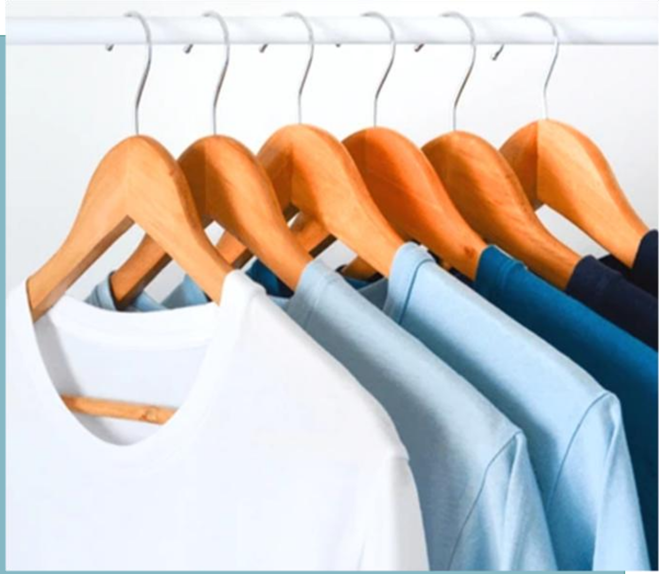

TEX-RAY

Textile Identification via Raman Spectroscopy

Group 8

Our Team

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Motivation and Background

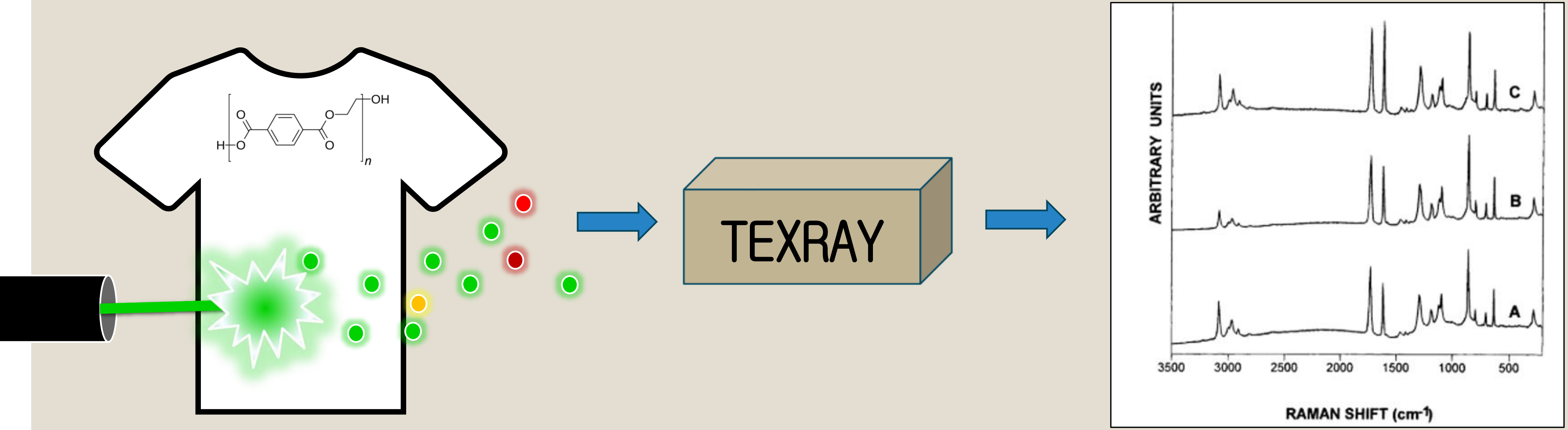
- Difficulty distinguishing counterfeit products
  - Easy to lie about fabric composition
  - Fake luxury goods almost identical to genuine articles

- Shifts in societal attitude
  - Preference for ethical consumption and environmentally friendly products
  - Clothing as long-term investment
  - Natural fibers are higher quality and more comfortable

- Consumer Rights
  - Buying expensive products, expecting to get the fabric you paid for
  - No affordable/convenient method of textile verification
  - Cheapest commercial product is $2,500

Raman Spectroscopy

- Molecules have distinct vibrational modes (vibration, rotation, stretching)
- The nature of these modes are uncovered from its Raman scattering
- The assessment of Raman scattering is therefore useful for nondestructive material identification



Core Goals

Material Classification

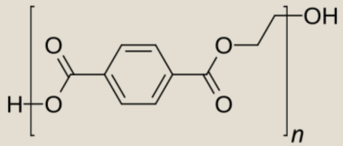
Classify an undyed and unblended cotton or polyester sample based upon their spectral signature

Product Comparison

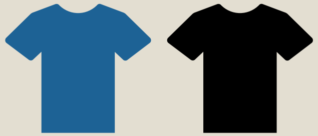
Conduct an accurate product comparison between two pieces of clothing

User Interfacing

Integrate an LCD touchscreen to easily view results and allow for user interaction



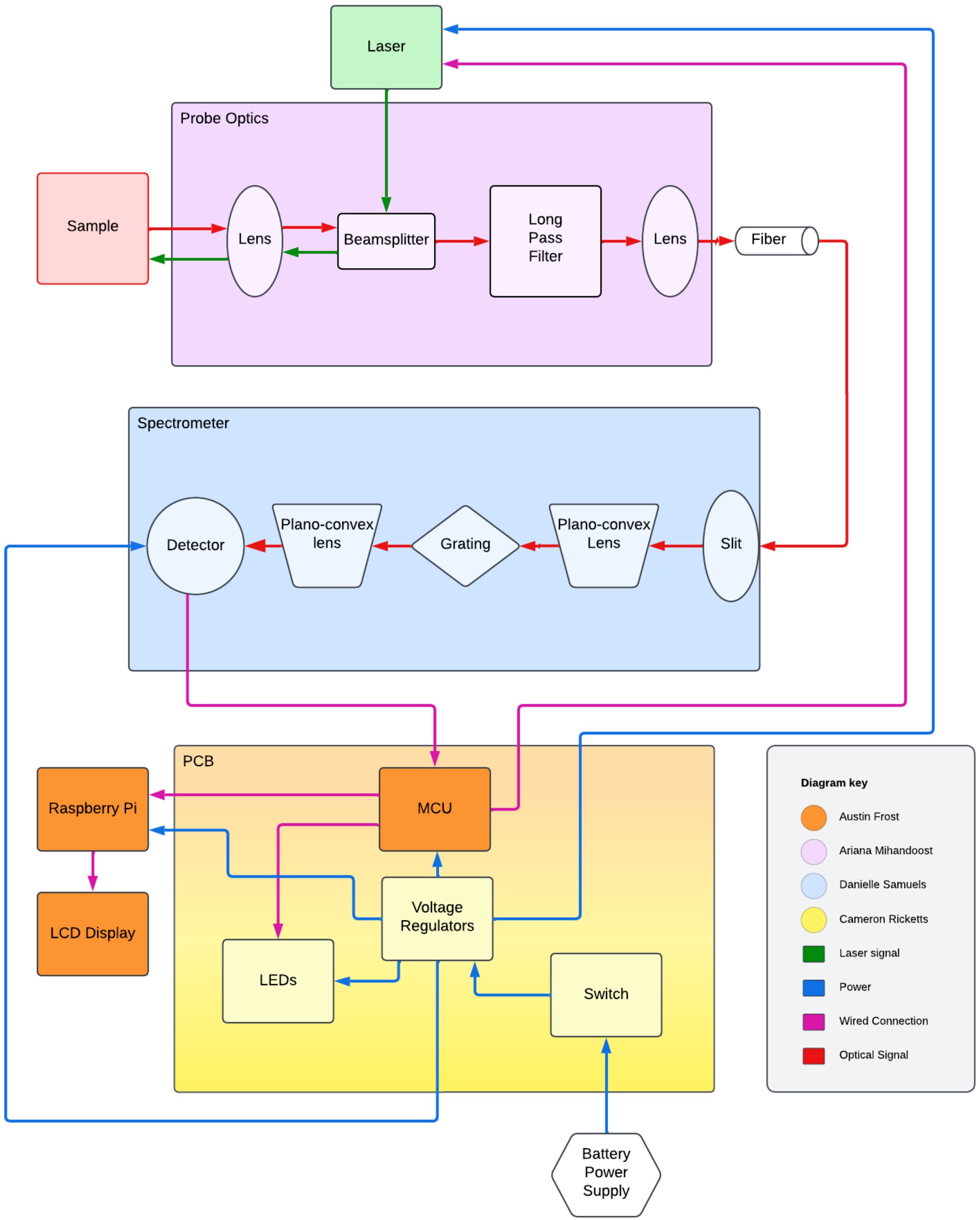
✓Polyester



❌ Not a match

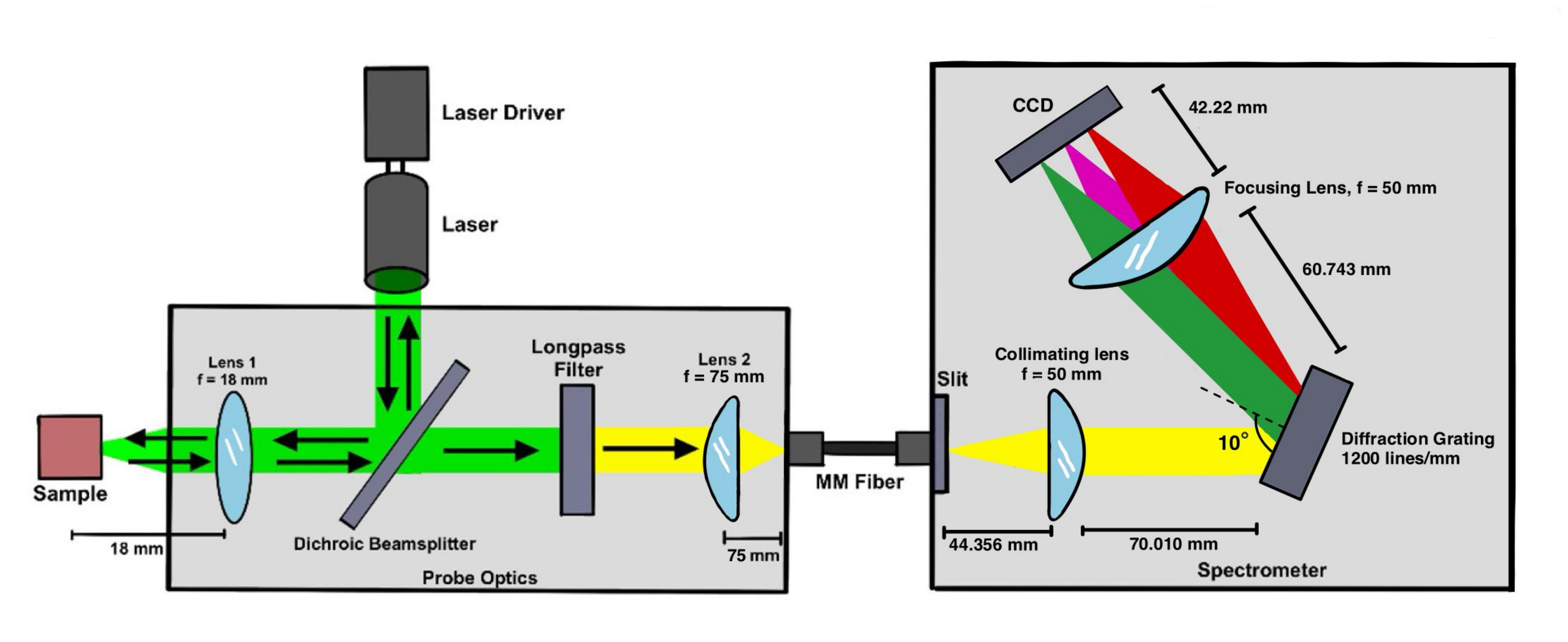
Core Objectives

Optical Design	Signature Comparison	Power distribution
Build an effective and cost-efficient spectrometer Implement backscattering light collection configuration	Develop quick and accurate comparison software using dynamic time warping and k-Nearest Neighbors clustering to analyze obtained spectral signature data	Implement an efficient power source for the system to enable portability



