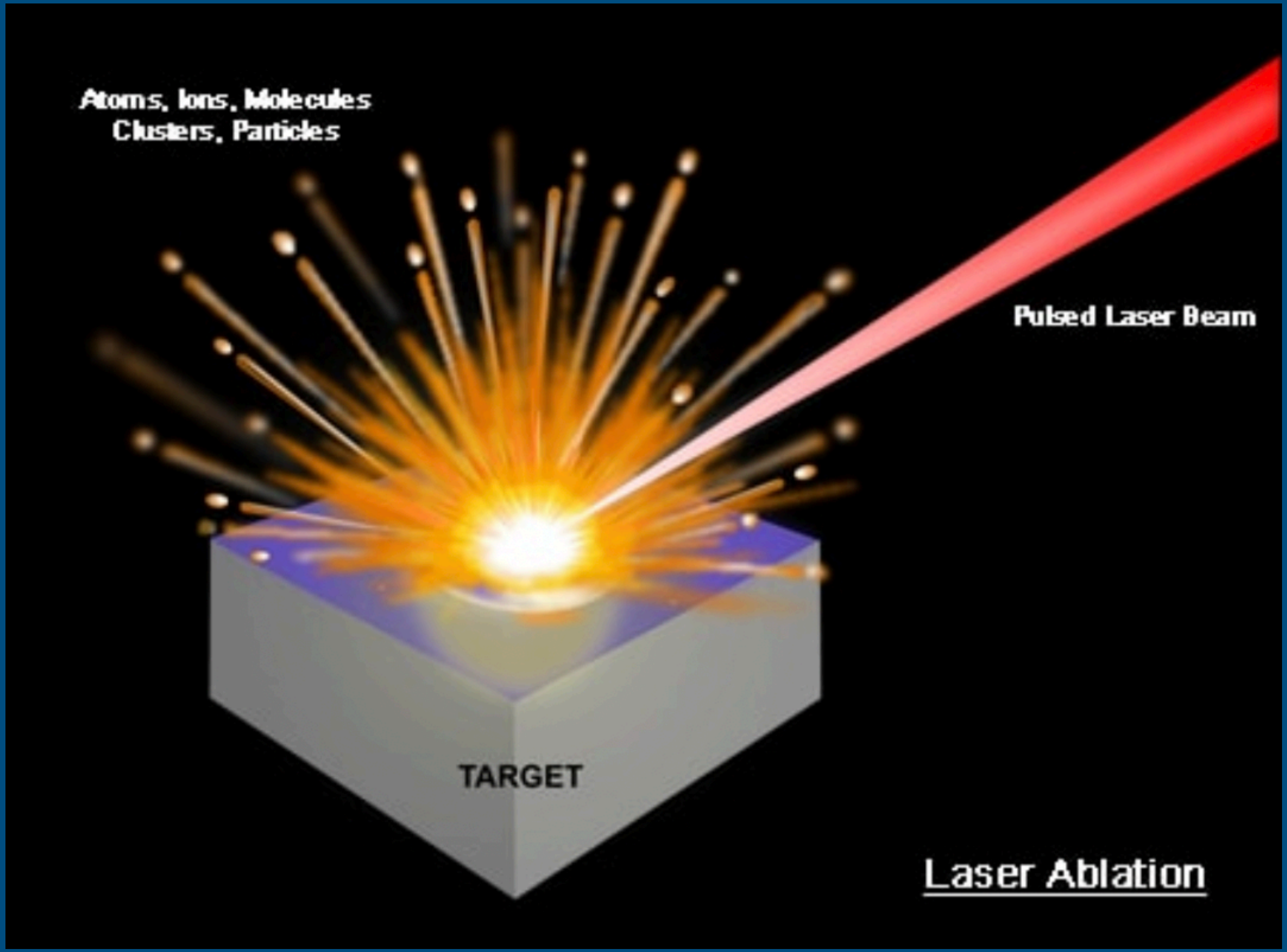
Spectral Laser Elemental Analyzer

Group 1

Senior Design 2: Spring 2024



Project Scope

Develop a low-cost, high resolution, laser induced break-down spectroscopy system for the elemental analysis of in-organic samples.

The Team

Benjamin Logan
PSE

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Introduction

The proposed system uses an Nd:YAG laser, which is focused through an optical system to strike a sample, generating plasma.

The light emission from the sample is guided into a Czerny-Turner spectrometer for diffraction and spectral analysis. The plasma bloom is detected by an IR sensor, which triggers the MCU to activate the CCD.

The diffracted light is directed to the CCD and the spectral data from the CCD is converted to digital form by an ADC. The spectral data is then displayed or transferred to an external device.

Ben Logan
PSE

Background and Motivations

- Laser induced break-down spectroscopy (LIBS) is a method that uses a laser pulse to generate plasma on a sample surface, from the plasma a spectrometer can be used for elemental analysis based on the emitted light.
- LIBS works by a process called atomic emission spectroscopy
- The use of a LIBS system employs measures to tackle both, cost and speed.
- Identifying and analyzing inorganic samples
- Design and build a LIBS system that is both cost effective and easy to use for students and institutions.
- Assist researchers and scientists in the exploration and understanding of space.

Ben Logan
PSE

Goals

- Create a laser system that will consistently generate a plasma plume.
- Create a LIBS system that produces measurement results with less than 10% variance over 5 samples.
- Use of the LIBS system to identify known inorganic sample within 90% accuracy.
- LIBS system is controlled digitally.
- Convert analog spectrometer data into digital form.
- Output analyzed results in under a minute.
- Powered by wall outlet.

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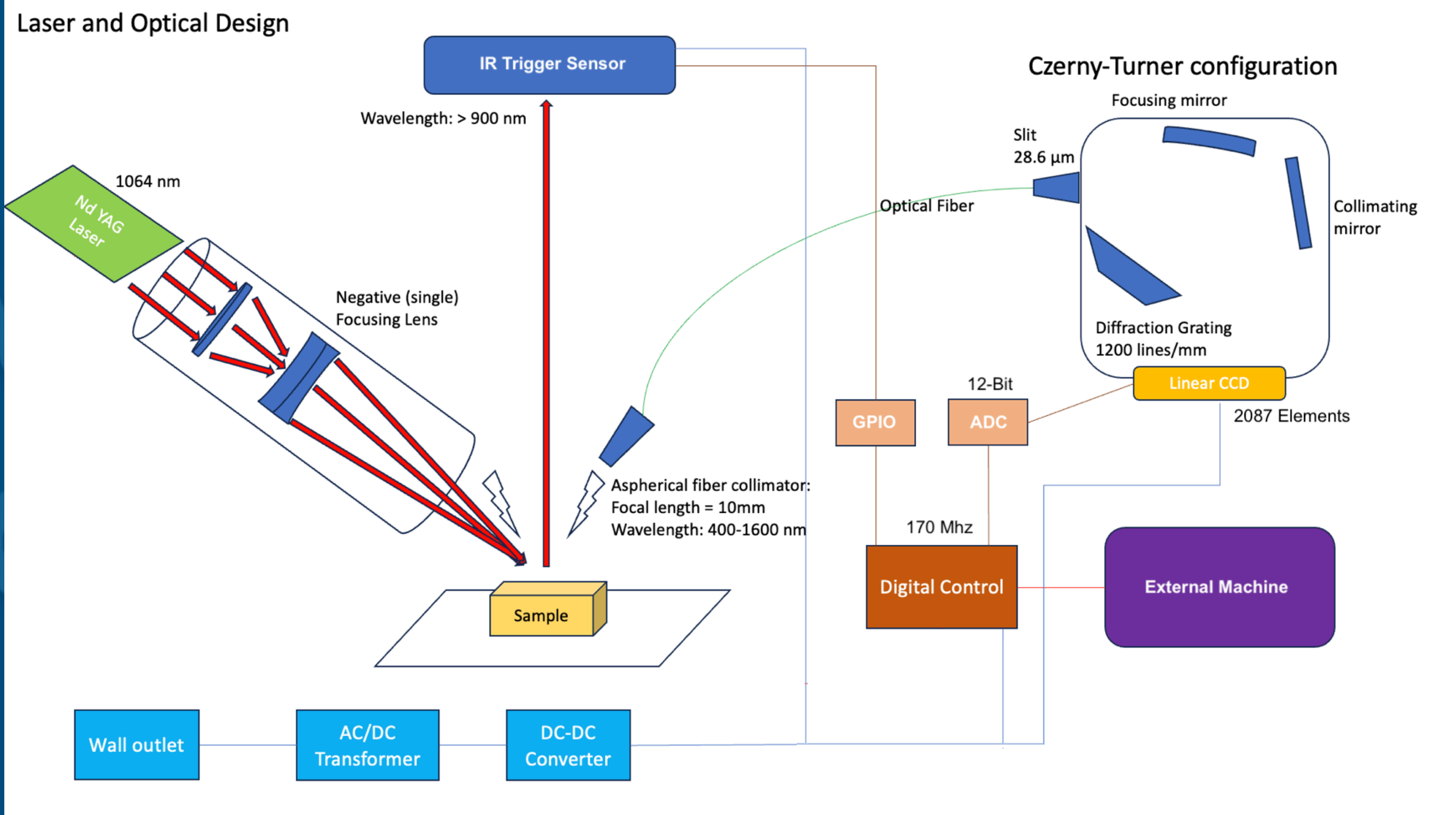
Schematic Prototype:



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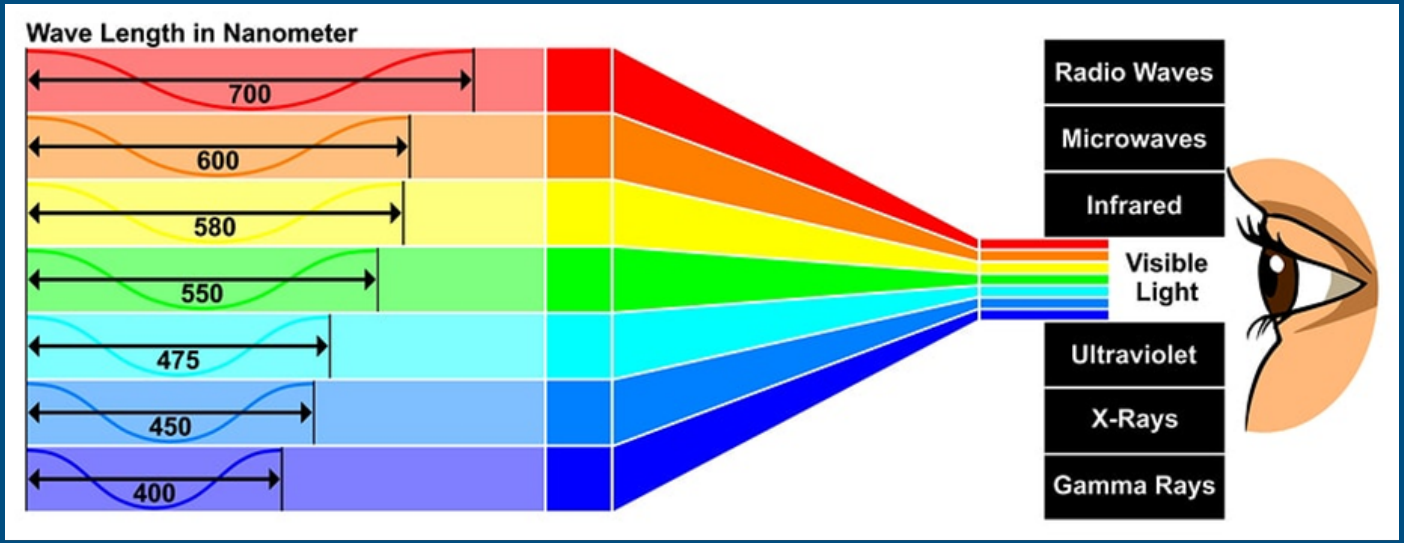
Engineering Requirements

Laser Strength	1000 - 1200 Watt laser (Peak power-pulsed output)
Creation of plasma	Pulse width 6-8 ns, Spot area 1-5 mm
Identify object	To within 90% accurate of its expected spectral emission
Emission measurement results	Results are with less than 10% variance over 5 samples
Results output	LIBS sample results in under a minute
Diffraction grating	600-1200 lines/mm
Q-switch for Laser	1 - 10 Hz pulse rate
Sensor Wavelength detection	300 nm - 1200 nm
Analog to digital resolution	12-bit
communication protocols	USART, SPI, I2C
Linear CCD Resolution	2048 pixel
Laser excitation sensor detection range	750 - 1100 nm
Digital Power Regulation Type	Linear DC-DC converter
Digital controller Speed	64 MHz
Total System cost	≥ $4,000
Number of sample data sets stored	>5
Laser excitation detection time	<1.6 us

Liam Collins
ECE

Objectives: Laser system

- To create a lens system to extend the focal point of the beam
- Create a measurable amount of plasma.
- Design the system so it can be operated in a safe manner.



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Laser Selection

When selecting the laser for our project it needed to meet several criteria for our needs.

- The laser must create plasma
- Be within budget
- Be relatively transportable
- Be operated and maintained in a safe manner
- Be compatible with the system as a whole

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Power Specification for the Laser

Power	1000 W (Peak Power)
Frequency	1-10 Hz
Power Supply	110 V
Pulse Energy	Single Pulse ≥ 160 mJ, Double Pulse ≥ 270 mJ, Multi-pulse ≥ 700 mJ
Spot Area	1-5 mm / 0.03-0.019 in
Laser Housing/Cooling	49x32x31cm
Pulse Width	8 ns

The laser selected is the “**Q Switch ND YAG Laser Machine For Tattoo Removal**”

Laser Testing and Safety Housing

We have conducted several tests with our laser.
The main criteria for the laser is that it will create plasma for the spectrometer to measure.

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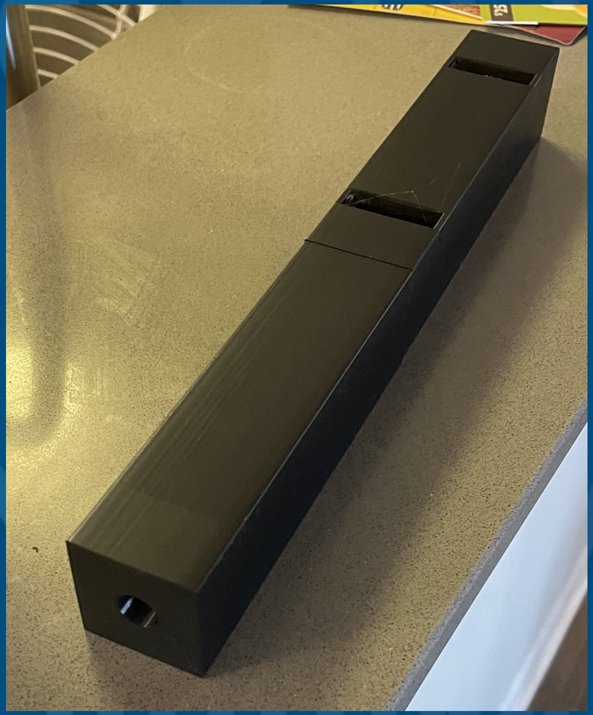

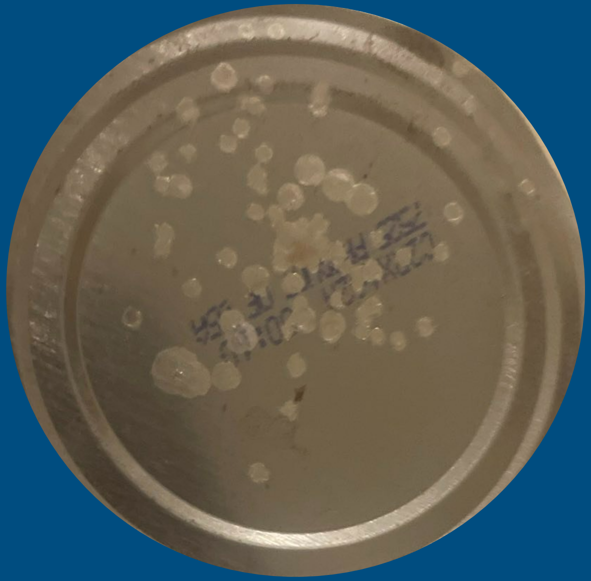

Objectives: Spectrometer System

- Determine the spectral range of the system.
- Choose a gradient that suits the spectral range and resolution.
- Create an optimal system for spectroscopy: Design a slit entrance, collimating mirror, and focusing mirror.
- Determine location in system for light to enter a fiber-optic cable to connect to the spectrometer.
- Select the correct detector array based on the needs for the system. (system of detector, pixel size, quantum efficiency, read-out noise).

