Project HULK:
X-Ray Dose Rate Detector

Group 26

Final Presentation

Meet the team

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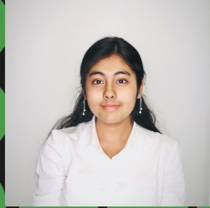
Motivation & Background

- The Radiation and Reliability Lab (RERL) requires real-time performance data from microelectronic devices under X-ray exposure
- Device behavior varies significantly across different radiation environments, making dose-rate (measuring radiation dose absorbed by sample) monitoring critical
- Current testing lacks immediate feedback during irradiation
- The X-Rad 320 in Research I is used for irradiation experiments
- However, it does not provide a real-time dose-rate measurement system
- Project is being sponsored by Dr. Enxia Zhang

X-RAD 320 in Research 1

Goals and Objectives



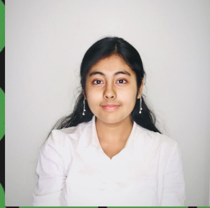
Basic Goals:

- Build a portable, real-time radiation dosimeter
- Measure dose rate in real time
- Ensure accuracy, sensitivity, and safety

Basic Objectives:

- Use a silicon PIN diode to detect radiation
- Design a low-noise transimpedance amplifier (TIA) for diode signal conversion
- Use precision op-amp to minimize noise and improve accuracy
- Develop firmware on the ESP32 to compute dose rate from diode signals
- Convert voltage readings into dose-rate values with ADC
- Display real-time results on an LCD

Goals and Objectives



Advanced goals:

- Display real-time voltage and dose-rate measurements on the LCD
- Implement SD card data logging for storing historical radiation measurements
- Enclose the system in a protective housing to ensure durability and safe operation

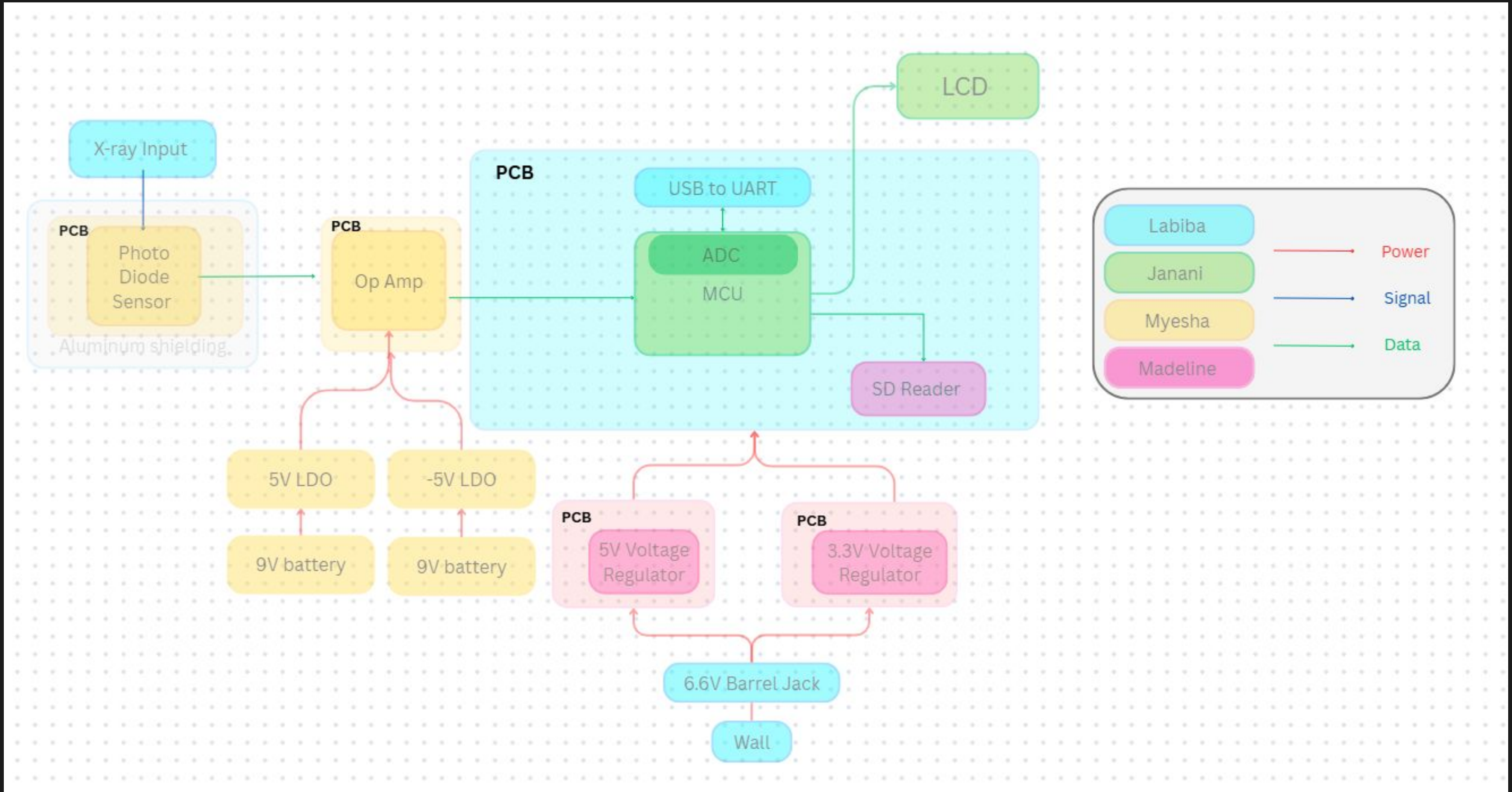
Advanced Objectives:

- Achieve <2 second latency by optimizing ESP32 firmware, ADC sampling, and Arduino-based handling of real-time LCD updates
- Implement microSD data logging using Arduino programming to store dose-rate measurements for later PC retrieval
- Design and fabricate a 3D printed protective housing to secure components

Specifications

Parameter	Value/Spec
Dimensions of Housing	6'' L x 5.5'' W x 3'' H
X-ray energy limit	<320 keV
Minimum detectable dose rate	>2400 Gy/second
Weight	<3lbs
Power supply	6.6V AC to DC
Cost	$2000
Display time	2-5 seconds
Accuracy	>90%
Display	Onboard 480×320 SPI TFT (3.5inch)
Sensor	Photodiode (AXUV20HS1)

System overview



Diode Selection

Parameter	Why It Matters	ARACOR	AXUVH25	AXUV20HS1	AXUV20A
Sensitive Area	Larger area = more signal collected	10 mm²	1 mm²	**20 mm²**	**23 mm²**
Signal Strength	Determines if signal is easy to amplify	High	Low	**High**	High
Capacitance	Lower = lower noise & easier analog design	N/A	15–50 pF	**300–900 pF**	500–1500 pF
Response Speed	Important for real-time or pulsed measurements	N/A	0.7 ns	**3.5 ns**	2 μs
X-ray Energy Range	Must match source spectrum	8–60 keV	8–60 keV	**10–100 keV**	10–100 keV
Best Use Case	Ideal application	Absolute dose reference	Fast lab measurements	**High-signal research systems**	Low-voltage systems

