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Microcontroller and Memory Card Survivability in Space Conditions

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Introduction

The USU Materials Physics Group (MPG) is interested in the effects of space and upper atmosphere environments on electronic components such as microcontrollers, sensors, and memory cards. High-energy electrons from the space radiation environment can cause signal spikes and noisy data in electronics. Ionizing radiation can also cause displacement damage to sensitive electronics on an atomic scale. Different orbits expose satellites to different levels of radiation. The Low Earth Orbit (LEO) total dose level is about 2 krad/yr. This is relatively low compared to the Medium Earth Orbit (MEO), (~100 krad/yr), and Geosynchronous Orbit (GEO) (~krad/yr) [1]. These values could be assuming some amount of shielding. Figure 1 shows that many of the electrons in LEO are low-energy which can be stopped by very minimal shielding.

By being exposed to radiation, microprocessors can experience different types of failure ranging from soft errors to total system failure. A soft error, also known as a single-event upset (SEU), is when radiation causes enough of a charge disturbance to alter the state of a memory bit. These are called soft errors because they are reparable, the system is still functional after a SEU. There are both multibit upsets and single bit upsets, but the latter is more common [3]. A single-event effect (SEE) happens when high-energy particles in the space environment strike the components of the microcontroller circuit [4]. A SEE can cause a range of damage including, “no observable effect, a transient disruption of circuit operation, a change of logic state, or even permanent damage to the device or integrated circuit (IC) [4].” The long-term damage done by radiation in space environments is typically due to the total ionizing dose (TID), which is the total amount of radiation an object is exposed to. Electronics are particularly susceptible to radiation because there are moving electrons in the circuitry. The beta radiation is hitting these circuits with electrons, which cause the SEE’s. Also, small circuits such as those set up with microcontrollers are sensitive because they are usually not very well shielded.

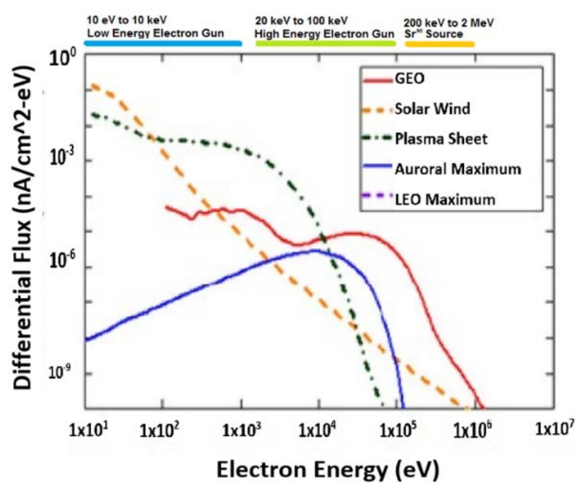

Figure 1: Electron flux versus electron energy in various space environments [2].

CubeSats are small satellites, weighing only a couple kilograms. CubeSats are a popular choice for Low Earth Orbit (LEO) missions because of the low cost of building and deploying them compared to the larger, traditional satellite. CubeSats often use microprocessors as the primary controller of taking measurements and operating the satellite. The MPG has developed the Space Survivability Test (SST) Chamber that can simulate various aspects of a space environment such as varying temperatures from 100

K to 450 K and pressures between 10^{-7} Pa and ambient pressure [2]. The outcome of testing microcontroller survivability during radiation exposure in the SST chamber could have implications in future flights of CubeSats, possibly providing information for fights beyond LEO.

Chamber Capabilities

The Sr^{90} beta radiation source (Figure 2) in the SST chamber has a dose rate of 0.1 krad/hr at a 30 cm distance over a 15 cm diameter sample area [2]. This dose rate provides an upper bound approximation of the dosing rate in GEO with minimal shielding. To expedite the testing process, the distance to the radiation source can be decreased; the relationship is shown in Figure 3.

There are many instrumentation cabling feedthroughs available on the SST chamber, including both USB and D-pin serial adapters, able to accommodate a maximum voltage of 100 V and a maximum current of 1 A. Using these, an Arduino microprocessor can be placed inside the chamber, and its diagnostics can be monitored and logged on an external computer. Inside the chamber there is an adjustable platform (Figure 4) that can be oscillated while the chamber is sealed. This allows the sample, or the Arduino board and sensors, to be oscillated during testing.

Proposed Tests

The objective of this research is to observe a microprocessor during radiation exposure inside the chamber and compare its functionality to an identical control setup outside the chamber. Arduino Unos are cost effective choice Commercial Off the Shelf (COTS) microcontrollers that are used on CubeSats. Attached to the Arduino will be several different sensors as well as memory card readers. The proposed sensors are a Hall sensor, a photodetector, and an accelerometer. Memory cards are used on CubeSats to store data and that is collected while the satellite is in orbit. These sensors were chosen because they could possibly be flown on CubeSats and can also be used for monitoring the breakdown of the microcontroller in the chamber. The Arduino and sensors will be attached to the rotating platform inside the chamber. A magnet and LED will be placed at a fixed distance from the sensors inside the chamber, so when the platform moves a fluctuation in the magnetic field and light exposure will be sensed by the Hall sensor and photodetector, respectively.

