# Enhanced Laser Inkless Printer

Final Presentation
Group 5

# Meet the E.L.I.P.Team

Jack McCain

Electrical Engineer

Miguelangel Otero

Optics & Photonics Engineer

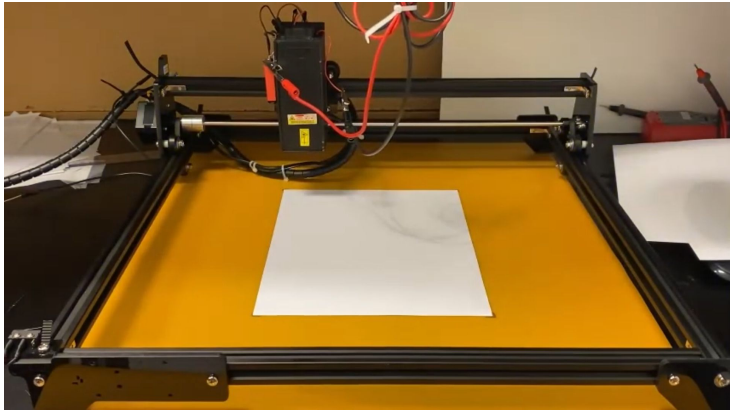
Sarah Siverio

Computer Engineer

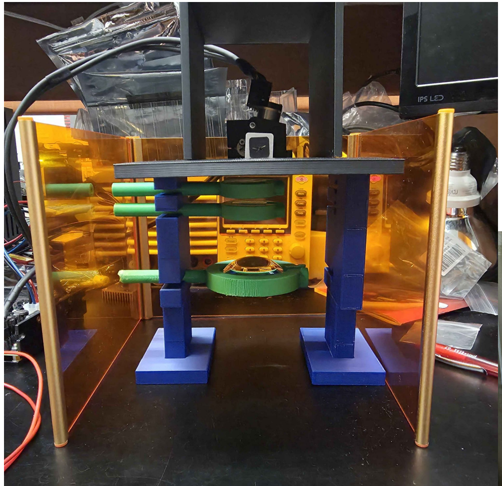
# Motivation and Background

- 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.

Original L.I.P.



E.L.I.P.



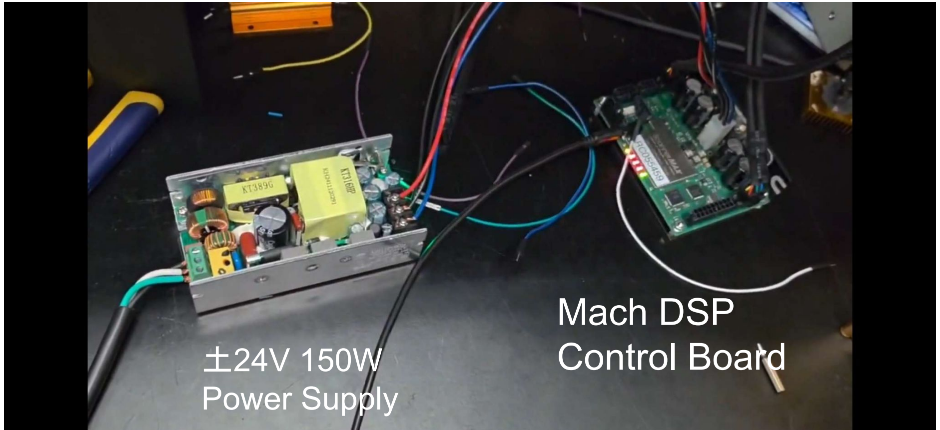
# Requirement Specifications

| 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” |
| Output Linewidth | The resulting marks should be fine and legible, like when writing with a pencil.. | ≤ 0.9 mm |

| Goals | Objectives |
|---|---|
| B - Utilize alternative technologies to advance upon the previous design. | Develop a laser galvanometer-based system to improve on the print speed of the previous deisng. |
| B - Expand upon the character list, ensuring fine and legible marking on paper. | Implement a multi-lens design to proper focus and correct for mirror adjustments. |
| B - Ensure user-friendly operation. | Utilize a basic LCD interface for updates and control inputs. |
| A - 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. |
| A - 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. |
| S - 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. |
| S - Implement capabilities for adjustable font size. | Incorporating a means of pulse-width modulation of the laser to vary burn depth or darkness. |

# The Laser Galvanometer (Galvo)

- Custom ordered galvanometer, 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 galvanometer.
  - Attached are some of the included parts for the galvanometer.





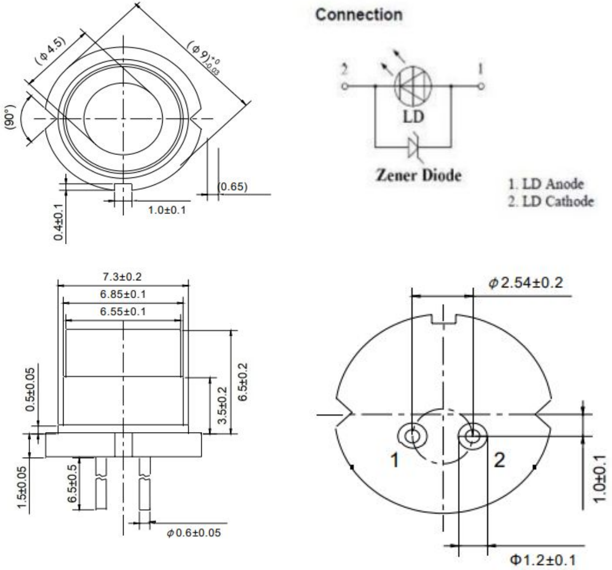
# Laser Comparison

| | 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.