Op-Amp selection

Parameter	Why it matters	TI OPA141	ADI ADA4530-1	ADI LTC6268
Input Type	JFET provides high impedance for accurate photodiode current sensing.	JFET	CMOS	CMOS
Input Bias Current	Low bias current minimizes added noise	10 pA	20 fA	3 fA
Input Offset Voltage	Low offset helps maintain measurement accuracy	120 µV	20 µV	200 µV
Input Voltage Noise	Improves stability	5.1 nV/√Hz	7 nV/√Hz	4 nV/√Hz
Supply Voltage Range	Must support ±5V	4.5–36 V	4.5–16 V	2.7–5.25 V
Package Options	Simple package for soldering	SOT-23-5, SOIC-8	SOIC-8	SOIC-8, DFN-8

LDO Selection

Parameter	Why it matters	78L05 / 79L05
Output Voltage	Provides regulated ±5V rails required for op-amp operation.	+5V / –5V
Low Noise	Minimizes power supply noise in sensitive analog circuitry.	Low-noise linear regulation
Simplicity	Easy to implement with minimal external components.	Simple 3-pin design
Professor Recommendation	Dr. Weeks suggested this component	Recommended by advisor
Availability	Easy to obtain and available in lab	Widely accessible

MCU Selection

Parameter	Why it matters	ESP32-DevKitC	ESP32-WROOM-32	ESP32-WROVER	ESP32-S3 DevKit
ADC Resolution	12-bit resolution is sufficient analog measurement for precise sensor readings.	12-bit	12-bit	12-bi	12-bit
Processing Power	Dual-core processing supports sensor reading, display control, and multitasking.	Dual-core Xtensa	Dual-core Xtensa	Dual-core Xtensa	Dual-core Xtensa LX7
Memory (RAM/PSRAM)	Enough onboard memory supports firmware and display	~520 KB RAM, no PSRAM	~520 KB RAM, no PSRAM	520 KB RAM + 4–8 MB external PSRAM	512 KB RAM + optional PSRAM
Display	Supports TFT display	Reliable, but limited memory for complex graphics	Library support depends on the clone board	PSRAM allows smoother display updates and data logging	Improved GPIO count and memory help multitasking
Community / Library Support	Strong support simplifies debugging and implementation.	Strong, official Espressif docs	Very strong, widely used in education/prototyping	Strong but fewer examples than WROOM	Currently expanding

SD Card Reader Selection

Feature	Why it matters	DM3AT-SF-PEJM5	MEM2067-02-180-00-A	MEM2075-00-140-01-A	MEM2052-00-195-00-A
Voltage	Able to be supported by our power supply	125 V AC	100V AC/DC	30 V AC	10V AC/DC
Current	Handle current for SD card communication	0.5 A	0.5A AC/DC	0.5A per pin	0.5A AC/DC
Operating Temp	Stable operation in extreme environment	-25°C to +85°C	-40°C to +85°C	-25°C to +85°C	-40°C to +85°C
Price	Affordable	$2.85	$1.06	$1.80	$1.08
No. of Pins	Needs required pin count for SD card interfacing.	10(8+2)	8	9(8+1)	9(8+1)

LCD Display Selection

Feature	Why it matters?	Parallel TFT LCD	Character LCD	SPI TFT LCD	I2C TFT Touch LCD
Screen Size	To determine the amount of information displayed at once	3.5–5.0 in., full graphics	16×2 or 20×4, text only	2.4–3.5 in., graphics	3.5–4.0 in., graphics + touch
Resolution/ Output	Affects how detailed the data will appear	High (320×480+)	Limited to text characters	240×320 – 480×320	320×480, interactive
Interface Complexity	Determines how easy software is to integrate	High (many GPIO lines)	Low (simple but limited)	Moderate (4 to 5 pins)	Only 2 data lines
Integration with ESP32	Determines how easy data can be connected	Difficult, heavy routing	Easy but non-scalable	Good, requires optimized drivers	Minimal wiring, easy PCB integration
Data visualization	Determines the type of information the display can show	Supports plots and graphics	Only numeric text	Supports plots and graphics	Full graphics + touch interaction
Power Consumption	Affects power requirements	Moderate	Very-low	Moderate	Moderate

Power Distribution

Component	Voltage	Current	Power
ESP32	3.3V	~60mA	~200m W
SD card Reader	3.3V	500mA max	~1.65 W
LCD display	5V	~100-250mA	~500-1250 mW
Filter (Op-Amp)	±5V	2.3mA	11.5 mW
USB to UART	5V	~15-25mA	~75-125 mW

Regulators- 3.3V

Quality	Why it matters	LM25575	LM2592	LM20242	LM22680
Input Voltage	Voltage supplied to the system is 6.6V	6V-42V	4.5V-60V	4.5V-36V	4.5V-42V
Output Voltage	Must work to supply 3.3V and 5V	3.3V	3.3V	3.3V	3.3V
Output Voltage Tolerance	The allowed range of variance from expected output voltage	2.76%	4.00%	2.35%	2.73%
Output Current	The system will need about 2A of current supplied	1.5A	2A	2A	2A
Efficiency	Higher efficiency= higher performance	83.7%	76%	88.8%	84.2%
Price	Affordability	$3.63	$6.97	$4.90	$4.84

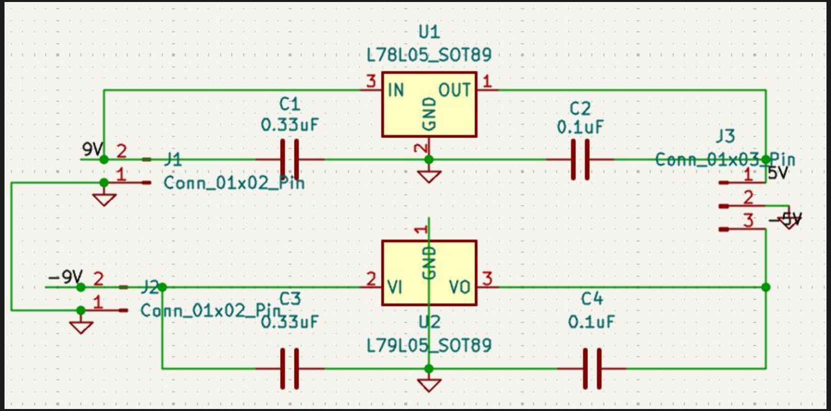
Regulators- 5V

Quality	Why it matters	LM25575	LM2592	LM20242	LM22680
Input Voltage	Voltage supplied to the system is 6.6V	6V-42V	7-60V	4.5V-36V	4.5V-42V
Output Voltage	Must work to supply 5V and 3.3V	5.02V	N/A	5.02V	5V
Output Voltage Tolerance	The allowed range of variance from expected output voltage	3.02%	N/A	3.22%	3.00%
Output Current	The system will need about 0.5A of current supplied	0.5A	N/A	0.5A	0.5A
Efficiency	Higher efficiency= higher performance	92.8%	N/A	94.8%	92%
Price	Affordability	$3.63	$6.97	$4.90	$4.84

