Enhanced Laser Inkless Printer

Critical Design Review
Group 5

Meet the Team

Jack McCain

Electrical Engineer

Miguelangel Otero

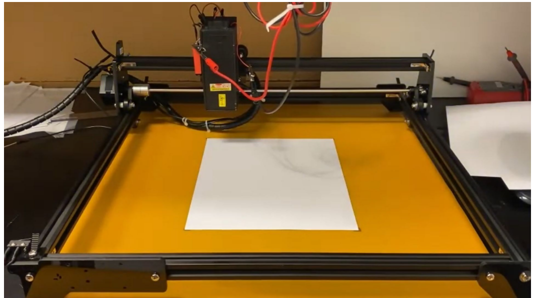
Optics & Photonics Engineer

Sarah Siverio

Computer Engineer

Motivation and Background

- Printers are an essential technology in the home and office space.
  - The ink cartridges used by these printers pose great financial and environmental risks over the long term.
- In 2020, SD2 Group 2 designed the Laser Inkless Printer (L.I.P.).
  - It was able to mark messages out on paper via pixel designs, successfully showcasing the proof of concept for this technology.
- We were inspired by their idea and message, and hope to iterate and advance upon the design.
  - Specifically, improving in the areas of speed, reliability, and system integration.



Goals and Objectives

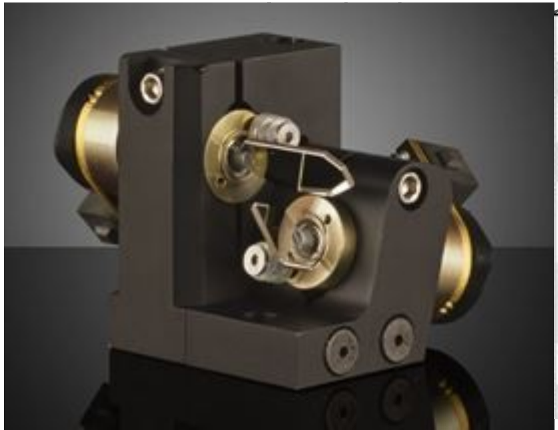
Expand character set support (letters, numbers, symbols) with software-controlled formatting.	Develop and implement laser scanning algorithms within our galvo to achieve desired horizontal and vertical movement of the laser across paper.
Achieve character linewidth of less than 30 microns.	Implement a multi-lens design to proper focus and correct for mirror adjustments.
Ensure user-friendly operation.	Utilize a basic LCD interface for updates and control inputs.
Integrate bluetooth or USB connectivity for wireless/remote print commands.	Store print logs and diagnostics in non-volatile memory, allowing persistent data across power cycles.
Incorporate safety error detection (e.g., motor stall detection, laser shut off due to overheating).	Implement dynamic power scaling for idle subsystems, and maintaining a set threshold of power consumption during operation.
Enable higher-resolution printing (>600 dpi) for more detailed text or graphics.	Investigate machine learning techniques for adaptively optimize print speed and path planning for different document layouts.
Implement capabilities for adjustable font size.	Incorporating a means of pulse-width modulation of the laser to vary burn depth or darkness.

Requirement Specifications

Engineering Requirements	Engineering Specifications	Parameters
Input Processing speed	The system will process inputs from an external source within a specified time frame.	≤ 1s
Laser error margin	The X and Y axis motors will move the laser to the correct location within a certain margin of error.	≤ 5 mm
Safe temperature	The system will maintain safe operating temperature during printing to ensure safety for users.	≤ 150 °F
Printing Speed	The system will complete a full-page print within a specified time frame	≤ 120s
Print Resolution	The system will achieve a minimum print resolution to make each letter readable, should exceed that of the previous design.	≥ 30 DPI
Printer Weight	The system will not exceed a weight that would make it not portable.	≤ 25 lbs
Printer Size	The system will be able to be fixed on a standard desk.	30” x 60”
Laser Linewidth	The system will produce characters of a linewidth on par with available items on the market.	≤ 20 µm

The Laser Galvo

- red guidance on how to use it.
- Custom ordered Galvo,Primary variation for the E.L.I.P.'s design
    - Difficulty in finding a reliable galvo from cost effective retailers like Amazon.
- Contact with ScannerMax proved very fruitful.
- Provided us a quote for their Compact 506 galvo and offe expected arrival time end of February.



COM-302-084	Compact 506 Galvo - Molex Connector, Aluminum Shaft
AMP-501-021	C506 MachDSP 24V
MOS-306-206	C506 6mm RH XY Mount (Single Piece)
CAB-500-045	45cm Standard Scanner Cable
MXG-106-002	6mm Glass X Mirror, Visible Dielectric **CONFIRM SUBSTRATE WITH RS BEFORE MFG
MYS-006-001	6mm Silicon Y Mirror, Visible Dielectric **CONFIRM SUBSTRATE WITH RS BEFORE MFG
LAB-S-2	Dual axis tuning
POW-500-060	Power Supply +- 24V 150W

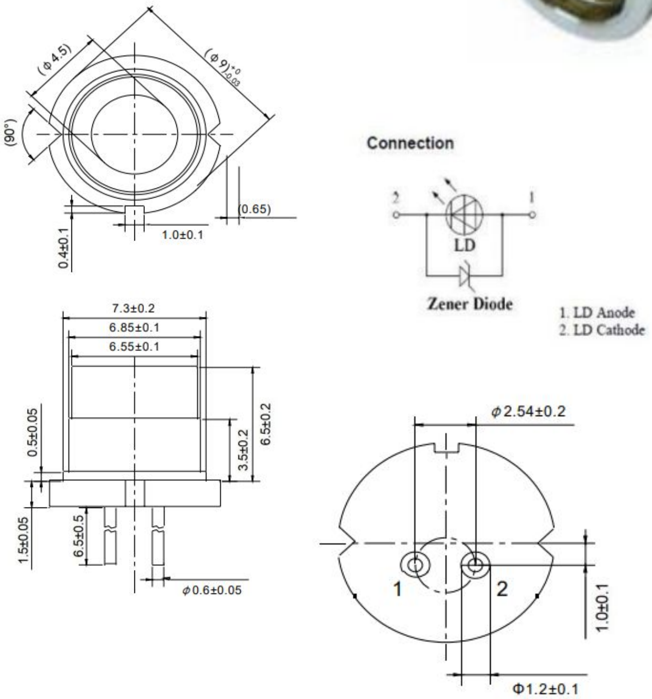
Laser Comparison

	Green Laser Diode	Blue Laser Diode	Nd: YAG Laser
Wavelength [nm]	530	445	1064
Average Power [W]	0.6 - 2.75	6 - 8	25
Beam Quality [M^2]	>2	1 - 1.1	1.2 - 1.7
Beam Divergence [mrad]	0.4	0.2	0.34
Lifetime [h]	25,000	30,000	830 (lamp)

- Nd:YAG, while well researched and effective, had too many cons if implemented.
- Blue provided an excellent mix of benefits that outweighed its negatives for the previous design.
- Green is capable of engraving non-paper materials (e.g., xTools), but was disregarded in the previous design.