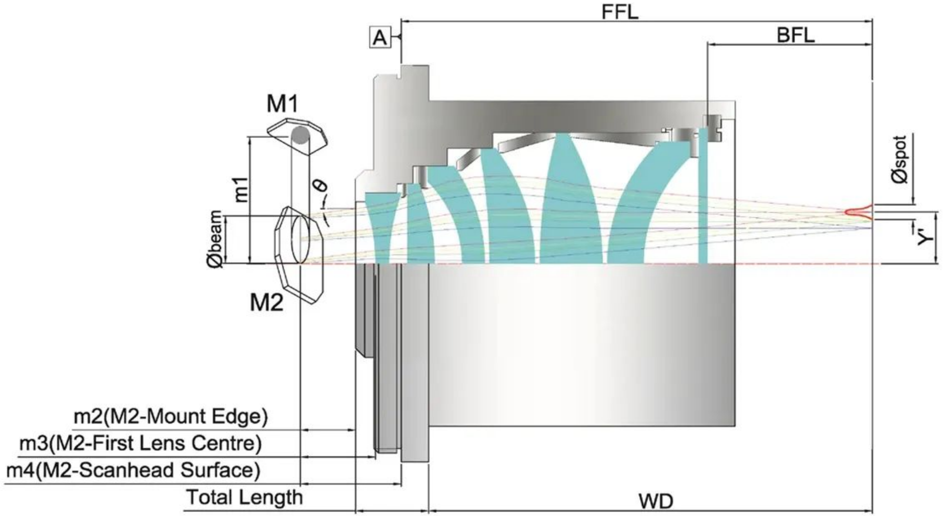
# Selected Laser Diode

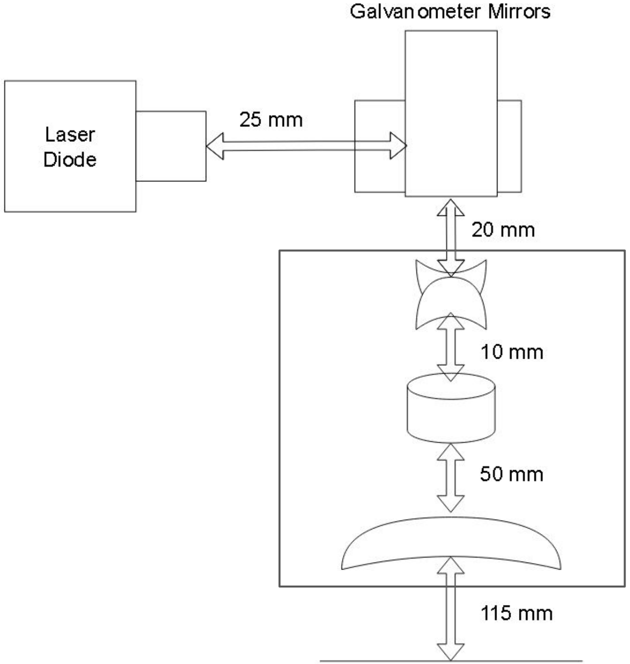
- LaserTree Green Laser Zener Diode: 530 ± 2 nm
- Multimode
- Built-in Fast Axis Collimation Lens (FAC)
- Optical Output Power: 1.65 W
- Forward Current: 2.3 A
- Operating Voltage: 4.0 - 5.5 V
- Parallel Divergence: 0.2 - 0.6°
- Perpendicular Divergence: -1.0 - 1.0°




# Optical Hardware Components-Lenses

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




# Lens, Power, and Spot Size Calculations

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

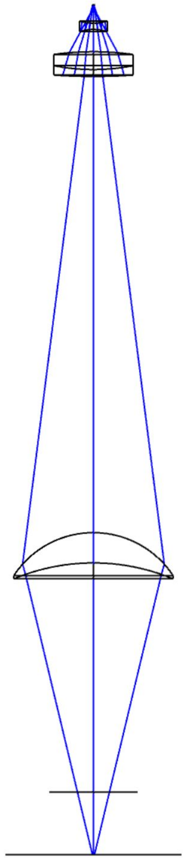
- $f_{AB} = (1/fbiconcave + 1/fachromatic - dAB/(fbiconcave * fachromatic))^{-1}$
- $f_{eff} = (1/fAB + 1/fmeniscus - dBC/(fAB * fmeniscus))^{-1}$
  - $f_{eff} = 115.4\ mm$

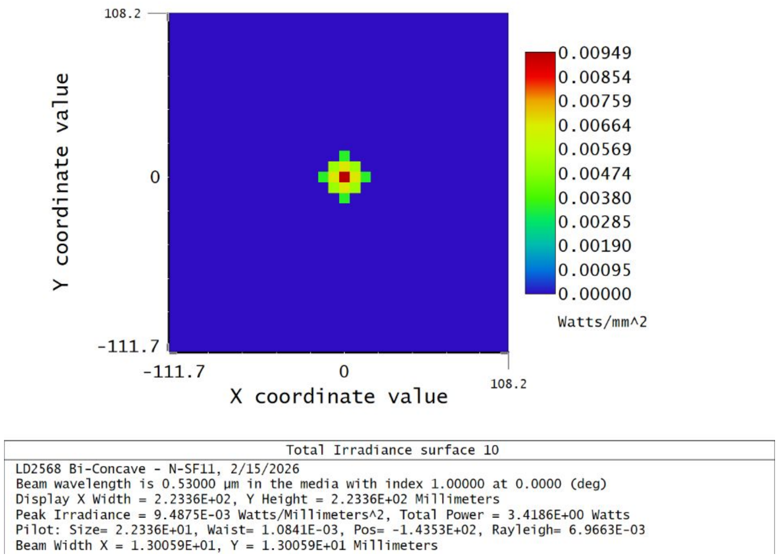
- Power loss calculations
  - For each lens surface: Pt = Pin*(1 - T)^n
  - For the reflectance of the mirrors: Pr = Pin*R
    - Pout = 1.5385 W
- Diffraction Limited Spot Size
  - M^2 = 2

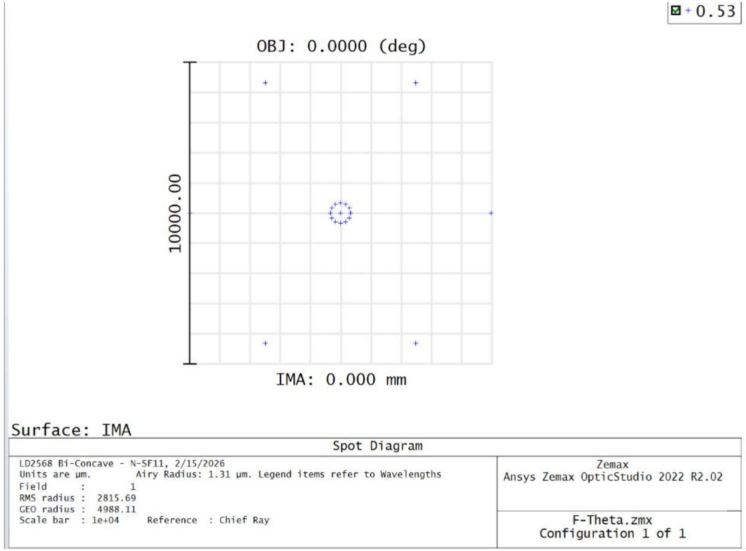
- $Ds = (1.27 * M^2 * 530nm * 115mm)/4.5mm$
  - Ds = 34.5 µm

| | |
|---|---|
| Biconcave Lens | D = 9 mm<br>Coating = 350 - 700 mm<br>f = -9 mm |
| Achromatic Doublet Lens | D = 25.4 mm<br>Coating = 400 - 700 mm<br>f = 150 mm |
| Positive Meniscus Lens | D = 50.8 mm<br>Coating = 350 - 700 nm<br>f = 100 mm |

