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Portable Muon Detector

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Abstract

This paper aims to describe the principle and construction of a portable muon detector that makes use of readily available electronic components to accurately detect the elementary particles that are muons. The portable muon detector utilizes the medium of a plastic scintillator for detection and a silicon photomultiplier for the collection of emitted light, all present in a self-containing package. The detector is powered by a portable battery, which through the Arduino code mounted on it, is able to detect the desired particles. The detector, therefore, is a cost-effective and low-power solution to the problem of portable muon detection.

Background

A flux of different particles, known as cosmic rays, bombard the earth in a continuous manner. Most of these cosmic rays, about 74 percent, are made up of Hydrogen – in ionized form – while about 18 percent of these rays are made up of helium nuclei and the rest are heavier elements in small amounts [1]. A greater portion of these rays strikes the earth at relativistic speeds which means that the kinetic energy that they possess is greater than their rest mass. Upon the collision of primary cosmic rays with the nuclei in the earth's upper atmosphere, energies are of such high scale that the primary particles or the target nuclei can be broken apart. In such collisions, a significant portion of this energy is taken up for the production of particles with short lifespans such as mesons – among which the most common are pions followed by kaons. The pions with a charge on them tend to decay, in about ten-billionth of a second, into muons with the same charge and neutrinos. Muons travel with relativistic speeds which makes it possible for an observer on earth to detect these particles courtesy of time dilation. For these particles to be detected on earth, they ought to interact with the material of a detector, the composition and working of which is the subject of discussion in the ensuing portion.

Components Used

The device that would be used to detect muon is composed of a small scintillator that emits light upon the passage of a charged particle, which is passed onto the photomultiplier that helps in the detection of the light. The components are placed in a small box, powered by a portable battery, which helps in registering the time of the muon impact, the number of these events, and the peak voltage, all with the help of a microcontroller – Arduino nano in this case.

[1] Olive, "Cosmic Rays - Particle Data Group."

Scintillator

Scintillators prove useful as they emit light when a charged particle passes through them. The amount of energy released depends on the initial kinetic energy of the particle striking and the distance that is covered by the particle. The working of the scintillators is based on the absorption of energy – by Coulomb interactions – and the reemission of energy through electromagnetic radiations – which might be otherwise termed scintillated light. Scintillators are of two types, that is, organic and inorganic scintillators. Organic scintillators tend to be costly, the reason being that they have a higher density and can therefore emit a greater number of photons based on the amount of energy that is added. Inorganic scintillators, on the other hand, are cost-effective as they are submerged in a low-density material, enabling them to be manufactured at a grander scale. These scintillators are made to be transparent in nature so that the scintillated light can travel through the medium and reach the photon detector. The Portable Muon Detector makes use of an organic plastic scintillator doped in a fluorescing agent, which emits light over the base limit of 400nm and below the upper limit of 420nm [2].

Silicon Photomultiplier

When some particle travels through the scintillator, it produces scintillated light, which is detected with the help of some light collection equipment. In traditional muon detectors, photon multiplier tubes are used to observe this light coming from the scintillators, but these tubes require a high voltage to operate, and they also tend to be costly. To this end, a single Silicon Photomultiplier is used which makes use of low reverse-biased voltage – that is, the source of negative voltage is connected with the anode while a source of positive voltage is connected with a cathode. Moreover, since a large portion of the light emitted by the scintillator is in the blue

[2] Beznosko et al., "FNAL-NICADD Extruded Scintillator."

region, the Silicon Photomultiplier, which also has peak sensitivity in this very region, becomes the perfect component to be used for the observance of light emitted. The Silicon Photomultiplier also makes for an inexpensive mode of light detection as it has a low reverse bias, requiring little production cost to manufacture.

