Proton Single Events Effects Testing by Undergraduate Students for University CubeSat Mission Assurance

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I. Abstract

The PROVES (Pleiades Rapid Orbital Verification Experimental System) Flight Controller Board was irradiated with 200 MeV Protons to a total fluence of 1e10 across multiple runs. Using the n/2000 method [1], this report has concluded the Non-destructive Single Event Effect (SEE) error rate of the Flight Controller Board to be 0.183 SEE per system day.

Figure 1:
(Top Left) Loma Linda Medical University Center,
(Top Right) Exterior Set Up, (Bottom Left) Debugging and Resoldering,
(Bottom Right) Beam Preparation Set Up

II. Introduction

The PROVES CubeSat is a low-cost, modular bus that has been launched into Low Earth Orbit (LEO) three times. In the first launch, the PROVES CubeSat failed to deploy into orbit due to an issue with the host vehicle. However, with the following launches, the PROVES CubeSat lasted for 50 minutes in the second launch and for 9.5 hours in the third launch.

In response to the short lifetimes of both missions, radiation testing was performed to help deduce whether radiation was a root cause. Specifically, SEE testing was conducted to see how critical electronic components would behave to High Energy Proton and Heavy Ion induced SEE. Out of the two, High Energy Protons were chosen since they are of concern in Polar LEO where trapped protons from the Van Allen Belts and protons from solar flares become a concern and can induce SEEs into the system. [2] It is also cost effective to test for SEEs with High Energy Protons and are the particles standardly used in the industry for the board-level method. [1] Due to the 97.5-degree inclination of the satellites, heavy ions also become a concern since the path of the satellite crosses the South Atlantic Anomaly (SAA) in which there's a dent in the Earth's magnetic field. However, heavy ions will not be the focus of the poster.

For the purposes of the PROVES program, Board Level testing was chosen over the traditional radiation testing method where each individual component on a particular board gets tested for SEEs. While the latter does provide more insight and detail, the board level method was ultimately chosen due to its cost effectiveness and as a first step to understanding the effects of radiation on a system level.

The Flight Controller Board is the computer for the PROVES Satellite and it provides all the command and data handling for the satellite. The FC board hosts the RP2040 microcontroller, 128 Mbit QSPI Flash memory, HopeRF 433 MHz Radio Module, an External Watchdog Timer, Bent Dipole Antenna, LiDAR sensor to detect the deployment of Antennas, and a MicroSD card slot. There is also a 12-pin Molex Picolock connector that is used to interface with the Electrical Power System (Battery Board) of the satellite.

III. Procedure

Three Flight Controller Boards were irradiated with 200 MeV protons at varying fluences. They are labeled RSN (Radiation Sample Number) 1, RSN 2 and RSN 3 respectively. To simulate flight like conditions of the second PROVES CubeSat that was launched, RSN 1 both did not have a configured Watchdog Timer. On the other hand, RSN 2 did have a configured Watchdog Timer to simulate flight-like conditions of the third PROVES CubeSat that was launched.