# Lens Simulation Results

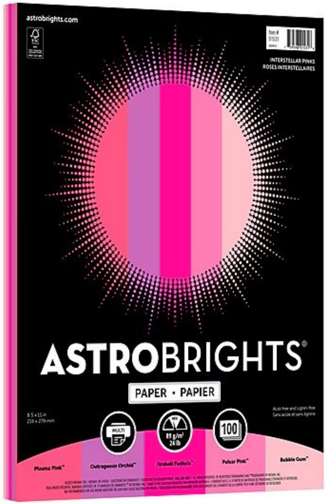





# Paper Analysis

| |
|---|
| 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

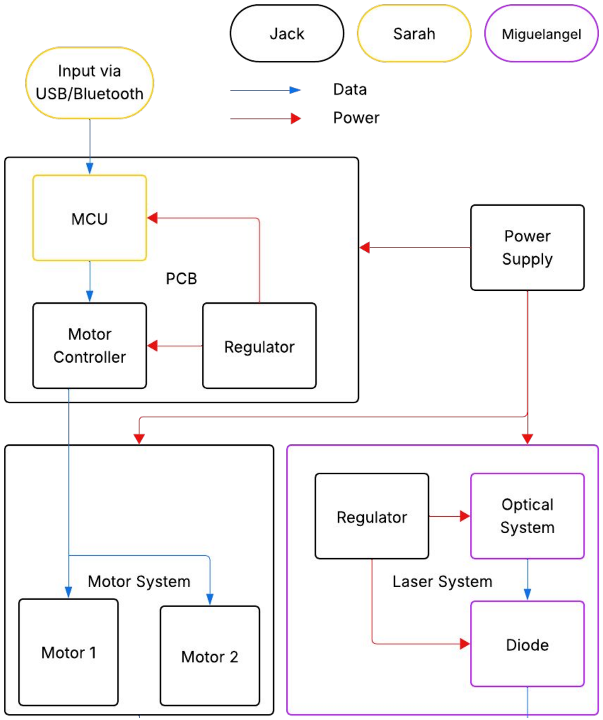
| Layer | Technology | Rationale |
|---|---|---|
| Firmware Platform | ESP32 + FreeRTOS | Dual-core isolation of real-time control and communication tasks. |
| Control Logic | C/C++ | Low-latency DAC control, direct hardware access |
| Task Management | FreeRTOS | Preemptive scheduling, priority inheritance, 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 |

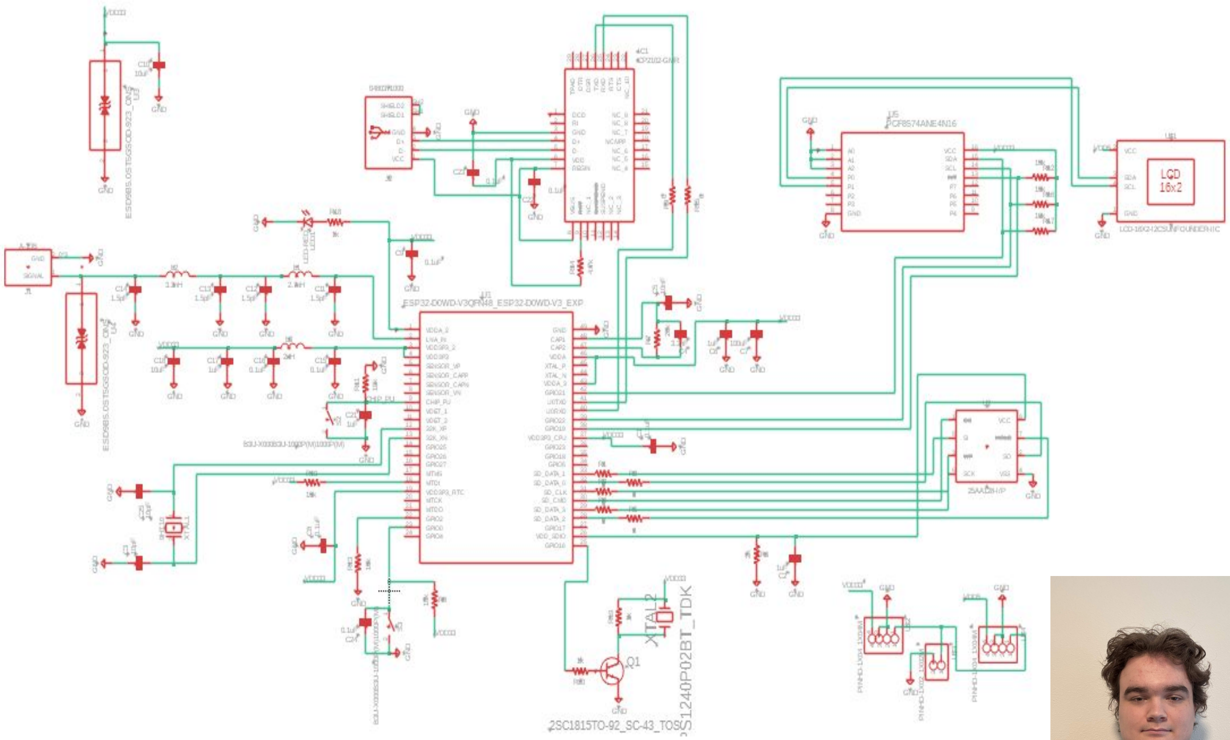
# Hardware Block Diagram

- 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



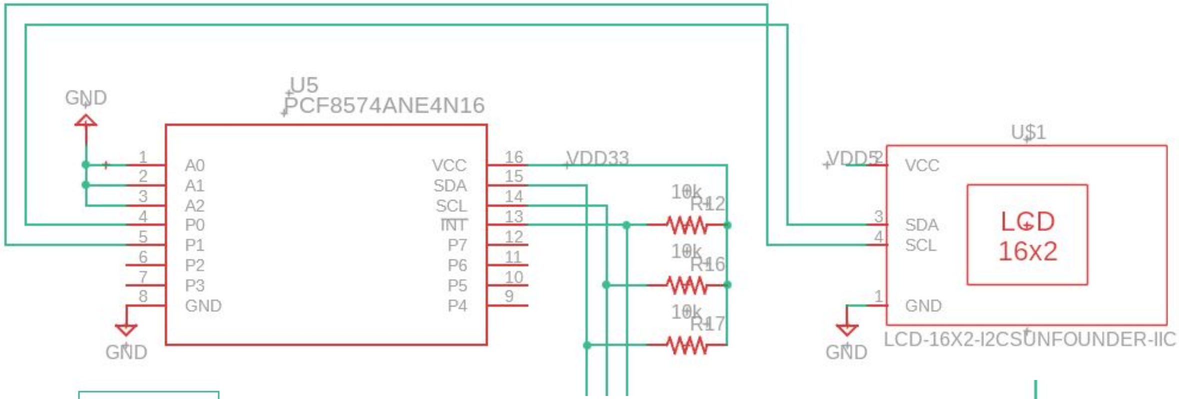

# PCB Design: MCU

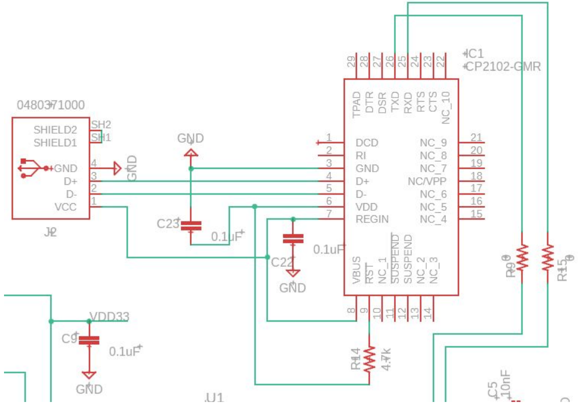
- ESP32
- Antenna for improved bluetooth performance
- Connected to regulators with 1x4 pin headers