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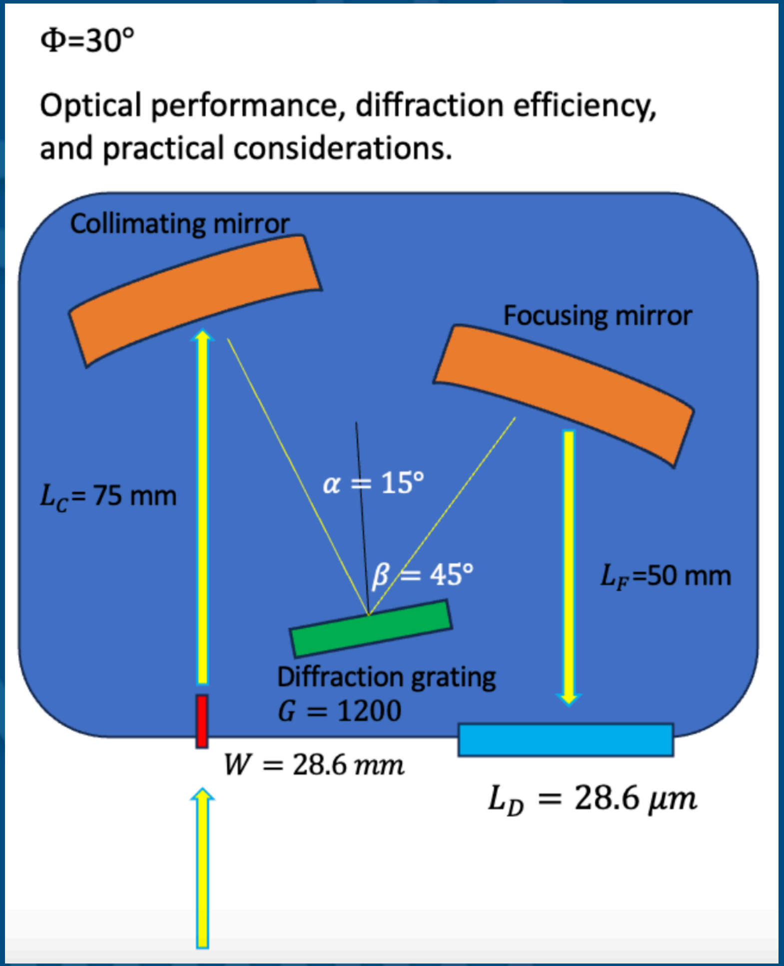
Spectrometer Design:



Requirements:

- Determine spectral range – Visible (400 – 700 nm)
- Geometry
- Diffraction grating
- Slit size
- Detector size

Key Design Concepts:

- Choose a geometry: 30-degree angle geometry
- Selection of grating -Blaze wavelength (500 nm)
- Reduce stray light
- Alignment considerations

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Spectrometer Component Selection:

Getting light efficiently to the spectrometer

56 cm B & W Tek Fiber Patch Cord
SMA905-FC 600-micron core

Ocean Insight 74-Vis Collimating lens:

- Lens for visible-NIR (350-2500 nm)
- Focal length: 10 mm
- f/2 BK-7 glass

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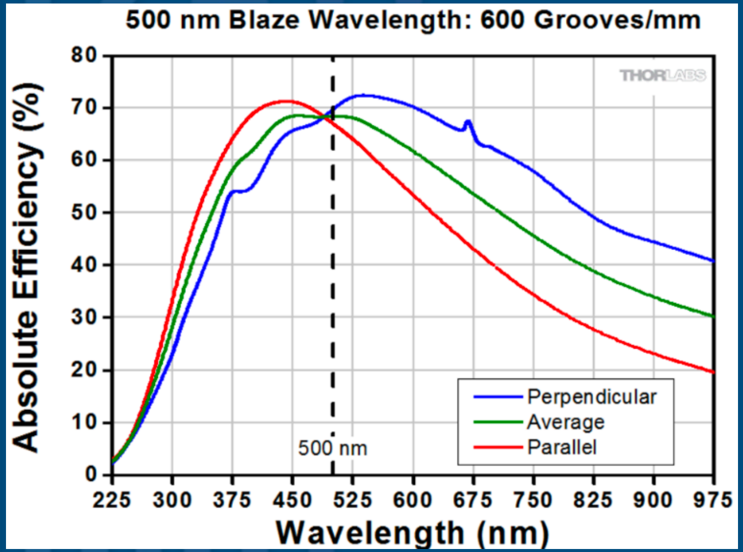
Spectrometer Component Selection:

Brand	Groove Density (groove/mm)	Wavelength range (nm)	Blaze wavelength (nm)	Dimensions (mm)	Price
Edmund Optics	600	200-900	500	12.7x12.7 25.0x25.0	$80 $134
Edmund Optics	1200	200-1600	500	12.5x12.5 25.0x25.0	$80 $134
Thor	600	200-900	500	12.7x12.7 25.0x25.0	$76.58 $125.77
Thor	1200	200-1600	500	12.7x12.7 25.0x25.0	$76.58 $125.77



Czerny Turner Spectrometer Diffraction grating:

- Plane ruled reflective grating
- 1200 lines per mm
- Blaze wavelength of 500 nm

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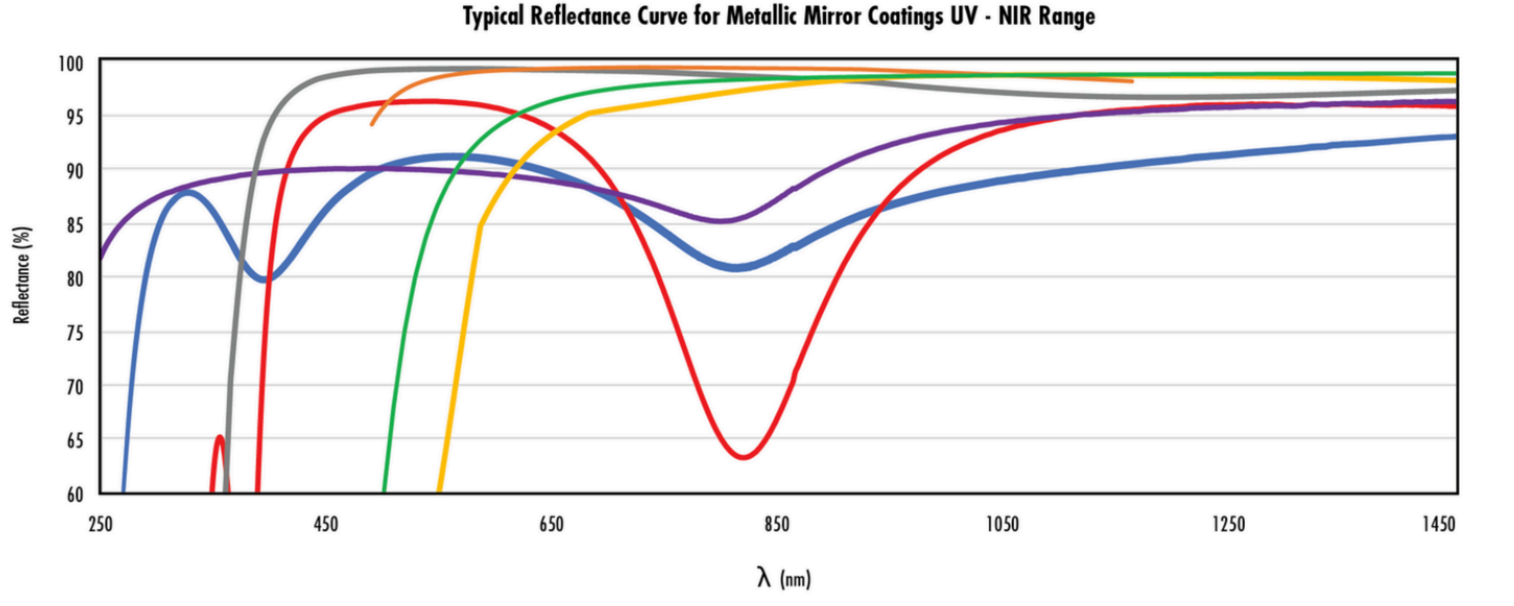
Spectrometer Component Selection:



Protected Aluminum		Enhanced Aluminum		UV Ehanced Aluminum		Protected Gold		Bare Gold		Protected Silver		Ultrafast Enhanced Silver	
Range (μm)	% Reflection	Range (μm)	% Reflection	Range (μm)	% Reflection	Range (μm)	% Reflection	Range (μm)	% Reflection	Range (μm)	% Reflection	Range (μm)	% Reflection
0.4 - 0.7	85	0.45 - 0.65	95	0.25 - 0.45	89	0.7 - 2.0	96	0.7 - 0.8	94	0.45 - 2.0	98	0.6 - 1.0	99
0.4 - 2.0	90	–	–	0.25 - 0.70	85	2.0 - 10.0	96	0.8 - 2.0	97	2.0 - 10.0	98		
								2.0 - 12.0	98				

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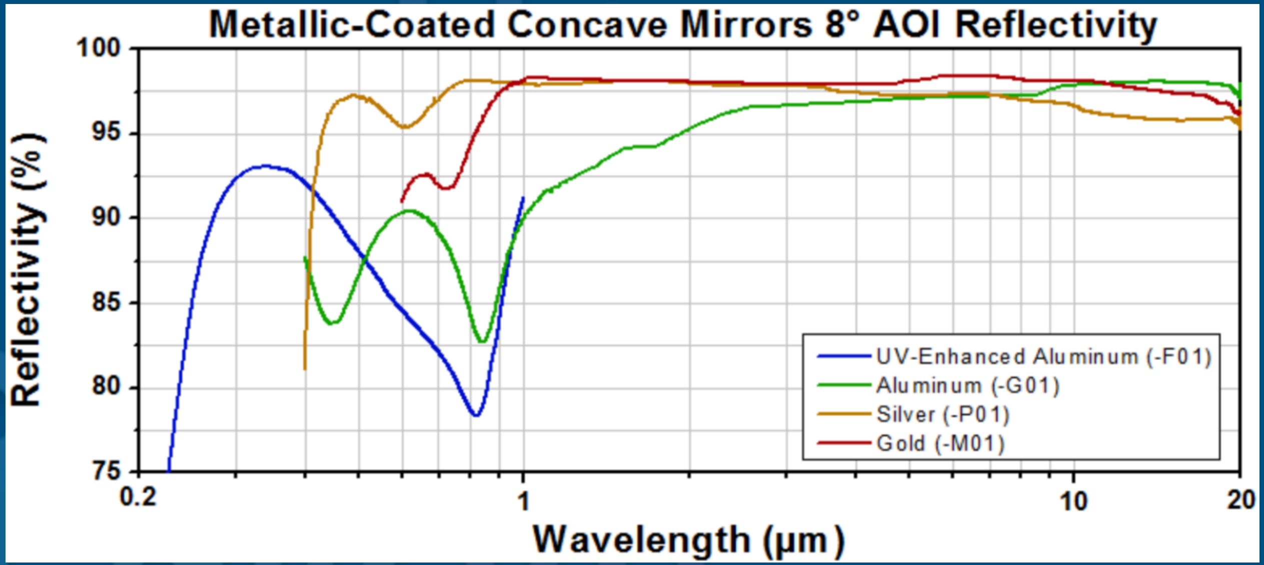
Czerny Turner Crossed Spectrometer: Concave mirrors

- Cost vs efficiency
- Protected aluminum

Spectrometer Component Selection:



Brand	Part number	Coating	Reflectivity	Wavelength range(nm)	Aperture	EFL (mm)	Diameter (mm)	Price
Edmund Optics	43-465	Protected Aluminum	>90%	400-2000	f/1	25	25	$46
Edmund Optics	43-471	Protected Aluminum	>90%	400-2000	f/2	100	50	$55
Thor	CM127-012-G01	Protected Aluminum	>90%	450-2000	f/1	25	12.7	$42.51
Thor	CM254-075-G01	Protected Aluminum	>90%	450-2000	f/3	75	25	$66.24

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Czerny Turner Spectrometer
Concave mirrors: Focusing mirror and collimation mirror

- Edmund Optics
- Thor Labs

Spectrometer calculations for Design:

Step Method of Creating a spectrometer system:

- Select Geometry: Φ
- Select diffraction grating
- Find diffraction angles
- Select a detector width
- Calculate Focal length of focus mirror
- Calculate focal length of collimation mirror
- Determine input slit size

Minimum wavelength: λ_1
Maximum wavelength: λ_2
Wavelength range: $\lambda_2 - \lambda_1$
Resolution: $\Delta\lambda$
Center wavelength: $\lambda_c = (\lambda_2 + \lambda_1)/2$

Angle of incidence: α
Diffraction angle: β
$\Phi = \alpha + \beta$

Grating groove density: G
Focal length collimation: L_C
Focal length focus: L_F
Detector width: L_D
Input slit width: ω_{slit}