HARDWARE BLOCK DIAGRAM

Optical Schematic



Engineering Requirements

Parameter	Specification	Units
Material Analysis Accuracy	>90%	Percent
Total Response Time	<15	Seconds
Product Comparison Accuracy	>90%	Percent
Spectral Resolution	<30	cm^{-1}
Spectral Range	800 – 3100	cm^{-1}
Signal Strength	>1	pW
Signal to Noise Ratio	50	N/A
Battery Life	>2	Hours
Regulated Voltage	3.3 - 5	Volts
Power Consumption	<35	W
Battery Energy	>=72	Wh
Regulated Current	1	Amps
Unit Size	<24’’x18’’	Inches
Unit Weight	<10	lbs
Cost	<$2,500	USD

Wavelength and Laser Selection

Blue vs. Green:

- 473 nm expensive and hard to find
- 450 nm pushes the risk of uncontrollable fluorescence
- 532/520 nm proven suitable for our fabric samples

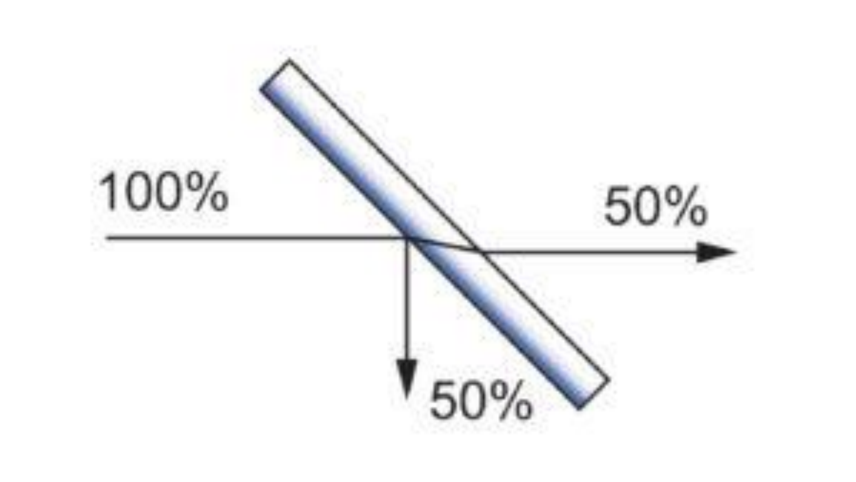
Q-Baihe laser module:

- Module eliminates need for collimating lens
  - Minimal beam divergence
- 40 mW output power sufficient for Raman signal generation
- Very narrow spectral linewidth
- Cheapest of all options

Specification		Thorlabs DJ532-40	ams-OSRAM PL 520B	Q-BAIHE 532 nm module	Thorlabs L450G3	Civil Laser GH04580 A2G
Peak Wavelength		532	520	532	450	450
Output Power (mW)		40	80	40	100	80
Operating Current (mA)		330	200	500	80	110
Threshold Current (mA)		160	40	N/A	12	22
Operating Voltage (V)		1.9	6	12	5.2	5.3
Beam Divergence	Parallel	.69°	6.3°	<1 mrad	8.4°	10°
	Perp.	.69°	22.5°	<1 mrad	21.5°	24°
Spectral Linewidth		.0283 pm	1 nm	1 nm	1.25 nm	N/A
Price		$212.64	$46.00	$43.98	$138.57	$9 (min. 10 purchase)

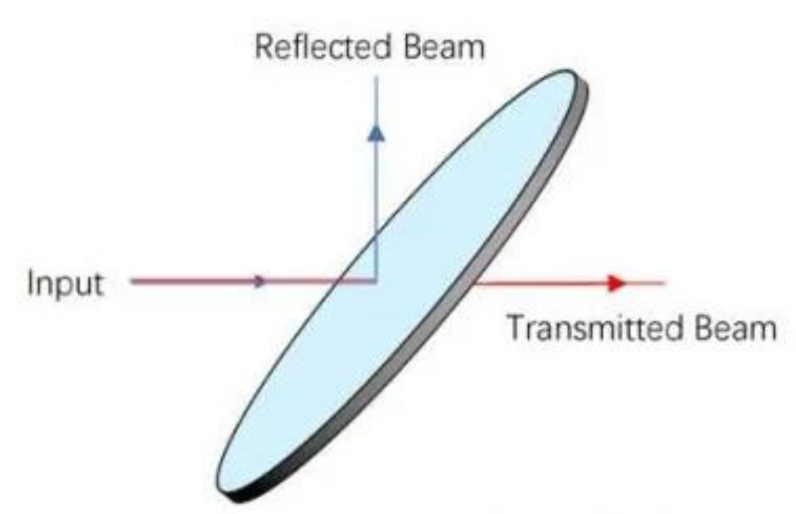
Beamsplitting Technology Comparison

50/50 Beamsplitter



- Reduces laser power incident on sample by 50%, limiting signal generation
- Reduces collection of back-scattered signal by 50%
- Allows laser line and Rayleigh scattering to pass through with the Raman signal

Dichroic Mirror



- Selectively reflects light below a certain wavelength
- Enables full reflection of laser line onto sample
- Prevents significant amount of Rayleigh scattered and laser light from transmitting

Dichroic Mirror Selection

The ideal dichroic must:

- Completely reflect 532 nm light
- Minimize reflection above 532 nm
- Have high % maximum transmission
- Have a large diameter
- Be as cheap as possible

Chroma T550lpxr:

- Relatively budget friendly
- Fully reflects laser line, maximizing intensity at the sample
- OD4 blocking until 538 nm
- Large diameter and high transmittance
- Limits spectral range to 800 cm^{-1}

	MKS Newport DCM13	**Chroma T550lpxr**	**Chroma RT532rdc**	**Edmund Optics #86-393 / #86-386**	**Thorlabs DMLP550 / DMLP550T**
Cut-on wavelength (nm)	552	550	536	552	550
Transmission wavelength (nm)	561.4 - 790	550 - 1000	536 - 1000	561.4 - 790	565 - 800
Reflection Wavelength (nm)	514.5-543.5	390 - 540	390 - 532	514.5- 543.5	380 - 533
Diameter (mm)	25	25	25	25 / 12.5	25.4 / 12.7
Thickness (mm)	3.5	1	3	3.5	3
Reflectance	>98%	>97%	>97%	>98%	>90%
Transmittance	>95%	>96%	95.97%	>95%	>85%
Angle of Incidence	45°	45°	45°	45°	45°
Clear aperture diameter (mm)	22	22.5	22.5	21.33 / 8.8	>22.9 / > 11.4
Cost	$359	$250	$600	$280 / $202	$200.76 / $134.24

Filter Technology Comparison and Selection

Notch Filter	Longpass Filter
Band-reject filter, only blocks the laser line	Edge filter, reject all light below cut-on wavelength
Large transition width between stopband and passband	Steeper transition widths, minimizing Raman signal loss
Wavelength tunable	Available in large variety of wavelengths

Chroma ET542lp:
- OD6 blocking until 539 nm
  - Limits spectral range to 244 cm^{-1}, meaning the dichroic is the main limiting factor
- 98% transmission at 544 nm
- Large clear aperture to collect more Raman signal
- Balances performance with budget

	Semrock BLP01-532R-25	*Chroma ET542lp*	*Chroma RET537lp*	*Edmund Optics #29-191*	*MKS Newport 10CGA-530*
Cut-on wavelength (nm)	541	542	537	550 ± 1	550 ± 5
Rejection wavelength (nm)	270 - 532	300 - 540	300 - 536	200 - 539	N/A
Transmission wavelength (nm)	546.9 - 900	555 - 1000	540 - 1100	560 -1650	N/A
Transmission (%)	> 93	> 98	> 98	> 91	> 90
Optical density OD (average)	> 6	6	> 6	> 4	> 5
Diameter (mm)	25	25	25	12.5 ± .2	25.4
Clear Aperture (mm)	>22	22.5	22.5	> 10	> 22.86
Cost	$409.00	$365.00	$600.00	$199.28	$47.00

Diffraction Grating Selection

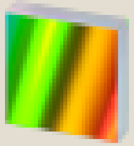
Ruled	Holographic
Diffraction efficiency is defined by blaze wavelength and angle, and is higher for higher groove densities	Lower diffraction efficiency for greater groove densities
Irregularities in rulings can result in stray light	Holographic manufacturing practices limit stray light
More cost efficient	More costly

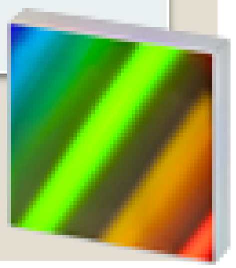
Resolving Power $R = \frac{\lambda}{\Delta\lambda} = mN$

$$\frac{595\ nm}{\Delta\lambda} = 1200\ \frac{grooves}{mm} * 25\ mm$$

$\Delta\lambda$ = 0.01983

	Thorlabs GR25-1205	**MKS Newport 33025FL01-280R**	**Edmund Optics 43-751**	**MKS Newport 3025FL01-266R**
Groove density (grooves/mm)	1200	1200	1200	900
Blaze Wavelength	500 nm	500 nm	500 nm	550 nm
Blaze angle	17° 27’	17.5°	17.45°	14.3°
Efficiency	~90%	~ 95%	~85%	~90%
Size (mm)	25 x 25	12.5 x 12.5	12.7 x 12.7	12.5 x 12.5
Price	$128	$94	$81	$155



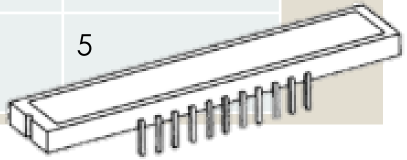


Detector Selection

CCD	CMOS
Higher sensitivity towards low Raman signal	Increased noise in low signal conditions
Higher QE (standard BI ~ 90%)	Lower QE (standard ~45%)
Consumer CCDs are well established in Raman spectrometer systems	Specialized, sCMOS sensors can be implemented

- Large detector width
- Small pixel size
- High QE in our desired region at room temperature
- Adequate dynamic range
- Low power consumption

	SONY CCD IXL511	TOSHIBA CCD TCD1304DG	TOSHIBA CCD TCD2717BFG	TOSHIBA TCD1209DG	HAMATSU S14660-1024
Pixels	2048	3648	7500	2048	1024
Pixel size (μm)	14 x 200	8 × 200	4.7 x 4.7	14 x 14	14 x 14
Total Detector Width (mm)	28.6	29.1	53.3	28.6	14.3
Spectral Response	70-90%	~100%	90-100%	N/A	~75%
Package/ Case	22 pin DP	22 pin CERDIP	32 pin CLCC	22 pin CERDIP	24 pin ceramic DIP
Operating temperature	-10 to 60℃	-25 to 60℃	0 to 60℃	-25 to 60℃	-50 to 50℃
Dark Current	3 to 6 mV	2 to 5 mV	1 to 6 mV	1 to 2.5 mV	50 - 500 (e-/ pixel/s)
Dynamic Range	267	300	N/A	2000	3330 - 6660
Data Rate (MHz)	2 (Max)	2	0.5 to 1 (35 Max)	1	0.5
Power Supply Voltage (V)	5	3 (min)	10	12	5



Spectrometer Design

Desired spectral range: 800 – 3100 cm^{-1} (550 – 640 nm)
Desired Spectral Resolution: <30 cm^{-1} (1 nm)

