Microcontroller Survivability in Space Conditions

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I. Introduction

- The purpose of this experiment was to observe the effects of space conditions on electronic components such as Commercial Off the Shelf (COTS) microcontrollers.
- Microcontrollers are often used on CubeSats, small inexpensive satellites that are flown in Low Earth Orbit (LEO).
- There is a large area of interest in COTS microcontrollers (Figure 1) because they are a much more cost effective alternative to other satellite technology.

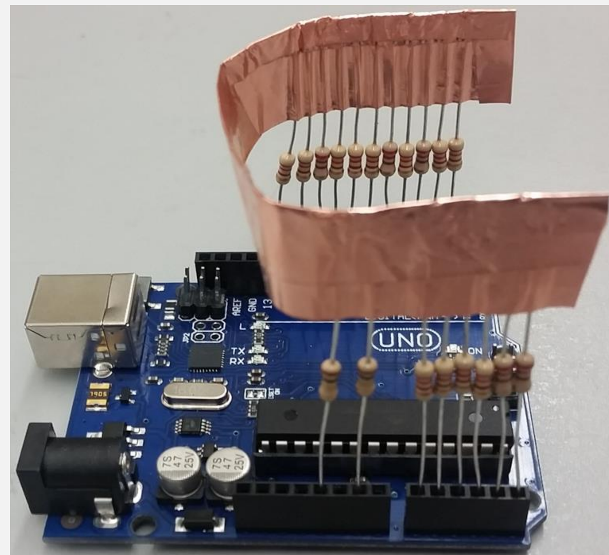
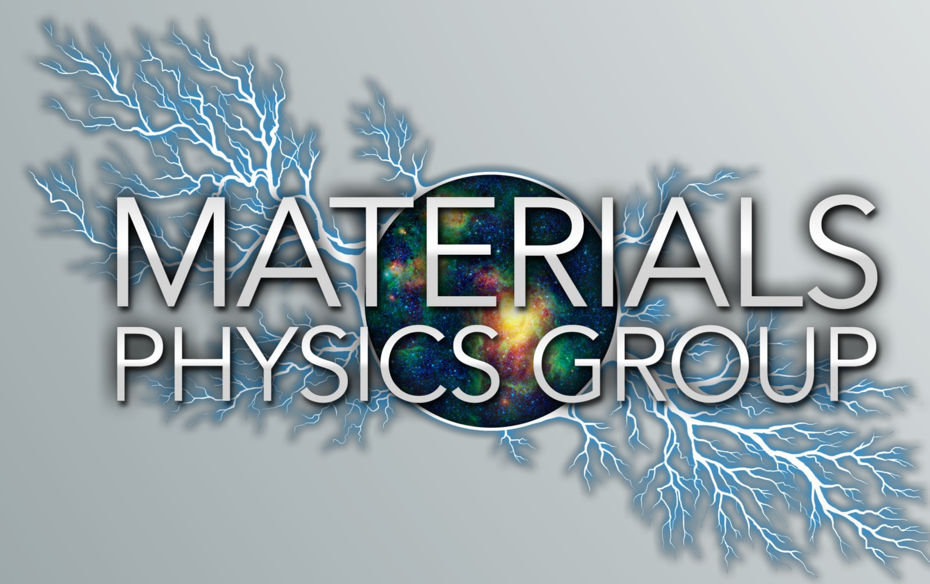


Figure 1 - Control setup for this test.

- This experiment focused on an Arduino Uno's ability to function properly inside the Materials Physics Group's (MPG's) Space Survivability Test (SST) Chamber.
- A program was used to monitor for soft errors as well as permanent failures.
- The results from this research and future related tests could shed light on future CubeSat flights in Medium Earth Orbit (MEO) and Geosynchronous Orbit (GEO) which both have higher radiation dose rates than LEO (~100 krad/year and ~20 krad/year, respectively) [1].



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II. Space Environments

- The main component of space environments examined in this experiment was radiation exposure.
- Electron flux and energy vary in space (Figure 2).

