Laser Beam Characterizer

Senior Design Fall 25 – Spring 26

Group 3

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Sponsor: Lockheed Martin

Motivation and Background

- Proper characterization of a laser is necessary in any laser application
- Model matching important for sponsor's applications
- Need to know as many properties of laser as possible
  - Wavelength
  - Polarization
  - Divergence
  - Beam Quality
- Seek a system that automates the process of data collection

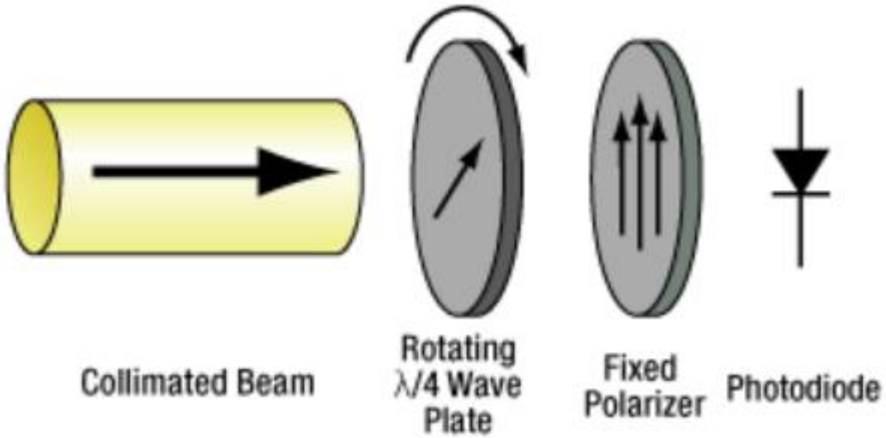
Goals

Goals			
Basic		Advanced	Stretch
Measure Polarization	Measure M2 Factor	Broad range of input powers	Broad range of wavelengths
Measure Wavelength	Measure Divergence	Broad range of input beam sizes	Measure beam waist size and location

Objectives: Measuring Polarization

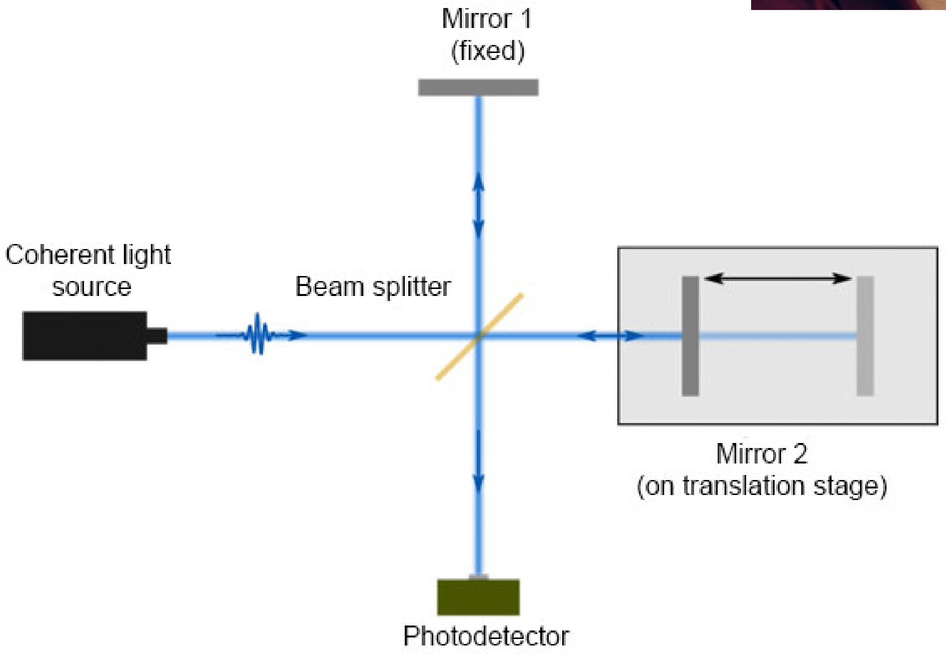
- Use Rotating Quarter Waveplate Method [1]
  - Quarter Waveplate
  - Linear Polarizer
  - Power Meter
- Measures the Stokes Parameters
- Will implement lens to focus large beams into power meter head
- Will use stepper motor to control angle of waveplate

$$I(\theta) = \frac{1}{2}(S_0 + S_1 \cos^2 2\theta + S_2 \cos 2\theta \sin 2\theta + S_3 \sin 2\theta).$$



Objectives: Measure Wavelength

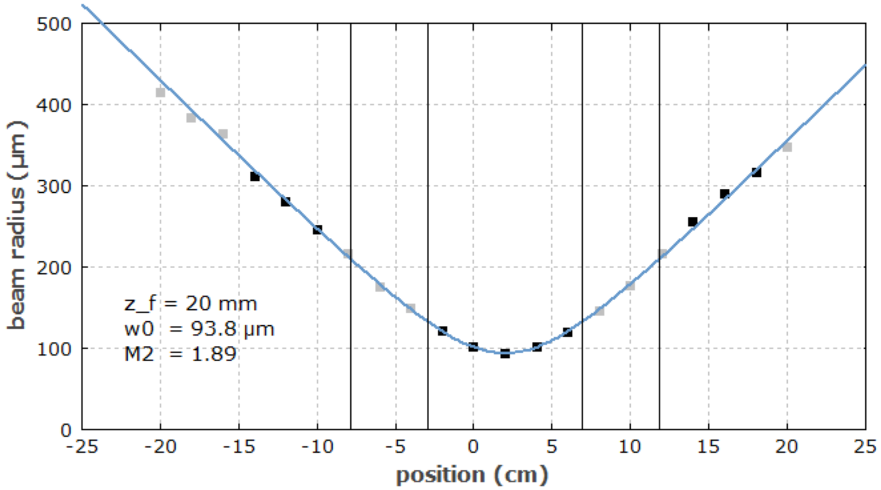
- Use a Michelson Interferometer
  - Non-Polarizing Beam Splitter
  - Two Mirrors
  - Motorized Stage for one mirror
  - Photodetector
- Will use a lens to transform linear fringes into Newton rings
- Will use a stepper motor stage to translate one mirror



Objectives: Measure M2 Factor

$$\theta = M^2 \frac{\lambda}{\pi w_0}$$

- Use a scanning knife edge to measure the intensity distribution of the beam
- Use a lens to focus the beam to measure points both close and far from the beam waist
- Use a 300 mm stepper motor stage to translate the beam profiler across the path of the focused beam

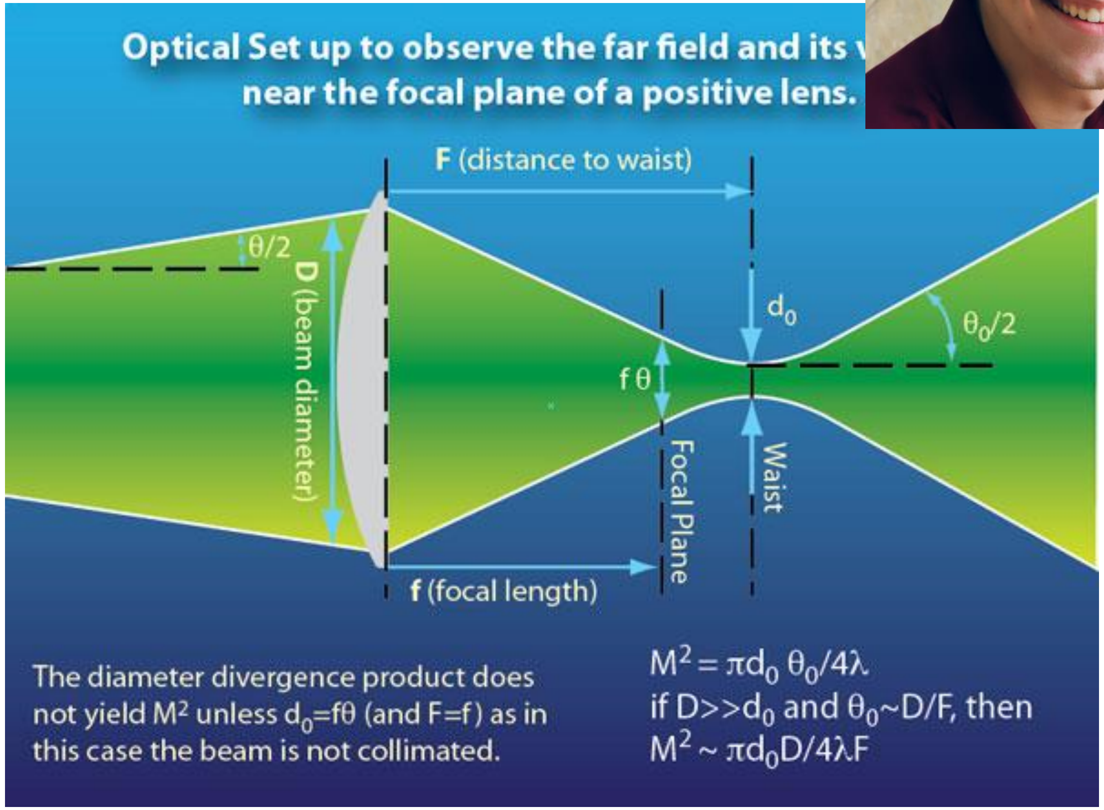


Intensity profile measurements performed at several points along the focused bath of the beam to obtain a beam width vs. propagation distance plot [2]