Chosen Laser Diode

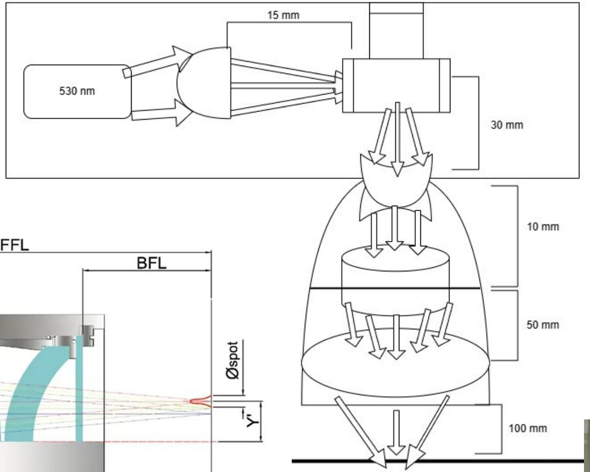
- LaserTree Green Laser Zener Diode: 530 ± 2 nm
- Multimode
- Optical Output Power: 1.65 W
- Threshold Current: 150 - 500 mA
- Operating Voltage: 4.0 - 5.5 V
- Parallel Divergence: 0.2 - 0.6°
- Perpendicular Divergence: -1.0 - 1.0°

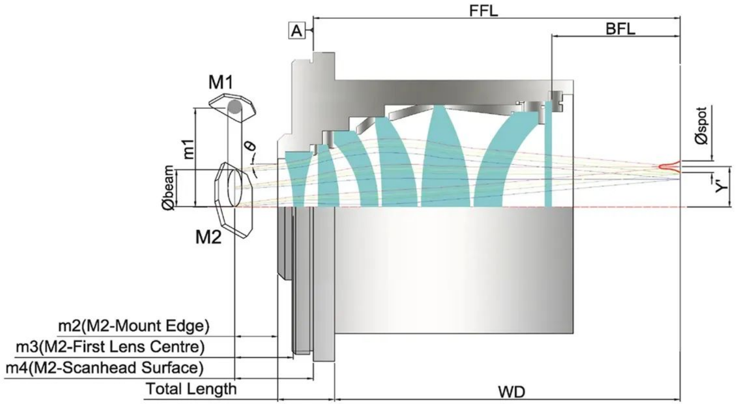


Optical Hardware Components-Lenses

Aspheric Lens	D = 5 mm Coating: 350 - 700 nm f = 15.3 mm
Biconcave Lens	D = 9 mm Coating = 350 - 700 mm f = -9 mm
Achromatic Doublet Lens	D = 25.4 mm Coating = 400 - 700 mm f = 150 mm
Positive Meniscus Lens	D = 50.8 mm Coating = 350 - 700 nm f = 100 mm

- For effective galvo usage, flat-field image plane is required.
- Focused → Reflection → “F-Theta” Setup





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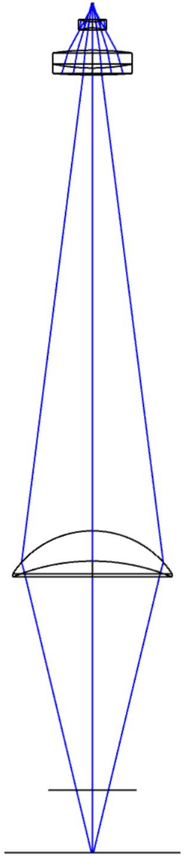
Lens and Power Calculations

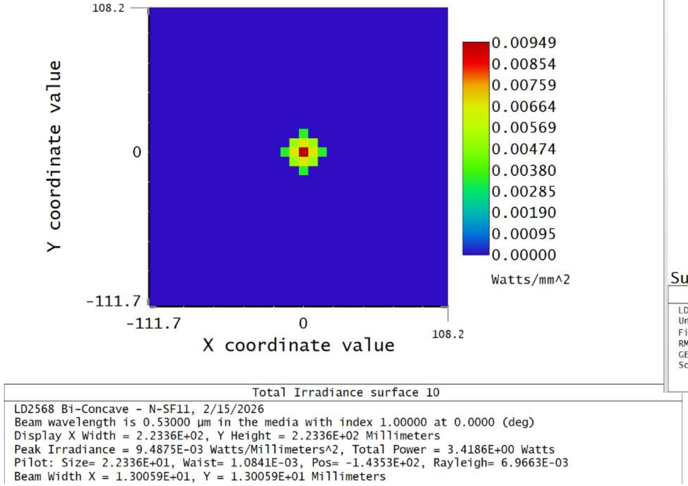
- Effective focal length calculations
  - dAB = 10 mm, dBC = 50 mm

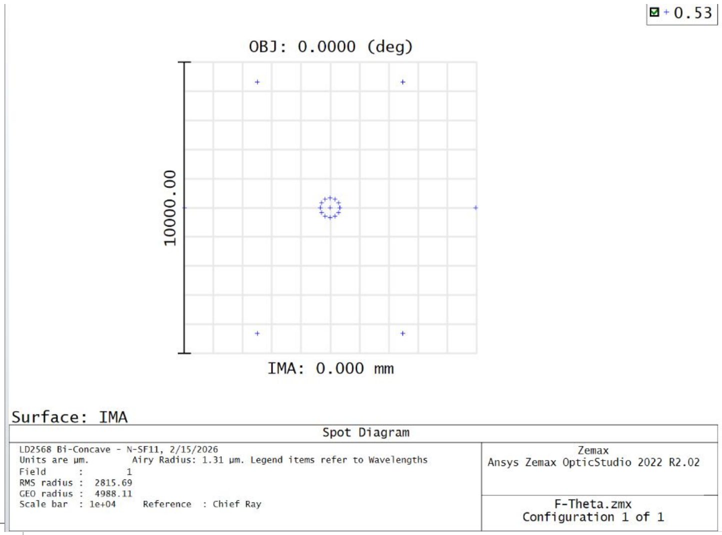
- $f_{AB} = (1/fbiconcave + 1/fachromatic - dAB/(fbiconcave * fachromatic))^{-1}$
- $f_{eff} = (1/fAB + 1/fmeniscus - dBC/(fAB * fmeniscus))^{-1}$
  - $f_{eff} = 115.4\ mm$

- Power loss calculations
  - For each lens surface: Pt = Pin*(1 - T)^n
  - For the reflectance of the mirrors: Pr = Pin*R
    - Pout = 1.5385 W

Lens Simulation Results

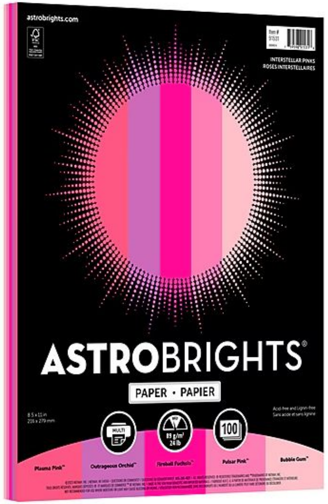






Paper Analysis

- Astrobrights: Interstellar Pinks
- Magenta colored - complementary to green
- Weight: 89 g/sm
- Estimated Thickness: 0.0045 - 0.005 in
- 20% thicker than standard paper
- Lignin and Acid-free



Comparison of software

- Embedded Control, OS, and Communication Technologies

Component	Options Considered	Key Comparison Factors	Selected
MCU Platform	Arduino, STM32, ESP32	Real-time capability, wireless integration, processing headroom	ESP32
Operating Model	Superloop, TI-RTOS, FreeRTOS	Determinism, task scheduling, synchronization	FreeRTOS
Firmware Language	Python, MicroPython, C/C++	Latency, hardware control, timing accuracy	C/C++
Wireless Protocol	USB/UART, Wi-Fi, BLE	Latency, mobility, system integration	BLE (NimBLE)

