Radiation Damage Threshold of Satellite COTS Components: Raspberry Pi Zero for Opal CubeSat

Jonh Carlos Mojica Decena, JR Dennison, Brian Wood, Ryan Martineau, Michael J. Taylor

Material Physics Group, Physics Department , Utah State University; Space Dynamics Laboratory

Introduction

The Design of electronics that can maintain full functionality over the duration of a satellite mission requires careful determination of the space radiation environment and total ionizing dose (TID) delivered to the components.

Radiation survivability of a *Raspberry Pi Zero* was studied with the USU Space Survivability Test (SST) Chamber using 0.2 to 2.5 MeV beta radiation from a Sr^{90} source to determine the amount of ionizing radiation that the memory and processor of a commercial off-the-shelf (COTS) *Raspberry Pi* unit can be exposed to before they exhibit radiation-induced damage or stop working altogether.

The results of these evaluations will be used in the USU-led OPAL CubeSat which plans to incorporate a *Raspberry Pi* as its basic processor unit and to determine if this inexpensive microcomputer will be able to survive the TID received during its mission in Low Earth Orbit (LEO) lasting 1-2 years.

Theory

The *Raspberry Pi* is an inexpensive and tiny computer, about the size of a credit card that normally runs with the Raspbian OS (a type of Linux based OS for *Raspberry Pi*). A *Raspberry Pi Zero* will be placed inside the SST chamber, where it was then radiated until it stopped working. The SST chamber 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 Sr^{90} source produce a TID of 0.1 krad/hr at 12” distance over an area of 6” of diameter and falls as $\frac{1}{r^2}$ (Figure 1). The *Raspberry Pi zero* has a cross section of ~ 3”. Therefore by decreasing the distance by half we can increase the TID of the sample exposure.