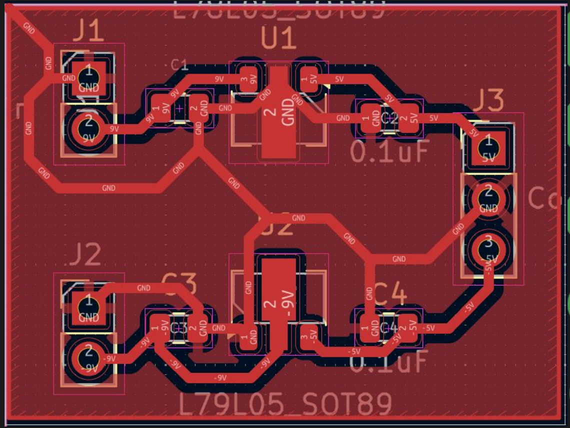
Main PCB Power Supply Selection

Parameter	Why it matters	AA Alkaline batteries	Zinc-carbon batteries	6V AC to DC
Voltage	The components being used in the project need a range of voltage to operate	4X1.5 = 6 V	4X1.5 = 6 V	6V
Current	The components will not operate if current is too high or too low	50 – 250 mA	1,100 mAh	2 A
Temperature	If it’s too high or too low then it will break the PCB	-18°C to 55°C	-18ºC to 55ºC	0~40℃
Cost	Affordability	$3.02	$0.49	$6.39
Life span	Depends on how long the system will last	10 years at 21°C	2-3 years at 21°C	3-10 years

LDO Design



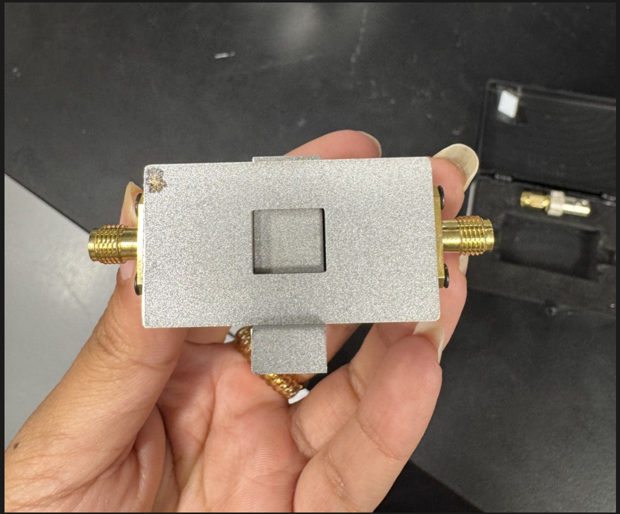
Schematic

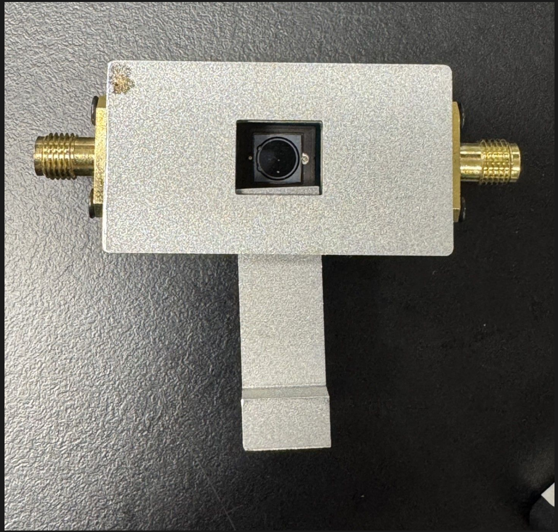


PCB Layout

- L78LO5 supplies 5V
- L79LO5 supplies -5V
- Header pins to connect to filter PCB to power op-amp

Diode PCB

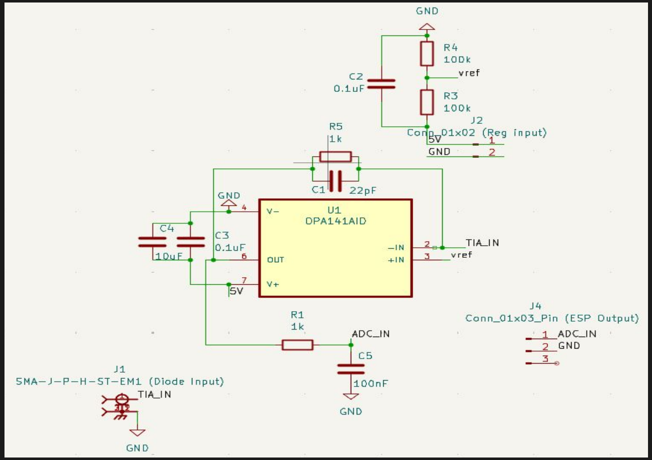




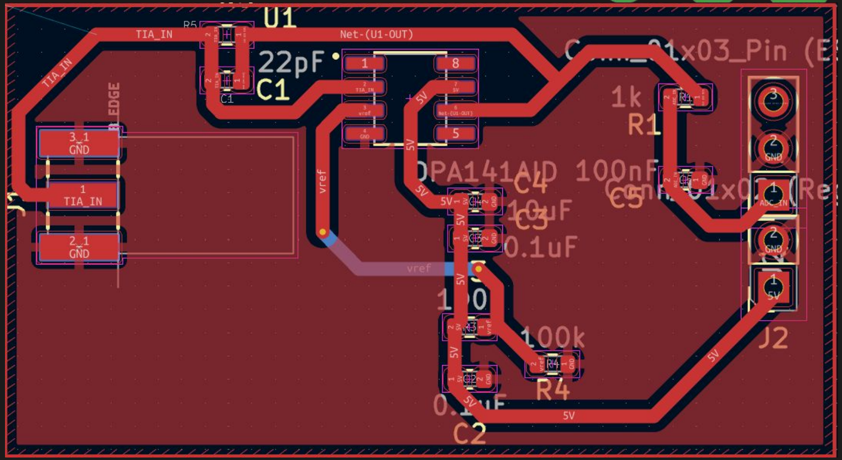
Aluminum housing with SMA connectors to hold the diode

- Photodiode is soldered onto PCB and connected to coaxial cables to receive signal from X-ray and sent to filter
- Aluminum slot to cover diode when not exposed

