Handheld Geiger Counter

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Abstract

Geiger counters are devices designed to detect and measure ionizing radiation. They are generally used to survey the surrounding environment for radioactive sources and relay information back to the user. It isn't uncommon for devices to exceed prices of $1k. This project describes an economic, handheld Geiger counter. The system uses a radiation sensor in the form of a Geiger-Müller tube (GM tube) which outputs a detectable pulse upon being ionized by a radiation source. A microcontroller (MCU) keeps track of the number of pulses it receives. This counted value is then displayed on the LCD in counts-per-minute (CPM) through a simple conversion. GM tubes generally operate at high voltages (HV) – 300V to 1.2kV – to function properly. Thus, a HV transformer is used to generate the necessary operating conditions. The system is powered by a rechargeable lithium-ion battery.

Chapter 1: Introduction

This chapter discusses the background of Geiger counters. Additionally, it covers important factors to consider when purchasing or designing a Geiger counter.

Hans Wilhelm Geiger invented the first detector of radiation in 1908. While this was a breakthrough, the invention could only detect alpha particles. It wasn't until 20 years later in 1928 when the Geiger-Muller counter was introduced which sparked the integration of electrical devices into radiation research [1]. This GM counter could measure alpha and beta particles as well as ionizing photons.

A few popular manufacturers for GM counters exist in the United States including Ludlum, PCE, and Magnii [2]. GM counters cannot differentiate between the type of radiation being detected. Additionally, the output pulse remains the same independently of the energy of the radiation. Due to these facts recent market growth has been hampered. Moreover, due to scare manufacturing, it can be reasonably difficult to find a device that meets requirements that isn't sky high in price ($1k+).

Geiger counters pose many multiple threats to those who choose to design them. The first threat stems from the fact that GM tubes, or the main radiation sensing element, require voltages anywhere from 300V-1.2kV. These high voltage operating conditions can cause unwanted shocks of current to run through the body of anyone who isn't following the proper precautions when dealing with the device. Secondly, as with any fresh PCB there is the issue of electrostatic discharge. The third and final harm stems from the battery. Without proper placement and layout, during high load conditions, the battery can overheat and potentially cause chemical leakage.

Chapter 2: Project Planning

This chapter broadly details project planning. Customer needs come before anything else. From these needs, the engineer creates high-level requirements and then more detailed specifications. Individual subsystems are derived from these specifications and are defined and functionally decomposed. Lastly, a Gantt chart and a cost estimate is provided for the customer.

2.1 Customer Needs, Requirements, and Specifications

This section covers first and foremost the customer needs. Additionally, there is a focus on the high-level requirements and more detailed specifications. This project was tackled from a system-level, top-down approach. The initial steps were to create a system-level block diagram from high-level requirements. At this level of abstraction, the functional description of what the circuit would achieve is what guided the work. From that system-level block diagram we can then proceed to individual subsystems and their respective specifications. After analyzing specific subsystems, component selection went underway and the schematic drafting stage started. Importing the schematic into layout file allows nets to be checked off and can expedite the process. Layout stage and ordering the BOM are the next components and finally SMA to yield the final product.

2.1.1 Customer Needs Assessment

The main customers for this project would be individuals who are concerned with their safety. Every place in the world has some amount of background radiation. Folks who are interested in learning more about the radiation they are exposed to in a specific area would benefit. This device must be capable of detecting beta radiation. This device must also be able to accurately measure the amount of radiation in the surrounding environment within a reasonable timeframe and report the results back to the user.

2.1.2 Requirements and Specifications

Table 1: *Geiger Counter Requirements and Specifications*

Marketing Requirements	**Engineering Specifications**	**Justification**
2, 4	Device should be standardized; parts should be easy to obtain	Use of standardized parts will lower bill of materials cost
4	Device production cost should not exceed $350	Cost of the device needs to be better than the market
1, 3, 4	Device battery life should exceed 9 hours	Battery life is a big concern for portable devices. This will ensure the device stays competitive in the market
3	Device high-voltage biasing element should be between 300V to 1.2kV	For the sensing element to operate properly this condition must be met
1, 4	Device should consume less than 1W	This will guarantee customer satisfaction and keep the device competitive in the market

Marketing Requirements

1. The device should be user-friendly and easy to use
2. The device can operate effectively in a wide variety of environments
3. The device power supply should be reliable
4. The device should be competitive in radiation measurement devices market

Table 1 details the requirements and specifications of the device. Marketing requirements stem from the customer needs while the engineering specifications address common key factors for compact embedded systems like power consumption, battery life, and cost. Additionally, justifications for each are provided.

2.2 Functional Decomposition

This section displays decomposition at two different levels of abstraction. While Level 0 displays a high-level view of the system, Level 1 goes into detail of the individual subsystems that compose the device.

2.2.1 Level 0 Decomposition

Figure 1 and Table 2 represents the whole system as a single block. Resultantly, there is an input radiation signal that is then processed by the system that eventually comes to display the output CPM signal.

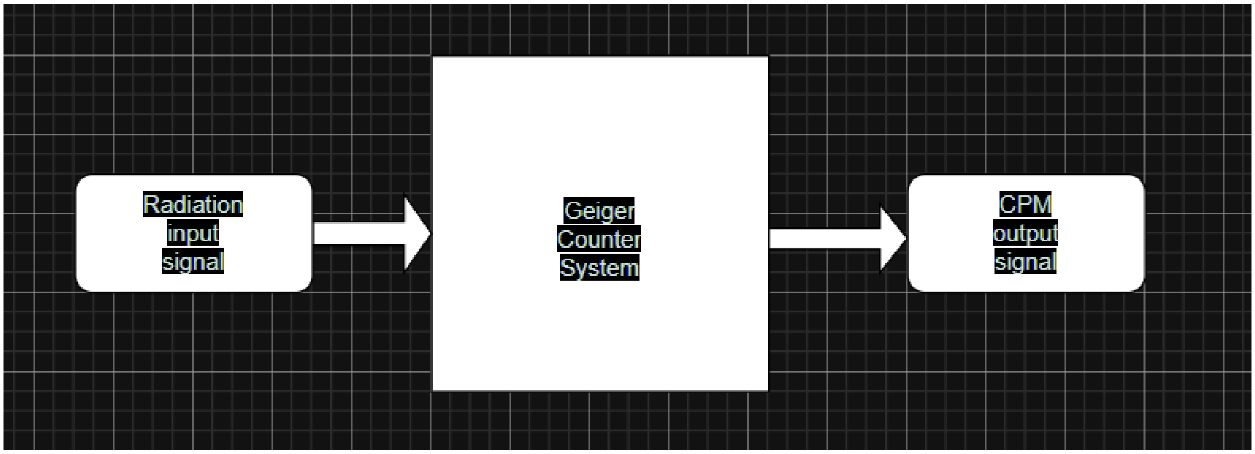

Figure 1: *Level 0 Geiger Counter System Functionality*

Table 2: *Geiger Counter Module Breakdown*

Module	**Geiger Counter**
Inputs	Ambient radiation
Outputs	CPM data output
Functionality	The Geiger counter has an onboard computer and independent power source. The device monitors ionizing radiation and reports the results back to the user.

2.2.2 Level 1 Decomposition

Figure 2 showcases the system made up by its constituent subsystems. They key subsystems are the MCU, pulse buffering circuit, GM sensor, HV transformer, boost converter, battery, and the LCD. Tables 3-9 go into detail about each block.