Calculate α and β as

$$\alpha = \sin^{-1}\left(\frac{\lambda_c G}{2\cos(\Phi/2)}\right) - \frac{\Phi}{2}$$

$$\beta = \Phi - \alpha$$

Calculate focal length of focus lens/mirror: L_F

$$L_F = \frac{L_D \cos(\beta)}{G(\lambda_2 - \lambda_1)}$$

Calculate focal length of collimation lens/mirror: L_C

$$L_c = L_F \frac{\cos(\alpha)}{M\cos(\beta)}$$

Calculate input slit width: w_{slit}

$$w_{slit} = \frac{G\,\Delta\lambda\,L_c}{\cos(\alpha)}$$

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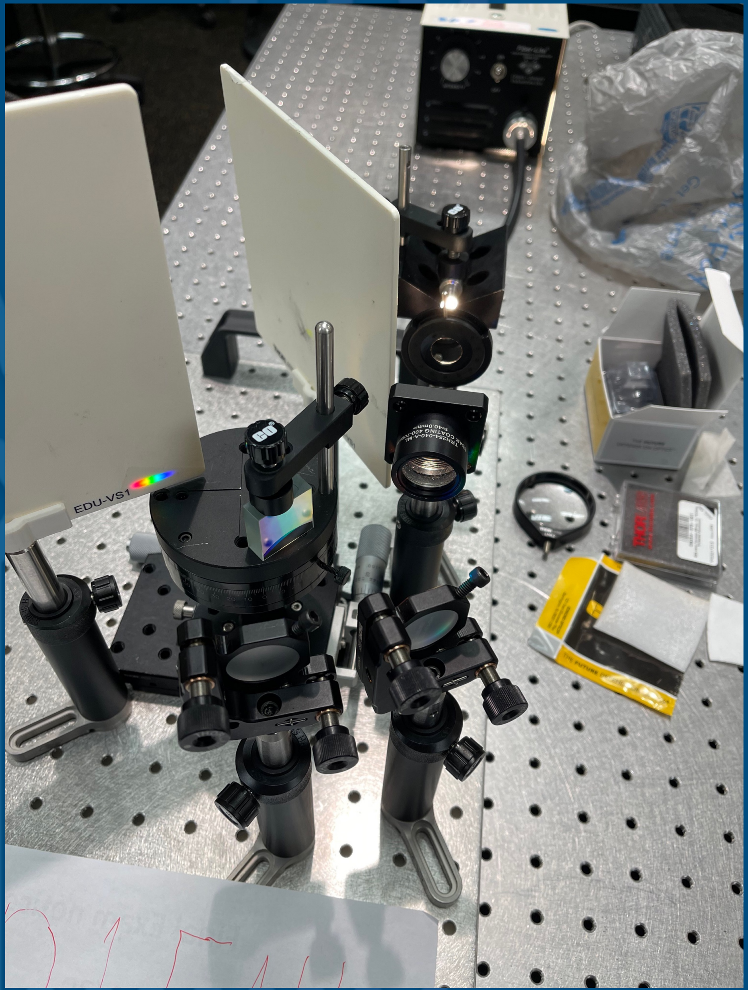
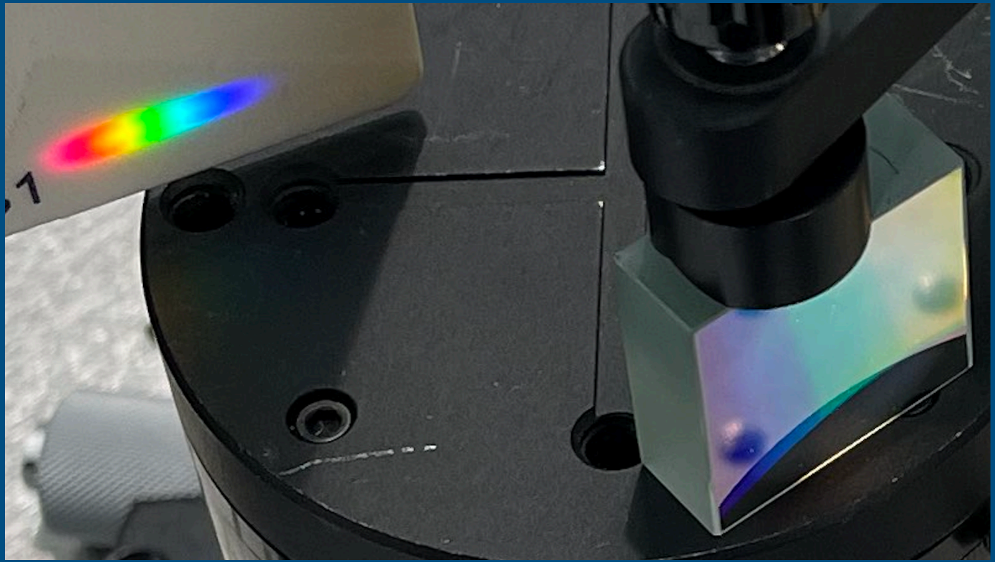
Spectrometer Sub-System Component Testing:





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Fiber coupling power

Core Diamater	Power coupling
50 μm	19.83 μW
600 μm	1.2 mW
1000 μm	1.368 mW

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CCD Spectral responce

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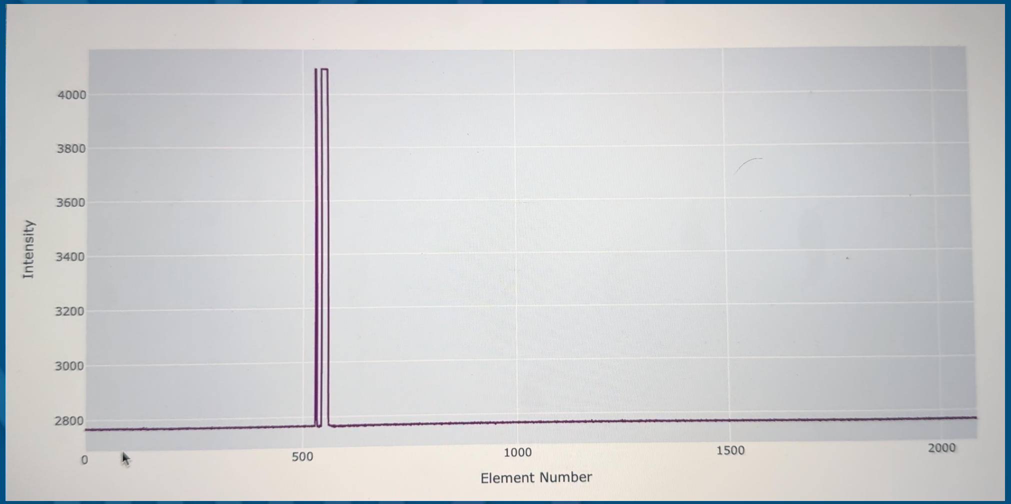
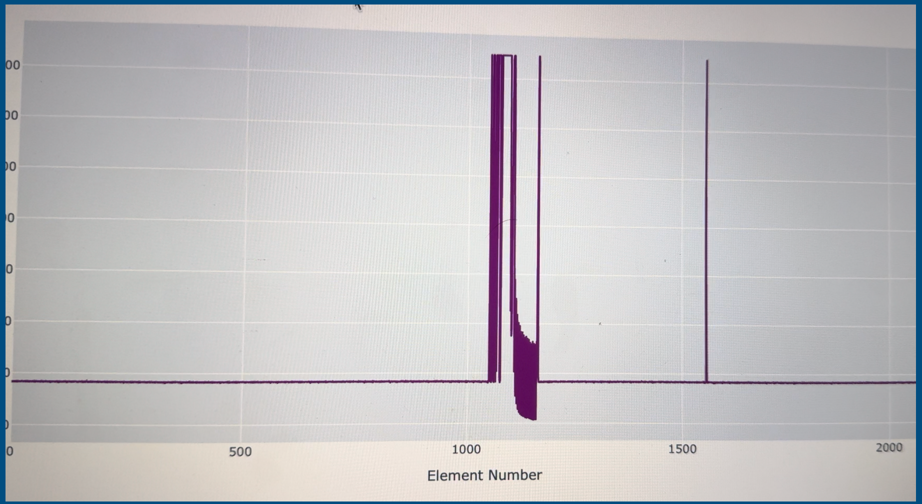
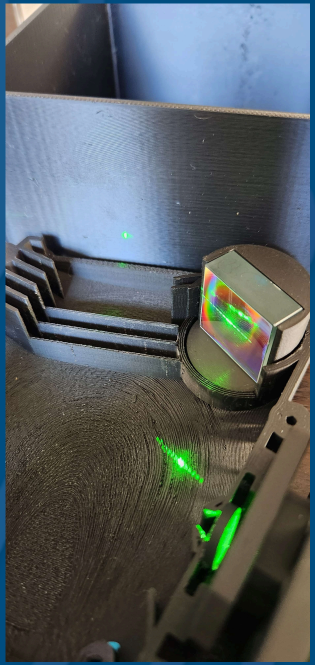
532 Green laser pointer

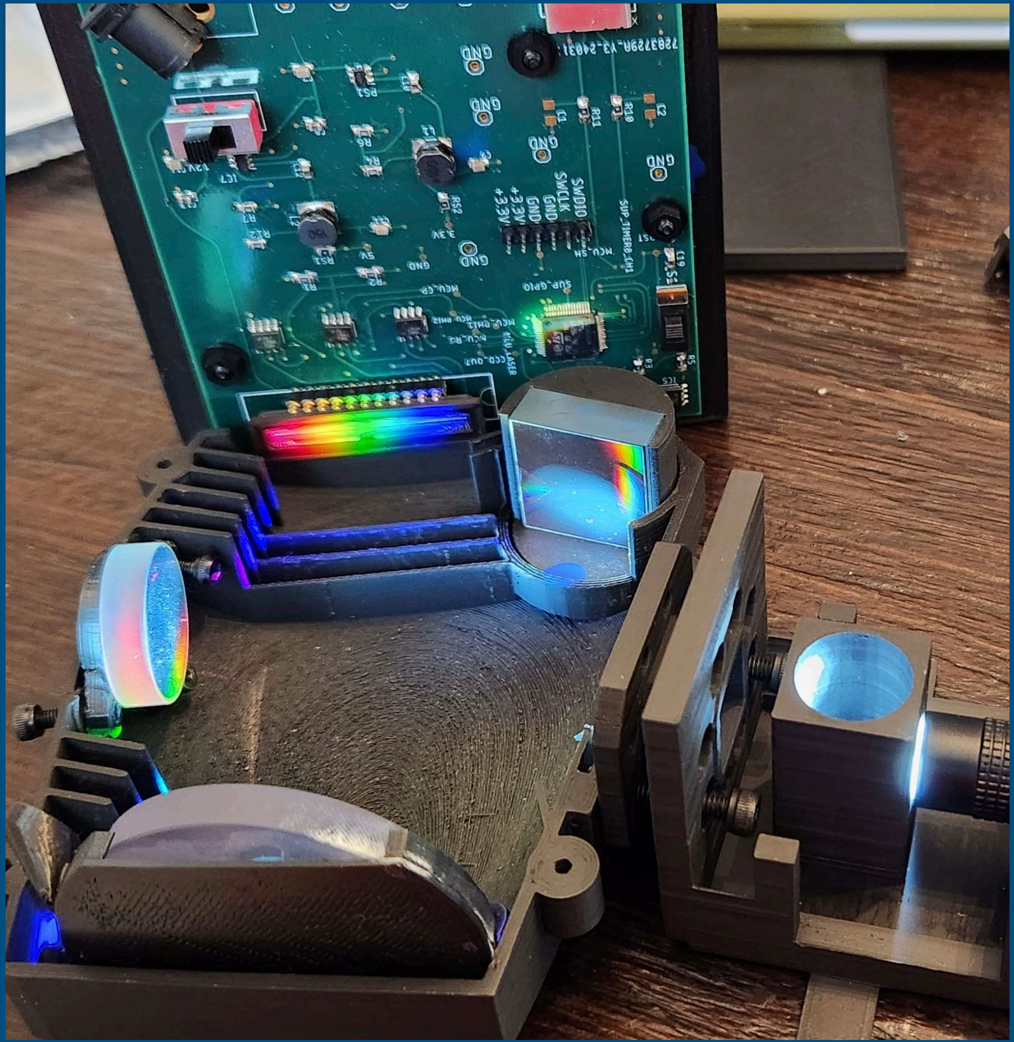


HeNe Laser



Spectrometer Alignment





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Objectives: Digital Control

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Detect Laser Firing Sequence

Capture & Convert Spectral Sample Emissions

Output Measurement Results

Digital Controller Technology Comparison

- Sufficient speed 20 MHz - 50 MHz
- Sufficient I/O Resources 19 or more
- Low Cost

	Microcontroller	FPGA	CPLD
Speed	1 MHz- 1 GHz	10 KHz - 500 MHz	2 MHz - 22 MHz
I/O	2 - 293	32 - 2072	5 - 360
Cost	$2 - $3053	$34 - $173901	$9 - $598
Design Complexity	100s of features	1000,000+ logic blocks	1000s of logic elements
Hardware Type	Fixed Hardware	Fully Customizable	Fully Customizable

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Spectral Emission Sensor Technology Comparison

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- High Dynamic Range
- Sufficient Speed
- Low Cost

	CCD Sensor	CMOS Sensor
Dynamic Range	66 dB - 90 dB	52 dB - 73 dB
Cost	$30 - $900	$800 - $2000
Power Consumption	160 mW - 400 mW	0.5 W - 3.85 W
Data Transfer Speed	6 MHz - 30 MHz	10 MHz- 80 MHz

Software Technology Comparison

- Portability
- Popularity in Data analysis

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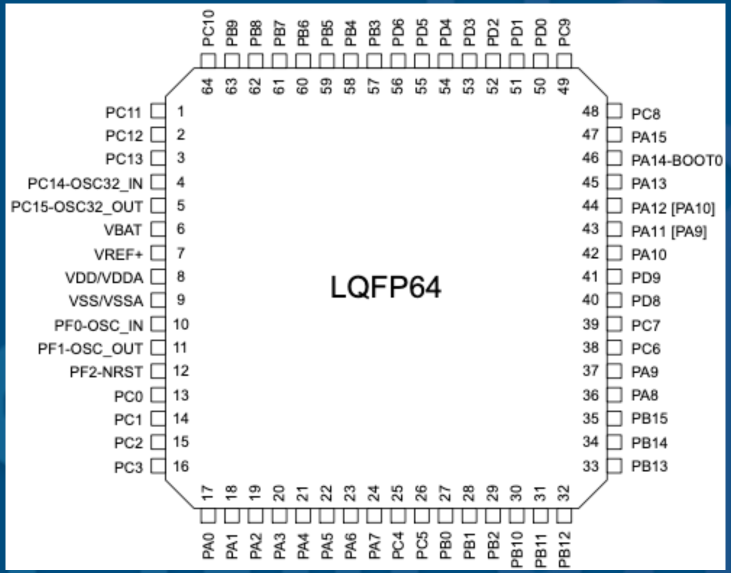
	Rust	Python	C++
Speed (Binary Tree Sorting)	1.19s	50s	1s
Popularity (Github Pull Requests)	13th	1st	5th
Code Processing	Compiler	Interpeter	Compiler

MCU Comparison



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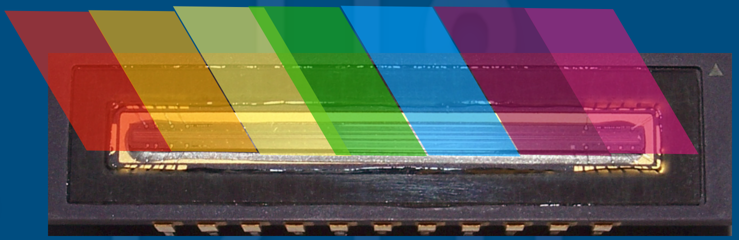
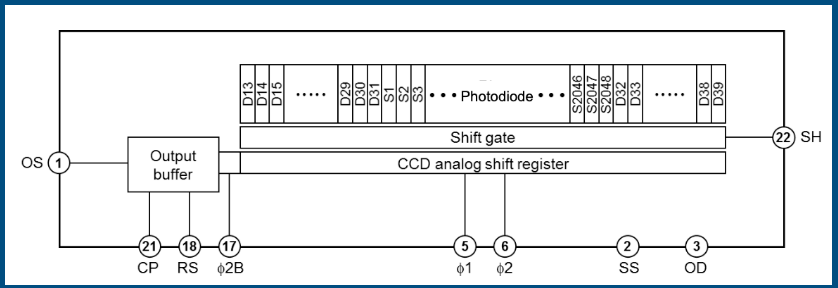
	STM32G474RET6	SPC5601PE F0MLH6	ATSAM3S1A B-AUR
ADC Sample Rate	250 ns	<1 us	1 us
Power Consumption	700 mW	725 mW	745 mW
GPIO	58	45	34
RAM	128 Kbyte	20 Kbyte	16 Kbyte