Filter PCB design



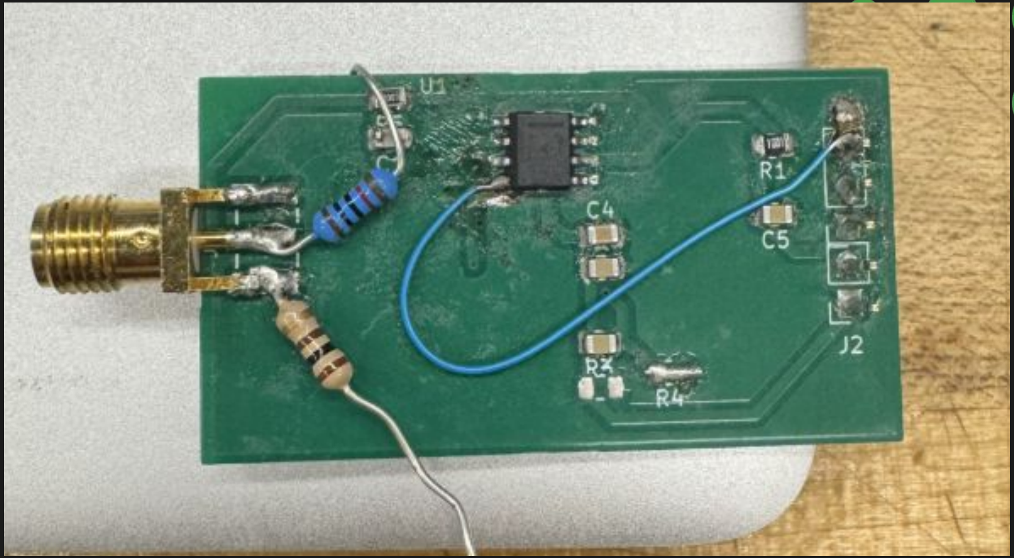
Schematic



PCB Layout

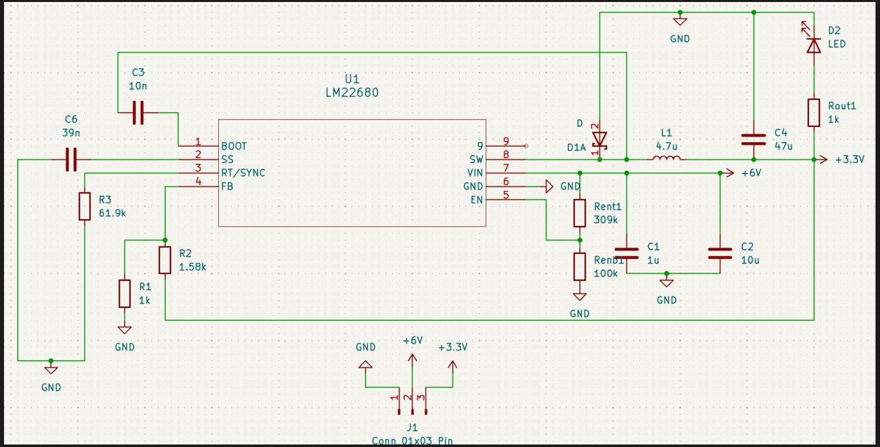
- Filter contains the TIA, op-amp, and lowpass filter
- SMA connector to receive signal from diode
- Header pins to supply 5V and -5V to op-amp and connect to ESP for processing

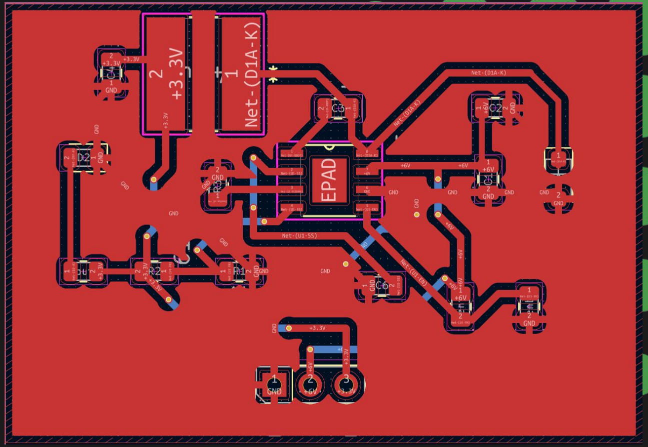
Filter PCB design



- When constructing the filter we switched to using dual-supply for the op-amp so we added a -5V connection
- Removed local vref
- Added resistors for testing

Regulator PCB Design

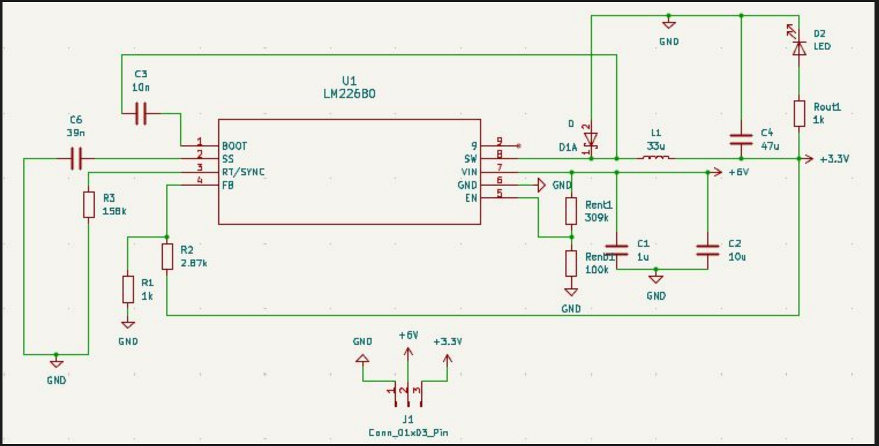


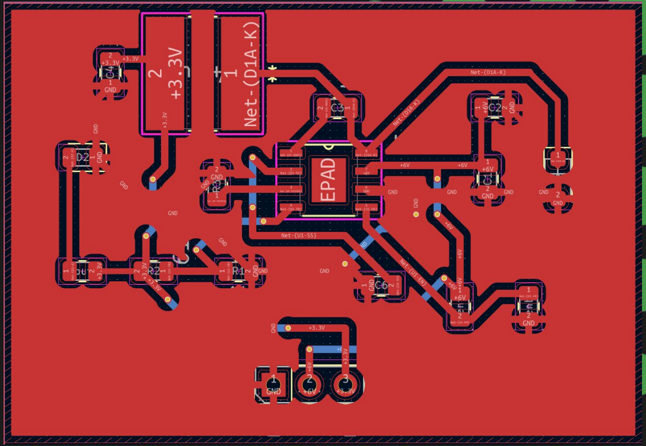


- This image shows the PCB schematic for the 3.3V regulator
- This design is based on the information provided on TI's WeBench and the regulator's data sheet

- This image shows the PCB design and layout for the 3.3V regulator that is used in our final design
- This design is based on the information provided in the regulator's data sheet

