Making a Geiger Muller Radiation Counter

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Abstract: Henry Hook

Through the design and implementation of the gamma ray detector we constructed a handheld device, powered via a 9V battery, capable of detecting primarily gamma rays, utilizing a Geiger Muller tube. In order to cause ionizing events within the gas filled chamber of the tube a high voltage was required. The output of the tube produced a current pulse that with proper manipulation was outputted to a LCD to print the Counts per Second of radiation activity. The GM tube presented our greatest difficulty in determining both what the output of the tube would look like and how reactive it would be to the radiation source. After integrating each members' subsystem, we were able to simplify our original design and package the components in a clear box, capable of being viewed from any angle, to allow high school students the opportunity to have an immersive experience.

Table of Contents: Ian Denick

1. Introduction: Ian Denick

A Geiger Muller Radiation counter was requested by the ECEN department for the purpose of getting high school students interested in Electrical Engineering. The device needed to be simple to use and understand while being aesthetically appealing. This report will talk about our goals, our strategy to achieve those goals, our distribution of work, what we achieved, and what mistakes were made along the way.

2. Desired Specifications: Chadwick Aryeequaye

The following is a list of desired specifications:

- Block α and β rays
- LCD backlit display
- Clicking noise from piezo speaker
- 9V Battery powered
- No computer necessary
- Detects radiation on contact
- Handheld device
- Robust casing
- CPS with CS-137 in range of 100-200 CPS

3. Technical Description of Solution

Geiger Muller Tube Selection: Henry Hook

The most critical part in our design was both the selection of the GM tube and determining the output of the tube. In order to block out alpha particles entirely, and weaken beta particle detection, we needed a tube free of windows and one with a thick metal exterior wall. Both alpha and beta particles travel through the window and ionize the fill gas directly whereas gamma rays ionize the gas indirectly by interacting with the metal wall of the GM tube in a way in which the electrons are knocked off the inner wall of the detector. This electron can then ionize the gas inside the tube and if the electric field is strong enough, cause a Townsend avalanche capable of producing the critical current pulse(PLACE ORAU). In order for the ionizing events to occur a potential difference strong enough to cause the electric field is needed. After comparing and contrasting several tubes the SBM-20 tube was selected. This tube was selected based on its absence of walls, thick metal exterior, simplicity, and the price point of around $15.

Towards the end of our design a characteristic curve was developed shown in Figure 2. This curve displays Counts per Second versus voltage applied to the tube. The curve allows us to see the operating region voltage needed. For gamma radiation detection sensitivity, it is important that the tube is presented transversely to the source of radiation (PLACE CENTRONIC). A resistor of size 5.1 M Ohms at the anode of the tube helps to reduce anode voltage after a discharge is initiated. This drastic reduction in anode voltage allows both the tube and the circuit to recover from the discharge event. Additionally, the anode resistor effectively shortens or lengthens the plateau or operating region. A lower value produces a shorter plateau length (PLACE CENTRONIC)

Power Regulation Design: Henry Hook

The critical and restrictive design element that affected the power component was to keep the device handheld and thus battery supplied. After selecting 9-V for the supply voltage two requirements were formed. First, to regulate the voltage to 5-V for certain components. Second, to step up the 9-V DC to a voltage high enough to cause the ionizing events previously mentioned. In order to discover this value formulating a characteristic curve was necessary.
In order to regulate or step down the voltage of the 9-V DC supply to 5-V DC a LM78L05ACZ linear voltage regulator was used. This 5-V was used as the supply voltage of the Arduino, the LCD, the inverter and finally for the step-up converter required to supply high voltage to the GM tube. It was critical that this voltage did not go above 5-V in order to prevent damage to both the LCD and Arduino as well as to make sure the high voltage output of the step-up converter remained in the desired range.