Diffraction Grating Equation

$m\lambda = d(\sin\alpha + \sin\beta)$ $\alpha = 10° \rightarrow \beta = 32.7°$

Reciprocal Linear Dispersion

$$\frac{dv}{dl} = \frac{d\cos(\beta)\left(v_0 - v_j\right)^2}{mM_F} = 396.12\ cm^{-1}$$

Slit width

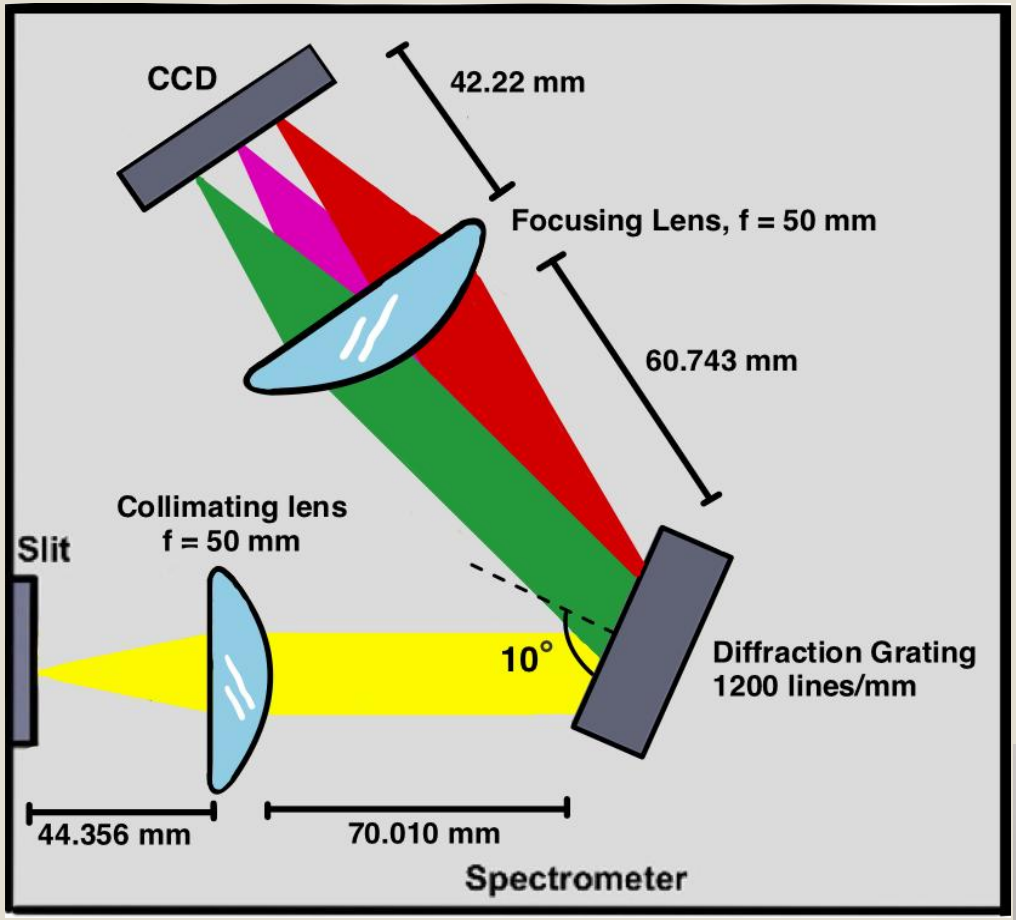
$$w_{slit} = \frac{G\Delta\lambda L_C}{\cos(\alpha)} = 25\ \mu m$$

Resolution

$$dv = \left(\frac{dv}{dl}\right) * Wp = 9.9\ cm^{-1}$$

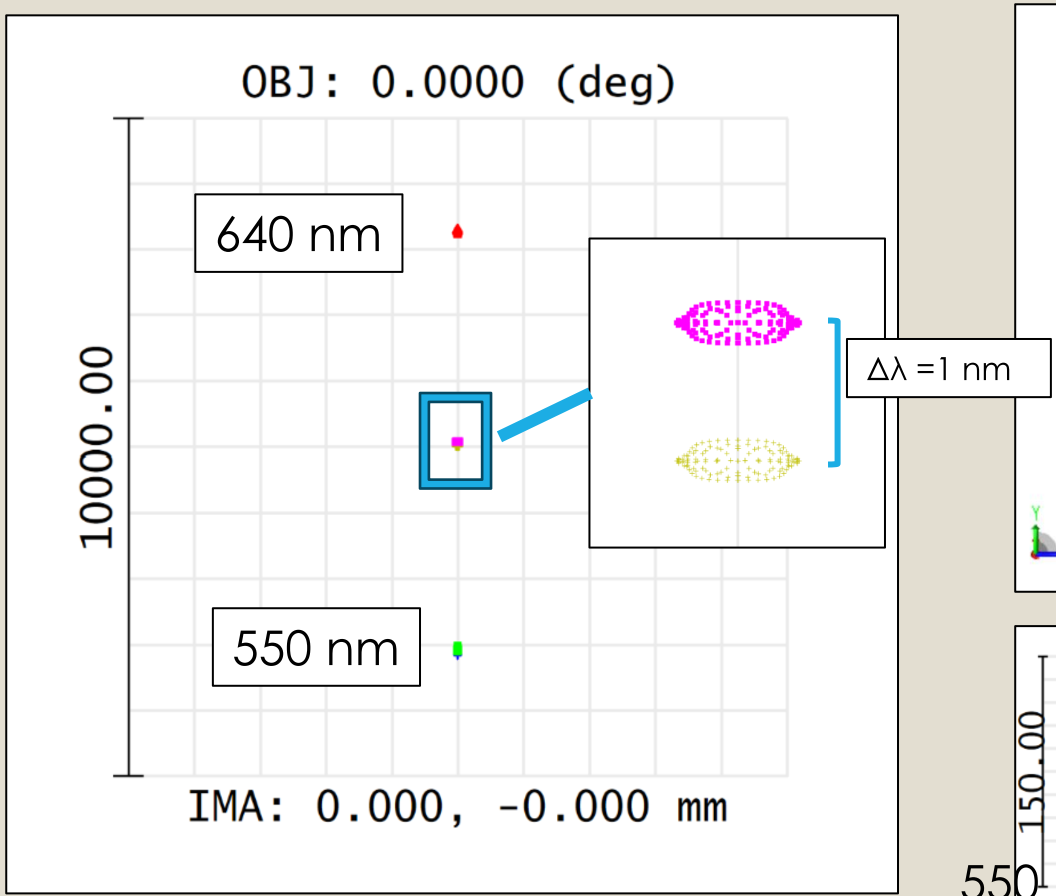
Spectral Range

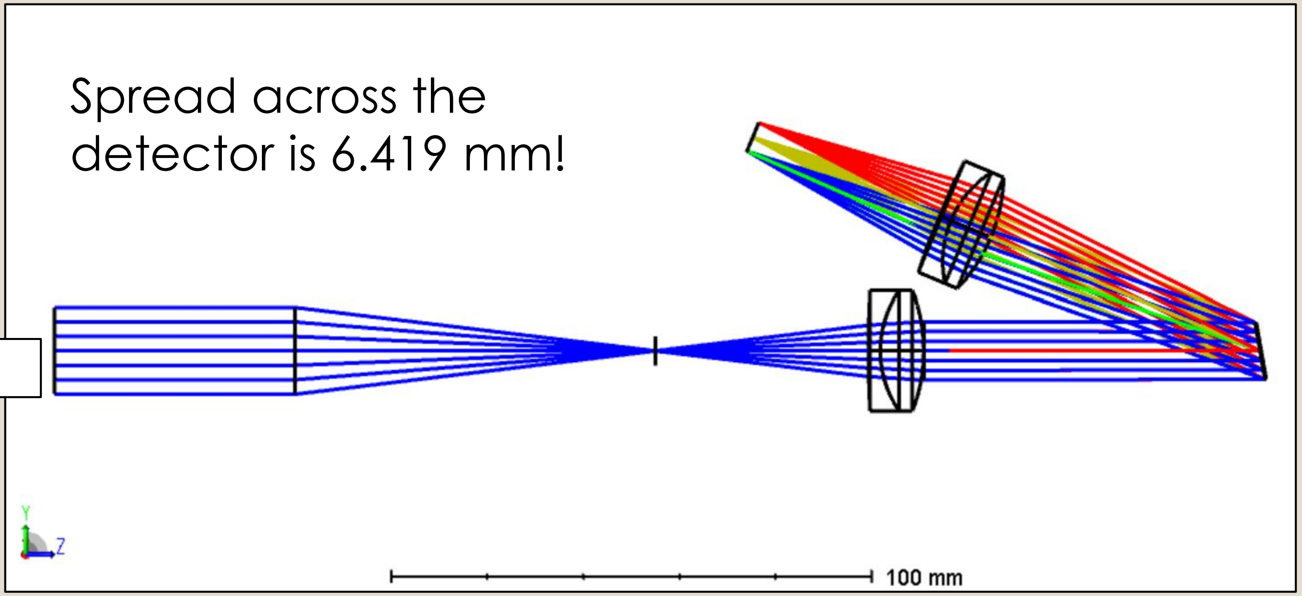
$$x = v_0 - v_j - \left[\left(v_0 - v_j\right)^{-1} + \frac{dWd}{mM_F}\right]^{-1} = 8756\ cm^{-1}$$