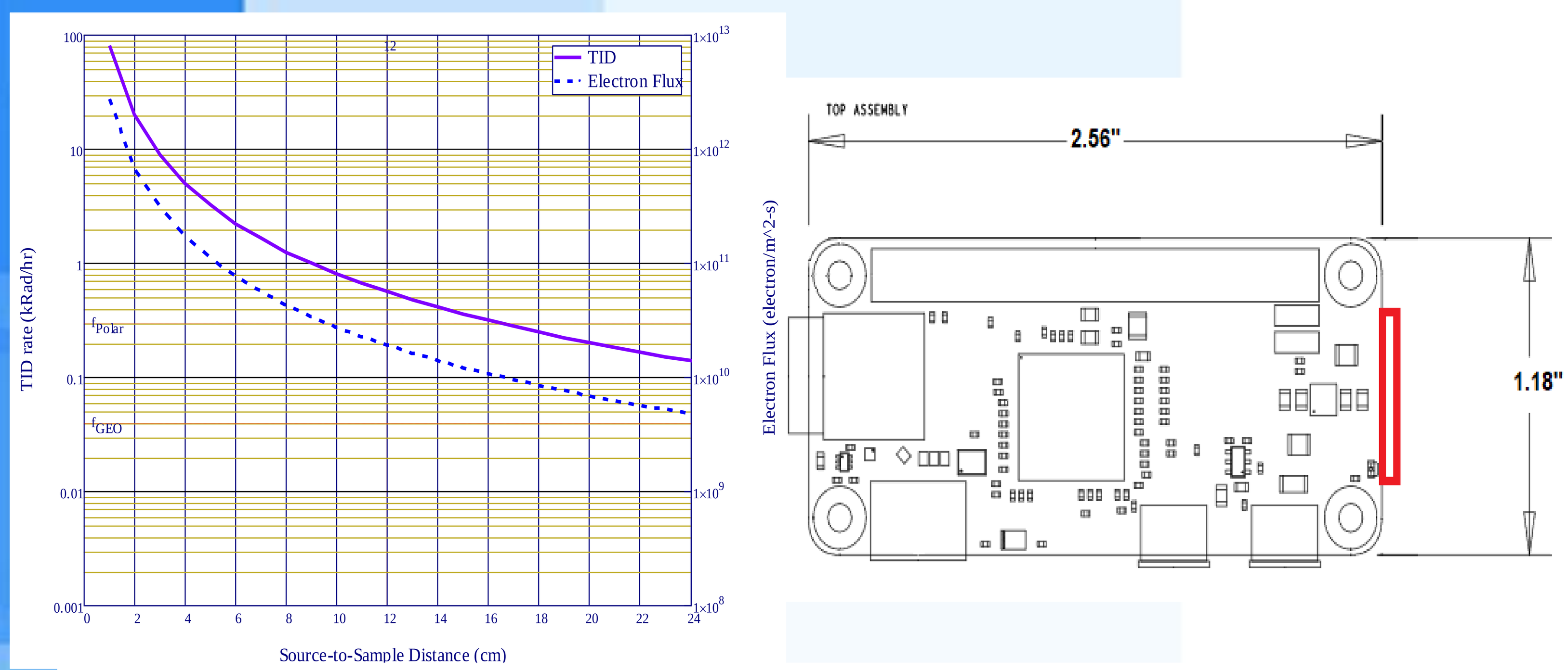

Figure 1. Source-to-sample distance vs TID rate graph of the sr^{90} (left); Raspberry Pi Zero Dimensions (Right).

The purpose of using a beta radiation source is because beta emission has a deeper penetration in material than heavy ions particles (Figure 2), overcoming the shielding of the integrated circuits and CMOS. For electronics, radiation creates a profound effect because they are moving electrons in the circuitry which can be altered to any excited state easily. By being exposed to radiation, microprocessors can experience a variety of failure modes, these are known as Single-event effect (SEE) [1]. For the proposed experiment we looked for Single-event latch-up (SEL) which are critical errors.

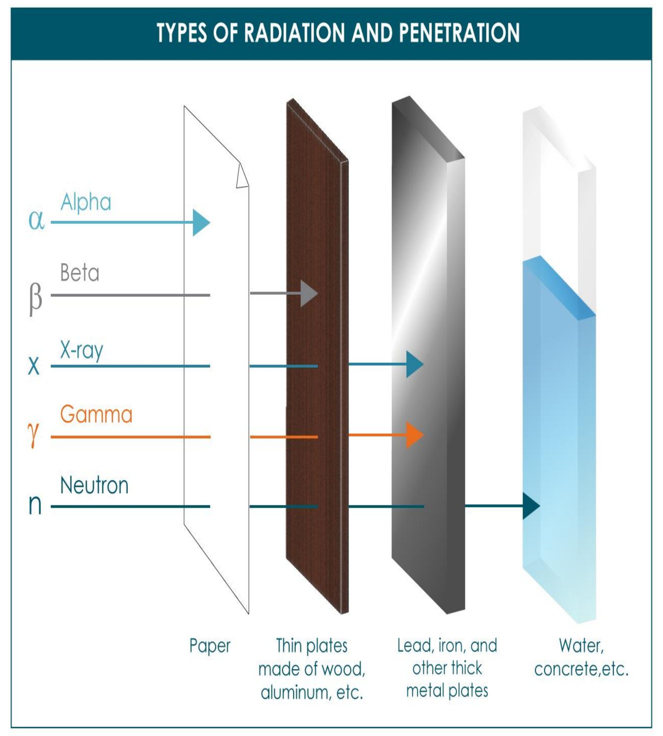

Figure 2. Types of radiation and penetration depth.

$$krad := 10 \cdot Gy$$

$$DR_o := 0.1 \cdot \frac{krad}{hr}$$

$$DR := DR_o \cdot \left(\frac{6 \cdot in}{2.75 \cdot in}\right)^2 = 10.476 \cdot \frac{krad}{hr}$$

$$TID_{yr} := 2 \cdot \frac{krad}{yr}$$

$$T_{mission} := 1yr$$

$$sf := 2$$

$$TID_{Mission} := TID_{yr} \cdot T_{mission} \cdot sf = 40 \frac{m^2}{s^2}$$

$$T_{exp} := \frac{TID_{Mission}}{DR} = 8.403\,hr$$

Figure 3. Calculation of the time of exposure and TID

In our experiment we will put a *Raspberry Pi* inside of the SST for a period of 8.4 hours at a dose rate of 0.4 krad/hr at a distance of 6” by an area of 2.75” to simulate the LEO TID (~2krad/yr) (Figure 3). To monitor the performance of the *Raspberry Pi* we will be using the secure shell via Wi-Fi to catch any changes in internal temperature, and error display happening inside the chamber. The secure shell connections allows to remotely operate a Linux based system, and import and export any files. Once the connection its being stablished we will use a stress test to look for errors (Figure 4).

In the first run (a period time of 8 hours), it will be determined the stability of the Raspberry Pi for the construction of the OPAL CubeSat. Then our second run will be to determine the TID at which the raspberry stop working and which area was affected the most.

