Deciphering Cosmic Rays on Earth

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Abstract

Spark chambers detect primary cosmic rays. In order to do, this, they have to be sealed from the outside elements and filled with a mixture of Helium and Neon gas. Along with sealing the chamber, a trigger circuit is needed to see a visible spark in the chamber. For my contributions to this project, I created a working circuit and sealed the chamber.

Introduction

A spark chamber displays to the observer the existence of elementary particles such as electrons and muons. J.J. Beaty states that a muon has the same charge as an electron, but a muon's mass is 200 times larger than an electron's. Between the 1930's and the 1960's, spark chambers were the ideal tool to use to detect these types of particles. A spark chamber is a box filled with stacked aluminum plates and a mixture of helium and neon gas. The gas mixture is used instead of air, because the breakdown voltage of air is much higher than the gas mixture's. When a charged particle moves through the box, it ionizes the gas between the metal plates. Once the detectors between the plates detect a particle passing through, a high voltage is applied to the plates. The sparks in the chamber will show the path that the particle took.

To achieve a visible spark within the current chamber CNU has, a trigger circuit had to be created. To study the dynamics of a spark chamber, a prototype was used. To utilize this prototype, a trigger circuit had to be created. The way I attempted to create the required circuit is raise the voltage from a lower voltage to a higher voltage with the use of transistors. I believed this method would have been the best because it was the most cost effective.

Theory

The particles that the spark chamber will be detecting originally come from primary cosmic rays which originate from supernova explosions and the sun. These cosmic rays are very rarely detected on the ground levels of earth, so the spark chamber will only detect secondary cosmic rays. Secondary cosmic rays include: pions which decay to muons, neutrinos, and gamma rays. Muons also decay to positrons and electrons. As shown in Figure 1, the primary cosmic ray will collide with an atom in the atmosphere. This collision will produce the secondary cosmic rays the spark chamber will detect.

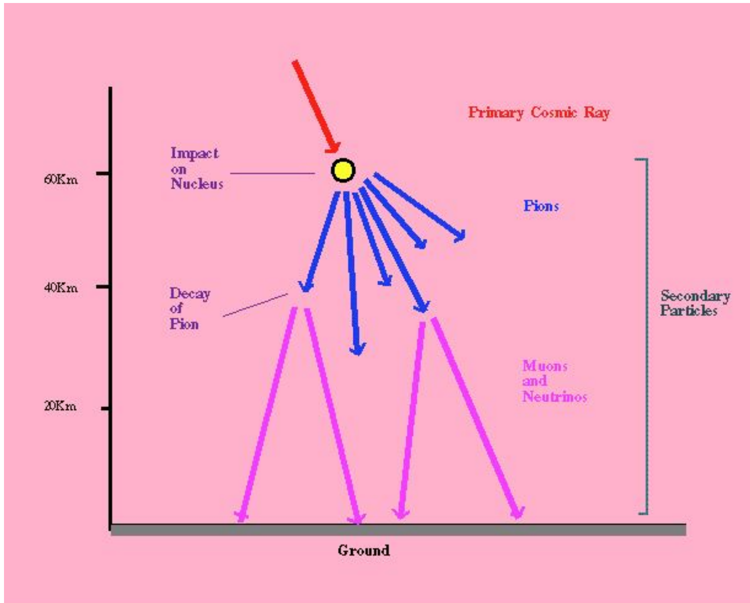

Figure 1: The primary cosmic ray colliding with an atom to produce secondary cosmic rays

Although there are many types of secondary cosmic rays, the chamber will primarily detect the muons because they are more likely to penetrate through the plates. According to CERN, a muon is an elementary particle with the charge of an electron, a mass of $105.7\frac{MeV}{c^2}$, and a mean lifetime of 2.2s. Muons are able to reach the round level of Earth because they move at relativistic speeds, 0.99c. They have the ability to pierce through the air in the atmosphere, and they only interact with weak forces and electromagnetically.

Once the muon comes in contact with the top of the chamber, it will cause a spark inside of the chamber. Collins states that the breakdown voltage of air ,3MV, is too high for most voltage supplies to make a spark in the chamber, so different gas must be used. The most common gas to use is a mixture of helium and neon. The muon will ionize the gas inside of the chamber which will cause a high voltage to be sent to the inside of the chamber. The discharge will follow the easiest path through the chamber, which creates the trail of ionized gas left by the muon.