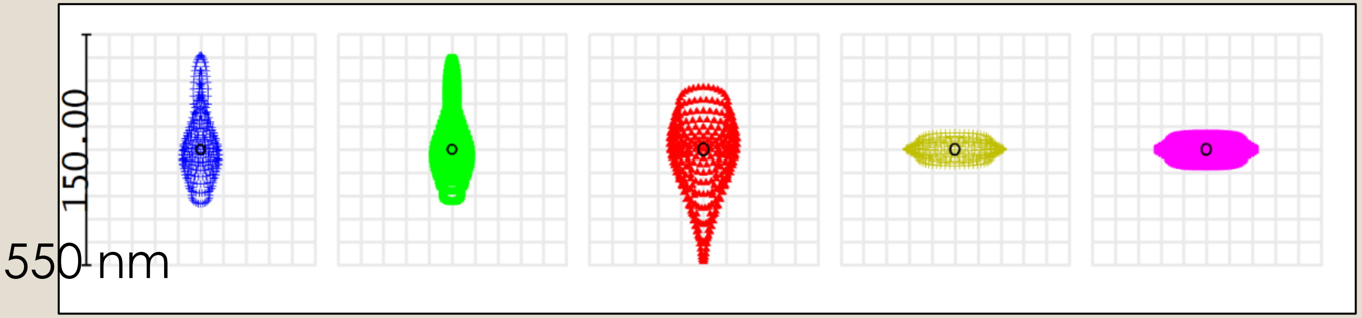


Spectrometer Zemax Design Simulation

Comparable results to the design calculations







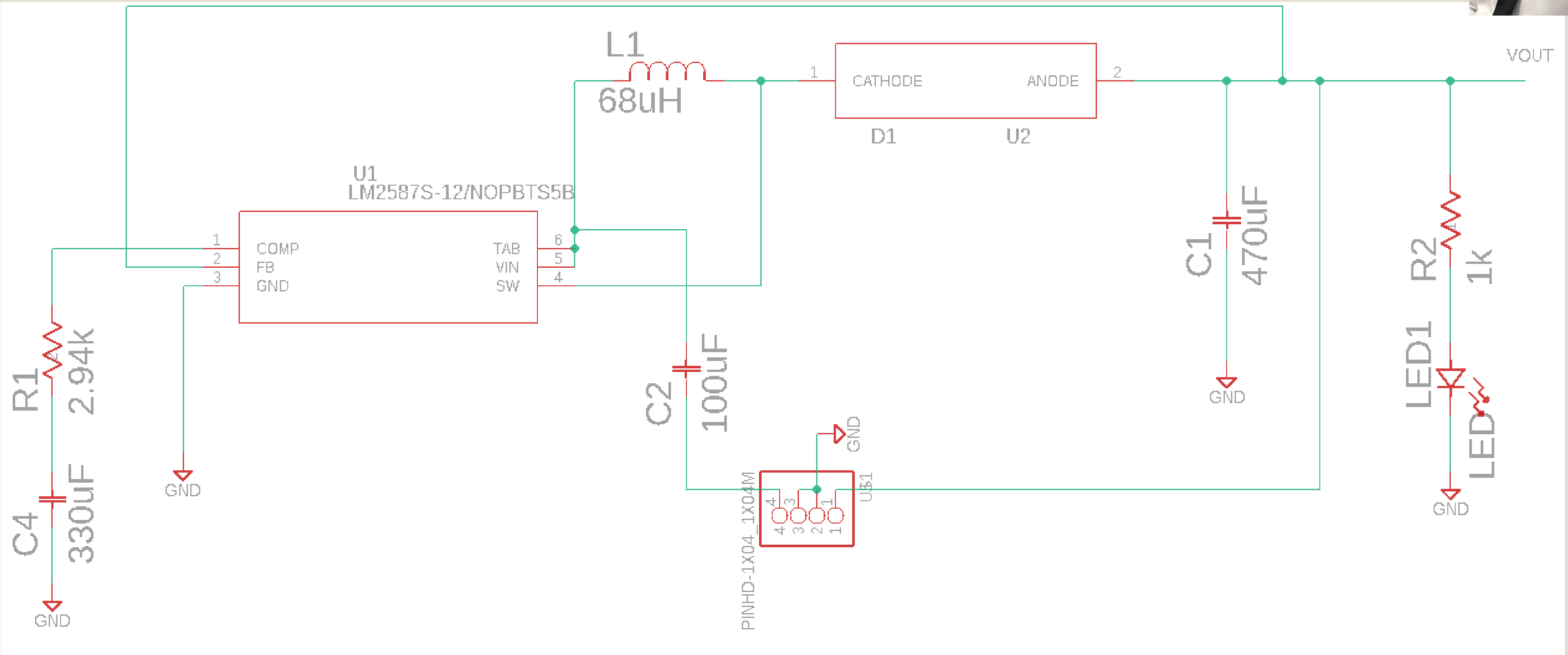
Power Source Selection

	Battery (DC)	AC	Solar Power (DC)
Current type	Direct Current	Alternating Current	Direct Current
Portability	High (size and weight dependent)	Low (stationary)	Moderate (mostly stationary with exception of some portable panels)
Power Storage	Chemical energy stored	None (continuous supply)	Can store in batteries
Reliability	Great at short distances; depletion may impact	Great	Varies heavily
Ease of Use	Simple	Requires at least one outlet	complex
Stability	Very stable and constant	Fluctuates do to alternating current	Stable as DC, light intensity may cause fluctuations
Efficiency	Moderate	High	Lower
Cost	Low to moderate	Low	High
Maintenance	Medium	Low	Medium
Uses	Portable sensitive electronic devices	Stationary high demand loads	Hybrid systems

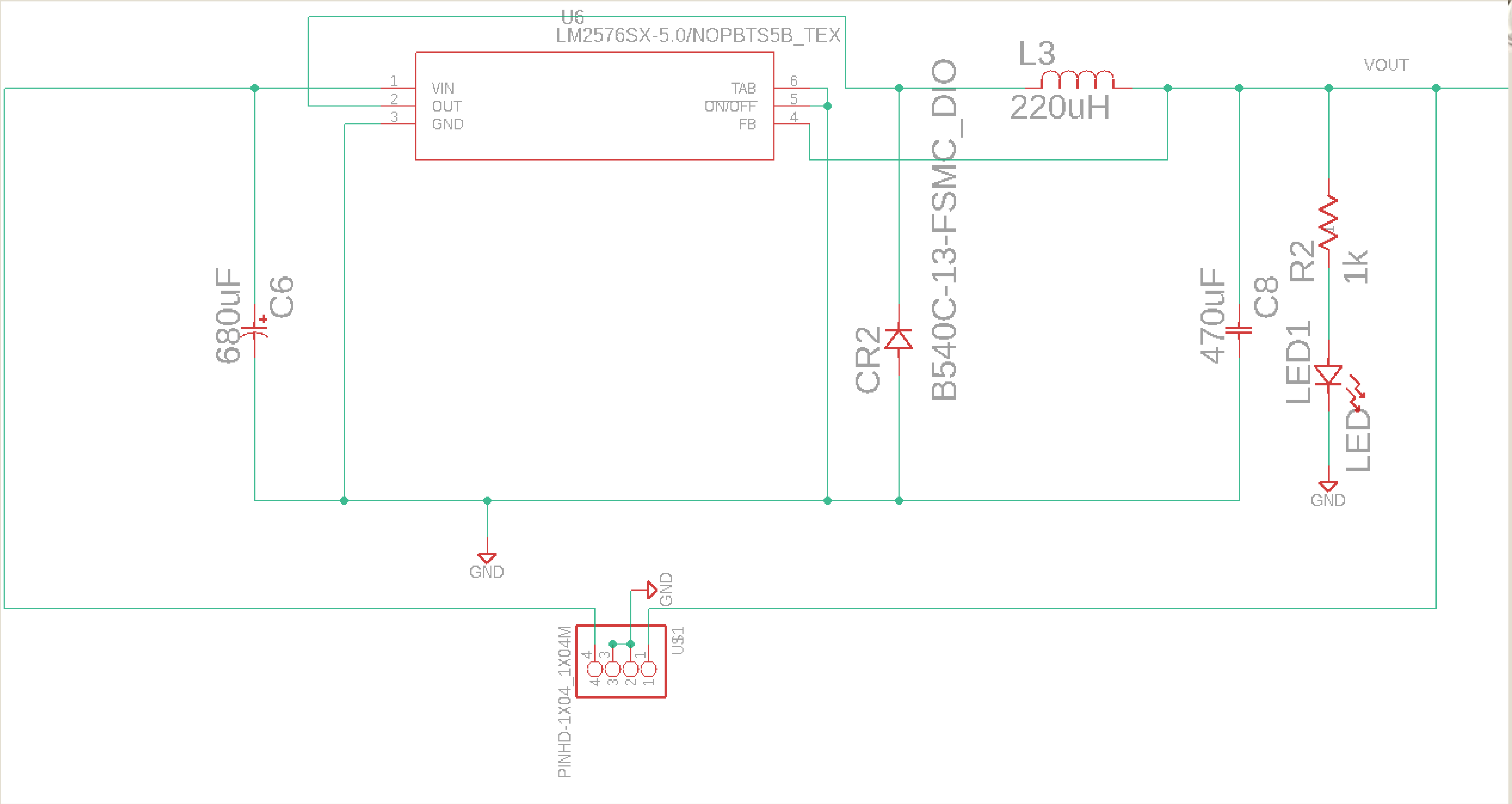
Battery Selection

	Lithium-Ion	Lithium Iron Phosphate	Sealed Lead Acid
Energy Density	High	Moderate	Low
Portability	Excellent	Good	Poor
Charge Cycle Lifespan	2000-5000 cycles	2000-5000 cycles	300-500 cycles
Charge Retention	1-2% loss per month	2-3% loss per month	Excellent
Capacity	3.5 Ah	6 Ah	7 Ah
Maximum Discharge Current	4.2 A	5 A	70 A
Maximum Power Output	46.6 W	76.8 W	840 W
Cost	$90	$53	$16
Weight	0.15 kg	0.75 kg	1.91 kg
Safety	Moderate	High	High

