Project HULK
X-ray dose-rate detector for material irradiation

Initial Divide and Conquer Document
EEL4914 - Senior Design I
Group 26

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1.1 Introduction

Radiation research is more critical than ever as we continuously evaluate the effects of ionizing radiation on all types of electronic devices. Radiation is a powerful tool that enables advancements in medicine, security, and electronics testing. X-ray irradiation, in particular, plays a key role in simulating specific environments and testing radiation effects and device reliability. The measurement of absorbed radiation, known as dosimetry, is essential for such studies. Measuring radiation accurately in real-time is essential to protect people, ensure equipment reliability, and conduct meaningful scientific research. Without proper monitoring, researchers and engineers risk drawing incomplete conclusions or, worse, exposing themselves and their equipment to unsafe conditions.

The current industry standard for measuring X-ray dose rates involves ionizing gas chambers . While highly accurate, these systems are bulky, expensive, and require specialized infrastructure such as gas lines, high-voltage supplies, and complex cabling (1). This makes them inaccessible for many laboratories and impractical for flexible, low-cost setups. As a result, there is a critical need for a simpler, more affordable way to monitor X-ray dose rates without sacrificing accuracy.

At the University of Central Florida, the Precision X-ray 320, which delivers a precise radiation dose with energy up to 320 KV is going to be used for irradiation experiments. But there is currently no integrated system to measure or display real-time dosimetry during operation. This limits the ability to benchmark device degradation under controlled dose conditions.

To tackle this challenge, our project proposes the development of a portable, solid-state X-ray detector based on a silicon PIN photodiode. In order to make it simple, affordable and portable, the project will use low-noise amplification techniques and digital readout electronics. The photodiode will generate a current proportional to the incident X-ray flux (1). This current will then be converted into a voltage by the precision transimpedance amplifier and read by Raspberry Pi. Raspberry Pi will convert these measurements into dose rates by applying calibration formulas. Finally, the dose rates will be logged and visualized on a PC/display for real-time monitoring (4).

We will use the AXUV20HS1 PIN diode, selected for its fast response, low capacitance, and adequate active area coverage. The diode will be connected with a transimpedance amplifier circuit for current readout, Raspberry Pi for real-time conversion of diode current into dose rate, and a USB interface for PC-based visualization and logging.

The system will further include:

- Filter integration (e.g., 150 μm Al or 2 mm Al + 1 mm Pb) to approximate Co-60 spectra and enable energy-dependent calibration.
- A benchmarking mode to compare diode readings with reference MOSFET degradation data to ensure consistency with industry-standard Co-60 irradiation (4).
- Error-handling features, including saturation detection, baseline zeroing, and range switching, to improve measurement reliability (4).
- Stretch functionalities, such as a handheld display, wireless data transfer, and onboard memory for storing historical dose measurements.

By combining these features, our project aims to close the gap between complicated, high-cost dosimetry methods and the need for a real-time, accessible, and reliable radiation measurement tool for research purposes.

1.2 Goals and Objectives

The goals and objectives are provided below. The goals define our expected outcome from this project and the objectives define the specific means to achieve that.

<u>Basic goal:</u>

Build a safe, portable, real-time radiation dosimeter using a silicon PIN diode that is capable of measuring, displaying, and logging dose rates during X-ray irradiation experiments.

<u>Basic Objectives:</u>

- Build a transimpedance amplifier circuit with precision, low-noise, low-input-bias-current operational amplifiers for diode current readout (1).
- Implement a program on Raspberry Pi to convert diode current into dose rate.
- Log data using a high-resolution Analog-to-Digital Converter (ADC) (5), then process these values with a Raspberry Pi to convert them into dose rates. The dose rates will be stored in a CSV file on a USB drive, which can later be accessed on a PC.

<u>Advanced goals:</u>

Integrate digital calibration curves, compare measurements against reference standards and implement an automated error-checking function.