CCD Comparison





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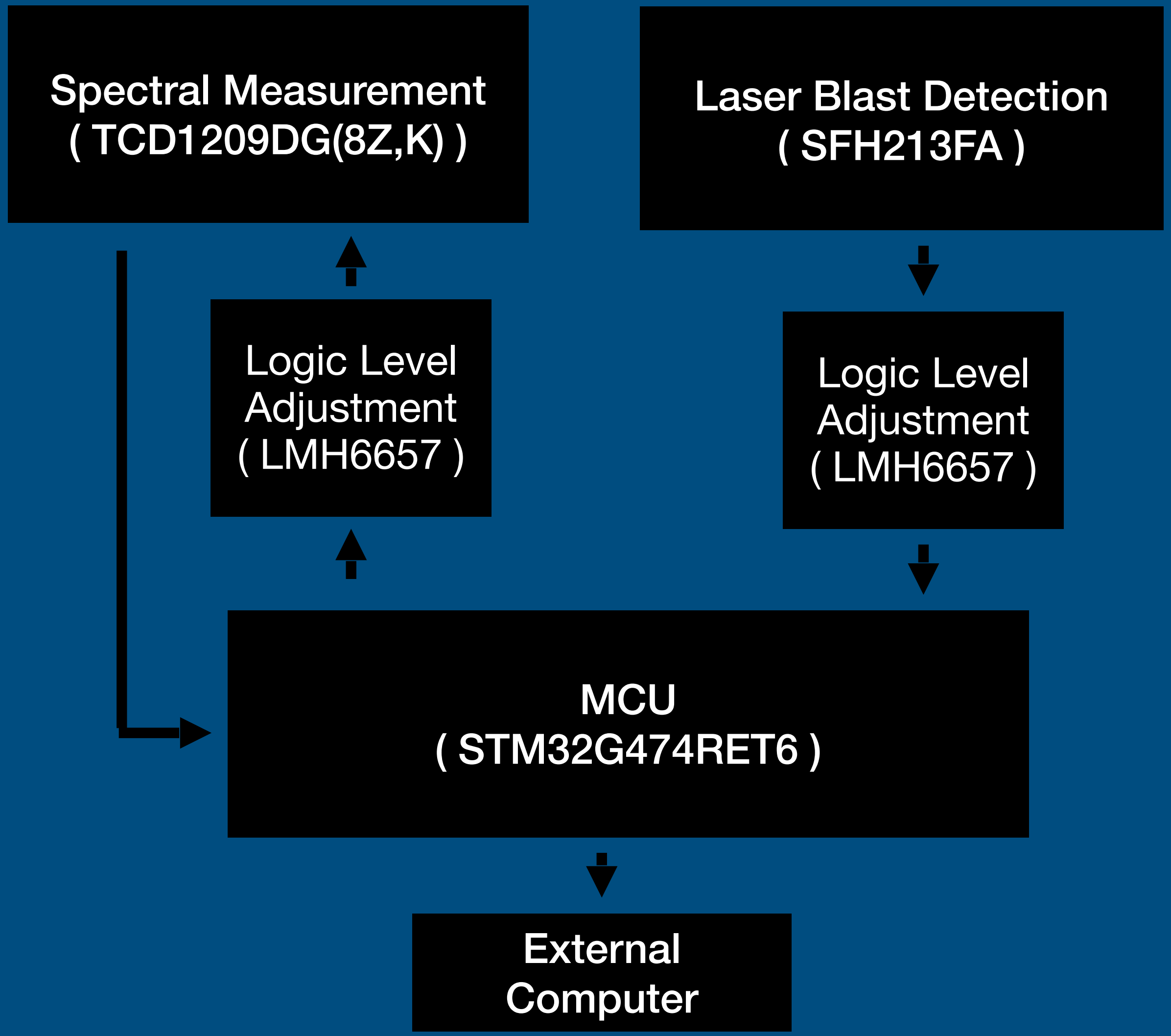
	TCD1209DG(8Z,K)	UPD3747D-A	UPD8828AD-A
Price	$48.61	$46.23	$73.92
Dynamic Range	2000	250	1000
Photocells	2048	7400	7500
Max Frequency	20 MHz	22 MHz	20 MHz

Digital Control Core Systems Overview

- Laser Excitation Detection
- Driving CCD
- ADC Trigger
- External Data Transfer
- Data Organization



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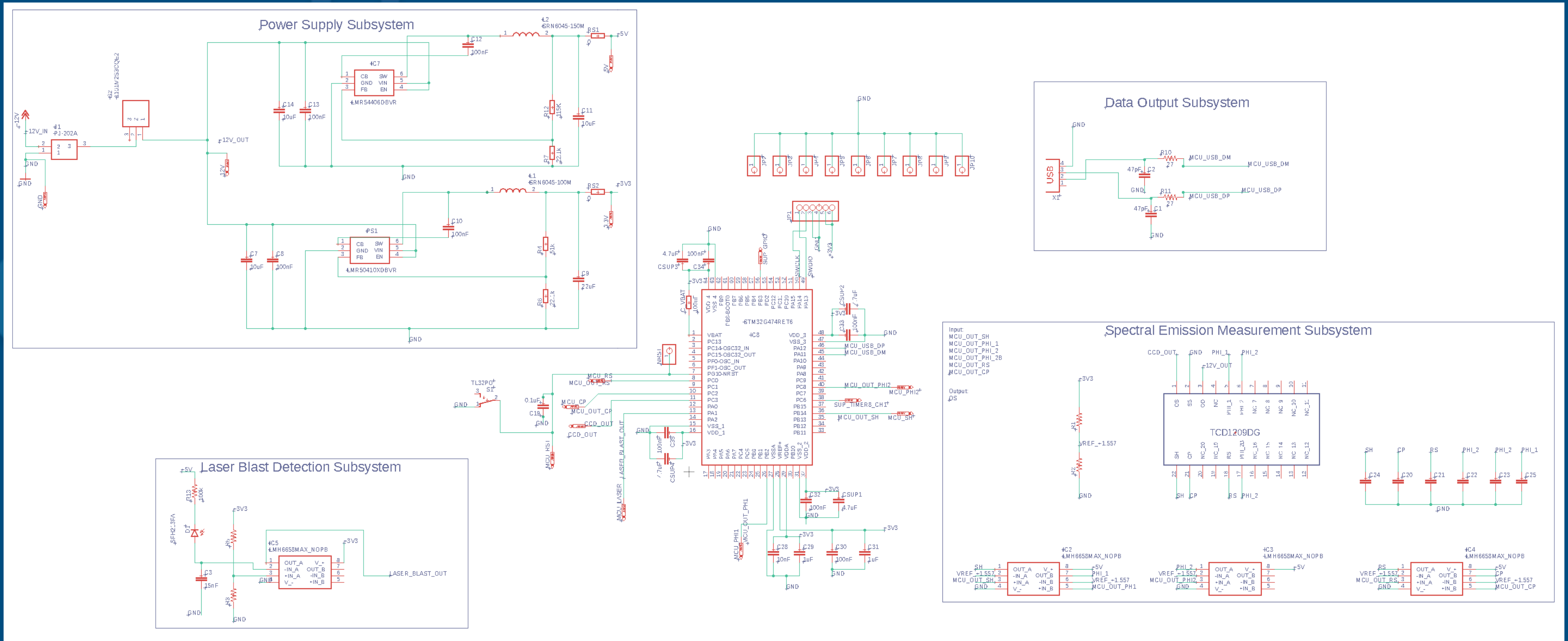
PCB Schematic



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Laser Blast Detection Subsystem

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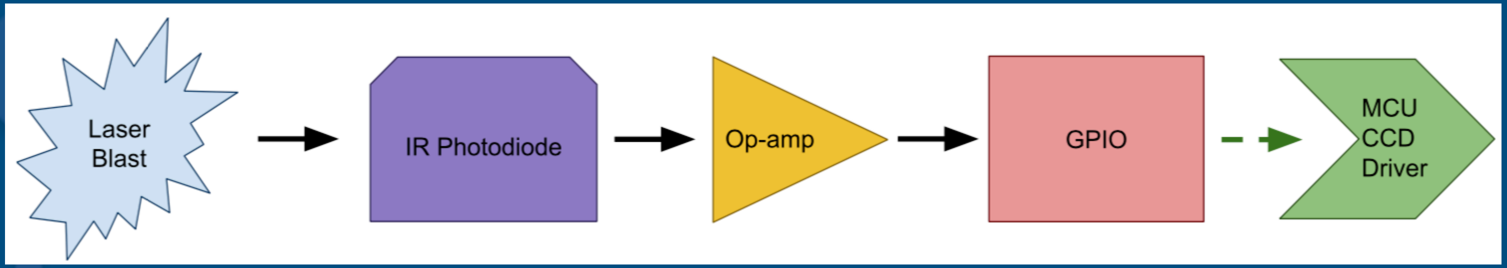
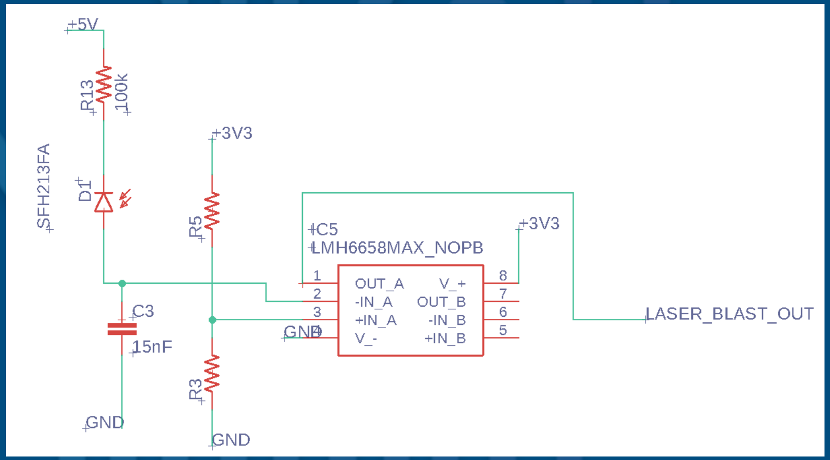
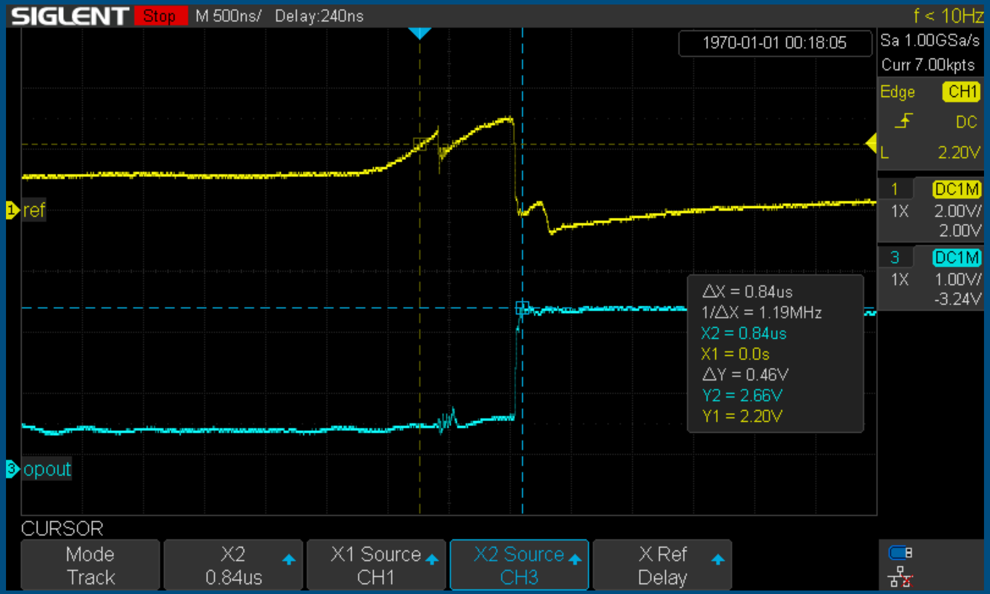
- IR photodiode reversed biased at 5V
- Delay between detection and system start is 84 ns







Spectral Emission Measurement Subsystem

- CCD 12 V Supply
- 5 Driving Control Signals
- 3.3 V to 5 V Logic Shift
- Op Amps offer per signal flexibility

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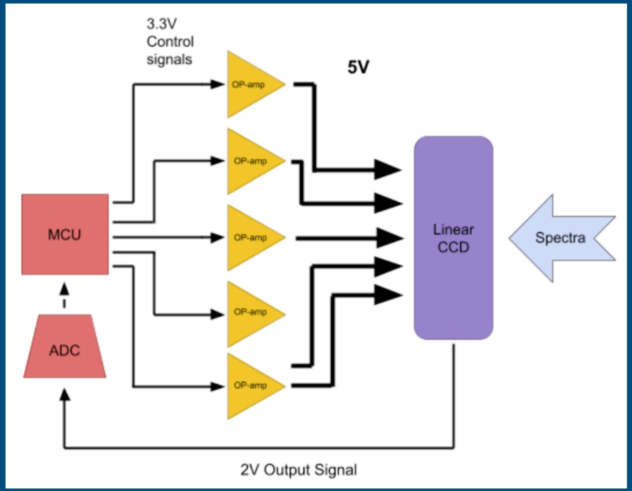
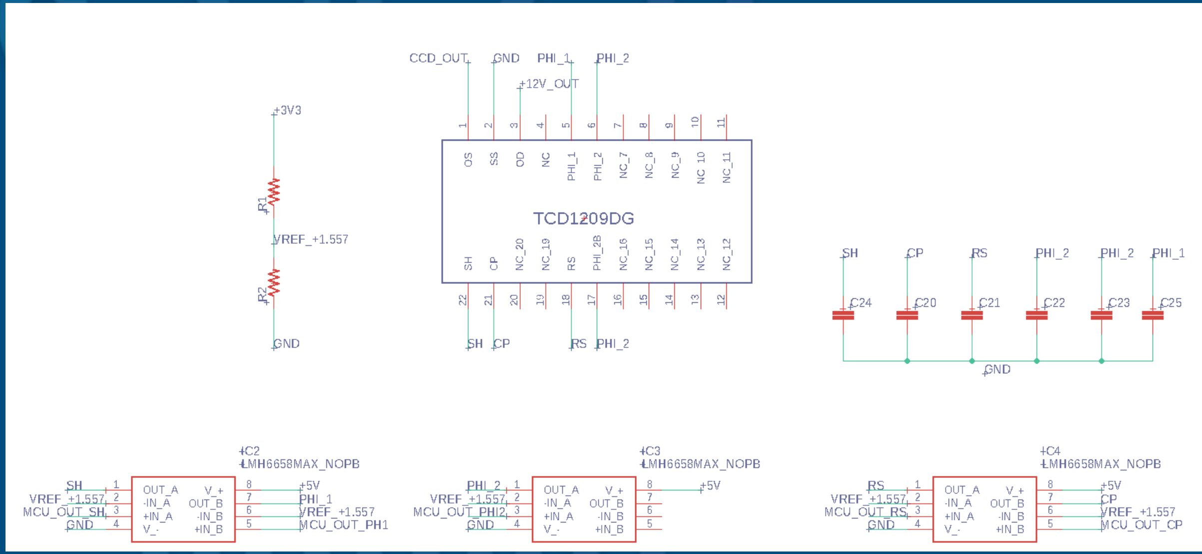
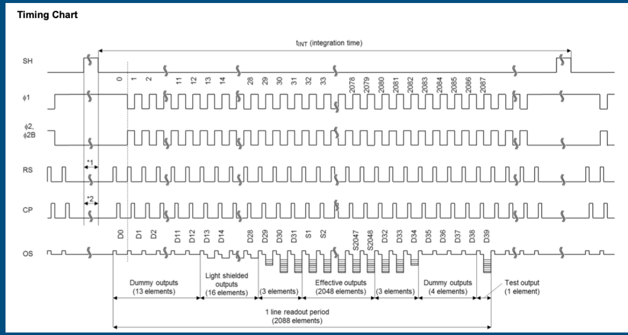
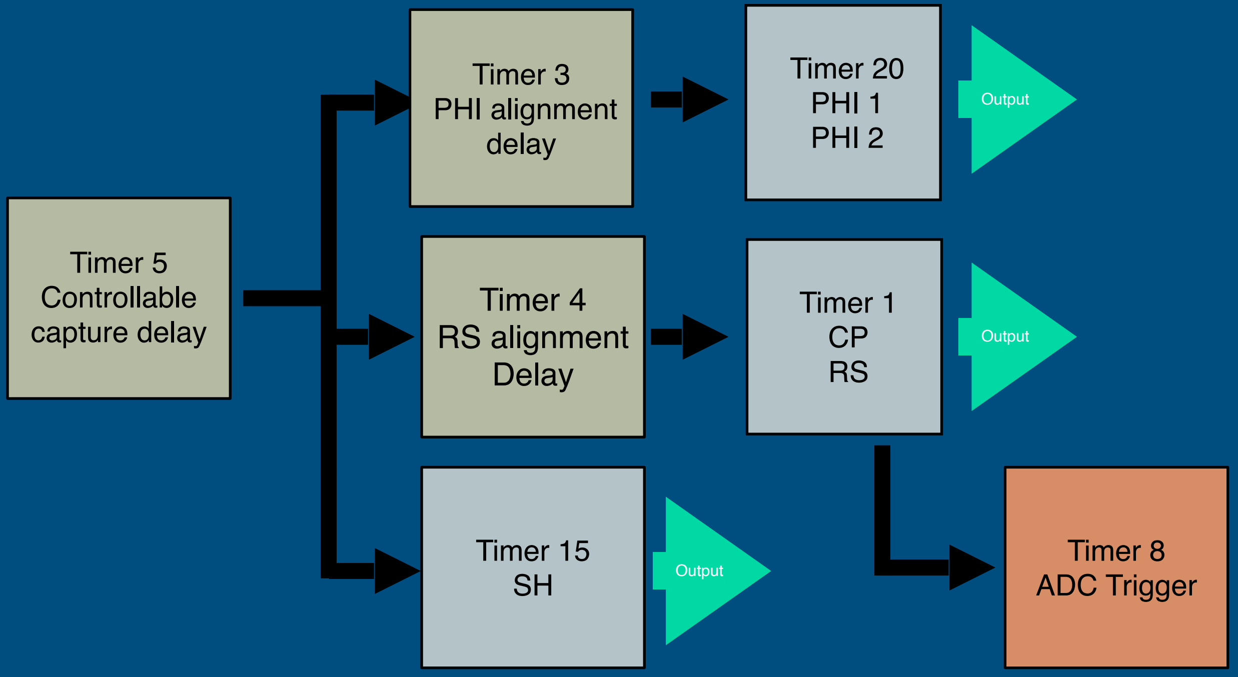