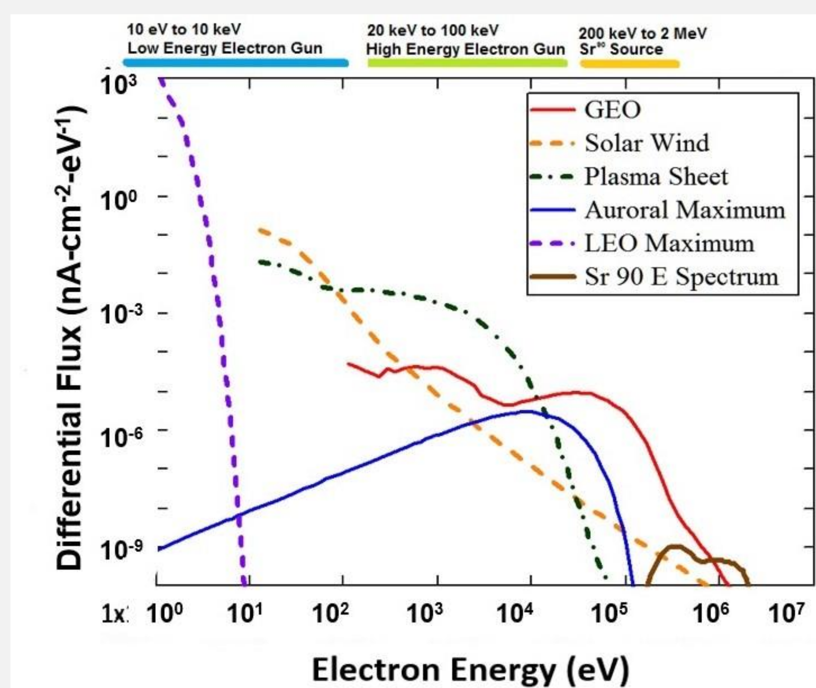

Figure 2 - Electron flux versus electron energy in various space environments [2].

- High-energy electrons can cause signal spikes and noisy data in electronics as well as displacement damage to sensitive electronics on an atomic scale.
- Microcontrollers experience problems ranging from soft errors to total system failure from beta radiation.
- A soft error, or single-event upset (SEU), is when radiation causes enough of a charge disturbance to alter the state of memory bits, but leaves the system functional [3].
- A single-event effect (SEE) is when high-energy particles strike the components of the microcontroller circuit and cause damage such as a disruption in circuit operation or permanent damage to the device [4].
- The SST Chamber was used to simulate space conditions in this experiment.
- The Chamber holds vacuum and contains a Sr^{90} beta radiation source with a dose rate of 0.1 krad/hr at a 30 cm distance over a 15 cm diameter sample area [2].
- The dose rate was only important as it related to the total ionizing dose (TID). This enabled closer placement of the Arduino to the source, increasing the TID rate to ~0.991 krad/hr (Figure 3).

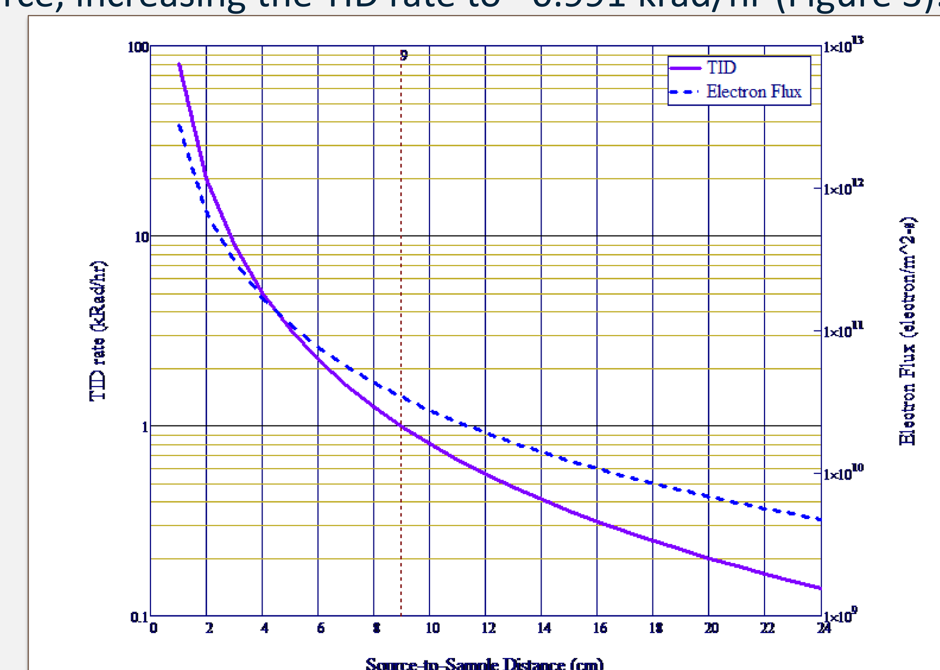

Figure 3 - TID versus Source-to-Sample Distance (0.991 kRad/hr). [5]

