

Radiation Damage in SRAM and Flash Memory

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Abstract

Damage to electronic memory due to cosmic radiation is a well-known issue. High-speed, charged particles from outer space have been known to cause errors, also known as single event upsets, in computer memory. The purpose of this experiment was to determine how altitude affected the number of errors encountered by different types of electronic memory. The experiment was performed by repeatedly writing and reading data to SRAM and Flash Memory in order to check for bit errors. This circuit was sent in a payload up to 100,000 feet along with several sensors, such as a Geiger counter, altimeter, and magnetometer. The results show that the incidence of ionizing radiation rises with altitude and then falls around 60,000 feet. The magnetic field varies negligibly with altitude so it was dismissed as a factor that would cause greater amount of errors. Overall results on the incidence of errors in electronic memory versus altitude were inconclusive.

1. Introduction

As computer memory has developed, relatively large, capacitor based storage such as DRAM (Dynamic Random Access Memory) has been almost completely replaced by smaller, more energy efficient, transistor based memory modules such as flash memory and SRAM (Static Random Access Memory). Through this transition, and as the newer technologies have developed, the physical size of the memory banks has decreased dramatically. This is in accordance with Moore's Law, presented by IBM cofounder Thomas Moore in 1965, who predicted that the number of components per integrated circuit would increase by a factor of two every year for at least a decade (1). This trend was seen through 1975, but the rate of increase was seen to decrease to doubling component number once every two years thereafter.

For computer memory, this means that the transistors that make up the components have gotten exponentially

smaller to accommodate the increasing density. As a result of their decreased size, the critical charge necessary to cause a bit flip has decreased. This is good for energy consumption but it also means that the modules are more susceptible to soft errors caused by ionizing radiation. A soft error is a non-permanent change in stored state caused by the undesired and uncontrolled movement of charge within the memory module. The errors do not cause any residual damage to the component and the error is potentially recoverable on the next write operation if it is caught. Soft errors have been observed in computing systems from the early days, but they were generally attributed to system noise. Ionizing radiation was not realized as a culprit until 1975, when May and Woods discovered the mechanism by which alpha particles caused soft errors in DRAM. This process can be generalized for all ionizing radiation. An ionizing particle loses energy as it travels through the substrate of a transistor and electron-hole pairs are created as a result. If the number of electron-hole pairs exceeds the critical charge of the transistor then a bit flip occurs (2). The architecture of the memory module then dictates whether or not this bit flip results in a soft error.

Cosmic radiation has been shown to increase with altitude which is why this is an important problem for aerospace applications. If the soft error rates are large at moderate altitudes then this would pose a serious threat to commercial avionics which rely upon SRAM and flash technologies. Satellites in geosynchronous orbit around the earth face even larger doses of this cosmic radiation so the rate of soft error occurrence versus incident ionizing radiation is an important quantity to determine so that appropriate preventative measures may be taken. Thus the main mission objective is to determine this rate of soft error occurrence versus incident ionizing radiation and altitude.

2. Design Overview

This payload is designed to accomplish all goals set out for it as well as to be in compliance with all DemoSat requirements set by the Colorado Space Grant Consortium. The payload consists of an outer polyurethane foam shell which surrounds an inner fiberglass cylinder, both of which are designed to protect a removable core which houses all electronics and sensors. A locking mechanism sits within the fiberglass cylinder which holds the electronics core in place and is designed to allow easy access to all electronics while preventing excess movement during the flight.

2.1. Outer and Inner Shell

The outer shell is made from two part pourable polyurethane foam. This foam gives good impact protection and heat insulation while being light weight. The outer shell was formed around a paint bucket with plastic sheeting on the inside to allow for proper dimensions to be formed. The inner shell is made of fiberglass and provides rigidity to the outer shell so that it does not deform too much on impact, causing it to fracture. The fiberglass was used due to its high strength and low cost. Most of the force that is encountered due to accelerations as well as landing is absorbed by the fiberglass inner shell. The outer and inner shells are connected by three nylon rods providing ample force to hold the two together throughout the flight. For a visual representation of the inner and outer shells, see Figure 1 and Figure 3.



Figure 1. Overall Assembly

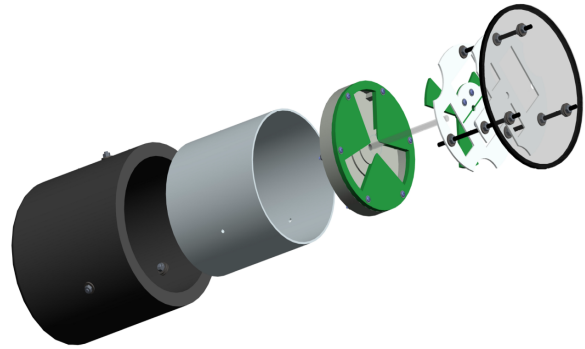


Figure 2. Exploded Overall Assembly

2.2. Locking Mechanism

The locking mechanism consists of three plates made of ABS plastic and three springs. The three plates were fabricated using filament extruding 3-D printers and the springs were purchased. The bottom plate is attached to the fiberglass shell and the spring plate and springs reside within the bottom plate. The spring plate is pushed down by the electronics core and when locked in place, transmits the holding force needed to prevent the core from moving. The top plate of the locking mechanism has three cut outs which the electronics core can pass through as well as three recesses which allow for the core to lock in after being turned into place. For a visual representation see Figure 3.