Other Components

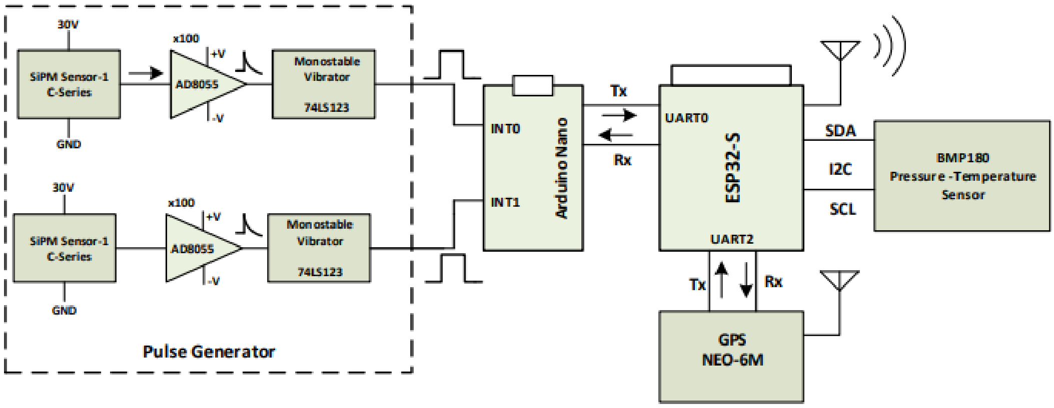
Three Printed Circuit Boards (PCBs) are employed in the Portable Muon Detector. The first of these PCBs are used to install the Silicon Photomultiplier, which helps the device in providing the bias filtering that is required. This PCB ought to be mounted directly on top of the scintillator so that pressure is applied on the Silicon Photomultiplier, which would make sure that a tight linkage is established between the two components and an optical connection is established between the two. The second Printed Circuit Board (PCB) is used to mount the electronic components that would be used in the amplification and shaping of the signal that is received from the Photomultiplier. The signal is tinkered with in such a manner that it enables the efficient measurement by the controller. In addition to this, the second PCB also helps in providing the filtration and regulation of the voltages that are to be utilized by the detector. The third PCB that is to be utilized is used to provide voltage to the components under consideration. The data that is to be generated is to be read by an Arduino Nano – 16 MHz, ATmega328 – which makes for an inexpensive a cost-effective controller [3]. The PMD code is uploaded to the Arduino before soldering the header pins onto the Arduino to ensure its accurate working. The current produced by the incident photons is sent from the PCB to the Arduino which measures the event timestamp and peak value on the analog-to-digital converter (ADC). If the measured ADC value is above a software-defined threshold, the micro-controller records the event data.

[3] Aqeel, "Introduction to Arduino Nano."

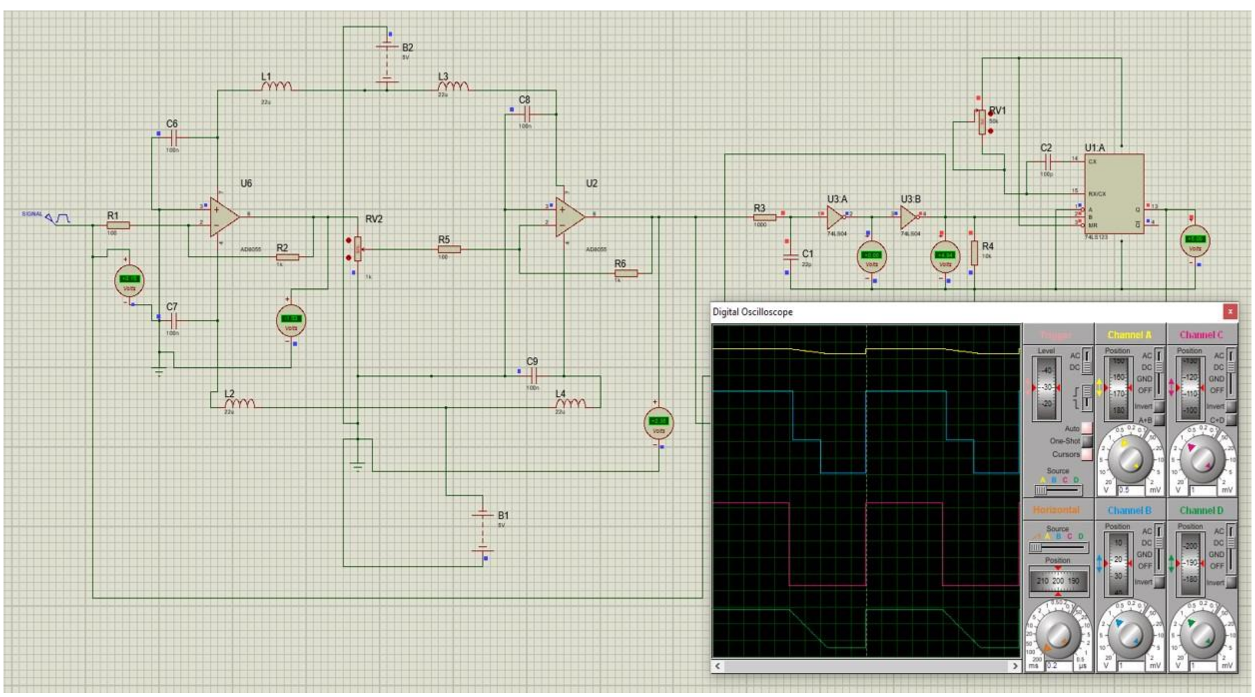
Working

When a charged particle passes through a scintillating material, part of its energy is absorbed and re-emitted as photons. The light-sensitive device – that is, the silicon photomultiplier – is used which is coupled to the scintillator to observe these photons. A single photon can make a measurable signal in the silicon photomultiplier. The produced signal is amplified and shaped in such a way that we can measure both how many photons were observed and at what time they arrived using an Arduino Nano.