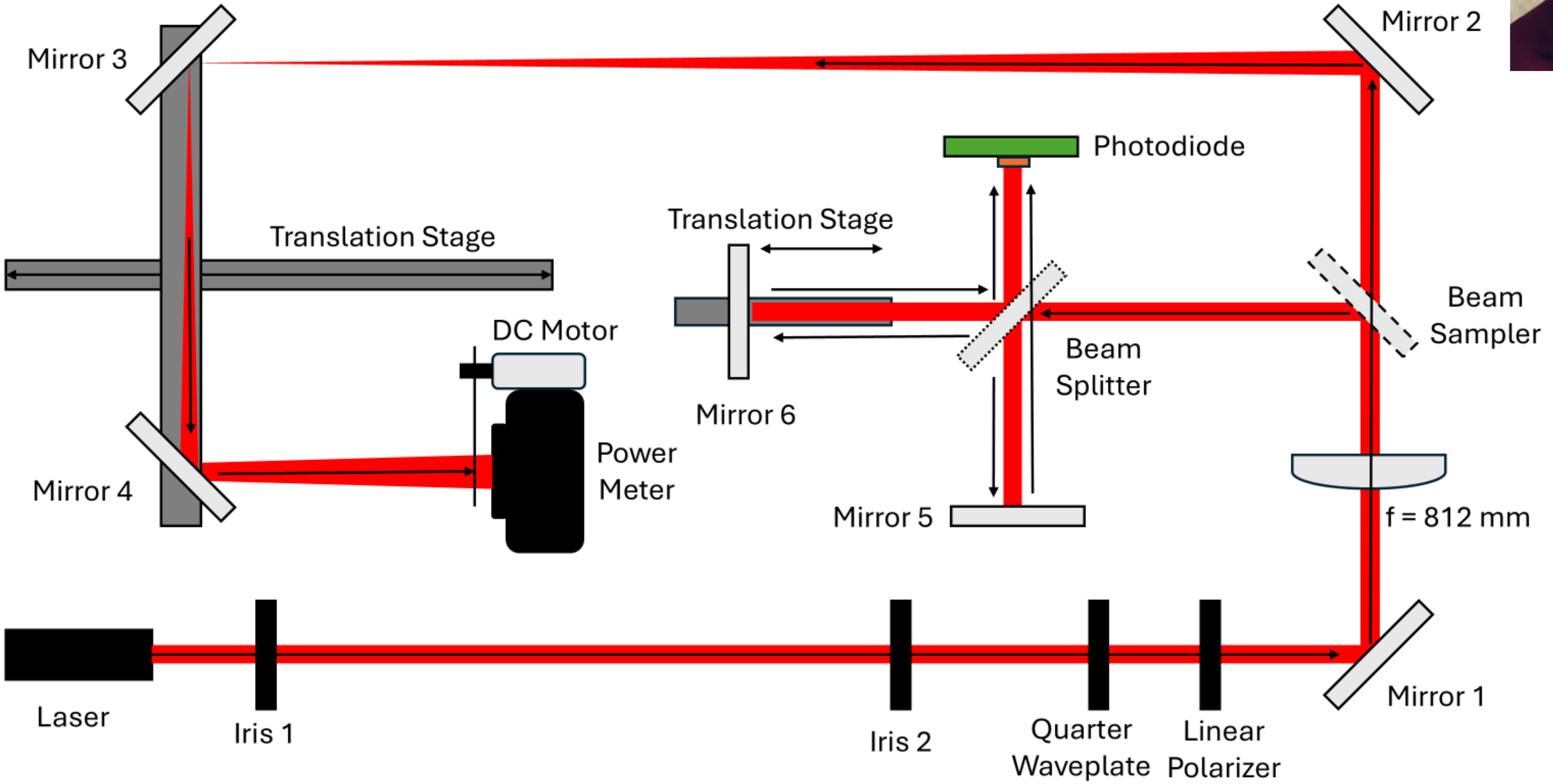
Objectives: Measure Divergence

- Use the knife edge scan method used in measuring M2 factor to measure the beam size at focus
- Use the beam width and focal length of lens to measure the divergence of the beam prior to the lens [3]