III. Hardware & Software

- The microcontroller used was an ATmega328 on an Arduino Uno (Figure 2).

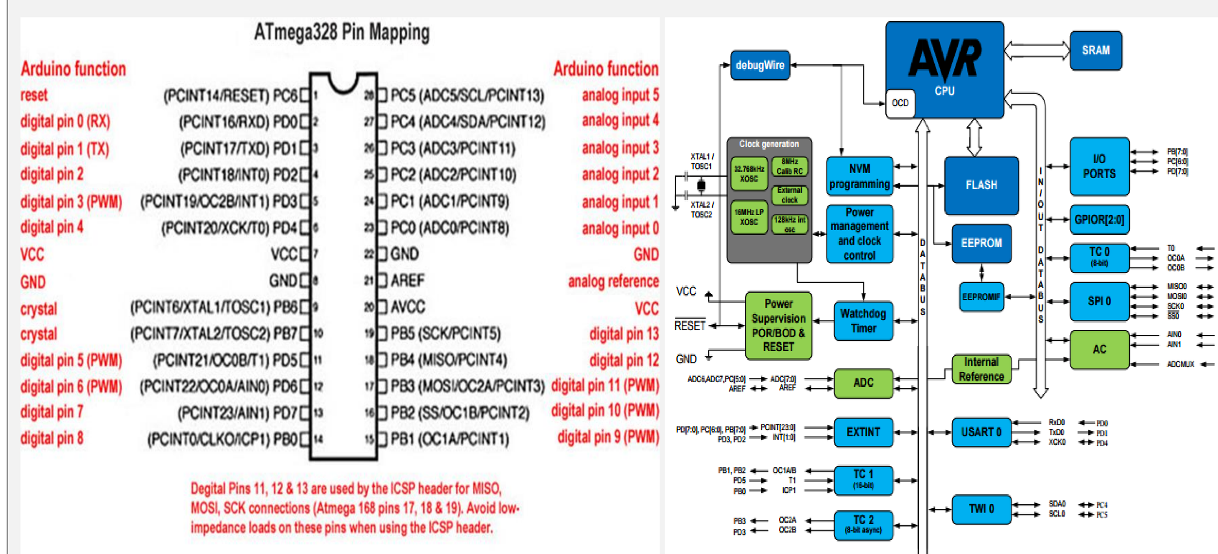

Figure 4 – Pin mapping and the block diagram for the ATmega328 chip.

- Open source diagnostic code was modified in order to test the performance of digitals pins 2-12 and analog pins A0-A5.
- Pins were considered functioning if they could sink or source a specified amount of current, keeping the common points between the resistors at a specified voltage.
- Any failures were then counted and displayed on the computer monitor.

IV. Experiment & Results

- The Arduino was place on top a large beaker with a piece of Kapton-insulated graphite inside the SST Chamber (Figure 5)

