuning a motor can be a very difficult and tedious process, but is also an advantage is the user will have more control over the behavior of the motor. Servo motor run more smoothly than stepper except when stepper motor running at microsteps. To access the motor more carefully before deciding, let take a closer look at the disadvantage and advantages side by side in the table below.

Advantages	Disadvantages
High torque to inertia ratio	Require tuning of control loop parameters
High intermittent torque	Cannot work open loop - feedback is required
High speeds	More maintenance due to brushes on brushed DC motors
Work well for velocity control	More expensive than stepper motors
Lower rotor inertia and good heat dissipation	Safety circuit required
Available in all sizes	Closed loop control system required (encoder)
Electrical commutation can perform low noise	If overload, motor can sustained damage

Table 4.6.2.3-3

It is no secret that stepper motor and servo have differences in performances because of how they operate. While stepper motor’s torque degrade at higher speed, the servo motor given a much higher torque at high speed. Most basic difference between stepper motor and servo motor is the control configuration. For the purpose of this project, hybrid stepper motor is picked among three types of stepper motor to compare with the brushless servo motor side by side to help with the decision of choosing the right motor for this project.

For fair play purposes, certain parameters are set up for both motors. Both motors have equal rated power. The servo motor is equipped with an encoder as in requirement. The stepper motor is not equipped with an encoder as under normal circumstance. The driver is assumed to provide the same features excluding feedback options because under normal circumstance, stepper motor is open loop control and servo motor is closed loop control.

Characteristics	Servo Motor	Hybrid Stepper
Cost	Higher than stepper	Cheaper while offer same power range
Versatility	Very versatile	More versatile due to simplicity of open loop control
Reliability	Depend on environments	Better since stepper motor is rugged, and no encoder.
Setup Complexity	More complex	Less complex
Low Speed High Torque	given low friction and the correct gear ratio	High torque at low speed (RPM)
High speed High Torque	Maintain torque	Decrease maximum torque
Repeatability	Need to set up correctly and depends on encoder's quality	Good repeatability with no tuning required.
Overload Safety	The motor will malfunction and sustained damage	Stepper likely to be undamaged and stalled
Power to Weight/Size ratio	More efficiency with power to size ratio.	Smaller power to weight/size ratio.
Efficiency	more efficiency with 80% to 90%	Consumed more power to given same output as servo
Flexibility In Motor Resolution	Determine by the attached encoder	Determine by microstep driver (not the motor itself)
Torque to Inertia Ratio	Capable of accelerating loads.	Also capable of accelerating load but might stall and skip step if motor is too weak.
Least Heat production	Less heat produced because current drawing is proportional to the loads	Stepper motor draw more current regardless of load, so excess power became heat
Reserve Power and Torque	A servo motor can supply about 200% of the continuous power for short periods.	Stepper motors do not have reserve power.
Noise	Little noise	Slight humming noise, can reduce with quality driver.
Resonance and Vibration	Servo motors do not vibrate or have resonance issues.	Stepper motors vibrate slightly and have some resonance issues
Motor Simplicity	More complex	Designed to be simpler

Table 4.6.2.3-4

After carefully reviewing advantages that fit best for the project specification, and reconsidering to overlook a few acceptable drawback. The hybrid stepper motor have economical cost for personal uses, capability of moving precisely with micro-stepping. Hybrid stepper motor is the motor that would fit the best for a CNC laser system.

4.7 Motor Controller Unit

Accuracy and precision of stepper motor is only as good as its driver and the motor controller unit. So choosing the right driver for the right application is also very important to the entire project. The motor controller has two main sections, the microcontroller and the stepper motor driver. This section will describe stepper motor controlling unit, which will included

There are many different types of stepper motor driver chip that are commonly used by many projects either industrial or personal. The chips range from multiple H-Bridges to dual full bridges. One of the popular motor driver family is the A498X offer DMOS micro-stepping drivers and dual full-bridge motor drivers, all have overcurrent protection. One of the most popular of A498X family is the chip A4988

A4988:

The A4988 is a complete micro-stepping motor driver with a built-in translator. The chip is designed to operate a bipolar hybrid stepper motor with five stepping modes 1/2/4/8/16. The translator played a big role in A4988's simplicity. Inputting one pulse on STEP input will drive the motor one micro-step. With translator, there are no phase sequence tables, in frequency control lines, or complex interfaces to program. The A4988 is best used with simple microprocessor or when microprocessor is overloaded. One feature is Mixed and Slow Decay modes. In Mixed decay mode, the device is set initially to a fast decay for a proportion of the fixed off-time, then to a slow decay for the remainder of the off-time. Mixed decay current control results in reduced audible motor noise, increased step accuracy, and reduced power dissipation. Improved power dissipation during pulse wide modulating, which reduce heat produced. Other noticeable features of A4988 are internal circuit protection which included: thermal shutdown with under voltage lockout, and crossover current protection.

DRV8811:

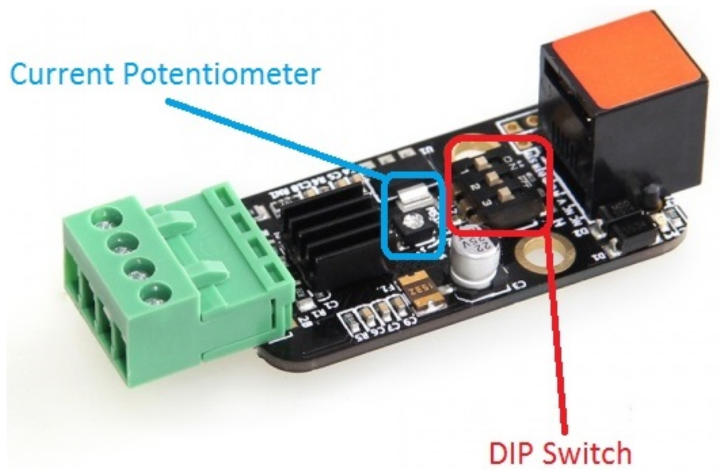
The DRV8811 is a Dual H-Bridges driver with implementation of micro-stepping indexer logic to control stepper motor. Unlike A4988, Mixed decay, MOSFETs configured as full H-bridges to drive the Off-Time features are now programmable. DRV8811 also has better protection features such as, VM under voltage lockout (UVLO), overcurrent protection (OCP), thermal shutdown (TSD) and Fault Condition Indication Pin (nFAULT). The DRV8811 is able to execute high-accuracy micro-stepping without requiring the controller to manage the current regulation loop. Current regulation is done through three modes of decay: fast, slow, mixed decay. A low-power sleep mode is incorporated which allows for minimal power consumption when the system is idle. DRV8811 have the same advantage of A4988 when the microprocessor lack complexity or resource to control the stepper motor. The drawback of DRV8811 driver compare to A4988 is it only have four steps mode: 1/2/4/8.

DRV8825

The DRV8825 provides an integrated motor driver. The device has two H-bridge drivers and a micro-stepping indexer, and is intended to drive a bipolar stepper motor. The DRV8825 is an improved version of DRV8811 with six steps mode: 1/2/4/8/16/32. The DRV8825 can be powered with a supply voltage between 8.2 and 45 V and is capable of providing an output current up to 2.5A, which is a step up from supply voltage between 8 V and 38 V and is capable of providing an output current up to 1.9A.

Makeblock Me Stepper Motor Driver

The kit that will be used is the predesigned Makeblock XY plotter kit without electronic parts. The full version of Makeblock XY plotter included all the electronic parts that contain drivers called Me Stepper Motor Drivers. There was a consideration to find more details on this part. It is a stepper motor driver board with chip A4988 at core. Me Stepper Driver uses to drive four wires bipolar stepper motors precisely. Any applications that need accuracy, this driver come in play. Application such as 2D, 3D printing, computer numerical control, micro-measurement. On the Makeblock driver board, there was an added DIP switch to change step modes, and a potentiometer to change current of the stepper motor. The four wires of 42BYG: green/ black and red/blue will connect to the driver in pairs, the order of pairs can switch as the stepper motor will change directions, but not switching colors.



Figures 4.7-1 Me Stepper Drivers

With the A4988 driver chip at the core, the Makeblock Me Stepper Motor Driver is fairly configurable without complex microprocessor, and able to regulate currents to reduce heat dissipating. Physical on-board DIP switches for simple interfacing of full, half, quarter, eight, and sixteenth step mode. It offers more advance safety circuitry with on board heat sink, helping with heat dissipation and allow driver chip current up to 1.35A. Makeblock Me Stepper Motor Driver was designed to fit for Makeblock parts with 16mm interval M4 mounting holes.

5.0 Related Standards

5.1 Microcontroller

IEEE754 -- Compliant Single Precision Floating Point Unit (FPU)

The IEEE754 standard defines Single Precision Floating Point Unit. It defines how decimal floating point data is represented in binary. This includes signed, not a number values, and infinities. It also handles how rounding is done between arithmetic calculations and conversions. This standard also defines how arithmetic operations are performed with error handling.

USB -- Compliant with USB-IF Certification Standards

The USB Implementers forum regulates and supports USB devices. The regulations vary from signal voltages, response time, and transfer rates. The TM4C123GH6PM in particular is acting as a HUB so it must also follow procedures such as self power, bus power, and remote wakeup.

UART – Utilizes RS-232C Serial Communications

The RS-232C is a standard for serial transmission of data was established in 1969. It is a serial port which the pins were arranged to be the connection lines between computers and mice, printers, or other peripheral devices. Furthermore it set signal regulations regarding signaling rate, timing, voltage levels, and maximum load capacitance. This is still as a frequent connection for UART applications that require RTS, CTS, and RTR but is seen as slow with transmission speeds compared to USB connections which make them more favorable in personal computing.

16C550 UART

Each UART in the TM4C123GH6PM is a 16C550 UART. They are FIFO triggered levels of 1/8, 1/4, 1/2, 3/4, and 7/8. They support up to 5 Mbps transmissions. It can be programmed for 5, 6, 7, or 8 data bit serial interfaced with even, odd, stick, or no parity bit.

IEEE 1149.1-1990 compatible Test Access Port (TAP) Controller

The IEEE 1149.1-1990 standard creates a language to describe the Standard Test Access Port and Boundary-Scan Architecture. It generates syntax for

Boundary-Scan Description Language (BSDL) which is based off of VHDL, VHSIC Hardware Description Language.

5.2 Software

ISO/IEC 9899:2011 (C11)

The ISO/IEC 9889:2011 standard, or more commonly referred to as C11, specifies the form and establishes the interpretation of programs written in the C programming language. It is designed to promote the portability of C programs among a variety of data-processing systems. C11 specifies the representation of C programs. C11 specifies the syntax and constraints of the C language. C11specifies the semantic rules for interpreting C programs. C11 specifies the representation of input data to be processed by C programs. C11 specifies the representation of output data produced by C programs. C11 specifies the restrictions and limits imposed by a conforming implementation of C.

AmbySoft Inc. Coding Standards for Java v17.01d

AmbySoft Inc. Coding Standards are based on sound, proven software engineering principles that lead to code that is easy to understand, to maintain, and to enhance. Existing standards from the industry were used wherever possible. The standards presented are based on real-world experience from numerous object-oriented development projects.

5.3 Laser System

The most relevant standards to the design are found in the ANSI Z 136.1 standard with regards to laser hazard and classification. All domestic and international standards divide lasers into four categories based on the lasers ability cause damage to eye and skin. All of this information is obtained directly from chapter 6 of the OSHA technical manual which is found in the reference section of this document.

Class I: These lasers cannot emit radiation at known or considerable hazard levels and are usually operating in the micro watt range in the visible wavelength spectrum. Little to no hazard control is required for these lasers. It is worth noting that the classifications are not based on beam access during service this class includes high power lasers that would usually be classified higher but are fully enclosed and isolated with protective labeling and a safety mechanism to prevent operation when an individual is within close proximity of an exposed laser.

Class I.A: This class is based on 1000-second exposure time and is used for lasers that are not intended to be viewed. The power limit for this class is 4 mW with a specific duration of 1000 second limit.

Class II: Low-power visible lasers that do not exceed 1 mW. This classification has few control specifications and the human reaction to bright light should suffice for protection.

Class III.A: Intermediate power lasers which range from 1 to 5 mW. Limited controls are recommended and are hazardous when viewing directly.

Class III.B: Moderate power lasers ranging from 5 to 500 mW. Limited controls are still recommended and the laser is still not considered a fire hazard.

Class IV: High power lasers above 500 mW and are considered hazardous to view either directly or to view the diffusion scattered by the laser. These lasers a potential fire hazard and can damage skin. These lasers require significant safety controls.

By these standards it is necessary to properly label the project. The power requirement for this design will put it in class IV and we must integrate a design to optically isolate the laser and prevent function while it is exposed. By taking these precautions the laser classification should ideally drop all the way to class I. Standards regarding the system not directly related to the beam must also be taken into consideration.

Industrial Hygiene: Potential hazards related to gases, cryogenic materials, toxic and carcinogenic materials are considered. The design would require adequate ventilation to reduce exposure to such materials. In this design we are intending to engrave wood but this laser can potentially produce fumes of just about anything it interacts with and therefore this should standard should not go unnoticed.

Electrical Hazards: Installation of the laser will require connections to a power supply circuit; therefore all equipment must be installed with accordance to the National Electrical Code and the Occupational Safety and Health Act.

Flammability of Laser Beam Enclosures: Enclosure of class IV lasers can result in fire hazards depending on the enclosing materials. Caution must be taken that the enclosure is not flammable or that it may produce toxic fumes due to interactions with the laser. Flame-resistant and laser material should be considered when creating an enclosure.

If the system design is be versatile and go beyond etching it must be as safe as possible to the user. Only the most relevant standards were listed and there are many more but given the overall size of the system and the initial design intentions the standards regarding safety take priority. Among other relevant standards those regarding time exposure only apply to low power laser, at this power level it is assumed human reaction is not a proper precaution and any damage caused by the laser is instant if directly exposed.

5.4 Power System

IEEE Standard for Electronics Power Transformers

The standard addresses power transformers and inductors which are used to power electronic equipment from power lines and generators that are similar to sine waves. The standard will address and recommend appropriate electrical tests, appropriate marking, and appropriate grounding.

Transformer Electrical Tests

The following properties to be tested are recommendations for all transformers. The ratio, polarity, making tests, no-load excitations, exciting currents, loss, corona test, induced voltage and electric strength of insulation. Any tests to insulation systems should be done with the windings shorted and all voltages should defined as a common term. Primary windings with rated voltage of 600 volts or less should be tested with sine wave alternating signal that is twice the highest rated voltage tap.

IEEE Recommended Practice for Electronic Power Subsystems: Parameter Definitions, Test Conditions, and Test Methods

The standard addresses recommended practices to properly test units. The purpose is to standardize specific parameters regarding power distribution systems for electronic subsystems. The standard is applicable to a wide range of power and voltage which includes our own system. It goes over several test methods fur units under test and defines parameters of importance. The standard discusses architectural configurations for distributing power to the subsystems. In practice these configurations are combined to meet system requirements and that will be the case for our design. Our system will take up an input that will be processed by several regulators to deliver the proper parameters to our subsystems. The risks for combining subsystem elements are outlined as well as the high frequency switching noise from the switching regulators. Overall system effectiveness which includes cost, live cycle, reliability and maintainability are covered by this document which will prove useful for our design.

6.0 Frame

6.1 Specifications

When we first designed the frame for our project, the base and supporting pillars did not have exact measurements. But more importantly, supporting base need to accommodate to the roof apparatus. That is where most of the hardware located. Constrains are dependable on each other. Such that we want to determine the size, and need to take in material's weight considerations. Focused to minimize the cost of the supporting base, the frame might not be able to hold the roof apparatus. We started to design the project from top down. We figured the roof apparatus need at least 2 stepper motors, each stepper motor will move bidirectional to the X and Y axis. On each X and Y axis, there is a linear motion shafts that will be soldered tightly together. The jointed shaft need to be big enough to install a laser and support it. 4 support pillars on each side joined by the base. We design to implement a method to hold object fixed while the laser is operating to increase stability.

In laser etching, the marking by laser needs to look exactly the same as the digital images, smallest details such as shading, contrast… We discussed two options that are available on how to implement Z direction to increase and decrease focus, concentration, create better shading. First option is to design the XY system to be able to move in the Z directions. Second is to have the base platform moves up and down. Our instructions specifically mentioned to avoid any mechanical designing because it was not relevant to computer and electrical engineering. The two options were both involved mechanical designing. We discussed both option extensively. In the first option, having the laser moving in Z direction while attached to XY system, this option will require a third stepper motor to lower and raise the laser at will. Backtrack on how will the XY system will be moving. We will use 1 motor to move the Y axis, the Y axis will be fixed on to a square frame and have its two shafts oriented horizontally so we can attached gears to rotate two timing belts, and the gears will be driven vertically by the a stepper motor. The movement of the X axis is base off the movement of Y axis. Entire X axis assembly will be place on top of Y axis thus the entire X axis will move in Y direction. This adds issue of stability, the stuttering of mechanical moving parts, but we can handle such issues with trial and error when we start building in the future. To move the X axis, the mechanical behind of moving X axis is similar to the Y axis assembly. For Z direction, we decided to use servo motor instead of stepper. Details on motors can be found on section 4 of this project. The Z servo motor will be install on a carriage that is installed on X axis that moving one end to another ends.

On the second option for implement Z axis, is to implement it in base platform. With our scope, designing base with capability to rise and lower is simply too hard because of our inexperience. Later in our designing process, we were concerns about our timeline; we might not be able to implement the XYZ system before submission. So we explore another routine, in the laser system. We can use microcontroller and laser driver to controller the intensity just as closing the laser to etching surface of object. This will eliminated the problem of different weight in objects and adjust mechanical powers. And instead of having the need to move either the base or roof in Z directions, the laser can be configured to increased and decreased intensity at will, thus one less designing problems.

Our entire positioning system must be stable, highly accurate, it must positions itself efficiently without stuttering, smoothness is the key. Designing the CNC system from scratch will consume much more time and effort based on mechanical prototyping and testing. Beside the budget, time is also one of our biggest constraining. With our past experiences combined, we doubt we will be able to construct prototypes, test the precision or smoothness and then install laser to complete the design within 3 months.

The roof frame that will be used in the project is one that is predesigned by the manufacturer Make Block. The particular product that would be chosen is called “XY-Plotter Robot Kit v2.0 (no electronic)” which includes the entire frame of roof apparatus and stepper motors. We would still need to manually configure the motors, electoral setup, and the control system in order to fulfill the project specifications. The composition of the frame is anodized aluminum which makes it light weight and durable. The physical dimensions are 620mm x 620m x 140mm with an actual working area of 310mm x 390mm.

6.2 Makeblock XY Plotter

The XY plotter is a system that operates in a two dimensional field that has the ability to trace motions and vectors that are both linear and nonlinear. Traditional methods found in inkjets and laser printers use a matrix of dots to form images. This is fundamentally different than the way the XY plotter moves. Makeblock XY-Plotter 2.0 is an updated variant of the XY-plotter V 1.0. The main difference between v1 and v2 are the stronger beams (24x24mm) which helps keep the system more stable while it is in operation. Another reason this product was taken into consideration of how versatile it can be by serving as a table in 3D printing and drilling applications to name a couple. The motions have been praised that it was able to be easily converted to a 3D printer and driller to name a couple of examples. The movement of the XY plotter is stable and precise with the improved dual-way transmission mechanism. This again reiterates that the redesigned structure is great solution to incorporate in the project. The last thing that would need to be done to the frame would be some modifications such as installing lasers system a reinforced base.

6.2.1 Features

There were many key highlights of the new XY Plotter V2 that were improved on from the previous edition. Makeblock increased the stability of the dual way transmission mechanism utilizing two shafts on each axis. The XY initially only supported the ability to draw items but since then the drawing apparatus has been modified to support multiple platforms including laser etching variant and a 3D printer. In this project the goal is to implement a custom laser and power system that allows more diversity than what is sold by Makeblock. The other addition the XY Plotter V2 has is the ability to raise and lower an apparatus. In section 2.3.1 the idea of raising and lowering the laser was discussed to help vary the laser etching intensity. This would of help reduce the necessity of power control. Other updates on the physical make of the plotter include stronger aluminum parts with anodizing surface, dual way transmission mechanism, the ability to raise and lower an apparatus attached to the center, non-elastic timing belt for increased accuracy, and smooth linear motion control.