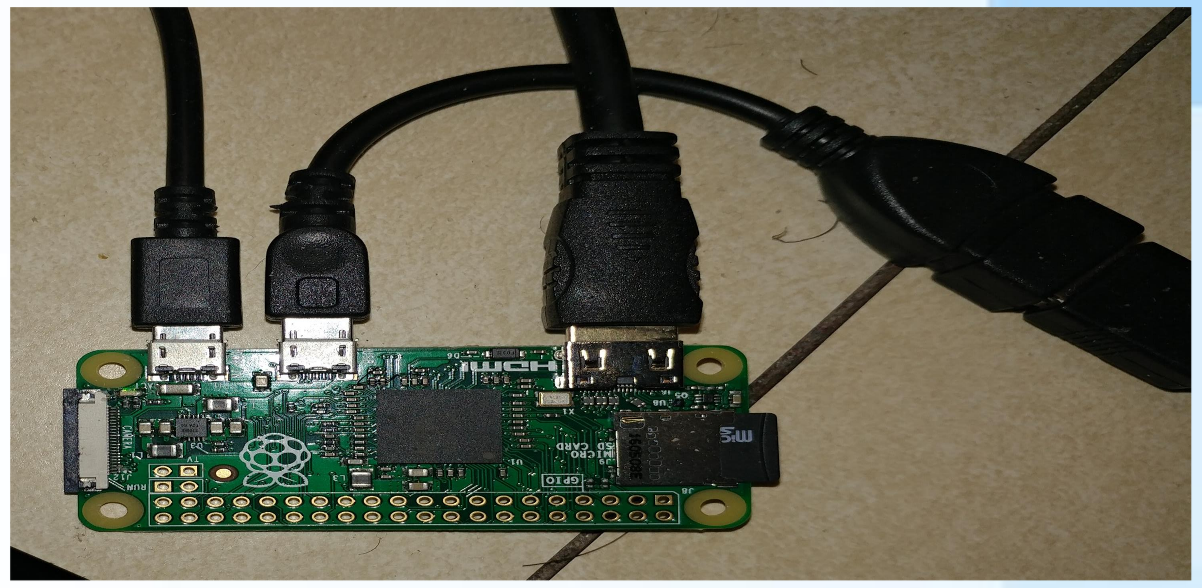

Figure 4. Raspberry Pi Zero connected for stress test

Results

Under normal conditions, the Raspberry is being fully operational for a period of 10 days, with no radiation exposure there has not been any source of error, in the following weeks the procedure to test for radiation exposure will begin at the indicated dose rate.

Conclusions and Future Work

Conclusions:

Up to now the Raspberry Pi seems like the good candidate for this mission, but nothing can be determined until the radiation test is completed. Previous experiments done by the MPG with an Arduino shows that the TID to see the first SEL occurs at ~150krad but where the error occurred was undetermined. The implications of determining the impact of radiation exposure could be of benefit for consumers and manufacturers since determining what areas are most affected will provide a guide to which area to focus on when building or using these microcontrollers. And what areas would benefit most from additional shielding.

Future Work:

- Add peripheral components for testing .
- Add a camera to analyze the radiation effect on the pixel (see AWE FPA radiation test from SDL).
- Understand the property of Si based IC and memory to create a model for Radiation effect on electronics components.
- Predict the proper amount of shielding necessary to ensure the components survivability.
- Test Solar effect with on electronics with the Solar simulator.
- Add sensors to test the time response.

UTAH STATE UNIVERSITY
MATERIALS PHYSICS GROUP

Scan code to access accompanying paper and references, as well as other USU MPG articles.

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REFERENCES

[1] Akihiro Nagata, Atsushi Yasuda, Hiromasa Watanabe, and Toshihiro Kameda, “Development of a Support System for Radiation Resistance Testing,” *University of Tsukuba* (July 22, 2017).
[2] JR Dennison, Kent Hartley, Lisa Montierth Phillips, Justin Dekany, James S. Dyer, and Robert H. Johnson, “Small Satellite Space Environments Effects Tests Facility,” *Proceedings of the 28th Annual AIAA/USU Conference on Small Satellites*, (Logan, UT, August 2-7, 2014), 7pp.
[3]Space Electronics Inc. “Space Radiation Effects Handbook for RAD-PAK Microelectronics.” (1997).
[4] Windy Olsen, Brian Wood, Donald Rice, and JR Dennison, “Microcontroller Survivability in Space Conditions,” Physics Department Utah State University, 2016.
[5] Violette, D. P. "Arduino-Raspberry Pi: Hobbyist Hardware and Radiation Total Dose Degradation." (2014).

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