The preliminary design utilized a Switch Mode Power Supply called a DC-DC boost converter. This design was picked due to simplicity of design and familiarity from previous coursework and could, theoretically, step up the 5-V supply to approximately 400-V DC. This design included the TL5001 PWM controller chip that used feedback from the output voltage in order to adjust the duty cycle and keep a steady output voltage. This preliminary design ended up failing upon design due to the high duty cycle required of nearly 98% on time. The output voltage was very unstable and an excessive amount of current was seen at the MOSFET switch often causing destruction. In order to remedy these solutions, it was found critical to simplify the switching mechanism by using a 555 timer to control the duty cycle and to lessen the dependence on the duty cycle.

After comparing and contrasting different step-up converters it was decided to use a flyback converter. A device similar in design to the boost converter with a few major differences: the isolation between the output and input, the use of a larger inductor, behaving similar to a transformer, and a 555 timer as opposed to the PWM controller. Additionally, the design includes a variable resistor that allows for tuning in the 100-V range and a variable input voltage range of 3.3 to 5-V DC that effectively outputs a voltage ranging from approximately 200-V to 800-V. Due to time restrictions and the cost of ordering all of the parts individually, it was decided to purchase the device. This allowed for a finished piece constructed on a PCB at a price of $8.

The high voltage output of the flyback converter is fed through the anode resistor and finally to the GM tube. At this point the characteristic curve could be created. In order to construct the curve, the Cesium-137 sample was placed transversely to the GM tube at a set distance of 2 inches. The voltage was then raised in 15-V increments from 200-V up until 800-V. At each voltage point I measured the CPS, read from the LCD, then took 5 seconds worth of values, and finally averaged those values to create a more accurate and smooth curve shown in Figure 2.

There are three critical regions on the characteristic curve. The starting voltage marks when enough counts are detected outside of the background radiation counts (0 – 3 CPS). This marks when the electric field is strong enough to cause the ionizing events. A slight slope forms and leads to the operating region. In this region a plateau forms and this becomes the ideal and optimal region and voltage to input into the tube. Finally, after the plateau, there was a sharp rise in the count rate. In this region the relationship between radiation intensity and count rate is no longer linear. The tube circuit begins to become unstable and the values are no longer accurate (CENTRONIC).

Pulse Manipulation: Chadwick Aryeequaye

The GM tube outputs a current which is then converted to a voltage by adding putting a resistor in series with it. The resistor chosen was a 5.1kΩ at the cathode of the GM tube. This value was chosen primarily due to wanting a lower output pulse amplitude. Another 5.1kΩ is used to help limit the current which comes from the GM tube. That voltage is then used in conjunction with a transistor used as an inverter [2]. In this design, a 2N3904 transistor was used. When the voltage across the resistors is low, the voltage builds up across the resistor attached to the collector side. It is then outputted at VCC (5V). When the voltage to the base is high enough to saturate the transistor, the transistor has enough current to flow through it and connect to the drain.

Since there were some uncertainties of which transistor would work, calculations for the 2N3904 had to be calculated as follows:
Equation 1: $I_C = V_{CC}/R_C = 5V/1k\Omega = 5mA$
Equation 2: $I_B = 2/B = 2/100 = 20mA$
Equation 3: $I_E = I_C + I_B = 5mA + 20mA$
Equation 4: $B_{min} = I_c/I_B = hFe$

These values were calculated to ensure the transistor could still work while dealing with high voltage and current values. When testing the GM tube output, the lowest current value outputted was taken and used to ensure (0.65V)V_{BE} was reached pushing the transistor to saturation. The main reason for choosing to use the transistor as an inverter was due to the ease and the availability of the parts. The transistor was already on hand along with most of the capacitor and resistor values it's used in conjunction with.

Data Acquisition: Ian Denick

A microprocessor was going to be needed for controlling the LCD so it was also used to count the pulses coming out of the GM tube and to keep track of time. There are several options for counting the pulses but the least resource intensive was to set up an interrupt to increment a counter. Similarly the best way to keep track of time was to use an additional oscillator built into the arduino to interrupt the arduino every 1 second to let the arduino know that 1 second had elapsed. If the arduino is in the middle of updating the screen while it gets interupted, it will stop to increment the counter and return back to finishing updating the LCD. This method of using interrupts ensures that no counts are ever missed.