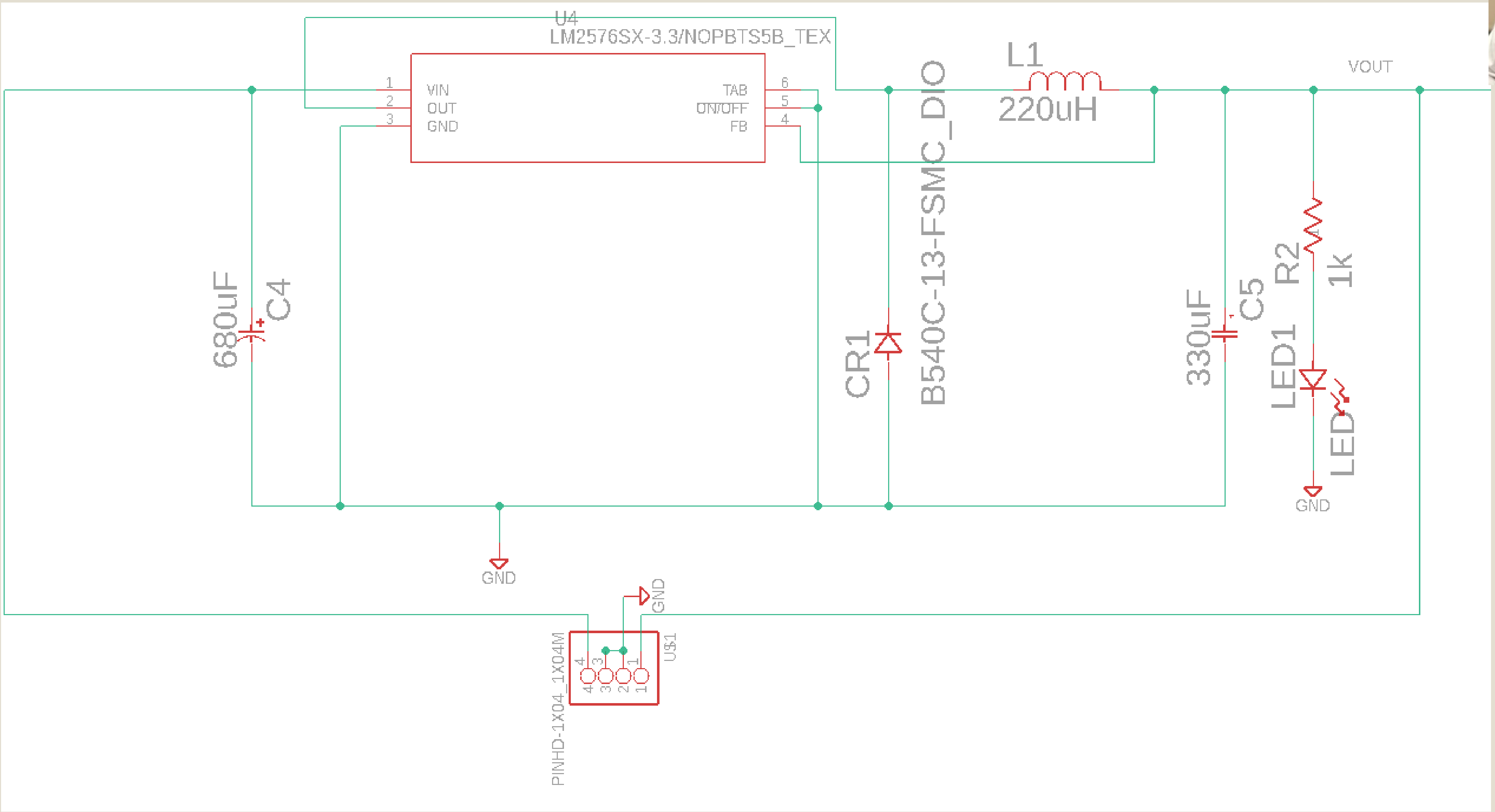
12 Volt Regulator schematic



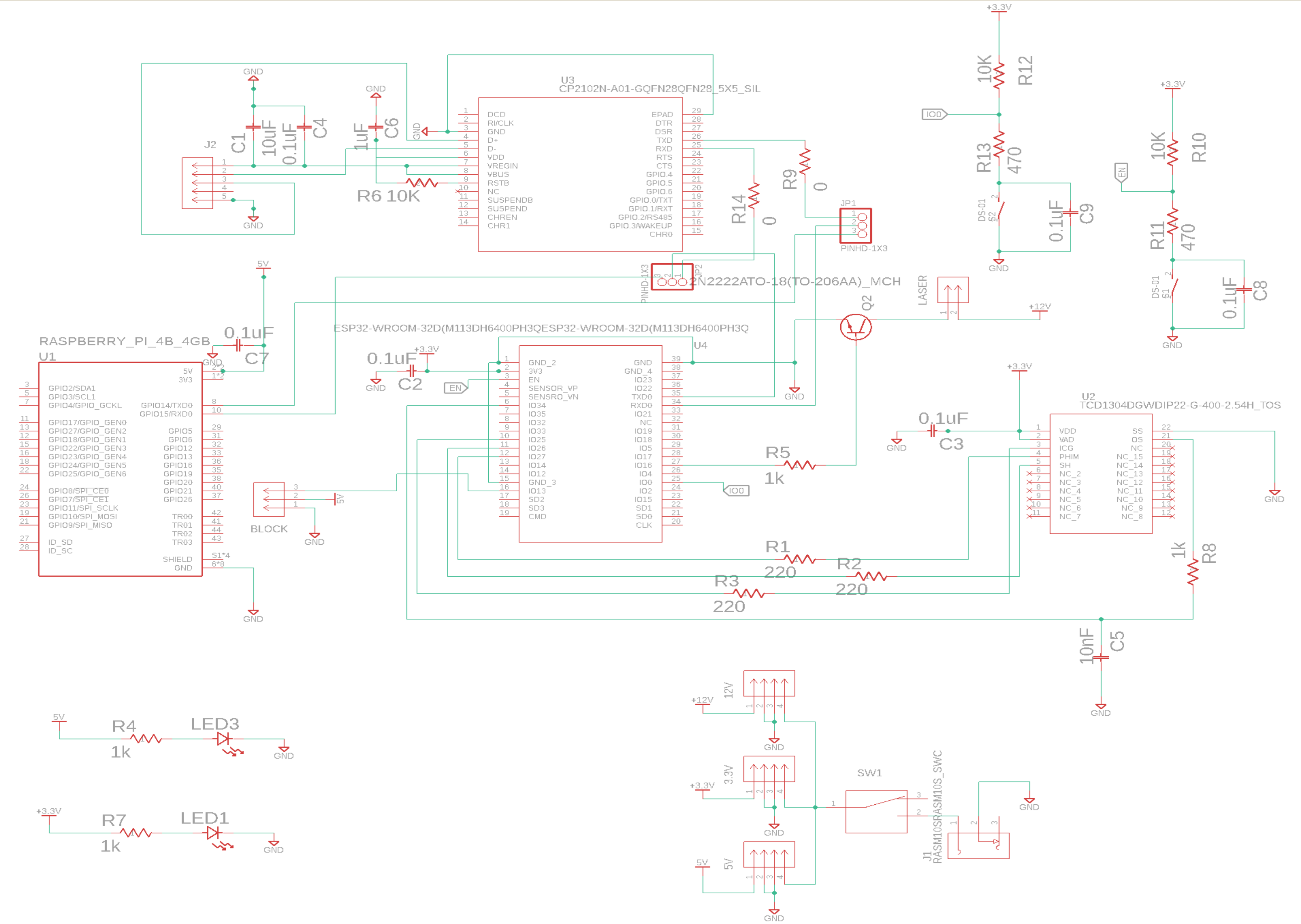
5 Volt Regulator Schematic



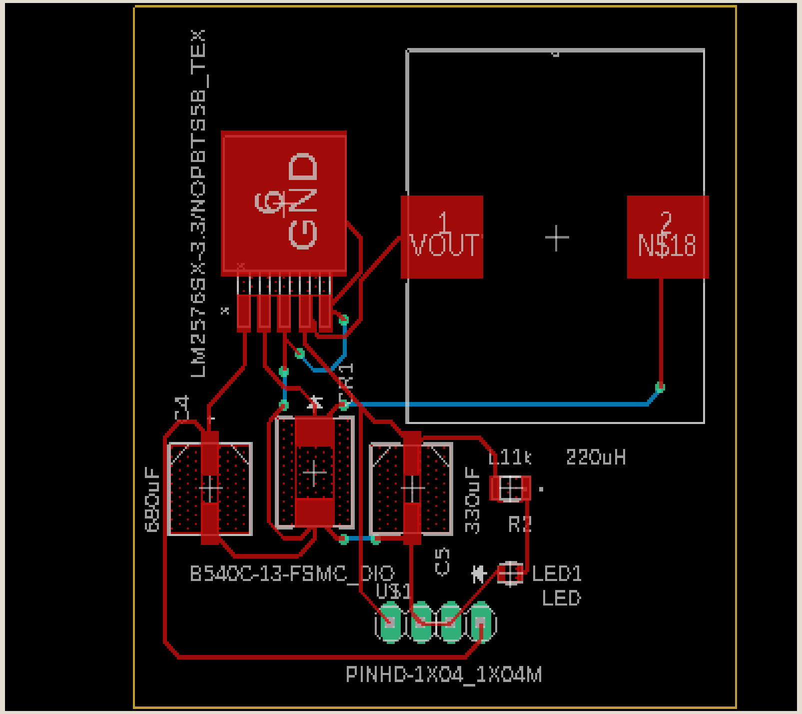
3.3 Volt Regulator Schematic

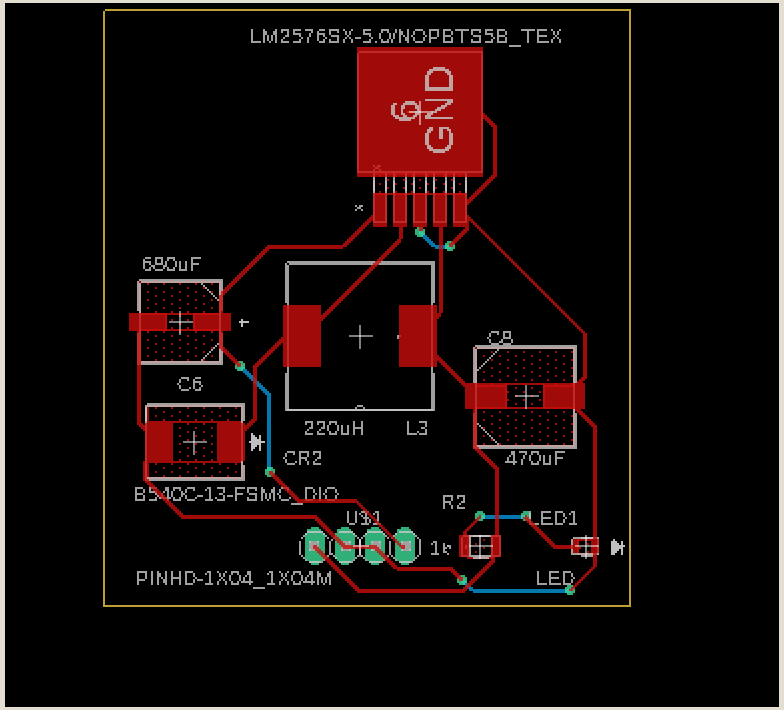


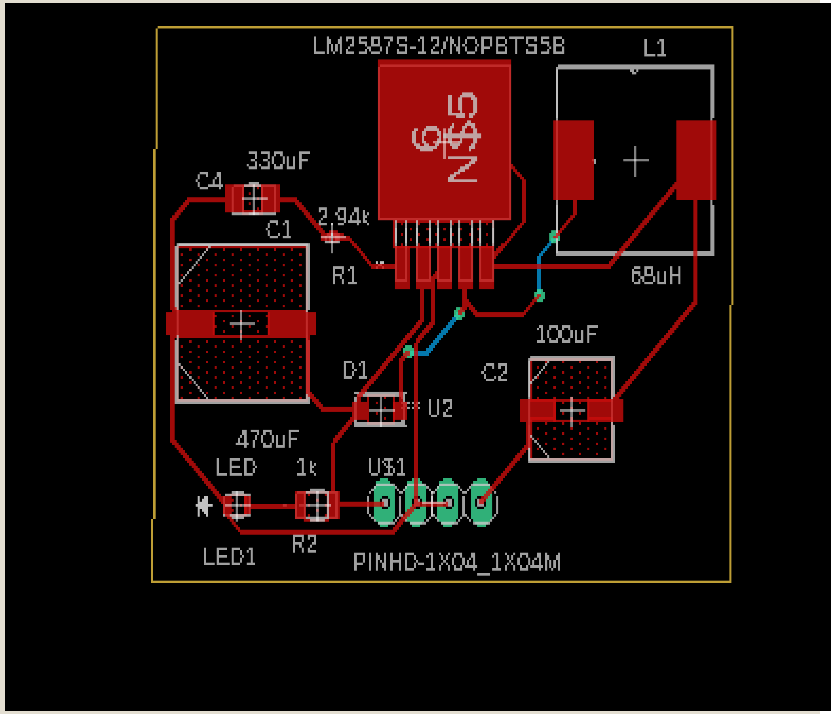
Main Board Schematic



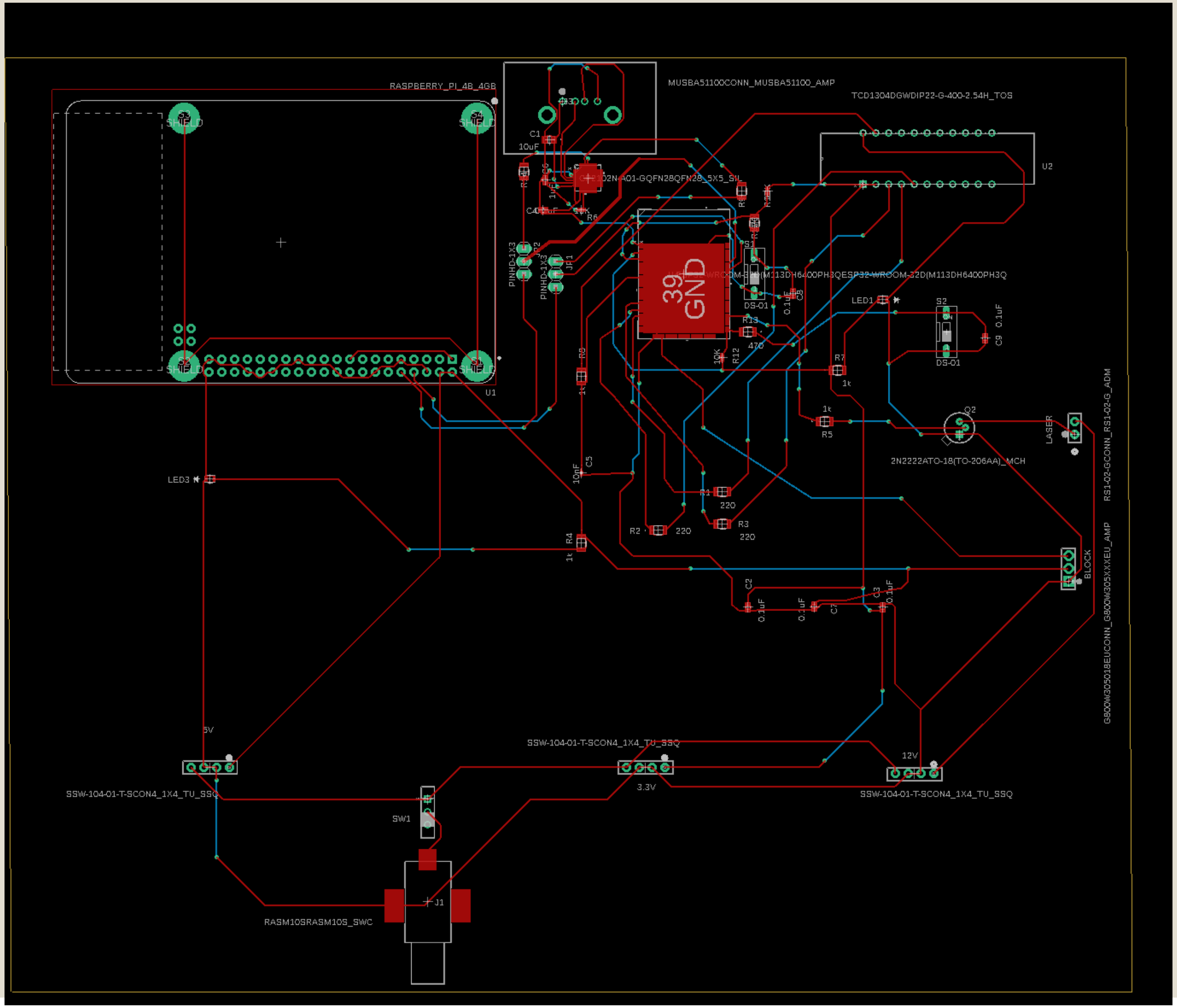
Voltage Supply PCBs





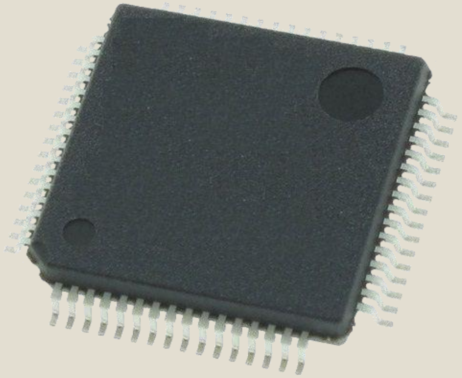


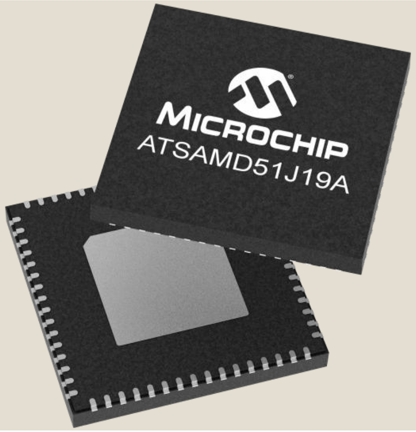
Main Board PCB Layout



Microcontroller Unit Selection

	STM32	ESP32	ATSAMD51J19A	NPX i.MX RT1060
Clock Speed	84 MHz	240 MHz	120 MHz	600 MHz
ADC Resolution	12	12	12	10
ADC Mega Samples Per Second (MSPS)	2.4	2	1	1
Price	$6.42	$1.85	$5.54	$11.16





Single-Board Computer Selection

	Raspberry Pi 5	**NVIDIA Jetson Nano**	**Coral Development Board**