Regulator PCB Design

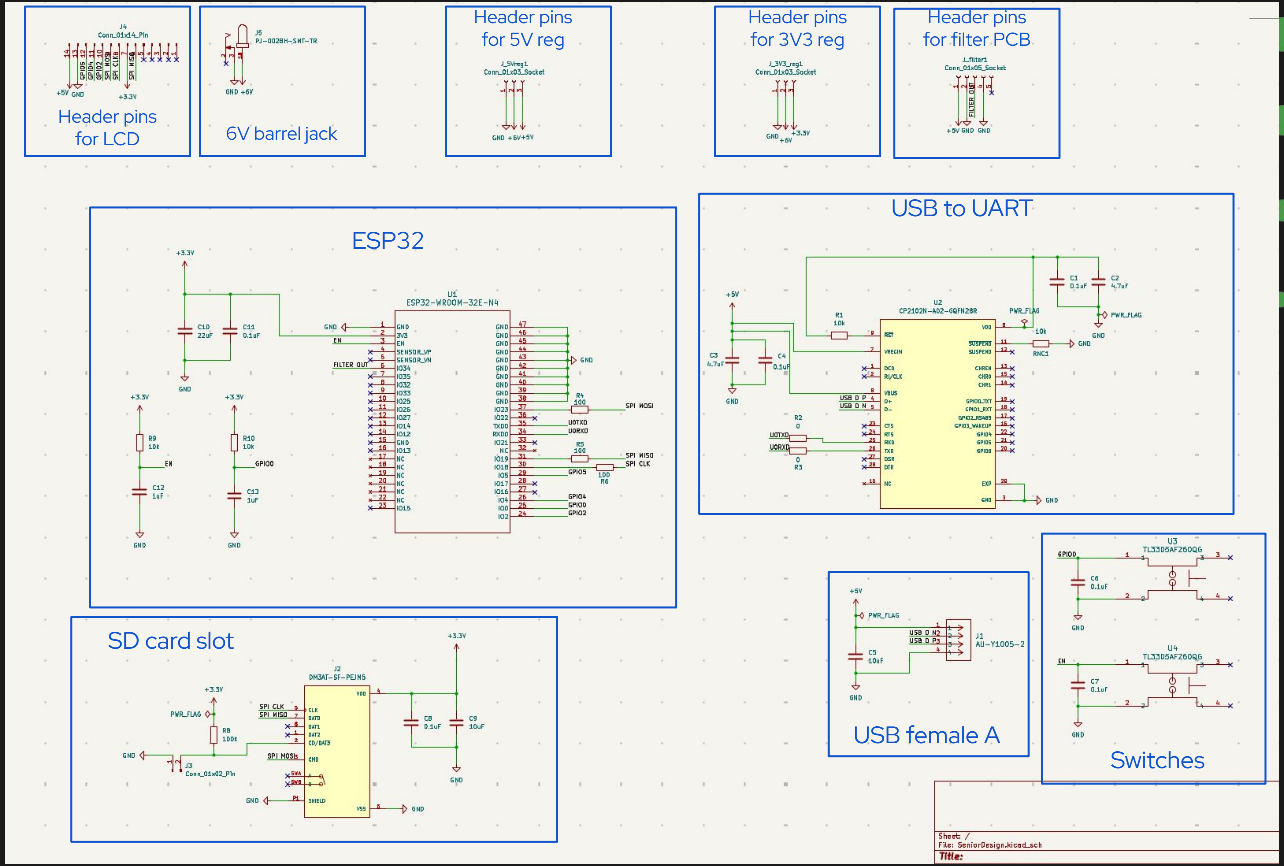




- This image shows the PCB schematic for the 5V regulator
- This design is based on the information provided on TI's WeBench and the regulator's data sheet

- This image shows the PCB design and layout for the 5V regulator that is used in our final design
- This design is based on the information provided in the regulator's data sheet

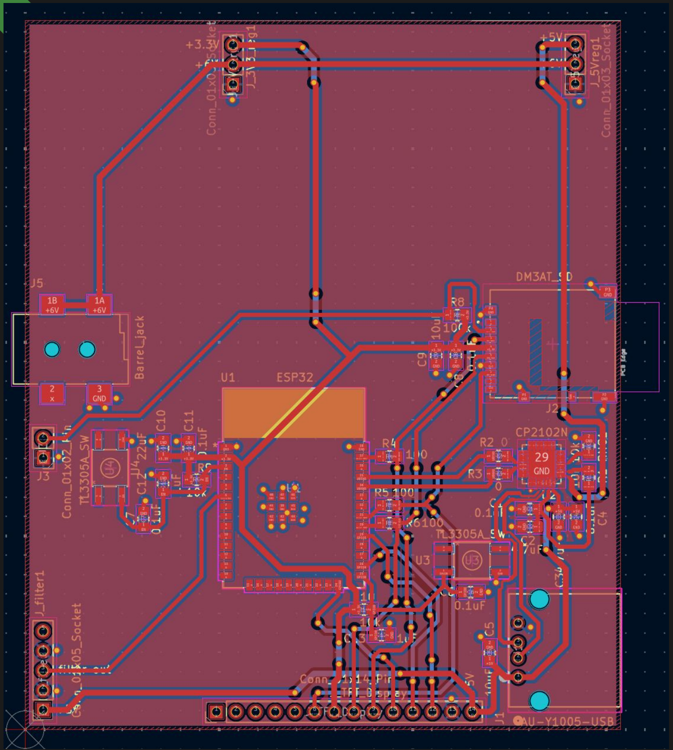
Main PCB Schematic



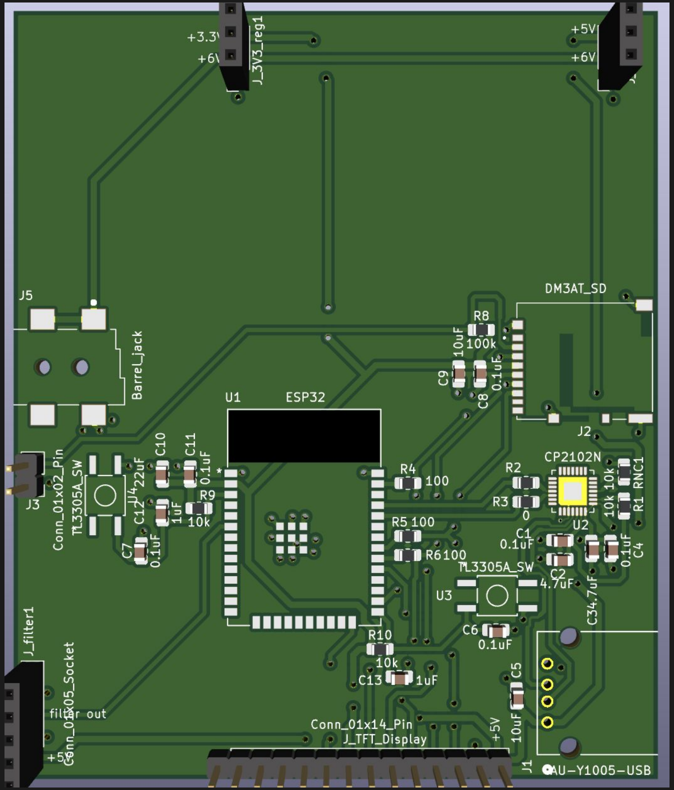
Schematic includes:

- MCU
- Power supply for 3V3 and 5V regulators, SD card and LCD display
- Connects 3V3 and 5V reg, filter PCB and LCD together

Main PCB Layout

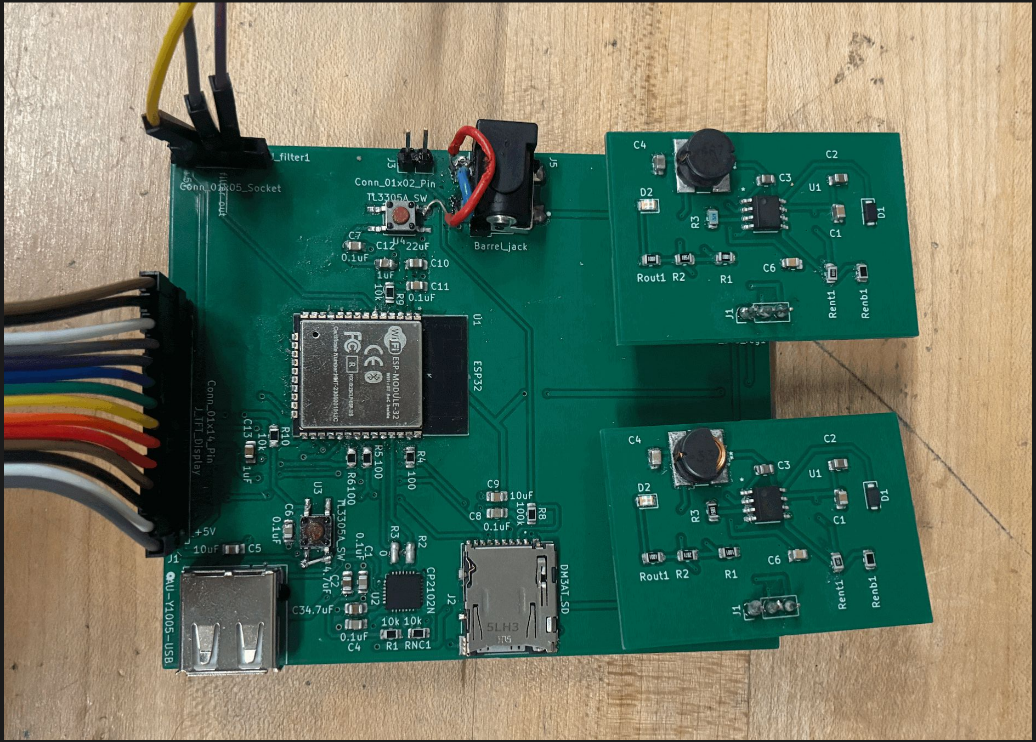


This is the layout of the PCB that includes the MCU, SD card, power supply and connections to the regulators, LCD and filter PCB