Display: Franklin

The goal of team 8 was to ensure that collected data was displayed in a way that information could be understood by any user regardless of engineering background. This portion of the overall circuit design was assigned to Franklin. Both an LCD (liquid crystal display) screen and Piezo buzzer were used in the final product for display purposes.

A Piezo buzzer is not technically considered a display, but is being included in this portion of the report because of the team's use of the component. In a typical Geiger-Muller radiation counter a clicking sound is produced when a gamma photon is detected. Our team wanted to reproduce this sound in our circuit, and decided that a Piezo buzzer was the most reliable option available. The normal use of a Piezo buzzer is to create an audio tone, but through the use of a resistor (R5A in schematic) and an internal Arduino function we were able to create a clicking noise.

From the beginning of the semester our team knew that displaying the counts of the gamma radiation sample was crucial to the overall functionality of our product; therefore, it was decided that an LCD screen be used as our display. Originally only the counts per second were displayed, but due to a suggestion of a professor we made use of the additional space on the LCD to list information regarding the team. The LCD is controlled via code in the Arduino, but powered by 5V from the voltage regulator. Also, a potentiometer (J7 in schematic) was used to the control the contrast of the screen, and a resistor (R6A in schematic) was used in series with the power input for optimal display.

PCB Design: Ian Denick and Chadwick

The goals of the PCB were to reduce the number of wires used and to ensure the project looked clean and impressive to any high school students who would see it. The only things not connected to the PCB were the DC to DC flyback converter, the gm tube, and the 9 volt battery. Leaving the GM tube off the PCB allows for the GM tube to be placed wherever it would work best. When designing the PCB, attention to the size of the LCD in relation to the other components positioning was vital.

Final Housing: Ian Denick and Franklin

The goal of the housing was to find a project box that was clear, had an external power button, screwed shut, and could easily be opened to replace the 9V battery. The case was clear so that the high school students who look at it can see inside the device and ask questions about the components. The external power button was for convenience. The case was going to be screwed shut so that the high school students could not easily open it up and disconnect something but the 9V battery could fairly easily be replaced. The case that was used had its extra space filled with mattress foam to help prop the LCD screen up as close to the edge as possible. The foam also prevented the circuit from moving around as well as provided some resistance to being dropped.

4. Important Figures

Figure 1 is our team's block diagram. Our diagram remained almost unchanged throughout the semester. We found that the block diagram was crucial to our overall design because it allowed for a clear overview of which team member was responsible for each part of the circuit. Also, this allowed for us to colorate with the correct person when integration was needed, and we found that we were able to integrate our parts with ease.