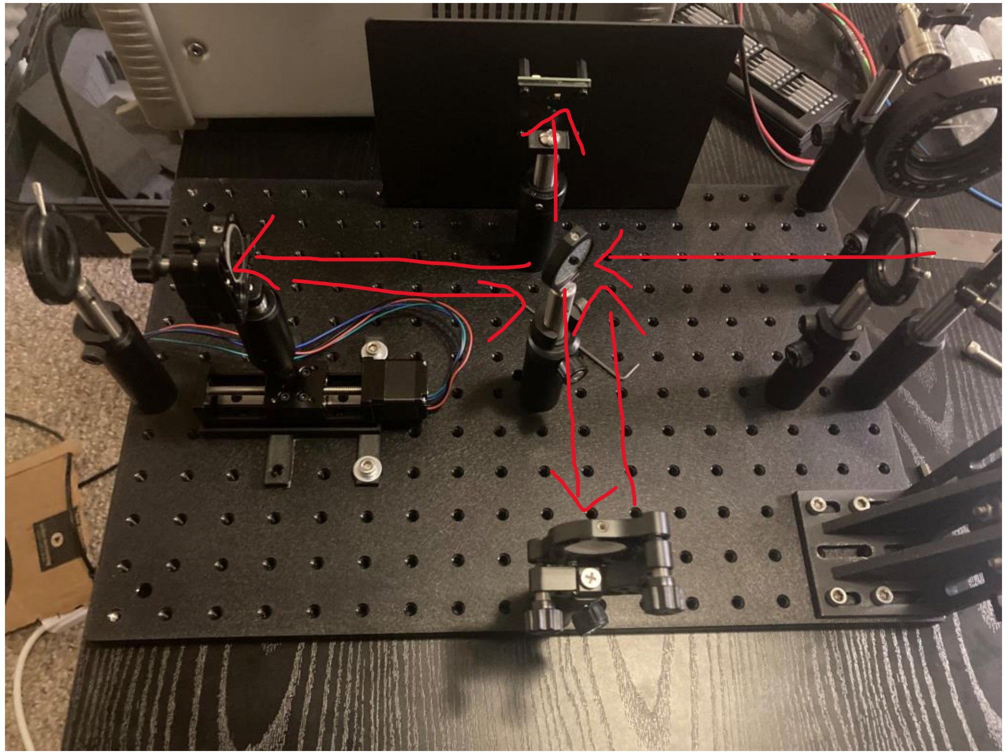
$$\boxed{w'_0 = \alpha w_0 = f\theta}$$



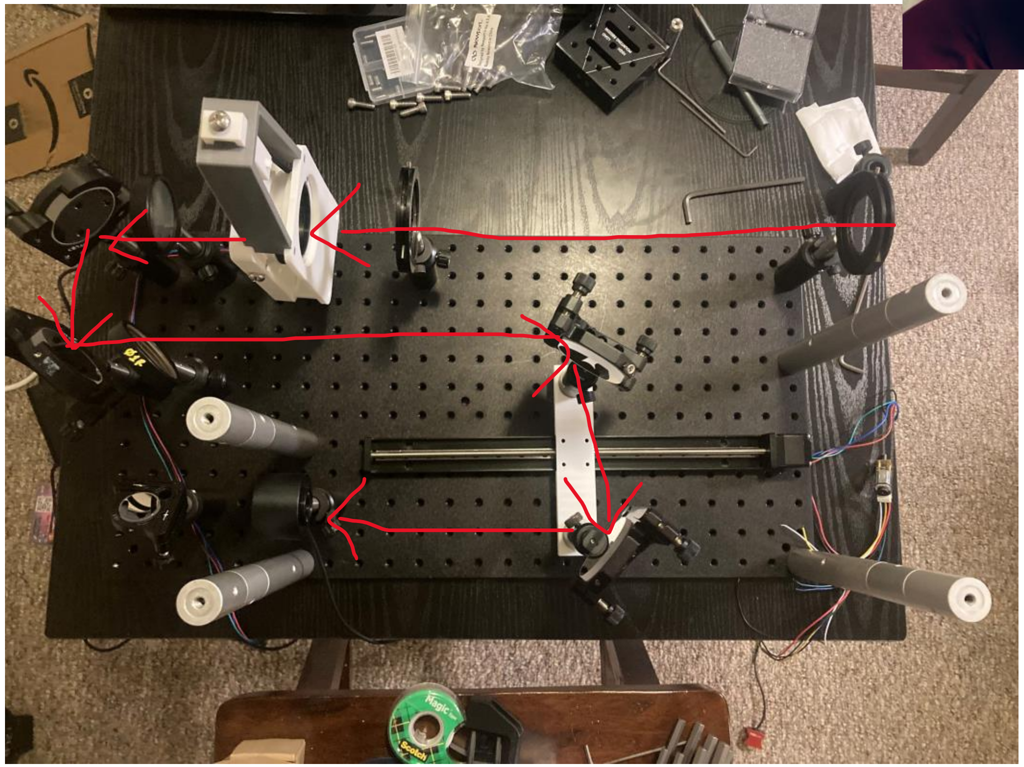
Optical Schematic Drawing



Full System Layout: 2 Layers



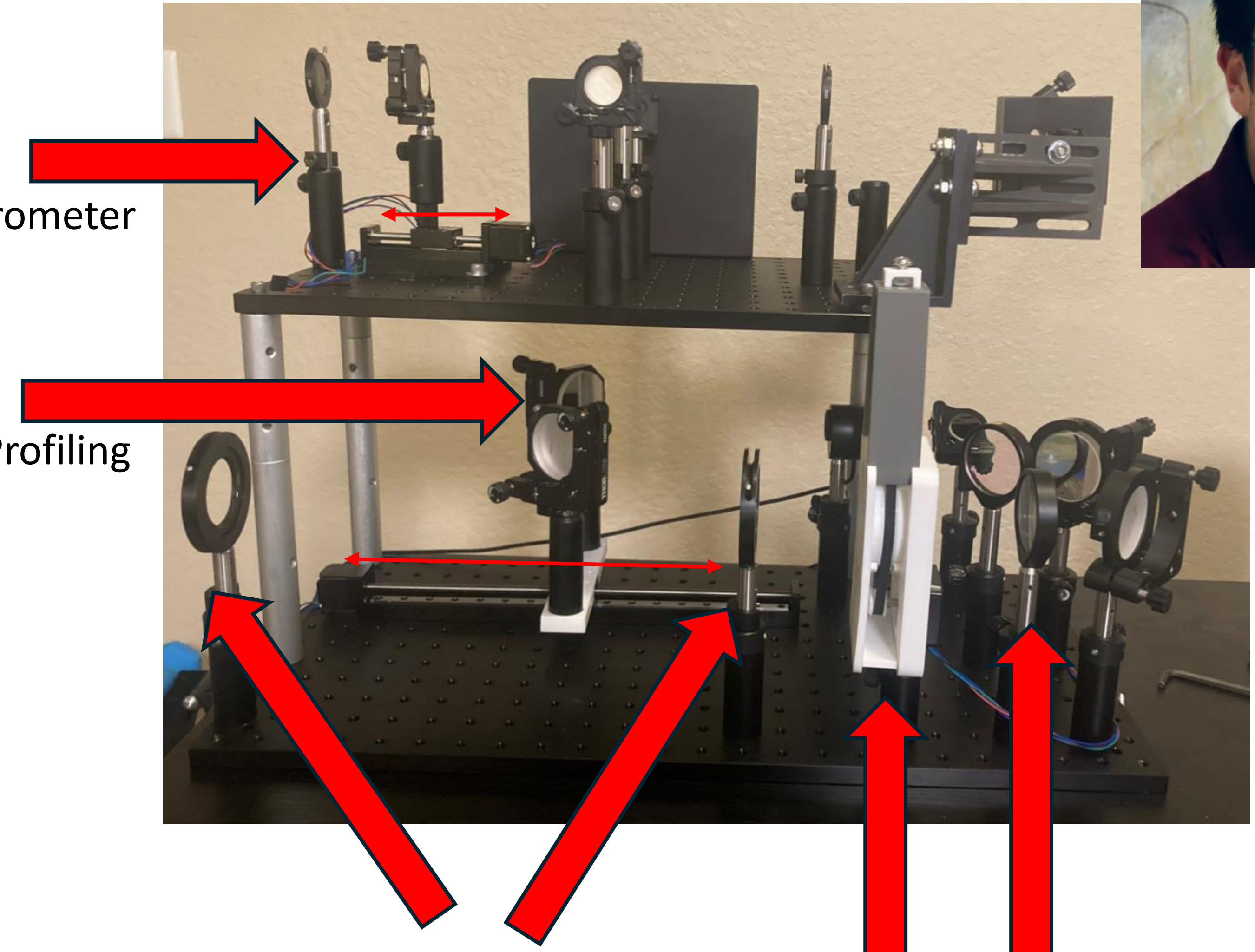
Top Layer



Bottom Layer

Full System

- Two Irises are used for easy user alignment
- Two layers stacked on top allows for conservation of space and reasonable portability
- Long focal length lens (800mm)
- Polarimeter is built as a custom mount with both the quarter waveplate and linear polarizer, integrated with a stepper motor to rotate the waveplate



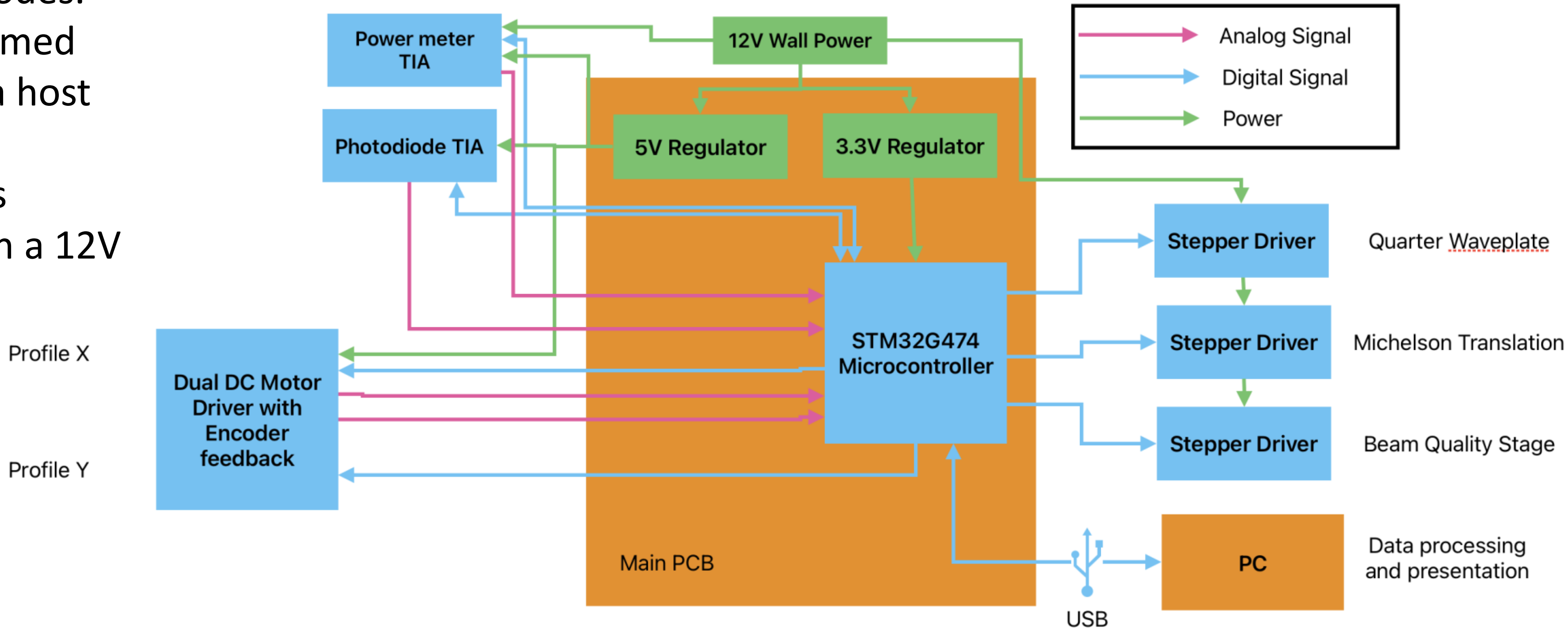
Engineering System Specifications

Input Beam Parameters		
Parameter	**Value**	**Units**
Wavelength	1.2 – 2.1	µm
Maximum Power	1 – 10	W
Minimum Power	1 – 50	mW
Beam Diameter	4 – 35	mm

