Compact Silicon PIN Photodiode Sensor for Secondary Cosmic Ray Detection at Aviation Altitudes

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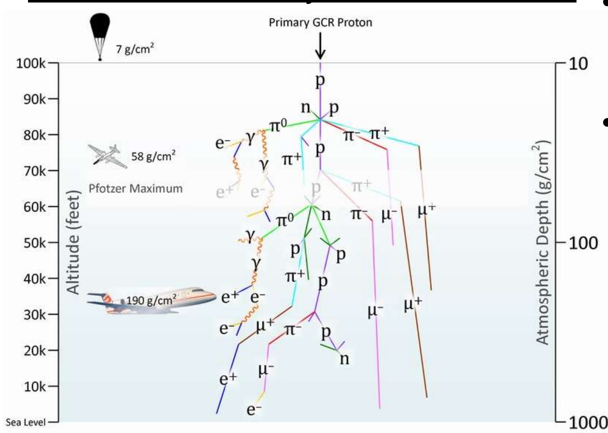
Abstract

Exposure to radiation caused by cosmic rays and solar events in space poses a threat to human health and travel in space. Current dosimeters for monitoring crew radiation dosage are often expensive and bulky. We propose a compact and economical design for a dosimeter suited for rocket flight. Drawing from established detector architectures, our design centers on a silicon PIN photodiode detector coupled to a charge sensitive preamplifier and pulse shaping amplifier. When a particle deposits energy into the active region of the photodiode, a current pulse is converted to a voltage pulse by the preamplifier, which is processed by the shaping amplifier to be read by an analog to digital converter. Measurements from this process will be used for obtaining dose rate as a function of time. To calibrate the dosimeter, known radioactive sources were used. A mounting system is subsequently being developed for rocket flight. Resulting prototypes will be flown with the OSU High Altitude Rocketry Club, and later models on the NASA WB-57 research aircraft, Blue Origin's New Shepard, and the International Space Station. The development of flight-ready radiation detectors made of readily available electronic components stands to make rocket-borne dosimetry more economical, providing another tool in the analysis of space and near-space radiation environments.

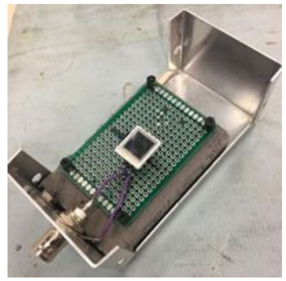
Galactic Cosmic Rays and Air Showers

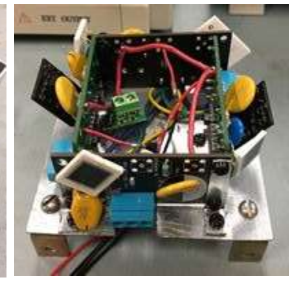


- Galactic Cosmic Rays (GCR) are highly energetic particles that consistently bombard the Earth's atmosphere.
- The GCR spectrum consists of 98% protons and heavier elements, and 2% electrons and positrons.
- When these primary high energy particles collide with nuclei in the upper atmosphere, they initiate cascades of secondary particles referred to as Extensive Air Showers.
- Commercial aircraft fly at altitudes where the radiation environment is commonly affected by these Extensive Air Showers.

Photodiodes

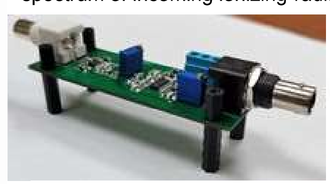
- Incoming ionizing radiation deposits energy into the silicon photodiode, creating many electron-hole pairs in the material.
- Freed electrons are swept to the detector's cathode by a high-voltage reverse bias.
- The movement of the electrons through the electric field generates a current pulse with magnitude proportional to energy of the incident particle

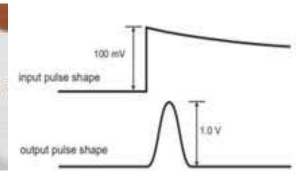




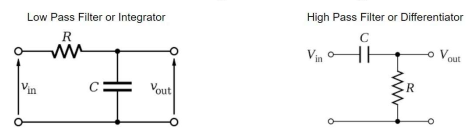
Analog Signal Conditioning

- The signal produced by the photodiode is input to a charge-sensitive preamplifier, The CSP converts the current pulse into a tailed voltage pulse on the order of millivolts.
- The pulse output by the CSP is then input to a shaping amplifier, which amplifies the pulse to the order of volts and shapes it from a tail pulse to a gaussian pulse while maintaining the relationship between the height of the pulse and the energy of the incident particle.
- The shaped pulse is then digitized using an analog to digital converter and placed into an energy bin using a multi-channel analyzer and software, allowing the detector to measure the full spectrum of incoming ionizing radiation.

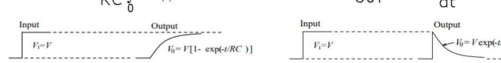




Filters & Signal Processing



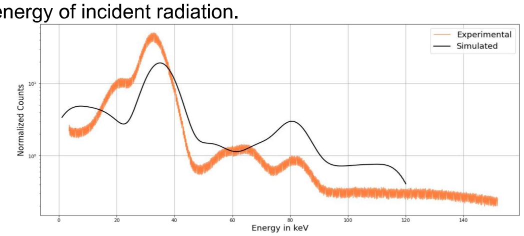
$$V_{OUT} = \frac{1}{RC}\int_0^t V_{IN(t)}\,dt \qquad V_{OUT} = RC\frac{dV_{IN}}{dt}$$



Images from Dr. Andrew Boston at University of Liverpool

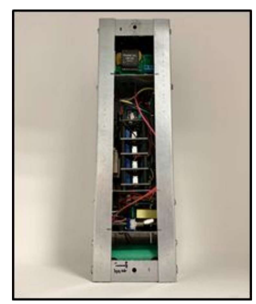
Calibration and Verification

- Useful sources are simulated using a Monte Carlo simulation called Fluka.
- FLUKA spectra must be convoluted with a gaussian curve to simulate the resolution of the detector. Shown is the gamma-ray spectrum of Barium-133.
- Using known gamma and x-ray peaks, a linear function can be obtained relating the amplitude of a voltage pulse and the energy of incident radiation.



Test Flights

Several test flights of the detector are planned over the next two years. Two preliminary flights of AirSiD (shown bellow) to 10,000ft using rockets built by the Oklahoma State University High Altitude rocketry club will be flown in 2022. Further flights on the NASA WB-57 (shown bellow) to altifudes in excess of 60,00ft are also planned for 2022. The detector will also be flown twice in 2023 as part of a suite of instruments, once on a suborbital flight using Blue Origin's New Shepard suborbital rocket (shown bellow), and on the International Space Station.



Acknowledgements

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