Microcontroller comparison

Microcontroller	Advantages	Disadvantages	Approx. Cost
STM32F4	Built-in DACs, strong RTOS support. Supports Ethernet for network integration.	Higher complexity in development compared to Arduino boards.	$14-20
Teensy 4.1	Extremely fast Cortex-M7 core, strong library support, excellent for high frequency control	No built-in DAC on 4.x series, requires external DAC hardware.	$29-35
Raspberry Pi Pico	Very low cost, strong support, PIO state machines allow precise waveform generation.	No onboard DAC; Ethernet/networking requires additional hardware	$4-6
ESP32	Integrated Wi-Fi and Bluetooth, moderate real-time performance, supports FreeRTOS by default.	Limited DAC resolution, high jitter for precision tasks	$5-10
STM32WB	Dual-core architecture(Cortex-M4 + M0+) with integrated Bluetooth low energy. Built-in DAC for precise galvo control.	Slightly higher development complexity due to dual-core coordination and BLE stack management	$10-15

Selection of software

- Selected Software Architecture

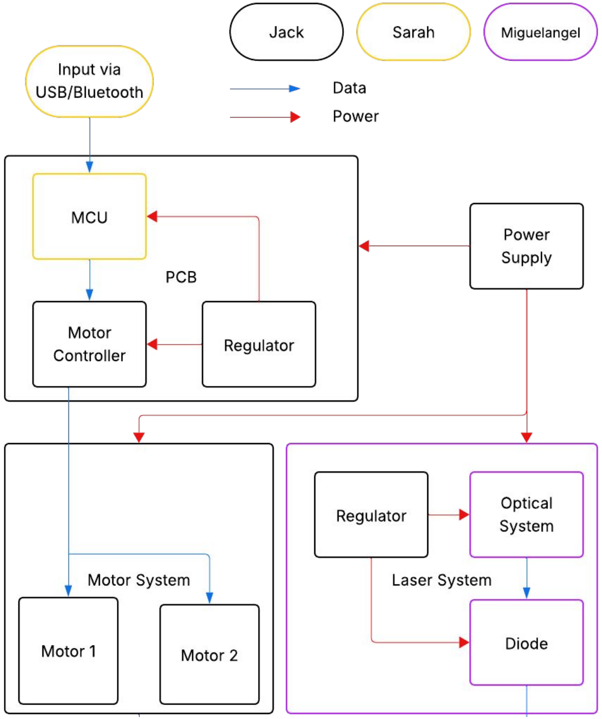
Layer	Technology	Rationale
Firmware Platform	ESP32 + FreeRTOS	Dual-core isolation of real-time control and communication tasks.
Control Logic	C/C++	Low-latency DAC control, direct hardware access
Task Management	FreeRTOS	Preemptive scheduling, priority inheritance, watchdog supervision
Communication	BLE (NimBLE)	Low-latency wireless control and OTA firmware updates
User Interface	nRF Connect	Protocol compatibility, BLE support, testing flexibility

Regulator Comparison

Regulator	Advantages	Disadvantages	Approx. Cost
Linear (LM7805)	Simple, low noise	Less efficient, generates more heat	$0.5-1
Buck (LM2596T)	Up to 3A output, wide input range, high efficiency, already comfortable with it.	Moderate output ripple	$1.50
Buck (TPS5430)	3A output, reliable with good efficiency	Not as comfortable with compared to LM2596T	$2-4

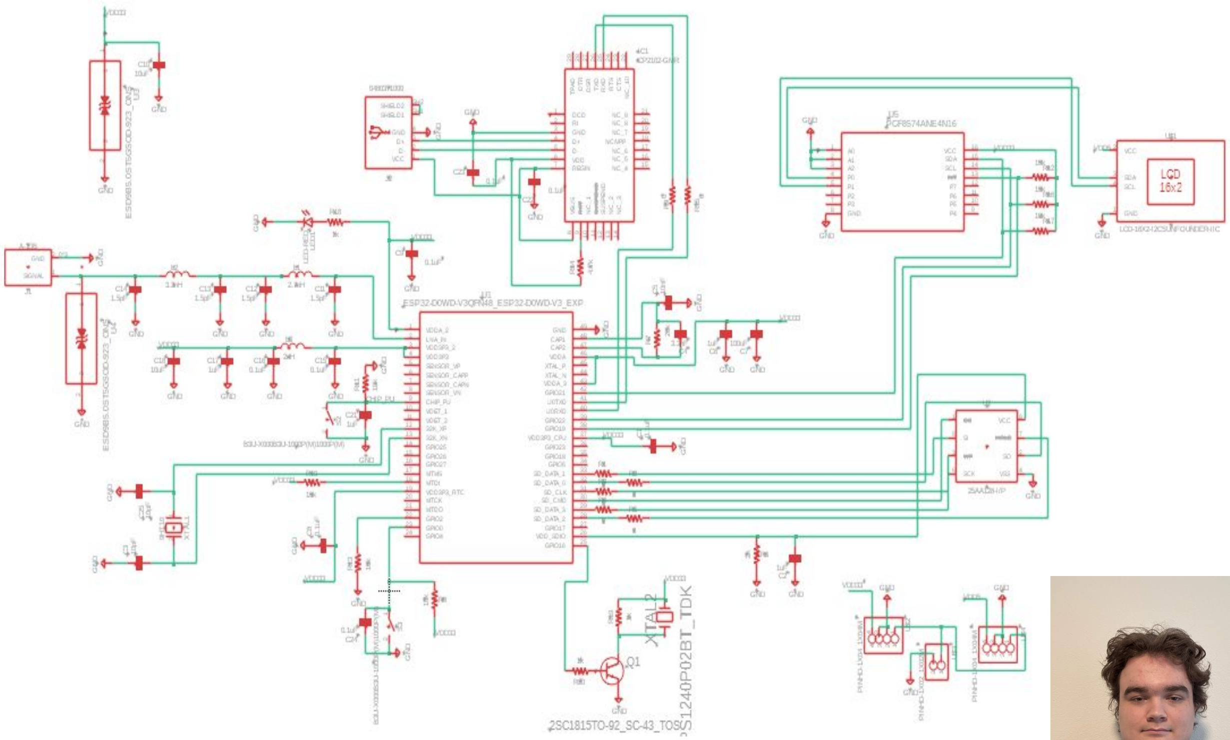
Hardware Block Diagram

- Hardware Goals:
    - Maintain stable output voltages in PSU and regulators.
    - Ensure the components don't overheat
    - Ensure data is able to be reliably transferred between MCU and Motor Controller
- Overview:
    - Data fed into MCU via USB/Bluetooth
    - MCU transfers data to Motor Controller
    - Motor Controller uses data to move galvo motors into position