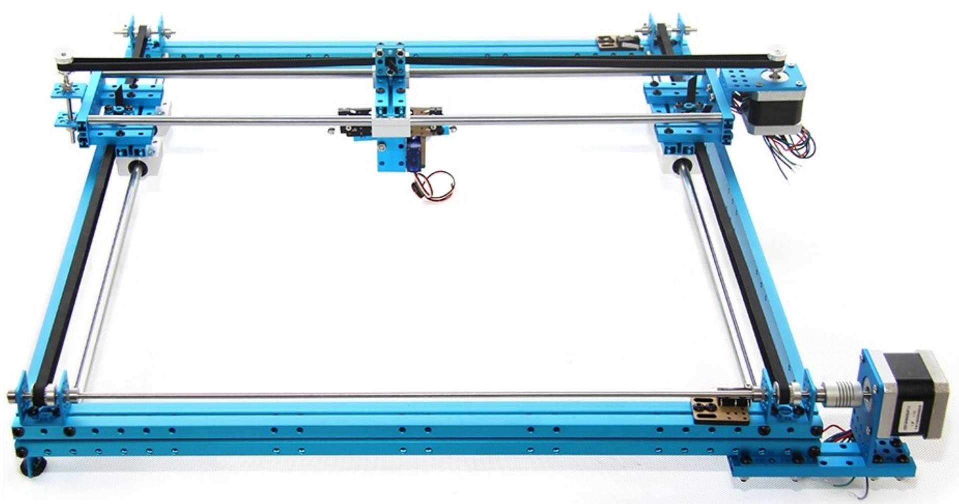


Figure 6.2.1 Finished build model of Makeblock (permission pending)

6.2.2 XY Plotter Specification

One of the major concerns of this project was the mobility of the frame for the laser etching system. The Makeblock XY plotter is made up of anodized aluminum which a light weight material which makes it very easy to transport and move around once the frame construction has been completed. The frame will occupy a 620mm by 620mm area and the projected height should not exceed over 300mm. The accuracy of the plotting device is 0.1mm which the microstep driver can be configured to a 1/128th step per step. Each phase is a 1.8 degree change. It has the advantage of high torque of stepper motor incorporated in the system that when maximized the workout speed is 50mm/s.

6.2.3 Parts List

In table 6.2.3-1 and figure 6.2.3-2 the parts that will be provided by Makeblock can be seen. The construction the frame will be done manually which allows small adjustments to be made to incorporate the laser etching components of the project.

1 × Beam 0824-16	2 × 42BYG Stepper Motor
4 × Beam 0824-48	6 × Timing Pulley18T
1 × Beam 0824-80	3 × Open-end Timing Belt (1.3m)
4 × Beam 0824-96	1 × Threaded Shaft 4x39mm
2 × Beam 0824-112	2 × D Shaft 4x56mm
2 × Beam 0824-496	1 × Linear Motion Shaft D4x80mm
1 × Beam 0808-072	1 × Linear Motion Shaft D4x512mm
2 × Beam2424-504	4 × Linear Motion Shaft D8X496mm
5 × Plate 3x6	10 × Shaft Collar 4mm
3 × Belt Connector	1 × Flexible coupling 4x4mm
6 × Cuttable Linkage 3	6 × Linear Motion Slide Unit 8mm
2 × Bracket 3x3	10 × Flange Bearing 4x8x3mm
5 × Bracket U1	1 × HEX Screwdriver 2.5mm
2 × Stepper Motor Bracket B	1 × Cross Screwdriver 3mm
1 × 9g Micro Servo Pack	2 × HEX Allen Key 1.5mm
1 × Wrench 7mm&5mm	36 × Socket Cap Screw M4x8-Button Head
30 × Socket Cap Screw M4x14-Button Head	28 × Socket Cap Screw M4x16-Button Head
12 × Socket Cap Screw M4x22-Button Head	18 × Socket Cap Screw M4x30-Button Head
10 × Countersunk Screw M3x8	26 × Headless Set Screw M3x5
50 × Nut M4	20 x Plastic Ring 4x7x2mm
30 x Nylon Cable Ties	5 × Rubber Ring
4 × Gasket	4 × Me Micro Switch B

Table 6.2.3-1

Figure 6.2.3-2 Pre-assembled XY plotter

6.3 42BYG Stepper motors

The laser engraving system requires precision to the smallest details, to move the laser precisely. That is why hybrid stepper motors are the best for supporting accuracy of the system. More details on stepper motor are provided in research section number 4. The following stepper motor is bundled with the Makeblock XY package. The default motors for predesigned Makeblock XY plotter are the 42BYG hybrid bipolar stepper motors. The 42BYG stepper motor will provide motion for the laser utilizing timing belts to move it in the operational range. The 42BYG stepper motor fall within NEMA 17 Stepper Motor standards.

The 42BYG stepper motor has 4 wires: black/green and red/blue. There are rules to take into condensation when connecting these wires. If rules are not followed correctly, it could damage the motor. The colors that indicated in the image needs to connect to the same polar terminal. This specific 42BYG stepper motor of Makeblock, it has two phases. Below is the wiring diagram if the two phase stepper motor.

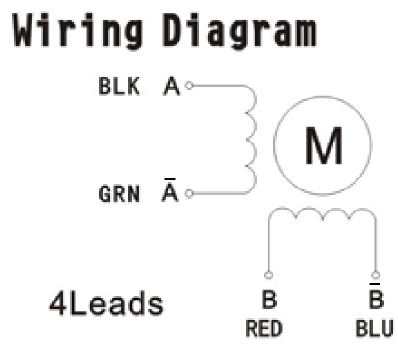


Figure 6.3-1 2 Phases Stepper Motor Wiring Diagram

In table 6.3.1-2 other important electrical aspects are listed which are deemed important when it comes to the schematic design for the power systems as well the timing that needs to be provided by the microcontroller.

Specifications:

Phase: 2 phase
Step Angle: 1.8+-5%°/step
Rate Voltage: 12V
Current: 1.7A/Phase
Resistance: 1.5 +-10%/Phases
Inductance: 2.8+-20%mH/Phase
Holding Torque: 40N.cm Min
Detent Torque: 2.2N.cm Max
Insulation Class: B
Lead Style: AWG26 UL1007
Rotor Torque: 54G.cm2

Table 6.3-2

In figure 6.3-3 shows the size dimensions of the motor. One of the critical components that should be looked at is the radius of the shaft of the motor. This needs to be taken into consideration when trying to calculate the displacement that will occur when the motor starts to rotate.

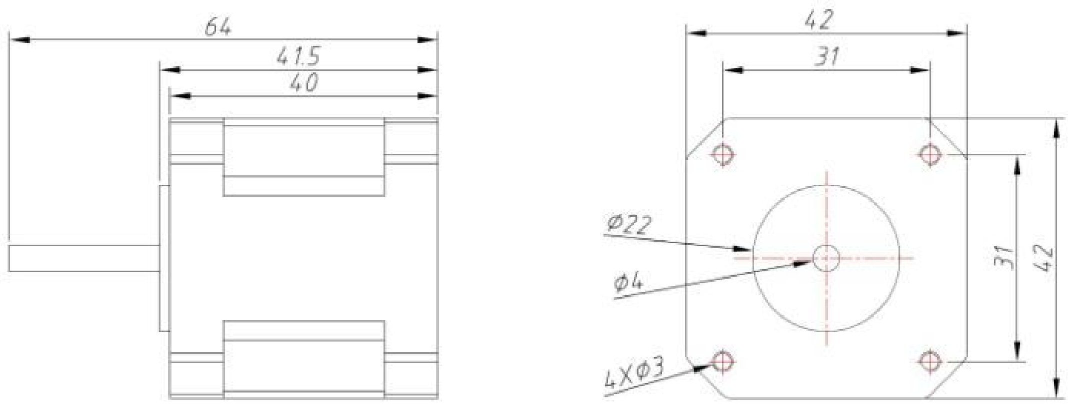


Figure 6.3-3 Physical Measurements of 42BYG Stepper Motor

Makeblock Me 2H Microstep Driver

Makeblock has another type of stepper motor drivers, the Me 2H microstep driver is also a two phase hybrid stepper motors. Designed to be compatible to drive 2 phase hybrid stepper motor of all type ranging 20mm to 42mm outside diameter and less than 2.0A phase current. With adaptation from circuit servo control family, this driver will able to drive motor more smoothly while reducing noise and vibration. It holds more torque then other drivers when the motor runs at high speed. With extra microstep modes, the accuracy of positioning is increased significantly.

Figure 6.3-4 Me 2H Microstep Driver

The following table 6.3-5 illustrates the key features of Me 2H Microstep Driver:

High performance, low price
Average current control, 2-phase sinusoidal output current drive
Supply voltage from 12VDC to 36VDC
Opto-isolated signal I/O
Overvoltage, under voltage, overcurrent, phase short circuit protection
8 channels subdivision(1/2/4/8/16/32/64/128) and automatic idle-current reduction
8 channels output phase current setting
Offline command input terminal
Motor torque is related to speed, but not related to step/revolution
High start speed
High holding torque at high speed
Custom made to easy installing on Makeblock parts

Table 6.3-5

The following table 6.3-6 illustrates the operational requirements that need to be met in order to safely utilize the Me 2H Microsteop Driver:

Input Voltage	12-36 VDC
Input Current	<2A
Output Current	0.44A – 2.83A
Consumption	40W
Temperature	-10℃~ 45℃
Stocking Temperature	-40℃ ~ 70℃
Humidity	Not condensation, no water droplets
Gas	Prohibition of combustible gases and conductive dust
Weight	125g

Table 6.3-6

Just as Me Stepper Driver, the Me 2H Microstep driver also use DIP switch to adjust Microstep accuracy, but DIP switches also use to control current. Microstep resolution is set by SW 5,6,7,8. The following table 6.3-7 will describe the settings:

SW5	ON	OFF	ON	OFF	ON	OFF	ON	OFF
SW6	ON	ON	OFF	OFF	ON	ON	OFF	OFF
SW7	ON	ON	ON	ON	OFF	OFF	OFF	OFF
Pulse/Rev	200	400	800	1600	3200	6400	12800	25600
Microstep	1	2	4	8	16	32	64	128

Table 6.3-7

Current controlling is done in the first three SW bits of DIP switches: SW1, SW2, SW3. Depending what the motor's required current the following table 6.3-8 picking the right setting:

SW1	SW2	SW3	Peak	RMS
ON	ON	ON	0.44 A	0.31 A
OFF	ON	ON	0.64 A	0.44 A
ON	OFF	ON	0.74 A	0.52 A
OFF	OFF	ON	0.86 A	0.61 A
ON	ON	OFF	1.46 A	1.03 A
OFF	ON	OFF	1.69 A	1.20 A
ON	OFF	OFF	2.14 A	1.51 A
OFF	OFF	OFF	2.83 A	2.0 A

Table 6.3-8

SW4 is use to stall current. OFF meaning that the standstill current is set to be half of the selected dynamic current and ON meaning that standstill is set to be the same as the selected dynamic current. When there is no step pulse after 200ms, the driver output current reduced to 40% of rated output current to prevent motor heat. This is called semi-flow function.

There are few rules to connect the Makeblock 2h Microstep driver with stepper motor 42BYGHW609, but the default connecting rules is shown below:

Pins	Wiring & Power Supply
A+	Black wire
A-	Green wire
B+	Red wire
B-	Blue wire
DC+	DC 12-36 DCV, Peak current must be < 2A
DC-	

Table 6.3-9

With 42BYG stepper motor, there are phase A and phase B, so it would not matter if connection order switched. Black/green could connected to A or B, red/blue can also be connected to A or B, and when connection order changed, the direction of motor will change. Another rule is in a phase, for example phase A, green or black wire can connected to either polar. Green can connected to A- or A+, and black will connect the correspondent A (+/-). Same rule apply for red and blue wire. Last important rule is wire blue and red must always connect on same phase; wire green and black must always be connected on same phase. The flowchart below describe a stepper motor controller units and the default wire configuration. The power source supply currents to microcontroller to operate and send signal to control the stepper motor. The power source also supply to the micro-step driver in which turn on and off the stepper motors.

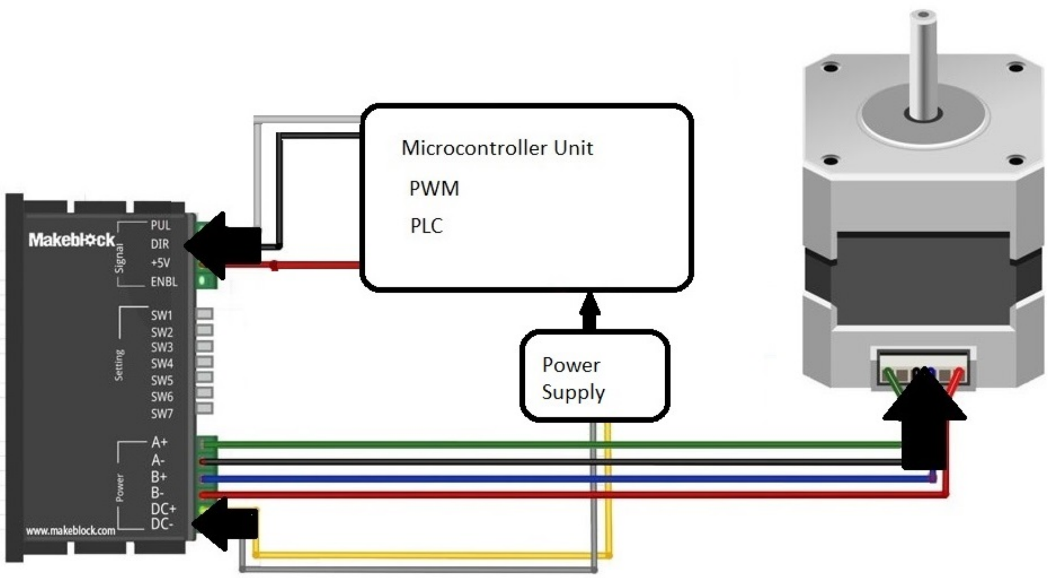


Figure 6.3-10 Interactive Flowchart of Stepper Motor Controller Unit.

7.0 Micro Controller

7.1 Communication

Primary communications to the controller will be done with a USB port when the software on the computer has completed its calculations and mapping. When the input has been received from the computer, the microcontroller will begin processing the data received via USB and run another algorithm which will be used to control the stepper motors. This will be done via a general input/output pin which will be used to into two of the four connections each motor requires. The two connections are the direction in which the motor needs to move followed by a series of pulses to perform the translation across the axes.

JTAG

The primary way of uploading the program for motor control will be done utilizing JTAG (Joint Test Action Group) port. When microcontroller is powered on pin 52 (TCK), pin 51 (TMS), pin 50 (TDI), and pin 49 (TDO) are preconfigured to be set to the JTAG functionality which enables writing to the flash memory without having to pre-configure any registers in memory. The JTAG functionality is also called when the controller is reset which allows easy resets for soft locks as long as the JTAG register is not modified. TCK is used for controlling to help synchronized communication for test data and the components on the chip. TDI is the data shifting into the microcontroller’s memory on the positive TCK edge. TDO is the output from the microcontroller on the negative TCK edge. The TM4C123GH6PM follows the IEE 1149.1 standards as well as offering ARM SWD although this solution will not be locked at.

Universal Asynchronous Receivers/Transmitters (UART)

The Tiva TM4C123GH6PM contains eight UART modules reaching up to 5 Mbps for regular speeds. To enable the UARTs a bit must be toggled in the GPIO Alternate Function Select (GPIOAFEL), the AFSEL bit, in order to toggle from a GPIO to UART. If the UART approach is taken, the pins that would be configured would be pin 17 (PA0) and pin 18 (PA1) to enable U0Rx and U0Tx respectively.

There is a high chance that the UART approach will be taken as most of the team has had experience in the past with working this type of communication. Another reason that this is a preferred method is that some of the team has working code to establish a UART connection between the microcontroller and the computer which enables a previous platform to build new code off of.

Synchronous Serial Interface (SSI)

The Tiva TM4C123GH6PM contains four Synchronous Serial Interfaces utilizing the Micro Direct Memory Access Controller (μDMA). The SSI performs serial to parallel conversion between the data received from the peripheral device and the controller. This protocol allows the data frame to be programmable between 4 to 16 bits. If the SSI functionality is to be used pins 19, 20, 21, and 22 must be configured by changing the value in the GPIOAFSEL register by writing the value '2' into it. This will change the functionality of the GPIO to SSI0 for pins PA2, PA3, PA4, and PA5 which PA2 would be SSI0Clk, PA3 would be SSI0Fss, PA4 would be SSI0Rx, and PA5 would be SI0Tx.

Inter-Integrated Circuit Interface (I2C)

The Tiva TM4C123GH6PM has the capability of enabling up t four I^2C interfaces. Each interface has four modes: master transmit, master receive, slave transmit and slave receive. In addition the I2C can be configured to four transmissions speeds including 100 Kbps (standard), 400 Kbps (fast-mode), 1 Mbps (fast-mode plus), and 3.33 Mbps (high-speed mode). Each transaction on the I^2C bus is done with nine bits long, of the nine bits eight of them are the data and one bit is the acknowledge bit.

Controller Area Network (CAN) Module

The Tiva TM4C123GH6PM contains two CAN modules. CAN modules are serial busses which are specifically designed to be robust in electromagnetically-noisy environments. The busses are capable of reaching rages up to 1 Mbps with distances less than 40 meters which this project will be well under. In order to enable the CAN module first the GPIO must be set. By default when the microcontroller starts pins that contain alternative functions are considered to be general input/output pins if a 0 is detected on the line.

Universal Serial Bus (USB)

The Tiva TM4C123GH6PM has the ability to mount a USB connection. It is compliant with the USB-IF certification standards established by the Implementer's Forum. It has a full speed of 12 Mbps with a low speed of 1.5 Mbps with integration with PHY. The microcontroller transfers four types of data: Control, Interrupt, Bulk, and Isochronous. The following table 7.1-1 below illustrates in more detail how the USB endpoints should be established as well as a small description of each mode.

USB Endpoints Selection	
Bulk	Bulk endpoints should be set to the maximum size of the packet (64 bytes) or twice the maximum packet size f double buffering is used.
Interrupt	Interrupt endpoints should be set to the maximum size of the packet (64 bytes) or twice the maximum packet size f double buffering is used.
Isochronous	Isochronous endpoints are flexible and can be set up to 1023 bytes.
Control	It is possible to set a separate control endpoint for the USB device however the device should use the dedicated control endpoint on endpoint 0.

Table 7.1-1

7.2 Operation Requirements

The following table 7.2-1 should be abided by to ensure no damage is done to the microcontroller.

Parameter	Parameter Name	Min Value	Max Value	Unit
V_{DD}	Supply Voltage	0	4	V
GND	Ground	-	0	V
$I_{GPIOMAX}$	Maximum current per output pin	-	25	mA
T_A	Ambient operating temperature	-40	85	°C

Table 7.2-1

The following table 7.2-2 illustrates the recommended operating conditions of the TM4C123GH6PM.

Parameter	Parameter Name	Min Value	Nominal	Max Value	Unit
V_{DD}	Supply Voltage	3.15	3.3	3.63	V
V_{DDA}	Analog Voltage	2.97	3.3	3.63	V
I_{MAXL}	GPIO current for left side of chip	-	-	30	mA
I_{MAXB}	GPIO current for bottom side of chip	-	-	35	mA
I_{MAXR}	GPIO current for right side of chip	-	-	40	mA
I_{MAXT}	GPIO current for top side of chip	-	-	40	mA

Table 7.2-2

An important noted to be taken from the table above is that each V_{DD} pin has a recommended voltage reading of 3.3 V. Something that isn't shown directly is that for each pin that is labeled VDD on the chip there should be an independent source. The design that will be implemented will be a dedicated voltage source for each pin such that each pin will maintain a clean signal non-shared source. This is done such that if a failure to maintain a voltage drops beyond the operation threshold the entire chip does not power down.

If for some reason VDD falls below the operational range a brown out will occur. This can be triggered if a reset is called or an interrupt is asserted which affects the pulse width of the clock. In figure 7.2-3, the affects of the brownout can be shown on the clock width.

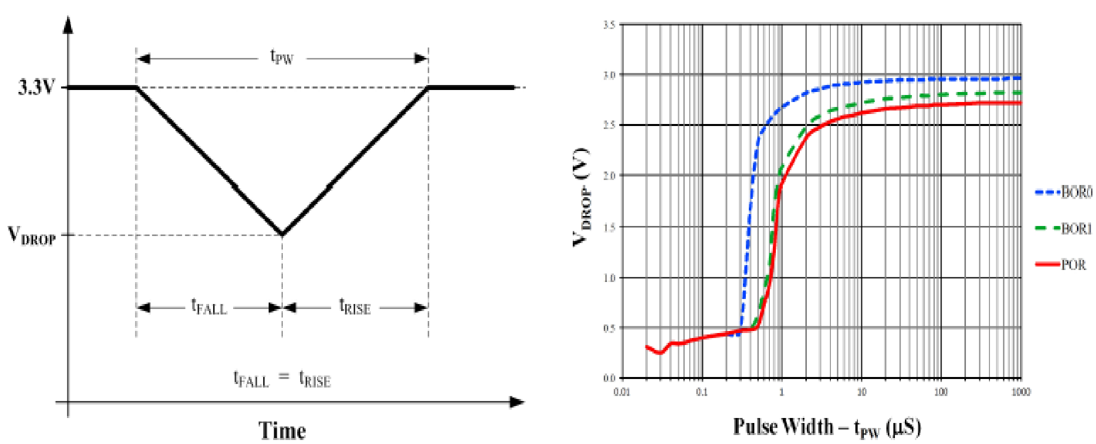


Figure 7.2-3 (Reprinted from Texas Instruments tm4c123gh6pm datasheet)

This action is defined as a VDD glitch, in Figure 7.2-4 the response of the glitch can be seen.