This is the 3D view of the MCU PCB

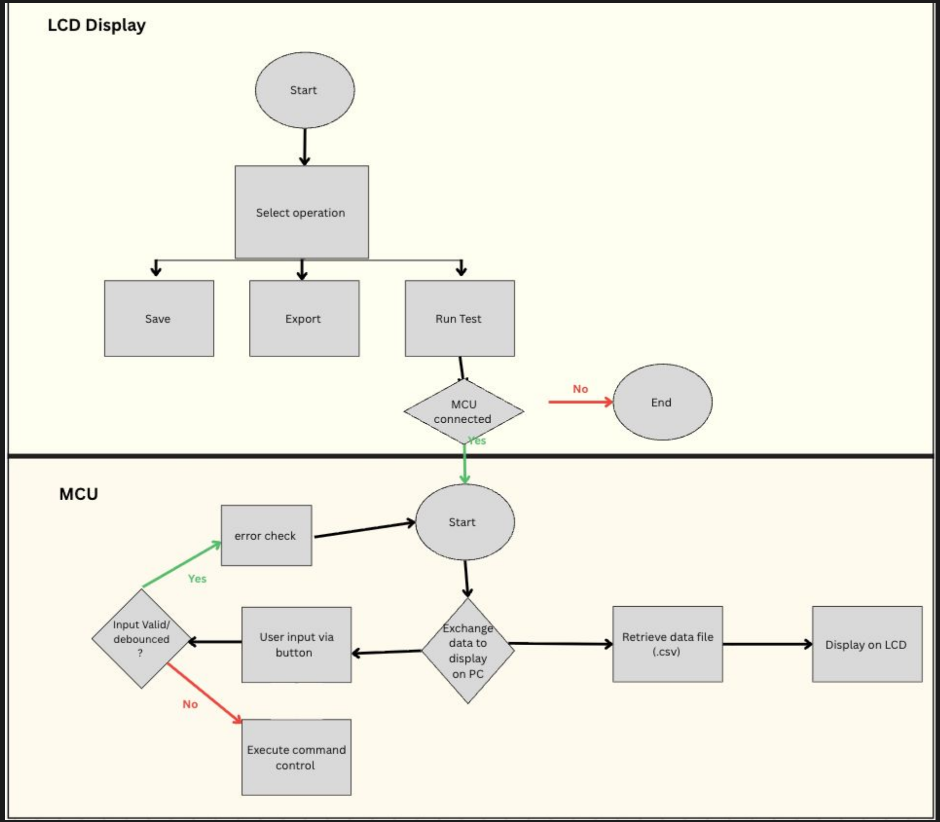
Fabricated and operating Main PCB



The picture shows the operating PCB with the 3V3 and 5V connected by the header pins.

The display and filter PCB are connected by jumper wires.

Software Block Diagram



- Displays main menu options (Save, Export, Run Test)
- Verifies MCU connection before starting test
- Performs input validation and error checking
- Processes and exchanges data between MCU and system
- Retrieves stored data and displays results on LCD

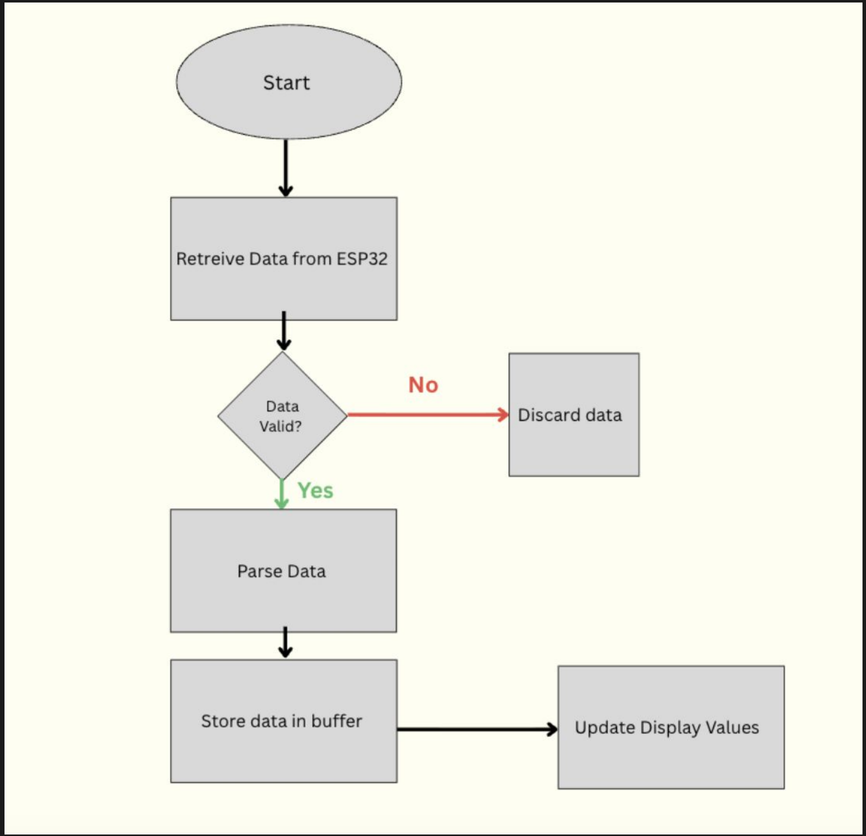
Software Component selection

Component	Description
ADC reading module	Configures and reads analog voltage from the photodiode through the ESP32 ADC. Handles sampling timing and resolution control.
Dose Calculation Module	Converts raw ADC values into voltage and applies the project’s calibration curve to compute dose rate in Gy/min.
Filtering and Averaging Module	Reduces measurement noise through averaging windows and smoothing algorithms to produce stable dose-rate readings.
Communication Handler	Packages processed dose-rate data and transmits it to the LCD using SPI or I^2C. Manages acknowledgments and retry logic for reliability.
LCD display handler	Updates the numerical dose-rate readout, refreshes graph frames, and switches between display modes selected by the user.
Error Detection Module	Detects invalid ADC values, communication failures, or signal outliers. Initiates corrective routines and triggers on-screen warnings when necessary.
Display mode controller	Allows the LCD to toggle between showing the graph only, the numerical reading only, or both simultaneously.