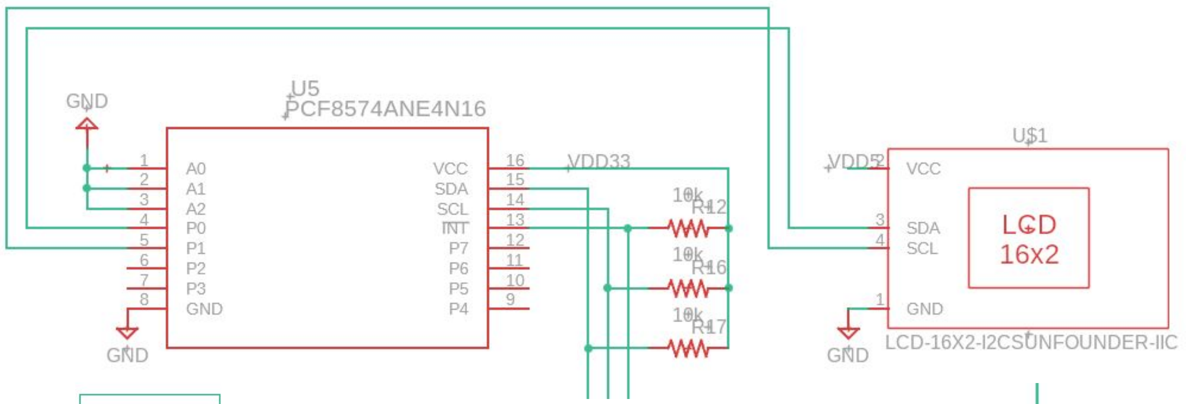
PCB Design: MCU

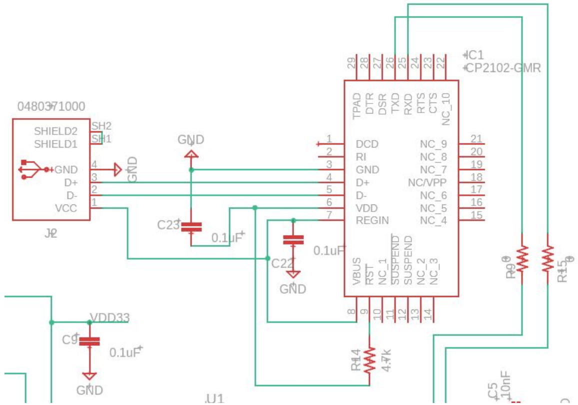
- ESP32
- Antenna for improved bluetooth performance
- Connected to regulators with 1x4 pin headers



PCB Design: ESP32 peripherals

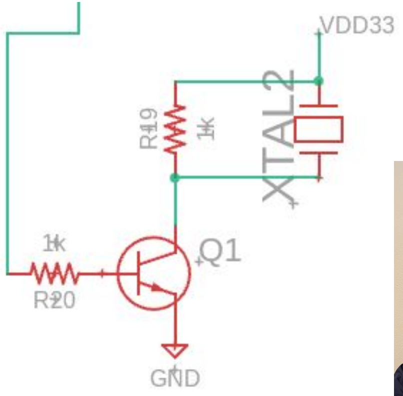
LCD using PCF8574 for I2C





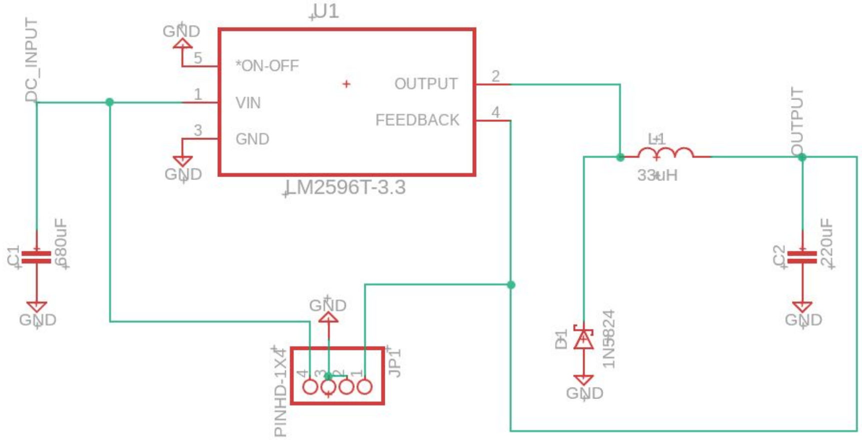
USB-A with CP2102 Serial Bridge

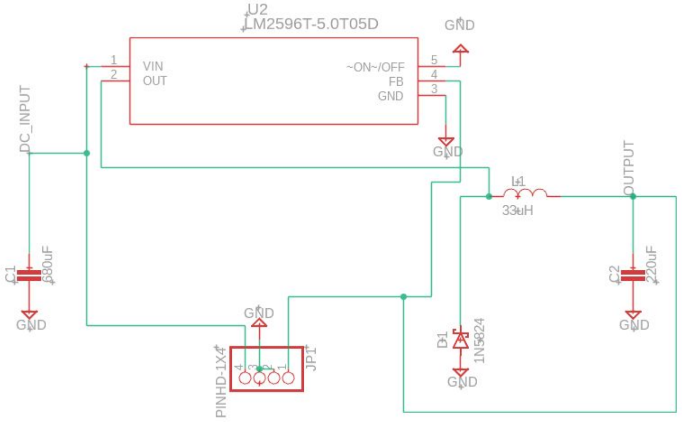
Buzzer



PCB Design: 3.3V and 5V regulator schematics

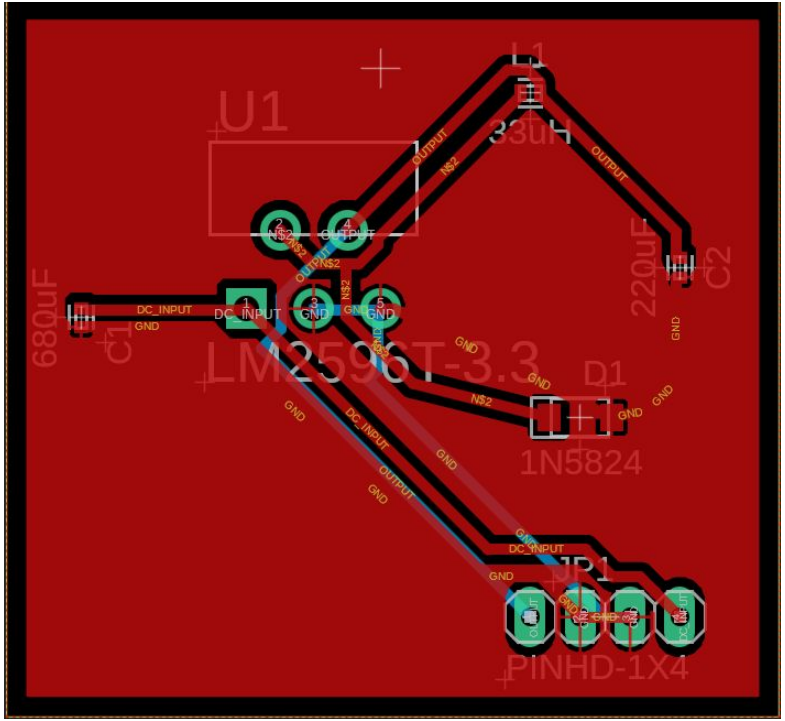
- 3.3V powers most peripherals on the MCU
- 5V powers the LCD and laser diode driver