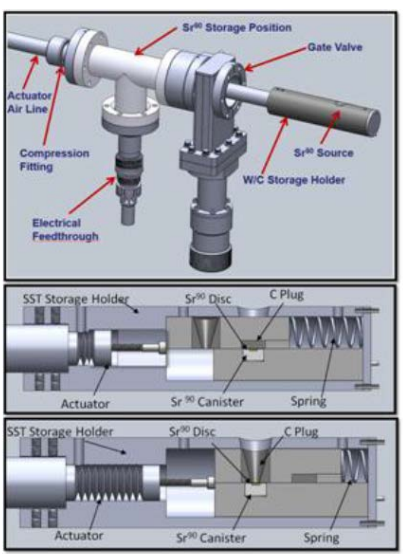

Figure 2: Sr^{90} source. (a) Exterior view. Cutaway views while in the (b) closed and (c) exposure positions, respectively. [2]

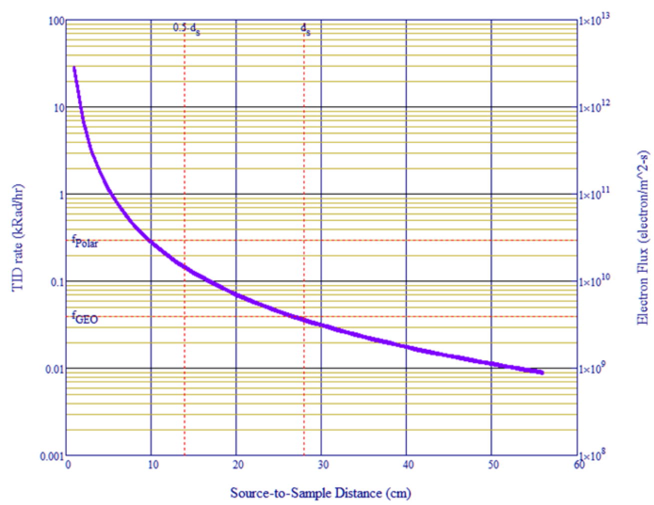

Figure 3: TID versus Source-to-Sample Distance [5]

The software uploaded to the Arduino Uno will need to initiate several operations. The program will need to run a self-diagnostic test on the microcontroller and send back an indication of its operating capability and error codes; it will also be able to read the incoming data from the sensors. A laptop will also be connected to the Arduino to plot the values from both the Hall sensor, the photodetector sensor and the accelerometer (while the platform is moving). The program will also read from the memory cards to show that the interface of the port is working properly and determine if and when the memory card has been damaged.

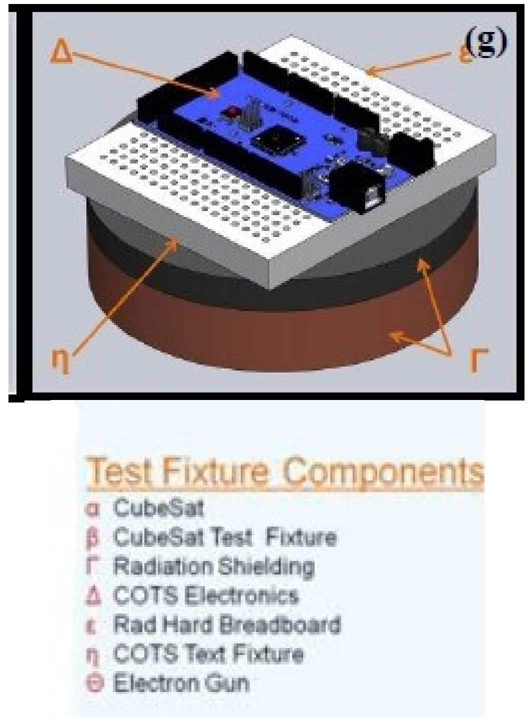

Figure 4: (a) Oscillating commercial of the shelf (COTS) test fixture and (b) the corresponding legend. [2]

The diagnostic testing for the Arduino and the memory card module testing can be run at an established interval such as every minute. Continuous monitoring of the sensors would be ideal to see the behavior of the magnetic field vs. time and light intensity vs. time graphs as the microcontroller or sensors begin to break down. Ideally, all tests would be run until failure that causes permanent damage to the microprocessor is observed and recorded, while taking note of the SEU's along the way. Assuming we will see a permanent failure at an estimated 100 krad TID or ~30 days at GEO dose rate of 0.1 krad/hr, I would hypothesize that the Arduino will experience complete failure within 10 days inside the SST chamber at ~0.3 krad/hr. Also, SEU's are expected to start showing up in the first 2 days of radiation exposure.

An issue that needs to be addressed is how to differentiate between failure of a sensor or memory card and the failure of the microcontroller. A proposed method of identifying which device is failing is to connect the sensors and memory card to two Arduinos, one inside the chamber and one outside. Then, if an SEU is recorded by both Arduinos, it will be known that it was a sensor or memory card failure. If an SEU is recorded by only the Arduino inside the chamber, it will be known that the failure was with the microprocessor. However, this could cause difficulties when trying to oscillate the platform inside the chamber.

Additional Tests:

Time permitting, the effects of shielding the microcontroller and sensors could be investigated. Also, a larger variety of sensors and brand of memory cards could be tested to check their survivability in the environments outlined above.

References

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