MCU Timer Wave Shaping

- Provides non-blocking waveform generation
- 2088 cycles needed for an entire integration



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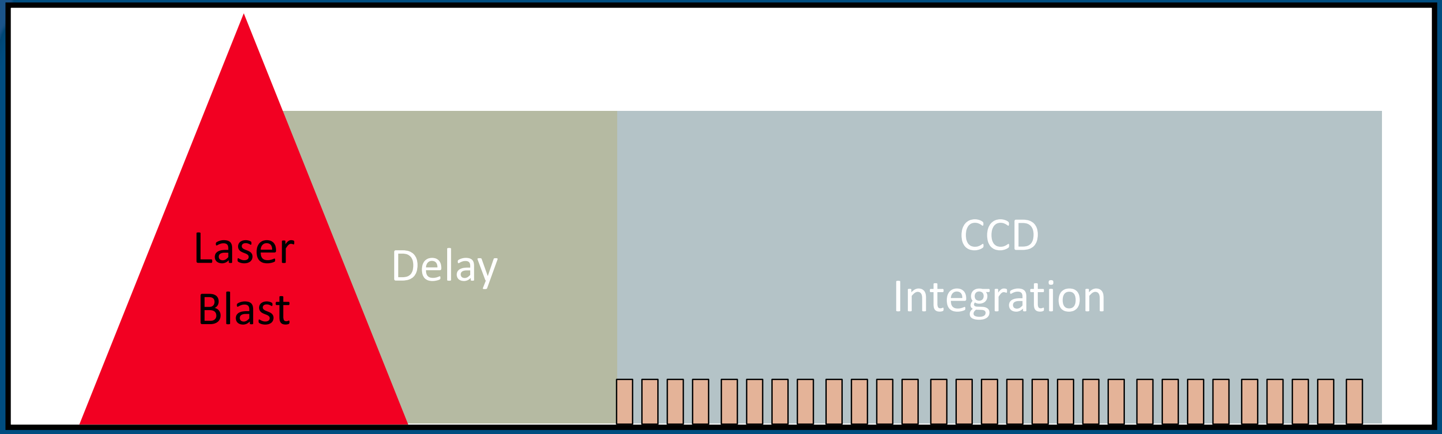
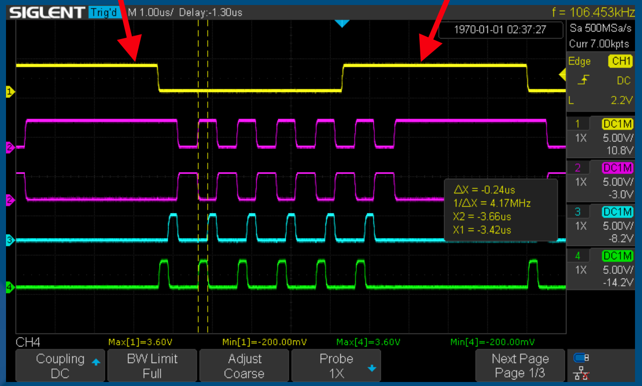


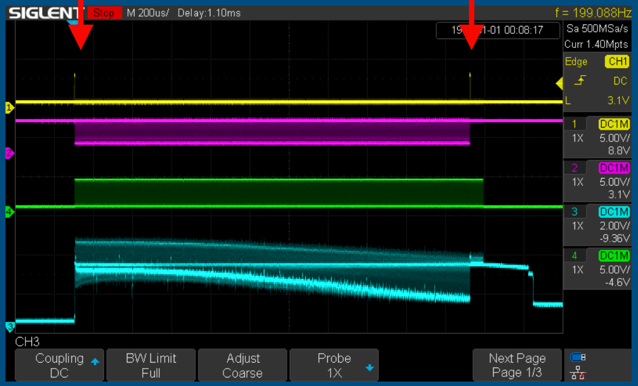
MCU Selection Evolution

- Original MCU timers could only generate 2 complex waveforms. This could not create sufficient waveforms to accurately match the CCD's signal timing requirements
- Original MCU had limited options to trigger and sync timers
- An upgraded MCU of the same family was chosen to replace the old MCU. This MCU had sufficient complex timers and more options for triggering and syncing timers

Incorrect Original MCU Waveform: high duration when pulse is desired at each end



Upgraded MCU Waveform generation creating desired pulses and timing



Old MCU timer triggering options

Table 115. TIM1 internal trigger connection

Slave TIM	ITR0 (TS = 00000)	ITR1 (TS = 00001)	ITR2 (TS = 00010)	ITR3 (TS = 00011)
TIM1	TIM15	TIM2	TIM3	TIM17 OC1

Table 126. TIMx Internal trigger connection

Slave TIM	ITR0 (TS = 00000)	ITR1 (TS = 00001)	ITR2 (TS = 00010)	ITR3 (TS = 00011)
TIM15	TIM2	TIM3	TIM16_OC1	TIM17_OC1

Table 119. TIMx internal trigger connection

Slave TIM	ITR0	ITR1	ITR2	ITR3
TIM2	TIM1	TIM15	TIM3	TIM14_OC1
TIM3	TIM1	TIM2	TIM15	TIM14_OC1
TIM4	TIM1	TIM2	TIM15	TIM14_OC1

New MCU timer triggering options

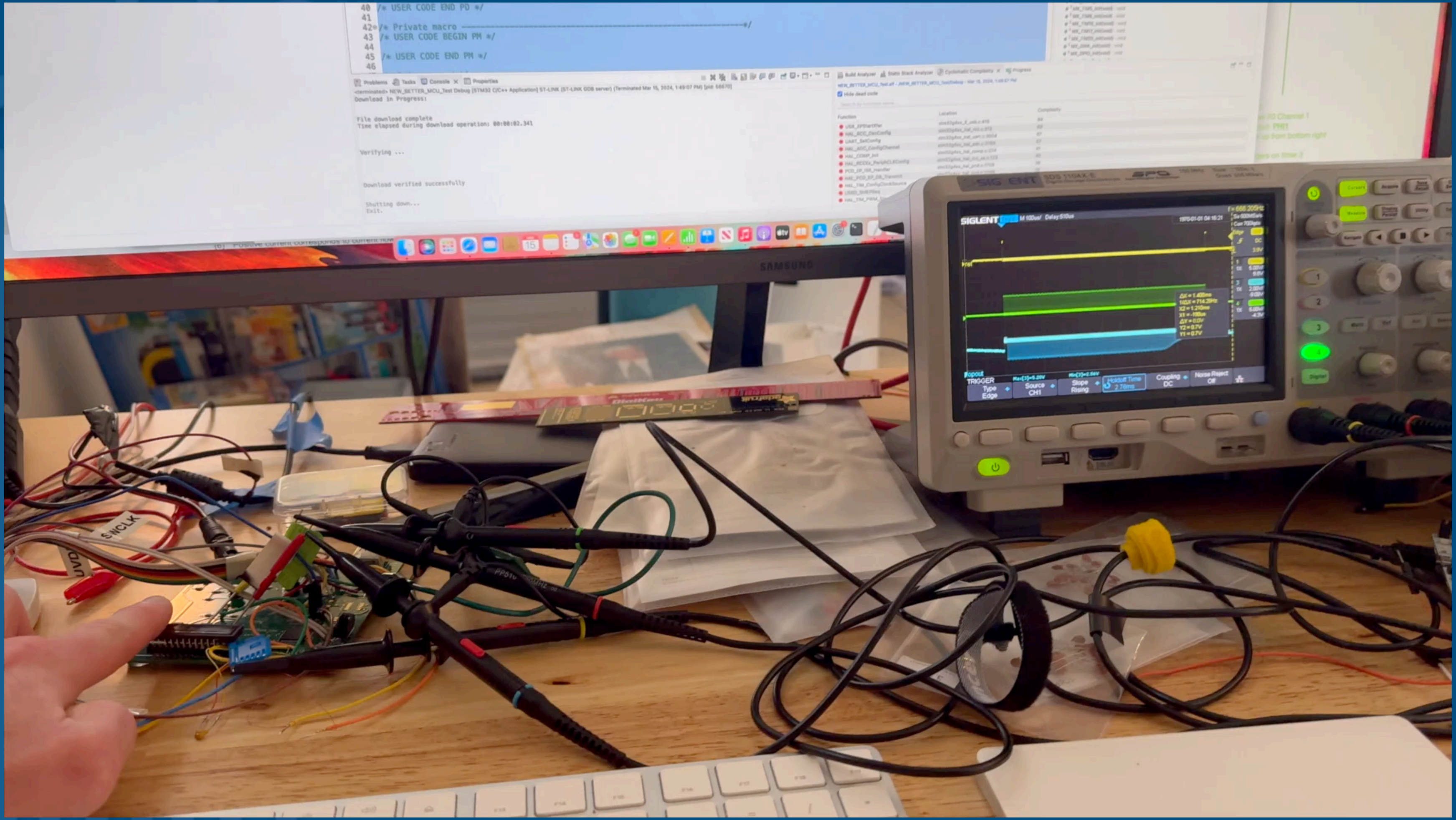
11.3 Interconnection details

11.3.1 From timer (TIMx, HRTIM) to timer (TIMx)

Table 61. Interconnect 1

Timer input trigger signal	Timer input trigger source assignment							
	TIM1	TIM2	TIM3	TIM4	TIM5	TIM8	TIM15	TIM20
timx_itr0	-	tim1_trgo	tim1_trgo	tim1_trgo	tim1_trgo	tim1_trgo	tim1_trgo	tim1_trgo
timx_itr1	tim2_trgo	-	tim2_trgo	tim2_trgo	tim2_trgo	tim2_trgo	tim2_trgo	tim2_trgo
timx_itr2	tim3_trgo	tim3_trgo	-	tim3_trgo	tim3_trgo	tim3_trgo	tim3_trgo	tim3_trgo
timx_itr3	tim4_trgo	tim4_trgo	tim4_trgo	-	tim4_trgo	tim4_trgo	tim4_trgo	tim4_trgo
timx_itr4	tim5_trgo	tim5_trgo	tim5_trgo	tim5_trgo	-	tim5_trgo	tim5_trgo	tim5_trgo
timx_itr5	tim8_trgo	tim8_trgo	tim8_trgo	tim8_trgo	tim8_trgo	-	tim8_trgo	tim8_trgo
timx_itr6	tim15_trgo	tim15_trgo	tim15_trgo	tim15_trgo	tim15_trgo	tim15_trgo	-	tim15_trgo
timx_itr7	tim16_oc	tim16_oc	tim16_oc	tim16_oc	tim16_oc	tim16_oc	xtim16_oc	tim16_oc
timx_itr8	tim17_oc	tim17_oc	tim17_oc	tim17_oc	tim17_oc	tim17_oc	tim17_oc	tim17_oc
timx_itr9	tim20_trgo	tim20_trgo	tim20_trgo	tim20_trgo	tim20_trgo	tim20_trgo	tim20_trgo	-
timx_itr10	hrtim_out_ scout2	hrtim_out_ scout2	hrtim_out_ scout2	hrtim_out_ scout2	hrtim_out_ scout2	hrtim_out_ scout2	hrtim_out_ scout2	hrtim_out_ scout2