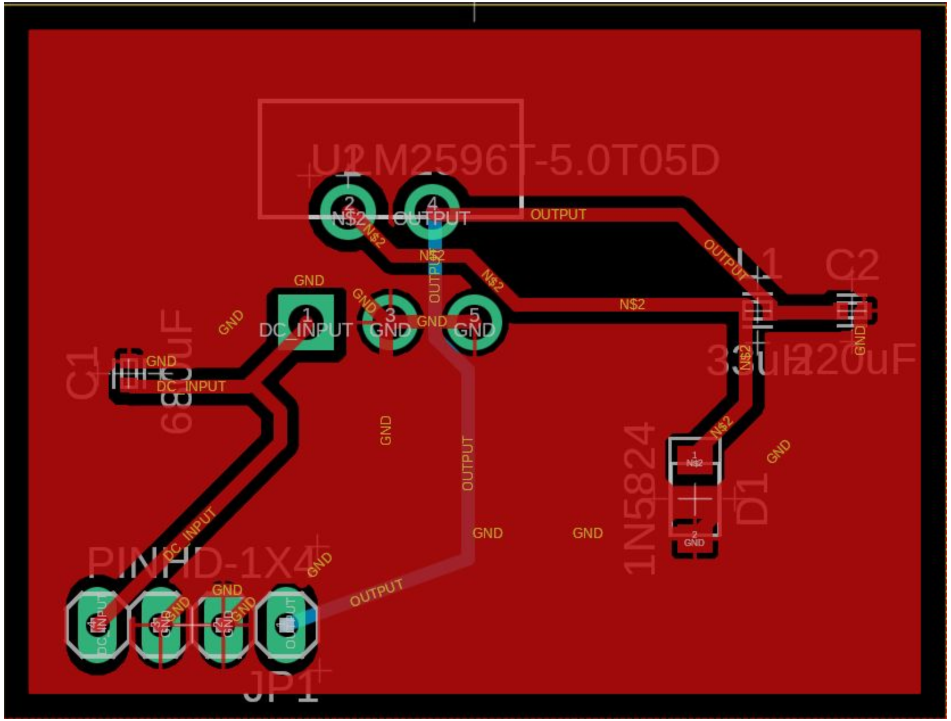


PCB Design: 3.3V and 5V regulator pcb

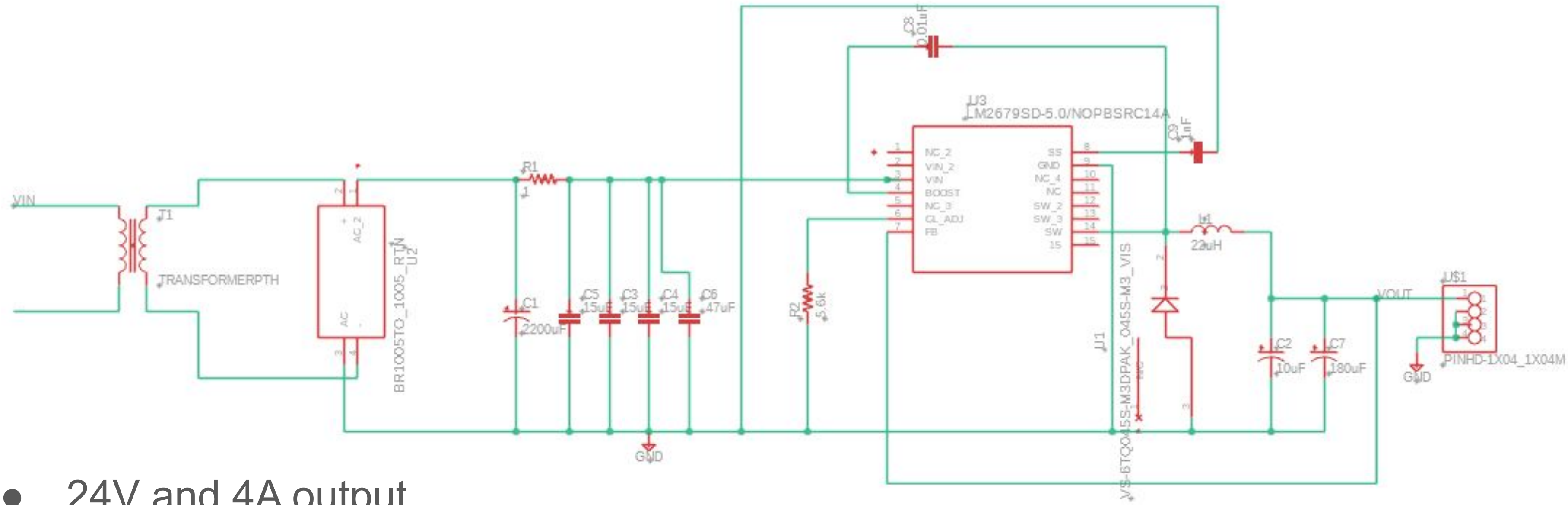
3.3V



5V

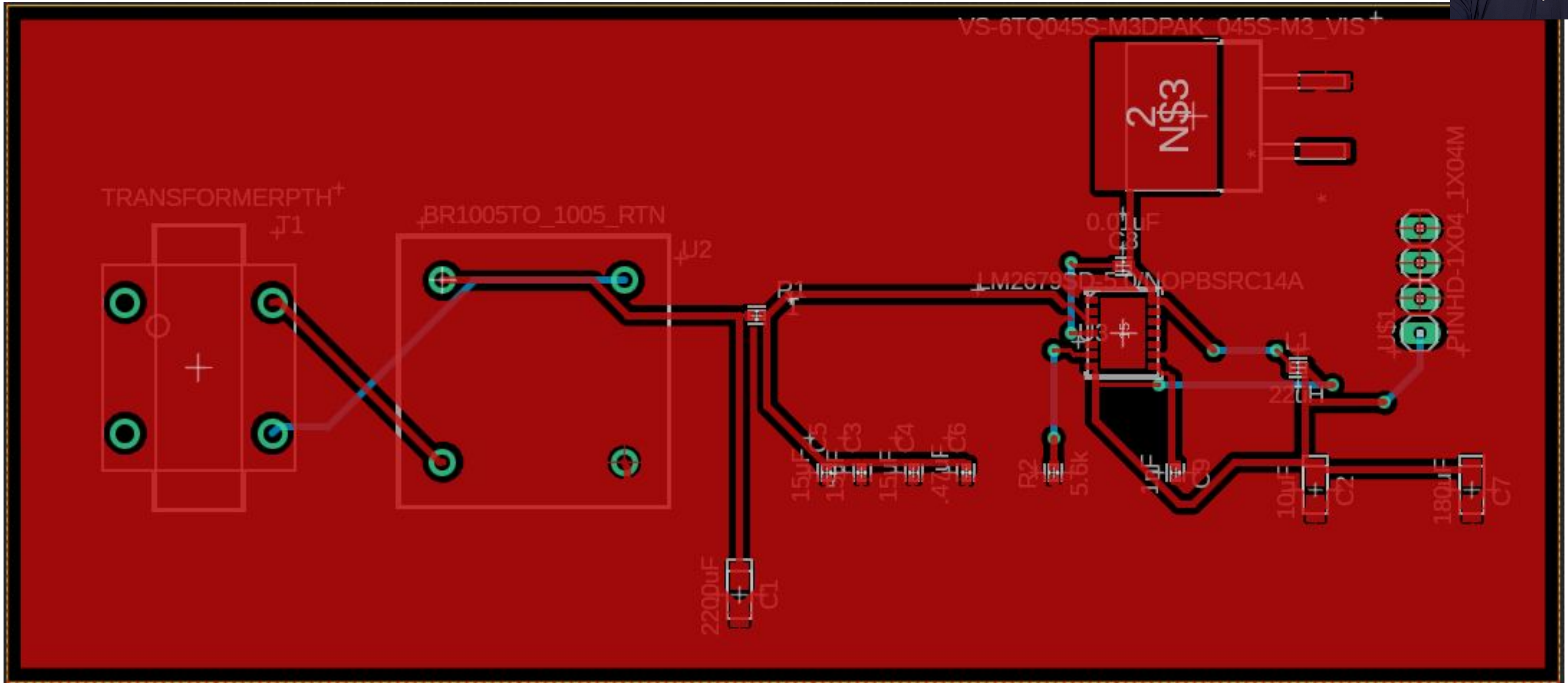


PCB Design: Power Supply schematic



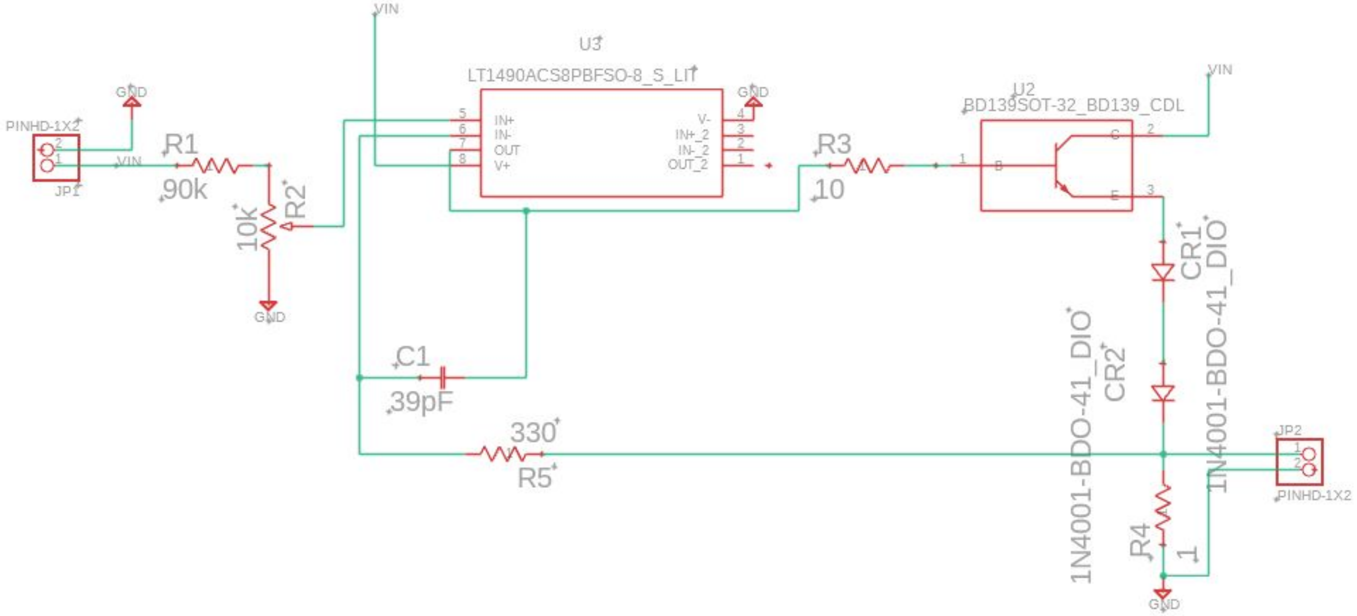
- 24V and 4A output