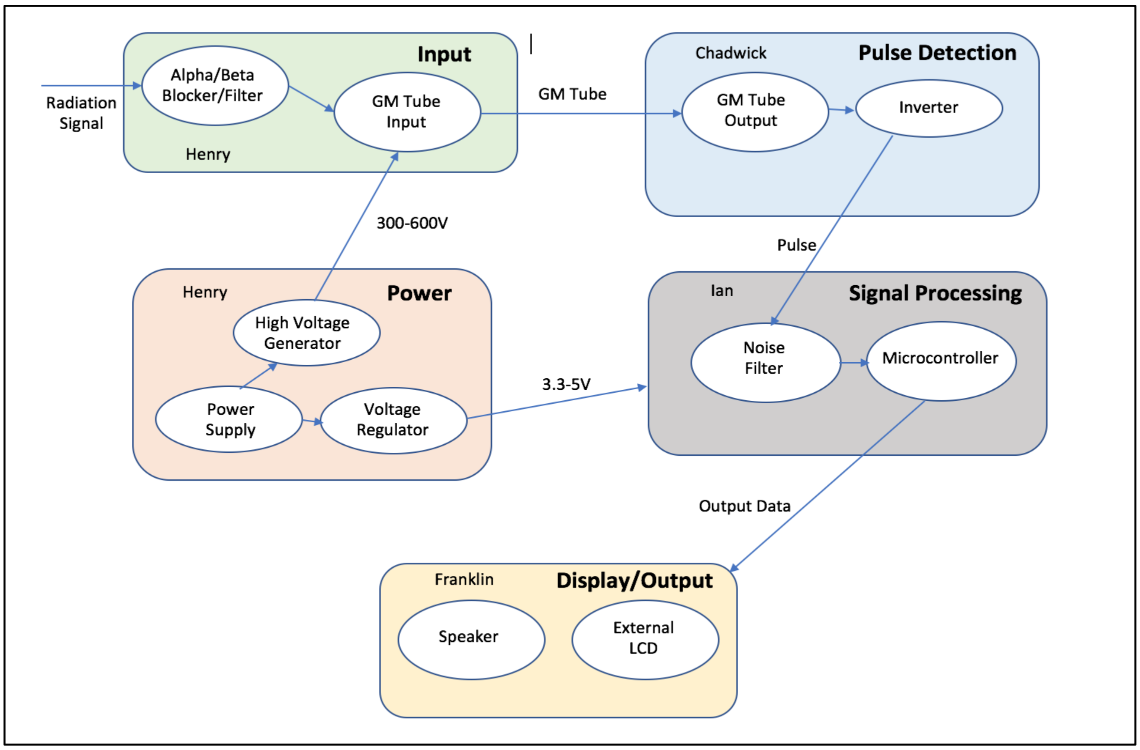


Figure 1: Functional Block Diagram

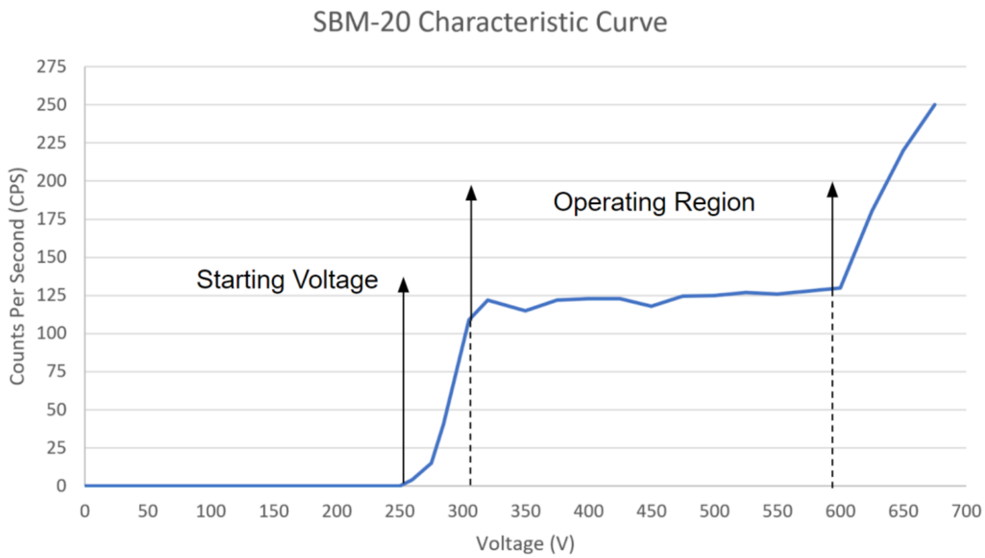


Figure 2: GM Tube Voltage Characteristic Curve

5. Discussion of Calibration Techniques: Ian Denick

A sample of 0.25 uCi Cesium 137 was used as a radiation source. It should be noted that the half-life of Cs 137 is about 30.17 years and the sample was 5 years old. This just means that the sample was about 0.22 uCi due to its age but was still a plenty strong source for detection purposes.

The output of the GM tube was probed using an oscilloscope. As the Cs 137 sample was held in place next to the tube the Hz of the oscilloscope were compared the the counts per second displayed on the LCD. These numbers were typically within about 5% of each other just from eyeballing the values. The timing of the Oscilloscope's counts and Arduino's counts was not synchronized and the values vary even with the radiation source held in place. This implies that it should be expected for the oscilloscope and LCD to show slightly different values even if every pulse is counted perfectly by each device. With a small deviation of about 5% and neither device consistently higher or lower, it was safe to assume that the arduino was accurately counting every pulse.