Price	$69.49	$88.99	$169.99
Floating Point Operations Per Second	32 G	472 G	4 T
RAM	4 GB	4 GB	1 GB
Product Support	High	Moderate	Moderate
Community Support	Very High	Low	Low

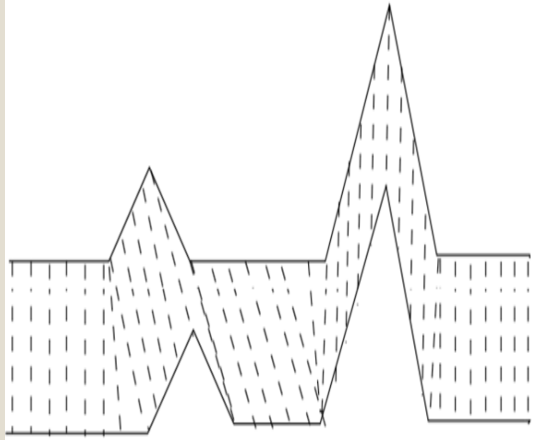
LCD Selection

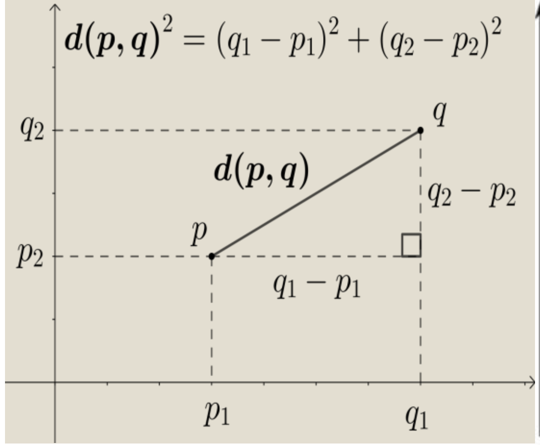
	Hosyond Raspberry Pi Display	DIYmall ESP32 Display
Price	$32.99	$19.99
Size (Inches)	6.02 x 5.63	4.72 x 3.19
Resolution (Pixels)	800x480	240x320
Supply Voltage	3.3 V	5 V
Communication Method	DSI	USB

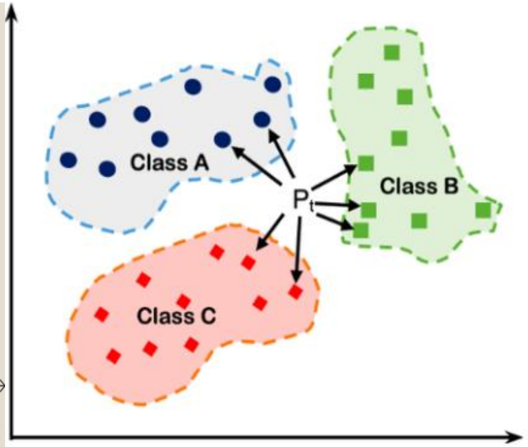
Comparison Algorithms

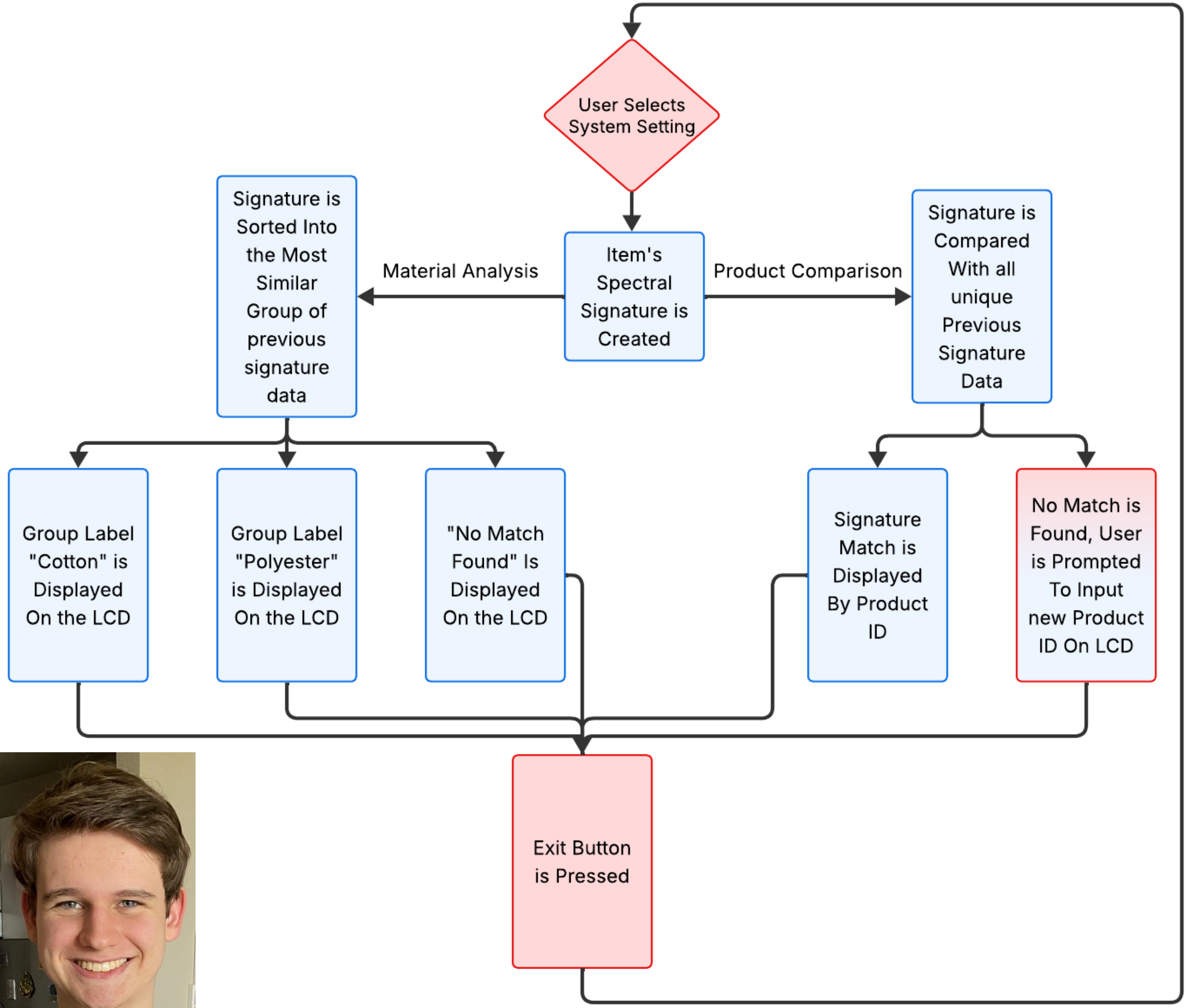
	Dynamic Time Warping	Euclidean Distance	K-Nearest Neighbors
Speed	Moderate	Fast	Moderate
Accuracy	High	Low	High*
Availability	Moderate	High	Moderate
Implementation Time	Fast	Fast	Moderate