<u>Advanced Objectives:</u>

- Add digital calibration curves for different filters (no filter, 2 mm Al filter, 2 mm Al + 1 mm Pb) by programming the Raspberry Pi to convert raw diode current to accurate dose-rates.
- Implement a real-time benchmarking mode to compare dosimeter measurements with MOSFET degradation data collected from a parameter analyzer.
- Automate error-checking functions: saturation detection, baseline zeroing, and range switching to ensure the software continuously monitors for hardware disruptions.

Stretch goal:

Increase system portability and usability by adding features that make the prototype standalone and user-friendly.

Stretch Objectives:

- Include wireless connectivity and mobile app to display dose-rates on a real-time dashboard for remote monitoring.
- Use the Raspberry Pi's microSD card to store data that can later be retrieved into a PC to access historical files (5).

1.3 Prior Related Work:

Development of a Silicon PIN Diode X-Ray Detector:

The Silicon PIN Diode X-Ray Detector is a PCB designed to detect radiation output by monitoring dose rate. As x-ray flux passes through a diode a current is produced. This current can be used to calculate the flux which leads to the calculation of the radiation dose. This project consists of many shared qualities with the PCB we will design.

The PCB consists of an AC and DC circuit to measure the radiation. The end goal for this project is to combine the AC and DC circuits to measure the pulses from the diodes at lower and higher dose rates respectively. The AC circuit was coupled to measure the radiation. A gamma ray is sent to a photodiode creating a photocurrent which is then sent through a high-pass filter coupled with a low-pass filter with a passband of 160 Hz to 18kHz.

In the DC circuit a high pass filter is placed in series with a non-inverting amplifier, two capacitors are also used to filter noise. This circuit worked and the output voltage measurements were taken at different distances from the source of the radiation. Using the Inverse Square Law and the known dose rates (at some of the distances), the dose rates at unknown distances were estimated.[1]

Experimental analysis of a novel and low-cost pin photodiode dosimetry system for diagnostic radiology:

The system for diagnostic radiology is a two stage amplifier to measure the photocurrent from the PIN sensor, this current is then processed to be displayed on an LCD screen. The first stage of this amplifier is a trans-resistive amplifier to measure current changes which are then converted to voltages and sent to the second stage, a voltage amplifier, to amplify the first stage output voltage to a range between 0V and 2.5V. The circuit design was found to be very sensitive to noise and was placed in a small metal box to shield it. To evaluate the signal changes a full-wave rectifier was used.

In addition to this circuit, in this project a Digital Processing Unit was used to process the data. The first block of this was an ADC to digitalize the voltage output from the circuit. A signal channel analyzer (SCA) is used to measure the noise sources, this is used as a trigger signal to activate the multichannel analyzer (MCA). When the SCA is active the MCA begins to capture the data from the input signal, when the SCA is not active the MCA uses the data collected to calculate the voltage.[2]

1.4 Required Specifications

1.4.1 Specifications Table

Parameter	**Value/Spec**
Dimensions of Housing	7 x 5 x 3 inches
X-ray energy limit to withstand	<320 keV
Dose rate detection range	~0.01 → ≥3 Gy/min
Weight	<3lbs
Power supply	5v battery
Cost	$2000
Display time	2-4 seconds
Accuracy	>95%
Power consumption	100 watts
Display / UI (Option A: LCD)	Onboard 480×320 SPI TFT (3.5inch)

Display / UI (Option B: PC/Web Dashboard)	PC Display Host website with live plots
Sensor	Diode (AXUV20HS1): -Active area: ≈20 mm² -Capacitance: 300–900 pF -Reverse Bias Voltage: 150 V -Responsivity: 0.1–0.3 A/W (broadband) -Rise time: 3.5 ns -Spectral match: 10–100 keV