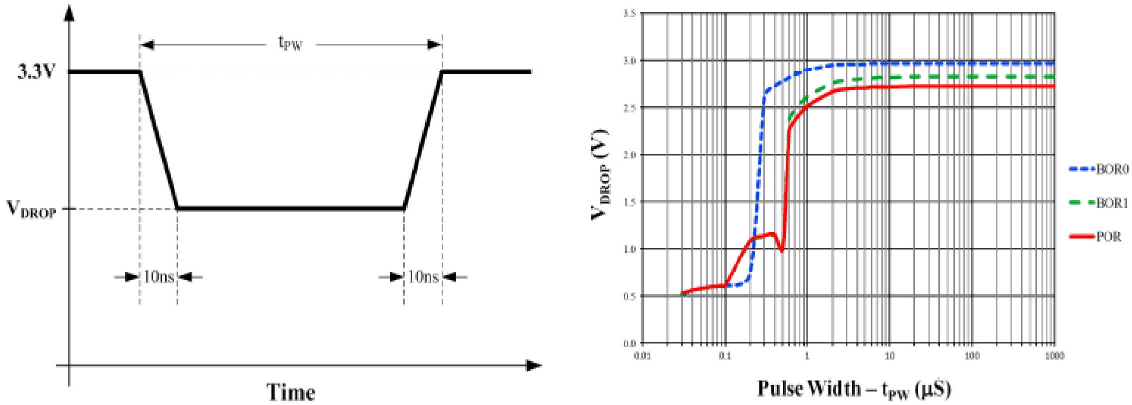


Figure 7.2-4 (Reprinted from Texas Instruments tm4c123gh6pm datasheet)

In both figures 7.2-3 and 7.2-4 POR represents the Power-Ok signal (POK) while BOR0 and BOR1 represent the brown out levels. The BOR0 threshold is set to 3.02 V while BOR1 is set to 2.92 V. POR has a threshold reading of 2.3 V.

8.0 Software

8.1 Programming Language

Two different languages will be used to program for this project, C and Java. Java will be used to design a program for the user to draw an image in. C will be used to take the image and etch it onto a physical material. Java was chosen as the language to be used due to a couple of factors. The first factor is that three out of four group members have done Java programming for two or more years prior to this project. Since the majority of the group members have done sufficient work with Java, it helps during development. The group members will be able to ask each other for help while programming if they need help. This helps since the group members do not have to learn a whole new language to develop what is needed and requires little research to get started. The second factor as to why Java was chosen is because it is cross platform. This will allow us to develop a user interface that a user can execute on any computer. There are three factors that contributed to C being chosen. The first reason is because at least three of the four group members have proficient knowledge in this programming language. It will be easy for the group members to assist each other during development if a group member runs into an obstacle while programming. Since the majority of the group members has proficient knowledge of C programming language, it will require little to no previous research in order to start development for this software. The second reason this language was chosen is because at least two of the four group members have moderate knowledge of programming and running a C language program on a microcontroller prior to this project. This will help when designing the initial software design. The final reason this language was chosen is because we are designing our own microcontroller. This will allow us to import the libraries as needed to be compatible with our microcontroller. We will be able to have similar control over the microcontroller as if we were programming in assembly.

8.2 Programming Environment

After considering many different integrated development environments, Eclipse and Code Composer Studios were chosen for our programming environments. We will be using Eclipse Kepler, version 4.3, to develop our Java program. Eclipse was chosen for the Java program due to its simplicity when it comes to creating user interfaces. With Eclipse we are able to import the Java libraries “swing” and “awt” to create the user interface. To make this process a little simpler, we will be using a third party plugin for Eclipse that will allow us to quickly design the user interface. The plugin we will be using is WindowBuilder Pro for Eclipse 4.3. This plugin will allow us to easily design the user interface and change it as needed. We will be using Code Composer Studios, version 6, to develop our C program. Code Composer Studios is an IDE that's combines the advantages of the Eclipse software framework with enhanced embedded debugging. Code Composer Studios supports a broad range of TI's embedded processors making it easy to interface the program with the microcontroller. This allows the IDE to easily transfer the program from the workspace to the microcontroller. Another feature is that the IDE comes prepackaged with the correct libraries for our microcontroller. The libraries will be made easily available without having to find and download them for another IDE. This will help ensure that the program is loaded and stored correctly

8.3 Program Description

Two programs will be designed for the functionality of the laser etcher. The first program will be programmed using Java with Eclipse as the developing environment. The second program will be programmed using C with Code Composer Studios as the developing environment. The first program will be a graphical user interface (GUI) that will be running on the user's computer. This program will allow the user to draw an image and submit it to be etched by the Computer Controlled Laser Engraving System (CCLES). The second program will be a driver controller that will run on the micro controller of the CCLES. The image below (Fig. 8.3-1) show how each program interacts with each other and the devices being used. The user and the GUI will interact with each other with bidirectional data flow. The user will be using a mouse to give inputs to the program and the program will be displaying the relevant information on the screen. The GUI will be interacting with the driver controller with bidirectional data flow. The GUI will be sending coordinates to the driver controller and the driver controller will be sending error codes back to the GUI. The driver controller will be interacting with the CCLES will unidirectional data flow. The driver controller will be sending out instructions to the various mechanical parts through data signals.

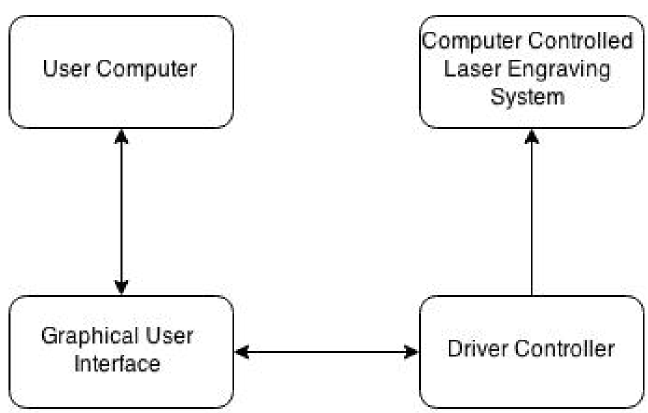


Figure 8.3-1: High Level Software Architecture

8.3.1 Graphical User Interface

The graphical user interface is the program the user will be interacting with. This program will offer a variety of options that the user will be able to select. The program will present the user with a canvas and six buttons. The canvas will start out as white and allow the user to draw an image. The first button will allow the user to select the pen. When this button is clicked, the mode of operation will be switched to pen and allow the user to draw on the canvas. The second button will allow the user to select the eraser. When this button is clicked, the mode of operation will be switched to eraser and allow the user to erase anything they have drawn on the canvas. The third button will allow the user to start with a completely blank canvas. When this button is clicked, the program will delete the old canvas and initiate a new one. The fourth button will allow the user to upload an image from their computer. When this button is clicked, the program will ask for a file path for the image they wish to upload. The program will then replace the canvas with the image they selected. The image will be scaled to fit the canvas if necessary. The fifth button will allow the user to etch the image. When this button is clicked, the program will disable the buttons to switch to pen, switch to eraser, start with a new canvas, upload an image, and etch the image. The program will also disable to ability to interact with the current canvas. In the background, the program will convert the image to a two dimensional array of integers. The program will then start traversing the array to find the coordinates the machine will need to etch the image on the material selected. The selected coordinates will be transferred to the microcontroller when appropriate. The sixth and final button will allow the user to close the program. When this button is clicked, the program will present the user with an option asking if they are sure they want to click. If they select no, they will be able to operate the program as normal. If the user selects yes, the program will close end execution.

There are different event that the user is able to initiate with the graphical user interface. What there user might not see is how exactly the program is responding to the interacting. Below is an event table (Table 8.3.1-1) that describes how each event is initiated. The first two events are activated when the user tries to draw or erase an image that is on the canvas. The last events are activated when the user clicks a button that is available in the menu.

Event Name	External Stimuli	External Response	Internal data and state
Draw	The user clicks and starts moving the cursor over the canvas.	The canvas shows what the user is drawing with the color black.	The canvas is saving data points of where the user is drawing.
Erase	The user clicks and starts moving the cursor over the canvas.	The canvas shows what the user is erasing with the color white.	The canvas is resetting any previously changed points to null or zero.
Pen	The user clicks the Pen Button.	The cursor changes to the pen.	The Boolean variable for pen is set to 1 and eraser to 0.
Eraser	The user clicks the Eraser Button.	The cursor changes to the eraser.	The Boolean variable for pen is set to 0 and eraser to 1.
New Canvas	The user clicks the New Canvas Button.	The canvas goes to all white.	A new canvas is initiated and stored over the old canvas.
Upload	The user clicks the Upload Button.	User will enter a file path and an image will appear on the canvas.	File will be opened, the image will be drawn to the canvas.
Etch	The user clicks the Etch Button.	The user will be asked is they are sure then the buttons will be unusable until etching is done.	Program will deactivate buttons, pass image to the communication object, be converted and etched.
Quit	The user clicks the Quit Button.	The program closes.	Any processes or communication lines are closed.

Table 8.3.1-1: Event Table

In the figure below (Fig 8.3.1-2), the basic logic flow for the graphical user interface is presented. When the program is executed, the first thing it will do is initiate the graphical user interface for the user to interact with. The program will then wait for the user to click a button. At this point the user will be able to start drawing or upload an image from their computer. When an input is detect, the program will run a check to see what event occurred. The program will first check to see if the user clicked a button. If no button was clicked go back to allowing the user to draw. If a button was selected, start a series of checks to determine which button it was. The first check will be to see if a new canvas was selected. If this button was clicked, the program will delete the current canvas object and initialize a new canvas object. If this button was not clicked, the program will check to see if the option to etch the current image was selected. If the button to etch an image was selected, the program will start a series of events that will communicate the proper data to the microcontroller. The first event is to convert the image and start transferring coordinate points to the microcontroller. The program will send a coordinate and wait for a response. The program will interpret this response to see if an error was returned. If an error was returned, the program will handle the error accordingly. After the error was handled or if no error was returned, check to see if there are no more coordinates that need to be sent to the microcontroller. If there are more coordinates start the process over. If there are no more coordinates, send the microcontroller a signal telling it that the image is complete. After this the program will tell the user the image is finished and close. If the button to etch the image was not clicked, the program will check to see if the pen was selected. If the button to select the pen was selected, the program will switch the mode of operate to the pen. After this the program will go back to waiting for user input. If the button was not clicked, the program will check to see if the button to select the eraser was selected. If the button to select the eraser was clicked, the program will switch the mode of operation to the eraser. After this the program will go back to waiting for user input. If the button was not clicked, the program will check to see if the user selected to upload an image from their computer. If the button to upload an image was clicked, the program will go to the file path the user enters and load the image to the canvas. After this the program will go back to waiting for user input. If the button was not clicked, the program will check to see if the user wanted to close the graphical user interface. If the button was clicked, the user interface will terminated. If the button was not clicked, the program will go back to waiting for user input. This event will occur when then the user was clicking inside the user interface that was not a button or they were drawing on the canvas.

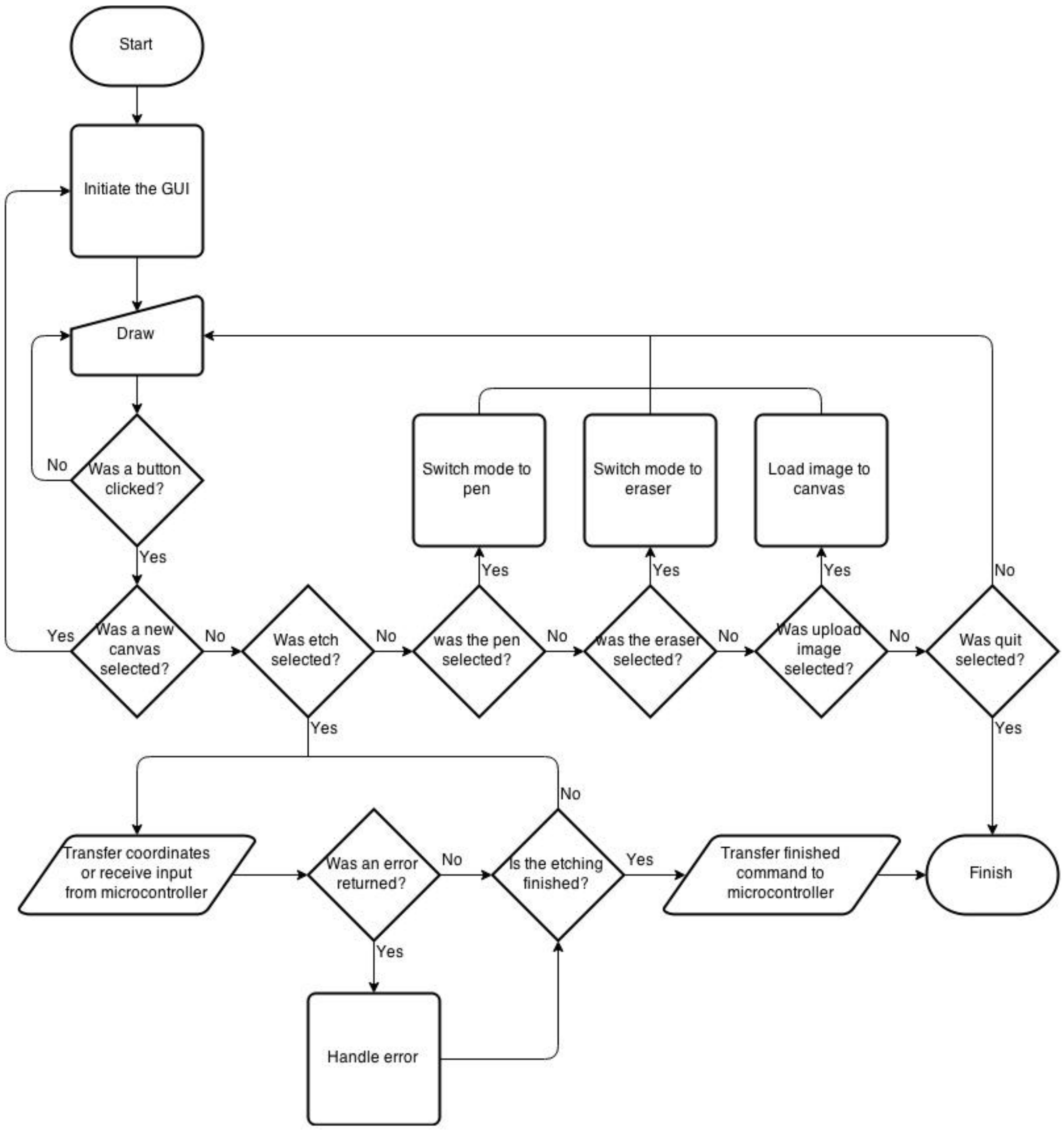


Figure 8.3.1-2: Graphical User Interface Flowchart

In the figure below (Fig 8.3.1-3) is the class diagram for the graphical user interface. There are four classes that will be programmed for the functionality of this program. The first class is GUI and will handle the user interface that the user will see and interact with. The next class is FileHandler which while handle uploading and saving images. The next class is Communication which will handle processing the image and transfer/receiving data from the microcontroller. The last class is ErrorHandler which will handle the codes that the microcontroller returns during operation. The GUI will be able to communicate with the FileHandler class and the Communication class. The FileHandler class will only be able to communicate with the GUI class. The Communication class will be able to communicate with the GUI class and the ErrorHandler class. The ErrorHandler class will only be able to communicate with the Communication class. The GUI class will have a few global variables that will be used to keep track of the user interface that the user will be interacting with. The first global variable is the frame which will contain everything the user can see. The rest of the global variables are buttons that the user will be able to click. These buttons include pen, eraser, new, upload, etch, and quit. The GUI class will contain a variety of methods that will be used during operation. The first method is the constructor for the class. This will be used when the main method instantiates this class as an object. There will be no variables passed into the constructor. The constructor will be used to initialize the user interface by calling the method canvasGUI(). The reason for doing this is so that the user interface object is not static. The canvasGUI() method will handle all of the logical to initialize the user interface. It will create the frame, the canvas, and the buttons. To do this it will use the libraries for “swing” and “awt”. This method will attach listeners to each of the buttons so that the program will know when a button has been clicked. There are five different methods that are event listeners for the mouse. The first listener is the mouseClicked() method. This method will be used to detect when a user clicks one of the buttons. When a click is detected, the method will check to see which button the event is referencing and act based on that button. The next listener is the mousePressed() method. This method will be used to detect when a user is holding down the mouse button on the canvas. This method will either draw or erase the path the user takes over the canvas when the mouse is pressed. The listeners mouseReleased(), mouseEntered(), and mouseExited() will not be used but need to be included due to standard policy. The last method main() will be used to instantiate a new version of the same class as an object. As mentioned before, this is to allow the methods to operate without being static.

The Second class FileHandler will handle any file reading or writing that the user needs to perform. This class will be instantiated from the GUI class as an object. There will be two global variables used in this class. The first global variable will be a string that will store the file path of the file being accessed. The second global variable will be an integer to represent which mode this object is in. The mode will be set to 0 if the operate is going to be read or set to 1 if the operate is going to be write. There are four methods that will programmed for the FileHandler class. The first method is the constructor for the class. The constructor will take in two parameters, the file path as a string and the mode of operation as an integer. The constructor will then call the process() method. The process method will setup the file handling based on the mode of operation. It will take care of any check and errors that may occur in this section. When this is done, this method will either call he upload() or download() methods. The upload() method will load an image from the file path and save it to the canvas. The download() method will save the canvas as an image.

The third class Communication will handle all communication between the main computer and the microcontroller. This class will be instantiated from the GUI class as an object. There will be one global variable used in this class. The global variable will be a JFrame that will store the frame of the user interface. This variable will be used to reference any components that are being displayed on the screen. There are five methods that will be programmed for the Communication class. The first method is the constructor for the class. The constructor will take in one parameter, the frame as a JFrame. The constructor will then call the processImage() method. The processImage() method will take care of organizing the work for this class. This method will first call convertIamge() to convert the image to a two-dimensional array of integers. Once this process is done the processImage() method will run a loop iterating through the two-dimensional array of integers. For each iterate of the loop the method will call trasnferCoord() and receiveCode() respectively. The loop will wait here until a code is returned from the microcontroller. Once a code is received the method will evaluate the code to determine if an error occurred. If an error did occur, the method will instantiate the class ErrorHandler as an object. The code will be passed as an integer to the object when it is created. When the method has finished looping through the entire array it will send a finished code to the microcontroller and the object will self-delete.

The last class ErrorHandler will handle all error responses that may occur during operation. This class will be instantiated from the Communication class as an object. There will be one global variable used in this class. The global variable will be an integer that will store the error code. This variable will be used to determine what error message will be displayed to the screen for the user. There are two methods that will be programmed for the ErroHandler class. The first method is the constructor for the class. The constructor will take in one parameter, the code as an integer. The constructor will then call the displayError() method. The displayError() method will handle all of the logic for this class. The method will first check to see what error occurred. The message that this class displays will depend on the code received. When the display message is terminated, the object for this class will be destroyed.

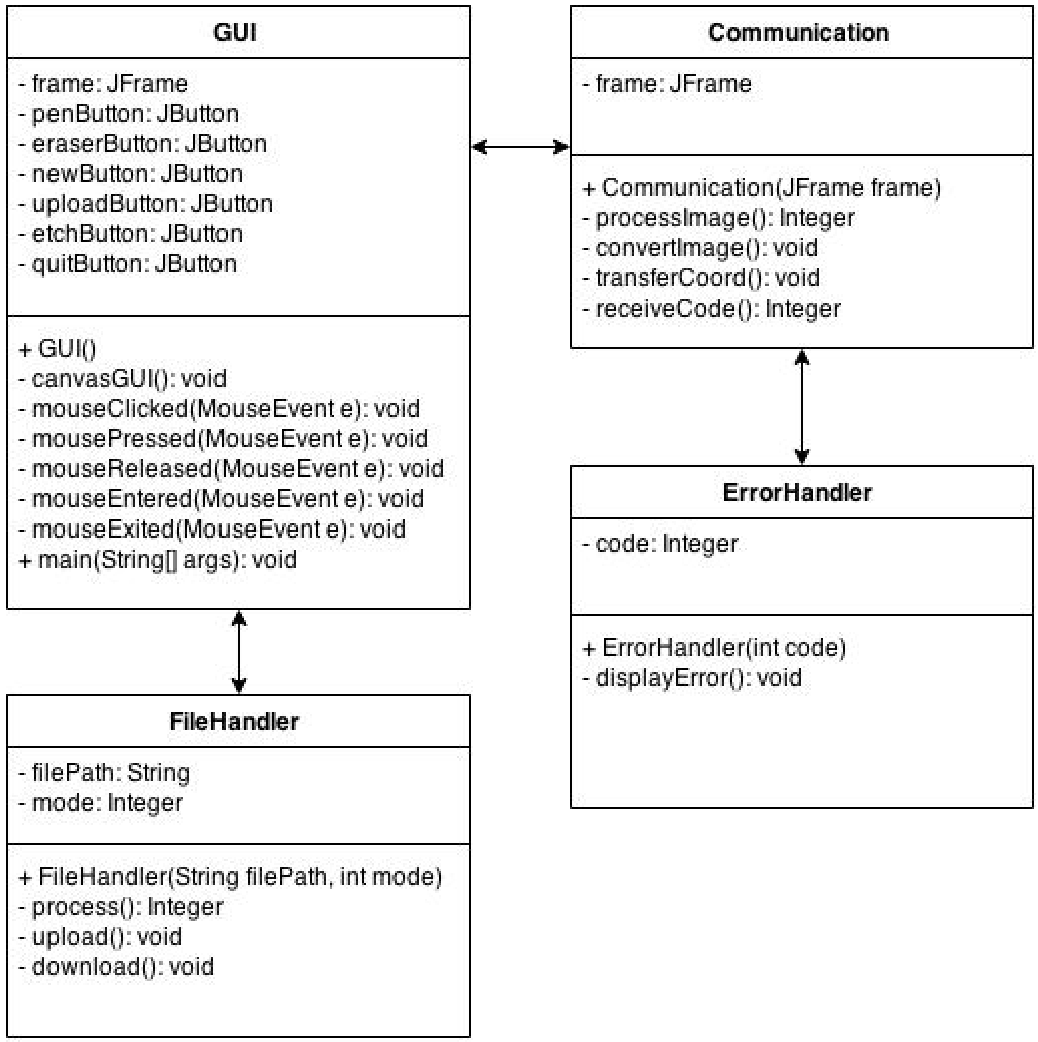


Figure 8.3.1-3: Graphical User Interface Class Diagram

8.3.2 Driver Controller

The driver controller (DRC) is the program that will be running on the microcontroller. This program will be used to controller the stepper motors on the xy plotter, the laser, and the LEDs. When an image has been submitted by the user to etch the DRC program will start receiving data from the graphical user interface. The DRC will receive one set of coordinates at a time and return a code based what occurred during performance. The program will convert the coordinates to instructions for the motor driver and send the signals to the correct components. When the motors move to the correct position, the program will turn the laser on to burn the chosen area. The program will finish execution when data received from the graphical user interface indicate the image is done. When this data is received, the program will return the motors to the initial starting point to be ready for the next time it is used.