Electrical systems
Testing



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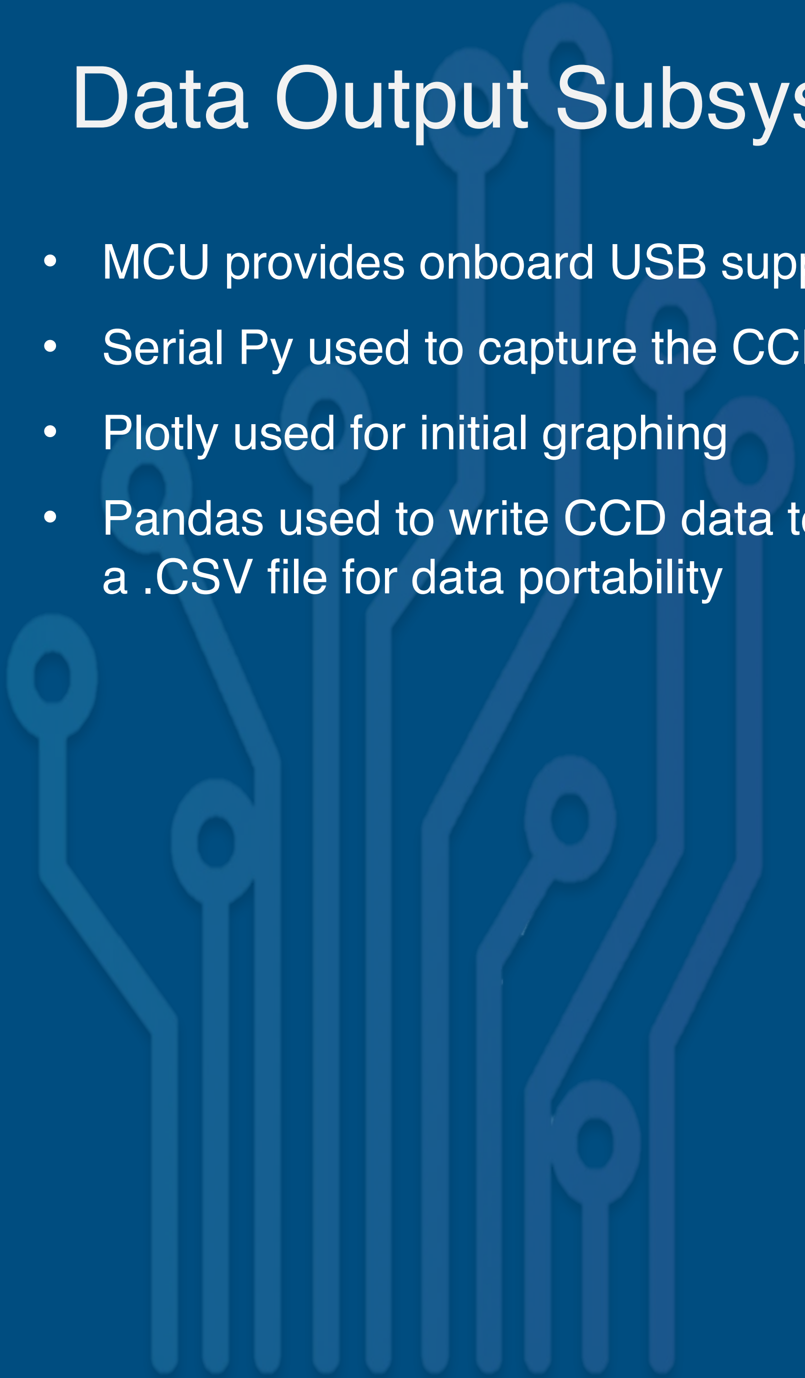
Data Output Subsystem

- MCU provides onboard USB support
- Serial Py used to capture the CCD data
- Plotly used for initial graphing
- Pandas used to write CCD data to a .CSV file for data portability



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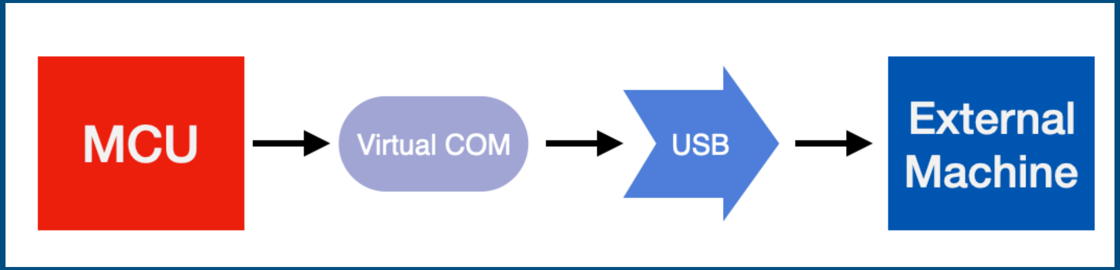
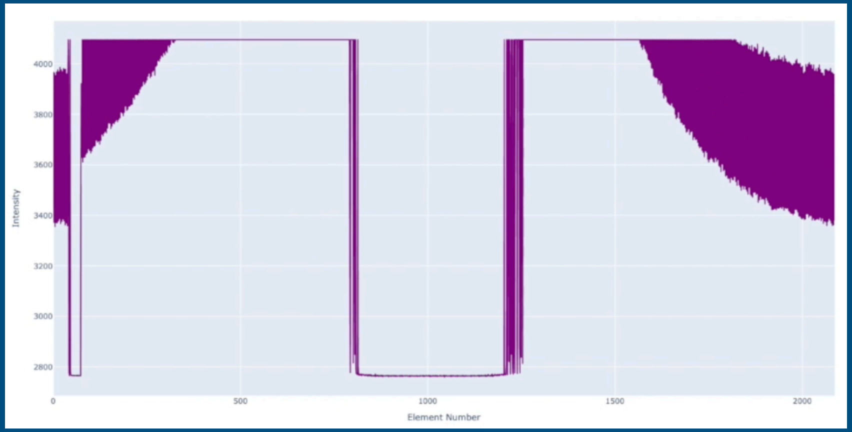
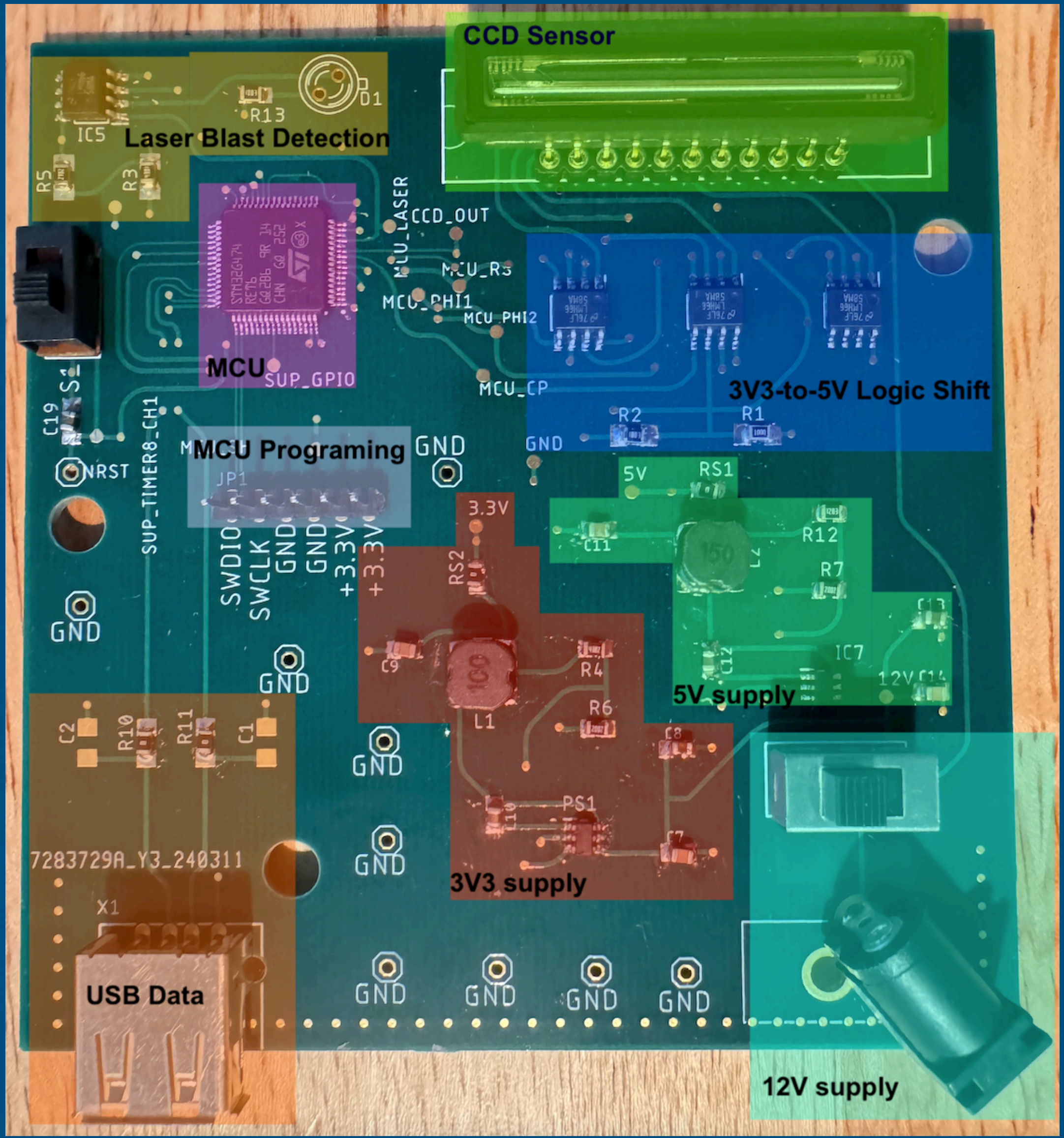




PCB Design

- Six layer stack up
- Signal-Ground-5V-3V-Ground-Signal
- 5 mm component spacing for Hand solder
- 20 mil traces for signal and power
- 0 ohm disconnects for troubleshooting
- Signal test points for monitoring and breakout expansion



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Objectives: Powered Systems

- Determine power requirements.
- Compare DC power source technologies.
- Determine subsystem power requirements.
- Compare tradeoffs of voltage regulator technologies.
- Design power converters for subsystems.

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Power Requirements

- **Power Supply of the Laser.**
- Q-switched Nd YAG laser requires 1 KW .
- Use the power supply that is included with th commercial laser.
- Safety and Time concern.
- **System Power Distribution table**

Item	Power	Voltage	Current
Q-Switched Nd YAG laser	1 KW	110 v	9 A
FT231XS-R	2.5 W_1	5V	0.5 A
Laser Sensor	87 mW	3.6v	24 mA (40mA peak)
MCU	720 mW_2	3.6V	180 mA
CCD sensors	400 mW_3	12V	0.5 A

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System Power Supply Comparison

- PCB Power Supply Sources
- WALL OUTLET (AC) VS DC
- DC batteries

Type	**Lithium-Ion Battery**	**Lead Acid**	**Lead-Carbon**
Cost / Price range	Most Expensive (up to 2000$)	Low (20-200$)	Moderate (100- 500$)
Weight	(7.5-15Kg)	35kg	(31- 35 kg)
Energy density	200-300Wh kg−1	30-40 Wh kg−1	30-45 Wh kg−1
Cycle life	High (~4000–5000)	Low (~500–1000)	Moderate (~1500–2000)
Power density	High (800-900 W kg−1)	Low (~40–50 W kg−1)	Moderate (~100-500 W kg−1)
DOD	High (~80–95%)	Low (~30–50%)	Moderate (~50–80%)
Efficiency	Most efficient (90%)	Low (50%)	High (85%-90%)

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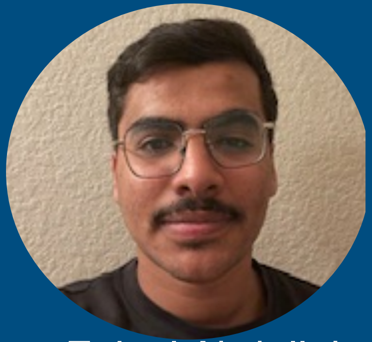
Power Source Technology Comparison



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- DC batteries have more Stability than the AC wall outlet
- DC batteries require Recharging and replacement.
- The Cost of DC batteries are too high

Types	DC batteries	AC Wall outlet
Stability	More	Less
Recharging	Required	Not Required
Replacement	Yes	No
Cost	Expensive($20-$500)	Cheap($10-$15)
AC-DC convertor needed	No	Yes

Power System Design

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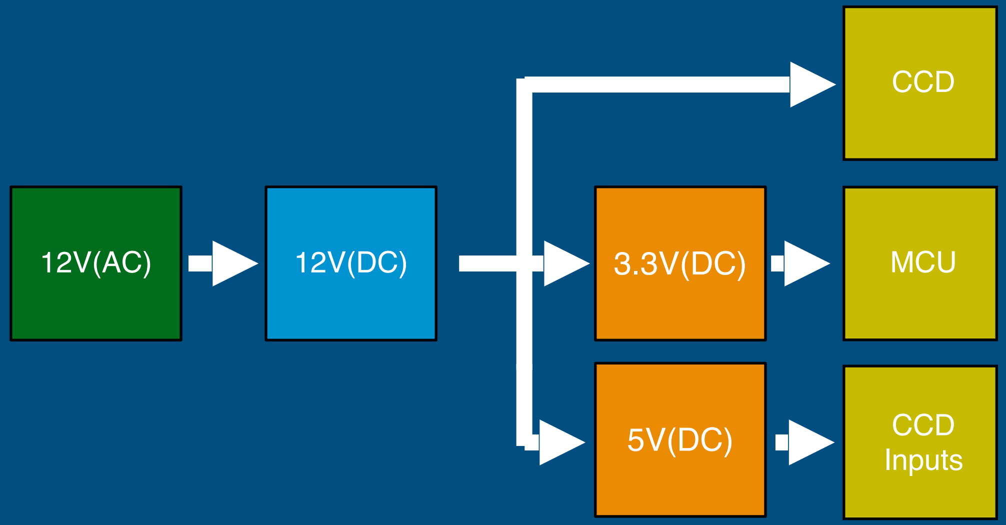
- Components power sources.
- Voltage Regulators
- CCD requires 12 V .
- 5 V voltage regulator will be used to supply CCD inputs and FT231XS-R.
- 3.3 V voltage regulator to supply the MCU.



Voltage Regulator Comparison

- Switching VS Linear Voltage Regulators
- power efficiency noise, Cost, heat, and design complexity .
- Linear regulators have less noise output .and more heat output.
- Switching regulators have less heat output and high efficiency.

The noise issues produced by the switching regulator, we can overcome this by careful component placement and routing the PCB.