Measurement Parameters		
Parameter	**Value**	**Units**
Normalized Stokes Parameters	±0.05 for all Parameters	N/A
Wavelength	±1	nm
M^2 factor	±0.1	N/A
Beam Divergence	±10	µrad
Total Power	< 5	% Error

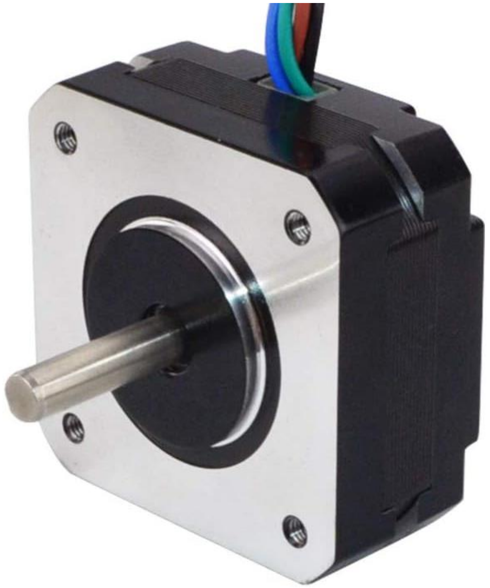
Hardware Diagram

- Main PCB controls the motors and reads from the two photodiodes.
- Live data is streamed through USB to a host PC.
- The full system is powered through a 12V DC all power adapter and stepped down to fit each component's needs.



Motors: Steppers

- Used 3 Stepper Motors in system
  1. Quarter Waveplate
  2. Beam Quality profile translation stage
  3. Michelson Interferometer mirror translation stage
- Used Nema 17 Stepper for Quarter Waveplate rotation
- Used Nema 13 Stepper Motor with integrated Stage for translation stages
- All steppers run on a 12V supply and are controlled by the MCU



Nema 17 Stepper

Nema 13 Stepper with Stage

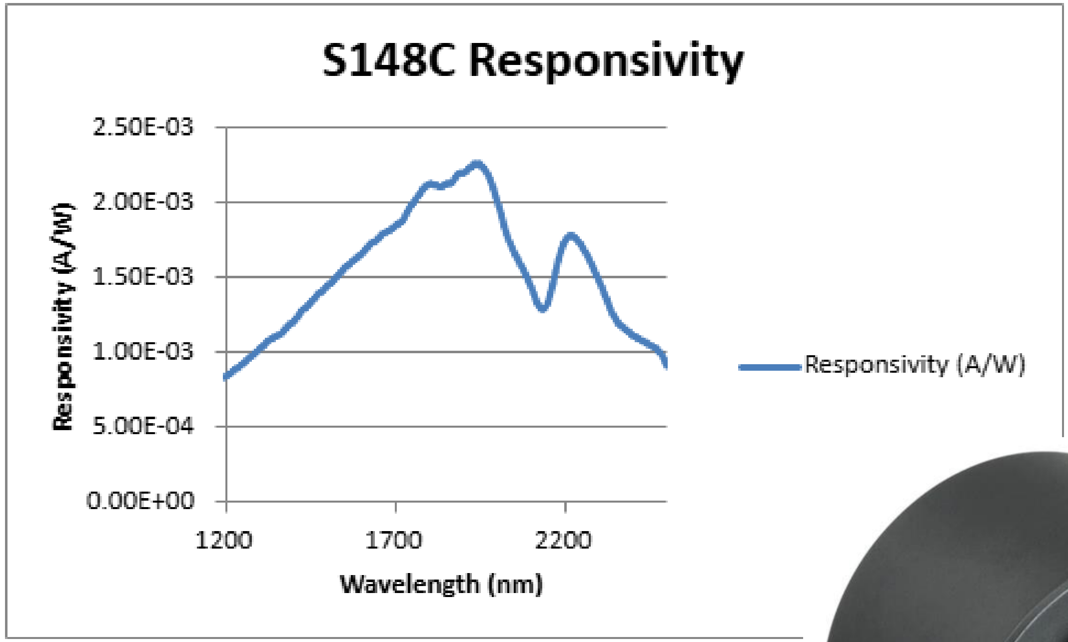
Motors: DC Motors

- We are using two DC motors with encoder feedback and gear ratio reduction to execute beam profiling.
- DC motors provide the constant speed required for the profiling calculations.
- The speed can be monitored and controlled using a feedback loop inside the MCU to ensure the motors are spinning at a constant rate throughout the measurements.

Hardware Selection: Power Meter Head

Part Selected: S148C

- Pros
  - 5 mm diameter input aperture (much better than most photodiodes ~1mm^2)
  - Low Responsivity ~mA/W
- Cons
  - Dsub Connector requires custom different connector for TIA board

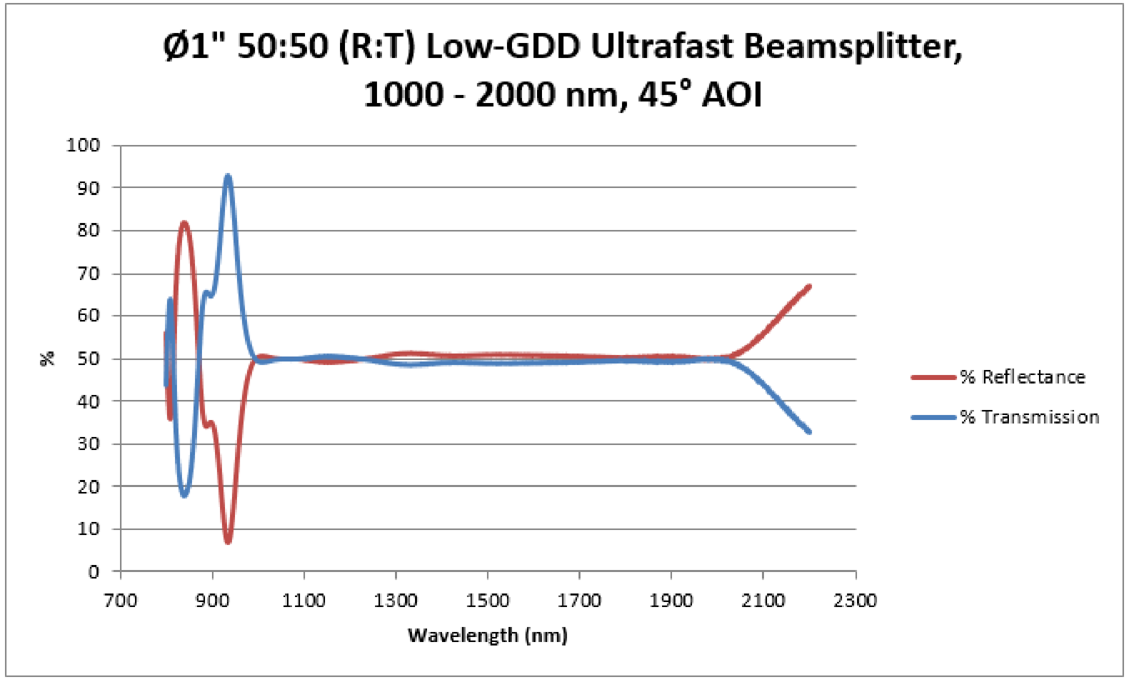


Hardware Selection: Beam Splitter

Part Selected: UFBS0502

- Pros
  - Spans desired wavelength range
  - Very good 50/50 split across full wavelength range
- Cons
  - Plate beamsplitters can have undesired ghost rays from surface reflections
  - Only optimized for P-Polarization