# PCB Design: ESP32 peripherals

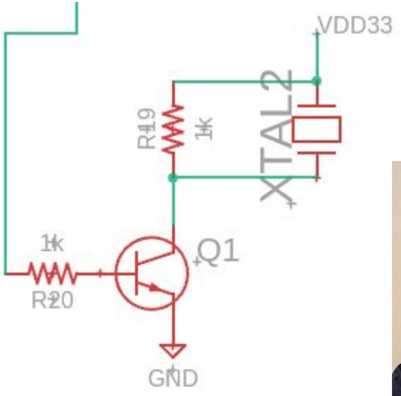
LCD using PCF8574 for I2C



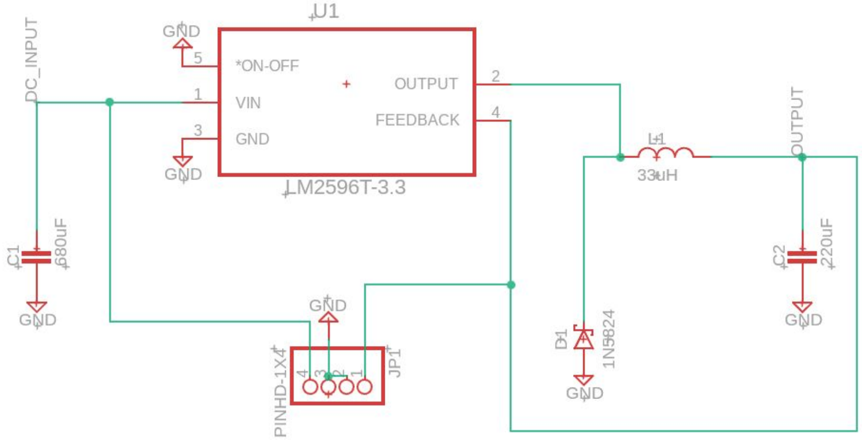

USB-A with CP2102 Serial Bridge

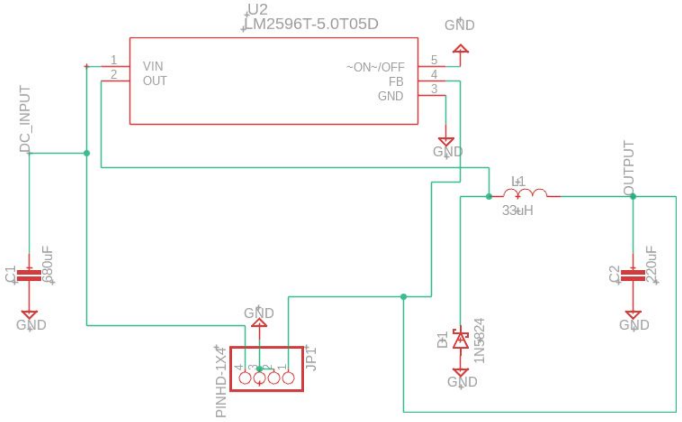
Buzzer




# PCB Design: 3.3V and 5V regulator schematics

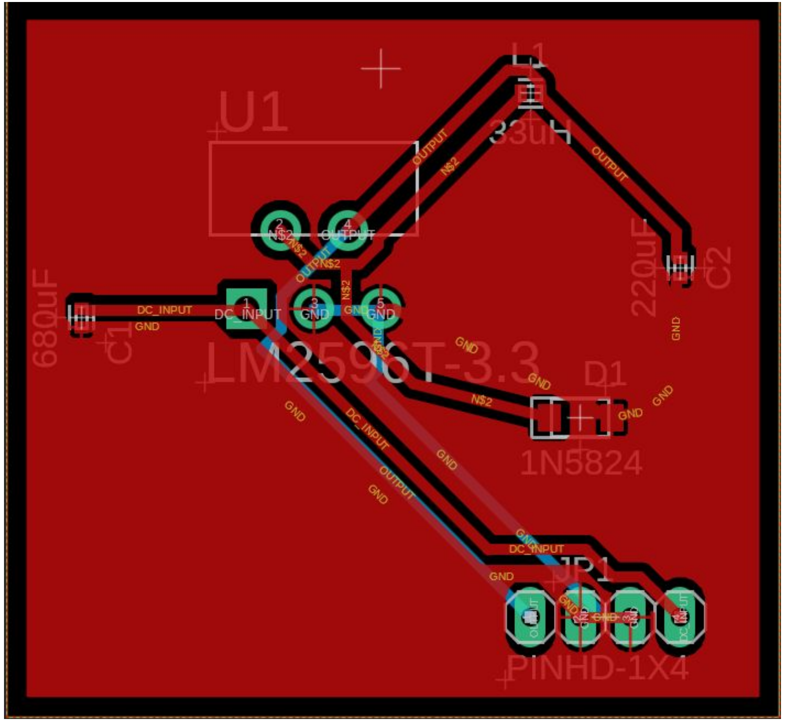
- 3.3V powers most peripherals on the MCU
- 5V powers the LCD and laser diode driver