ESP32 Development Environment Selection

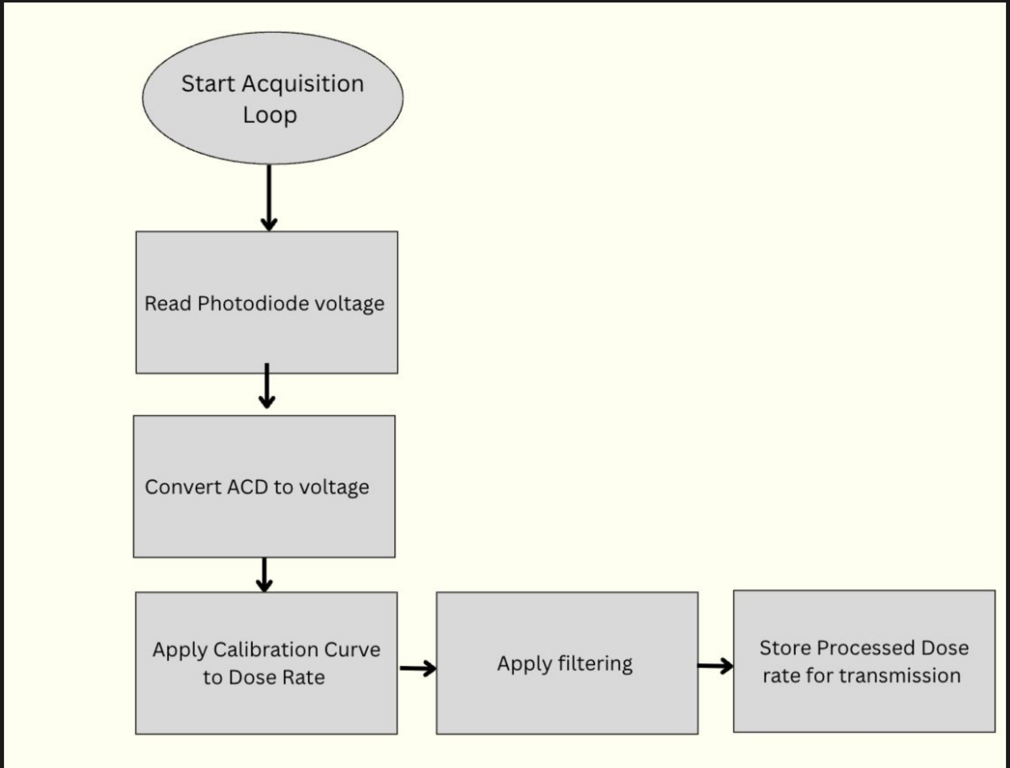
IDE	Advantages	Disadvantages
Arduino IDE	Faster Prototyping, Strong ESP support	Less low-level control
VS Code + ESP-IDF	Full framework access	Steeper learning curve
EspressifIDE	Native tools	Limited familiarity

LCD Application Design



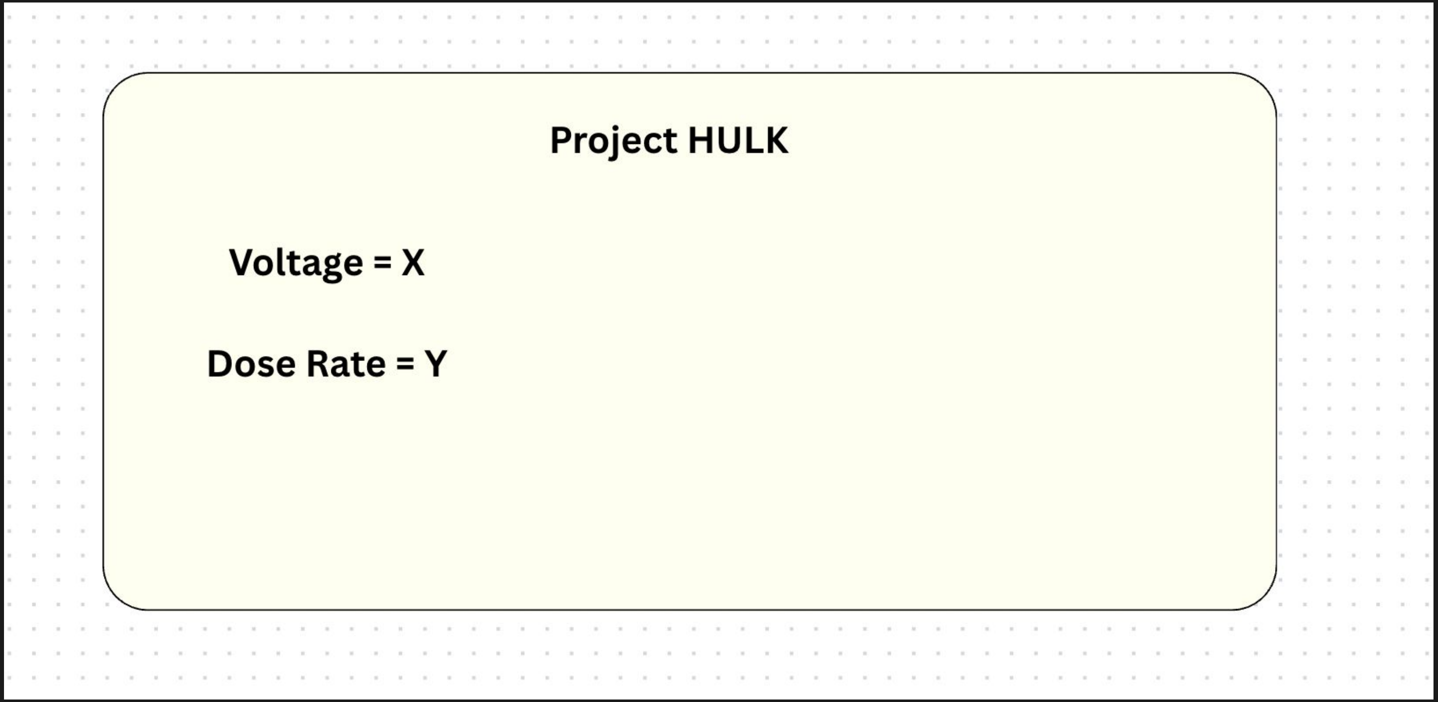
- Receives dose-rate packets from ESP32
- Validates and parses numeric + timestamp data
- Buffers readings for graph rendering
- Updates numeric display in real time
- Refreshes graph at defined sampling interval

ESP Software Integration



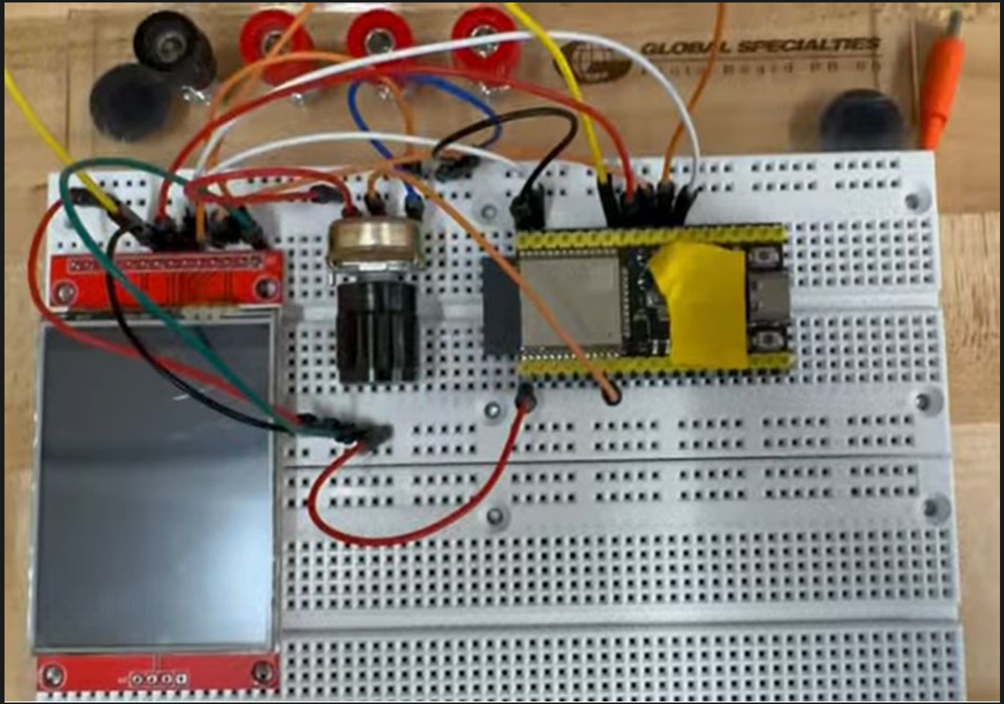
- Samples amplified photodiode voltage via ADC
- Converts analog voltage to digital value
- Applies calibration curve (Gy/min conversion)
- Implements averaging filter for noise reduction
- Packages processed data for SPI transmission

