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Study of Radiation Effects on CREAM Electronics

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Abstract: The Cosmic Ray Energetics and Mass (CREAM) instrument is currently being reconfigured for the International Space Station (ISS). The space radiation environment originating from several sources, such as galactic cosmic rays, energetic solar particles from the Sun, and trapped particles in the radiation belts, create special design challenges. Environments with high levels of ionizing radiation can cause Single Event Effects (SEEs), such as bit flips, current spikes, and other malfunctions in electronic components. SEEs in electronic components have been studied using heavy ion beams, 15 MeV/amu He, Ne, Ar, Cu, Xe, and Au nuclei, in the range of Linear Energy Transfer (LET) from 0.121 to 85.4 MeV-cm^2/mg. Single Event Latchup (SEL) and Single Event Transient (SET) rates were measured. Results from radiation tests performed at the Texas A&M University cyclotron beam facility and projections to the electronics' performance aboard the ISS are presented.

Keywords: CREAM, single event effect, ISS

1 Introduction

Cosmic Ray Energetics and Mass (CREAM) [1] is composed of many subdetectors that are designed to make measurements of cosmic ray spectra. It has flown by balloon a total of six times for a cumulative exposure of about 161 days. The CREAM design is currently being reconfigured attachment to the International Space Station (ISS) [2], where its electronic components will be exposed to higher radiation as the instrument orbits above the protection of Earth's atmosphere. The radiation flux on the ISS varies over the solar cycle. We consider two cases of radiation flux: the flux during a solar minimum and the flux during a solar maximum, both calculated for a quiet magnetosphere including trapped protons [3, 4]. We measured the SEE cross-sections of the various components, so we can implement protection from SEEs if needed. The fluence, or the number of particles per unit area that passed through the component without initiating a SEE, of each component was obtained by exposing the components to the Texas A&M University (TAMU)'s cyclotron beam [5]. The beam was forced to shut off if the signal in the component was disrupted by an SEL, so the fluences for the SEL runs were also recorded and analyzed. SETs caused only momentary disruptions that did not cause the beam to shut off; since it was only noted that the SETs occurred, but not the fluence at which the SETs occurred, it was necessary to estimate the SET cross-sections.

2 Experimental Setup

The plastic covering each of the tested electronics components was removed so that the silicon was fully exposed to the incoming ion beam. Six decapsulated components were exposed to TAMU's 15 MeV/amu ion beam: AD7663, MAX5353, 74HC123, MAX378, MAX924, and MAX4377. They were exposed to beam species including He, Ne, Ar, Cu, Au, and Xe. The incident angle of the beam between the normal of the electronic component and the beam was allowed to vary over different runs. The beam diameter was about 1 inch. The beam flux and fluence were determined by several 0.1 cm^2 detectors stationed a characteristic distance (4.71 mm) from the beam axis.

The experimental setup included the Device Under Test (DUT), which was housed on the DUT board. The specific DUT board varied depending on the DUT component. The DUT board was connected to a computer and monitored by a LabView program. A 5V power supply powered the DUT board. The DUT was exposed to the radiation beam while the computer and other test components were kept away from the test beam. All connections were USB.

3 Analysis

The LETs of 15 MeV/amu He, Ne, Ar, Cu, Xe, and Au ion beams projected normal to a silicon target have been provided by the TAMU facility. Higher LET than that when the beam is normal to the component was obtained by exposing components at an angle α. The LET at an angle α is given by Equation 1:

$$LET = LET_{\text{norm}}/\cos\alpha, \qquad (1)$$

where LET_{norm} is the LET when the beam is normal to the component, and α is the angle between the normal of the component and the beam.

The beam flux must be accounted for in a similar manner. The beam flux is monitored by the detectors stationed about the beam axis. When the component is oriented at an angle with respect to the beam, the beam flux decreases from the normal flux. The fluences for SEE cross section measurements were obtained by integrating the beam flux over the time duration from the beginning of the beam spill until the SEE signal appears. Multiplying the resulting cross-section by the radiation flux on the ISS and integrating over LET gives the predicted SEE rate of the component [6] as shown in the following equation:

$$R = \int_{LET} \sigma \cdot \phi \, \mathrm{d}(LET), \qquad (2)$$

where R represents the SEE rate, σ is the SEE cross-section, and ϕ is the radiation flux of cosmic rays on the ISS.