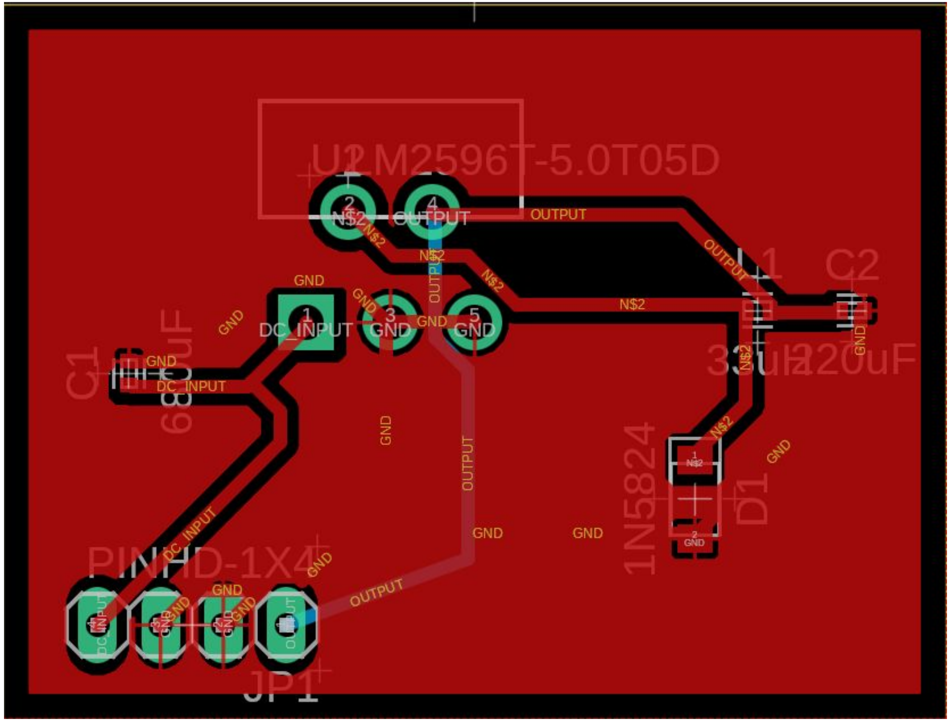




# PCB Design: 3.3V and 5V regulator pcb

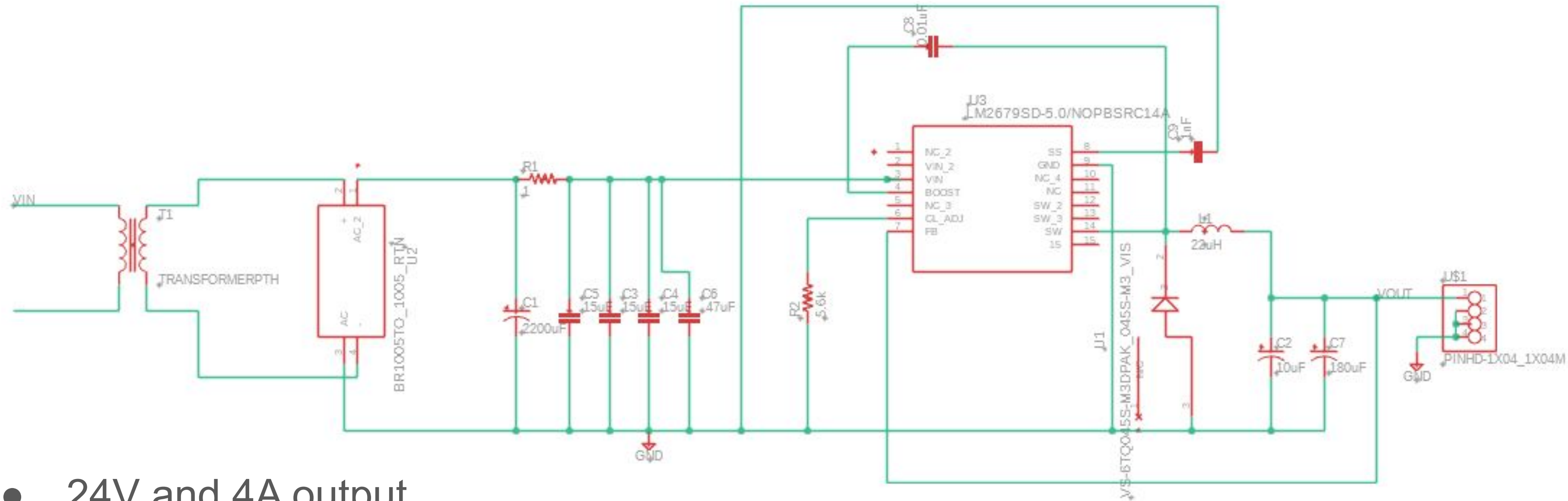
3.3V




5V

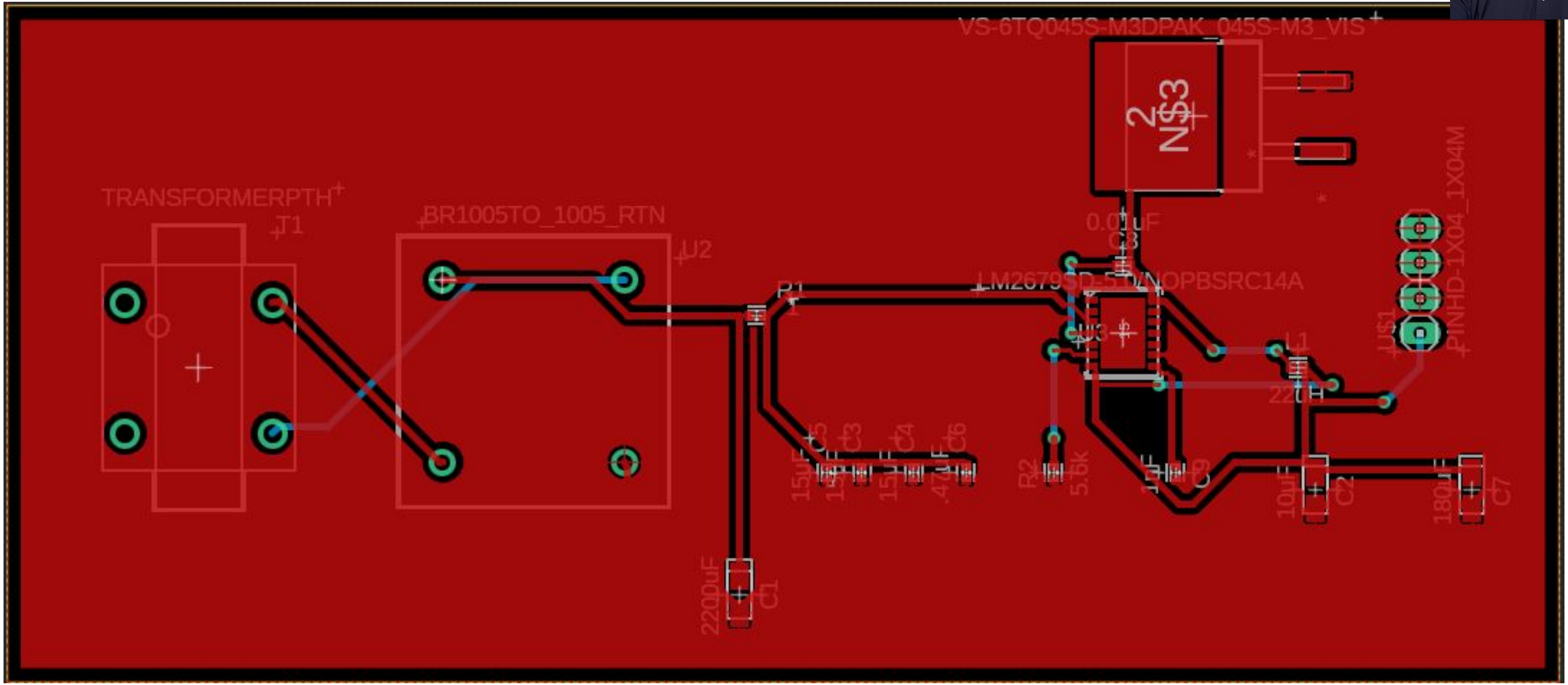