Voltage regulator type	Linear	Switching
Design	Simple(non-reactive elements)	Complex(reactive elements)
Efficiency	Low (30%-60%)	High (84%-97%)
Heat output C	High (up to 160°C)	Less (20°C ~ 85°C)
Noise/ripple voltage	Low (10 Vrms -20Vrms)	High (30mV)
Overheat protection	Thermal shutdown protection	Overheat protection
Step up / Step Down	Step down only	Step UP & Step down. Buck & Boost
Size	Small (1.00 mm × 1.00 mm)	Big (2.90 mm × 1.60 mm)
Cost	Low (0.24$)	High ($4.53)

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Switching Voltage Regulators

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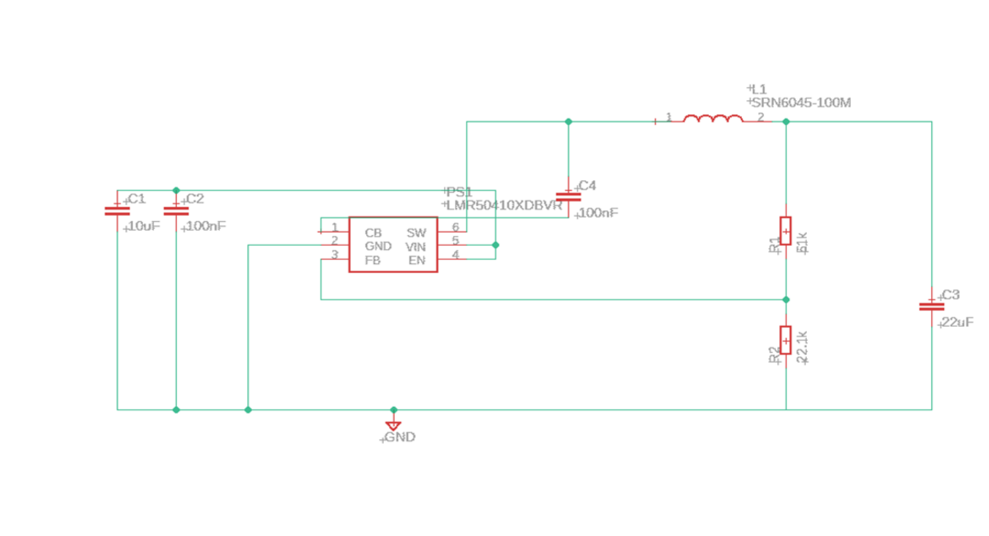
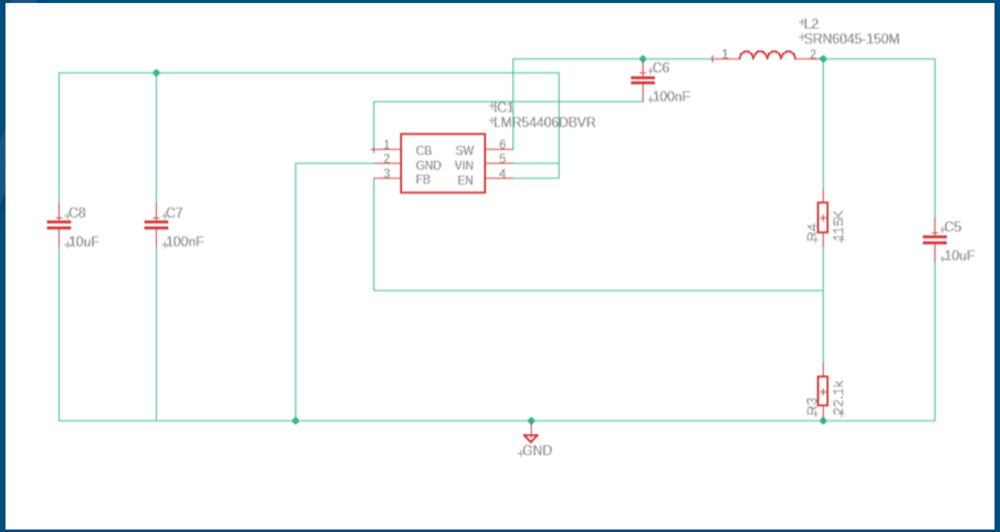
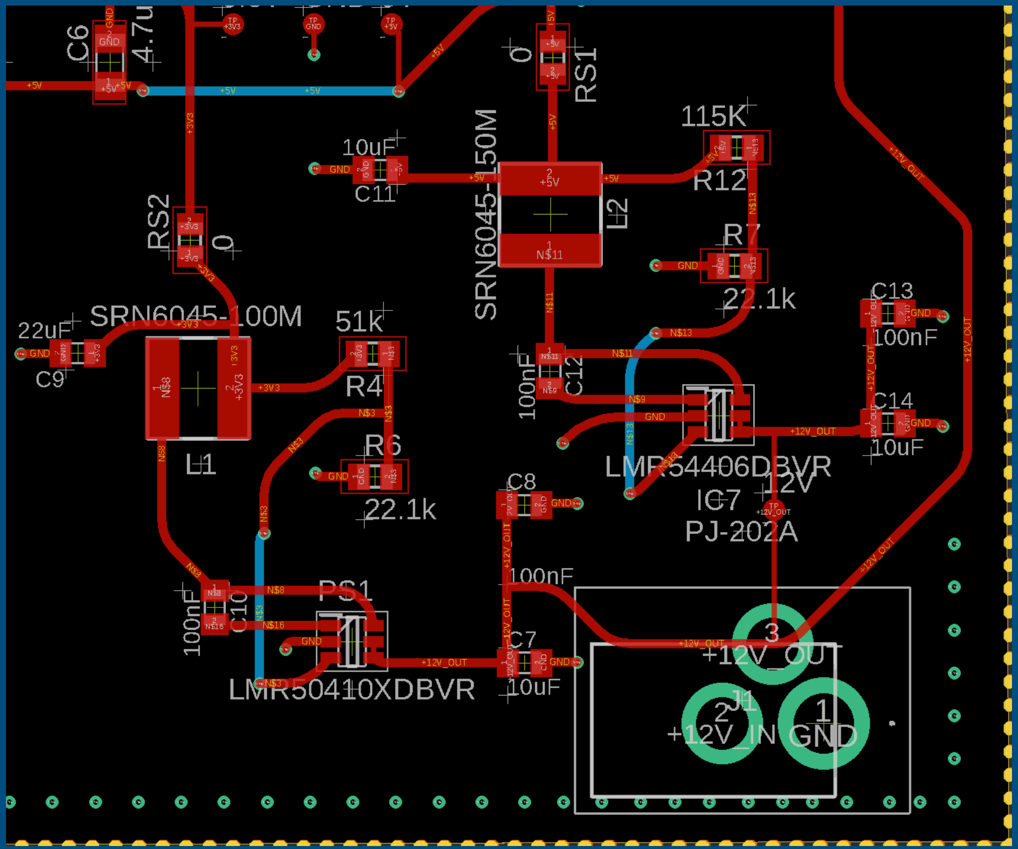
- MCU Voltage Regulator Schematic (3.3 V)
- CCD inputs and FT231 Voltage regulator Schematic (5V)
- LMR50410XDBVR
- lower output ripple voltage.
- high efficiency
- Low cost





Regulator Design

- Inductors perpendicular rotation to reduce magnetic coupling
- Space provided for additional thermal vias
- Prevent overheating.
- 0 ohm disconnects for each regulator output to test the regulators supply.



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Verified Engineering Requirements

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Creation of Plasma	Pulse Width 6-8 ns, Spot area 1-5 mm
Results Output	Sample Results in under a minute
Number of Sample data sets stored	>5

Plasma Creation

Ben Logan
PSE

Calculations for plasma creation with Peak Power

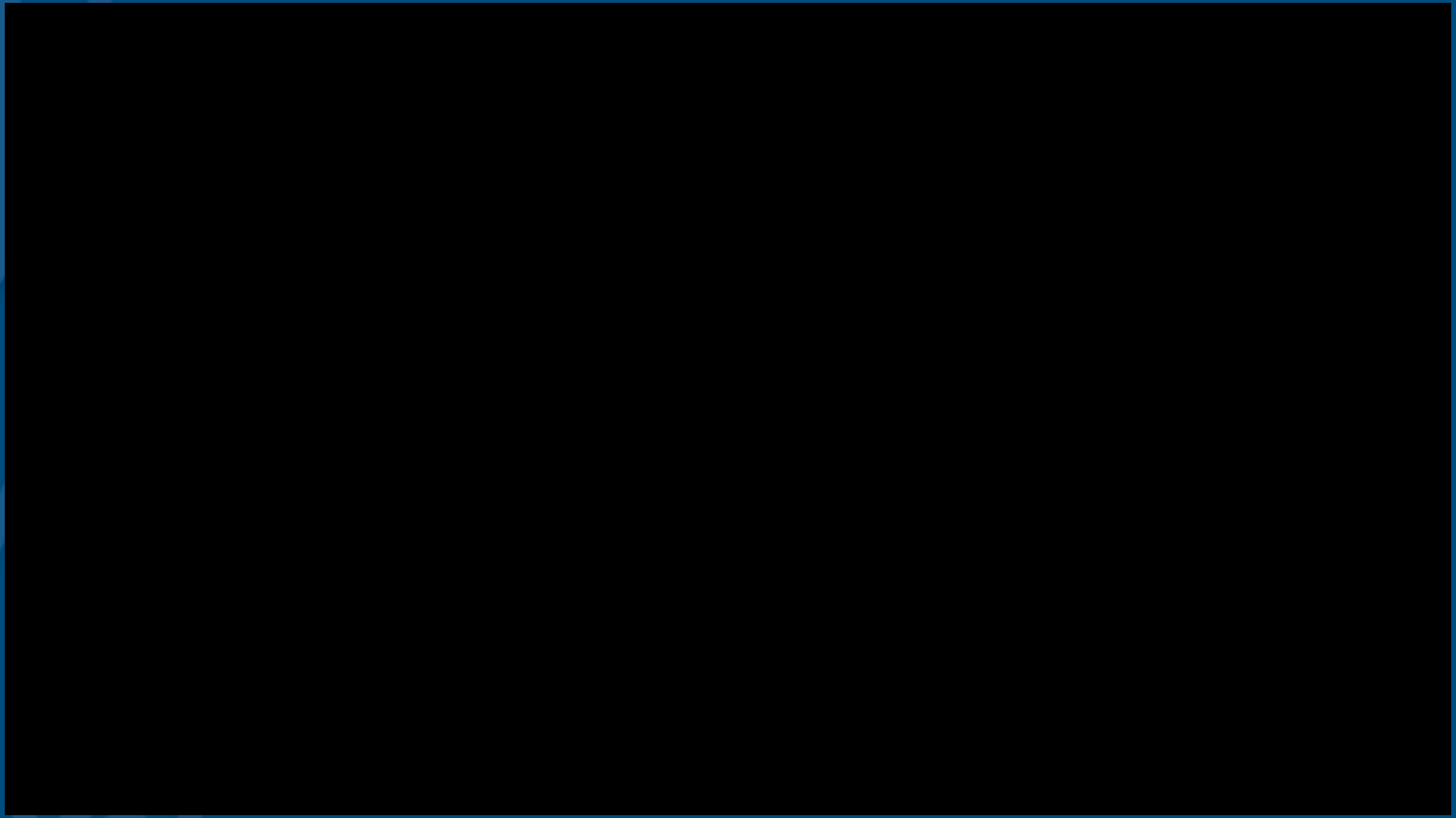
peak power is $\frac{700\ \mathrm{mJ}}{8\ \mathrm{ns}} = 87.5\ \mathrm{MW}.$

peak power is $\frac{270\ \mathrm{mJ}}{8\ \mathrm{ns}} = 33.75\ \mathrm{MW}.$

$$\mathrm{Intensity}\ (W/cm^2) = \frac{87.5\times10^9\ \mathrm{W}}{0.0001\ \mathrm{cm}^2} \approx 8.75\times10^{14}\ \mathrm{W/cm}^2$$

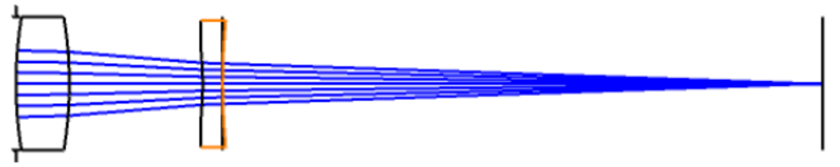
$$\mathrm{Intensity}\ (W/cm^2) = \frac{87.5\times10^9\ \mathrm{W}}{0.0005\ \mathrm{cm}^2} \approx 1.75\times10^{14}\ \mathrm{W/cm}^2$$

Plasma Creation



Plasma Creation

Parameter	Value		Parameter	Value
$w0$	5.38E-06		f_1	100
λ	1.06E-06		f_2	-50
Rayleigh Range (output)	Formula		d	20
z_R	8.55E-05		Effective Focal Length (output)	Formula
	85.5mm		systemf_{system}	-83.33333333



	Surface Type		Comment	Radius	Thickness	Material	Coating	Clear Semi-Dia		Chip Zone	Mech Semi-Dia	Conic	TCE x 1E-6
0	OBJECT	Standard		Infinity	Infinity			0.000		0.000	0.000	0.0...	0.000
1	STOP	Standard		Infinity	0.000			10.000	U	0.000	10.000	0.0...	0.000
2	(aper)	Standard	L1S1	60.990	8.000	N-BK7		10.000	U	0.000	10.000	0.0...	-
3	(aper)	Standard	L1S2	-60.9...	20.000			10.000	U	0.000	10.000	0.0...	0.000
4	(aper)	Standard	L2S1	-50.0...	3.000	N-BK7		9.000	U	0.500	9.500	0.0...	-
5	(aper)	Standard	L2S2	100.0...	0.000			9.000	U	0.500	9.500	0.0...	0.000
6		Standard	Focal Point	Infinity	89.995			10.000	U	0.000	10.000	0.0...	0.000
7	IMAGE	Standard		Infinity	-			10.000	U	0.000	10.000	0.0...	0.000

Results Output

One of the specification requirements for the system is that it displays results in no more that one minute.

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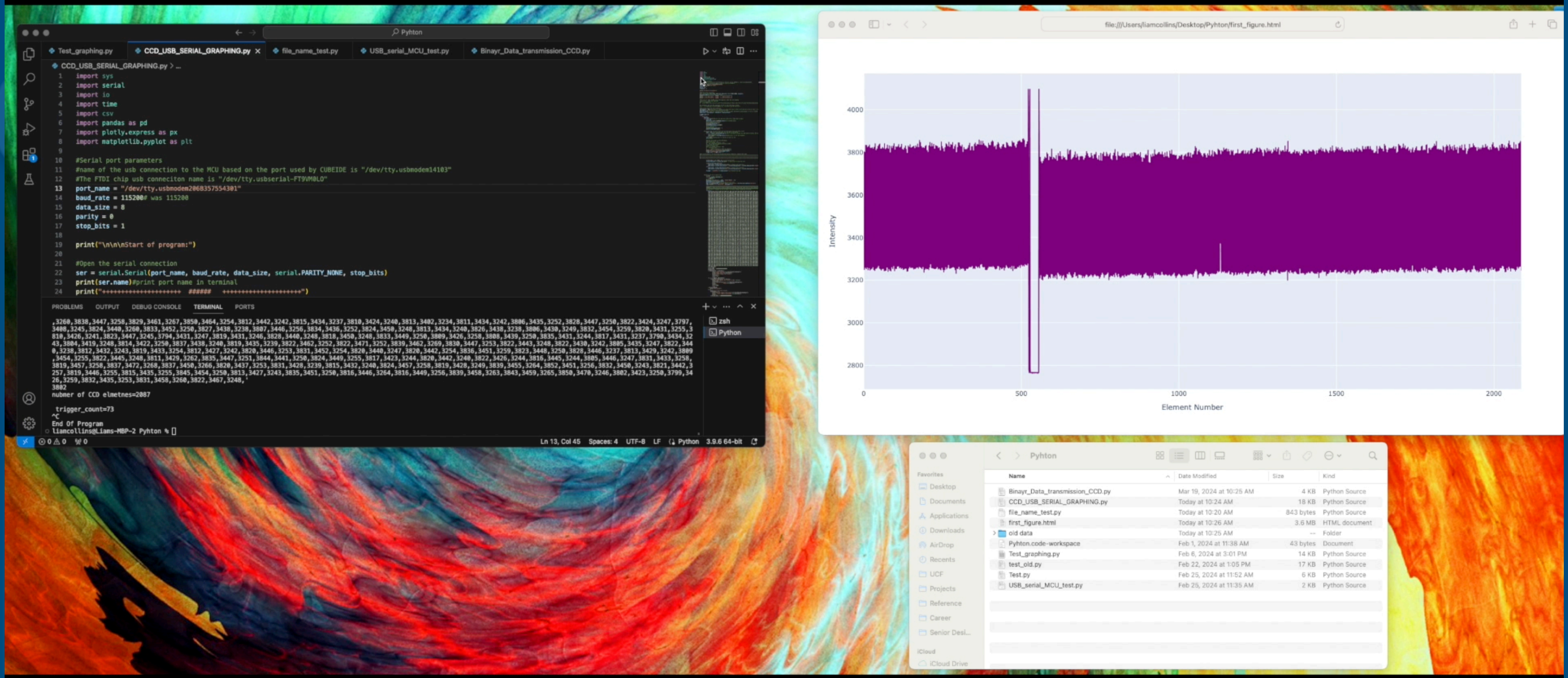
Results Output Testing



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Results Output Testing

Average time to present data was 2.41s

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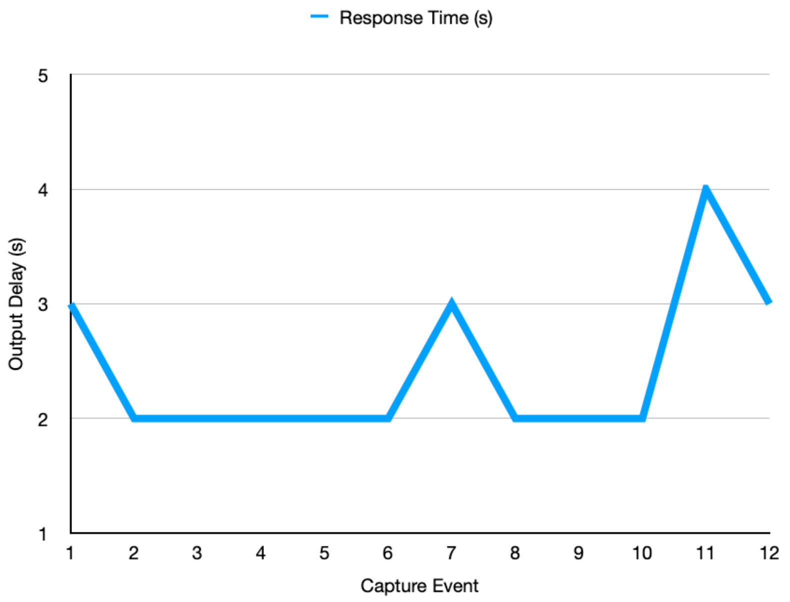
Data Output Response time

Time of change	Capture event number	Response Time (s)
3	1	3
5	2	2
7	3	2
9	4	2
11	5	2
13	6	2
16	7	3
18	8	2
20	9	2
22	10	2
26	11	4
29	12	3
		2.41666666666667



Samples Stored

The specification regarding the number of samples stored in the system is required to be greater than or equal to five.