UFBS50502



Reflectance vs Transmission Spectrum

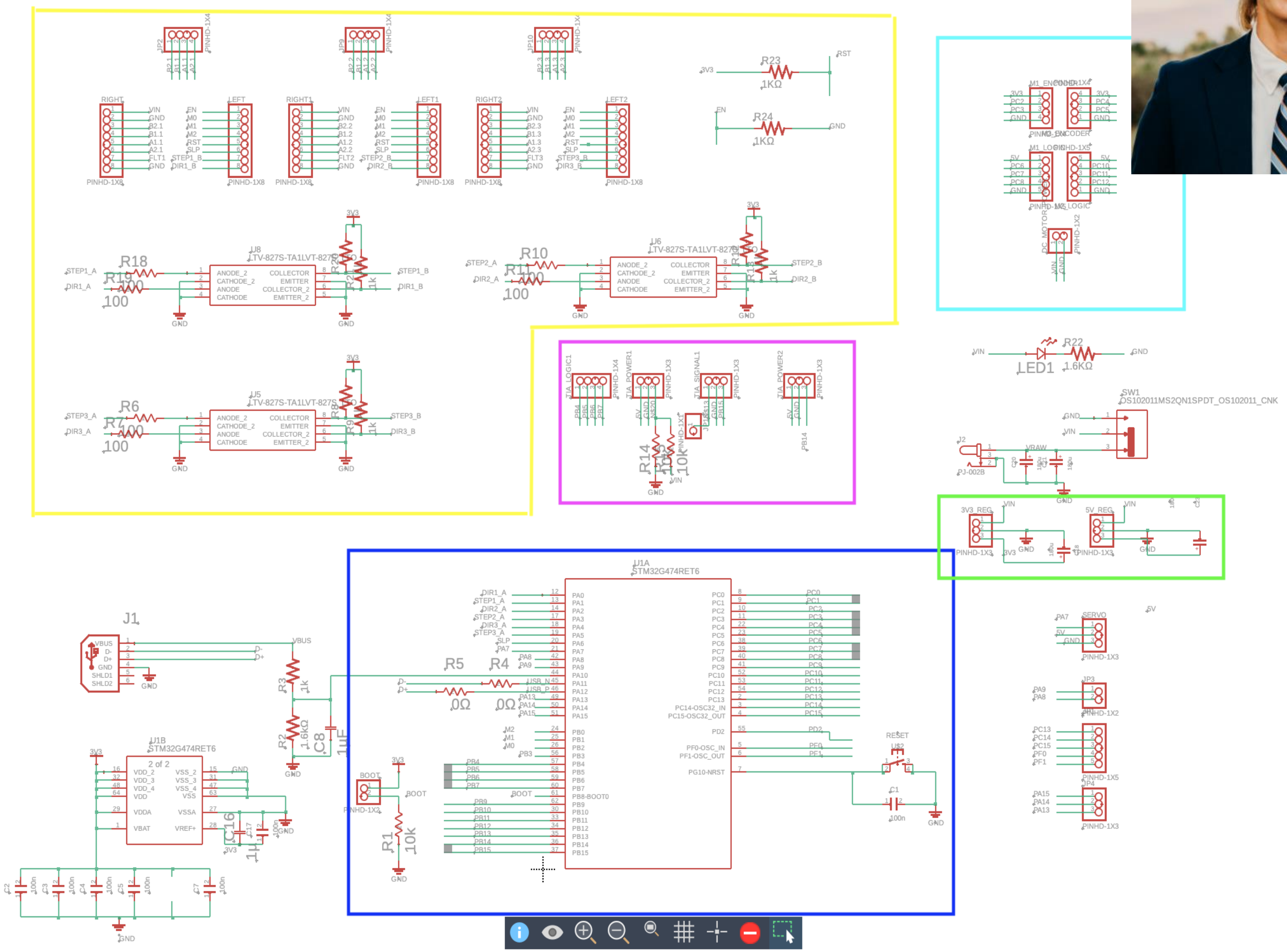
MCU Selection

- STM32 was chosen over ESP32 mainly for its better ADC which is more accurate and linear.
- Another advantage of STM32 is its native motor driving software which is important since we have multiple motors for this project.
- The more standard microcontroller in the industry and overall more robust than the ESP32.

Feature	STM32	ESP32
Reliable ADC	• Known for linearity • 16-24 ADC channels across 2-3 ADCs • Flexible DMA	• Struggles with noise • 18 ADC channels across 2 ADCs • DMA via digital control
Robust Motor Driving	• Many GPIO with advanced timers • Native software support	• Less advanced timers • Community libraries available for motor driving
USB Support	Native and robust	Included + drivers required
Additional Perks	Industry standard microcontroller family	Many native wireless communications

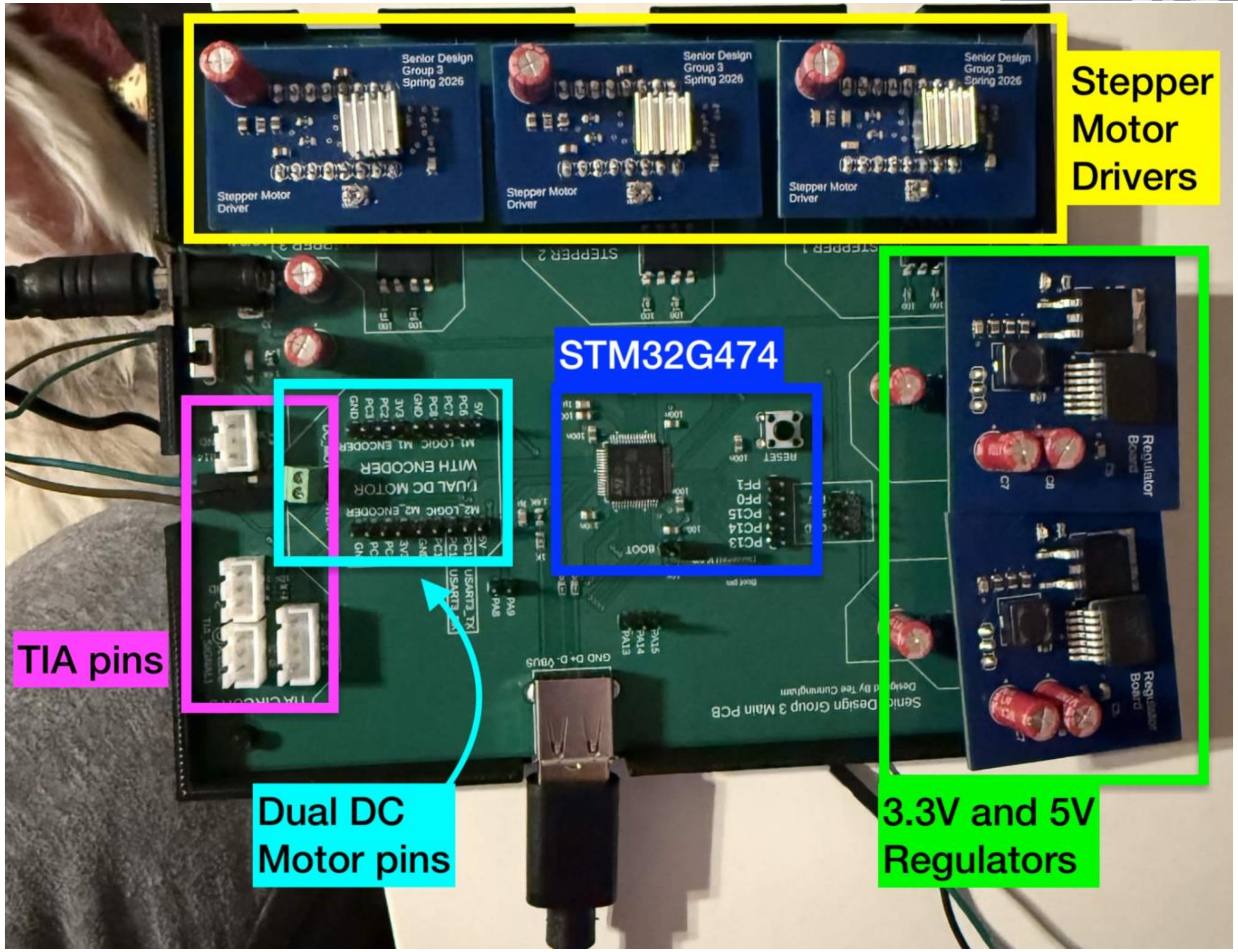
MCU Design

- The main PCB is designed to interface with the motors, sensors, and connect to a PC.
- They schematic follows the recommendations from the STM32 datasheet