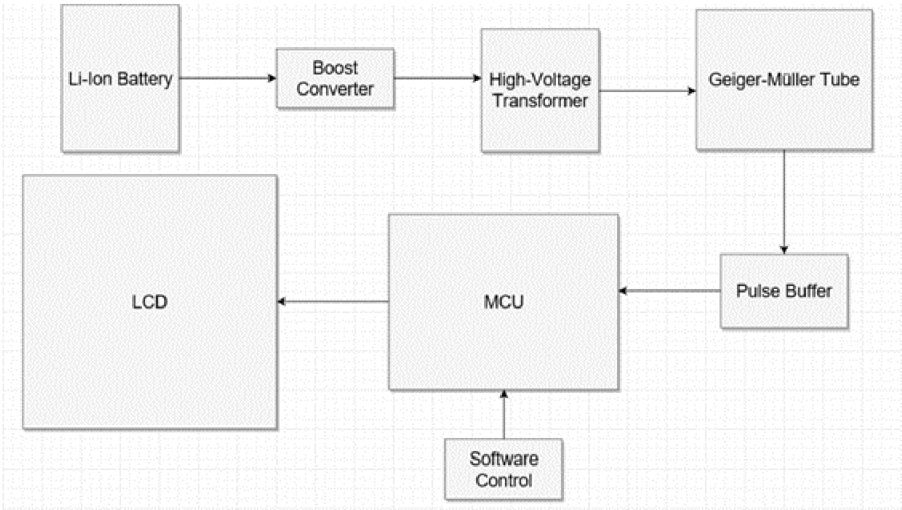

Figure 2: *Level 1 Geiger Counter System Design*

Table 3: *MCU Module Breakdown*

Module	**MCU**
Inputs	5Vdc SMA firmware, TTL signal
Outputs	Counts per minute to be displayed on the LCD
Functionality	MCU is the main controller for the Geiger counter. It is responsible for running the system firmware to compute average counts per minute and drive the LCD.

Table 4: *Pulse Buffer Module Breakdown*

Module	**Pulse Buffer**
Inputs	Sensing current pulse
Outputs	0-5V TTL interrupt signal
Functionality	The pulse buffer is used to generate a falling-edge, TTL interrupt signal for the MCU.

Table 5: *GM Tube Module Breakdown*

Module	**Geiger-Müller Tube**
Inputs	400Vdc
Outputs	Radiation dependent current pulse
Functionality	The Geiger tube is the main sensing element that is used to detect the presence of radiation.

Table 6: *HV Transformer Module Breakdown*

Module	**High-voltage transformer**
Inputs	5Vdc
Outputs	400Vdc
Functionality	High-voltage generation to satisfy the required operating condition for the sensing element.

Table 7: *Boost Converter Module Breakdown*

Module	**Boost Converter**
Inputs	3.7Vdc
Outputs	5Vdc
Functionality	The boost converter is used to step-up the gradually decreasing voltage waveform from the battery to a constant 5V.

Table 8: *Battery Module Breakdown*

Module	**Li-Ion Battery**
Inputs	N/A
Outputs	Nominal: 3.7Vdc Cutoff: 2.8Vdc Output Current: 500mA
Functionality	The li-ion battery is the support of the system used to power the circuitry.

Table 9: *LCD Module Breakdown*

Module	**LCD**
Inputs	5Vdc
Outputs	16x2 character display
Functionality	The LCD is used to visually provide the user with the measurements.

2.3 Gantt Chart

This section centers around the project timeline. There is a visual representation of the workflow to showcase the deadlines.

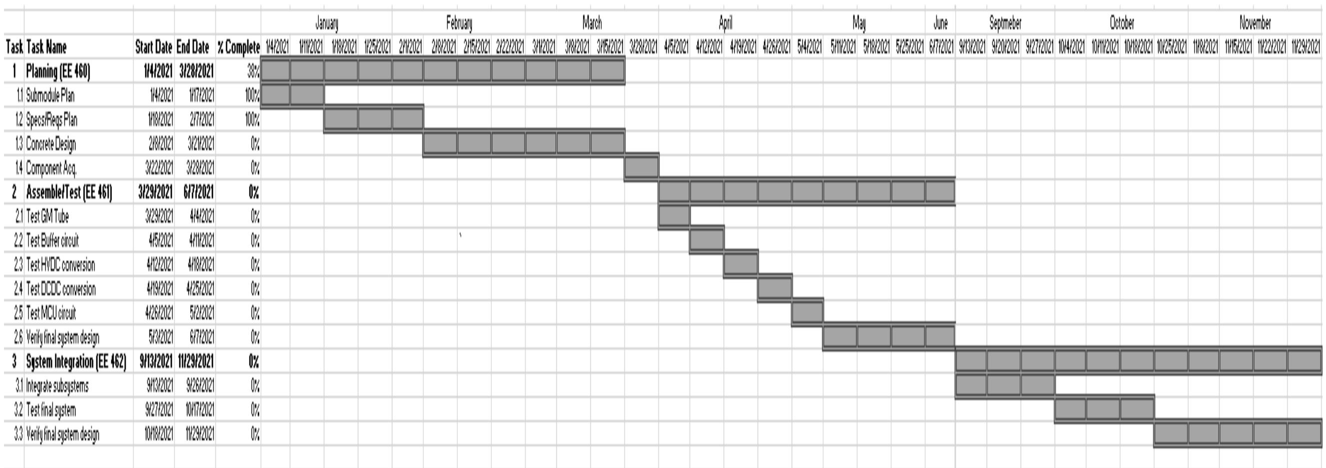

Figure 3: *Gantt Chart*

Figure 3 shows the Gantt Chart which is composed of a few different stages. After the initial planning work from EE460, there is an individual subsystem assembly and test phase from EE461 along with a final system integration and report finalizing for EE462.

2.4 Cost Estimate

This section uses the prices of individual parts from the BOM to estimate the total cost to build the device.

Table 10: *Cost Estimate*

Ref.	Part #	Supplier	Quantity	Price per	Ext. price
PCB	GeigerCounter	ExpressPCB	1	$150	$150
U1	613222A	TI	1	$1.00	$1.00
U2	Q04-5	EMCO	1	$115.00	$115.00
U3	ATMEGA328P	Microchip	1	$2.00	$2.00
GM Tube	SBM20	Amazon	1	$20.00	$20.00
Fuse Clip	01020071Z	Littelfuse	2	$0.25	$0.50
LCD	0216K1ZNSWBBWL	Newhaven	1	$13.00	$13.00
B1	3.7V/2500mAh	Adafruit	1	$15.00	$15.00
Q1	2N3904BU	ON Semi	1	$0.25	$0.25
L1	HMLQ25201T	Cyntec	1	$0.50	$0.50
D1	NSR0320MW2T1G	ON Semi	1	$0.50	$0.50
TP1	5000	Keystone	1	$0.50	$0.50
TP2	5001	Keystone	1	$0.50	$0.50
J1	S2BPHKS	JST	1	$0.20	$0.20
J2	61300211121	Wurth	11	$0.20	$2.20
C1	CL10B121KB8NNNC	Samsung	1	$0.10	$0.10
C2 – C4	GRM188R60J106ME84D	Murata	1	$0.40	$0.40
C5	08052A221JAT2A	AVX	1	$0.40	$0.40
R1	CRS2010FW4R99ELF	Bourns	1	$0.60	$0.60
R2	RC0805FR074M7L	Yageo	1	$0.10	$0.10
R3	RNCP0805FTD10K0	Stackpole	1	$0.10	$0.10

Ref.	Part #	Supplier	Quantity	Price per	Ext. price
R4	ERA6AEB273V	Panasonic	1	$0.36	$0.36
R5	ERA6AEB104V	Panasonic	1	$0.36	$0.36
R6	HV732ATTD1005F	KOA Speer	1	$0.62	$0.62
R7	RNCP0805FTD4K75	Stackpole	1	$0.10	$0.10
				Subtotal	***$324.29***

Table 10 shows the cost for each part, along with the supplier and part no.