# PCB Design: Power Supply schematic



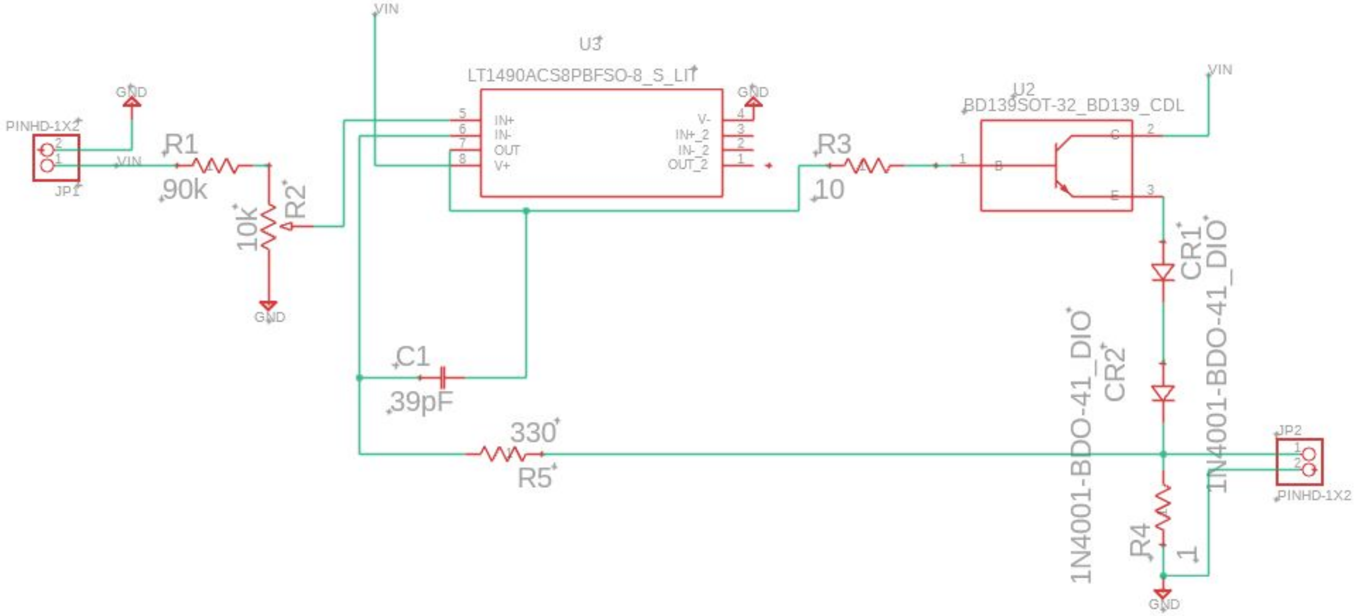

- 24V and 4A output
- Regulated by 3.3V and 5V regs on the MCU
- LM2679SD recommended by Dr. Weeks