4 Results

4.1 AD7663

The AD7663 is a 16-bit analog-to-digital (ADC) converter. It will be included in the calorimeter and will be used for data acquisition. No SETs were observed for any runs. There were no SELs for the He or Ne runs, with fluences of 10^7 cm^{-2}, but there were SELs for all the Ar, Cu, and Xe runs. The effective LETs for the He and Ne runs were 0.137 MeV-cm^2/mg and 3.52 MeV-cm^2/mg, respectively. There were a total of 3 runs of the Ar beam corresponding to an effective LET of 8.3 MeV-cm^2/mg, with fluences of 5.33×10^5 cm^{-2}, 8.05×10^5 cm^{-2}, and 1.11×10^6 cm^{-2}. There were 5 runs of Ar that corresponded to an effective LET of 10.8 MeV-cm^2/mg, with fluences of 5.68×10^4 cm^{-2}, 3.39×10^5 cm^{-2}, 4.09×10^5 cm^{-2}, 5.42×10^5 cm^{-2}, and 1.52×10^6 cm^{-2}. There were 5 runs of Cu corresponding to a LET of 19.6 MeV-cm^2/mg, with fluences of 1.33×10^4 cm^{-2}, 2.27×10^4 cm^{-2}, 5.17×10^4 cm^{-2}, 6.09×10^4 cm^{-2}, and 1.08×10^5 cm^{-2}. The Xe beam, with an effective LET of 49.3 MeV-cm^2/mg, had 6 runs with fluences of 2.90×10^2 cm^{-2}, 6.07×10^2 cm^{-2}, 6.37×10^2 cm^{-2}, 1.90×10^3 cm^{-2}, 2.41×10^3 cm^{-2}, 3.09×10^3 cm^{-2}. The AD7663 SEL cross-section data were fit to a power law with index 3.49 ± 0.53 (Fig. 1). An average was taken for multiple runs for the fluence data, with the error bars in Fig. 1 representing standard deviation. Assuming continuous operation of AD7663, estimated SEL rates are 1.19×10^{-7} SELs/day during solar maximum and 6.85×10^{-7} SELs/day during solar minimum.

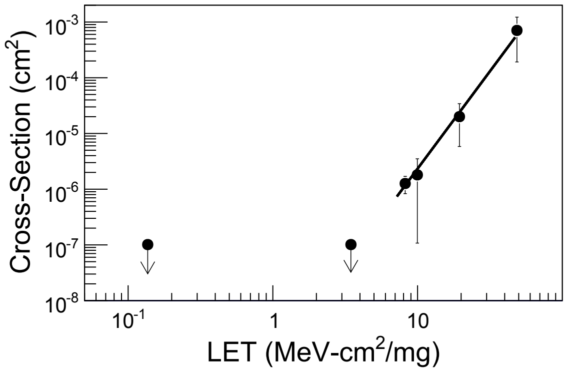

Fig. 1: SEL cross-section data for the AD7663 chip. The two leftmost data points represent the two measured LET values for which there were no SELs. A power law fit was taken for the four points (right) for which there were SELs.

4.2 MAX5353

The MAX5353 is a low-power, 12-bit voltage output digital-to-analog (DAC) converter with a serial interface. It will set the high voltage value and trigger thresholds. There were no SELs observed for any runs. There were no SETs for the He, Ne, or Ar runs, but there were SETs for the Cu and Xe runs. The effective LETs for the He, Ne, and Ar runs were 0.128 MeV-cm^2/mg, 3.30 MeV-cm^2/mg, and 10.1 MeV-cm^2/mg, respectively. Cu had an effective LET of 23.9 MeV-cm^2/mg and the Xe run had an effective LET of 49.3 MeV-cm^2/mg. The lowest measured effective LET at which a SET occurred for the MAX5353 component is 23.9 MeV-cm^2/mg, and the highest measured effective LET for which there were no SETs is 10.13 MeV-cm^2/mg. To be conservative, the SET cross-section was assumed to be zero for values below and including 10.13 MeV-cm^2/mg, and then take on a value of 1 cm^2 for all LETs greater than 10.13 MeV-cm^2/mg. The estimated rates for a single MAX5353 component operating continuously are no more than 4.47×10^{-3} SETs/day during solar maximum and 3.58×10^{-2} SETs/day during solar minimum.

4.3 74HC123

The 74HC123 component is a high-speed complimentary metal-oxide semiconductor dual retriggerable monostable multivibrator with a controllable output pulse width. It will be used for peak-hold delay. There were no SEEs for the He, Ne, Ar, Cu, and Xe beams, which had effective LETs of 0.121 MeV-cm^2/mg, 3.12 MeV-cm^2/mg, 9.58 MeV-cm^2/mg, 22.6 MeV-cm^2/mg, and 49.3 MeV-cm^2/mg respectively. The highest measured LET value was 49.3 MeV-cm^2/mg, so to be conservative, the cross-section was estimated to be zero before 49.3 MeV-cm^2/mg and 1 cm^2 above 49.3 MeV-cm^2/mg. The estimated SEE rates for a single 74HC123 component operating continuously are no more than 2.03×10^{-7} SETs/day and 2.03×10^{-7} SELs/day during solar maximum and 1.30×10^{-6} SETs/day and 1.30×10^{-6} SELs/day during solar minimum.