As for the circuit itself, Collins states it should deliver $<$8kV within 500ns of the input signal. The system uses a spark gap to deliver the 6kV which is triggered at a lower voltage of around 100V by an IGBT. A transformer is needed to raise 100V to 4kV. A spark plug is used to raise the voltage to 6kV. Finally, the IGBT needs to be triggered at its threshold voltage. To do this, a Bipolar Junction Transistor is needed to raise the coincidence unit's voltage from 1.6V to the IGBT's threshold voltage, 5V. Figure 2 shows a simplified version of this process.

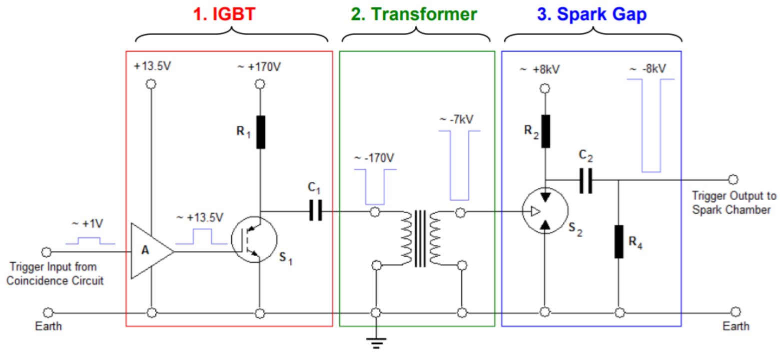

Figure 2: This circuit illustrates the primary components needed for the trigger circuit. There are three different phases: the first switches S1, the second phase uses a step up transformer which then goes to the spark gap, phase 3.

Methods

Currently, there are seven plates inside the chamber with a thickness of 0.25 inches and each plate spaced 0.3 inches apart from each other. The chamber itself was constructed of 0.7 inch thick acrylic. Figure 3 is an image of the prototype chamber. After the chamber was sealed, a test was conducted on it using an air compressor, water and soap. In order to tell if the chamber was truly sealed, the chamber was covered in soapy water. After covering the existing through holes of the chamber, an air compressor was set to 26 PSI. If any bubbles appeared anywhere near the chamber, that spot was leaky. This process was conducted for all 16 holes of the chamber. At the end of the procedure, no bubbles appeared on the chamber. Therefore, the chamber was ready for the trigger circuit.

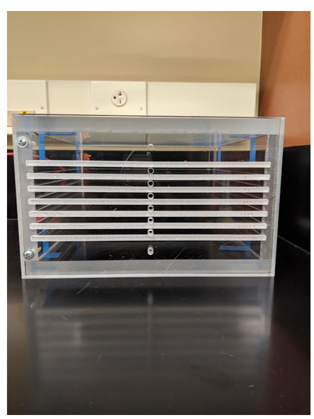

Figure 3: This is a picture of the chamber created by Nicholas McMahon

The three things needed to be done in order to complete the spark chamber were the following: a working trigger circuit, sealing the chamber, and having a gas flow system in place. Having a working trigger would prove to be the most challenging portion so the majority of the time was spent on that. The University of Cambridge has a cost effective spark chamber, so there trigger diagram was used as a reference. The circuit shown in Figure 4 is a more detailed version of Figure 2.

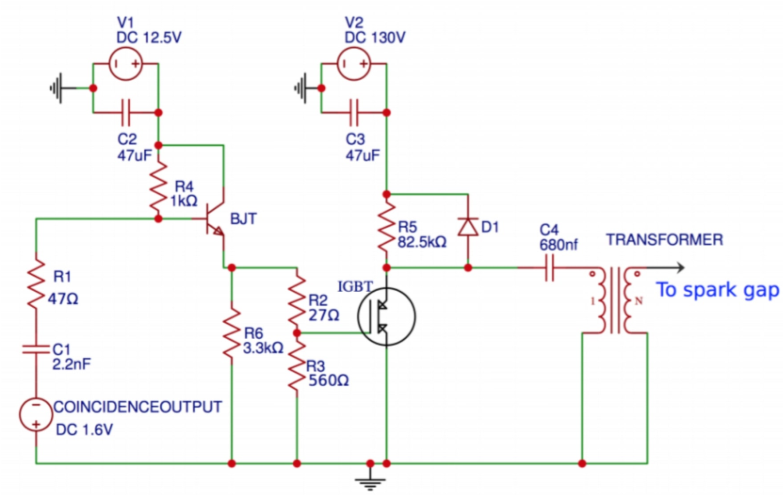

Figure 4: This is a more detailed version of the circuit shown in Figure 2.