- Regulated by 3.3V and 5V regs on the MCU
- LM2679SD recommended by Dr. Weeks

PCB Design: Power Supply schematic

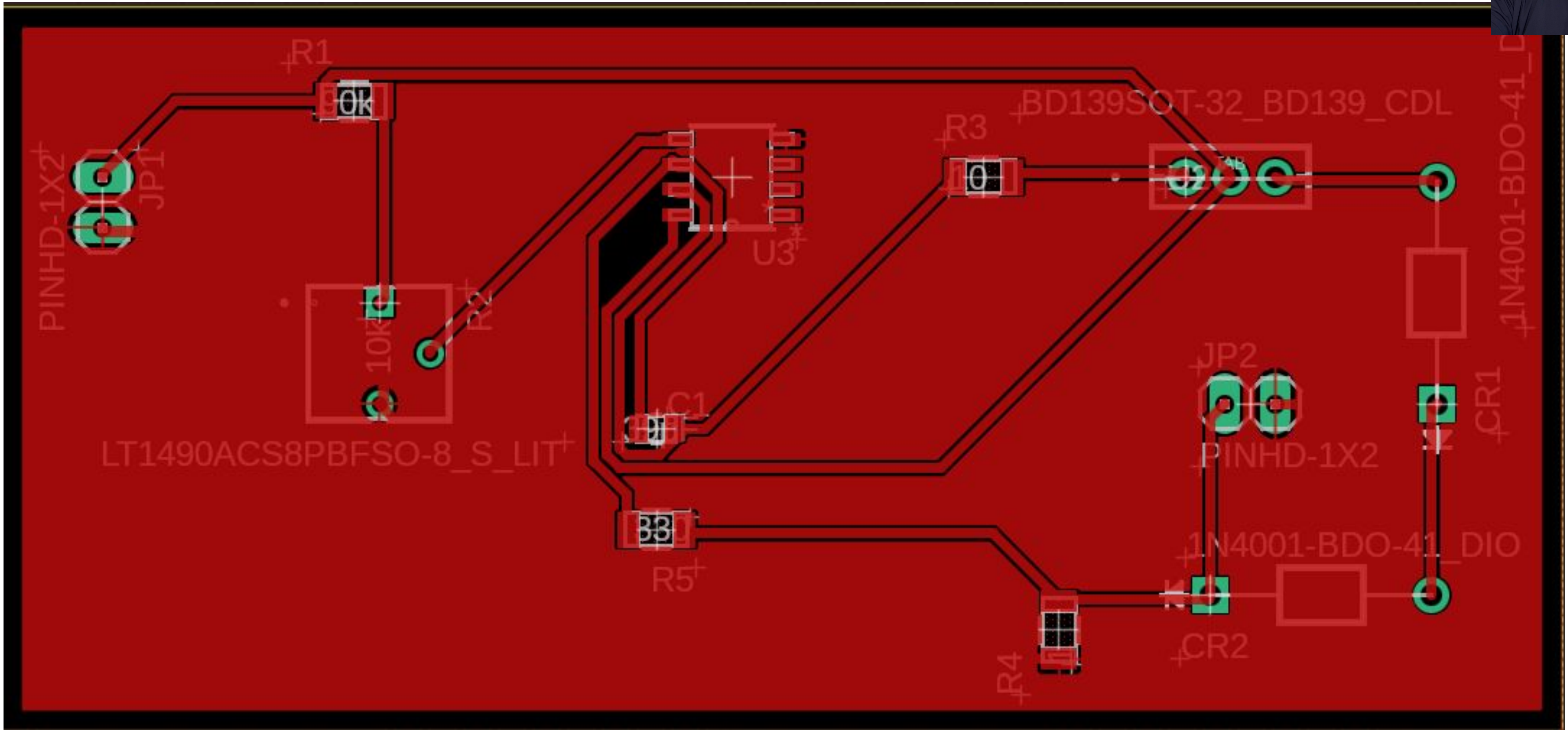


PCB Design: Laser Diode Driver schematic

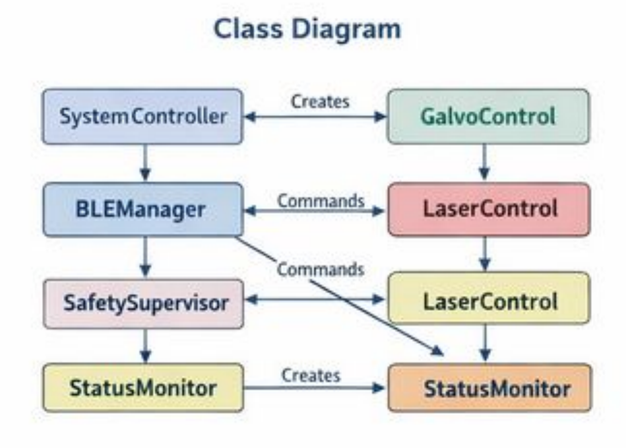
- 5V, 0-500mA laser diode driver
- Connected to 5V regulator on MCU board