In the figure below (Fig 8.3.2-1) the basic logic flow for the DRC is presented. When the program is executed, the first thing it will do is initialize the microcontroller pins and global variables. After this task is completed, the program will wait for the graphical user interface to send data to be interpreted. When data is received, the program will first check to see if the data sent is coordinates to be converted. If the data being sent is not coordinates, the program will check to see if the command to finish has been received. If the data received is the finish command, the program will return the motors to the initial position and reset the global variables for the next use. If the command to finish has not been received, then the data has a trash value and an error occurred. If this happens the program will return an error code to the graphical user interface. If the program had original received coordinates, the program will start a series of events to etch a spot at the specified area. The first step taken is to convert the coordinates to commands for the motor drivers. If the program is successful, the program will move to the next step. If the program is not successful, an error will be returned. The next step in the process is to move the motors to the correct position. If the program is successful, the program will move onto the next step. If the program is not successful, an error will be returned. The last step is to turn the laser on for a brief moment to etch a spot on the material. If the program is successful, the program will return a code saying that the current process was successful and to send the next command. If the program is not successful, an error will be returned.

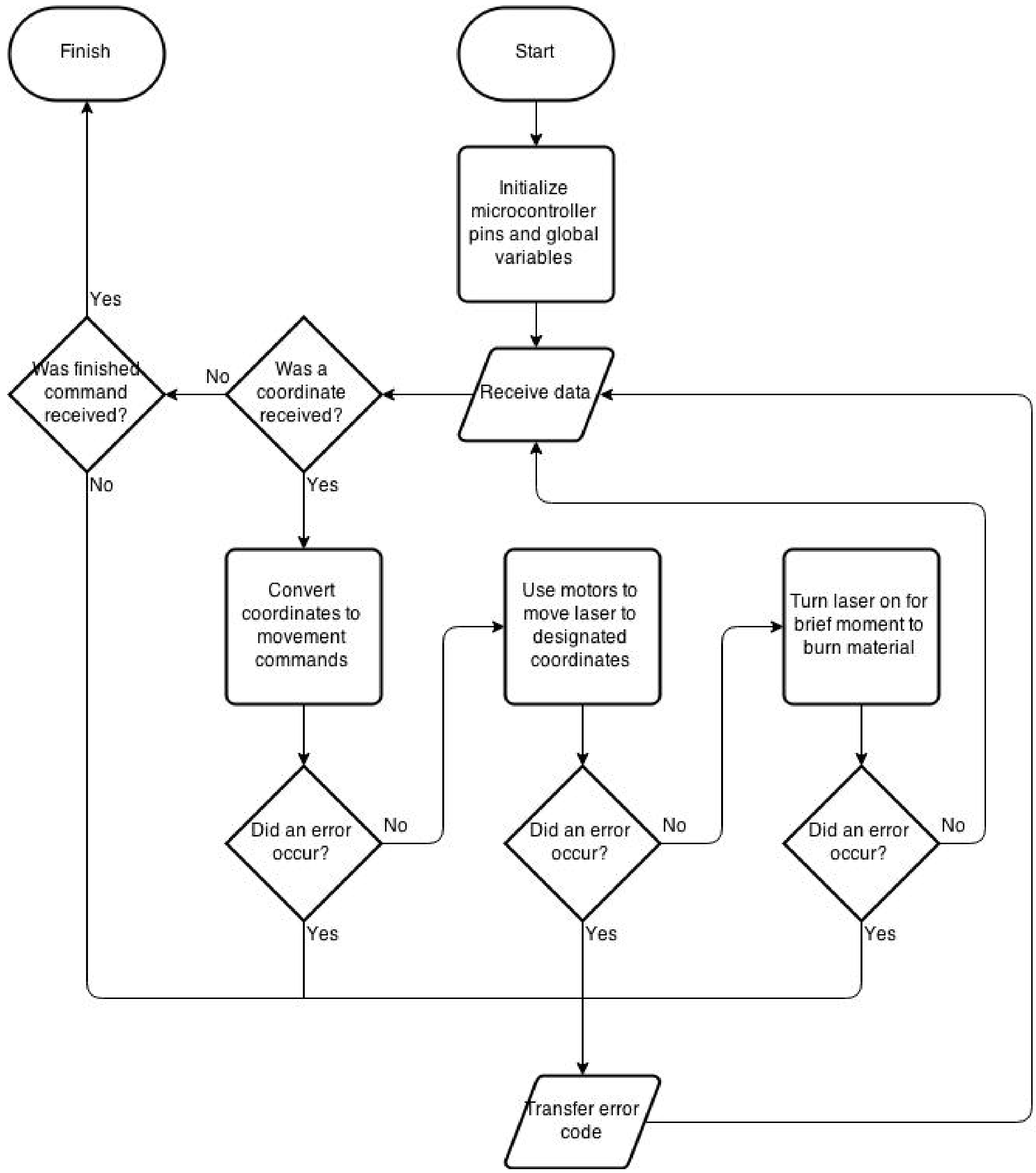


Figure 8.3.2-1: Driver Controller Flowchart

In the figure below (Fig 8.3.2-2) we see the class diagram for the driver controller. The program for the Driver Controller will have one global variable. The global variable coord will be used to store the coordinates that the Graphical User Interface sends through the UART communication. There are nine functions that will be program for the functionality of this program. The first function main() is the function that will be ran when the program first executes. This function will control most of the logic control for the entire program. When the function is first ran it will call the function iniPins(). After iniPins() finishes the program will wait for input from the Graphical User Interface. When data is received, it will check to see if the values are coordinates, the finish command, or something else. If it receives a coordinate, the function convertCoord() will be called. If it receives the finish command, the program will generate the number of steps to return the motor to the original position. If it receives something else, the function errorHandler will be called passing in the generated error code. When coordinates are received and the function convertCoord() has been called, the next step in logic is to call one of the rotate functions based on which direction the motors need to move. Motor 1 will be used for the x axis and motor 2 will be used for the y axis. If a positive x value is read in then the program will call rotateM1Right() with the number of steps that were calculated. If a negative x value is read in then the program will call rotateM1Left() with the number of steps that were calculated. If a positive y value is read in then the program will call rotateM2Right() with the number of steps that were calculated. If a negative y value is read in then the program will call rotateM2Left() with the number of steps that were calculated. After the motors are finished moving, the program will call the controlLaser() function passing in the amount of time to leave the laser on. When the laser control is finished the program will return a zero to the Graphical User Interface to tell it to send the next set of data. Thu function convertCoord() will use the values that were read from the UART communication and determine where the motors need to move. This can be done by subtracting the old x and y position from the new x and y position. This will return the number of steps for the motors. The next four functions to move the motors will use the number of steps to send the correct signals to the motor drivers. The controlLaser() function will send the correct signal to the laser driver to turn it on and off. The errorHandler() function will be used to return an error code that may be encountered during normal operation. The iniPins() function will configure the microcontroller pins to work for what is required.

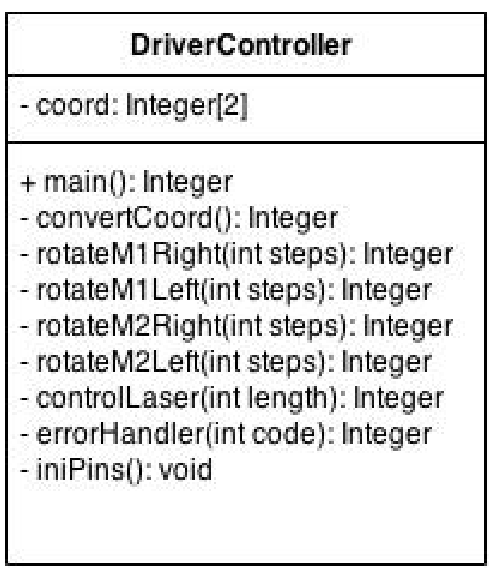


Figure 8.3.2-2: Driver Controller Class Diagram

There are various error codes that this program may be returning to the main computer to be processed by the user interface. These codes are to inform the user when something has gone wrong. These errors will be caused by incorrect logic and can only be fixed by modifying the program. In the table below (Table 8.3.2-3), are the explanations of the possible errors that could be returned and how they will be handled.

Code number:	Code description:	Code handling:
0	No errors occurred.	Function resumes normally.
1	Coordinate conversion failed.	The data being sent to the microcontroller will need to be tested to check if it is being sent and received correctly.
2	Motor control failed.	The algorithm sending the signals to the motor driver will need to be checked to see if functioning correctly.
3	Laser control failed.	The algorithm sending the signals to the laser driver will need to be checked to see if functioning correctly.
4	Data received was not of the correct type or format.	The data being sent to the microcontroller will need to be tested to check if it is being sent and received correctly.

Table 8.3.2-3: Errors returned to Graphical User Interface

8.4 Test Plan

The software development and testing will follow a prototyping software life cycle. This software life cycle model will allow for modification throughout the entire design and testing phases. Using this model will reduce risk and uncertainty during development and testing. In the figure below (Fig 8.4-1) is an example of the prototyping model that will be used for development and testing. The system requirements and design are outlined in this paper for the initial prototype design. Using this prototype design a prototype system can be developed for testing. After testing, if the system does not meet all of the requirements, certain aspects need to be changed, or new features need to be added, then a list of revisions will be made. With the list of revisions, the original prototype design can be revised and changed to accompany for the changes. After the design has been updated, a new prototype system can be designed with the new changes. This design can then be tested again to see if anything needs to be changed. If things still need to be changed, it will repeat the cycle until a complete system has been designed. When there are no more revisions then the system is ready to be delivered and used. When the system is ready to be delivered it will then start being tested with the other components in the project. During this testing only small changes should have to be made to the software.

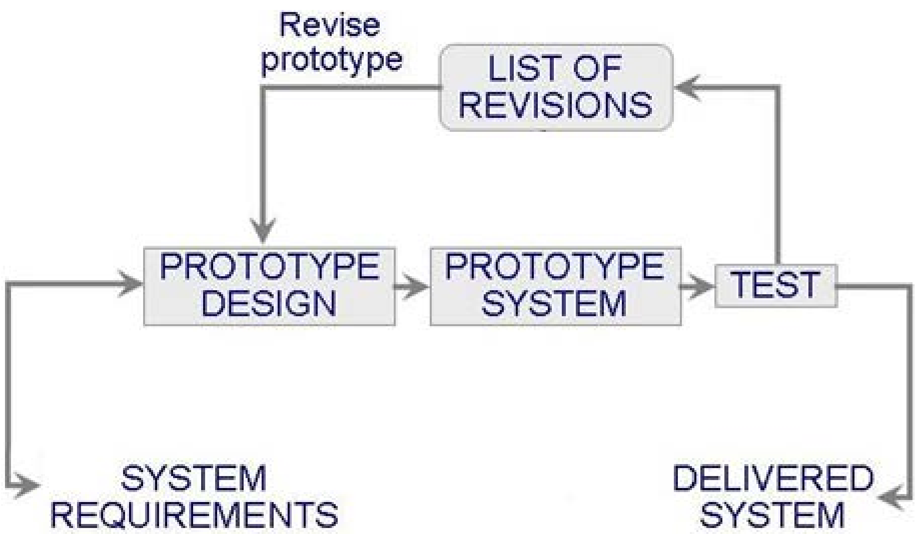


Figure 8.4-1: Development and Testing Software Life Cycle

9.0 Laser System

9.1 Laser Types

The primary laser medium pertaining to the design is the laser diode. It is considered the most common type of laser used to read and write discs, fiber optic communications, and laser pointers. The diode functions similarly to an LED; it is a direct bandgap semiconductor, which uses gallium arsenide rather than traditional silicon, with a wide intrinsic region with a heavily doped p-type semiconductor on one side and n-type semiconductor on the other side. When the diode is forward biased the respective majority carrier from the p-type region and n-type region drift to the intrinsic region where the holes and electrons recombine, this causes the electron to occupy the energy state of the hole in pair and the difference in energy is emitted as light, therefore the only things to consider when choosing a diode is the maximum power output and the optics.

The next potential candidate is a neodymium-doped yttrium aluminum garnet (Nd:YAG) based laser. This laser medium can potentially be designed to be light and small enough to be operated by the XY plotter and would allow for a larger range of materials for the system to operate on. Yttrium aluminum garnet is lightly doped with neodymium, the creating a medium which is then optically pumped by laser diodes, which creates excited states for the neodymium ions to occupy. The neodymium ions then returns to their ground state, acting as a laser amplifying medium and emitting 1064 nm wavelength light in the infrared. With proper optics the output wavelength can be modified, making it more versatile. The power output from an Nd:YAG laser is far higher from a standard laser diode, which allows for wider application short of cutting thick metals while attempting to maintain minimum size and weight. The costs for an Nd:YAG laser are however drastically higher when compared to a laser diode as the main lasing module, and this is without taking into account a cooling subsystem may be required. The Nd:YAG laser is therefore outside of the proposed budget for the project, but it is important enough to note for future modifications to the system even after it is created in order to increase the range of applications.

Carbon dioxide laser are very old but time tested designs, capable of very high power output at low cost. These lasers operate mainly in infrared; they are very high powered and efficient lasers. These lasers are very involved in design and size, and carry a cost of such a design. Generally they are used for cutting and welding and biological applications due to water’s reaction to infrared lasers. When compared to a laser diode and Nd:YAG laser I believe the carbon dioxide laser would be the primary candidate if budget was not limited. There can be compromise in its size and power output which makes it a viable laser medium for the system if the laser diode needs to be replaced. This would allow the XY table to have better capabilities for cutting and engraving more materials. From these candidates a laser diode will be chosen for the primary laser system. The appeal of the laser diode is that it is quite small, so weight is not an issue and it is cost effective. The goal of the project is to simply etch wood and possibly cut other material. These applications are all within the possibilities of a laser diode. The drawback however is that most laser diodes are not necessarily designed to operate in the region of power required for the system's purpose which is roughly between 2 to 3 watts, even the few that are will be pushed a bit beyond the power output for that diode and will result in a reduction of life. To address this issue multiple diodes can be used in an array to produce the necessary power output while optimizing the life expectancy of the diode. For the system's current specification 1 diode should suffice but it is within the budget to create an array should the design call for it.

9.2 Laser Diodes

The diode chosen so far for the system is the 2 watt 445 nm M140 laser diode. The diode can safely operate with an output of 2 watts and if necessary can reach up to 2.5 watts. The M140 has been proven in many projects done by hobbyists to satisfy the current laser specifications. The diodes can be purchased from manufacturers at quantity for roughly $600 which is outside the budget so the main source is out of the question. These diodes are used in M series projectors and will be obtained from a hobbyist selling never before used diodes extracted from digital light processing projectors for $45. The alternative option, and one that may replace the 445 nm diode, is a 405 nm wavelength diode. The 405 diode reportedly has a much smaller and well-rounded dot due to the smaller wavelength, which is critical for the etching quality. If the 445 diode does not meet the specifications after prototyping due to blemishes or low resolution then the 405 will be used in its place. A 405 nm diode will require less current to meet the specifications but it will cost roughly $65. When considering other diodes of varying wavelength their power output does not satisfy design requirements. Those diodes that do satisfy the power requirement are at a high wavelength, namely 808 nm diodes, and would cost more than a carbon dioxide laser system on its own.

9.3 Lens

Laser diodes have high divergence due to diffraction, therefore lens are required to produce a beam. Acrylic lenses are cheap and come with the mount but they are not capable of performing to the design specifications due to the expected power output of the laser diode. The acrylic lenses will begin to melt when exceeding 2 W and will not provide nearly as much power to the focus point since most of the laser will be absorbed. A glass lens will be used to collimate the beam and maximize power output by focusing the light to a fine point. The lens must have high penetration rate for blue lasers for proper function with the chosen laser diode's wavelength. Focal length is a critical aspect to consider and it must be a small as possible for the lens to bend rays such that light is strongly converged to a focus point.

9.4 Heat Dissipation

Laser systems operating at or above the necessary power output specified will inevitably produce large amounts of heat; therefore a critical aspect of effectively using a laser diode is heat dissipation. As the diode increases in temperature the internal resistance decreases, drawing out more current and compounding the effect until it finally blows out. Therefore without proper regulation and heat dissipation the lifetime of the diode is greatly reduced. The methods to help heat dissipation include liquid pumping systems, heat pipes, thermoelectric coolers, and heat sinks. Due to the expected size of the laser module proper heat sinking will be enough to maintain decent operational temperature for the laser diode. The only time to consider other options, namely thermoelectric cooling, is for a more involved laser module such as a neodymium-doped yttrium aluminum garnet laser. The mount which will host the laser diode will be made of copper which has a thermal conductivity of 355 watts per meter-kelvin. Circuit components such as voltage regulators may require additional heat dissipation. A heat sink can be installed in the large drop regulators if the heat dissipated becomes excessive. Furthermore a cooling fan is being considered to maintain ambient temperature low to avoid damage for the components. Any more measures to maintain temperature appear to be unnecessary at this point but will be revised during the project's prototyping stage if temperature becomes too high or parts begin to malfunction. The mount illustrated in figure 9.4.1 will serve as both an immediate heat sink and to hold the diode in place. The driver circuit will be soldered into the pins of the diode and surrounded by an aluminum cover. Aluminum is not as good as copper when it comes to thermal conductivity and the driver circuit will be expected to dissipate large amounts of heat due to voltage regulation.

Figure 9.4.1: Acquired Laser Diode Mount

The mounts must be ordered in bulk of at least 10 and will include acrylic lenses and a press to install the laser diode. If we decide to switch to a different diode the mounts and lens will be available and will provide no inconvenience other than additional costs for the diode itself. Due to the size of the aluminum casing the voltage regulator for the laser diode will be a low dropout voltage DC-DC regulator due to their small part requirements and small area when compared to other regulators. Because it is a low dropout voltage regulator the input voltage should be near the output voltage and the circuit will be able to control the current output while dissipating a minimal amount of heat. In order to maintain the circuit operating the mount will be further encased in a ribbed aluminum heat sink in figure 9.4.2.

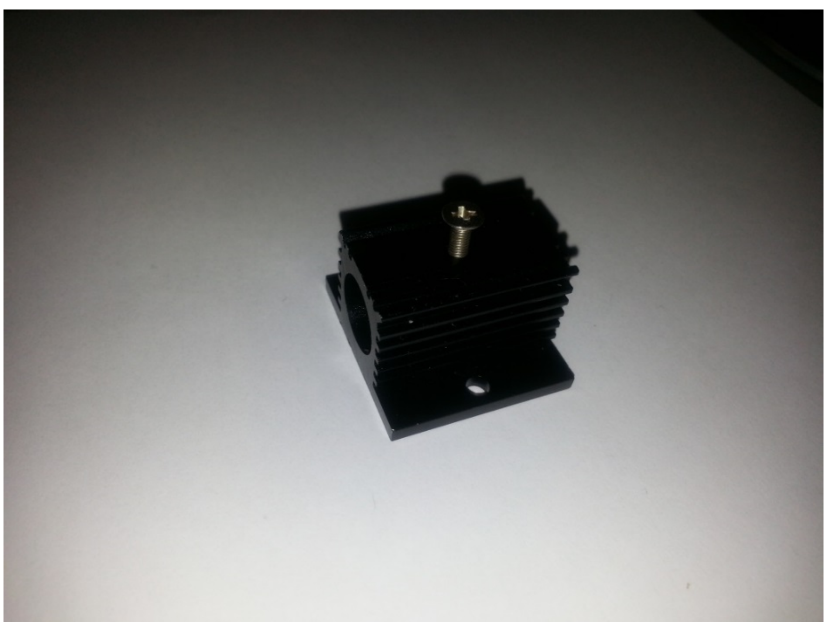


Figure 9.4.2: Acquired Laser Diode Host Heat Sink.

9.5 Safety

A laser capable of more than 500 mW of power output is classified as a class IV laser. The power output expected from the laser system is 2 to 3 watts and would be classified as such, the laser is capable of causing permanent eye damage and the diffusion can cause severe damage to the eyes. The system must therefore be optically isolated to prevent damage to the operator. In order for the laser to even operate the optical isolation module will serve as a switch for the laser to avoid accidental exposure. An LED will indicate the status of the laser when it is on and off to compensate for the visual confirmation that the laser is functioning. Depending on the material subjected to be etched some may produce fumes harmful to individuals. While this may not be the case with wood an air venting system may be required to ensure protection of the operator and to allow for the system to be modified to other materials that may be dangerous when subjected to the laser. The enclosure must be flame resistant and must not be capable producing fumes that are toxic or carcinogenic.