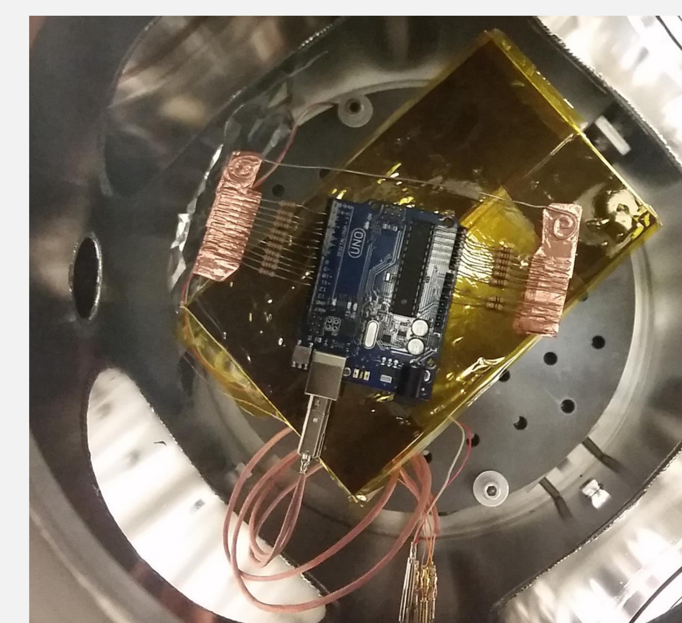

Figure 5 – The test Arduino in position inside the SST Chamber.

- The diagnostic code was tested with a 1 second delay while the vacuum chamber pumped down to a pressure of ~$1.7x10^{-7}$ torr and the radiation source was outside the chamber.
- It was then tested with a 10 second delay with the closed source inserted into the chamber.
- Finally, the source was opened and the Arduino was monitored for 35 minutes with a short delay followed by a delay of 15 minutes.
- After ~188 hours of exposure, the program detected no failures.
- However, an error occurred when trying to run the program with a shorter delay.

V. Conclusion & Future Work

Conclusion:

- The program did not show any failures even though the TID was well into the MEO range.
- Further testing needs to be conducted to determine survivability in MEO or GEO.
- An error code saying there was a mismatched memory byte was produced when trying to upload the program again.
- When attempting to upload the code once more, this same error was produced, indicating possible permanent failure.
- Possible explanations for this are damaged bytes in the SRAM or flash memory.

Future Work:

- Running memory tests to check the Arduino's flash and EEPROM memory to try and determine when bit flips occur.
- Testing sensors inside the chamber to detect SEU's and radiation effects on sensors themselves (Figure 6).

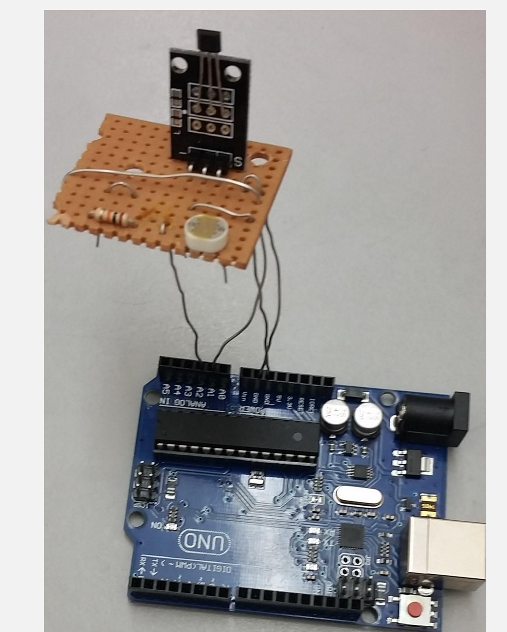

Figure 6 – Hall sensor and photodetector testing setup.

- Memory card testing for SEU's and other SEE's.
- Tests to ensure memory card – Arduino interfacing.
- Shielded tests to determine the scattering effect caused by the shielding.

References & Acknowledgments:

[1] Johnston, A. (2008). Space Radiation Effects on Microelectronics. *OPFM Instrument Workshop*, (pp.1-63). Pasadena
[2] Dennison, JR., Hartley, K., Phillips, L., Dekany, J., & Johnson, R. H. (2014). Small Satellite Space Environments Effects Tests Facility. *28th Annual AIAA/USU Conference on Small Satellites*, (pp. 2-6).
[3] Baumann, R. (2005). Radiation-induced soft errors in advanced semiconductor technologies. *IEEE Transactions on Device and Materials Reliability*, 305-316.
[4] Dodd, P., & Massengill, L. (June 2003). Basic mechanisms and modeling of single-event upset in digital microelectronics. *IEEE Transactions on Nuclear Science*, 583-602.
[5] Dennison, J., Wilson, G., Souvall, A., Russon, B., & Gamaunt, K. (2016). CubeSat Space Environments Effects Studied in the Space Survivability Test Chamber. *AIAA/USU Conference on Small Satellites.*

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