Chapter 3: Research and Design

This chapter goes into depth on research and design. During this stage the overall system is designed by identifying individual components and determining how they are interconnected.

3.1 Power Train

This section details the various power components of the system. Moreover, this includes the battery module, boost converter, and high-voltage transformer. These core components provide power rails to other components. Smooth power rails play an important role in system performance. Transients can cause unwanted noise to be amplified. To help against act against this, bypass capacitors are placed on sensitive rails.

3.1.1 Battery Module

The battery module is responsible for providing power to the board. As no device can function without power, this module is critical to device operation. High-energy density batteries are common in modern, compact embedded systems. A lithium-ion battery was ultimately chosen for its durability and reliability. To determine a suitable battery capacity to meet the initial battery engineering specification (over 9 hours), a quick power budget estimation must be calculated. Using various subsystem datasheets, the current draw is summarized in the Table 11 below.

Table 11: *Subsystem Current Consumption*

Subsystem	**Current Draw (mA)**
EMCO HV Transformer (5V input)	~60
GM Tube (Ionized)	0.01 (max)
MCU + LCD (Backlight on)	~25
Total	~85

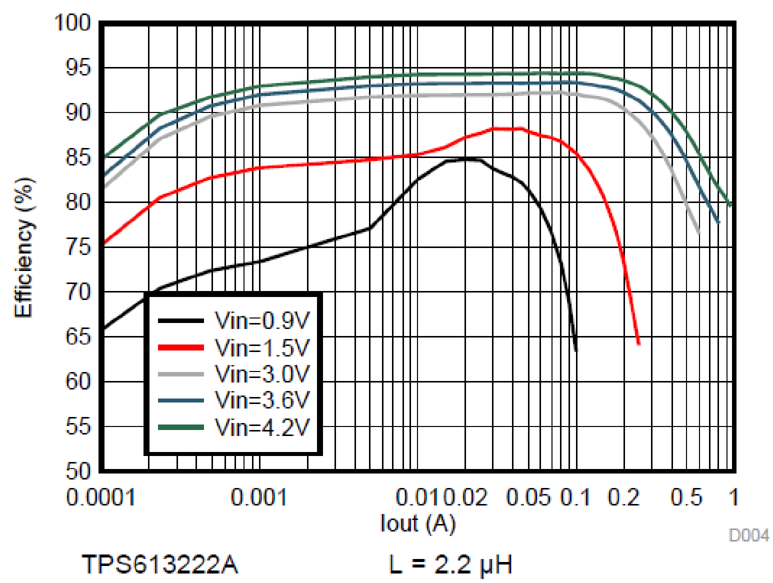

Figure 4: *Boost converter load efficiency*

Using Figure 4 along with the subsystem current consumption and a 100% buffer, we can determine the converter's efficiency. At 170mA current draw and following the Vin=3.6V curve from Figure 2 we arrive at roughly 92.5%. Thus, we can determine the total input current draw on the battery.

$$\frac{P_{out}}{P_{¿}} \times 100 = 92.5\% \text{(eqn 3.1)}$$

$$P_{out} = 5V \times 170\,mA = 850\,mW \text{(eqn 3.2)}$$

$$I_{¿}=\frac{P_{out}}{V_{¿}\times 0.925}=\frac{0.85\,W}{3.6\,V\times 0.925}=255\,mA \text{(eqn 3.3)}$$

At 255mA total system input current we can approximate 10 hours of battery life by selecting a 2500mAh capacity battery.

$$\frac{2500\,mAh}{255\,mA}\cong 10\,hr\,@\;\;918\,mW \text{(eqn 3.4)}$$

With this system current consumption and battery sizing, both engineering specifications are fulfilled. That is, at peak load the system consumes less than 1W and lasts over 9 hours. Please note that battery calculations are approximate and actual battery life will depend on load conditions.

3.1.2 Boost Converter

The boost converter plays an important role in creating the main logic level for the MCU as well as for the pull-up resistor of the pulse buffer circuit and the LCD supply rail. As there are multiple subsystems connected to this rail, a synchronous, high-efficiency boost converter was chosen [3]. To support high current applications, an external Schottky diode is placed in parallel with the internal rectifier FET.

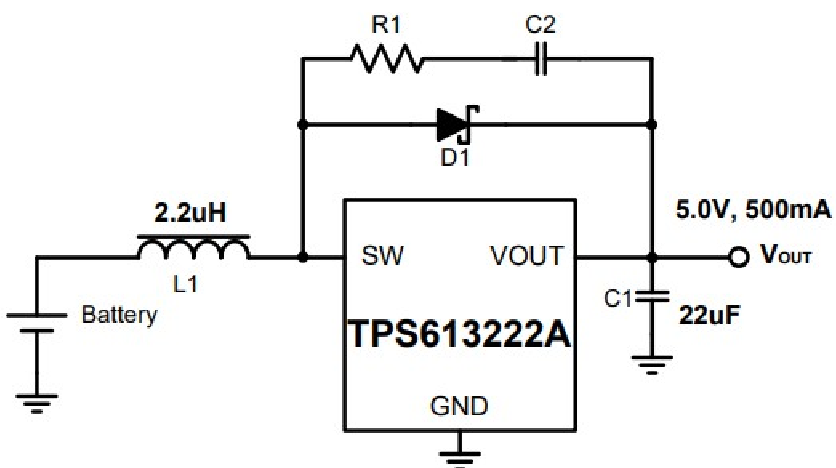

Figure 5: *Boost converter with external Schottky diode*

3.1.3 High-Voltage Transformer

To satisfy the operating conditions for the main sensing element (350-475V), a high reliability HV transformer was selected [4]. Additionally, this component has a small footprint making it ideal for a compact PCB design (0.125 cubic inches).

3.2 MCU

This section addresses the main control element in the system: the MCU. The MCU is responsible for interfacing with both the pulse buffer circuitry and the LCD. Furthermore, the MCU conducts interrupt handling triggered by the falling-edge signal from the pulse buffer circuit using 1 GPIO and drives the LCD via 7 GPIOs. Most importantly, the MCU runs the system firmware that displays the output signal in CPM to the user.

3.2.1 Hardware

An ATmega328P was chosen in consideration of low-power system requirements. This microcontroller is high performance and consumes minimal power. There is plenty of I/O capability on board with 23 programmable lines [6]. In total only 8 are needed for system operation. The ATmega328p also comes in a 28-pin DIP package which is ideal for PCB integration depicted in Figure 5. To flash and update the firmware running on the MCU an in-system programmer is needed. There are a variety of ISPs compatible with 8-bit AVR MCUs like the ATmega328p, however for this project an MK2 was chosen.