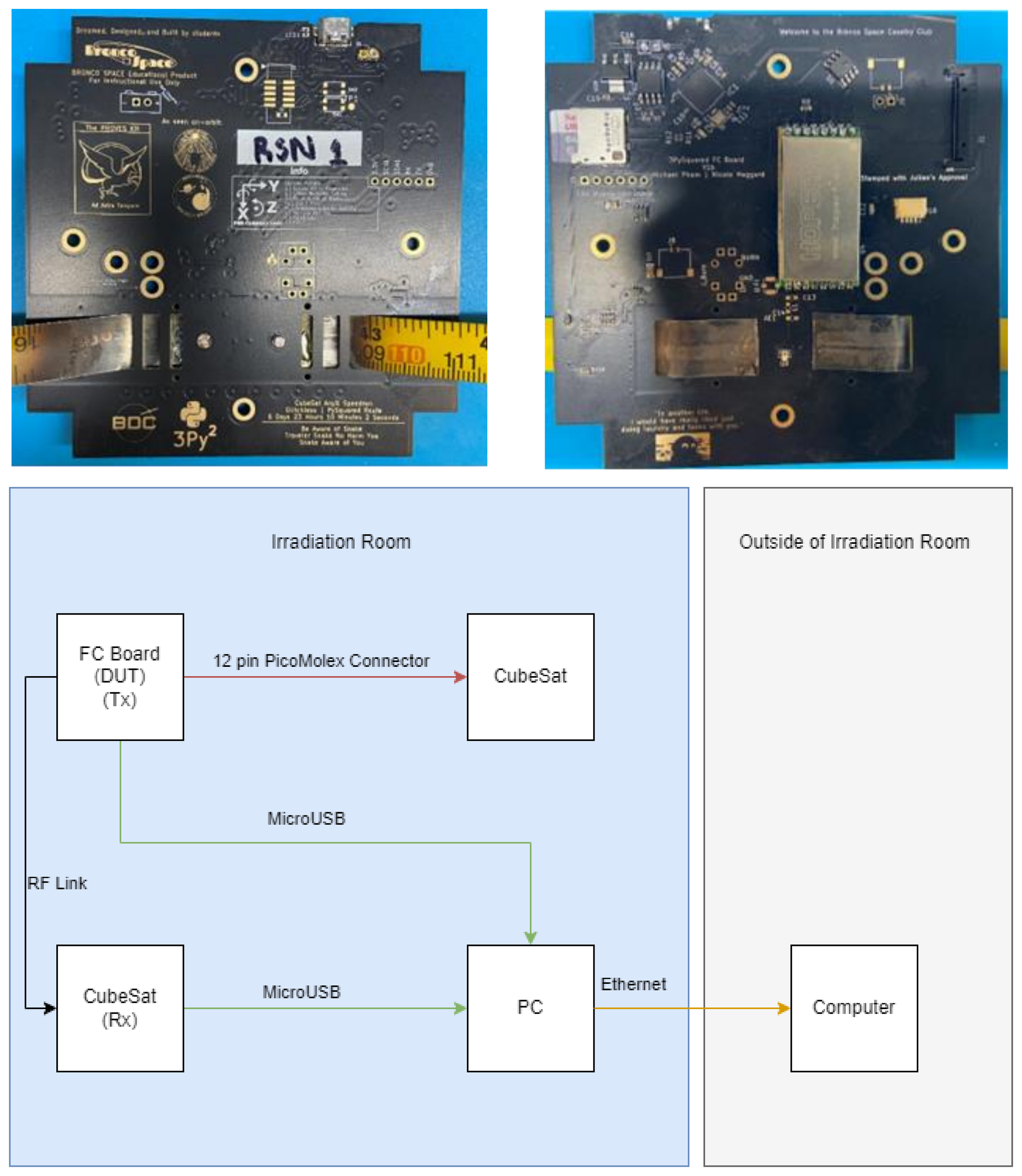

Figure 2:
(Top Left) PROVES FC Board Front View, (Top Right) PROVES FC Board Back View, (Bottom) System Block Diagram

IV. Results

RSN 1 has been irradiated a total of 9 times and has outputted 183 errors across all 9 runs. It has also been irradiated to a total fluence of 5.22e9. There weren't any observable SEEs from runs 1 – 5 but runs 6 – 8 constituted for 80 percent of the total SEEs during the test for RSN 1. There were non-destructive effects that were observed and data losses, but they did not pose a complete board failure and the board still operated nominally throughout the test with these errors. They were also recoverable after the test through a power cycle. RSN 1 has disconnected from the computer's terminal and stopped transmitting to the Rx Board in 6 out of the 9 runs but has been recoverable through power cycling the board. Due to this, RSN 2 was tested with the watchdog timer enabled. RSN 2 was irradiated to a slightly higher fluence of 7.20E+09 and 37 total errors were encountered. A lower number of errors occurred with the runs in RSN 2 and a power cycle after the test helped clear any existing non-destructive errors.

	RSN 1 Results			**RSN 2 Results**		
Run No.	**Errors**	**Flux (p/cm²/min)**	Fluence (p/cm²)	**Errors**	**Flux (p/cm²/min)**	**Fluence (p/cm²)**
1	0	1.01E+08	9.77E+07	0	1.07E+08	4.7E+08
2	0	1.04E+06	1.07E+07	0	1.03E+08	1.00E+09
3	0	1.00E+08	1.00E+09	4	1.05E+08	1.01E+09
4	0	1.03E+08	2.98E+08	0	7.33E+08	1.7E+09
5	0	9.43E+07	5.47E+08	1	6.97E+08	2.01E+09
6	78	1.04E+08	8.76E+08	32	1.07E+08	1.01E+09
7	70	1.05E+08	9.11E+08	---	---	---
8	32	1.03E+08	1.01E+09	---	---	---
9	3	1.02E+08	4.67E+08	---	---	---
Total	183		5.22E+09	37		7.20E+09

Figure 3:
Table of Results for RSN 1 and RSN 2

V. Next Steps

Valuable data about the functionality of the PROVES FC Board was collected with the 200 MeV Board Level test. Non-destructive errors were seen throughout the tests and ranged from data losses to functional interrupt in the board. To better trace down the root cause of the functional interrupts causing the board to disconnect from the terminal and subsequently the loss of radio transmission, a component level test will need to be performed using heavy ions or protons. The two main components that are seen to be the culprit of the functional interrupts of the board is the onboard microcontroller, the RP2040, and the onboard flash, the Winbond Serial NOR Flash (W25Q128JV). Depending on the outcomes of the data from component level tests of the flash, redundancy and error checking need to be implemented both in the software and the hardware of the PROVES FC Board. To enhance the reliability of the system against cosmic radiation, there is an option of replacing the Serial NOR Flash with MRAM (Magnetoresistive Random Access Memory), which is inherently tolerant to radiation, for the RP2040.