The purpose of this circuit is to take a small voltage from the coincidence unit, which is about 1.6V, and turn it to 6kV. R1, found in Figure 4, limits the amount of current going into BJT so that it does not burn. R2 and R3 divide the voltage going into gate of the IGBT. R4 preserves the voltage difference between the base and the emitter of the BJT so it does not turn on unnecessarily. R5 limits the current to protect the V2 power supply. The diode, labeled as D1, stops the current from flowing backwards which would damage the power supplies. The BJT acts as a current amplifier; a small current at the base is used to control a larger current from collector to emitter. The IGBT behaves similarly but it can handle higher voltages. C1-C3 reduce the noise from the power supplies. After C4 charges, it discharges into the transformer. Once the voltage of about 100V goes into the transformer, it will then go to the spark gap. The spark gap consists of a spark plug and a screw to amplify the voltage again. This new amplified voltage will go to the spark chamber.

The next step involved sealing the chamber. The choices on sealing the chamber were to either use a sealant or use some strong adhesive like epoxy. Sealants differ from adhesives by keeping the outside elements from inside the system, while adhesives are meant to bind things together. Both options are viable in order to keep the gas inside the chamber. If epoxy was used to seal the chamber, it would be permanent. To prevent that from happening Lexel sealant was used. Before sealant was applied to chamber, a test was applied to on the edges of the scrap acrylic. The sealant proved to be useful so it was applied to the chamber.

After the first portion of the trigger circuit was created, the transformer needed to be made. The original plan was to use a step up transformer to raise the voltage and create a spark gap. However, transformers are primarily used for AC circuits. This meant that the next step would have been to create a non ideal transformer in order to raise the voltages. On top of the tediousness and difficulty of that process, using a non ideal transformer would have been very dangerous. If one component was out of place, someone could get seriously injured. Because of the danger and difficulty of that procedure, a different approach was advised to be taken.

After further research of which solution would be best, the use of a thyristor seemed like the best option. A thyristor is silicone controlled rectifier which will switch to on or off based on the current applied to it. The greatest issue with that approach was the price of the component. The Elctro Store sells a thyristors rated at 6kV for $1250; for the new proposed circuit, two of these thyristors would be needed. There is however trigger circuit being sold for $1700.

Data

Before this circuit was crafted, the circuit was simulated in multisim as shown in Figure 5.

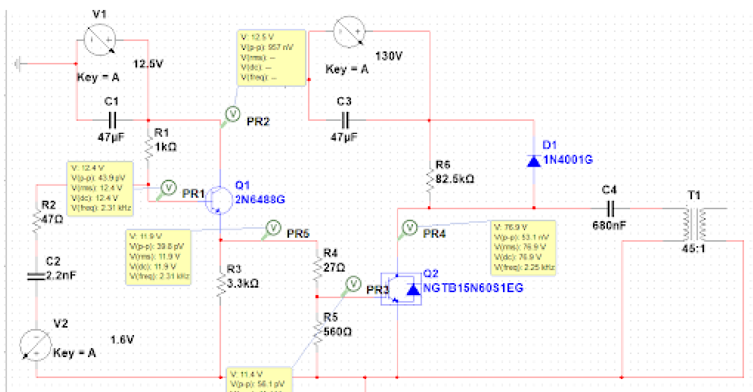

Figure 5: Simulated version of the trigger circuit

When the time came to craft this circuit, the components used in reality differed from the ones found in the simulation. The BJT was a tip42 rather than a 2N6488G and a SGP10N60RUFDTU IGBT was used instead of the one displayed in the diagram. Because of these changes, the variable power supply, V1, had to be changed from 12.5V to 17.6V In Table 1, the voltages that were probed can be seen.

Table 1: Measured Voltages

	Resistance
PR1	17.3V
PR2	17.4
PR3	4V
PR4	74.4V
PR5	4.7V

Although the changes made in the actual circuit created discrepancies in the simulation, the PR4 is the most important one. The goal of this circuit was to raise the 1.6V to around 75V. The circuit crafted in the real world scenario did just that.

Discussion and Conclusions

For future work, this project would have to be completed through the Summer Scholars program rather than through a capstone. The budget is not enough to support the price of safety for this project. If the summer scholar works closely with an electrical engineer, they could create the non ideal transformer and continue on the path I attempted to take. Although the project did not reach the original goals, the following was learned: knowing when to ask for help and applying physics and engineering to real world problems.

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