4.4 MAX378

The MAX378 component is an 8-channel, single-ended multiplexer with fault protection. It will be included in the calorimeter and will be used for housekeeping. It experienced no SELs during the beam test. The Ne and Cu had effective LETs of 3.30 MeV-cm^2/mg and 23.9 MeV-cm^2/mg, respectively. There were two Xe runs, with effective LETs of 51.5 MeV-cm^2/mg and 62.9 MeV-cm^2/mg. The Au run had an effective LET of 85.4 MeV-cm^2/mg. There were no SETs for the runs with effective LETs of 3.30 MeV-cm^2/mg, 23.9 MeV-cm^2/mg, or 62.9 MeV-cm^2/mg, but there were SETs for the runs with effective LETs of 51.5 MeV-cm^2/mg and 85.4 MeV-cm^2/mg. The lowest measured LET value at which a SET was observed is 51.5 MeV-cm^2/mg, and the next lowest measured LET value is 23.9 MeV-cm^2/mg. To be conservative, the SET cross-section takes on a value of 1 cm^2 for all effective LETs above 23.9 MeV-cm^2/mg. The estimated rates for a single MAX378 component operating continuously are no more than 2.96×10^{-4} SETs/day during solar maximum and 2.39×10^{-3} SETs/day during solar minimum.

4.5 MAX924

The MAX924 component is an ultra low-power, single/dual supply comparator with adjustable hysteresis. It will be included in the power module. There were no observed SELs in any of the runs. There were no SETs for the Ne run, but there were SETs for all the Cu, Xe, and Au runs. The Ne run had an effective LET of 3.30 MeV-cm^2/mg. There was one run of Cu with an effective LET of 23.9 MeV-cm^2/mg. There were three runs of Xe: two with an effective LET of 51.5 MeV-cm^2/mg, and one with an effective LET of 62.9 MeV-cm^2/mg. There was also one run of Au with an effective LET of 85.4 MeV-cm^2/mg. The lowest measured LET for which a SET occurred was 23.9 MeV-cm^2/mg, and the next lowest measured LET value was 3.30 MeV-cm^2/mg; to be conservative, the SET cross-section takes on a value of 1 cm^2 just above 3.30 MeV-cm^2/mg. The estimated rates for a single MAX924 component operating continuously were no more than 8.01×10^{-2} SETs/day during solar maximum and 5.53×10^{-1} SETs/day during solar minimum.

4.6 MAX4377

The MAX4377 component is a dual high-side current-sense amplifier with internal gain and buffered output. It will be included in the power module to monitor the current. There were no SEEs for MAX4377. The Ne beam had one run with an effective LET of 3.30 MeV-cm^2/mg. The only run of Cu had an effective LET of 23.9 MeV-cm^2/mg. There were two runs of Xe: one with effective LET of 51.5 MeV-cm^2/mg and the other with effective LET of 62.9 MeV-cm^2/mg. The Au beam had three runs with an effective LET of 85.4 MeV-cm^2/mg. The highest measured effective LET value for this component was 85.4 MeV-cm^2/mg, so to be conservative the cross-section takes on a value of 1 cm^2 just above this value. The estimated rates for a single MAX4377 component operating continuously are no more than 6.96×10^{-9} SETs/day and 6.96×10^{-9} SELs/day during solar maximum and 4.36×10^{-8} SETs/day and 4.36×10^{-8} SELs/day during solar minimum.

5 Conclusion

Eighty AD7663 components will operate continuously in the calorimeter. The estimated SEL rate due to the AD7663 components are 9.55×10^{-6} SELs/day during solar maximum and 5.48×10^{-5} SELs/day during solar minimum. A protection circuit is implemented in the board that houses the AD7663 components to minimize the number of SELs. The 76 continuously-operating MAX5353's components in the reconfigured CREAM instrument would result in SET rates of no more than 0.34 SETs/day during solar maximum and 2.72 SETs/day during solar minimum. A resistor-capacitor filter is implemented after the DAC to ensure the successful operation of the component. Fifty-two 74HC123 components are part of the experiment. The pulse output of the device will be used approximately 1% of the time, so the estimated SET rates would be below 1.06×10^{-7} SETs/day during solar maximum and 6.73×10^{-7} SETs/day during solar minimum. The estimated SEL rates are below 1.06×10^{-7} SELs/day during solar maximum and 6.73×10^{-7} SELs/day during solar minimum. These rates are low enough that protection from SETs is not required for this component.

Continuous operation of thirty-six MAX378 components in the calorimeter would result in SET rates of no more than 1.06×10^{-2} SETs/day during solar maximum and 8.61×10^{-2} SETs/day during solar minimum. The SET rate for this component only affects housekeeping data, which is updated every five seconds, so SET protection is not required. Continous operation of fourteen MAX924 components would have an estimated rate of 1.12 SETs/day for the solar maximum flux and 7.74 SETs/day for the solar minimum flux. Digital/analog filters are implemented to ensure the successful operation of the component. Continuously operating fourteen MAX4377 components would result in rates of no more than 9.74×10^{-8} SETs/day and 9.74×10^{-8} SELs/day during solar maximum and 6.10×10^{-7} SETs/day and 6.10×10^{-7} SELs/day during solar minimum. This current-sense amplifier will be filtered in order to mitigate SETs.

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