Simulation

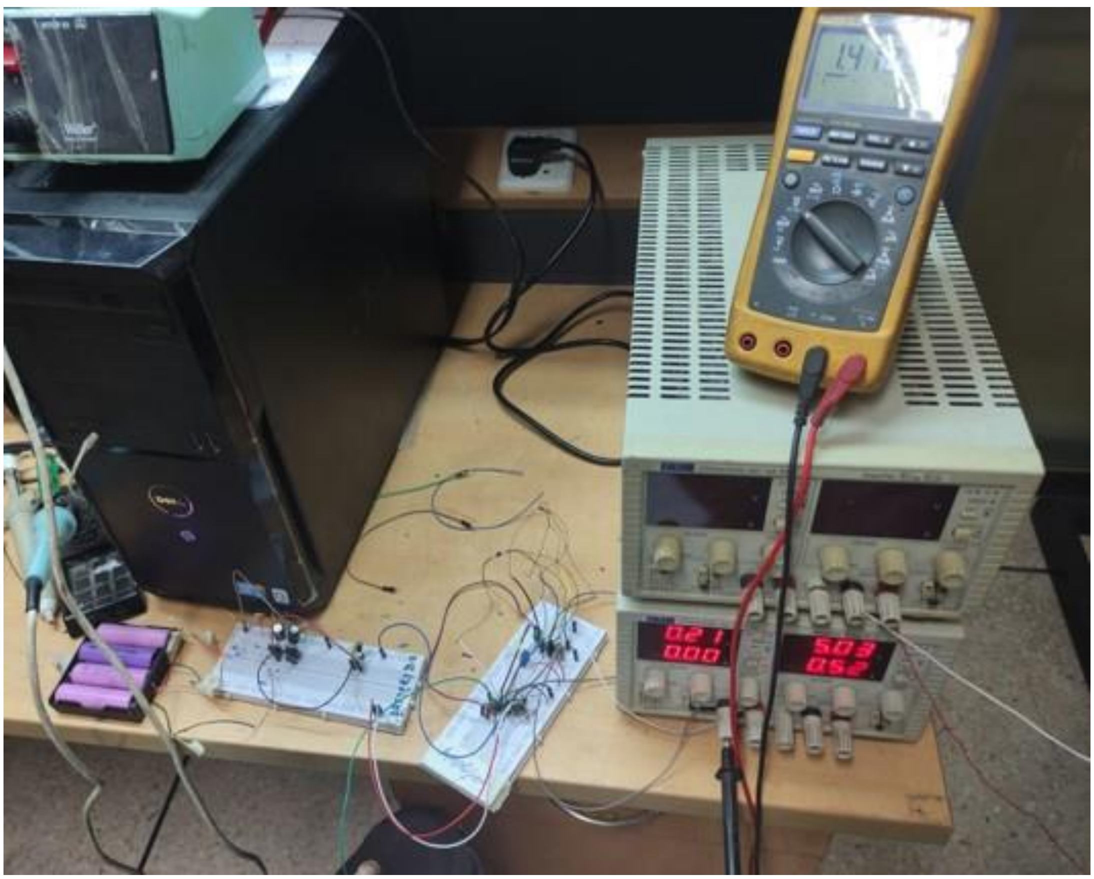


The first step in designing the portable muon detector was designing and simulating the pulse generator circuit in a digital environment. Proteus software was used for this purpose. By first running a simulation of our circuit, we were able to test that individual circuit inside pulse generator was working correctly and that we were getting right amount of amplification and wave shaping. Square wave output was necessary for the Arduino circuit to be able to count the number of muons passing through the setup.



Breadboard Circuit

After successfully testing pulse generator circuit on Proteus, next step was designing a barebone test setup using breadboard, connecting wires, rechargeable batteries and individual components without soldering them down on PCB. This allowed us to test individual components for any faults and interoperability. As the main pulse generator circuit is composed of three smaller circuits, working with breadboards also allowed us to design each smaller circuit on a separate breadboard so that when testing, we could focus on each circuit at a time.



Conclusion

During the project we designed and tested the pulse generator circuit that is to be used alongside plastic scintillator, Arduino Nano and ESP32 module to collect and record the number of muons passing through the package in a given time window. This entire package is designed to be highly portable, and battery operated and allows data to be transmitted and stored wirelessly using ESP32 protocol.

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