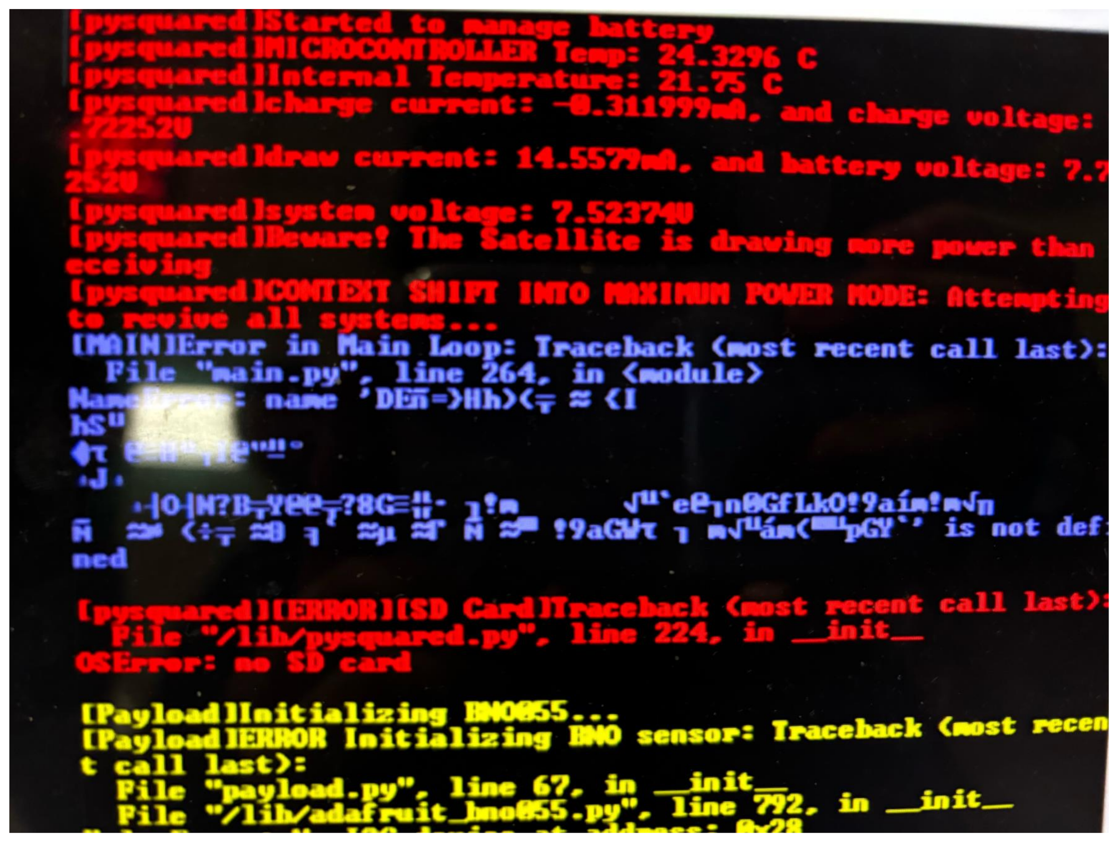

Figure 4:
Terminal Output of Corrupted Data During Irradiation

VI. Summary

The PROVES Flight Controller Board was tested with 200 MeV protons to determine its susceptibility to high energy proton-induced Single Event Effects (SEE). Using the n/2000 method, the board showed a non-destructive SEE error rate of 0.183 per system day. The testing was performed due to the short operational lifetimes of the PROVES CubeSat in previous launches, lasting only 50 minutes and 9.5 hours in the second and third launches, respectively. High-energy protons were chosen for their relevance in Polar LEO environments and cost-effectiveness. Two Flight Controller Boards (RSN 1 and RSN 2) were irradiated to a total fluence of approximately 1e10. RSN 1, tested without a configured Watchdog Timer outputted a total of 183 errors across nine runs where most of the errors occurred from the latter half of the runs. RSN 2, with a Watchdog Timer, had fewer errors but had the same error behavior as RSN 1 at a slightly higher fluence than RSN 1. In both samples, a power cycle resolved any errors the boards were experiencing during and after the irradiation. The testing has brought valuable data, but further testing needs to be performed such as component-level tests of the RP2040 and the Winbond Serial NOR Flash to address functional interruptions and improve reliability.

References

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2. https://www.jedec.org/standards-documents/docs/jesd234
3. https://www.ti.com/applications/industrial/aerospace-defense/space/radiation-handbook-for-electronics.html

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