9.6 Design

The current design for the laser module is a 2 W 445 nm M140 laser diode. The diode will be mounted in a copper host with a driver circuit soldered on the pins. The driver circuit will dissipated a small amount of heat and control current output while maintaining constant voltage in order for the diode to function in a safe and versatile manner. The light output will be collimated by a glass lens with an effective focal length of 4.02 mm purchased from a hobbyist supply source. The laser driver details will be discussed with the rest of the power regulation system in section 10 in great detail and its costs will not be included in this design section. If the design does not meet the specifications due to the resolution of the image the 445 nm M140 laser diode will be replaced with a 405 nm laser diode. The module will be enclosed to prevent damage due to diffusion of the laser and the system should be well ventilated to avoid health hazards from fumes. The bill of materials for the physical laser design using a 445 nm laser diode is illustrated in figure 9.6-1.

Item	Cost
2W 445nm M140 Blue Diode	$45.00
AixiZ aluminum mount and heat sink for 12mm modules	$3.50
AixiZ 12 X 30mm laser module blanks 10 pack	$20.00
3 pack 12 x 30mm Copper 5.6mm Laser Diode Mount Blank Module	$17.50
Total	$86.00

Figure 9.6-1: Bill of materials for 445 nm laser diode module.

9.7 Test Plan

The first thing that must be tested is the driver circuit. By using 6 1N4001 diodes and a 1 ohm resistor in series as a test load the parameters of the driver circuit can be measured with a load similar to the laser in order to confirm reasonable values before subjecting the laser diode to the driver circuit. This precaution is due to the cost of the laser diode and is done to protect it from being blown due to an error in prototyping. The diode itself must then be tested by setting it as the driver circuit's load. Once the diode is on the interaction between the driver and the laser output must be observed as the potentiometer changes the output voltage of the load. Once the laser is operational it will be used to burn various materials to measure its capabilities at specific power outputs. Finally the potentiometer must be replaced with a digital potentiometer and the interface with the microcontroller must be tested. If the driver circuit works, the diode functions, the material is etched within satisfaction, and the interactions with the microcontroller produce accurate results, the laser module will be ready to be mounted to the XY plotter and tested during the system's operation, and it must only do so when the laser is optically isolated.

10.0 Power System

10.1 Linear Power Supply

Linear power supplies meet these specifications by using a step-down transformer to reduce the AC amplitude of the signal which is then filtered by capacitors and then rectifies it using 2 to 4 diodes. A linear voltage regulator is then used to further step down the rectified signal. The advantages to linear power supplies are precise outputs and they are very simple to design around. However the drawbacks are cause for concern since the voltage difference from the input and output must be dissipated as heat, which is highly inefficient and the volume taken up by the power supply is relatively large. This means that the design would violate the weight and dimension specification and the ambient temperate would be rather high, which could compromise circuit components.

10.2 Switched Mode Power Supply

Switched-mode power supplies are far more efficient and relatively smaller than linear power supplies. The concept for switched-mode power supplies revolves around switching power storing elements into various configurations which results in better use of the power source. The design takes advantage of various transistors and the design is not as large or heavy as the ones used the linear power supplies, therefore the system generally takes up less volume than the linear power supply. Because the switching occurs at very high frequencies the transformer required for this design will be smaller, light, and less expensive than the linear counterpart. The drawbacks of switched-mode power regulators include electromagnetic interface due to constant and rapid switching the noise cause, the complexity of the design, and a higher cost. The cost is worth the benefits and the noise can be curved with proper electromagnetic interface filtering.

10.3 Power Source

Each subsystem could potentially be powered by a battery system of some degree. However the time required for a complete design to be etched would make it very limited in functionality to rely on batteries. The power supply needs to be precise in delivering the current to avoid damaging the loads, efficient to minimize heat dissipation, and reliable so designs can complete without error and interruptions. With these requirements the alternating current mains will be used to provide an input of 120 V at 60 Hz. In order for this source to power the system we must step down the voltage from 120 V to a safe value. The transformer will include an electromagnetic interface filter to reduce the noise from the switching regulators, which is particularly important due to the microcontroller, as well as surge protection. The main AC source will pass through an EMI filter to protect any other equipment that may be connected to the AC line. The source will then be stepped down with a 5 to 1 transformer which reduces the 120 V peak to 22 V peak. The signals will then pass through a full wave rectifier bridge and pass through the load that is parallel to a smoothing capacitor. The transformers used in this design need to have a high VA rating to allow sufficient current for the system. The primary candidate is the AT175 from Honeywell which has a 75 VA rating. Using this transformer should provide 24 to 27 V which is sufficient for our design. Based on the buck regulators we can settle for lower VA ratings for a cheaper cost. If the design of the voltage regulators allows it we can instead use the AT140 from Honeywell to provide the step down transformation with less current. The AC/DC converter is illustrated in figure 10.3-1 and contains the basic materials to be acquired for the design. The fuse may be replaced by metal oxide varistor in parallel with the EMI filter. If there is a power surge then the resistance of the varistor will change accordingly and protect the circuit without causing anomalies in the input during stable working conditions.

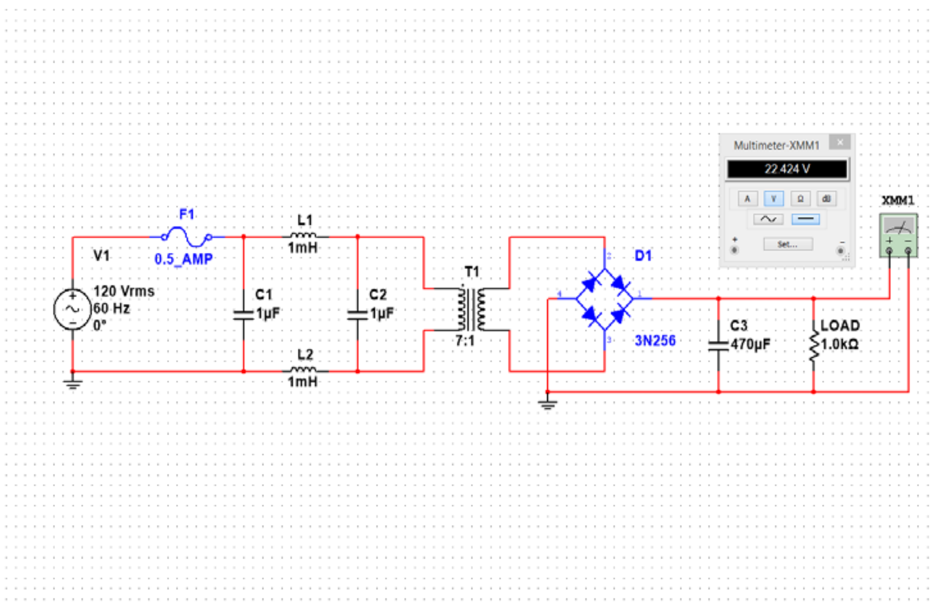


Figure 10.3-1: AC/DC converter circuit.

Due to the nature of switching power supplies a smaller transformer can be used if we can design for the rails at lower currents. The transformers used in switching-mode power supplies are mounted on the boards and are capable of dropping the voltage down to working amplitude with lower current than the typical bulky transformers such as the AT175. To use these transformers the buck converters must be design to grant the system the required current for the loads. If the voltage from the transformers is to low the current necessary to power all of our subsystems will be dangerously large to consider. Therefore our focus must be at least 20 V from the transformers step down. An inevitable parameter that will be changed is the footprint of our printed circuit board will be larger. By browsing the Digikey inventory we compare the candidate transformers regularly used in switching-mode power supplies. The choices picked from the store are based on requirement that they are used in AC/DC converters, they can handle the input voltage of 120 V from the AC mains, and can at least provide a 12 V output. The transformer Illustrated in figure 10.3-2 is the TILM3448 obtained from the datasheet provided by Wurth Electronics Midcom.

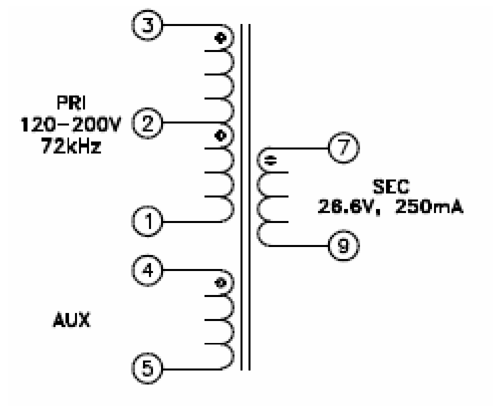


Figure 10.3-2: TILM3448 Transformer provided by Wurth Electronics Midcom

The transformer can provide an output of 26.6 V which suits our specifications to some degree. The OFFLINE XFRM WE-UNIT LT illustrated on figure 10.3-3 on the other hand can provide 24 V and 2 A output, much close to the design's specifications.

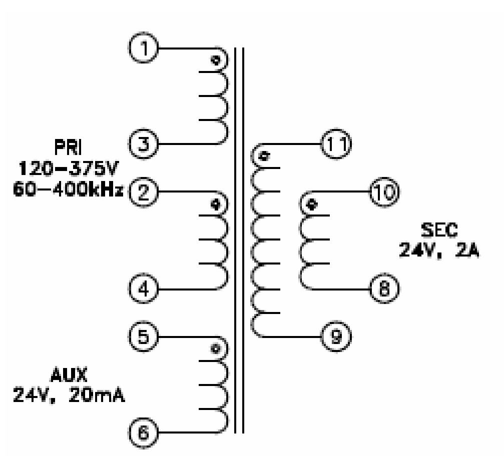


Figure 10.3-3: OFFLINE XFRM WE-UNIT LT Transformer provided by Wurth Electronics Midcom

A high voltage must still be considered depending on the amount of space we actually have to work with. If we settle for an output voltage of 36 V the design can be more efficient and use lower current overall in the power rails. The OFFLINE XFRM WE-UNIT LT3799 can provide a higher output voltage from the AC mains as seen in figure 10.3-4.

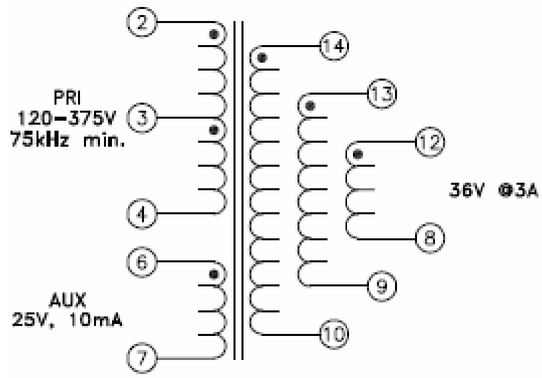


Figure 10.3-4: OFFLINE XFRM WE-UNIT LT3799 provided by Wurth Electronics Midcom

This transformer provides 36 V from 120 V AC input, the current in this case would not differ much from an AT175 transformer, which is pictured in figure 10.3-5. The overall design will therefore be based around the LT units.

Figure 10.3-5: AT175 Transformer obtained from Amazon.com

Using the LT units will provide a safer, efficient, and smaller system design which meets our specifications. The choice between LT and LT3799 will depend on the voltage regulators available at prototyping that will allow us to compromise between size, efficiency, and precision for our specifications.

10.4 Voltage Regulation

The power regulation for the laser diode will be separate from the primary power supply system. The circuit responsible for regulating power to the lase must be specifically tailored for the purpose of the laser and since by the system's design this laser can at any time be swapped out for another one the regulator must be removed along with it. The power regulator must limit the laser diode's tendency to draw more current than the intended amount so that the diode retains longevity. For prototyping purposes a linear laser diode driver will be designed using the current limiter design of an LM317 voltage regulator which will be used to deliver small current to the diode for testing purposes. Due to the inefficiency of linear regulators buck converters will be used, a type of switching regulator will be used for the power regulation of the final system. Buck converters are used to drop down voltages and increase current output. Typically the conversion is achieved by the rapid switching of a MOSFET and in order to maintain a constant output an inductor is used as the energy storing device when the circuit is on. The output voltage of the buck converter then depends on the time that the MOSFET switches the circuit on as per equation 10.4-2 where *Ton* is the time the circuit is on and T is the periodic time the circuit switches on. The laser diode will require relatively large currents up to 1.7 amps, higher than the expected output from the rectifier.

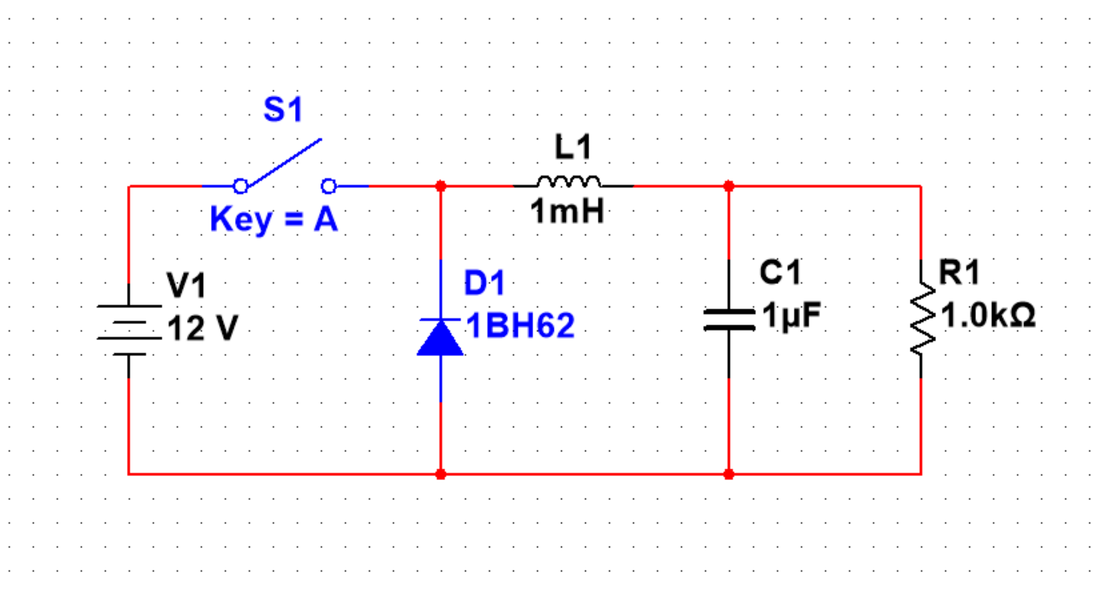


Figure 10.4-1: Simplified buck converter

$$Vout = Vin * \frac{Ton}{T}$$

Equation 10.4-2: DC output of buck converter.

The output current depends primarily on the switching frequency of the power of the converter, the step down voltage ratio, and the inductor. From the buck converter we can chose to use a low drop out voltage regulator instead of a simple buck regulator. The choice will depend on the footprint and cost of the designs. When attaching a load to the buck converter the specific laser diode will have a low dropout voltage regulator to attach to the buck converter which will be designed around the output of the buck converter and the parameters of operation for the specific diode. The primary design will use the switching regulators to deliver higher voltage and currents controlled by the microcontroller. Using the WEBENCH Power Architect tools provided by Texas Instruments two switching regulator were chosen based on high efficiency, low ripple voltage, and low dropout voltage design. The AC signal from the mains will be rectified and pass through the DC-DC buck converter, lowering the voltage and increasing the current. The signal will then be regulated by a low dropout voltage regulator, which will pass through a filter before reaching the laser diode. Low dropout voltage regulators are generally cheaper, use less parts, and have a smaller footprint than buck regulators. The most critical aspect of the laser driver is the footprint if the goal is to have the design allow for different types of laser diodes or different types of lasers altogether, therefore the low dropout voltage regulator must be as small as possible to go with the laser diode in its case. This means that any laser diode that the user needs for the system must have its own low dropout voltage regulator designed to interact with the main buck regulator. The first buck converter considered will be the TPS54531 as suggested by WEBENCH, a 28 volt and 5 am non-synchronous buck converter with a fixed frequency of 570 kHz. The voltage will be stepped down from 24 volts to 7 volts and provide 1.4 amps with following circuit parameters tabulated in table 10.4-3. The output voltage can be controlled by the resistor network in the device. And can be used to change the output of the network with a potentiometer controlled by the microcontroller. The goal is to obtain a device that will be configurable enough to provide versatility in the output of the laser. While the output voltage can be controlled it would be idea if the current could directly be controlled by changing a resistance value, this device is considerable for our specification but not ideal and requires additional consideration of other devices in comparison to this one. The suggested values on WEBENCH may also be unavailable which requires the project to shift its considerations to parts readily available in case they do not restock on the devices.

Output parameters of PS54531	
Vin	18 V - 24 V
Iin	0.44 A
Vout	7 V
Vout p-p	0.004 V
Iout	1.4 A
Power Dissipation	0.83 W
Efficiency	92.00%
Footprint	841 mm^2

Table 10.4-3: Circuit parameters of TPS54531

The previous circuit parameters are provided by the electrical network illustrated in figure 10.4-4.

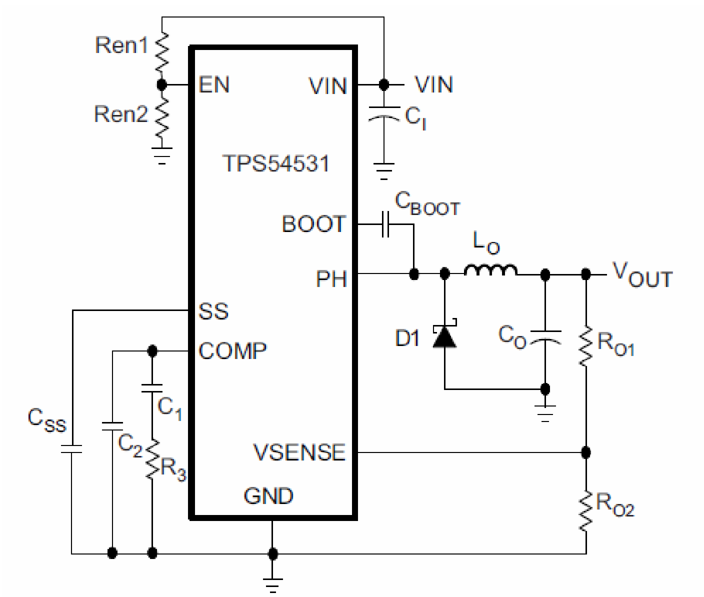


Figure 10.4-4: TPS54531 step down DC-DC converter from datasheet.

By changing *Rfbt* or *Rfbb* the output voltage can be manipulated as per the equation found in the datasheet for the device.

$$Vout = Vref * (\frac{Rfbt}{Rfbb} + 1)$$

Equation 10.4-5: Voltage output of TPS54531; Vref = 0.8 V

The output current is determined by the inductor and output voltage. The 22 micro-henry inductor was chosen using the equation:

$$Lmin = \frac{Vout * (Vin - Vout)}{Vin * Kind * Iout * fsw}$$

Equation 10.4-6: Minimum inductor value for desired output current.

Therefore if we wish to manipulate the output of the TPS54531 the inductor is the most important aspect of the network to alter, making it difficult to consider for the final design choice. The output of the TPS54531 will be stepped down again using a TPS54332 which serves as a low drop off voltage supply, a 28 volt and 3.5 amp non-synchronous buck converter with a fixed frequency of 1 MHz. The output voltage can be controlled by the resistor network in the device, by changing *Rfbt* or *Rfbb* the output voltage can be manipulated as per the equation found in the datasheet for the device similar to the TPS54531. The biggest difference between the TPS54531 and TPS54332 is the fixed switching frequency of the TPS54332 is 1 MHz and the dropout voltage is smaller. The device will step down the voltage from 7 volts to 6 volts with a 1.7 amp current using the network illustrated in figure 10.4.4 and will pass through a filter before reaching the laser diode with the circuit parameters illustrated in table 10.4.2. The goal is for the voltage and current to be controlled at this point by the microcontroller.

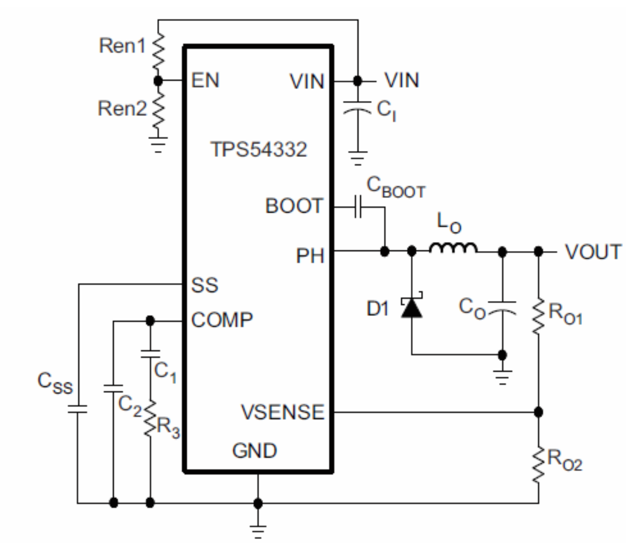


Figure 10.4-7: TPS54332 Regulator Network from datasheet

Output parameters of PS54332	
Vin	6.3 V - 7.7 V
Iin	1.4 A
Vout	6 V
Vout p-p	0.004 V
Iout	1.7 A
Power Dissipation	0.61 W
Efficiency	94.40%
Footprint	207 mm^2

Table 10.4-8: Circuit Parameters of TPS54332

The overall bill of materials regarding both of the TPS54531 and TPS54332 networks for the previously proposed design is illustrated in table 10.4-9 and table 10.4-10 respectively.

