Silicon Photomultipliers for JEM-EUSO

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Abstract

The Japanese Experiment Module – Extreme Universe Space Observatory (JEM-EUSO) mission is designed to explore the most energetic particles known to occur in nature, ultra-high-energy cosmic rays (UHECRS). By looking down at the night sky from the International Space Station, JEM-EUSO will be able to detect the UV photons produced by UHECRS air showers in our atmosphere. Current plans for the design of JEM-EUSO call for a focal surface utilizing photomultiplier tubes (PMTs). While PMTs have been used in similar projects before, a new technology may be replacing them as the better alternative. Silicon photomultipliers (SiPMs) are quickly becoming this new option. SiPMs demonstrate many of the same qualities of with superior performance in detection efficiency, angular resolution, and reliability. Since the SiPMs intrinsic background is affected by ambient temperature, the focus of this research is to test the performance of these detectors at cryogenic temperatures.

JEM-EUSO

The primary goal of the JEM-EUSO project is to study ultra-high-energy cosmic rays (UHECRS) and their sources, with exploratory objectives of studying high-energy neutrinos and particle physics beyond the Standard Model. Cosmic rays are not a rare phenomenon and most cosmic rays have been subjected to research since Victor Hess discovered them in 1912. But most of these cosmic rays have high flux. UHECRS air showers have a frequency of 1 per km^2 per century for energies above 10^{20} eV. JEM-EUSO is designed with a field of view of +/- 30°, which will give the project the highest exposure of any UHECRS test ever attempted. The annual exposure for JEM-EUSO is ~9 times greater then the Pierre-Auger Observatory in Argentina. The observatory will utilize three Fresnel lenses to focus photons on to a single focal surface. The focal surface must be optimized to operate in the near-UV spectrum and have a low power budget. Photomultiplier tubes are the planned detectors for the focal surface, but current research is being done on silicon photomultipliers to see if they are a better alternative.

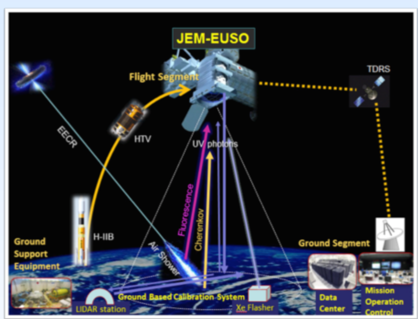

Figure 1. Cosmic ray air showers produce two types of light as they enter the atmosphere. The first source of light is from the excitation of nitrogen from the secondary particles in the air showers. This light is called fluorescence light. The second source is from Cherenkov light, which is produced because the secondary particles are traveling faster than the speed of light within our atmosphere.

Silicon Photomultipliers

SiPMs contain multiple micro-pixels of avalanche photodiodes (APDs) that are uniquely operated at a reverse bias voltage (operating voltage) above the APDs breakdown voltage. This overvoltage ($V_{bias} - V_{breakdown}$) creates an electric field in the APD that becomes high enough to cause an avalanche breakdown from very weak light entering the APD. The avalanche breakdown is the result of impact ionization from a single photon striking a silicon atom inside the diode. This method is effective at counting photons, but it is also susceptible to ambient heat firing the micro-pixels and causing noise.

A parameter that SiPMs must meet before replacing PMTs is maintaining a low-power budget per channel (<0.5 mW) and having a low dark count rate (<100 kHz).

	PMT	SiPM
• **Photon Detection Efficiency**	~40%	~50%
• **Operating Voltage**	900 V	70 V
• **Effected by Magnetic Field**	Yes	No
• **Charge Resolution**	Good	Very Good
• **Gain**	10^6	10^6

*PMT data is from a Hamamatsu Multi-Anode Photomultiplier Tube (MAPMT)
*SiPM data is from a Hamamatsu Multi-Pixel Photon Counter (MPPC)

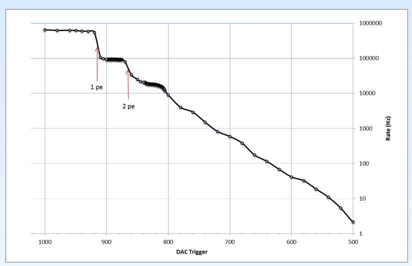

Figure 2. Dark pulses are a major factor in SiPM noise; they are caused by several factors, including ambient heat. Using the EASIROC application-specific integrated circuit (ASIC), an electrical signal caused by a dark pulse firing of the SiPM can be read out. The initial signal from the SiPM is amplified, shaped, and coupled to a discriminator to determine whether its value exceeds the noise threshold setting. The threshold is set using the DAC (digital-to-analog converter) trigger on the EASIROC. Higher DAC values allow more noise to be read out. The threshold at which the dark count rate abruptly decreases correspond to the level of one photoelectron, two photoelectrons, and so on from left to right. The data shown was taken at -30 °C.

Determination of $V_{Breakdown}$

The $V_{breakdown}$ of an SiPM is an important characteristic to understand if we are to lower the power of these detectors to meet the power budget per channel for JEM-EUSO. To achieve the goal of having the power per channel less than 0.5 mW, we decided to test if cooling the detectors down would lower the $V_{breakdown}$, and thus lower the operating voltage.

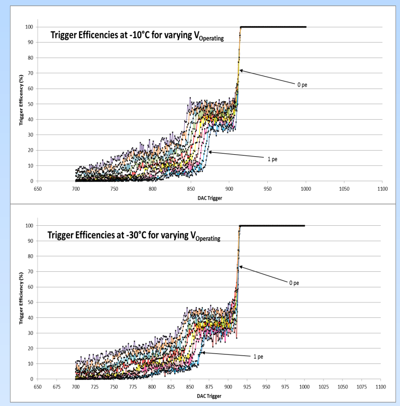

Figure 3. Using a LabView software developed for the EASIROC, trigger efficiencies can be read out over a sweep of threshold DAC trigger values for several different operating voltages. The left abrupt change is equivalent to 1 photo-electron and the right abrupt change is equivalent to 0 photo-electrons.

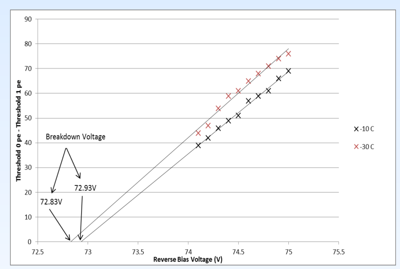

Figure 4. *Threshold 0 pe – Threshold 1 pe = Single Avalanche Breakdown.* Interpolating the data from the threshold DAC trigger sweeps at different reverse bias voltages can be used to find the $V_{breakdown}$. It is evident from the data that reducing the temperature of the SiPMs will reduce the $V_{breakdown}$.

Dewar

Further testing of the SiPMs must be done at cryogenic temperatures to see if the $V_{breakdown}$ continues to drop as the temperature is decreased. To achieve this task, we are putting a SiPM into a custom-built IRLabs dewar. This dewar can be depressurized and cooled down using liquid nitrogen. Using a temperature controller, temperatures can be maintained from 100K to +270K. With this scheme, we will be able to prove that SiPMs should replace PMTs on the JEM-EUSO project.

Conclusion

The dewar is almost ready to analyze a SiPM. Once set up, testing of the dark pulse rate and breakdown voltage can occur. The eventual goal will be to examine an array of 64 SiPMs within the dewar. If the SiPMs meet the standards that have been set by JEM-EUSO, they may eventually replace the PMTs that are already planned for the project. As SiPMs meet or exceed PMTs in many characteristics, this will only improve JEM-EUSO.

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This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Community College Internships (CCI) Program.