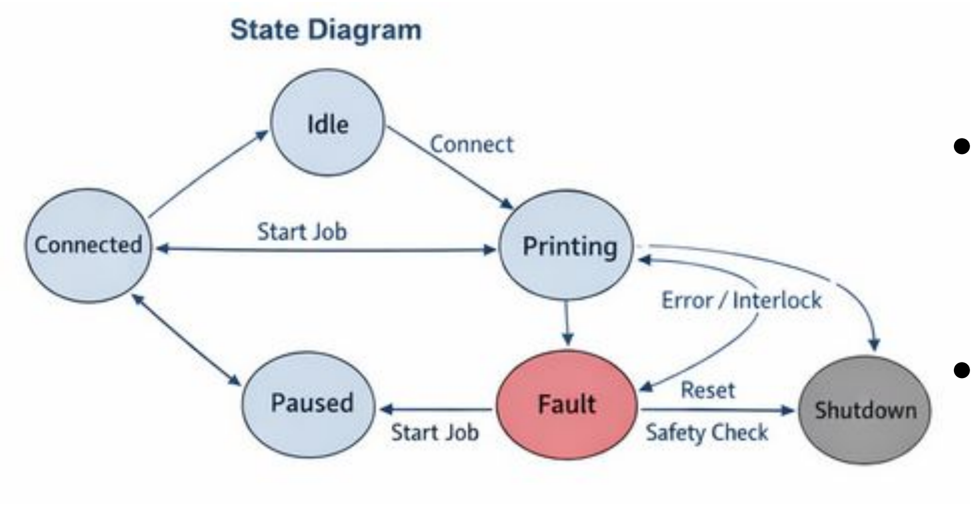
PCB Design: Laser Diode Driver



Software Design

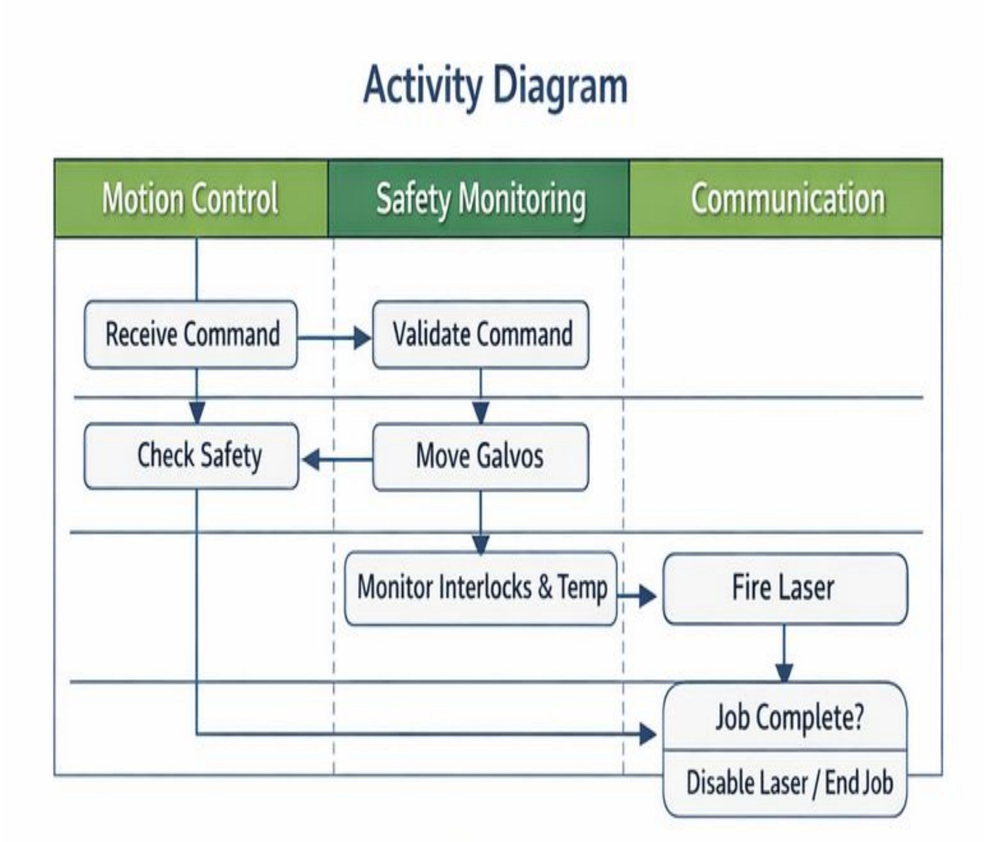


Software Design Cont.



- The system operates using a **finite state machine (FSM)** implemented within the ESP32 firmware.
- Upon BLE connection, the system transitions from **Idle** -> **Connected**, enabling command reception
- When a valid job command is received, the controller enters the Printing state, where galvo motion and laser firing are actively managed.
- If a safety violation or interlock trigger the system transitions immediately to the **Fault** state.

Software Design Cont.



1. **Motion Control**
   - Receives validated motion commands from the communication layer.
   - Converts command data into galvo positioning updates
   - Coordinates laser enable timing

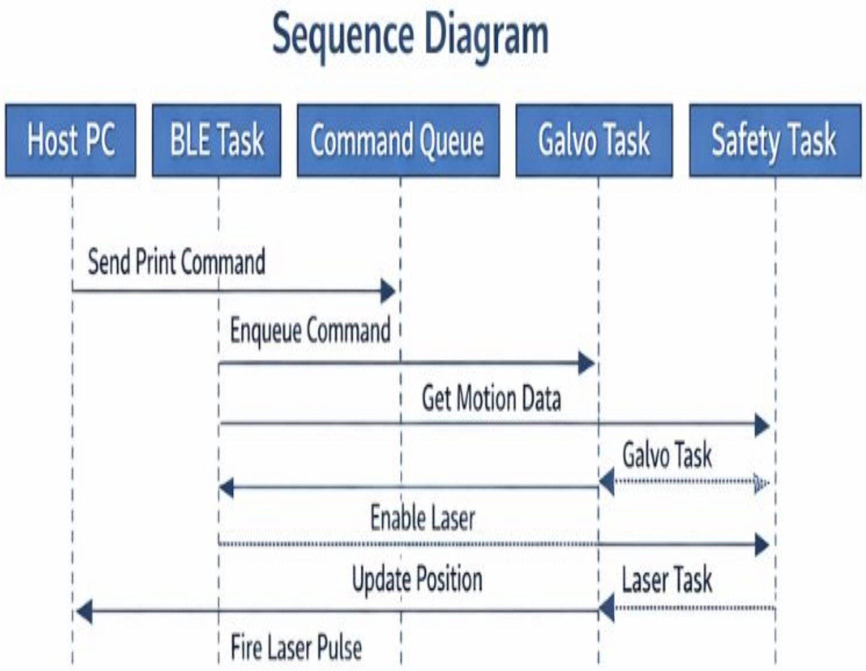
Safety Monitoring
- Continuously monitors hardware interlocks
- Validates each command before execution
- Can interrupt motion and disable the laser in real-time if violation is detected.