Part	Manufacturer	Part Number	Quantity	Price	Attribute 1 Name	Attribute 1 Value	Footprint
Cboot	AVX	08053C104KAT2A	1	$0.01	Cap	100nF	805
Ccomp	MuRata	GRM216R71H103KA01D	1	$0.01	Cap	10nF	805
Ccomp2	Yageo America	CC0805JRNPO9BN221	1	$0.01	Cap	220pF	805
Cin	MuRata	GRM32ER71H475KA88L	2	$0.31	Cap	4.7uF	1210
Cout	MuRata	GRM32ER61C226KE20L	1	$0.35	Cap	22uF	1210
Css	MuRata	GRM155R71C822KA01D	1	$0.01	Cap	8.2nF	402
D1	ON Semiconductor	MBRS2040LT3G	1	$0.13	VFatIo	0.43V	SMB
L1	Coilcraft	SER2915L-223KL	1	$2.05	L	22uH	SER2915L
Rcomp	Panasonic	ERJ-6ENF9531V	1	$0.01	Resistance	9.53kOhm	805
Rfbb	Panasonic	ERJ-6ENF1331V	1	$0.01	Resistance	1.33kOhm	805
Rfbt	Panasonic	ERJ-6ENF1022V	1	$0.01	Resistance	10.2kOhm	805
U1	Texas Instruments	TPS54531DDAR	1	$0.75			DDA0008E
Total Cost:	**$3.97**						

Table 10.4-9: Bill of Materials for TPS54531

Part	Manufacturer	Part Number	Quantity	Price	Attribute 1 Name	Attribute 1 Value	Footprint
Cboot	TDK	C1005X5R1A104K	1	$0.01	Cap	100nF	402
Ccomp	Yageo America	CC0805KRX7R9BB821	1	$0.01	Cap	820pF	805
Ccomp2	Kemet	C0805C180K5GACTU	1	$0.01	Cap	18pF	805
Cin	MuRata	GRM32ER61C226KE20L	1	$0.35	Cap	22uF	1210
Cout	Kemet	C0805C106K8PACTU	2	$0.04	Cap	10uF	805
Css	MuRata	GRM033R61A822KA01D	1	$0.01	Cap	8.2nF	201
D1	Diodes Inc.	1N5819HW-7-F	1	$0.08	VFatIo	0.45V	SOD-123
L1	Bourns	SRR5028-2R6Y	1	$0.26	L	2.6uH	SRR5028
Rcomp	Vishay-Dale	CRCW040234K0FKED	1	$0.01	Resistance	34kOhm	402
Rfbb	Vishay-Dale	CRCW04021K58FKED	1	$0.01	Resistance	1.58kOhm	402
Rfbt	Vishay-Dale	CRCW040210K2FKED	1	$0.01	Resistance	10.2kOhm	402
U1	Texas Instruments	TPS54332DDAR	1	$0.73			DDA0008H
C_filter_1	Kemet	C0805C105K4RACTU	1	0.02	Cap	1uF	805
L_filter_1	TDK	NLCV32T-R10M-PFR	1	$0.10	L	100nH	NLCV32
Total Cost:	**$1.69**						

Table 10.4-10: Bill of Materials for TPS54332

The initial design from WEBENCH could fulfill the specifications for the laser module using the TPS54531 and TPS 54332. However the system could be improved by using a buck regulator which allows for more versatility and a smaller footprint. Judging from the alternative parts it is possible to increase efficiency, reduce the footprint, and increase versatility. For this reason the TPS53915 and the TPS61232 are the next parts for consideration. The TPS53915 is a small synchronous buck converter. The part was primarily chosen due to the high efficiency parameters reported by WEBENCH which is critical since this regulator will rest with the main power components. Furthermore the following features illustrated in the datasheet are of importance. Several parameters can be programmed directly using a microcontroller. Namely the output voltage can be changed which increases versatility. Therefore the TPS53915 possesses high efficiency, a tolerable footprint, and it is programmable. This creates a versatile environment for adjusting the preliminary output for laser diodes and allows for optimized configurations when changing the laser module. The following schematic in figure 10.4-11 is used to change the configuration of the TPS53915.

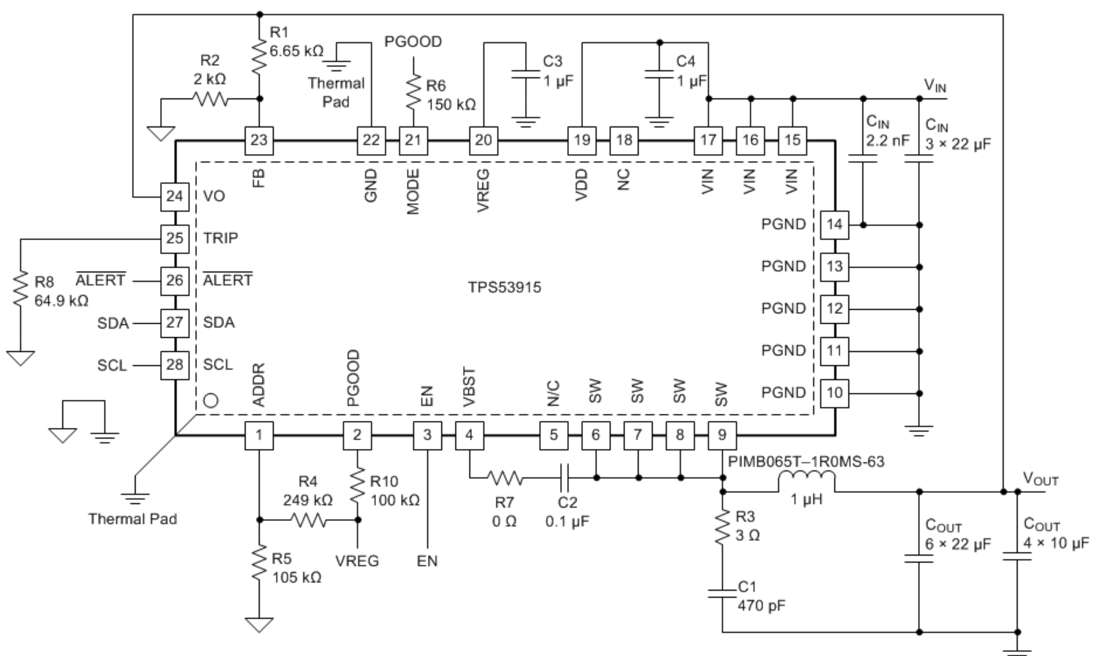


Figure 10.4-11: TPS53915 Schematic Diagram from datasheet

For our overall power design in this case our system will produce the parameters illustrated in table 10.4-12.

Output parameters of TPS53915	
Vin	10.8 V - 13.2 V
Iin	0.8 A
Vout	4.1 V
Vout p-p	0.007 V
Iout	2.49 A
Power Dissipation	0.43 W
Efficiency	96.00%
Footprint	259 mm^2

Table 10.4-12: Circuit Parameters of TPS53915

The output of this circuit will be input of the low dropout voltage regulator, which is the TPS61232. The most critical aspect of this for the design of this regulator is a small footprint. The TPS61232 will be inside the host casing for the laser diode with the lead wires leading to the TPS53915. The necessary circuit parameters for the TPS61232 are presented in table 10.4-13 and will be achieved using the electrical network illustrated in figure 10.4-14.

Output parameters of TPS61232	
Vin	3.7 V - 4.5 V
Iin	1.4 A
Vout	5 V
Vout p-p	0.017 V
Iout	1.7 A
Power Dissipation	0.73 W
Efficiency	92.10%
Footprint	212 mm^2

Table 10.4-13: TPS61232 circuit parameters

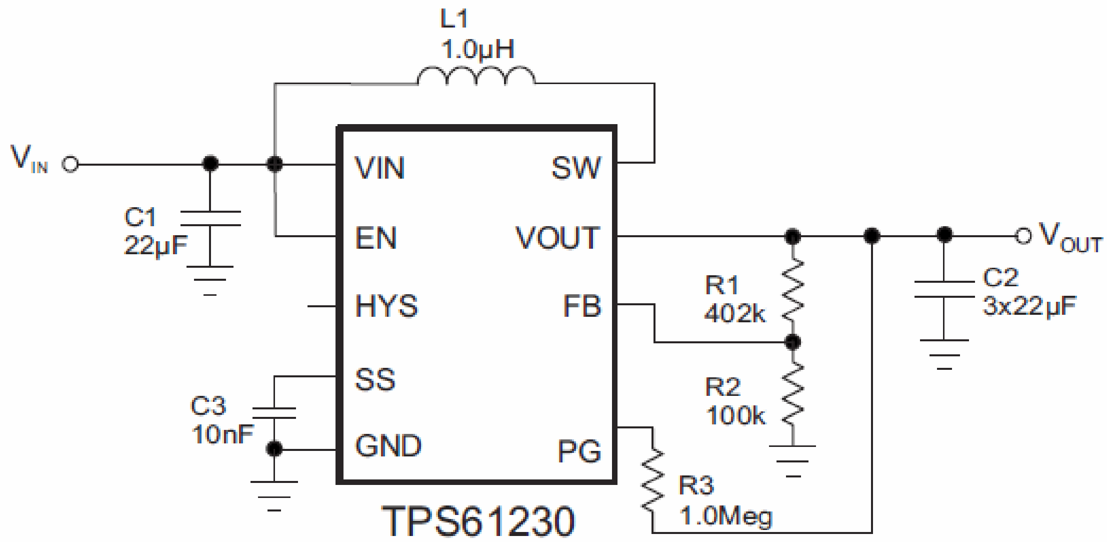


Figure 10.4-14: TPS6123X general electrical network from datasheet

The TPS61232 uses few parts to achieve the desired results, the ripple voltage is slightly higher than other designs but as long as the current remain constant and between 4.5 V – 5.3 V it is not an issue. The footprint however is unnecessarily large for the intended design but the case which will host the laser diode is not final. If a larger host is selected a more efficient driver may be designed when it can be accommodated near the laser to maintain the project's versatility. A primary issue with this device is controlling the output current reliably to control the laser output using the microcontroller. This design lacks the ideal configuration that would allow a basic variable component to interact with the main control unit. The overall bill of materials regarding both of the TPS53915 and TPS61232 networks for the previously proposed design is illustrated in table 10.4-15 and table 10.4-16 respectively.

Part	Manufacturer	Part Number	Quantity	Price	Attribute 1 Name	Attribute 1 Value	Footprint
Cbst	TDK	C1005X7R1H104K	1	$0.02	Cap	100nF	402
Cin	MuRata	GRM32ER61C226K	4	$0.16	Cap	22uF	1210
Cout	MuRata	GRM21BR60J226M	2	$0.05	Cap	22uF	805
Creg	MuRata	GRM21BR61E225K	1	$0.04	Cap	2.2uF	805
Cvdd	MuRata	GRM21BR61E225K	1	$0.04	Cap	2.2uF	805
L1	Coilcraft	XAL6060-472MEB	1	$0.82	L	4.7uH	XAL6060
Raddrb	Vishay-Dale	CRCW04021K00FK	1	$0.01	Resistance	1000Ohm	402
Raddrt	Vishay-Dale	CRCW0402301KFK	1	$0.01	Resistance	301kOhm	402
Rfbb	Vishay-Dale	CRCW040210K0FK	1	$0.01	Resistance	10kOhm	402
Rfbt	Vishay-Dale	CRCW040259K0FK	1	$0.01	Resistance	59kOhm	402
Rmode	Vishay-Dale	CRCW0402150KFK	1	$0.01	Resistance	150kOhm	402
Rpgood	Vishay-Dale	CRCW0402100KFK	1	$0.01	Resistance	100kOhm	402
Rtrip	Vishay-Dale	CRCW040220K0FK	1	$0.01	Resistance	20kOhm	402
U1	Texas Instrument	TPS53915RVER	1	$3.00			RVE0028A
TOTAL COST	$4.73						

Table 10.4-15: TPS53915 bill of materials

Part	Manufacturer	Part Number	Quantity	Price	Attribute	Attribute 1 Value	Footprint
C_filter_1	MuRata	GRM188R71C104KA01D	1	$0.01	Cap	100nF	603
L_filter_1	TDK	NLCV32T-R15M-PFR	1	$0.10	L	150nH	NLCV32
Cin	Taiyo Yuden	LMK212BJ226MG-T	1	$0.12	Cap	22uF	805
Cout	TDK	C3216JB1A336M	1	$0.29	Cap	33uF	1206
Css	MuRata	GRM155R61A273KA01D	1	$0.01	Cap	27nF	402
L1	Vishay-Dale	IHLP2020CZER1R0M11	1	$0.99	L	1uH	IHLP-2020CZ
U1	Texas Instruments	TPS61232DRCR	1	$1.15			DRC0010G
TOTAL COST	$2.67						

Table 10.4-16: TPS61232 bill of materials

These designs provided a good starting point for picking the parts necessary for our system. The choice of the buck regulator will be determined in the power system section and for the LDO laser we will use the TPS53915 to pick our low dropout voltage regulator. The previous designs use a linear voltage regulator to provide the loads to the microcontroller from a low power rail. However if we include the design in WEBENCH we can use a more reliable switching regulator for a higher cost rather than using a linear regulator. The design would use the TPS62140A for the low dropout voltage to be used with the laser module. The TPS6214X family is a synchronous step-down dc-dc converter; the device like many others provides a specific current based on the inductor and the voltage depends on a ratio of resistors. The voltage regulator suggested for the microcontroller is the TPS62177. This regulator has an extremely small footprint, 49 mm^2 to be precise, and an efficient of 91%. This device is an extremely strong contender for the regulator to be used for the microcontroller since it fits the desired specification by not taking up a large amount of space, being sufficiently efficient, and having a low cost of $1.15. This option is critical to maintain in consideration, the part itself is in stock. The other options previously discussed are great alternatives but so far this is the optimum driver for low voltage and low current in our design. The relevant network contains very few components which are illustrated in figure 10.4-17. Despite these design linear voltage regulators may serve a purpose to the system's design.

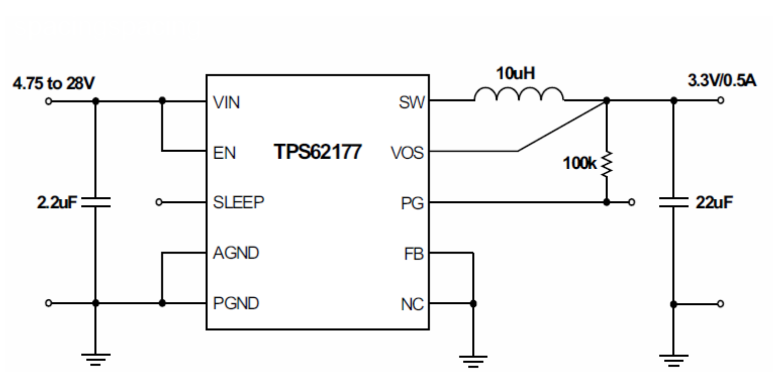


Figure 10.4-17: TPS62177 Electrical Network from datasheet

A linear laser diode driver will use an LM317 voltage regulator to adjust the current output which will prevent the diode from drawing more current than necessary. The current output will be determined by the potentiometer at the voltage regulator output terminal. The resistance values will be controlled by a digital potentiometer to interface with the microcontroller and it will adjust the laser power output as the system operates. A 0.1 uF capacitor is used at the input to act as a filter for noise and a 1 uF capacitor is placed parallel to the laser diode to prevent damage from instantaneous changes in voltage and to improve transient response. The current output is calculated by equation 10.4-18.

$$I = \frac{Vref}{Rpot}$$

Equation 10.4-18: Driver output current

The reference voltage, *Vref* for the LM317 is 1.25 V and *Rpot* is the resistance of the potentiometer. This linear regulator in practice is the simplest design and will be used to test the function of the laser diode before applying large current. Since the power supply of the laser will have much higher voltage than the forward bias voltage required for the laser diode to turn on the voltage regulator will dissipate more energy and result in the most inefficient driver option, yet it will suffice for its intended purpose. The schematic capture of the linear driver is illustrated in figure 10.4-19, the figure will use 6 1N4001 diodes and 1 ohm resistor in series to simulate a 445 nm laser diode load, which would require at least 4.5 volts.

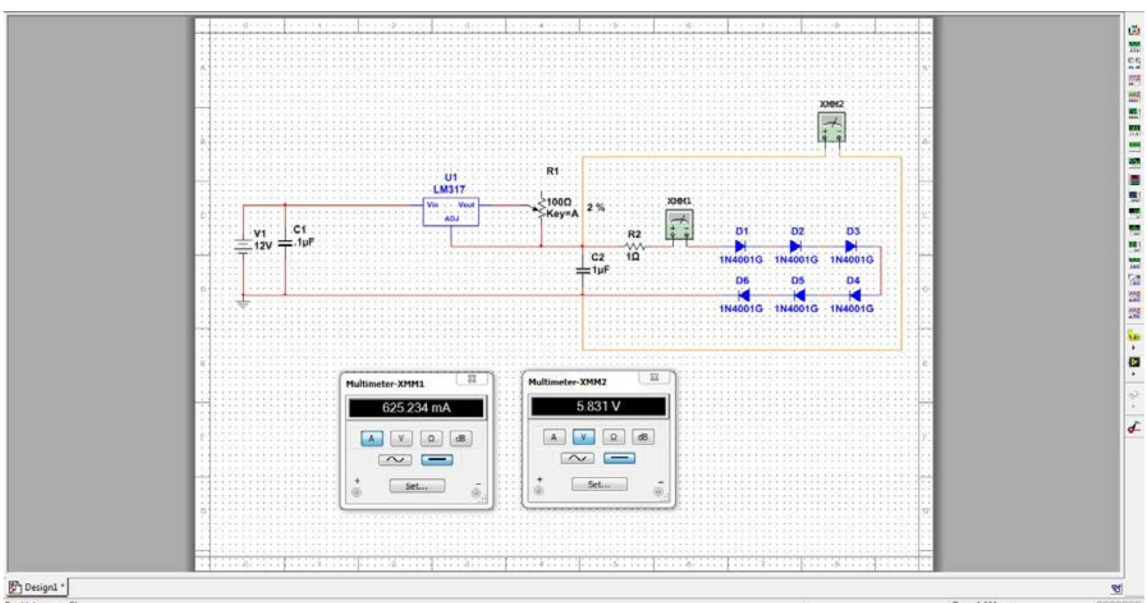


Figure 10.4-19: Current limiter configuration using LM317

The most limiting aspect of this driver is that it must use its reference voltage of the LM317 voltage regulator to provide a current output, greatly limiting the power output of the laser. Linear voltage regulators however can be used to curve the cost of the power system by using them as the regulators for the microcontroller loads. The system would be less efficient and take up more space but the precise voltage and current from linear configurations guarantees the device will be in working order throughout the entire operation time.

10.5 Safety

When dealing with power distribution system there are sections where high voltage is expected. A heavy duty enclosure is mandatory to contain the transformer as it can shock users, especially if the AT175 is used as the transformer unit for the AC/DC conversion. The rest of the circuit will use relatively high currents in some areas so the wires delivering loads must be thick enough to safely transport current and insulated enough to prevent human contact with the wire. A project enclosure box can be purchased from RadioShack and is illustrated in figure 10.5-1.

Figure 10.5-1: Project Enclosure Box

The boxes come in various sizes and it may be necessary to enclose all circuit components due to the current flowing through the circuit to maintain a degree of safety. All subsystem will also be properly grounded.

10.6 Design

The system needs to primarily provide power for the laser module, the stepper motors and the microcontroller. The methods for powering these systems have to be as efficient as possible while minimizing minimize heat dissipation. The size of the power supply must be of limited size to allow mobility of the XY plotter. The system has too many subsystems that require high voltage or current to be sustained by batteries. The primary source will be utility mains supply converted by a switched-mode power supply. The ideal design will be presented in this section regardless of part availability at this time. When prototyping the parts referenced in this section the ones unavailable will be replaced with candidates from the voltage regulator sections. The switching regulators will take priority over the linear regulators when picking the replacement parts. Using the WEBENCH the optimal system as per our specifications is chosen and is illustrated in figure 10.6-1.