LCD Display View



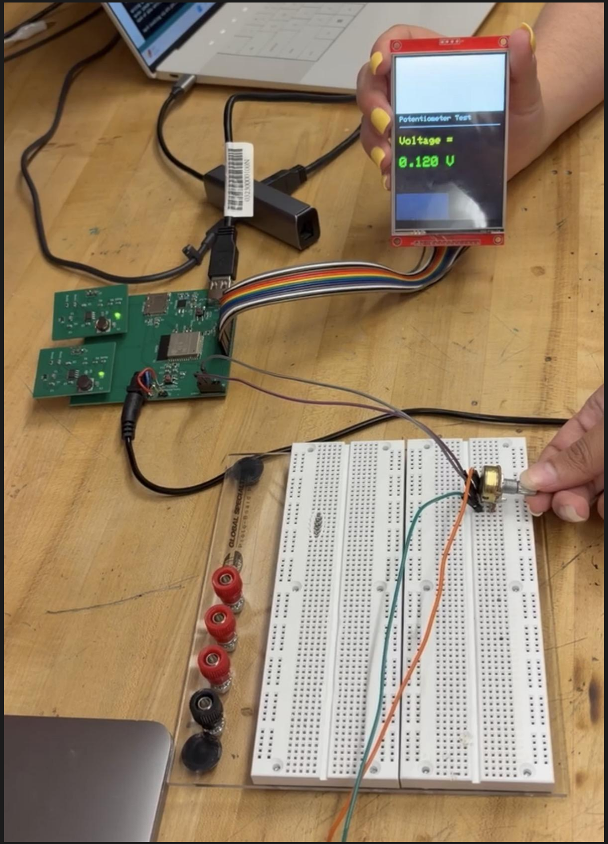
- Display will show the voltage and the dose rate
- Display will auto export to SD card reader

Prototyping and Testing



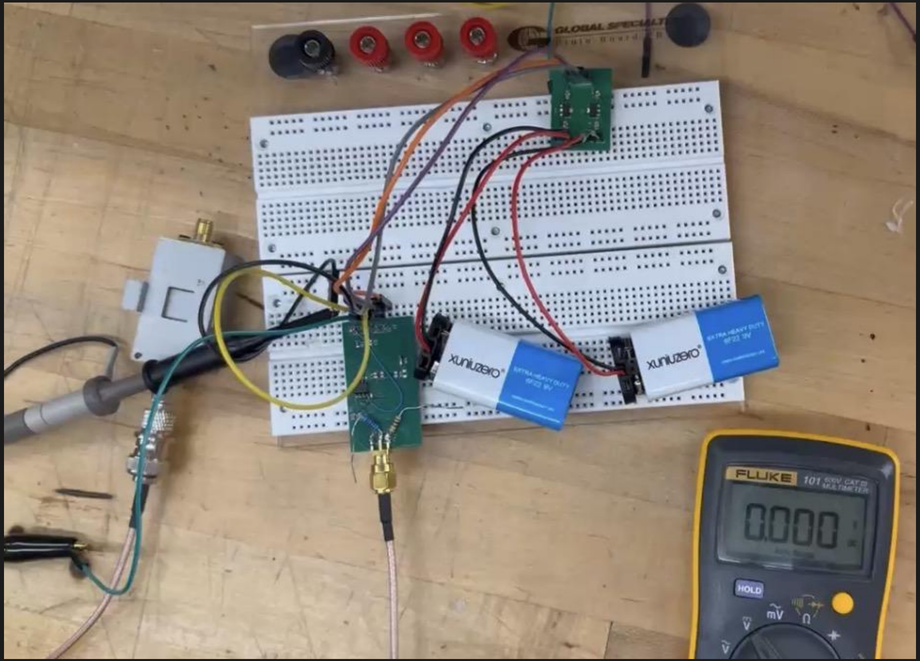
- This slide shows the initial prototyping we made for our design to demonstrate the overall concept of the design.
- This first prototype uses an ESP32 devkit connected to our LCD screen.
- To demonstrate the system's ability to analyze a changing voltage input, we used a potentiometer to to vary the voltage into the ADC of the ESP32 devkit.

Prototyping and Testing



- For this prototype we used the main PCB board (with our ESP32 chip) connected to the LCD screen.
- To show the systems ability to process changing voltages, we connected a potentiometer to the ESP's ADC input.
- Using our test code, the system was able to accurately display changing voltages outputted by the potentiometer on the LCD display which updates in real time.

Prototyping and Testing



- This slide shows the setup used to test the filters ability to output a voltage from the photodiode.
- In this test the filter is powered from the LDO and connected to the photodiode.
- When different levels of light were shone on the diode, the voltage read at the output of the filter changed showing the accuracy of the design.

Budget

Component Part Name	*Quantity*	*Unit Price (USD)*	*Total Price (USD)*
Core Circuit Components			
MicroSD Card Breakout Board+	2	$7.50	$15.00
ESP32 Dev Kit	1	$10.00	$10.00
ESP32-WROOM-32E-N4 MCU Module	2	$4.84	$9.68
LM22680 Regulator IC	4	$4.84	$19.36
OPA141AIDR	4	$2.61	$10.44
DM3AT-SF-PEJM5	2	$2.85	$5.70
Additional Components (resistors, capacitors, etc.)	–	–	$61.81
AXUV20HS1 Opto Diode	2	$627.06	$1254.12
PCB's	4	–	$163.07
Additional Components			
2.8" TFT Resistive Touch Shield (LCD Display	3	$24.95	$74.85
Total			
Grand Total	–	–	$1,624.03

Total spent: $1,624.03
Total budget: $3,000

Work Distribution

Team Member	Responsibility
Myesha	Diode PCB design, Filter PCB design, LDOs, hardware testing, integration
Madeline	Regulator Design, hardware testing, integration
Labiba	MCU board design, Power supply selection, hardware testing, integration
Janani	Software architecture design, ESP32 firmware development, LCD implementation, system integration

Challenges

- Switching op-amp from single-supply to dual supply required creating a new connection on the filter board and using a new power supply via low-noise LDOs
- Connecting the MCU to the TFT LCD and getting the LCD to display words instead of just the backlight.
- Integrating the correct equations to accurately display data on the LCD.
- Fixed PCB shorts, unclear barrel jack connections, and unknown switch pinouts by tracing circuits and testing components to ensure proper operation.

Thank you