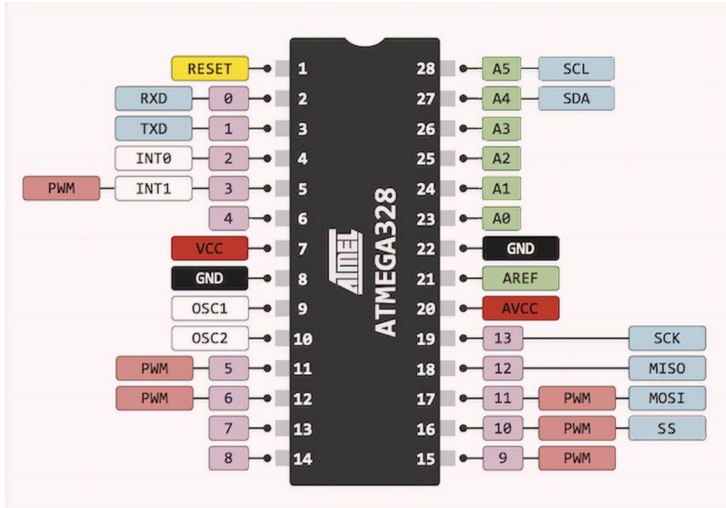

Figure 6: *ATmega328p pinout*

3.2.2 Software

To program the system firmware Microchip Studio, an IDE that supports development in C, was chosen. Microchip Studio also has functionality for generating new builds and debugging. After being flashed the MCU is responsible for running the firmware that displays the output signal to the user in CPM. Displaying CPM can be implemented in firmware by using a moving average. Count samples can be stored in an array. By first initializing the array, C, with N samples (C_1, C_2 …. C_N $\in$ C) and T sampling time (amount of time between each sample), we can then enter the main while loop and continue to write over the oldest array value in each iteration after averaging the contents. This will give us average counts-per-second which can then be converted to CPM as shown below:

$$\frac{\sum_{i=1}^{N} C_i}{N*T} \times \frac{60\, seconds}{1\, minute} = \text{CPM (eqn 3.5)}$$

```
    // Loading function to fill array
    while(idx < ARR_SIZE){              // ARR_SIZE is N
        _delay_ms(SAMPLE_TIME);         // SAMPLE_TIME is T
        count_array[idx++] = count;     // Populate array with count samples
        count = 0;
    }

    // Main while loop
    while(1){
        if(idx == ARR_SIZE) idx = 0;    // Once all values have been overwritten, wrap back around and repeat
        count_array[idx++] = count;     // Oldest sample is updated
        count = 0; sum = 0;
        for(int i=0; i<ARR_SIZE; i++) sum += count_array[i]; // Sum contents of array and normalize
        _delay_ms(SAMPLE_TIME);
        LCD_display_number(sum*60/ARR_SIZE); // Outputs in cpm
    }
    return 0;
}
```

Figure 7: *Moving average implementation in C*

Variables N and T can be chosen based on the GM tube used. Depending upon the degree of accuracy needed (larger sample size N is more accurate) and the dead time of the tube (time where the tube cannot output a signal after being ionized), values can be optimized through experimentation.

3.3 GM Tube

This section describes the main sensing element or the GM tube. GM tubes are two terminal devices that can measure alpha, beta, and gamma radiation. Generally, a stainless-steel tube (cathode) is filled with an inert gas and a tungsten wire (anode) that runs inside it carries a high voltage. When incident radiation in the form of a particle or a photon contacts the tube there is a brief conduction period or current pulse. Each conduction event corresponds to a count. Geiger counters cannot be used to measure the energy level of radiation but only the frequency of counts which indicates radiation intensity. Background radiation varies depending upon physical location; however, the steadfast rule is that anything over 2x the background is deemed radioactive. For this system an SBM20 tube was chosen for its widespread popularity and sensitivity [5]. This tube is used in a variety of commercial grade Geiger counters. Another reason why it was chosen was because of it's 97mm length and 10mm width which make it relatively simple from a system integration standpoint.

3.4 LCD

This section involves the display chosen for the project. A blue/white character display was decided upon in consideration of power requirements. With the backlight on, the display draws around 25mA. Displays in the same category draw currents around 100mA+ so this is a large improvement. To interface with the LCD in 4-bit nibble mode, only 7 GPIO pins are needed. 4 of these are for data and the other 3 are for control. The contrast voltage reference can be generated internally using a voltage divider. After initialization, the LCD can operate in any mode. Following the device controller datasheet (ST7066U) to initialize the LCD is recommended [7]. In order to display numbers with more than one-digit, additional logic is required as shown in Figure 7. This logic takes the number to be displayed and isolates each digit using the modulus operator and then moves the cursor of the display by shifting the display data RAM (DDRAM) address.

```c
void LCD_display_number(uint16_t number) {
    unsigned char array [];
    unsigned char idx = 0;
    unsigned char address = 0x84;   // Initial DDRAM address
    while (number) {                // Populates an array with each digit in the number, first element is rightmost digit and so on
        array[idx] = number % 10;
        number /= 10;
        idx++;
    }
    for (int i = idx-1; i >= 0; i--) {  // Accesses array in reverse
        LCD_command(address);           // Go to DDRAM address
        LCD_write(array[i] + 0x30);     // Send data with added 0x30 offset according to Table 4
        address++;                      // Increment DDRAM address
    }
}
```

Figure 8: *Logic for displaying counts containing multiple digits*

3.5 Pulse Buffer

This section covers the pulse buffer circuitry used to generate the falling-edge interrupt signal. Shown in Figure 8 and connected to the resistor divider branch of the RC is a BJT with a pull-up resistor connected to 5V. This generates a falling-edge interrupt on the MCU which can then be handled by an interrupt service routine (ISR) to update a global variable (count).

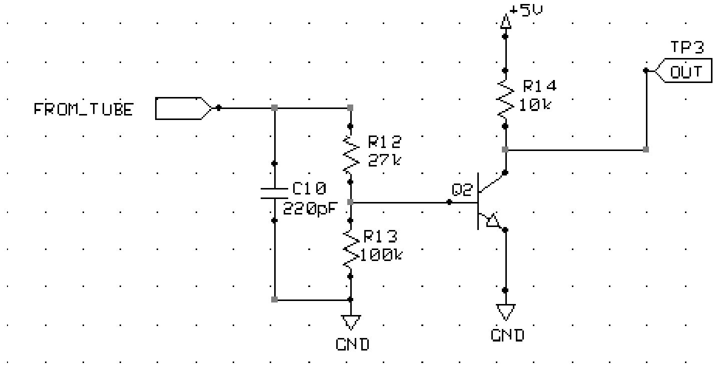

Figure 9: *RC pulse buffer to generate falling edge interrupt signal*

3.6 Final Design

The final design details a compact, low-power, handheld Geiger counter as shown in Appendix B. Placement of the components is tightly spaced to ensure compactness. The HV transformer circuitry is placed in the northeast corner isolated from the digital electronics placed in the southwest region. Another detailed placement concerns the GM tube which is situated along the north edge of the board to protect the user while using the device. All components have been selected in consideration of low-power system requirements. A 4-layer PCB was chosen for it ease of layout. The final PCB resembles that of an iPhone 7 form factor, comfortably fitting into the hand of the user.