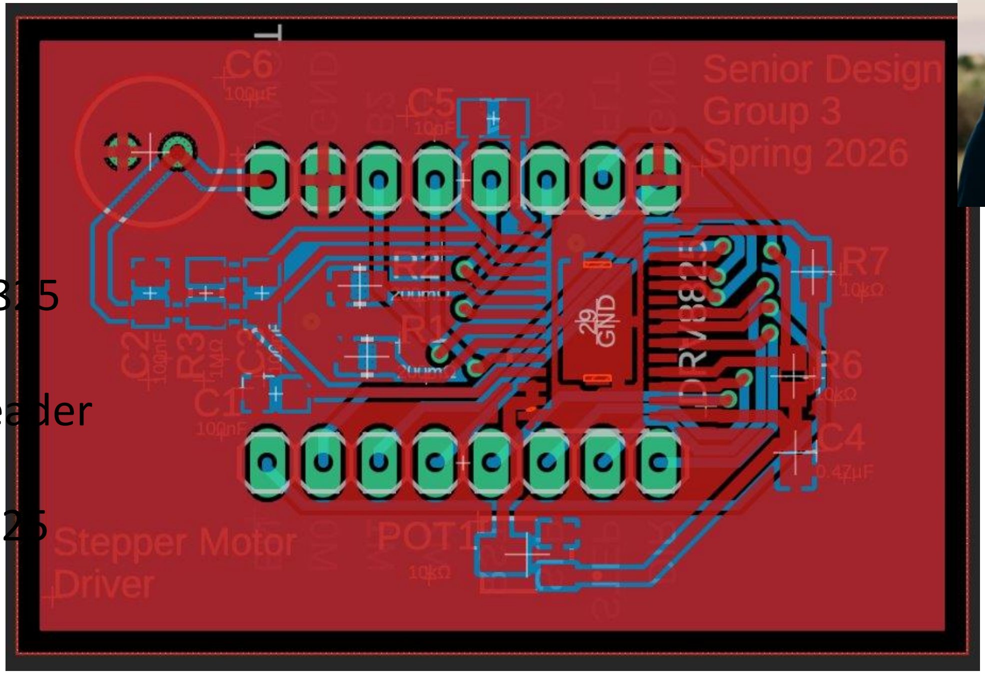


MCU Design

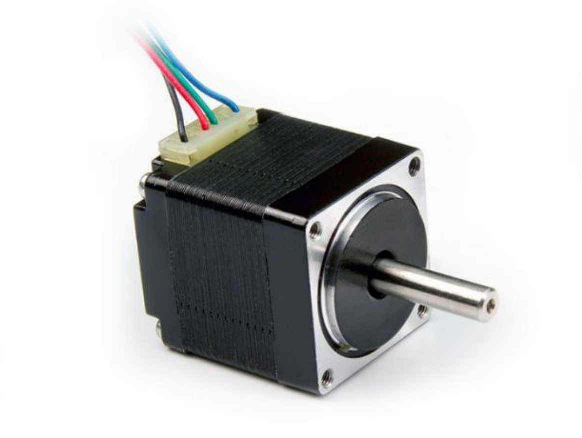
- The Main board layout is designed to be modular and accessible.
- The three motor drivers and two voltage regulators connect directly onto the board via header pins.
- JST connectors are used for the TIA pins to ensure a firm connection



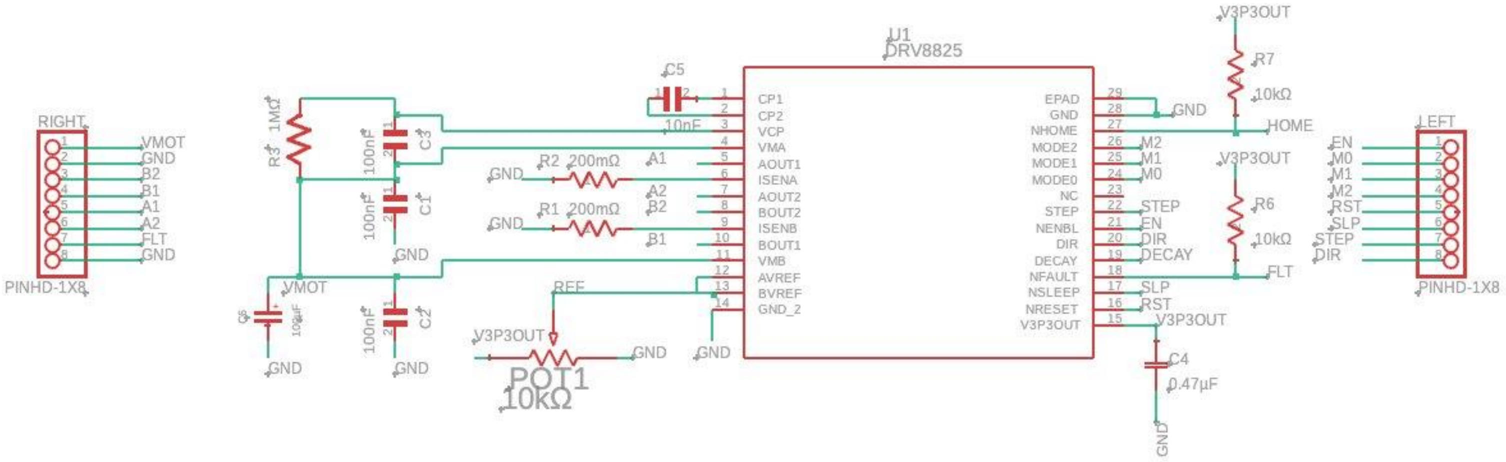
Motor Driver Design



- The stepper motor drivers utilizes the TI made DRV8825 chip.
- The board is designed to fit onto the main PCB via header pins.
- The circuit is laid out as recommended by the DRV8825 datasheet.