6. Improvements in Future Designs: Everyone

1. The orientation of the LCD on the PCB was backwards. To fix this, the underside of the PCB was used and the Arduino was modified to be plugged into the PCB upside down. Luckily all components were through hole and could be placed on the underside without looking bad.
2. While designing the PCB, the autotrace function was used to lay the traces. One of the traces that were laid came too close to a via and connected when it should not have been connected. No errors were given by Ultiboard, the program used to design the PCB. Using the autotrace may have saved 30 minutes but ultimately caused 2 hours of troubleshooting due to this one extra connection.
3. While designing the PCB, little caution was given to protect the board from noise. As the signals worked with were not very large in frequency, EMI noise was not taken into consideration. This is something to improve on for future designs.
4. The GM tube was purchased from Ebay. It took about a month for the GM tube to arrive. Since the GM tube is an essential part, progress was severely hindered by the long wait time.
5. It was assumed that the metal tube would block all α and β radiation and that all ionizing events in the GM tube would be caused by Gamma. The truth is that only some of the β radiation is blocked. If the sample is held up to the GM tube with the plastic container between the two, then the counts per second are about 1/10 of what they are with no barrier. Gamma radiation penetrates through the thin plastic with ease. This means that a significant portion of the counts are coming from β radiation when the sample is held up to the GM tube where there is a hole in the container. It also means that the plastic container can be used to shield β which means the device can be used to see just Gamma or Gamma and β. This is a good thing but was not intentional and kind of done out of luck and ignorance.
6. The original Piezo buzzer that was purchased was larger than expected, and we found it difficult to produce a clicking noise 100% of the time. We were able to get the desired results at times, but it would not be satisfactory for our final product. However, Ian happened to come across a smaller Piezo buzzer, and the issue was resolved eventually through multiple attempts to find the correct resistor value and constants to be used in code. Our product now produces a clicking noise 100% of the time.