# PCB Design: Power Supply schematic

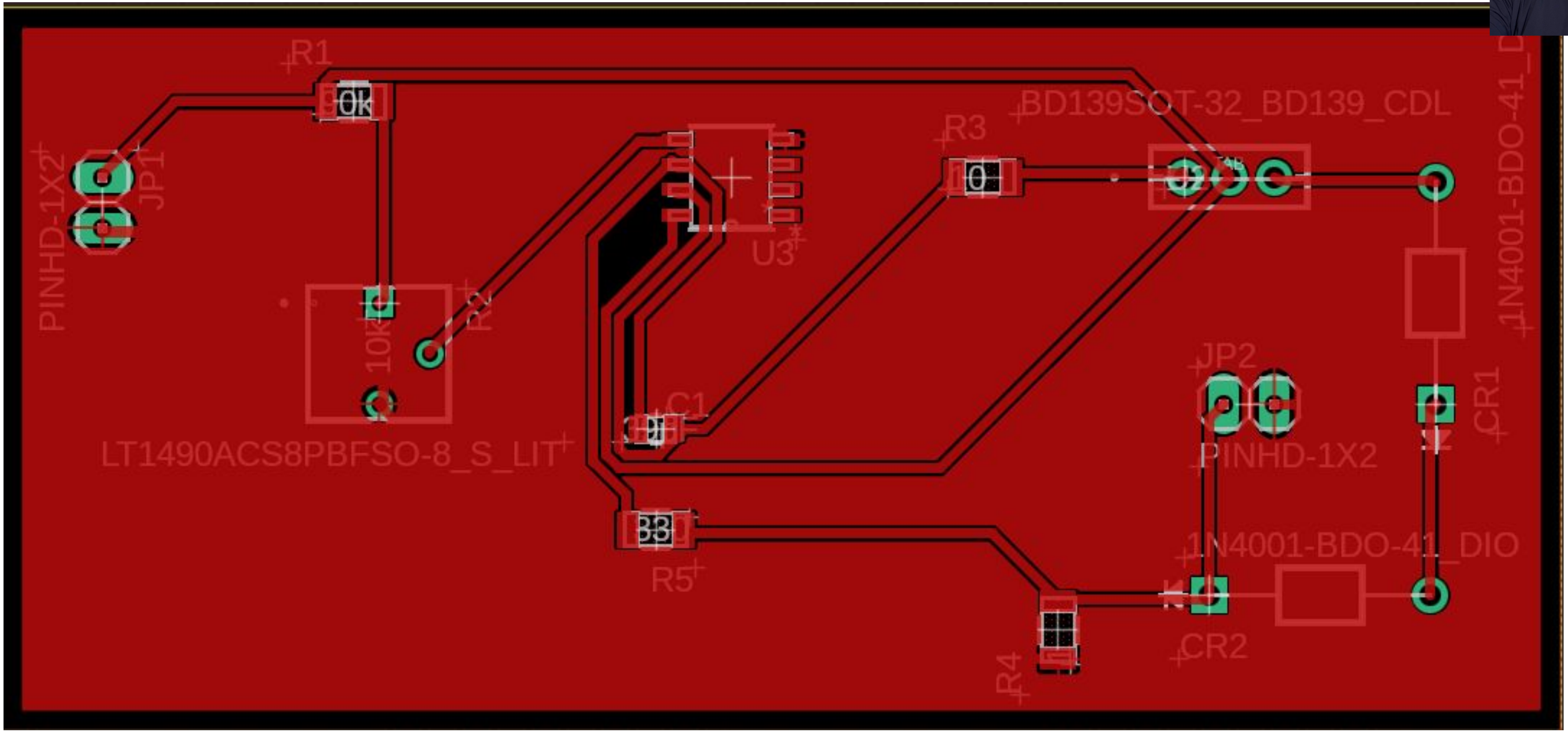



# PCB Design: Laser Diode Driver schematic

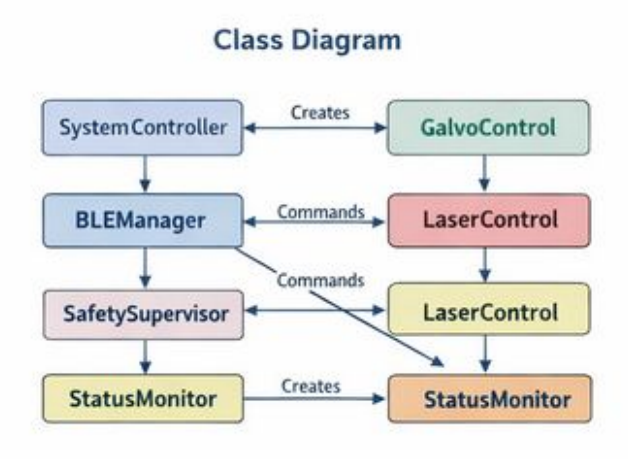
- 5V, 0-500mA laser diode driver
- Connected to 5V regulator on MCU board

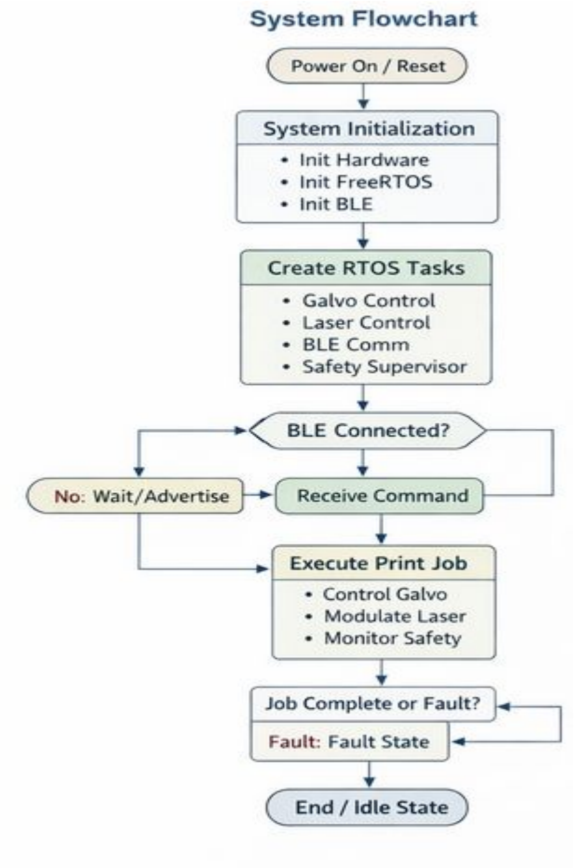


# PCB Design: Laser Diode Driver

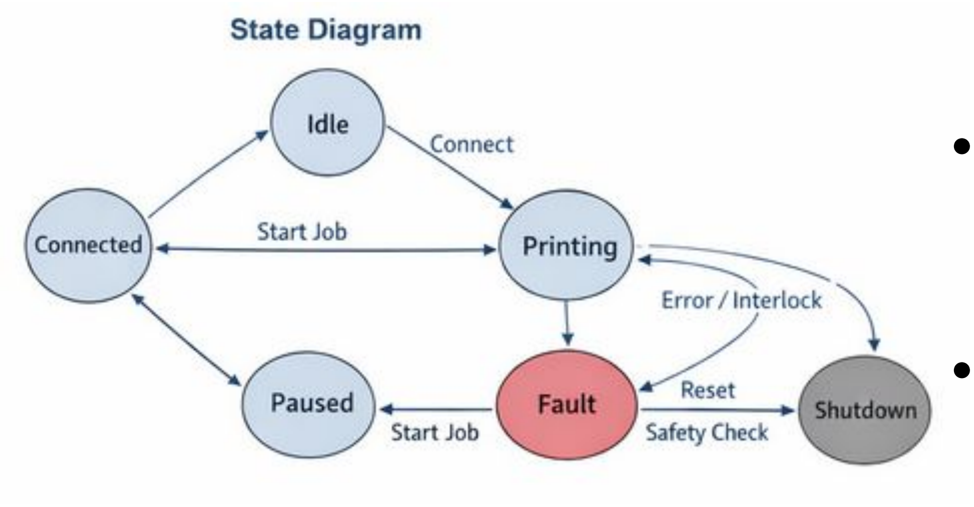



# Software Design



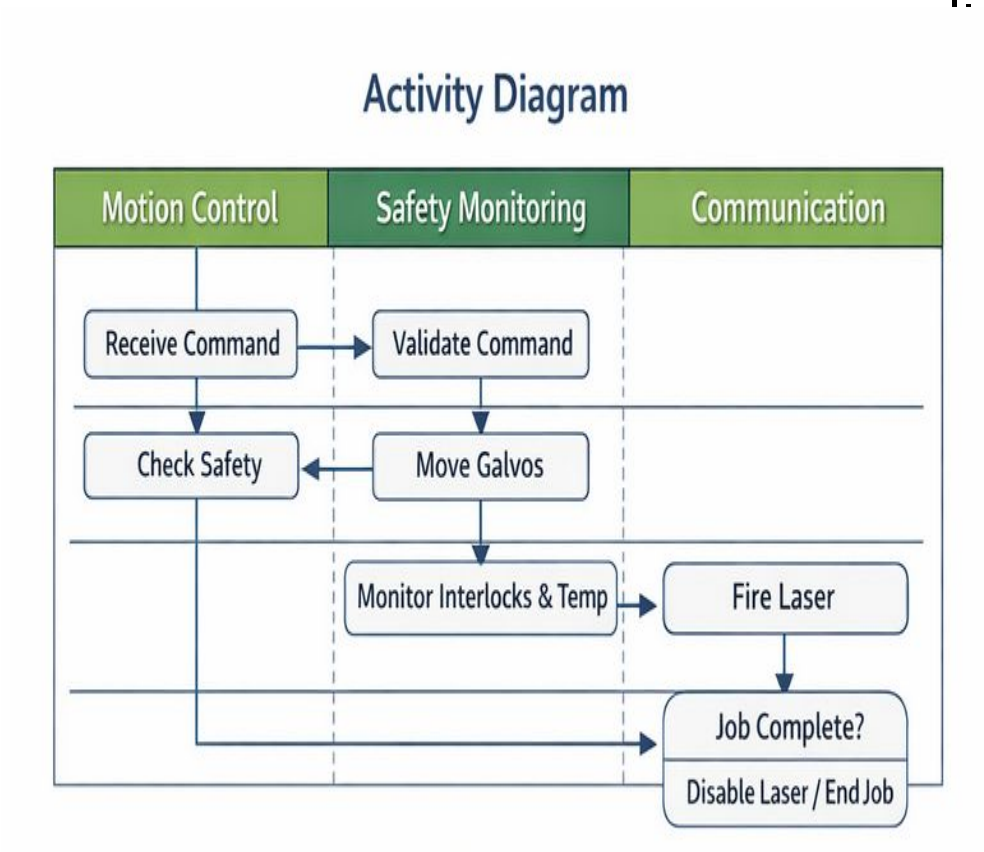




# Software Design Cont.




- 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.

