Geiger–Müller Counter Lab Report

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Physics / Experimental Project

Abstract

A Geiger-Müller (GM) counter circuit was designed, built, and tested using a GM tube with an Arduino. The circuit included resistors, capacitors, a comparator, and a high-voltage DC-DC step-up module and was first simulated on LTSpice to ensure components remained at safe operational voltages. Python scripts to read Arduino inputs, record counts, and plot live data were made. The counter successfully measured background radiation but was not sensitive when tested with autunite sample (uranium ore).

1 Introduction

Radiation counters have been in use for well over a century, with the first one being the Geiger counter, invented by Ernest Rutherford and Hans Geiger (1908). It would later be improved by Geiger and Walther Müller (1928) with the creation of the Geiger-Müller (GM) tube; a rather simple object which turned out to be revolutionary.

Inside, there is a low-pressure gas between a cathode (glass walls) and an anode (centre wire) with a potential difference between them in the hundreds of volts (≈ 400V for this project). When ionising radiation goes through the tube's thin glass walls, it ionises the gas inside creating positive ions and free electrons. Due to the electric field from the high voltage, the positive ions are accelerated towards the cathode walls, and the electrons towards the central anode wire. A chain reaction called a Townsend avalanche ensues and enough charge carriers are created as to make the usually non-conductive gas (commonly argon or helium) conductive, producing a pulse that can be detected electronically (Knoll, 2010).

This project aimed to build, test, and gather data from a GM counter in order to deepen personal understanding of the operation of such devices.

2 Materials

Below is a comprehensive list of all the materials used for this project:

- 1 Geiger-Müller tube (J321$\beta\gamma$ M4011)
- 4 AA batteries
- 1 battery holder
- 1 high voltage DC-DC step-up converter
- 5 1MΩ resistors
- 2 10kΩ resistors
- 1 680pF high-voltage ceramic capacitor
- 1 comparator (LM393N)
- 1 Arduino Uno
- 1 perfboard
- Jumper wires (male-to-male)
- Soldering kit, eye protection, and multimeter
- 1 buzzer module (optional)
- 2 oz autunite uranium ore sample (optional, for testing)

3 Methods

Prior to construction, LTSpice was used to model and simulate the final circuit in order to ensure all components did not exceed maximum voltage thresholds.

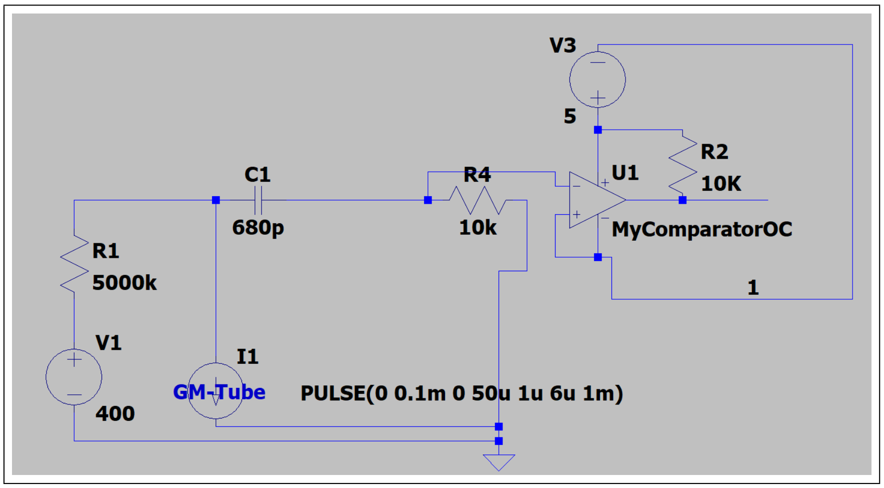

Figure 1: Simplified LTSpice schematic of the GM counter circuit Comparator adapted from (Alonso, 2023)