1.5 Prototype Illustration:

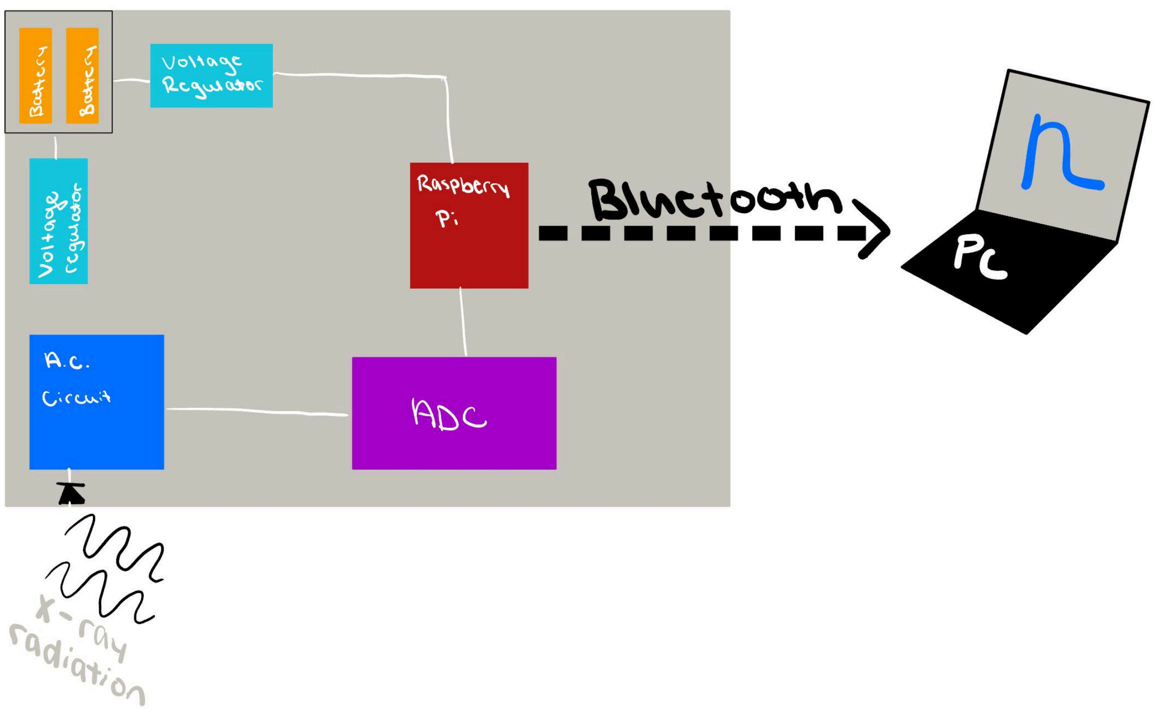


Figure 1.5.1 