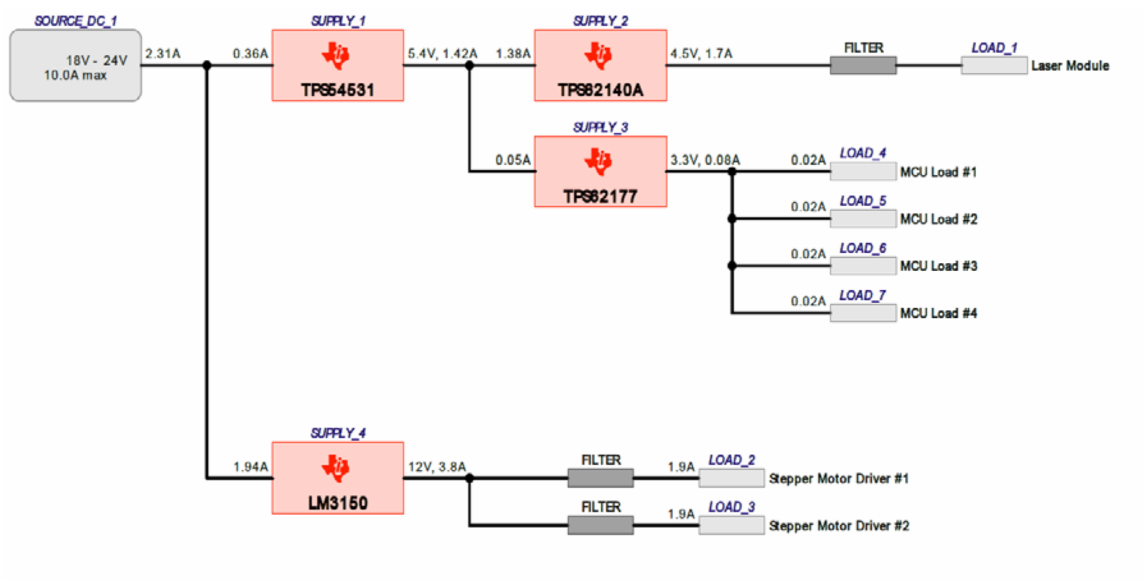


Figure 10.6-1: WEBENCH system representation provided by TI WEBENCH

The primary source will be the mains AC signal which will be filtered, stepped down, and rectified using the OFFLINE XFRM WE-UNIT LT transformer from the source section. The first power rail will be regulated by the TPS54531 voltage regulator network illustrated in figure 10.6-2 which provides the power rail for the laser module and microcontroller.

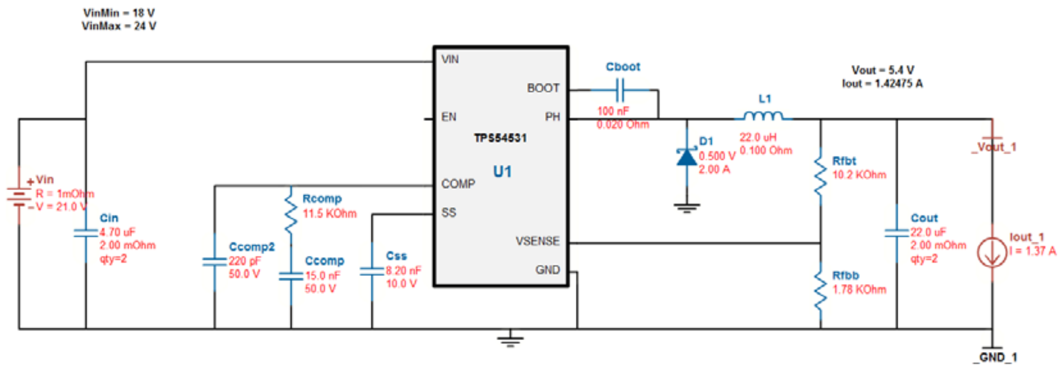


Figure 10.6-2: TPS54531 network

The LM3150 regulator network illustrated in figure 10.6-3 provides the stepper motor driver's power. The TPS54531 was chosen doe to the small footprint and cost. The LM3150 was chosen primarily for its efficiency of 97.5% and low cost compromise. The footprint is relatively large 545 mm^2 but the devices used for this application dissipated far too much power to leave as it was. By using this device the power dissipated is roughly 1 W as opposed to 3 W with smaller devices.

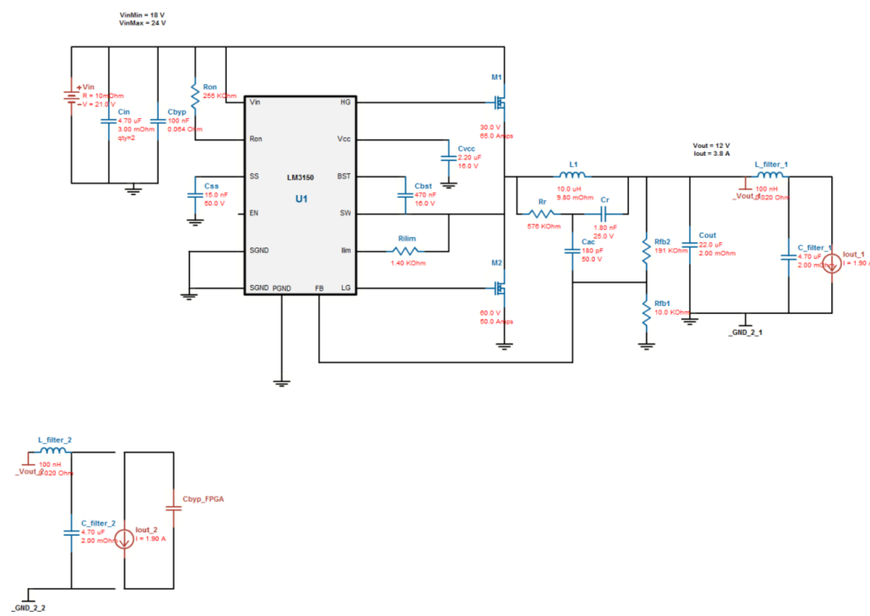


Figure 10.6-3: LM3150 Network provided by TI WEBENCH

The drivers for the stepper motor will receive a 2 V DC load with a current not exceeding 2 A. The network contains a ripple filter for the outputs before reaching the stepper motor drivers. The TPS62140A network in figure 10.6-4 will provide the laser module's power by maintaining a 4.5 V output. A digital potentiometer will be used between the load and the regulator to control the current provided to the laser diode. The laser module and stepper motors have low-pass filters to reduce noise and ripple voltage.

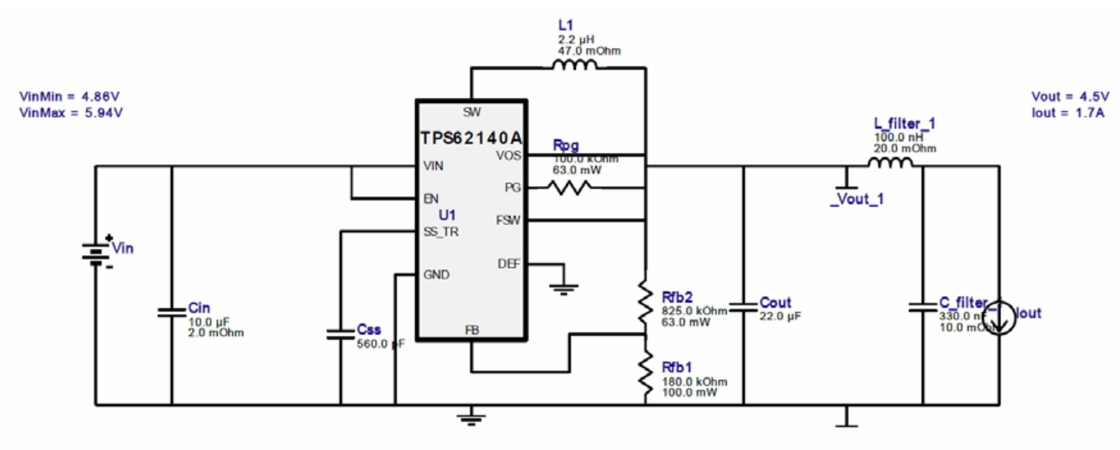


Figure 10.6-4: TPS54531 network provided by provided by TI WEBENCH

The microcontroller will be powered by the TPS62177 network illustrated in figure 10.6-5. The outputs will maintain very low currents and constant voltage for the microcontroller. The processor will not have the standard voltage regulation so it is critical that the power being delivered to the unit low precise.

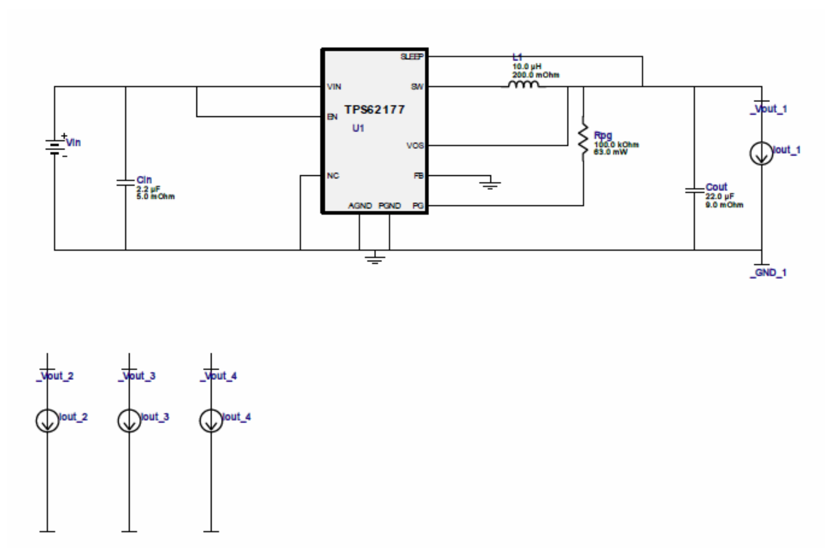


Figure 10.6-5: TPS62177 network TI WEBENCH

The overall bill of materials is tabulated in table 10.6.1. The total cost comes to \$28.98. As it stands most of the parts are available for purchase. The cost will increase if we decide to order the printed circuit board pre-built with our design.

Part Number	Manufacturer	Component	Footprint	Qty Req Per Kit	Total
GRM21BR61A106KE19L	MuRata	Cin	805	1	$0.20
SDR0403-2R2ML	Bourns	L1	SDR0403	1	$0.47
CRCW0402100KFKED	Vishay-Dale	Rpg	402	1	$0.80
NLCV32T-R10M-PFR	TDK	L_filter_1	NLCV32	1	$0.29
RR1220P-184-D	Susumu Co Ltd	Rfb1	805	1	$0.11
TPS62140ARGTR	Texas Instruments	U1	S-PVQFN-N16	1	$3.12
GRM033R71E561KA01D	MuRata	Css	201	1	$0.10
CRCW0402825KFKED	Vishay-Dale	Rfb2	402	1	$0.80
GRM188R71C334KA01D	MuRata	C_filter_1	603	1	$0.15
GRM31CR61A226KE19L	MuRata	Cout	1206	1	$0.37
TPS62177DQCR	Texas Instruments	U1	R-PWSON-N10	1	$2.29
LPS4018-103MRB	Coilcraft	L1	LPS4018	1	$0.00
GRM21BR60J226ME39L	MuRata	Cout	805	1	$0.27
GRM155R60J225ME15D	MuRata	Cin	402	1	$0.00
CRCW0402100KFKED	Vishay-Dale	Rpg	402	1	$0.80
CRCW040211K5FKED	Vishay-Dale	Rcomp	402	1	$0.80
GRM32ER71H475KA88L	MuRata	Cin	1210	2	$2.08
C1005X5R1A104K	TDK	Cboot	402	1	$0.10
SRN8040-220M	Bourns	L1	SRN8040	1	$0.58
CC0805JRNPO9BN221	Yageo America	Ccomp2	805	1	$0.10
GRM32ER61C226KE20L	MuRata	Cout	1210	2	$1.36
CC0805KRX7R9BB153	Yageo America	Ccomp	805	1	$0.10
GRM033R61A822KA01D	MuRata	Css	201	1	$0.00
CRCW04021K78FKED	Vishay-Dale	Rfbb	402	1	$0.80
CRCW040210K2FKED	Vishay-Dale	Rfbt	402	1	$0.80
B240A-13-F	Diodes Inc.	D1	SMA	1	$0.54
TPS54531DDAR	Texas Instruments	U1	DDA0008E	1	$2.59
GRM21BR61E475MA12L	MuRata	C_filter_2,C_filter_1	805	2	$0.58
NLCV32T-R10M-PFR	TDK	L_filter_2,L_filter_1	NLCV32	2	$0.58
GRM31CR71H475KA12L	MuRata	Cin	1206	2	$0.00
BSC100N06LS3 G	Infineon Technologies	M2	PG-TDSON-8	1	$0.97
ERJ-6ENF1002V	Panasonic	Rfb1	805	1	$0.10
GRM32ER61C226KE20L	MuRata	Cout	1210	1	$0.68
ERJ-6ENF5763V	Panasonic	Rr	805	1	$0.10
LM3150MH/NOPB	Texas Instruments	U1	MXA14A	1	$4.49
C0805C181K5GACTU	Kemet	Cac	805	1	$0.10
EMK212B7474KD-T	Taiyo Yuden	Cbst	805	1	$0.12
ERJ-6ENF1913V	Panasonic	Rfb2	805	1	$0.10
ERJ-6ENF1401V	Panasonic	Rilim	805	1	$0.10
CC0805KRX7R9BB153	Yageo America	Css	805	1	$0.10
GRM216R71E182KA01D	MuRata	Cr	805	1	$0.00
ERJ-6ENF2553V	Panasonic	Ron	805	1	$0.10
EMK212B7225KG-T	Taiyo Yuden	Cvcc	805	1	$0.18
CSD17507Q5A	Texas Instruments	M1	TRANS_NexFET_Q5A	1	$0.96
SER1360-103KLB	Coilcraft	L1	SER1360	1	$0.00
C0805C104K5RACTU	Kemet	Cbyp	805	1	$0.10
TOTAL:					$28.98

Table 10.6-6: Bill of materials for power regulation system

10.7 Test Plan

The test plan for the voltage regulator system will begin once parts are acquired. Each subsystem will be built in the senior design lab and measured for anomalies and the desired output. The AC/DC converter will be wired into a project box and plugged into an outlet where the signal will be stepped down and delivered to a high ohm resistor. The resistor will be measured with a digital multimeter for accuracy. Each subsystem will receive the expected input from a signal generator or direct power supply and a dummy load which simulates the actual load will be set up to gather measurements. Once the functionality of each subsystem is stablished the subsystems will be wired together one by one to confirm functionality, ending with the AC/DC converter powering the loads. The transformer will be thoroughly tested before being used with the rest of the circuit. The step down voltage will be confirmed so that it may satisfy our design requirements. It will have a solid ground connection with very low resistance and the converter will be isolated by a heavy duty insulator to assure complete safety.

Once functionality is confirmed digital potentiometers and switches will be added to increase control over the regulation though the microcontroller as well as adding linear low dropout voltage regulators to power specific LEDs that may be added to the project. The expected results from the prototype testing are a constant voltage of 4.5 V and a controllable current of up to 1.7 A for the laser module. Four 3.3 V leads to power the microcontroller that will not exceed 0.02 A. Two stepper motor drivers powered by 12 V with a current not exceeding 1.9 A. The laser module and stepper motor drivers will have an LC filter to reduce noise and ripple. The transient and steady state response of the output of these systems must be carefully measured to confirm the proper value of the inductor, since large inductance will cause a delayed response. The ripple voltage in these systems should be small enough that they are negligible, which means anywhere from 0 to 5 mV. The design will be declared successful if the prototype can maintain operation of the laser module, the microcontroller, and stepper motors only from the mains AC signal.

11.0 PCB

11.1 Design Overview

Designing a PCB from scratch is a very new concept for all the team members in the group. For this reason a closer look on the basics of PCB design and construction was spent. Initially the terminology and composition of components on the PCB were looked at. The layers in PCB are the cheapest to produce but should be kept to a minimum when designing a PCB. The reason it should be kept so low is that it adds complication when trying to create a design. The design will become complicated and become more expensive to produce as more layers at added. The copper tracing on the PCB is important to keep mind. This is not just because the traces act as wires to connect components but also the thickness, length, and angles determine how well the flow of current will move throughout the system. Vias serve as a way to electrically connect layers to one another. There are three main types of vias that can be considered when designing a PCB. Through hole vias are hole that are drilled completely through the board with an electric connection is made so that the layers pass through one another, blind vias are connections that exist between multiple planes that don't go completely through the board that start with a surface connection, finally buried vias are nearly identical to blind vias except the connections are done completely in the internal layers of the PCB which are not connected to any surface planes. The first aspect after understanding the basic terminology of PCB design is to start creating the PCB. This is done when the electrical schematic has been completed and tested. Each element of the schematic should be chosen from manufacturer that fulfills the need in the circuit and the physical dimensions of each part should be modeled listed for later use.

To help facilitate the designing process a program named EAGLE was used for schematic and board conversions. EAGLE is a free program that contains a schematic editor for designing circuit diagrams. It also has a feature that allows the schematic to be easily converted into a PCB layout. In order to do this conversion EAGLE must be loaded with a library of parts that have a schematic and board definition to allow this translation. In this project the schematics were generated by Webench design which is provided by Texas Instruments. Initially a document was created for the power needs of each component. When the power requirements were met the next step was to find parts to help regulate the proper current, voltage, and handling the ripple voltage. When the requirements were identified the next step was to find out how large we wanted boards to be so we looked at the footprint sizes. Footprint is a measurement of the pattern on the circuit board which includes a variety of characteristics. Some of these characteristics are copper tracing, silk layers, and solder locations. Essentially the smaller the footprint the smaller the design and design will be. The design selection that was chosen was to find a design that had a small footprint.

11.2 Design

TPS54531

The TPS54531 is a buck switching regulator that will step down the high voltage output from the rectifier. The output of this device will be primarily used to provide power to the microcontroller and the laser module after further regulating. Due to the low voltage requirements of the loads but strict current constraints this regulator was necessary to maintain high efficiency and to promote a better life cycle by not providing power to the loads after a very large voltage drop.

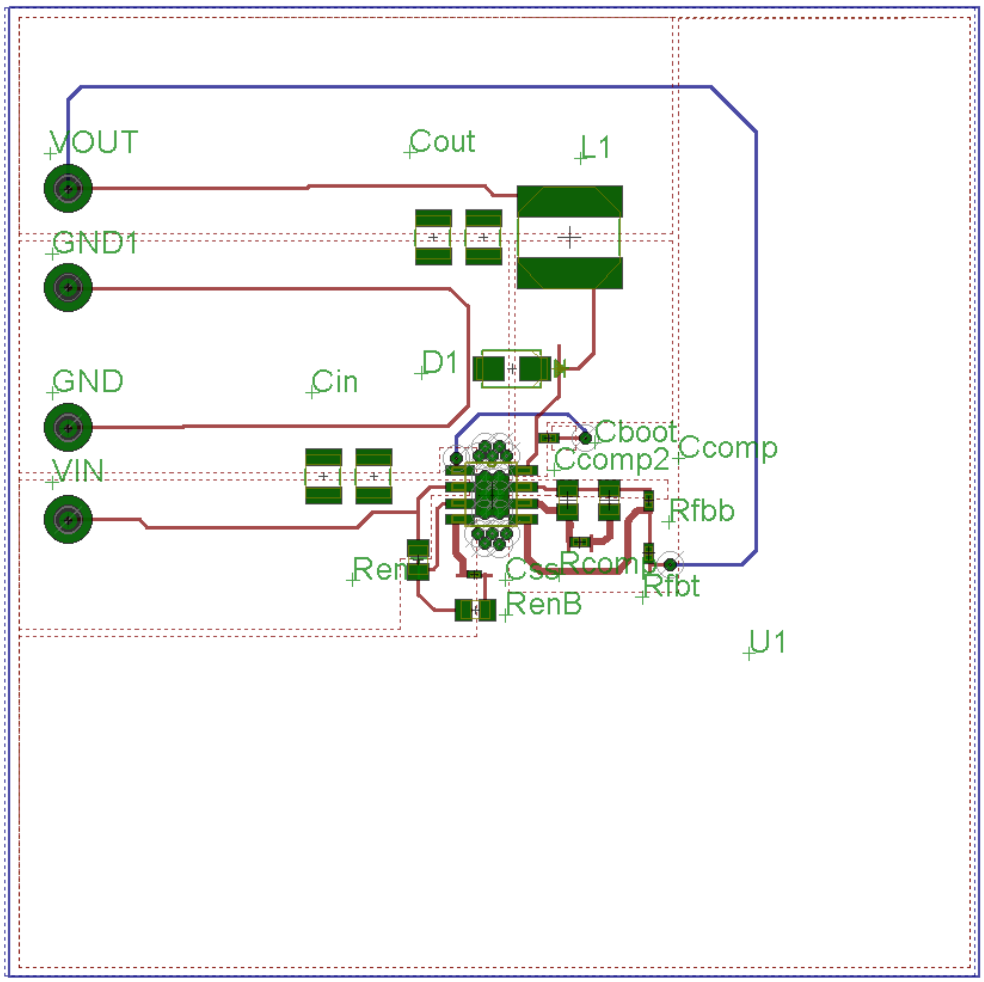


Figure 11.2-1

TPS62140A

The TPS62140A will be the low dropout voltage regulator responsible for the operation of the laser system. This buck voltage regulator will decrease the voltage from the TPS54531 and increase the current output. The device will be configured to not allow more than 1.7 A to pass through the laser diode to maintain a reasonable life cycle. The TPS62140A was chosen due to the nature of low dropout voltage regulators being compact and have few components. The board will rest within the laser diode aluminum mount as it is designed specifically for this laser diode.