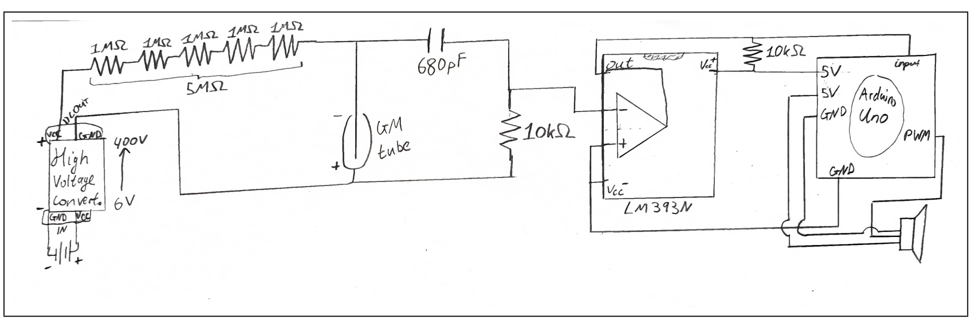

Figure 2: Sketch of complete circuit for clarity

All the components were soldered together on a perfboard and the comparator's output and V_{cc} were connected to the Arduino with M-M jumper wires, and the Arduino's PWM and power pins were connected to the piezo buzzer with M-M jumper wires. The 10kΩ resistor between the comparator's V_{cc}^{+} and output was connected in pull-up configuration. The total of 5MΩ of resistors after the HV converter were added to ensure the comparator did not exceed safe voltage levels as its max input voltage was 34.5V according to its TI datasheet. The HV module's potentiometer had to be manually adjusted via screwdriver to reach the desired 400V.

The coupling capacitor further ensured that the high voltage was blocked from reaching the lower rated components. The $\tau = RC_c$ was calculated to be $\simeq$ 3.4ms which is much longer than the pulse duration (usually in microseconds), and hence allows the pulse to pass mostly unaffected without attenuating the pulse amplitude (Knoll, 2010, p. 217).

The buzzer was added for audible feedback to ensure detector was functional without having to observe the live graph. Two python scripts were developed. The first, `readinput.py`, to collect data from the Arduino via `pyfirmata` and put it into a csv file, running a PWM signal to the buzzer if the voltage exceeded an arbitrary threshold. The other, `makegraph.py`, to plot a live graph to show the detected voltage at the analog input pin of the Arduino. Both are included in the repository under the `/scripts` directory.

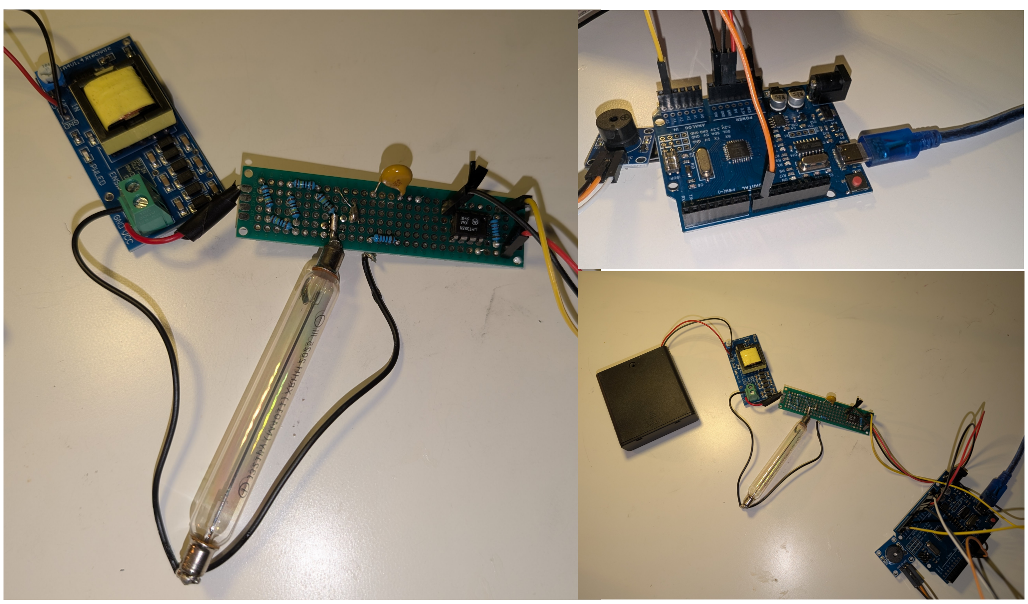

Figure 3: Assembled GM counter. Left: HV module, GM tube, and perfboard with resistors, comparator, and capacitor; Top right: Arduino Uno with buzzer and USB connection; Bottom right: complete assembled counter.