Chapter 4: Assembly and Testing

This chapter focuses on assembly and testing. For this project stage the overall system has been researched and designed and it is now a matter of assembling and testing the various subsystems.

4.1 Power Train, GM Tube, and Pulse Buffer

This section describes the assembly and testing of the analog circuitry. More specifically, the circuitry all the way up to and including the pulse buffer is validated. Testing of this circuitry is critical as these subsystems are responsible for producing the main signal that is processed by the MCU. Without this signal, the system can simply not operate.

4.1.1 Power Train

To test the power train various test points are placed on the PCB so that they can be probed by a digital multimeter. Key voltage levels are at +5V and +400V. This through hole test points are small yet completely necessary to test proper voltage regulation.

4.1.2 GM Tube

Testing the GM tube is a matter of probing across its terminals and ensuring it is receiving the proper voltage. Additionally, a small current pulse should emanate during ionization in the presence of radiation. This current is on the scale of 10uA so it is difficult to measure directly. A current probe is not accurate enough to measure this small of a current. Using a small series resistor and current sense amplifier is another idea, however due to restricted board space this is not a viable option. Proper biasing of the pulse buffer circuit from the current pulse will help ensure it is indeed present.

4.1.3 Pulse Buffer

Probing the collector of the BJT in the pulse buffer circuit ensures that the main signal is present. This is an active-low, falling-edge interrupt signal that is tied to the MCU. With a pull up resistor to +5V, this node can be probed by a multimeter or oscilloscope probe to verify functionality. Whenever radiation is detected the node should pull low as seen in Figure 9 below which displays a zoomed in representation of the falling-edge radiation detection signal. The MCU will monitor this signal and trigger an interrupt every time it pulls low. This is the mechanism by which radiation is measured. Every interrupt increments the previous count value.

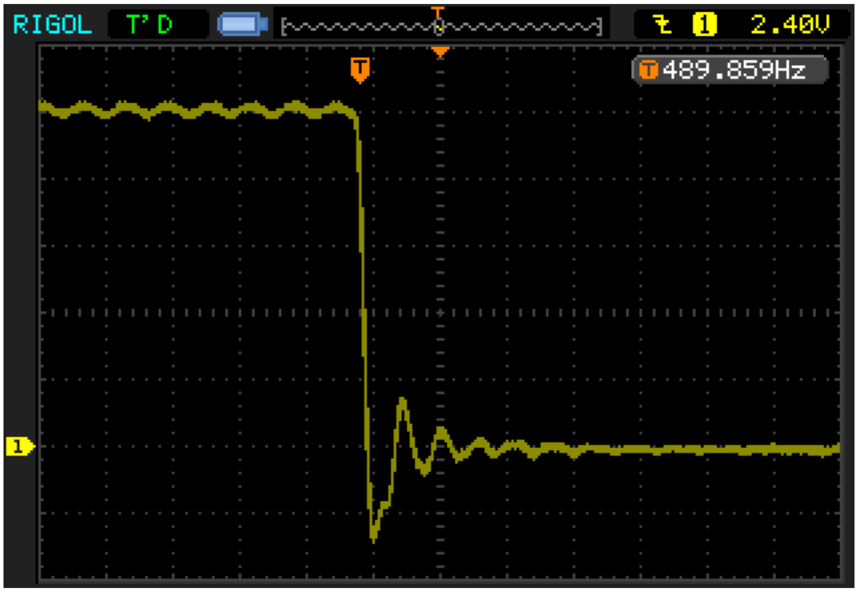

Figure 10: *Scope shot of buffer circuit output – an active low interrupt signal*

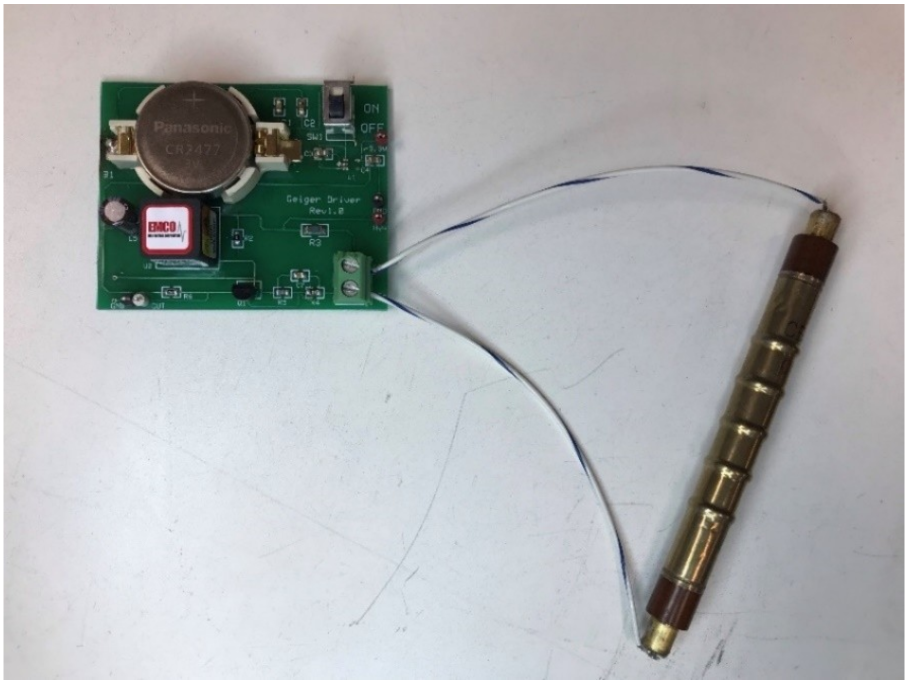

Figure 11: *Analog test circuitry*

Figure 10 above shows the PCB and GM tube that tests analog circuitry functionality. The key test element is checking for the main system interrupt signal in the presence of radiation.

4.2 MCU and LCD

This section describes the assembly and testing of the digital circuitry. In other words, both the MCU and the LCD are investigated. The system firmware is validated by using one of the MCUs on board components while the LCD is tested independently.

4.2.1 MCU

Since the digital circuitry is tested independently of the analog circuity there is no interrupt signal for the MCU to monitor. Due to this fact, a timer is used to generate interrupts synchronously. After arbitrarily setting the number of interrupts per minute the system firmware is tested. Probably displaying the CPM is the central component of the test.

4.2.2 LCD

The display test focuses upon the functionality of the individual control and data lines. Additionally, it checks that the initialization sequence is correct and does not time out.