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Sample Storage Specifications

Internal RAM of the MCU is 128KB the current program occupies 9.6 KB leaving 118.5 KB for data acquisition

Build Analyzer | Static Stack Analyzer | Cyclomatic Complexity | Disassembly

NEW_BETTER_MCU_Test.elf - /NEW_BETTER_MCU_Test/Debug - Mar 24, 2024, 12:16:45 PM

Memory Regions | Memory Details

Region	Start address	End address	Size	Free	Used	Usage (%)
RAM	0x20000000	0x2001ffff	128 KB	118.45 KB	9.55 KB	7.46%
FLASH	0x08000000	0x0807ffff	512 KB	454.77 KB	57.23 KB	11.18%

With the ADC set to 12-bit and accounting for all 2087 CCD elements, using a 16-bit array allows for 28 samples to be stored before requiring transmission

Variables | Breakpoint | Expressio | Disassemb | Registers | Live Expre | SFRs

Name	Type	Value
buffer	uint16_t [1]	0x2001ffe0
buffer_size	uint16_t	2048
CCD_Output	uint16_t [2089]	0x2001ef8c
[0...99]	uint16_t [100]	0x2001ef8c
[100...199]	uint16_t [100]	0x2001f054
[200...299]	uint16_t [100]	0x2001f11c
[300...399]	uint16_t [100]	0x2001f1e4
[400...499]	uint16_t [100]	0x2001f2ac
[500...599]	uint16_t [100]	0x2001f374
[600...699]	uint16_t [100]	0x2001f43c
[700...799]	uint16_t [100]	0x2001f504
[800...899]	uint16_t [100]	0x2001f5cc
[900...999]	uint16_t [100]	0x2001f694
[1000...1099]	uint16_t [100]	0x2001f75c
[1100...1199]	uint16_t [100]	0x2001f824
[1200...1299]	uint16_t [100]	0x2001f8ec
[1300...1399]	uint16_t [100]	0x2001f9b4
[1400...1499]	uint16_t [100]	0x2001fa7c
[1500...1599]	uint16_t [100]	0x2001fb44
[1600...1699]	uint16_t [100]	0x2001fc0c
[1700...1799]	uint16_t [100]	0x2001fcd4
[1800...1899]	uint16_t [100]	0x2001fd9c
[1900...1999]	uint16_t [100]	0x2001fe64
[2000...2088]	uint16_t [89]	0x2001ff2c
i	int	0
j	int	536879160
delay_var_1	int	134218237
test_2	int	0
string	char [6]	0x2001ef84

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Sample Storage Specifications

Continuous sample transmission allows for an extremely large number of samples to be stored, as long as the sampling delay exceeds approximately 5 seconds

Name	Date Modified	Size	Kind
CCD_OUTPUT_Feb_1_2024_Time11h40m25.csv	Feb 1, 2024 at 11:40 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time11h43m18.csv	Feb 1, 2024 at 11:43 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time11h46m14.csv	Feb 1, 2024 at 11:46 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time11h47m07.csv	Feb 1, 2024 at 11:47 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time11h47m53.csv	Feb 1, 2024 at 11:47 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time11h48m28.csv	Feb 1, 2024 at 11:48 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time11h49m07.csv	Feb 1, 2024 at 11:49 AM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h05m37.csv	Feb 1, 2024 at 12:05 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h05m39.csv	Feb 1, 2024 at 12:05 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h05m48.csv	Feb 1, 2024 at 12:05 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h06m16.csv	Feb 1, 2024 at 12:06 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h06m18.csv	Feb 1, 2024 at 12:06 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h06m39.csv	Feb 1, 2024 at 12:06 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h06m41.csv	Feb 1, 2024 at 12:06 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h06m43.csv	Feb 1, 2024 at 12:06 PM	19 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m10.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m16.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m19.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m22.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m25.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m27.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m32.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m35.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m36.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m39.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m41.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
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CCD_OUTPUT_Feb_1_2024_Time12h07m45.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h07m46.csv	Feb 1, 2024 at 12:07 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h08m17.csv	Feb 1, 2024 at 12:08 PM	21 KB	CSV Document
CCD_OUTPUT_Feb_1_2024_Time12h08m18.csv	Feb 1, 2024 at 12:08 PM	21 KB	CSV Document

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Laser Blast Detection

The delay between detection of the laser blast and the start of the CCD integration sequence. The time between the diode excitation, and the MCU Starting the integration sequence of the CCD should be less than or equal to 1.6 us

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Laser Blast Detection

The designed sub-system has an average delay of 0.890 us between diode excitation and the start of the CCD integration sequence.

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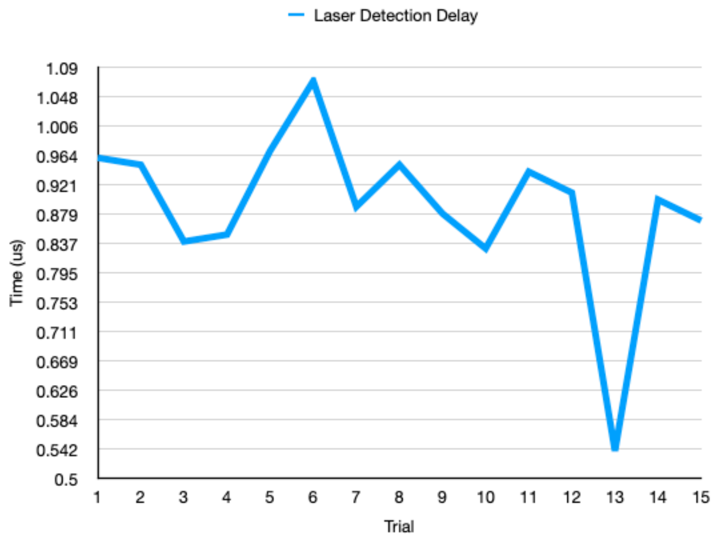
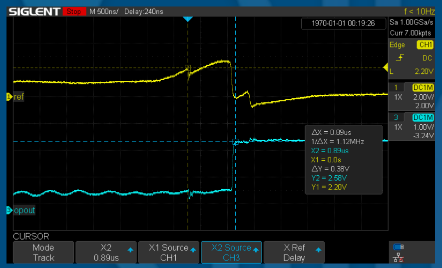
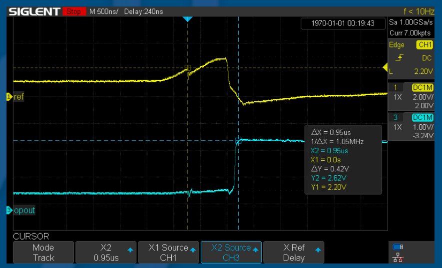
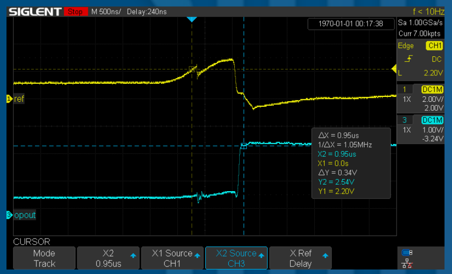
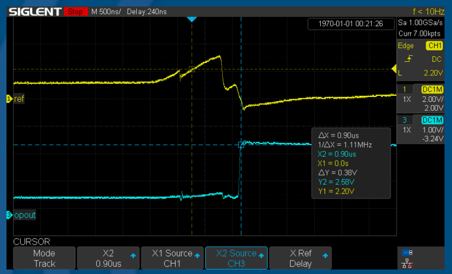
Trial	Laser Detection Delay
1	0.96
2	0.95
3	0.84
4	0.85
5	0.97
6	1.07
7	0.89
8	0.95
9	0.88
10	0.83
11	0.94
12	0.91
13	0.54
14	0.90
15	0.87
Average	0.89









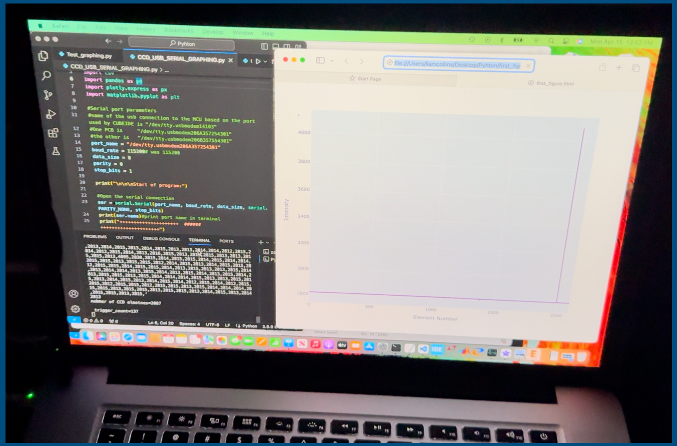


Results

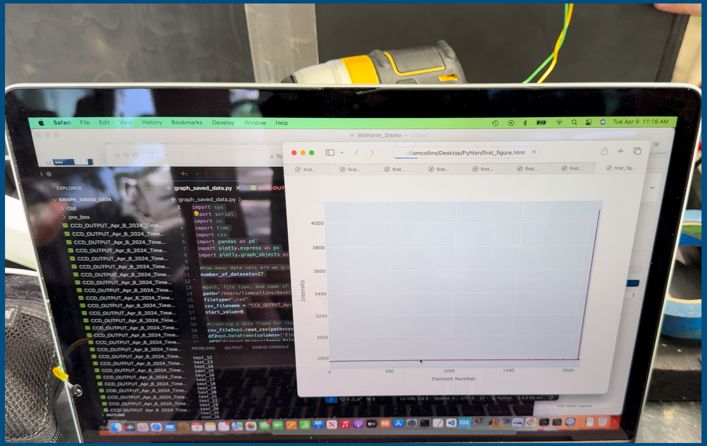
- All subsystems functioning Independently
- Insufficient light entering system
- Combinations of different Light guides, Collimating lenses, and CCD integration times attempted
- More detailed coverage in the Demo video

Overall system Test results

Longer CCD Integration with new Light guide

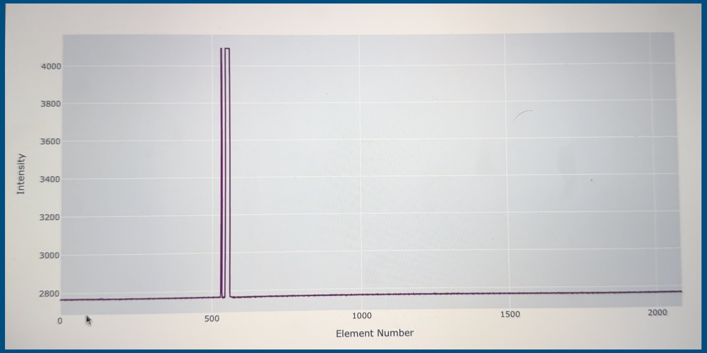


Original CCD Integration with original Light guide

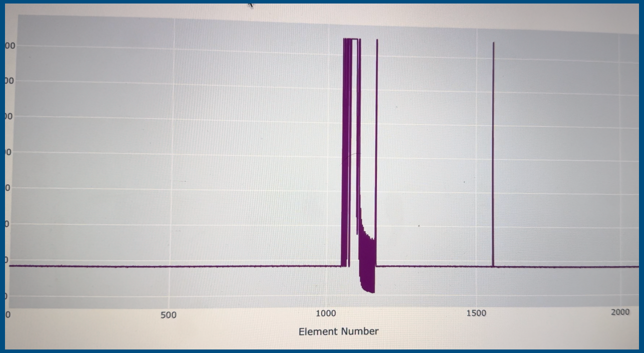


CCD and Spectrometer Test results Correct

532 Green laser pointer



HeNe Laser



Current and Projected Budget

We are using 3D printed components to hold the Optics for the laser and the Mirrors and Diffraction Grating for the Spectrometer

The final PCB has been implemented in the system

This budget Reflects the cost of research and development of the entire system

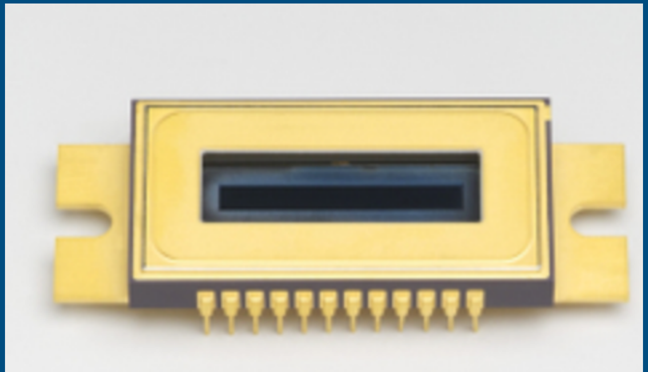
Component	Price	Quantity
Laser	$ 553.80	1
Safety Housing	$ 297.74	15
Laser Safety Goggles	$ 266.25	3
Calipers	$ 25.55	1
Work Cart	$ 144.19	1
ThorLabs	$ 218.99	1
Newport	$ 260.82	4
Edmund Optics	$ 740.46	5
Amazon	$ 164.83	6
CCD	$ 388.72	8
MCU/Opamps	$ 48.59	2
PCB	$ 18.28	3
Total	**$3,128.22**	

Ben Logan
PSE

Potential Future Work

- Aquire sponsorship
- Integrate new components
  - Faster & more sensitive CCD
  - Higher quality Collimating lens

Hamamatsu S7031



Spectroscopy linear CCD
Price: ~$2000

Edmund Optics Collimator

Spectroscopy linear CCD
Price: ~$500

Work Distribution:

- Benjamin Logan – Laser, alignment, focusing optical system.
- Faisal Abdullah Salim Al-Quaiti – Power System (excluding laser).
- Liam Collins – Digital control, sensors, and data output of system.
- Stephen Styrk – Spectroscopy system and the sample emission optical guidance system.

Ben Logan
PSE