Communication
- Handles BLE commands & job status updates
- Determines job completion conditions
- Ensures laser is disabled at the end of a job

Software Design Cont.

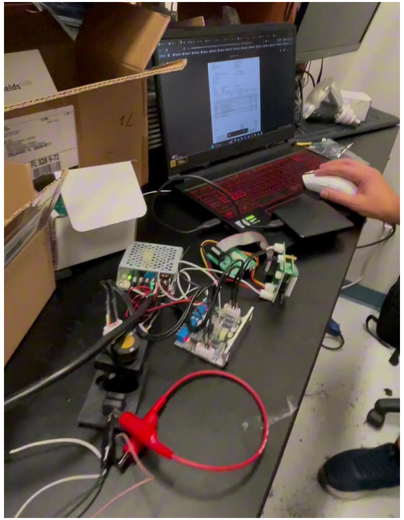
Real-Time Command Execution Flow

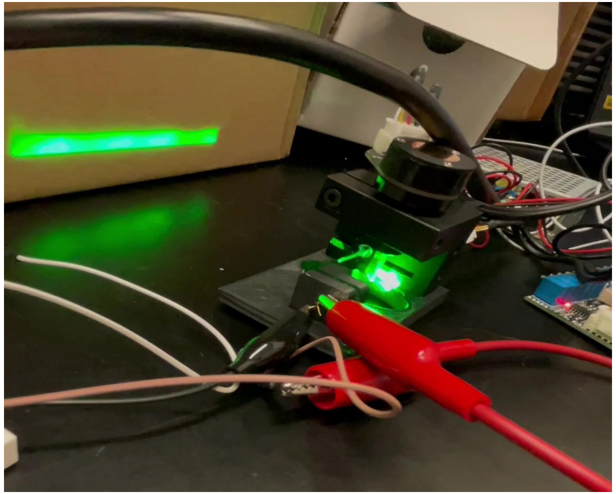
1. The Host PC sends a print command over BLE.
2. The **BLE Task** receives and parses the command.
3. The command is placed into a **FreeRTOS** queue for processing.
4. The **Galvo Task** retrieves motion data and updates mirror positioning.
5. The **Safety Task** verifies conditions before enabling the laser.
6. Once Cleared, the system:
    - Enables the laser
    - Updates galvo position
7. The system repeats this cycle until job completion.



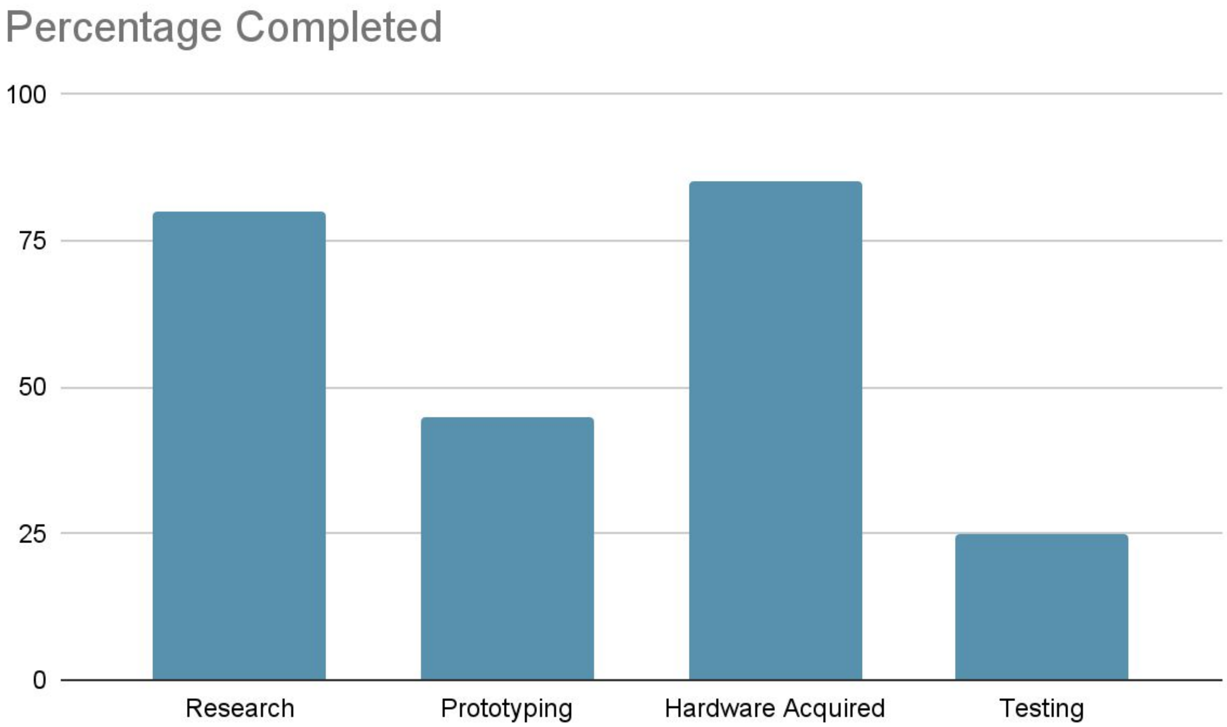
prototyping and testing

- Software testing:
  - ESP32 Dev board testing
- Hardware testing:
  - Testing regulators with breadboards
  - Testing laser diode with the breadboarded regulators
  - Used a cheap galvo to ensure we could power it
  - We also tested the thermals
- Our initial testing showed that the parts worked together
- We need the main galvo to ensure that we can control it effectively with the esp32
- During our testing we saw that we would need more cooling than initially planned





Progress Chart



Progress and Plan of Action

- Progress
  - Most essential hardware materials have been acquired or ordered and are expected to arrive before March.
  - Initial versions of the software are ready for initial implementation.
- Plan of Action
  - The galvo obtained from Amazon will be experimented on for the Midterm Demo.
  - Further iterate on 3D models for holding the system as the electronics and final galvo are used.

Budget

Component	Part Number/Number	Quantity	Unit Price
Green Laser Diode	Laser Diode LT-LD-530-1650M-C	1	$130.00
Laser Diode Driver	LDS9 (TL)	1	$107.10
Safety Goggles	EaglePairOD7+ 190nm - 540nm	1	$54.00
Safety Window	Foldable Laser Shield	1	$100.00
ScannerMAX Compact 506 Galvo		1	$2,316.80
Glass Aspheric Lens	A260TM-A	1	$105.32
Biconcave Lens	LD2568-A	1	$ 44.81
Achromatic Doublet Lens	AC254-150-A	1	$ 95.34
Positive Meniscus Lens	LE1076-A	1	$ 61.64
PCBs	JLCPCB	4	~$150.00
PCB Parts	DigiKey	~50	~250.00
Fans + Heatsinks	Amazon	3	$15.00
Paper	Astrobrights: Interstellar Pinks	1	$7.00
Filament	Bambu PLA, Polymaker ASA	3	$65.00
ESP32	ESP32-DevKitC-32	6	$28.26
Tentative Total			$3,388.24

Work Distribution

Jack McCain: EE

- ESP32 Design
- Power System
- PCB Building

Miguelangel Otero: PSE

- Laser System
- Lens design
- 3D printed housing designs

Sarah Siverio: CPE

- ESP32 Firmware Development
- BLE Communication Integration
- System Control & Task Management (FreeRTOS)

Thank you for watching!