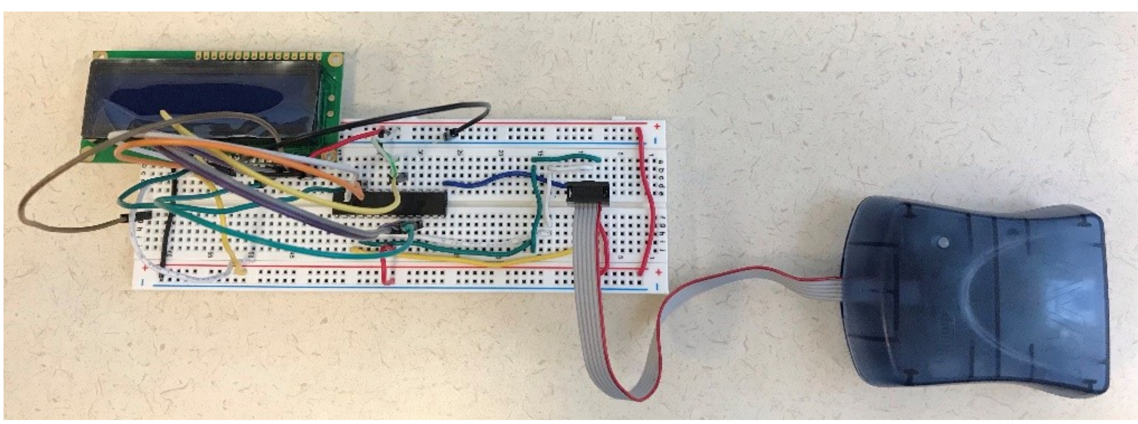

Figure 12: *Digital test circuitry*

4.3 Final Design

The final design comprises a Geiger counter whose function is to accurately monitor radiation. To test the final design and assembly an experiment was carried out in a controlled environment with a radiation source. Sensitivity varies widely among GM tubes as well as their electrical and mechanical specifications [5]. This experiment involves obtaining a standardized check source of a radioactive isotope and taking various bench measurements at varying distances from the isotope. This allows the designer to account for gain and offset error present within the tube by fitting a regression to produce the best result. Shown below are the results of the system against a Ludlum 26-1 commercial-grade Geiger counter (retails ~$800) using a Cesium-137 isotope. Clearly, the Ludlum device returns a higher readout across the board and this is mainly due to the geometry of the tube used. Instead of a "hot-dog" cylindrical shape like the system's SBM-20, the Ludlum employs an LND-7317 "pancake" tube with a much larger surface area for detection. These tubes are notorious for giving high readings due to their geometry. The firmware calibrates the system by using the following data such that the system performs similarly to a commercial-grade product. Table 12 displays the calibration data where the distances are taken from the source center with the devices oriented toward the source.

Table 12: *Final system calibration data at various distances from source*

Test Condition	**SBM-20 (cpm)**	**L26-1 (cpm)**
Background	28	38
2 in. from source	2065	5784
4.5 in.	1152	2750
12 in.	663	1160
21 in.	94	205

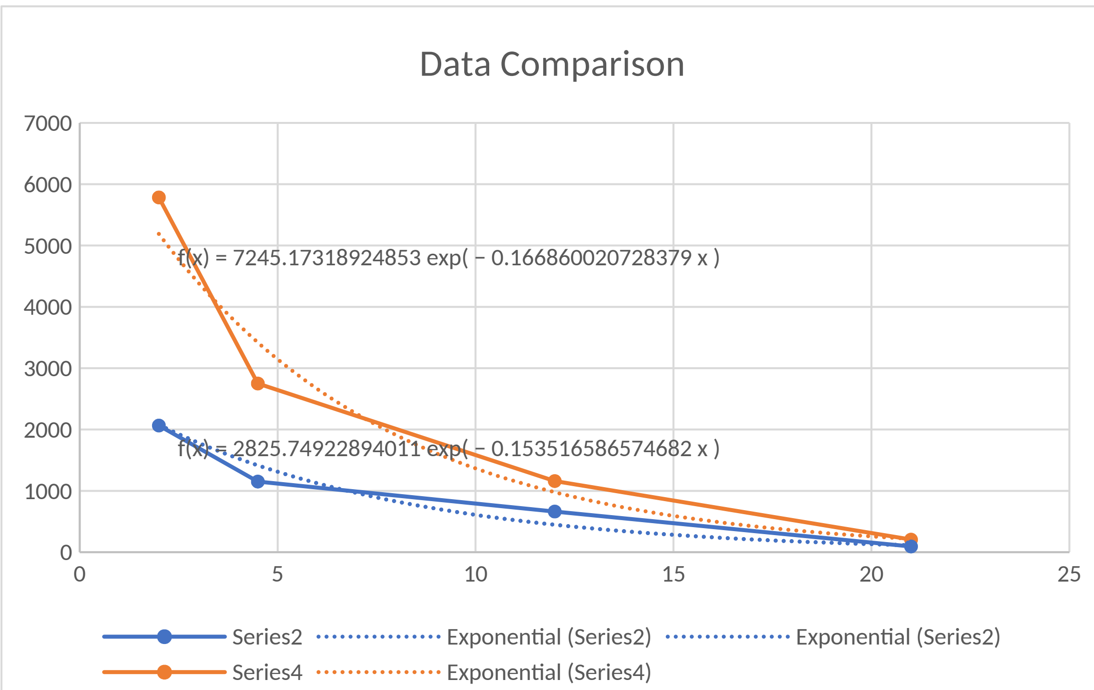

Figure 13: *Calibration curves*

Figure 14: *Final design with Green LED indicator enabled*

Chapter 5: Conclusion

This chapter summarizes the project as whole detailing things that went well along with room for improvement in the future. The initial functionality table is revisited after the system has been designed and tested to see if requirements were met. Additionally, a final cost table is provided for the system along with a section detailing what could be done if there was more time and resources available.

5.1 Functionality

This section describes the engineering requirements met by the final system. As seen in the table below all the requirements were met by the system. The system successfully operates under these initial requirements.

Table 13: *Geiger Counter Requirements Check*

Requirements	Requirement met?	Justification
Device should be standardized; parts should be easy to obtain	Yes	All parts can be obtained from mainstream electronics manufacturers like Digikey and Adafruit aside from GM sensor which is available on Amazon
Device production cost should not exceed $350	Yes	The cost of a single device was around $330 and goes down with quantity
Device battery life should exceed 9 hours	Yes	Based on subsystem current consumption and a 100% margin, the battery life was computed to be around 10 hr at worst case
Device high-voltage biasing element should be between 300V to 1.2kV	Yes	A HV transformer was used to provide this voltage which sits at 400V
Device should consume less than 1W	Yes	Based on the power consumption of the main boost converter this was computed to be around 918mW including margin

5.2 Final Cost

This section addresses the final cost associated with the system. Compared to the original estimate the final BOM turned out to be marginally more expensive. Due to part shortages for components like the MCU and HV transformer, 3rd party vendors were utilized resulting in higher cost. Additionally, it should be noted that only one PCB was fabricated as is the most expensive item on the BOM. If production were to scale the cost per PCB would be driven down dramatically as just ordering 2 PCBs reduces the per unit cost by nearly half. Another factor for increased cost is that indication LEDs and current limiting resistors were added.