Prototype illustration

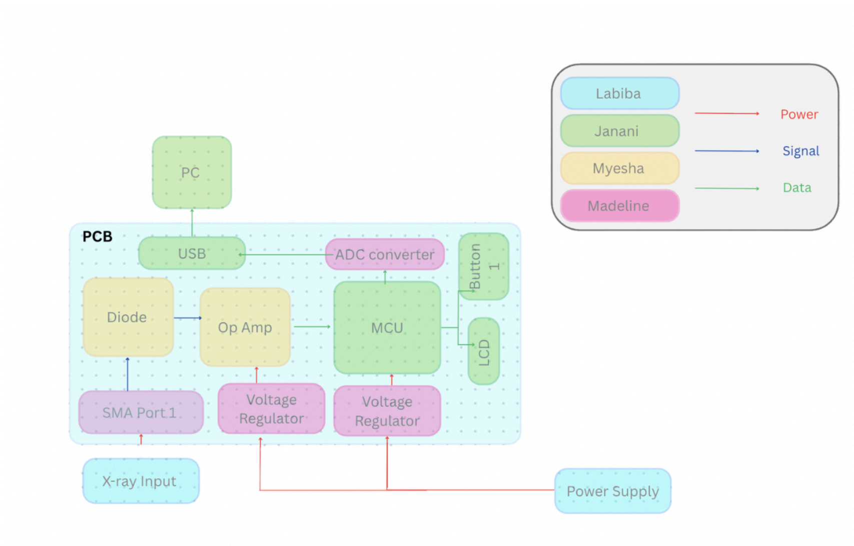


Figure 1.5.2 Hardware Diagram