7. Appendix: Everyone

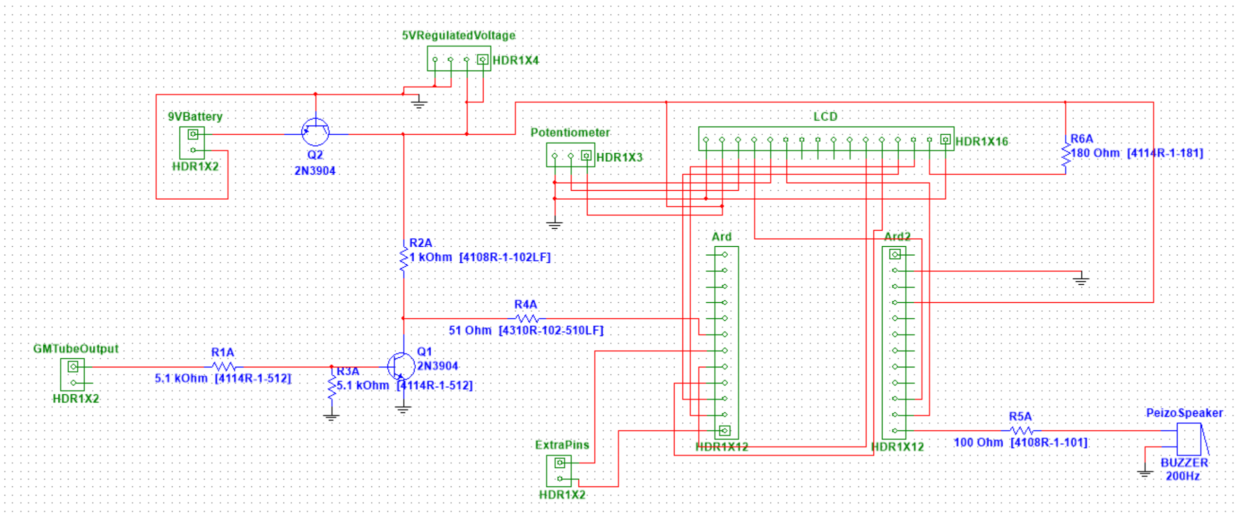


Figure 3: PCB Schematic