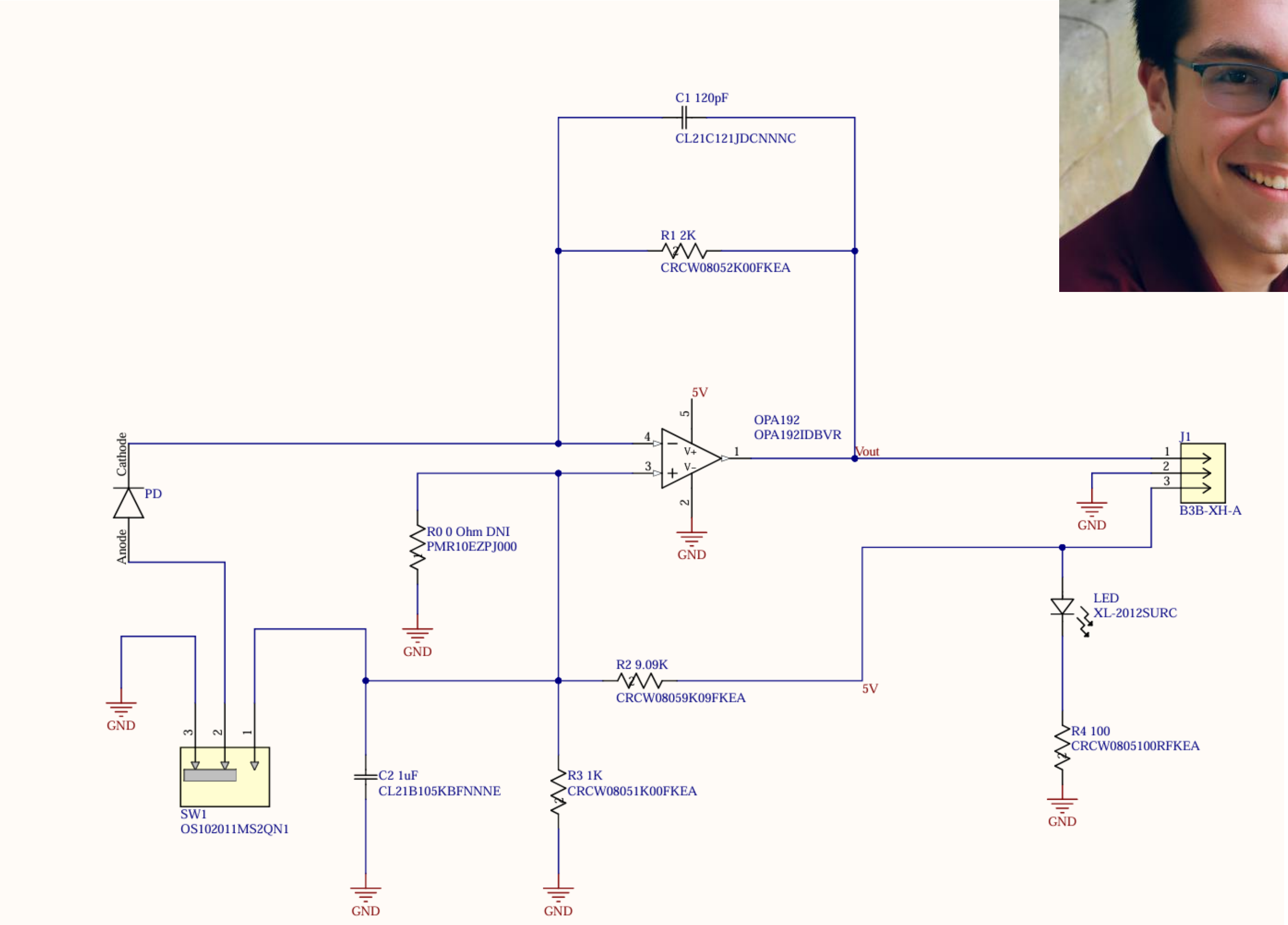


NEMA 13 stepper motor



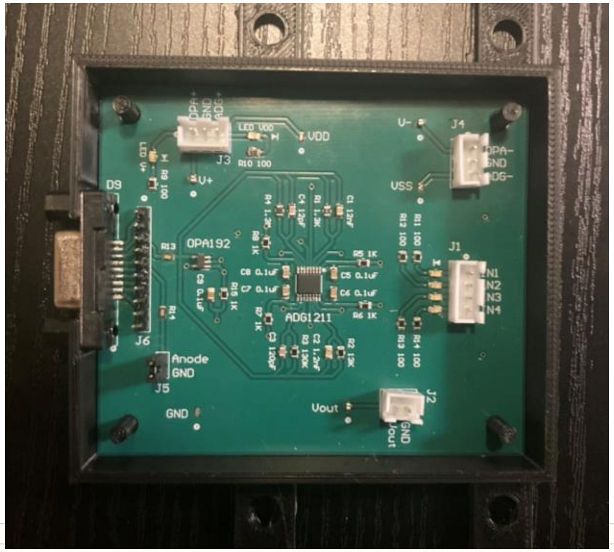
Photodiode TIA Design

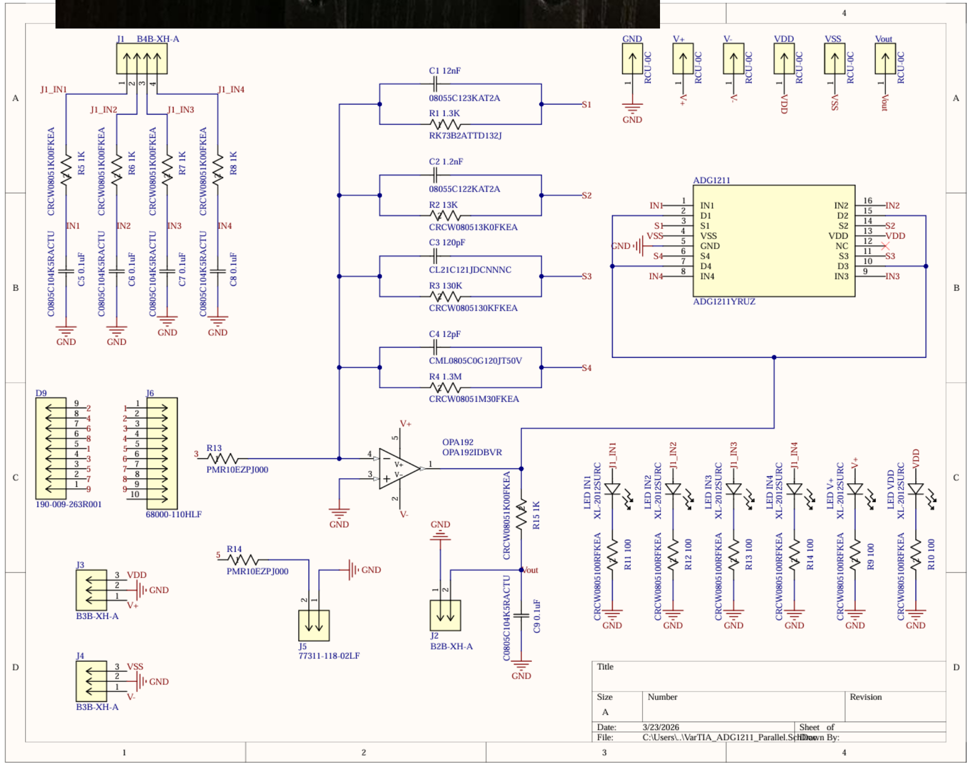
- Simple Extended InGaAs Photodiode (800 – 2600nm Spectral Range)
- OPA129 Op Amp used for its low noise features



Variable Gain TIA Design

- Uses ADG1211 voltage-controlled switches to enable the MCU to control the feedback resistance of the TIA
- Four feedback resistors wired in parallel each connected to a switch of the ADG1211
    - R1 = 1.3 kΩ
    - R2 = 13 kΩ
    - R3 = 130 kΩ
    - R4 = 1.3 MΩ