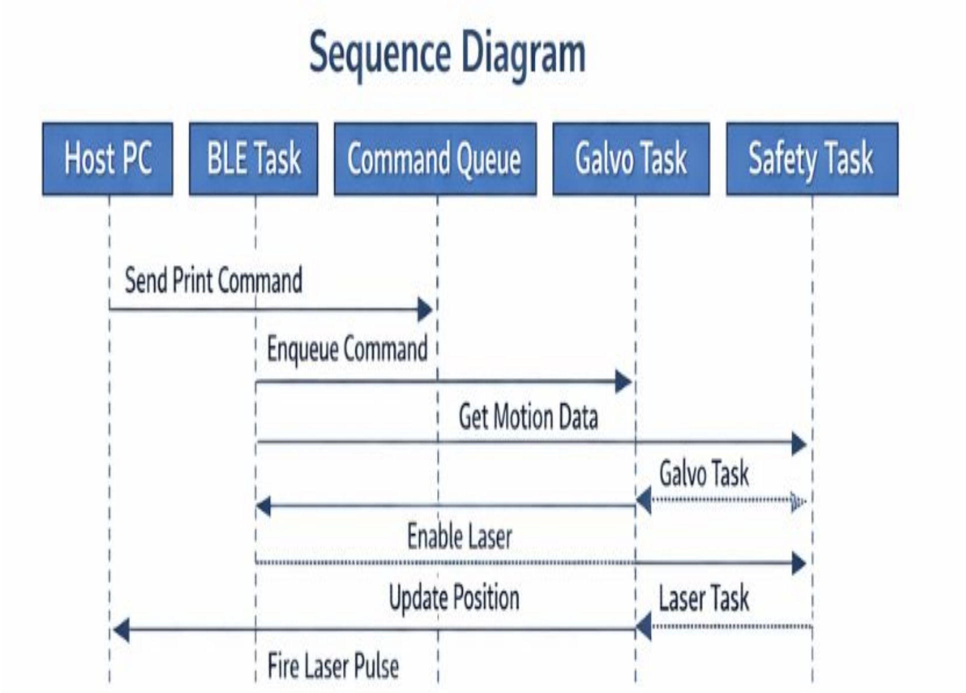
**Communication**

- 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

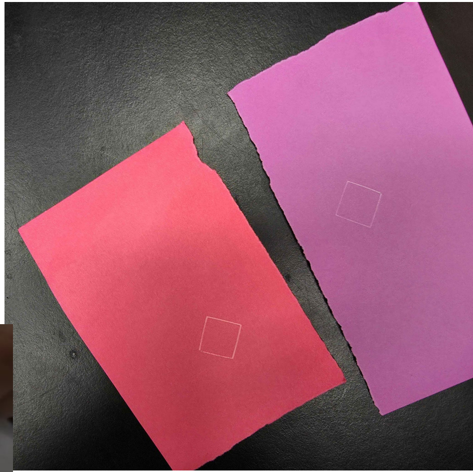
1. The Host PC sends a print command over BLE.
2. The **BLE Task** receives and parses the command.
3. The command is placed into a **FreeRTOS** queue for processing.
4. The **Galvo Task** retrieves motion data and updates mirror positioning.
5. The **Safety Task** verifies conditions before enabling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




# CPE/EE Results near the end

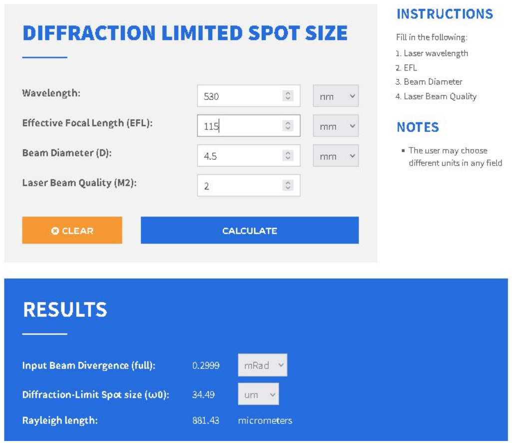
# Paper Results

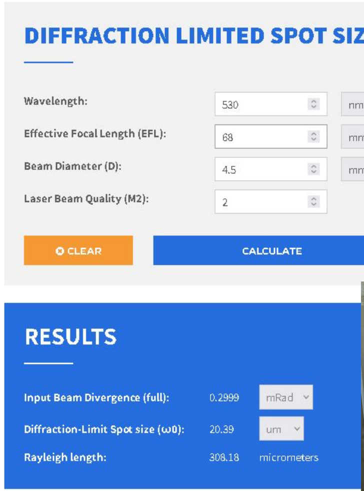
- The darker shades worked best for visible marks without damaging the paper.
  - Lighter shades produced less visible marks.
  - Width of designs were within specification.

# Optical Problems, Difficulty, and Solutions

- Ineffective heat management of the diode.
  - Resolved by, per reviewer recommendation, to purchase an aluminum socket.
- Failure to mark at initial prototype stage, prior to galvanometer movement.
  - Resolved after removing the initial aspheric lens and moving the laser diode closer. The fast axis collimating lens helped.
- Failure to mark at calculated effective focal length after galvanometer movement.
  - Resolved but adjusting system height from Pos. Meniscus from 115 mm to approximately 68 mm. Significant Change of Diffraction Limited Spot Size.
- Critical diode failure near the final deadline.
  - Partially resolved with the help of Group 2 providing us a diode of higher power UV diode. Replacement was ordered, but expected to arrive later.




# Budget

| Component | Part Number/Number | Quantity | Unit Price |
|---|---|---|---|
| Green Laser Diode | Laser Diode LT-LD-530-1650M-C | 1 | $130.00 |
| Calipers | Amazon | 1 | $8.00 |
| Safety Goggles | EaglePairOD7+ 190nm - 540nm | 1 | $54.00 |
| Safety Window | Foldable Laser Shield | 1 | $100.00 |
| ScannerMAX Galvanometer | Compact 506 | 1 | $2,316.80 |
| Aluminum Diode Socket | JLCPCB | 1 | $48.00 |
| 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 |
| Stepper Board | Amazon | 1 | $10.39 |
| Tentative Total | | | $Recalculate |

# Work Distribution

Jack McCain: EE

- ESP32 Design
- Power System
- PCB Building

Miguelangel Otero: PSE

- Lens and laser system design
- 3D printed housing designs

Sarah Siverio: CPE

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

# Thank you for watching!