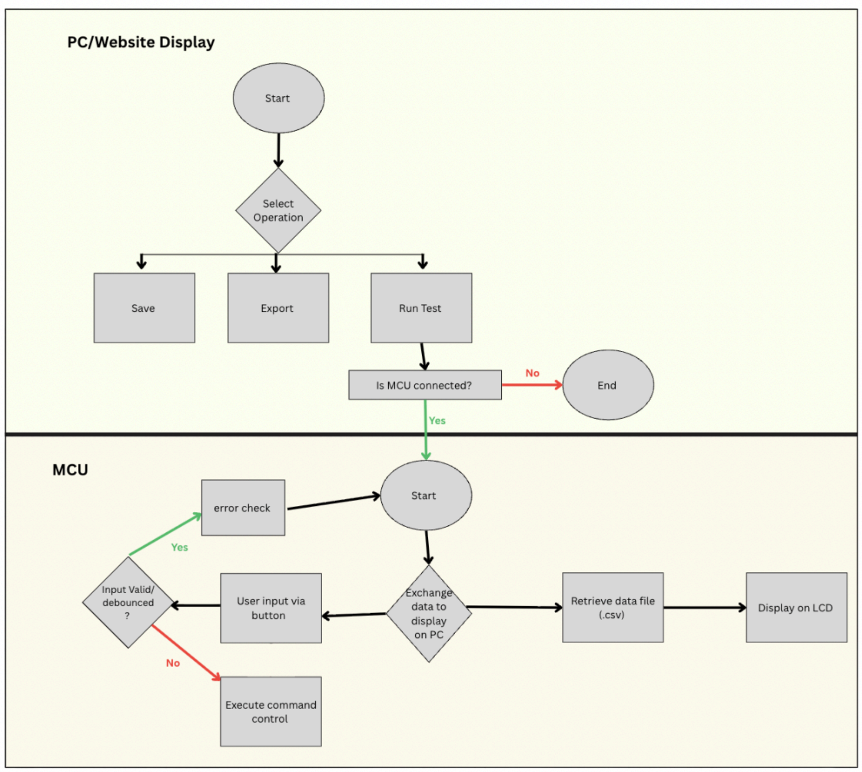
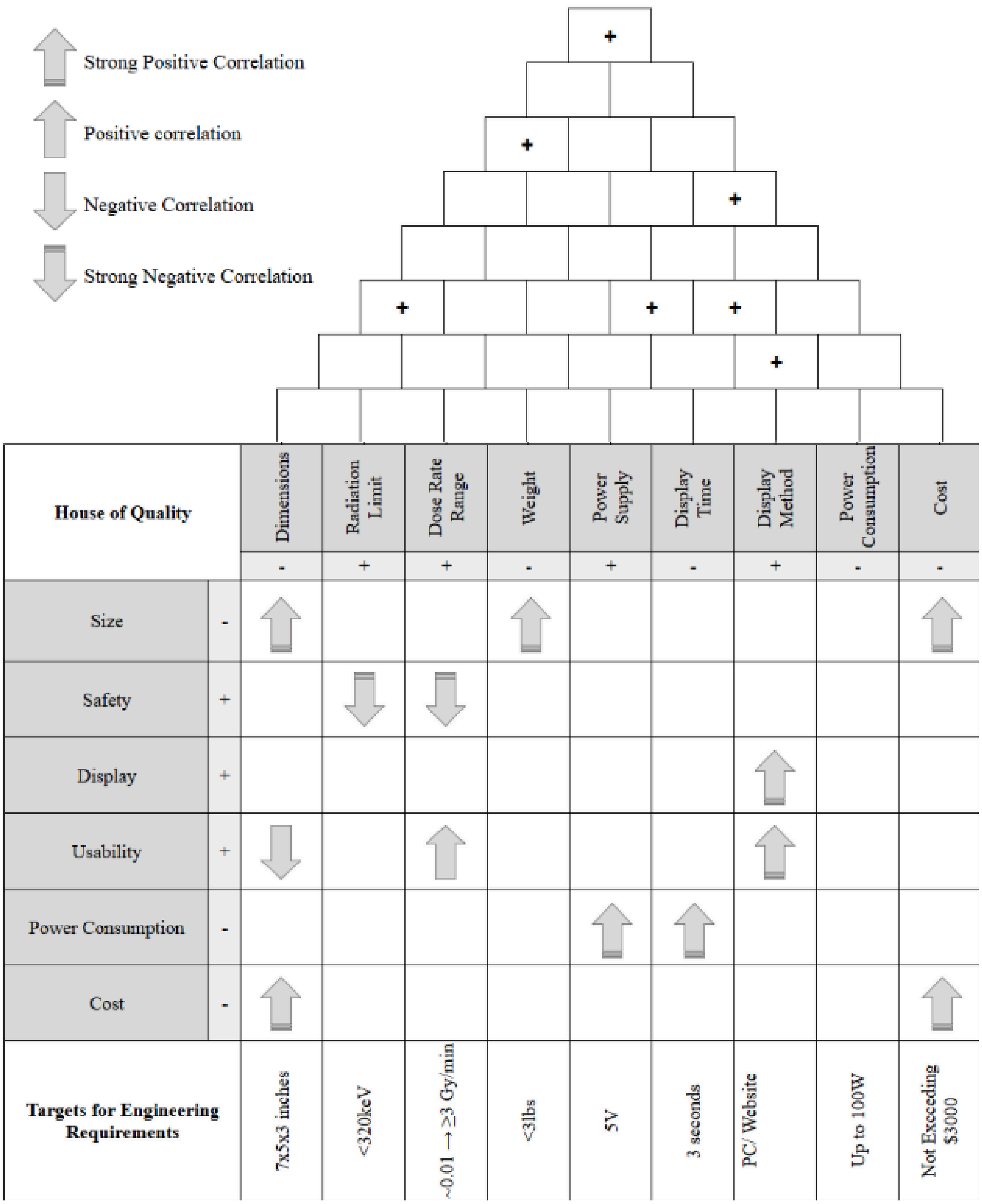