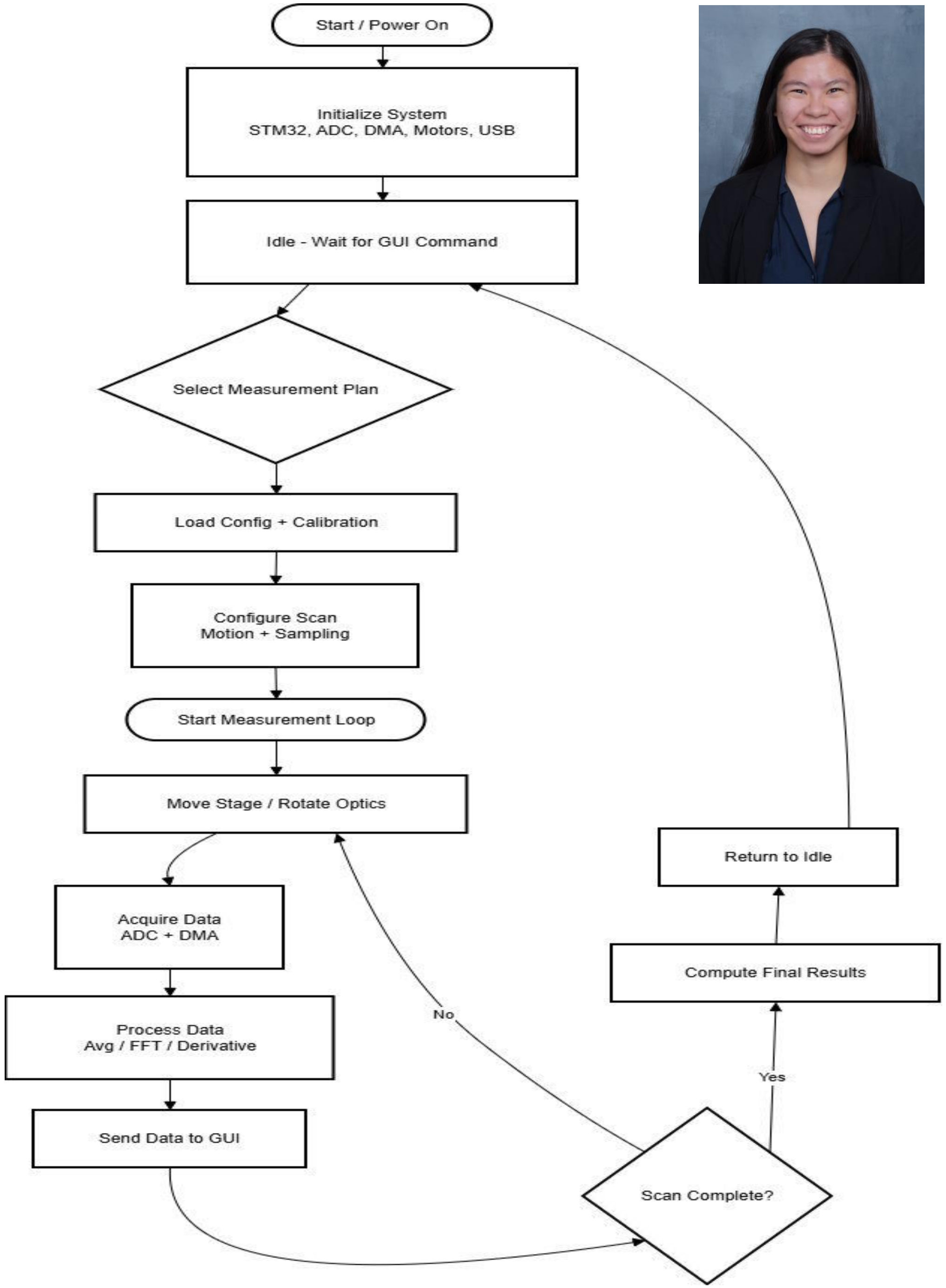
Software Selection

- Our choice of Embedded C as the programming language allows for precise ADC timing, DMA, motor control and deterministic behavior.
- The main reason of using Python as our main PC GUI programming language is because it allows for a scalable GUI for system control and data analysis.
- Additionally able to create nice looking plots for data visualization.

Layer	Option	Performance/Real Time	Hardware Access
Embedded Firmware	Embedded C	Highest	Full
Embedded Firmware	MicroPython	Low	Limited
PC GUI / Analysis	PySide6(Qt)	High	Indirect (USB)
PC GUI / Analysis	Tkinter	Low-Moderate	Indirect

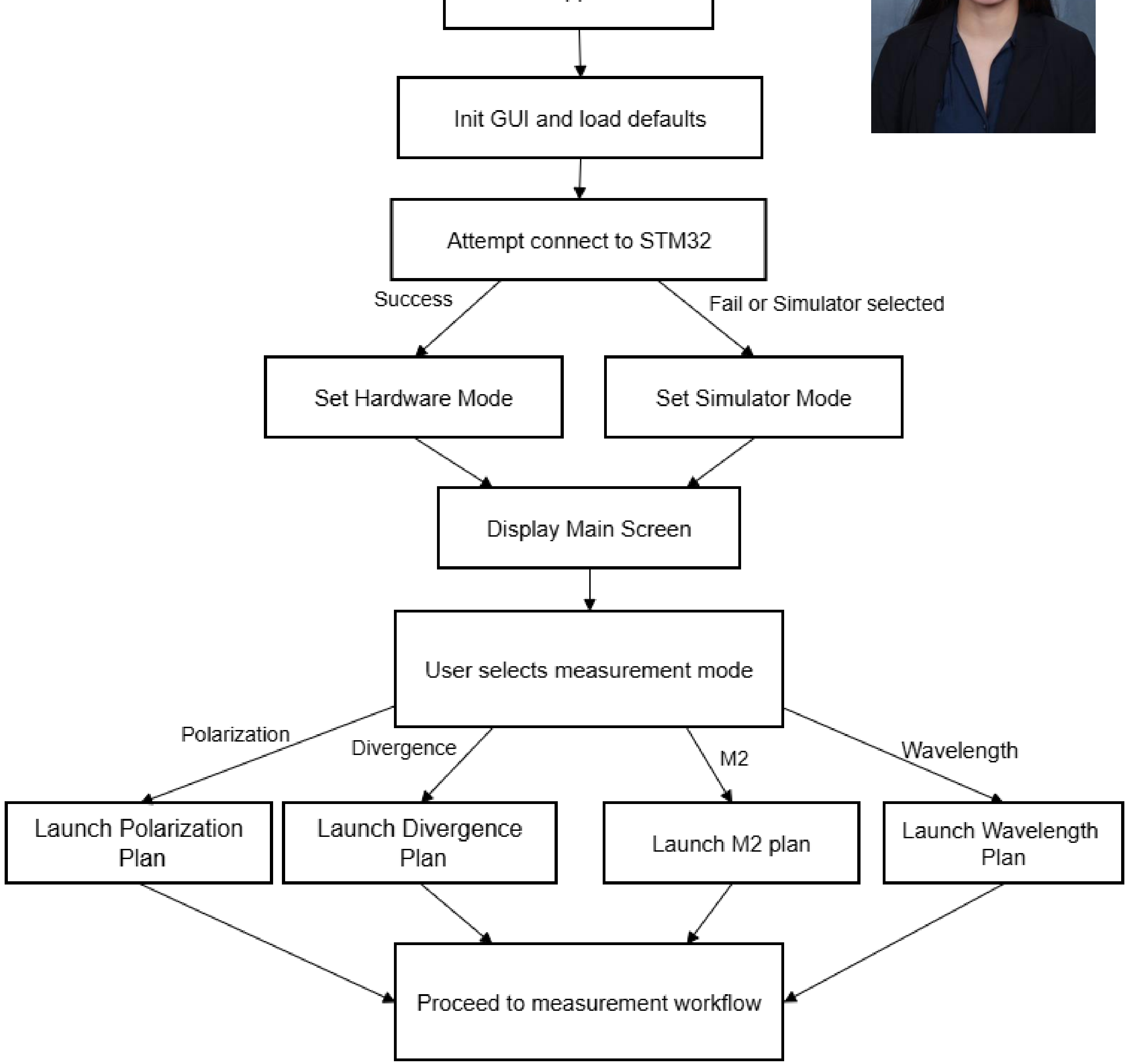
Embedded Firmware: Software Flowchart

- System initializes STM32 peripherals(ADC, DMA, timers, motors, USB)
- Firmware waits for measurement plan selection from GUI
- Selected plan configures scan parameters and calibration
- Closed-loop measurement process:
  - Motion control (stages/optics)
  - Sensor data acquisition (ADC + DMA)
  - Real-time signal processing
- Processed data is streamed to GUI for visualization
- Final beam parameters computed and system returns to idle



GUI: Software Flowchart

- Once the application is started it initializes the GUI and loads up the defaults.
- It should automatically search for a serial communication port to attempt connection to.
- If success, main screen is shown and you are able to select the measurement system (or automatically run all measurements systems in order).
- Once measurement system is selected GUI sends commands to start the measurement workflow scripts on STM32.
- And in turn data collection is sent back to GUI for data processing



Problems and Troubleshooting

- General
  - Hardware Acquisition Delays
  - Alignment
- Electrical
  - TIA Nonlinearity
  - MCU Stepper driver
- Software
  - Beam Profile Timing
  - Noise Filtering (especially for beam profiling)

Work Distribution

Photonics Engineering	Responsibilities
Zachary Andreasen	Project Lead Optical Alignment Polarimeter, Michelson, M^2 System Design Photodiode Selection
Electrical Engineering	**Responsibilities**
Tee Cunningham	MCU Selection + Design Motor/Motor Driver Selection + Design Power Supply Design
Zachary Andreasen	Michelson TIA Design Power Meter Variable TIA Design
Computer Engineering	**Responsibilities**
Lynzie Smith	GUI Software architecture + Implementation Serial Communication Integration STM32 Firmware Website Design

References

1. B. Schaefer, E. Collett, R. Smyth, D. Barrett, and B. Fraher, “Measuring the Stokes polarization parameters,” *Am. J. Phys.*, vol. 75, no. 2, pp. 163–168, Feb. 2007, doi: 10.1119/1.2386162.
2. R. Paschotta, “M^2 factor – M squared, laser beam, quality factor, beam divergence, caustic, ISO Standard 11146.” Accessed: Sep. 05, 2025. [Online]. Available: https://www.rp-photonics.com/m2_factor.html
3. Edmund Optics, “Gaussian Beam Propagation | Edmund Optics Knowledge Center.” [Online]. Available: https://www.edmundoptics.com/knowledge-center/application-notes/lasers/gaussian-beam-propagation/