Table 14: *Cost Estimate*

Ref.	Part #	Supplier	Quantity	Exp. price	Ext. price
PCB	GeigerCounter	ExpressPCB	1	$150	$137.35
U1	613222A	TI	1	$1.00	$1.16
U2	Q04-5	EMCO	1	$115.00	$131.50
U3	ATMEGA328P	Microchip	1	$2.00	$6.60
GM Tube	SBM20	Amazon	1	$20.00	$20.00
Fuse Clip	01020071Z	Littelfuse	2	$0.50	$0.54
LCD	0216K1ZNSWBBWL	Newhaven	1	$13.00	$13.58
B1	3.7V/2500mAh	Adafruit	1	$15.00	$12.50
Q1	2N3904BU	ON Semi	1	$0.25	$0.38
L1	HMLQ25201T	Cyntec	1	$0.50	$0.38
D1	NSR0320MW2T1G	ON Semi	1	$0.50	$0.39
TP1	5000	Keystone	1	$0.50	$0.50

Ref.	Part #	Supplier	Quantity	Exp. price	Ext. price
TP2	5001	Keystone	1	$0.50	$0.50
J1	S2BPHKS	JST	1	$0.20	$0.13
J2	61300211121	Wurth	11	$2.20	$1.43
C1	CL10B121KB8NNNC	Samsung	1	$0.10	$0.10
C2 – C4	GRM188R60J106ME84D	Murata	3	$0.40	$1.10
C5	08052A221JAT2A	Kyocera	1	$0.40	$0.32
R1	CRS2010FW4R99ELF	Bourns	1	$0.60	$0.68
R2	RC0805FR074M7L	Yageo	1	$0.10	$0.10
R3	RNCP0805FTD10K0	Stackpole	1	$0.10	$0.10
R4	ERA6AEB273V	Panasonic	1	$0.36	$0.70
R5	ERA6AEB104V	Panasonic	1	$0.36	$0.36
R6	HV732ATTD1005F	KOA Speer	1	$0.62	$0.56
R7	RNCP0805FTD4K75	Stackpole	1	$0.10	$0.10
R8-R9	SFR10EZPF1500	Rohm	2	NA	$0.34
D1	LTSTC191KRKT	Liteon	1	NA	$0.26
D2	LTSTC191KGKT	Liteon	1	NA	$0.26
			Subtotal	***$324.29***	***$329.81***

5.3 Future Considerations

This section addresses what could be done in the future to improve the system. While the system does meet all the requirements, there are places were improvements could be made. The first improvement would be a mechanical enclosure to house the electronics. With this addition the user would be protected from the high voltage circuitry and could easily operate the device without thinking about hand placement. Another improvement would be to add solar recharging circuitry since the system is powered by a battery. To make this work an additional port would have to be added to the device for a PV array to connect into. A switch could disconnect the battery from the main circuit and connect to the battery circuitry, and a small PV array could be plugged in to charge it. Finally, a speaker could be interfaced with the MCU so that the user could get audio feedback that varies in intensity with the radiation content.

References

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[4] Design Considerations for the Q Series. XP EMCO, www.emcohighvoltage.com/pdfs/XP_EMCO_AN9_Design_Considerations_for_the_Q_Series.pdf.

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Appendix A - Analysis

Project Title: Handheld Geiger Counter
Student's Name: Jack Shaquer **Advisor's Name:** Ben Hawkins

1. Summary of Functional Requirements

The handheld Geiger counter monitors background radiation and relays information back to the user. Its central function is to measure the radiation content in whatever environment the device is being used in and provide a readable number that the user can look at.

2. Primary Constraints

There are several constraints present in this project. One key constraint is the battery-powered nature of the device. This means that there is finite energy that can be delivered for the circuit to operate. Since the device consumes relatively low amounts of current there are solutions within proper component/source selection. Another key constraint is the sensor operating voltage which is no less than 300V. That requirement places a large constraint on the design as it must take safety precautions to ensure safety of operation.

3. Economic

Economic impacts are endless. Anyone who is concerned about their safety can benefit from this product. Those living in areas susceptible to more than average background radiation levels because of geographical location can especially benefit. This product becomes very useful if there is some sort of event where radiation safety awareness rises as a result. For example, after 2011 Japan earthquake there was nuclear spillage, and many people were left concerned about the air around them. At this point in time Geiger counters were in high demand. It is always good to be prepared.

4. If manufactured commercially

With the right manufacturing setup, the cost to make these Geiger counters can be driven down while the overall profit margin can increase. For instance, if the cost estimate table went through a specialized manufacturing line there is no reason all the component costs would be dramatically reduced including the PCB costs which is the most expensive.

5. Environmental

Environmental factors are the incentive behind this product. Thus, the environment is at the center of the picture. With this device you are more in touch with the environment around you and can act responsibly on the new information that is available to you because of this device.

6. Manufacturability

In terms of manufacturability there a few causes for concern. One of which is the supply chain distribution. PCB fabrication is one key component while another is SMA. Both pieces being intertwined is the key solution, but it is likely they will need to be split up due to logistical reasons.

7. Sustainability

Sustainability is an important concept for any product that will be used for some time. Since this device is battery-powered its lifetime is limited. A potential upgrade to this project would be a solar battery charger that can recharge the battery to increase its lifespan. There are many challenges with implementing this upgrade as it will require a sizeable PV-array that may be hard to acquire and expensive.

8. Ethical

People who use this product must choose how they want to use it. Some people may decide to use the product in ways that it was not designed for. The possibilities are endless, but the important part is that this product be used safely. Misuse of this product could result in serious harm to either the user or people around the user.

9. Health and Safety

Safety is a concern for everyone. This device can help folks feel smarter and safer about their surroundings and their overall health by monitoring what is around them. Without this device, it is difficult to fully understand the background radiation levels one is living in.