4 Results

The scripts were run for ≈ 60 minutes, gathering 60 data points (i.e. how many times voltage exceeded set threshold of 0.5V) that were used to plot the histogram in Fig. 3.

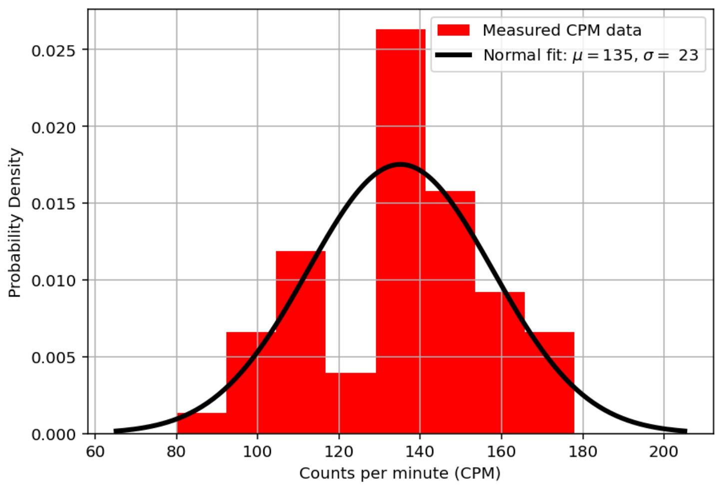

Figure 4: Histogram of the counts per minute (CPM) with normal distribution fit

Using `matplotlib` and `scipy`'s `norm`, the mean and standard deviation were found to be $\approx$ 135CPM and $\approx$ 23CPM respectively. The data has significant noise likely due to the relatively small dataset, and the standard deviation is rather large ($\approx 17\%$ of the mean) possibly due to certain design decisions that will be discussed in section 5. Nevertheless, the shape of the data clearly resembles a normal distribution. The raw data used to plot this graph is in the repository under `/data` with `counts.txt` and `data.csv`.

A source of radiation in the form of a 2oz autunite sample (uranium ore) was subsequently used to test the GM counter. However, no meaningful effect in the data or graph was observed, possibly as a result of certain factors that will be discussed now.

5 Discussion

The reason for the spread being relatively large (and data at times unreliable) could be attributed to the HV module being a premade one, which made its output voltage vary with a margin of ± 50V at times (measured with multimeter over the course of an hour). This could be resolved by instead winding a fly-back converter with a pre-determined primary to secondary ratio, and driving it with a 555 timer module to achieve a much more stable and purpose-built voltage. There could also be an unaccounted inefficiency in the circuit's design which could be affecting the voltage passing through the GM tube, or the GM tube itself, however this is not as likely to be the case as the distribution in Fig. 3 does suggest the counter working to an extent.

The shape would also likely be further refined to fit the actual distribution if more datapoints were collected (> 200), as that would reduce the effect of noise and statistical uncertainty.

The autunite sample not significantly affecting the data/observed CPM could also be explained. One is that the ore was either not radioactive enough to be visible (i.e. less than standard deviation), its radioactivity was not the type the GM tube could detect, or both. This is supported by the fact that autunite should be around 50% uranium by weight and uranium is mainly an alpha, weak beta, and gamma emitter (Sofield & Kantar, 2013), while our GM tube is meant for hard beta, gamma, and x-rays, meaning our GM tube could simply not be meant for this ore's radiation. Furthermore, our sample (Fig.5) looks quite different from typical autunite samples, which appears to be due to it being more rock than autunite, further decreasing its radioactivity. Nevertheless, it could also signal to a fatal flaw in the design itself.

Figure 5: Our autunite sample (left) vs. typical autunite samples (right)
Top right: Reno_Chris, Public Domain, https://commons.wikimedia.org/w/index.php?curid=10828273; Bottom right: Didier Descouens, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=6845895

6 Conclusion

This project successfully demonstrated the design, construction, and operation of a Geiger-Müller counter with an Arduino. The counter measured background radiation, but the small autunite sample did not produce a measurable increase in counts, likely due to its lack of activity and or the GM tube's sensitivity range. Future improvements could include a purpose-built high-voltage supply; a GM tube sensitive to alpha particles, which would enhance detection of uranium ore samples; or a more radioactive sample. Overall, this project provided hands-on experience in electronics, radiation detection, modelling software, and data acquisition.

References

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