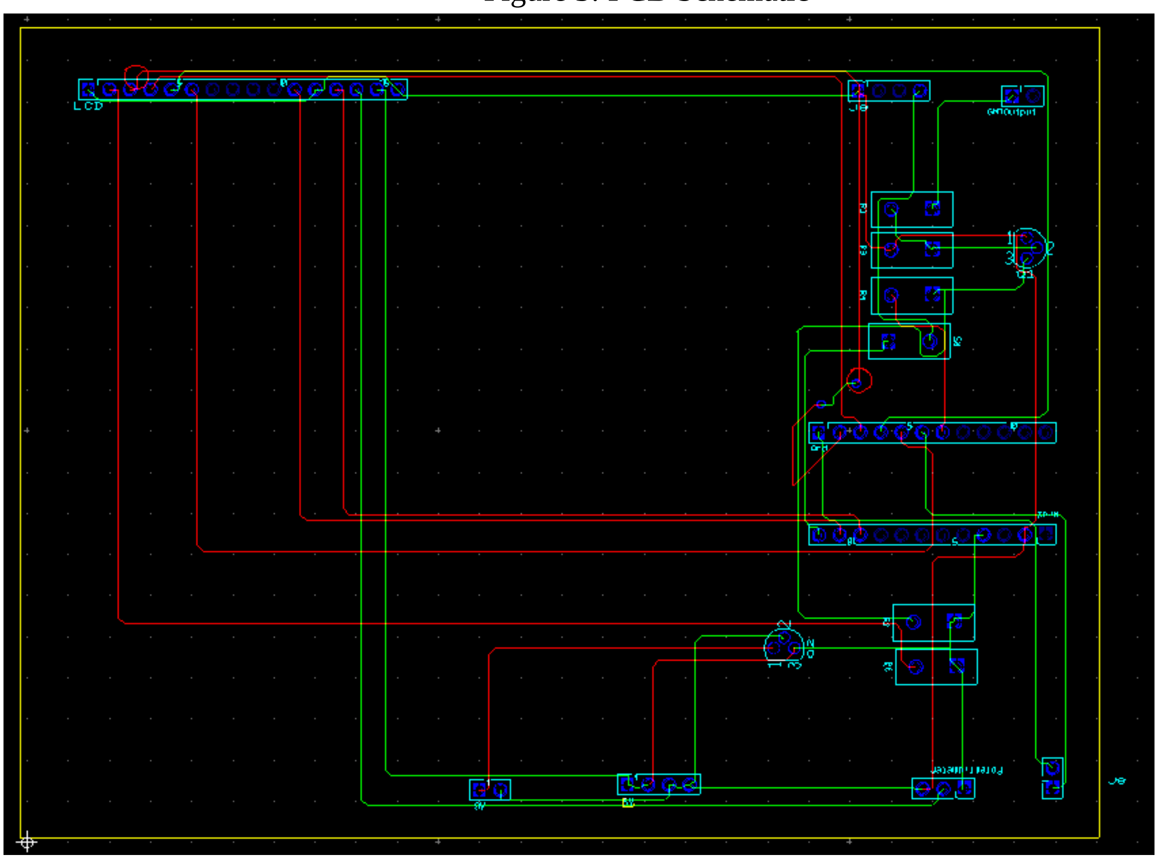
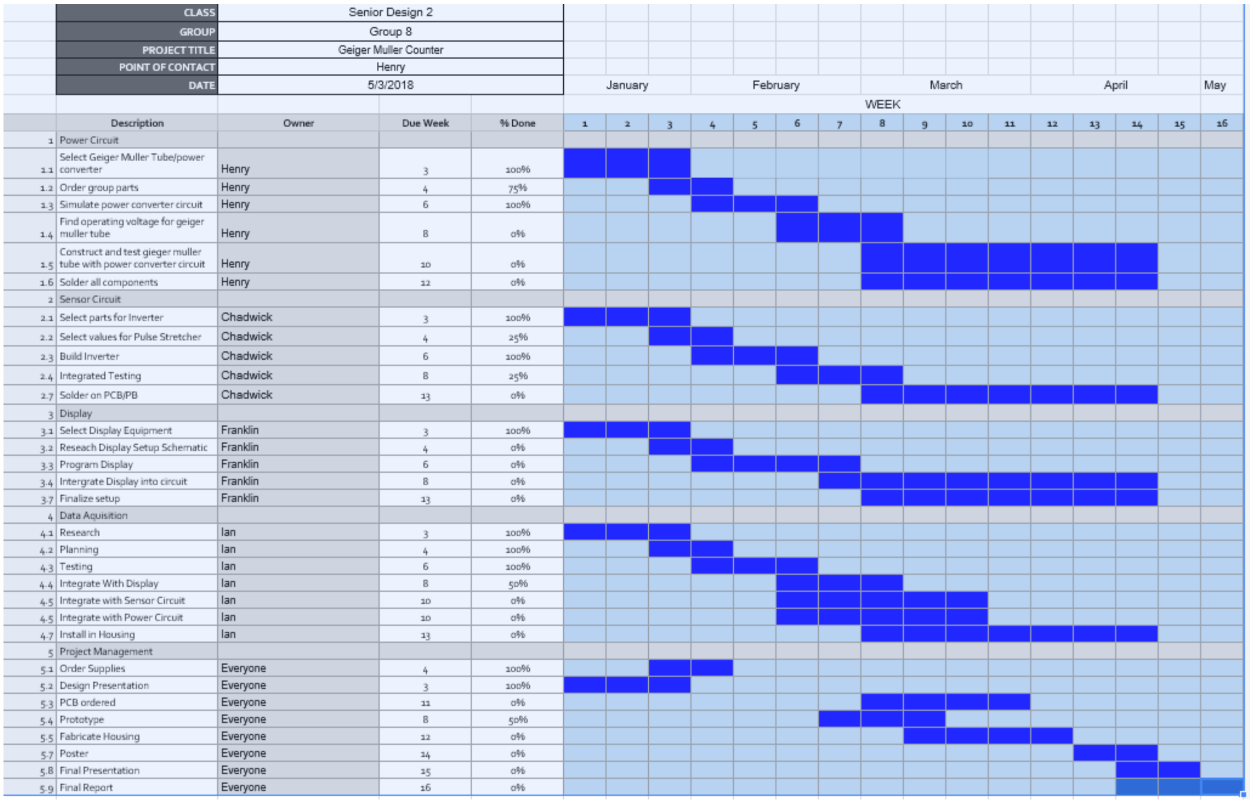