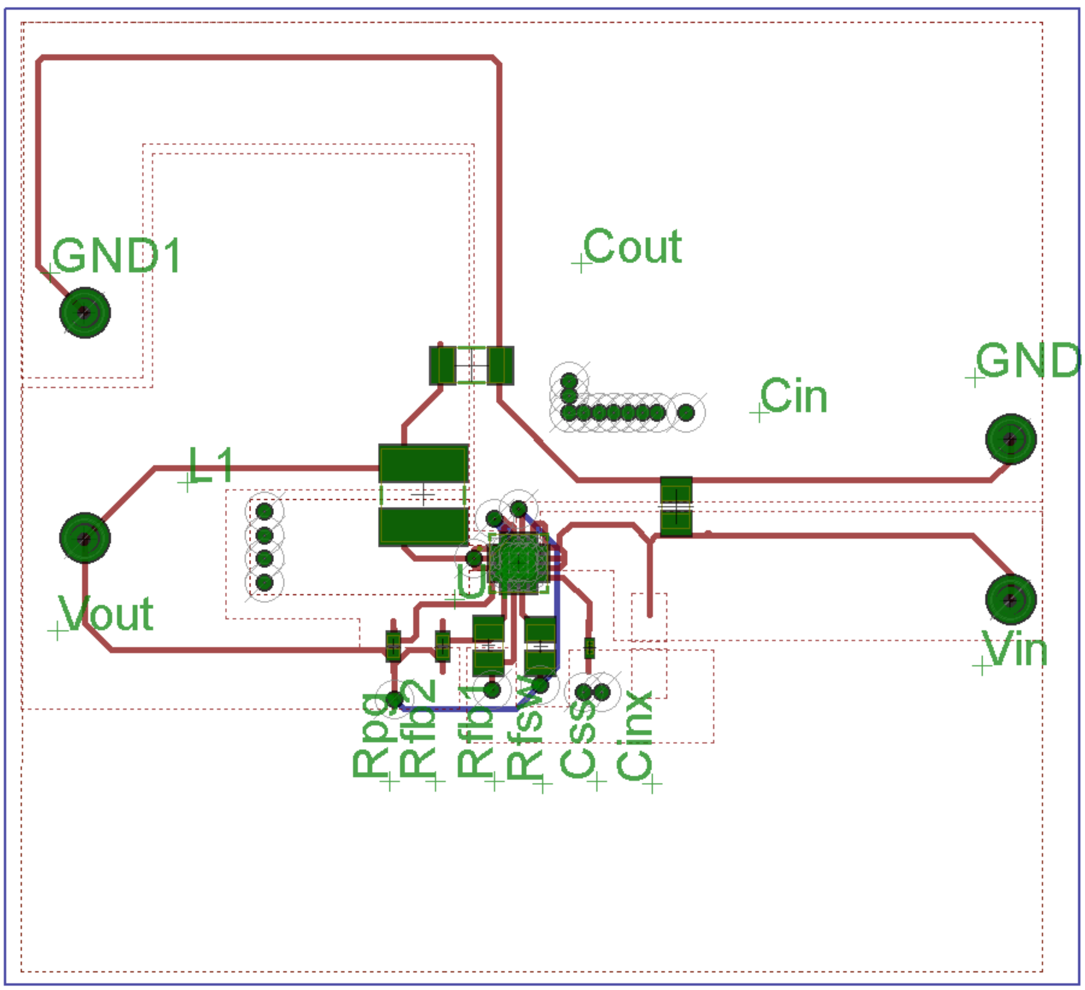


Figure 11.2-2

TPS62177

The TPS62177 will regulate the voltage output of the rail provided by the TPS54531 for the microcontroller unit. The microcontroller requires four inputs of 3.3 V and no more than 25 mA for each one. To this end the current will be limited to 20 mA per input. The TPS62177 was chosen due to the compromise of small footprint and efficiency. Since the voltage from the TPS54531 is roughly 5 V the power dissipated by this device will not be an issue.

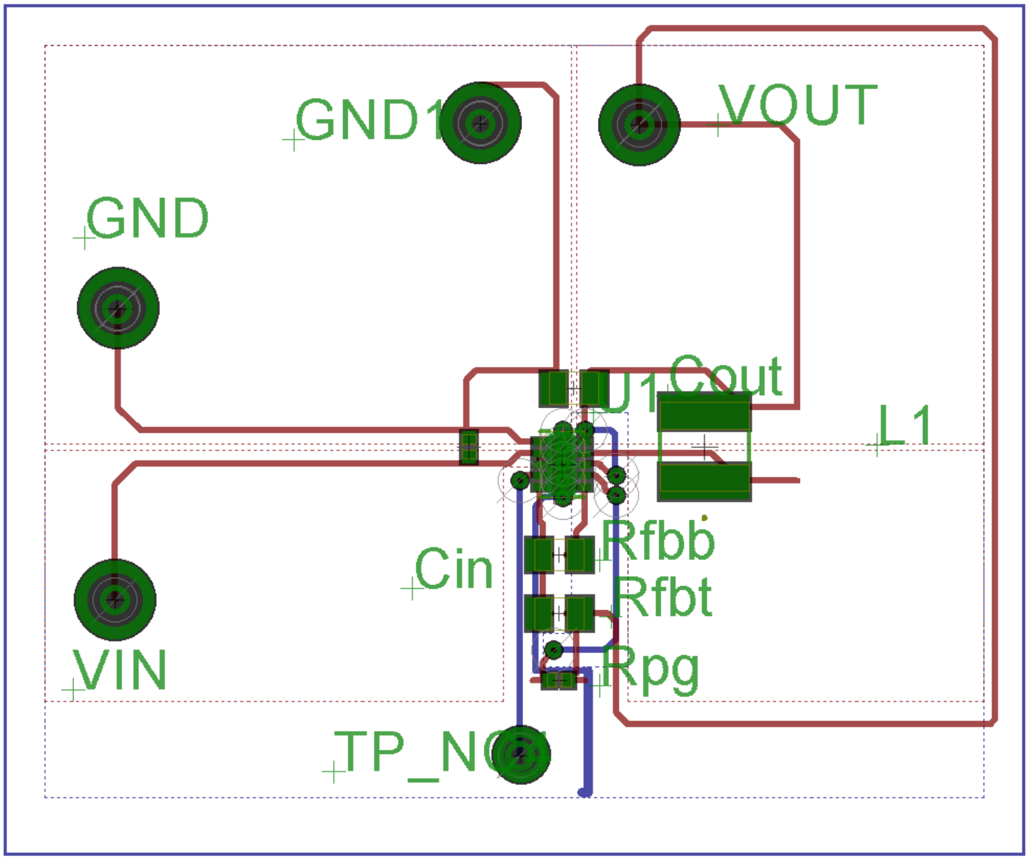


Figure 11.2-3

LM3150

The LM3150 will share the input rail with the TPS54531, as they both use the rectified AC mains signal to regulate their output. This device will be used to maintain a 12 V output and a total of 3.8 A output. Because of the strict and demanding regulations for the stepper motor drivers the LM3150 had to be as efficient as possible, the power dissipated by this device is relatively larger compared to the other regulators so no expense was spared, the footprint of the device was largely sacrificed to maintain proper power dissipation.

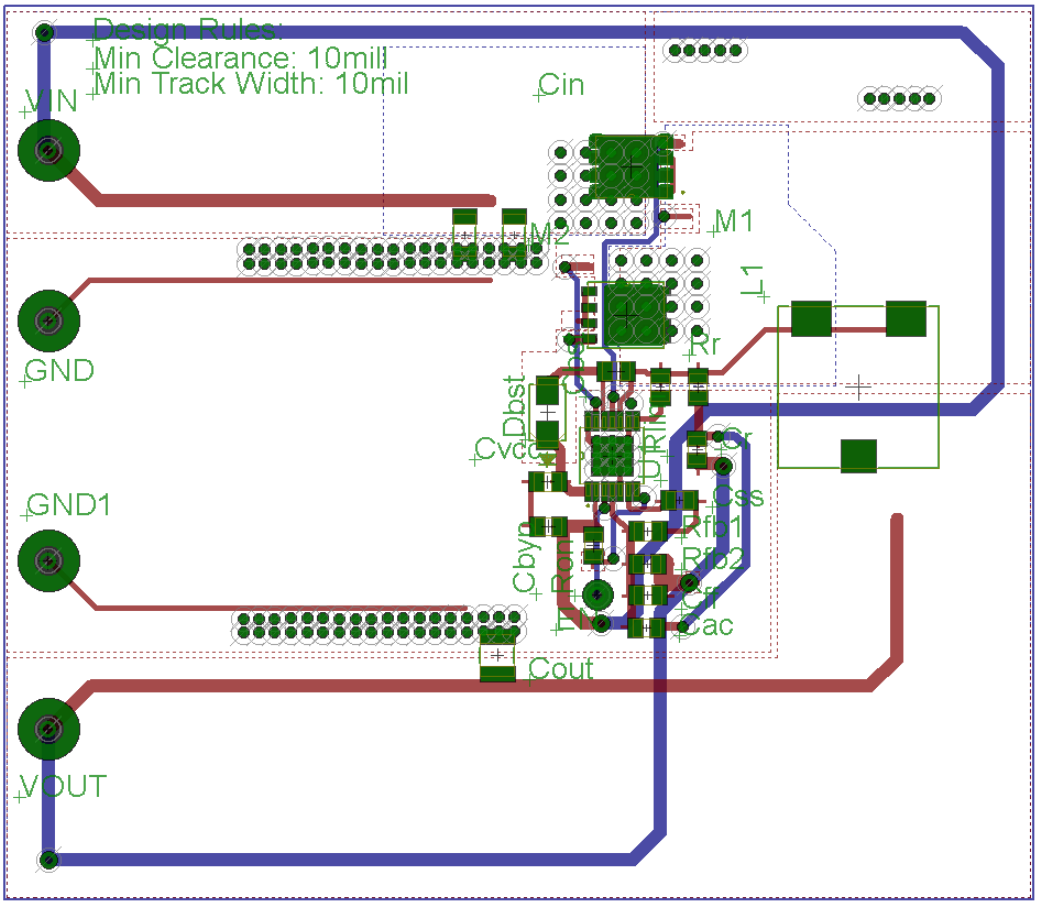


Figure 11.2-4

12.0 Project Prototype Testing

12.1 Software Testing

Each of the tables below describes a different test that will be performed on the software to validate them. The test need to pass to ensure that the project will successfully operate. The testing will be done using the previously mention prototype life cycle in figure 8.4-1. Each test that fails will be added to the list of revisions to be checked or redesigned in the next design prototype. Each test needs to be run for the cycle iteration even if it was not changed. This is due to the fact that something is relates with may have changed.

12.1.1 Graphical User Interface

Test Name	Draw
Test Description	The tester will click and hold the mouse button on the canvas and begin moving the mouse.
Expected Results	When the tester moves the mouse, the canvas should draw a black line in the wake of the mouse cursor.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds and seamlessly to the movement of the cursor. The program should track the movement accurately to a degree of 5 pixels.

Test Name	Erase
Test Description	The tester will click and hold the mouse button on the canvas and begin moving the mouse.
Expected Results	When the tester moves the mouse, the canvas should draw a black line in the wake of the mouse cursor.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds and seamlessly to the movement of the cursor. The program should track the movement accurately to a degree of 5 pixels.

Test Name	Pen Button
Test Description	The tester will click the Pen Button.
Expected Results	The mode of operation and the cursor should change to the pen. The tester should then be able to draw.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds.

Test Name	Eraser Button
Test Description	The tester will click the Eraser Button.
Expected Results	The mode of operation and the cursor should change to the eraser. The tester should then be able to erase.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds.

Test Name	New Button
Test Description	The tester will click the New Button.
Expected Results	The program should replace the canvas with a blank white canvas.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds.

Test Name	Upload Button
Test Description	The tester will click the Upload Button.
Expected Results	The tester should be presented with an option to enter a file path. If the file path is valid, the image will be drawn onto the canvas removing the previous data.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds. The image should be no larger than 310 pixels wide and 390 pixels high.

Test Name	Etch Button
Test Description	The tester will click the Etch Button.
Expected Results	The program should display all the buttons except for the quit button. The xy plotter should then start etching the image onto the material.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds.

Test Name	Quit Button
Test Description	The tester will click the Quit Button.
Expected Results	The program will terminate and close.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds.

Test Name	Static Window
Test Description	The tester will try to resize the user interface.
Expected Results	The tester should not be able to resize the user interface so that it does not distort the canvas.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	NA

Test Name	Transfer Data
Test Description	The tester should try to transfer any data from the user interface through the UART connection.
Expected Results	The data should be returned through the UART.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should be 100% accurate.

Test Name	Receive Data
Test Description	The tester should try and transfer any data through the UART to the user interface.
Expected Results	The data should be stored and printed to screen.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should be 100% accurate.

Test Name	Convert Canvas to Image
Test Description	The tester should click the etch button.
Expected Results	The image should be converted to an image and passed to the new object.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should be 100% accurate.

Test Name	Convert Canvas to Array
Test Description	The tester should click the etch button.
Expected Results	The image should be converted from an image to a two dimensional array of integers.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should be 100% accurate.

Test Name	Process Image
Test Description	The tester should click the etch button.
Expected Results	The user interface should convert the canvas to an image a then to a two dimensional array of integers. The image should then be iterated through to determine where the user had drawn.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds. The image should be drawn in under ten minutes.

Test Name	Handle Error
Test Description	The user should send invalid data to the microcontroller to receive an error code.
Expected Results	The user interface should display the correct error message for the given error that occurred.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	The program should respond in under three seconds.

Test Name	Send Coordinates
Test Description	The tester should hit etch.
Expected Results	The user interface should send coordinates for given array indices and the motors should move to the new position.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should be 100% accurate.

Test Name	Send Finished
Test Description	The tester should hit etch.
Expected Results	The user interface should send a command to the microcontroller and the motors should return to the starting position.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should be 100% accurate.

12.1.2 Driver Controller

Test Name	Store Program
Test Description	The tester should see if the program can be stored on the microcontroller.
Expected Results	The compiler will say successfully if it was completed.
Response to Errors	Check to see if configuration of JTAG is correct and that the code size is below 256 KB.
Response Time Degrees of Accuracy	NA

Test Name	Control Motor
Test Description	The tester should send a set of coordinates to the microcontroller to see if the motors move to a new location.
Expected Results	The motors should move, if not an error code should be returned.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should respond in under 10 seconds.

Test Name	Control Laser
Test Description	The tester should send a signal to the microcontroller to see if the laser turns on and off.
Expected Results	The laser should turn on and off, if not an error code should be returned.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should respond in under 10 seconds.

Test Name	Return Error
Test Description	The tester should send an invalid input to the microcontroller to see if an error code is returned.
Expected Results	An error code should be returned if the logic is correct.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should respond in under 10 seconds.

Test Name	Finished
Test Description	The tester should send the finished signal to the microcontroller to see if the motors return to the initial starting location.
Expected Results	The motors should move to the initial position, if not an error code should be returned.
Response to Errors	Reevaluate the program coding, find the incorrect logic, and attempt to find a solution.
Response Time Degrees of Accuracy	Should respond in under 10 seconds.

12.2 Hardware Testing

12.2.1 Laser

Test Name	Burn Radius
Test Description	Put the laser a specified distance from a material and determine the burn radius.
Expected Results	Expected to burn a 0.5 mm radius.
Response to Errors	Check design of laser and modified what is needed. If needed change diode.
Response Time Degrees of Accuracy	Burn radius should be accurate to +/- 0.1 mm.

Test Name	Burn Wood
Test Description	The laser should be able to burn a spot onto a piece of wood.
Expected Results	The wood should be burned.
Response to Errors	Check design of laser and modified what is needed. If needed change diode.
Response Time Degrees of Accuracy	NA

Test Name	Burn Glass
Test Description	The laser should be able to burn a spot onto a piece of glass.
Expected Results	The glass should be burned.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	NA

Test Name	Burn Paper
Test Description	The laser should be able to burn a spot onto a piece of paper.
Expected Results	The paper should be burned.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	NA

Test Name	Burn Plastic
Test Description	The laser should be able to burn a spot onto a piece of plastic.
Expected Results	The plastic should be burned.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	NA

Test Name	Burn Acrylic
Test Description	The laser should be able to burn a spot onto a piece of acrylic.
Expected Results	The acrylic should be burned.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	NA

Test Name	Cut Wood
Test Description	The laser should be able to cut a thin layer of wood.
Expected Results	The wood should be cut.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	NA

Test Name	Cut Paper
Test Description	The laser should be able to cut a thin layer of paper.
Expected Results	The paper should be cut.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	NA

Test Name	Temperature
Test Description	The laser should not overheat with extended use.
Expected Results	The laser should stay at a consistent relatively low temperature.
Response to Errors	Check design of laser and modified what is needed. If needed changed diode.
Response Time Degrees of Accuracy	Average working temperature should be between 30 - 40 degrees Celsius.

Test Name	Communication
Test Description	A digital potentiometer will be used to control the current going into the diode. The changes in current with respect to resistance will be measured to determine settings for the laser power output.
Expected Results	The current should vary between 1 to 1.7 A.
Response to Errors	Remove the potentiometer.
Response Time Degrees of Accuracy	NA

12.2.2 Power Supply

Test Name	TPS54531 Voltage Regulator
Test Description	The output voltage will be tested with a multimeter.
Expected Results	The results should be between 5.4 V and 1.2 A.
Response to Errors	Reconfigure or change device design.
Response Time Degrees of Accuracy	No more than 2 mV of ripple voltage.

Test Name	LM3150 Voltage Regulator
Test Description	The output voltage will be tested with a multimeter.
Expected Results	The results should be between 12 V and 3.8 A.
Response to Errors	Reconfigure or change device design.
Response Time Degrees of Accuracy	No more than 2 mV of ripple voltage.

Test Name	TPS62140A Voltage Regulator
Test Description	The output voltage will be tested with a multimeter.
Expected Results	The results should be between 4.5 V and 1.7 A.
Response to Errors	Reconfigure or change device design.
Response Time Degrees of Accuracy	No more than 2 mV of ripple voltage.

Test Name	TPS62177 Voltage Regulator
Test Description	The output voltage will be tested with a multimeter.
Expected Results	The results should be between 3.3 V and 80 mA.
Response to Errors	Reconfigure or change device design.
Response Time Degrees of Accuracy	No more than 2 mV of ripple voltage.

Test Name	AC/DC Converter
Test Description	The output voltage will be tested with a multimeter.
Expected Results	The results should be between 24 V.
Response to Errors	Reconfigure or change device design.
Response Time Degrees of Accuracy	NA

Test Name	AC/DC Ripple Voltage
Test Description	The ripple voltage will be tested with a multimeter.
Expected Results	If the value is to large increase he output capacitance or add an inductor.
Response to Errors	Reconfigure or change device design.
Response Time Degrees of Accuracy	NA

Appendices

Appendix A – Copyright Permissions

https://www.osha.gov/dts/osta/otm/otm_toc.html

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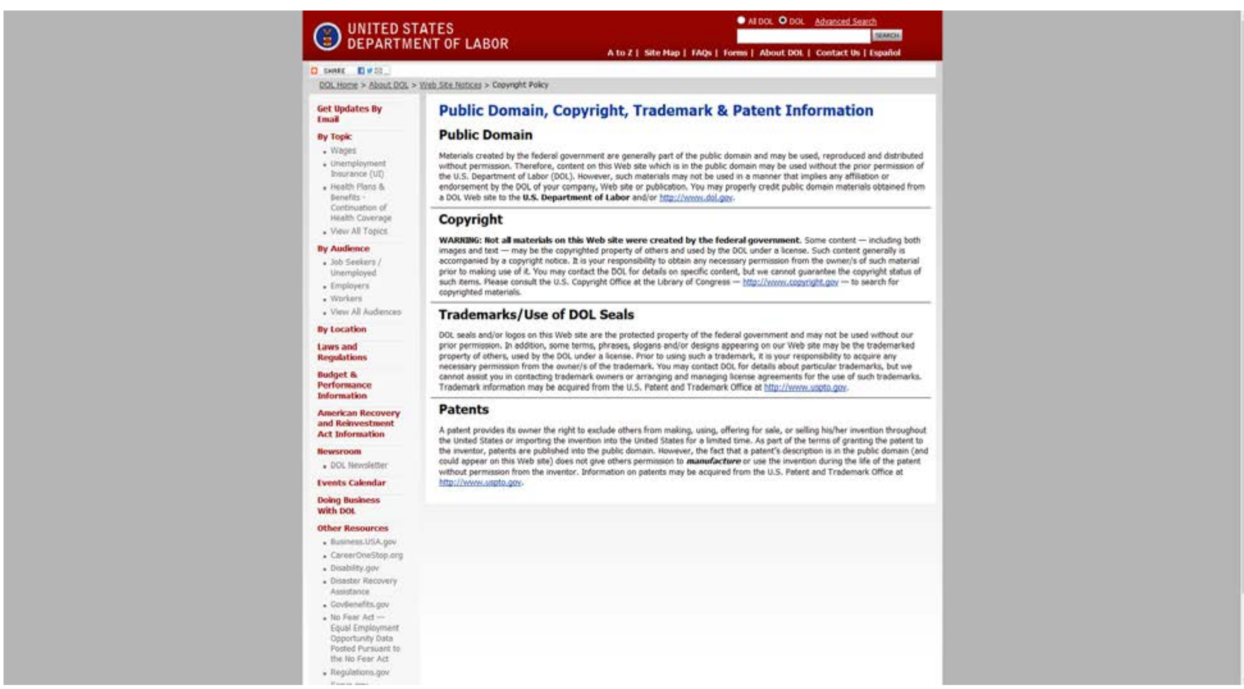
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