*Varies Strongly by Distance Metric



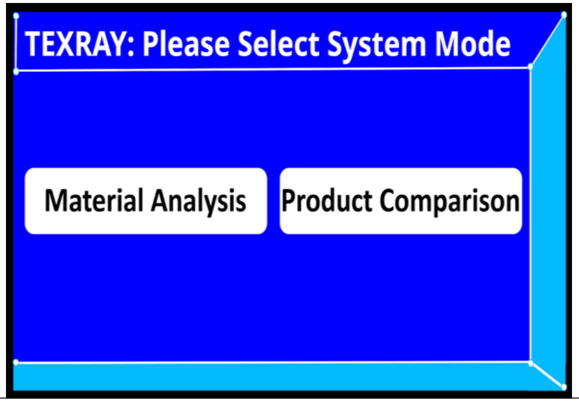




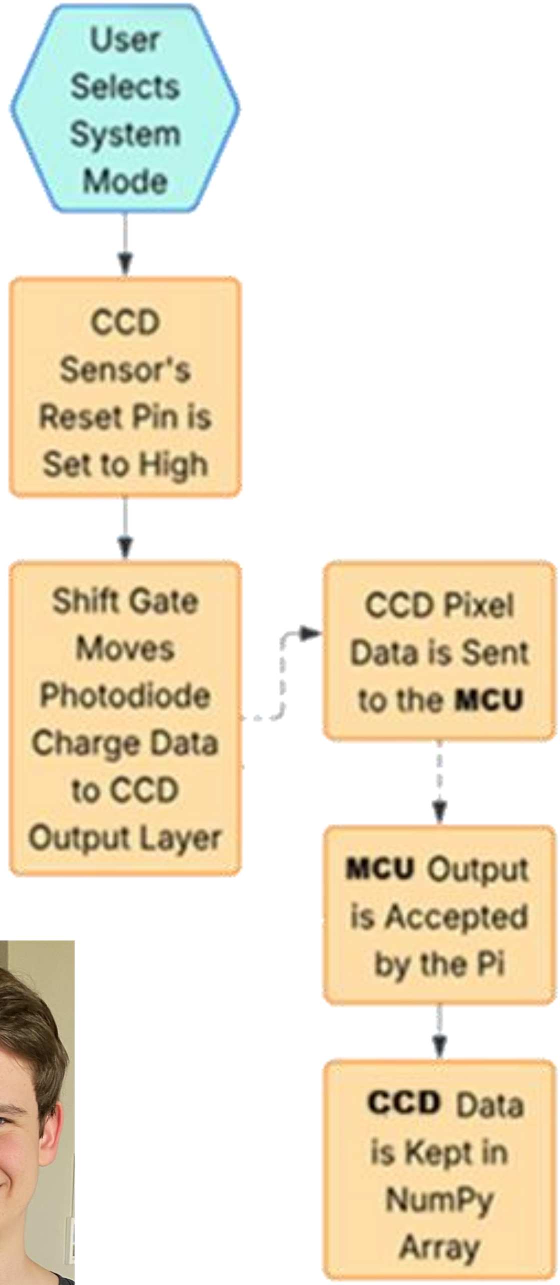


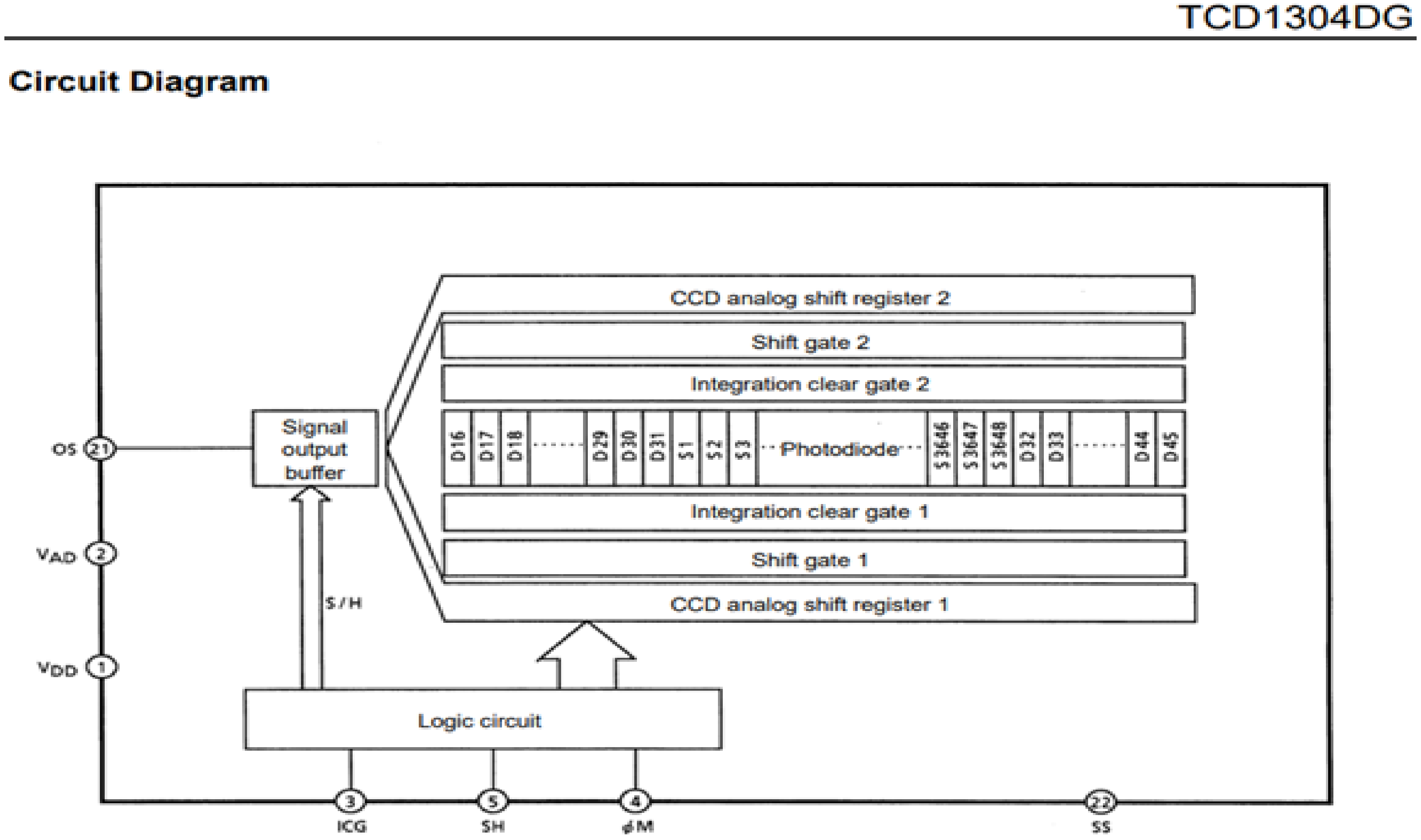
SOFTWARE FLOWCHART

System Mode Selection Screen

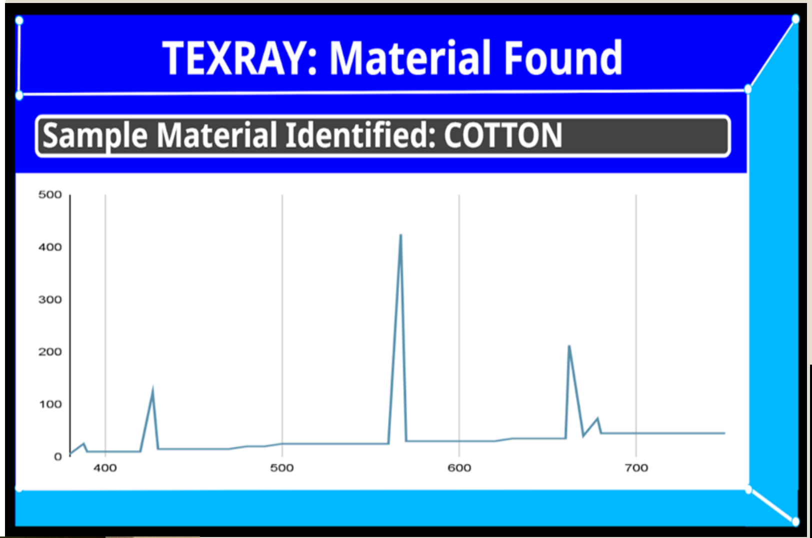


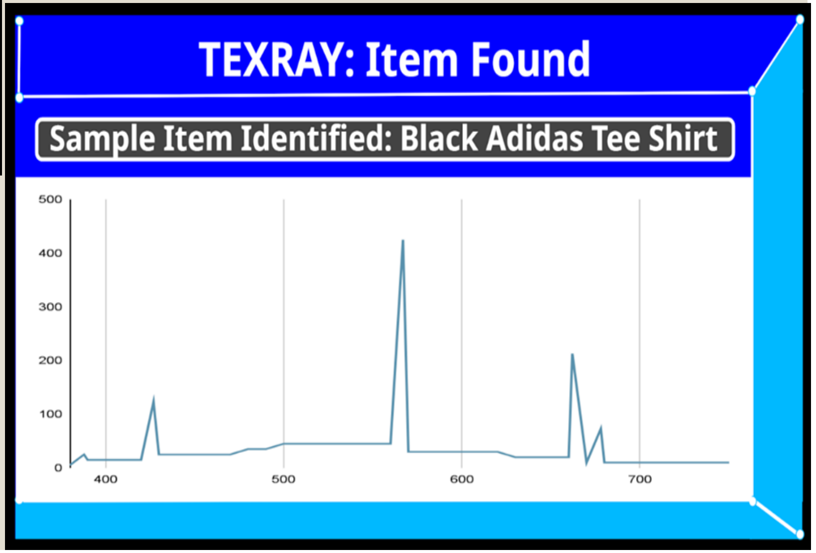
CCD Data Aquisition

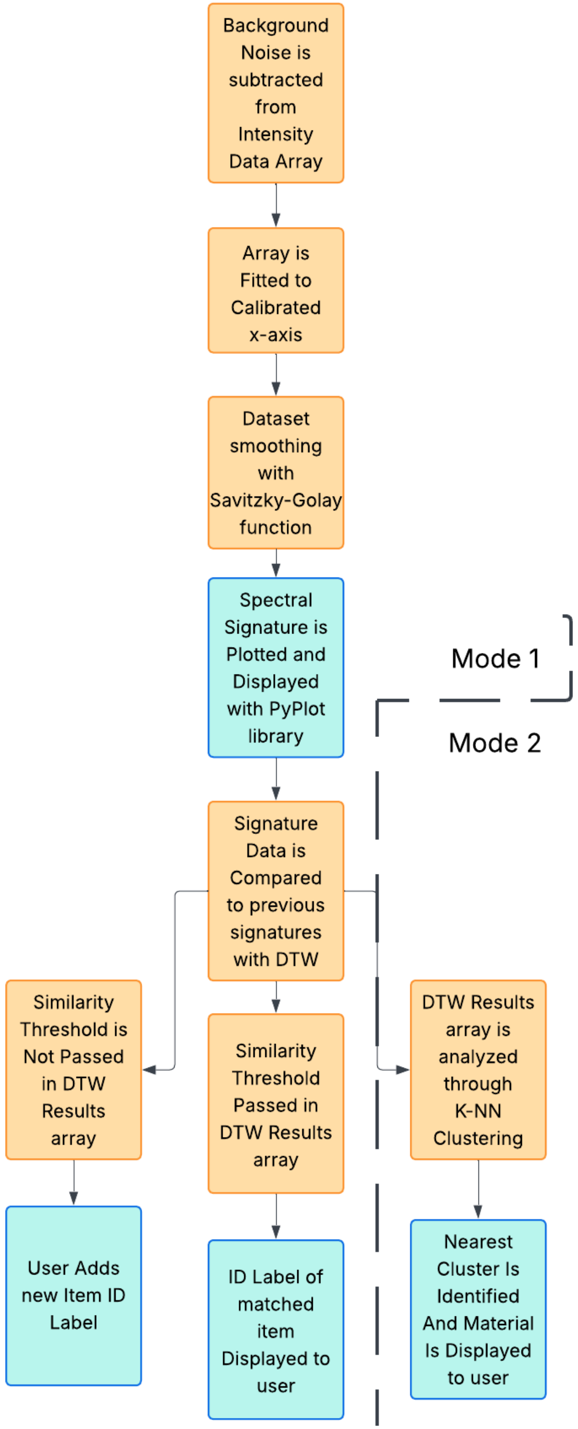




Spectral Signature Generation and Identification







Software Used

Environments

ARDUINO

Raspbian

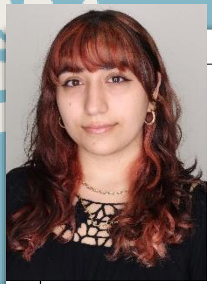
Libraries

NumPy

SciPy

scikit learn

matplotlib



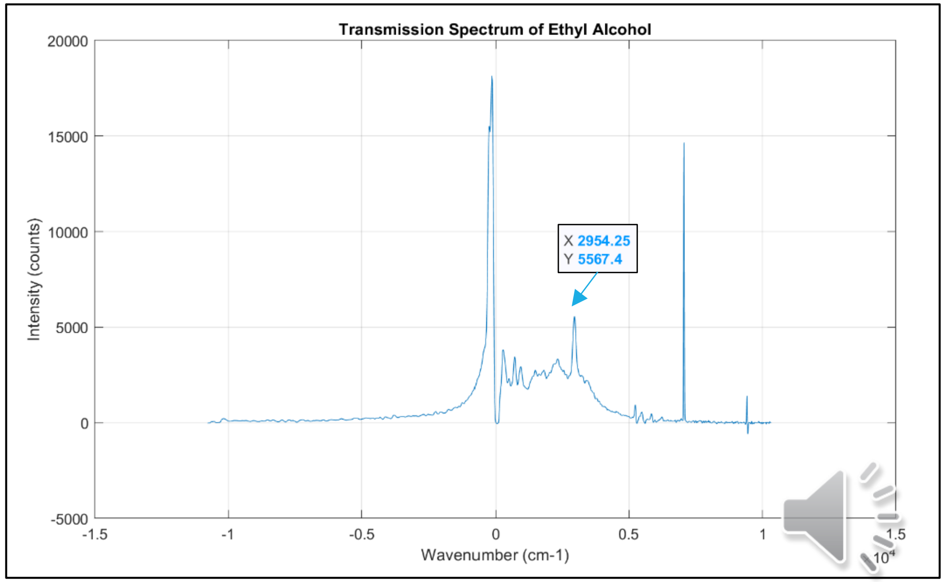
COLLECTION OPTICS PRELIM TESTING

Testing Setup:

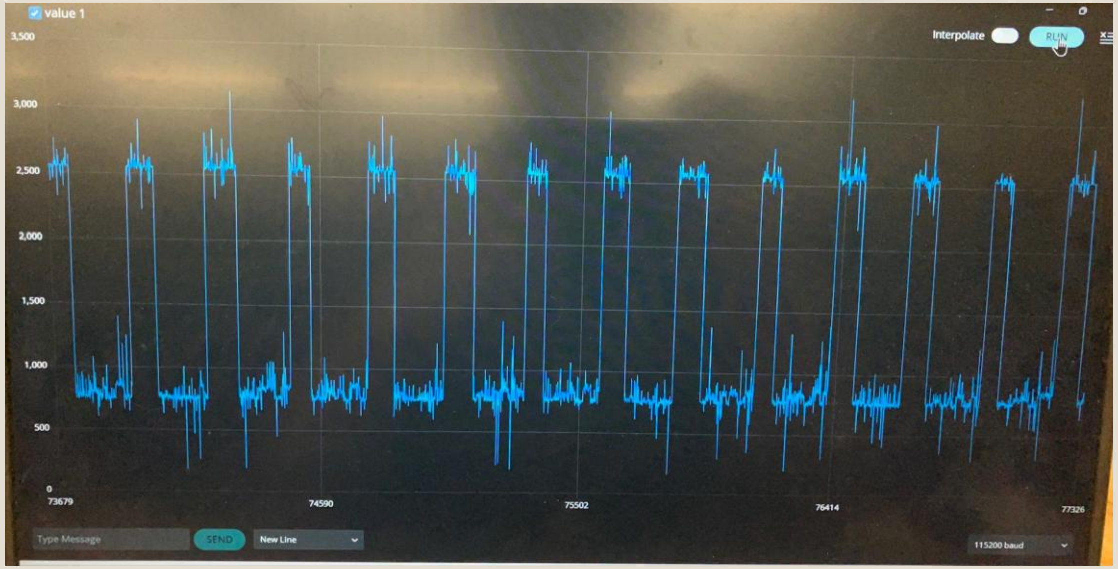
- 100 mW DPSS laser with 800 nm pump
- Bandpass filter centered near 532 nm to block pump wavelength
- F = 50 mm focusing lens increasing intensity onto Ethyl Alcohol sample
- F = 50 mm collimating lens to collect Raman scattered light
- 550 nm cut-on longpass filter to isolate Raman signal
- F = 50 mm focusing lens to focus light onto spectrometer fiber
- 10 sec spectrometer integration time

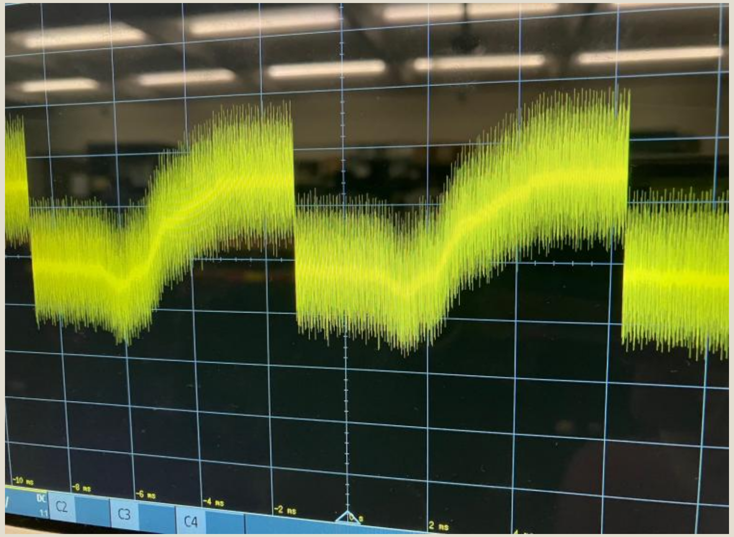
Results:

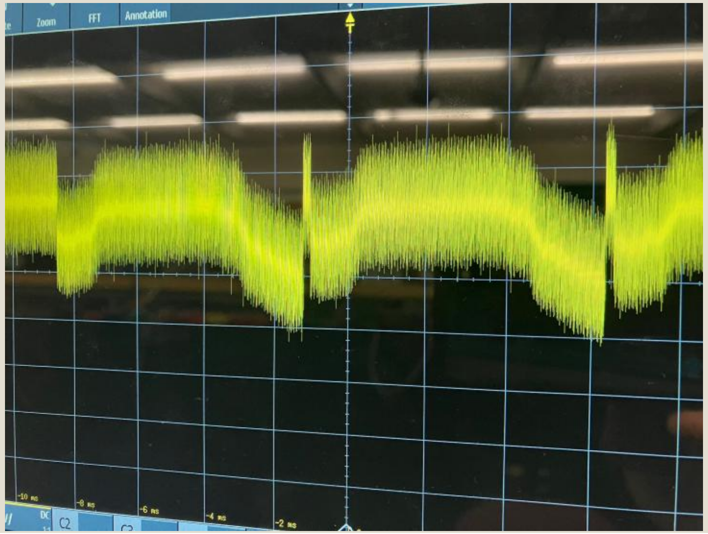
- Clearly defined peak at 630.5 nm, or 2936 cm^{-1}
- Integration time was sufficient to acquire a signal
- Raman signal discernible from 600 lines/mm groove density
    - Our personal CCD has 1200 lines/mm, meaning higher resolving capabilities
- Linear CCD array in the spectrometer was sensitive enough to detect the signal

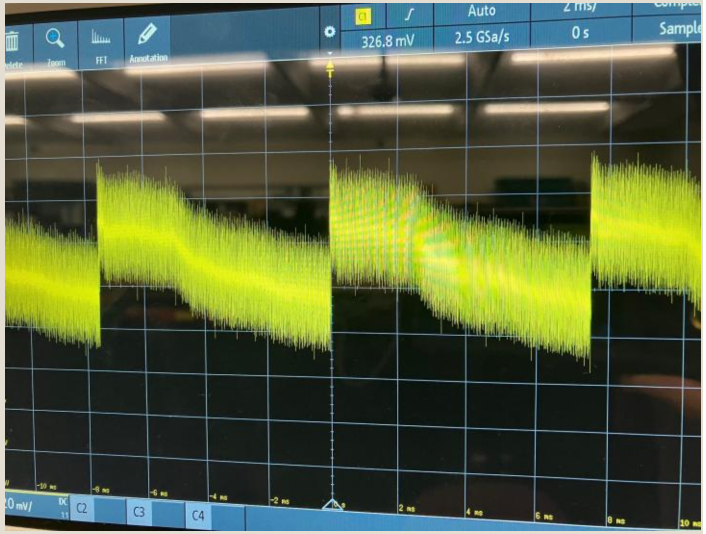


CCD Testing


value 1
Interpolate
RUN
3,500
3,000
2,500
2,000
1,500
1,000
500
0
73679
74590
75502
76414
77326
Type Message
SEND
New Line
115200 baud


C2
C3
C4


Zoom
FFT
Annotation


Auto
326.8 mV
2.5 GSa/s
0 s
FFT
Annotation
C2
C3
C4

Successes and Difficulties

	Laser Source	Spectrometer	Mounting Optics	CCD Data Acquisition	PCB
Difficulties	Balancing linewidth and laser output power at 532 nm	Finding a combination of collimation and focusing lenses for best resolution	Creating custom fitted 3D-printed mounts for delicate and expensive optics	The precision necessary to achieve the timing requirements of the CCD output signal delayed the success of this area of the project	Creating a design for the main board ensuring minimal noise
Successes	Finding an affordable laser with narrow spectral linewidth	Simulated an acceptable combination of optics that upholds our requirements	Maintaining the integrity of alignment with 3D-printed mounts	Code driving the CCD sensor has been completed. CCD output data has been obtained by the ESP32 development board and converted by the ADC	Approved power supply design for the system

Plan for Completion

Illumination and Spectrometer alignment

- Calibrating and aligning the spectrometer, then aligning the spectrometer to the illumination portion

CCD integration with optics

- Aligning CCD with spectrometer optics to test responsivity with our procured signal

Spectral analysis software

- Testing software to resolve and display spectral signatures resulting from optical signal
- Test comparison algorithm with obtained signature data

PCB implementation

- Fully operational system, ensuring prover supply to the desired components and data transmissions

Designing the housing

- Isolating and holding all collection/spectrometer optics within darkness
- Enabling user access to LCD touchscreen

Bill of Materials

Item	Part number	Cost per unit	Quantity	Total Cost
Laser diode module	Q-BAIHE 532 nm laser module	$43.98	1	$43.98
Dichroic mirror (Beamsplitter)	Chroma T550lpxr	$250	1	$250
Long Pass Filter	Chroma ET542lp	$365	1	$365
Plano-Convex Achromatic Coupling Lens	Edmund Optics #47-639	$120.84	1	$120.84
Plano-Convex Focusing Lens	Edmund Optics #48-423	$31	1	$31
Multimode Fiber	MKS Newport F-MCC-T	$11.50	1	$11.50
Slit	Edmund Optics #58-541	$154.35	1	$154.35
Plano-convex Achromatic lens	Edmund Optics #47-637	$120.84	2	$241.68
Diffraction grating	Thorlabs GR25-1205 Grating	$128	1	$128
CCD	Toshiba TCD1304DG	$34	1	$34
PCB		$70	1	$70

Item	Part number	Cost per unit	Quantity	Total Cost
LCD	B0CXTFN8K9	$32.99	1	$32.99
Raspberry Pi	B0CK3L9WD3	$69.49	1	$69.49
ESP32 Development Board	B0718T232Z	$9.99	1	$9.99
3.3 Volt Regulator	LM2576SX-3.3/NOPB	$2.66	1	$2.66
5 Volt Regulator	LM2576SX-5.0/NOPB	$2.04	1	$2.04
12 V Regulator	LM2587S-12/NOPB	$7.63	1	$7.63
Battery power supply	PS12-BK60-LF60NA	$53.47	1	$53.47
Switch	09.03201.02	$1.77	1	$1.77
Transistor	2N2222A	$2.68	1	$2.68
Resistors, Capacitors, Inductors, LEDs		$10	1	$10
Fabric Samples		$0	1	$0
Total Cost				$1522.23

Work Distribution

Danielle	Ariana
• Spectrometer Design • Spectrometer Housing	• Collection Optics Design • Optical Mounts Design
Austin	**Cameron**
• CCD Data Acquisition • Spectral Signal Processing • Signature Data Analysis & Classification	• PCB Design • Power Distribution

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Thank You