Figure 4:PCB Layout



CLASS	Senior Design 2
GROUP	Group 8
PROJECT TITLE	Geiger Muller Counter
POINT OF CONTACT	Henry
DATE	5/3/2018

	Description	Owner	Due Week	% Done
1	Power Circuit			
1.1	Select Geiger Muller Tube/power converter	Henry	3	100%
1.2	Order group parts	Henry	4	75%
1.3	Simulate power converter circuit	Henry	6	100%
1.4	Find operating voltage for geiger muller tube	Henry	8	0%
1.5	Construct and test gieger muller tube with power converter circuit	Henry	10	0%
1.6	Solder all components	Henry	12	0%
2	Sensor Circuit			
2.1	Select parts for Inverter	Chadwick	3	100%
2.2	Select values for Pulse Stretcher	Chadwick	4	25%
2.3	Build Inverter	Chadwick	6	100%
2.4	Integrated Testing	Chadwick	8	25%
2.7	Solder on PCB/PB	Chadwick	13	0%
3	Display			
3.1	Select Display Equipment	Franklin	3	100%
3.2	Reseach Display Setup Schematic	Franklin	4	0%
3.3	Program Display	Franklin	6	0%
3.4	Intergrate Display into circuit	Franklin	8	0%
3.7	Finalize setup	Franklin	13	0%
4	Data Aquisition			
4.1	Research	Ian	3	100%
4.2	Planning	Ian	4	100%
4.3	Testing	Ian	6	100%
4.4	Integrate With Display	Ian	8	50%
4.5	Integrate with Sensor Circuit	Ian	10	0%
4.5	Integrate with Power Circuit	Ian	10	0%
4.7	Install in Housing	Ian	13	0%
5	Project Management			
5.1	Order Supplies	Everyone	4	100%
5.2	Design Presentation	Everyone	3	100%
5.3	PCB ordered	Everyone	11	0%
5.4	Prototype	Everyone	8	50%
5.5	Fabricate Housing	Everyone	12	0%
5.7	Poster	Everyone	14	0%
5.8	Final Presentation	Everyone	15	0%
5.9	Final Report	Everyone	16	0%

Figure 5: Gantt Chart

Arduino Code:

```
#include <LiquidCrystal.h>
#include <MsTimer2.h>
#include<avr/interrupt.h>
#include <avr/io.h>
LiquidCrystal lcd(12, 11, 5, 6, 7, 8);
const int TimerInterruptPin = 2;
const int CounterInterruptPin = 3;
const int BuzzerPin = 10;
long int Counter = 0;
long int ICounter = 0;
int TimeCounter = 0; // increments every Period to keep track of cumulative
time passed. May or may not be used.
float CPS = 0;
int Period = 1000; //in milliSeconds

void setup() {
```

```
  lcd.begin(20, 4);
  Serial.begin(9600);
  pinMode(13, OUTPUT);
  pinMode(10, OUTPUT);
  digitalWrite(10,HIGH);
  pinMode(TimerInterruptPin, INPUT);
  pinMode(CounterInterruptPin, INPUT);
  lcd.clear(); //clears the LCD screen
  lcd.setCursor(0, 0);
  lcd.print("OSU Spring 2018");
  lcd.setCursor(0, 1);
  lcd.print("Senior Design 2");
  lcd.setCursor(0, 2);
  lcd.print("Team 8");
  lcd.setCursor(0, 4);
  MsTimer2::set(Period, CalculateCPS);
  MsTimer2::start();
  Serial.println("CPS          Total Counts       Total Time");

attachInterrupt(digitalPinToInterrupt(CounterInterruptPin),IncrementCoun
ter,RISING);
}
void loop() {
  //Leave this blank otherwise interrupts will be wonky.
}
void CalculateCPS() {
 CPS = ICounter*1000/Period;
 TimeCounter++;
 DisplayToSerial();
 ICounter = 0;
 DisplayToLCD();
}
void DisplayToSerial(){
Serial.print(CPS,DEC);
Serial.print("      ");
```

```
Serial.print(Counter,DEC);
Serial.print("       ");
Serial.println(TimeCounter,DEC);
}
void IncrementCounter(){
 Counter++; ICounter++;
 MakeBuzzerBuzzAndLEDFlash();
}
void MakeBuzzerBuzzAndLEDFlash(){ //This will get called every time a
pulse is sensed.
tone(BuzzerPin, 5000, 1);
}
void DisplayToLCD(){
  lcd.setCursor(0, 4);
  lcd.print("                    ");
  lcd.setCursor(0, 4);
  lcd.print("CPS:");
  lcd.print(CPS);
  //lcd.setCursor(0, 0); //BASED ON MATRIX
  }
```

8. Works Cited

[1]"An Introduction to Geiger-Mueller (GM) Detectors", *Orau.org*, 1999. [Online]. Available: https://www.orau.org/ptp/collection/gms/introgms.htm.

[2] (2018). *Transistors - learn.sparkfun.com*. [online] Available at: https://learn.sparkfun.com/tutorials/transistors/applications-i-switches [Accessed 3 Mar. 2018].