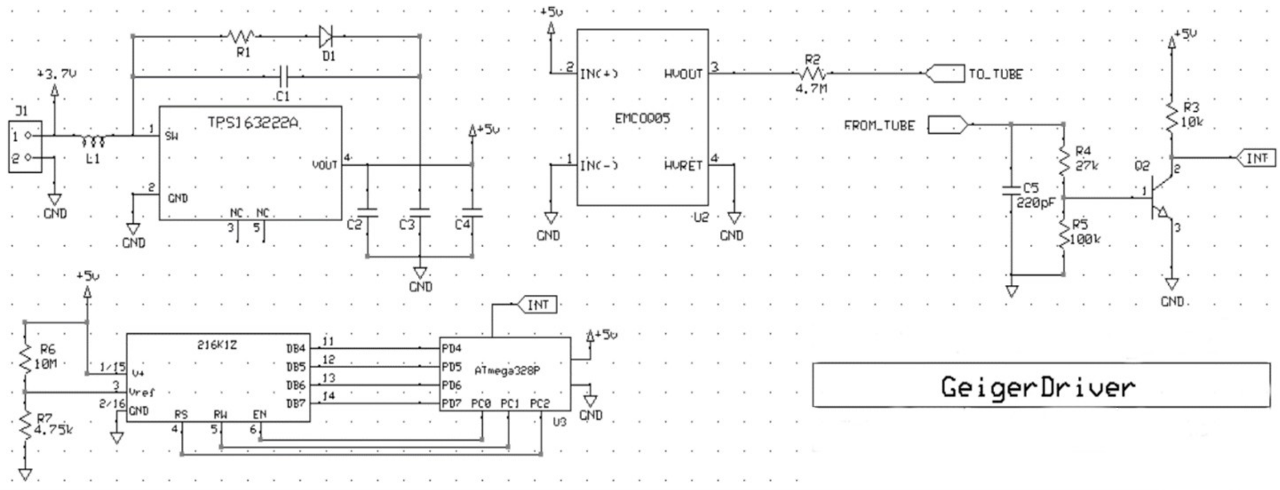
10. Social

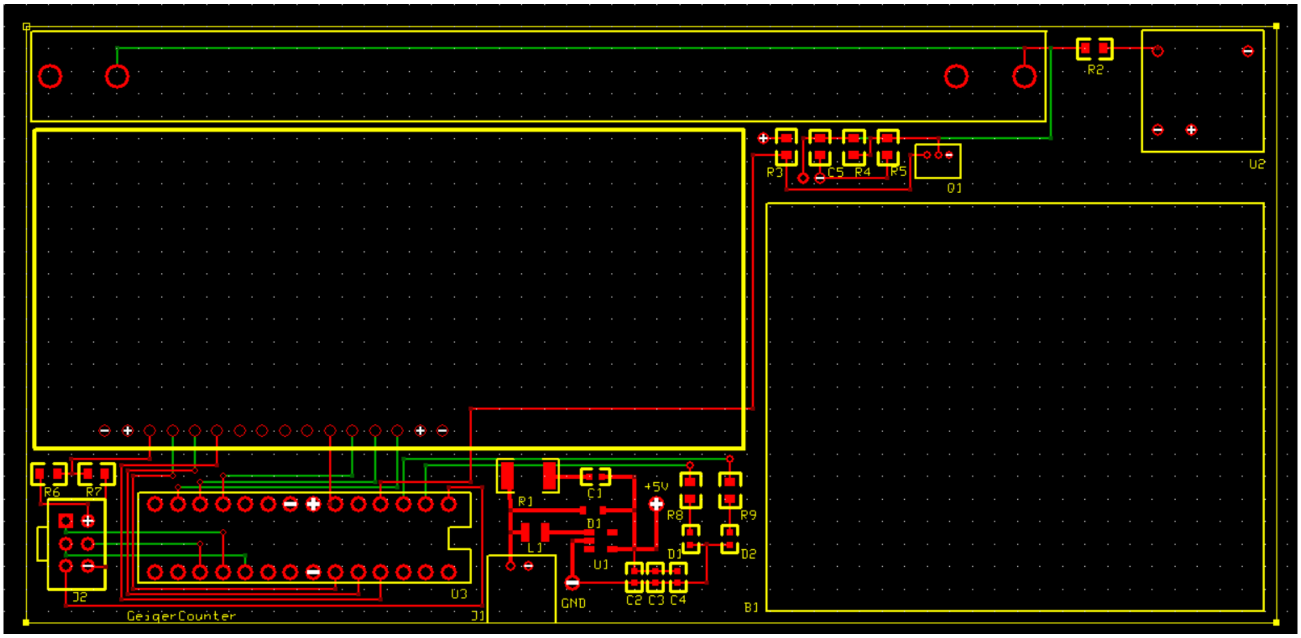
Socially this product has the potential to change the way we think about our environment. Generally, we think about things like temperature or maybe even air quality but rarely about background radiation content. With an increased use of these devices this will raise awareness and help everyone in the long run.

11. Development

The development of this project demonstrated how difficult it is to create an economical product. Individual PCB fabrication drives up cost drastically ($150). Additionally, I have learned about what makes good schematic/PCB software and how to go about interacting with it to maximize productivity.

Appendix B – Schematic/Layout





Appendix C - Software

```
#include "LCD.h"
void LCD_init(){  // initialization sequence per ST7066U datasheet
		PORTC &= ~EN;
		_delay_ms(100);
		PORTD = 0x30;
		_delay_ms(30);
		Pulse_enable();
		_delay_ms(10);
		Pulse_enable();
		_delay_ms(10);
		Pulse_enable();
		_delay_ms(10);
		PORTD = 0x20;
		Pulse_enable();
		LCD_command(0x28);
		LCD_command(0x10);
		LCD_command(0x0F);
		LCD_command(0x06);
}

void LCD_command(unsigned char command){  // function to send command
		PORTD = command;  // put command data on port
		PORTC = 0x00;  // RS and RW = 0 for command and write mode
		Pulse_enable();  // send upper byte first
		command = command << 4;  // send lower byte next
		PORTD = command;
		Pulse_enable();
}

void LCD_write(unsigned char data){  // function to write single character
		PORTD = data;  // put data on port (ascii value)
		PORTC |= RS;   // RS = 1 for data
		PORTC &= ~RW;  // RW = 0 for write mode
		Pulse_enable();  // send upper byte first
		data = data << 4;  // send lower byte next
		PORTD = data;
		Pulse_enable();
}

void Pulse_enable(){  // pulses EN signal to transmit data per timing diagram
		PORTC |= EN;
		_delay_ms(1);
		PORTC &= ~EN;
		_delay_ms(20);
}



void LCD_write_string(unsigned char *array){  // function to write word
		while(*array) {  // this word is known at runtime, write until "\0"
				LCD_write(*array);  // dereference pointer to get character
				array++;  // increment pointer
		}
}

void LCD_display_number(uint16_t number){  // function to display
		unsigned char array [2];  // assume number will be no more than 2 digits
		unsigned char idx = 0;
		unsigned char address = 0x84;  // initial DDRAM address for cursor
		while (number) {  // populate array where each member is a digit
				array[idx] = number % 10;  // first member is the rightmost digit
				number /= 10;
				idx++;
		}
		for (int i = idx-1; i >= 0; i--){ // access array in reverse
				LCD_command(address);  // go to DDRAM address
				LCD_write(array[i] + 0x30);  // write for digit and so on
				address++;  // shift cursor to the right for the next digit
		}
}
```

Figure A: "LCD.c"

```c
#include <avr/io.h>
#include <avr/interrupt.h>
#include <util/delay.h>
#include <stdint.h>

void LCD_init(void);  // function prototypes
void Pulse_enable(void);
void LCD_command(unsigned char);
void LCD_write(unsigned char);
void LCD_write_string(unsigned char*);
void LCD_display_number(uint16_t);

#define RS 0x01  // macros for accessing port pins
#define RW 0x02
#define EN 0x04
```

Figure B: "LCD.h"

```c
#include "LCD.h"
#define ARR_SIZE 50  // ARR_SIZE and SAMPLE_TIME are user variable
#define SAMPLE_TIME 500

unsigned char word[] = "CPM:";  // words displayed on LCD at start-up
unsigned char word2[] = "GeigerCounter";
unsigned char word3[] = "LOADING...";
uint16_t sum = 0;
uint16_t count = 0;
uint16_t count_array[ARR_SIZE];

int main(void)
{
		LCD_init();  // initialize LCD
		_delay_ms(100);
		LCD_command(0x01);  // CLEAR
		LCD_command(0x02);  // RETURN HOME
		LCD_write_string(word3);  // display loading stage

		DDRD &= ~(1 << DDD2);  // configure interrupts

		EICRA |= (1 << ISC01);
		EIMSK |= (1 << INT0);

		sei();

		uint8_t idx = 0;

		while(idx < ARR_SIZE){  // loading function to fill array
				_delay_ms(SAMPLE_TIME);
				count_array[idx++] = count;
				count = 0;
		}

		LCD_command(0x01);
		LCD_command(0x02);
		LCD_write_string(word);  // display CPM: and GeigerCounter after loading
		LCD_command(0xC0);
		LCD_write_string(word2);

		while(1){  // continually run mva by updating oldest variable in array
			if(idx == ARR_SIZE) idx = 0;
				count_array[idx++] = count;
				count = 0; sum = 0;
				for(int i=0; i<ARR_SIZE; i++) sum += count_array[i];
				_delay_ms(SAMPLE_TIME);
				LCD_display_number(sum*60/ARR_SIZE);
		}
		return 0;
}

ISR(INT0_vect) {  // minimized interrupt service routine
		EIFR = 0x01;
		count++;
}
```

Figure C: "main.c"