Figure 1.5.3 Software Diagram

1.6 House of Quality:

Figure 1.6.1 House of Quality



Marketing Requirements	Engineering Requirements
1, 4, 6	7x5x3 inches
2, 4	X-ray energy limit <320keV
2, 4	Dose rate range ~0.01 → ≥3 Gy/min
1, 4	Weight of <3lbs
4, 5	DC power supply of 5V
4, 5	Display time of 3 seconds
3, 4	Display Method
5	Up to 100W power consumption
6	Cost not exceeding $3000

Marketing Requirements:
1. Size
2. Safety
3. Display
4. Usability
5. Power Consumption
6. Cost

Figure 1.6.2 Work Distribution

Task	Primary	Secondary
Voltage Input	Labiba	Myesha
SMA Port 1	Madeline	Janani
Diode	Myesha	Labiba
Op Amp	Myesha	Labiba
SMA Port 2	Madeline	Janani
USB	Janani	Madeline
MCU	Janani	Madeline
LCD	Janani	Madeline
PC	Janani	Madeline
Power Supply	Labiba	Myesha
Voltage Regulator	Madeline	Janani
PCB	Labiba	Myesha

1.7 Milestones:

Figure 1.7.1 Senior Design 1 Milestones

Senior Design I - Fall 2025		
Milestone	Planned Duration	Status
Project idea	Week 1	Completed
Divide and Conquer Doc	Week 2-3	Completed
Meeting with Advisor (Dr. Sahawneh)	Week 4	In Progress
Research and Design	Week 4-7	In Progress
Create initial PCB schematic	Week 7	Incomplete
Select components	Week 8	Incomplete
Initial PCB Design	Week 9-Week 10	Incomplete
60 Page Document Submission	Week 10	Incomplete
Initial prototyping	Week 11	Incomplete
Troubleshooting	Week 12-15	Incomplete
Final 120 Page Document Submission	Week 16	Incomplete

Figure 1.7.2 Senior Design 2 Milestones

Senior Design II - Spring 2026		
Milestone	Planned Duration	Status
Order final PCB and parts	Week 1	Incomplete
Design and fabricate housing	Week 2-3	Incomplete

Fabricate/print housing	Week 4	Incomplete
PCB assembly	Week 4-6	Incomplete
Build website	Week 5-8	Incomplete
Configure digital processing unit	Week 6-8	Incomplete
Integration	Week 7-9	Incomplete
Testing and Troubleshooting	Week 8-12	Incomplete
Presentation Prep	Week 12-13	Incomplete
Final Presentation	Week 14	Incomplete

1.8 Budget:

The budget for this project is set at $3,000, as agreed upon by our team and faculty sponsor, to ensure financial feasibility for the radiation lab while providing flexibility for replacement parts and prototyping. This budget covers a wide range of components, including our core circuit elements, PCB fabrication costs, and the high-cost photodiode at the center of our design. Additionally, funds are allocated to account for potential replacements or design modifications, allowing us to address unforeseen expenses without jeopardizing project progress. A detailed breakdown of cost is provided in the Bill of Materials table below.

Bill of Materials:

As seen by the table above, we are below the goal limit of $3000 by exactly $1,515.38 allowing for prototyping and replacement parts.

Table 1.8.1 Bill of Materials

Component Part Name	***Quantity***	***Unit Price (USD)***	***Total Price (USD)***
Core Circuit Components			
Resistors (standard 1/4W,	20	$0.05	$1.00

assorted values)			
Capacitors (ceramic/electrolytic assorted values)	15	$0.10	$1.50
Texas Instruments LMC662CN Op-Amp (dual, DIP)	2	$2.50	$5.00
AXUV20HS1 Opto Diode	2	$627.06	$1344.12
9V Battery	1	$2.00	$2.00
Additional Components			
LCD Display (480*320 MUC SPI Serial TFT)	1	$16.00	$16.00
Custom PCB (small batch fabrication, 2-layer 3”x3”)	2	$30.00	$60.00
Raspberry Pi 4 Model B (4GB)	1	$55.00	$55.00
Total			
Grand Total	–	–	$1484.62

References

[1] J. Abramovitch, “Development of a Silicon PIN Diode X-Ray Detector,” *SMU Scholar Undergraduate Research*, Southern Methodist University, Apr. 15, 2014. [Online]. Available: https://scholar.smu.edu/cgi/viewcontent.cgi?article=1031&context=upjournal_research

[2] Nazififard M;Suh KY;Mahmoudieh. “Experimental Analysis of a Novel and Low-Cost Pin Photodiode Dosimetry System for Diagnostic Radiology.” The Review of Scientific Instruments, U.S. National Library of Medicine, pubmed.ncbi.nlm.nih.gov/27475554/. Accessed 4 Sept. 2025.

[3] Feng, Hua, et al. “Double-Layer Silicon Pin Photodiode X-Ray Detector for a Future X-Ray Timing Mission.” ADS, ui.adsabs.harvard.edu/abs/2006NIMPA.564..347F/abstract. Accessed 4 Sept. 2025.

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