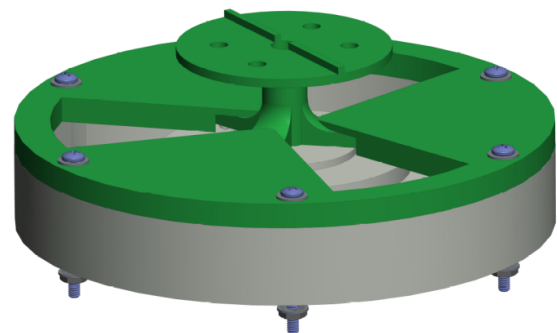


Figure 3. Locking Mechanism with Tri-Blade

2.3. Electronics Core

The electronics core consists of two trays to which all electronics are attached and a “tri-blade” which locks the core into the top locking plate. The electronics core also includes the lid which seals the inside of the payload from the outside environment. Both trays as well as the locking component were fabricated using a filament extruding 3-D printer. The lid was fabricated using acrylic cut on a laser printer. The bottom plate is attached to the locking mechanism via fasteners and a slot cut out of the bottom plate which has a matching rib on top of the

tri-blade. The bottom plate houses two Arduino Megs, an SD shield, and all sensors except the Geiger Muller Tube. The top plate houses the flash memory and SRAM that will be tested for soft errors as well as the Geiger Muller Tube. This way as little ionizing radiation as possible will be blocked by the shell components as well as other electronics. The two trays and the lid are attached using three threaded nylon rods and nylon nuts. Both trays contain gaps that are molded around the circuits as to save payload weight. See Figure 4 for a visual representation.

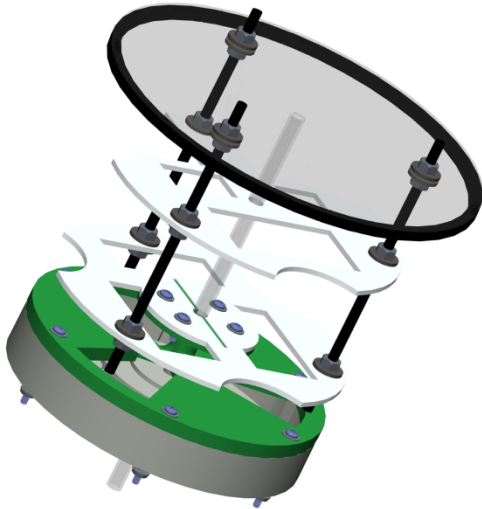


Figure 4. CAD Electronics Core

2.4. Data Collection

Two Arduino Mega microcontrollers are used to control all electronics in the payload. The master Arduino is used to control all sensors except the Geiger Muller Tube. The master Arduino also writes all data to the microSD card. Data points will be recorded every 30 seconds and acceleration data will be constantly recorded in order to detect any sudden acceleration that may cause one or more aspects of the payload to fail. All data that is recorded will be time stamped using a real time clock chip and altitude stamped using the altimeter. The second Arduino is used to constantly read and write an array to the SRAM and Flash Memory that is being tested for soft errors. When an error is detected an appropriate software counter is increased. The value of these counters are sent to the master Arduino during each write cycle and subsequently reset. The second Arduino then rewrites the memory modules to correct the soft error so that errors do not compound.

2.5. Geiger Counter

A PIC16F88 microcontroller is used to communicate between the master Arduino and the Geiger counter

circuit. The Geiger Muller Tube sends a 5V square wave of approximately 300 millisecond width to the PIC each time ionizing radiation is detected. Smaller amplitude waveforms were seen when the signal was routed to an oscilloscope, which were deemed to be noise which caused false reads. These waveforms had a peak of about 1.3V and were attenuated out by using a 39 mega ohm pull down resistor on the signal line. When the 1.3V waveforms were included in the count, readings of greater than 60 counts per minute were seen. These values did not agree with known background radiation levels. When the smaller waveforms were attenuated out, the tube gave around 25 counts per minute consistently. This agrees with background radiation levels for Colorado. The PIC communicates with the master Arduino via standard protocol SPI once a minute so the data is stored directly as counts per minute. After communication the counter is reset.

2.5. Thermal Control

The temperature of the payload will be maintained by two thin film heaters being controlled by the master Arduino. Initially the heaters were controlled by another PIC16F88 which would duty cycle the heaters according to the temperature inside the electronics core. This system was scrapped as it was found that the heaters worked best on a 100% duty cycle, tied to active mode.

2.6. Idle and Active Mode

The main program running on the master Arduino will control the overall function of the device in flight. Program operation is separated into two subroutines; idle and active mode. When the device is powered on the program enters idle mode, during which the altimeter is routinely checked and the altitude compared against in the initial altitude. If the altitude is 20m greater than the initial reading then active mode is entered. In active mode accelerometer data is logged every 10ms and sensor data is logged every thirty seconds. The data is written to an SD card in various files for convenience.

3. Budget

The total amount of money spent on this project was \$998.66. This number does not reflect the amount of money actually represented by the payload however. One of the Arduino microcontrollers was donated from a previous CSU DemoSat group, saving approximately \$60. There were also several components that were purchased that are not integrated into the final payload. There are a few reasons for this. The biggest reason is that throughout the testing process some components became damaged and had to be replaced. Some components also

ended up not being needed and thus are not in the final payload.

4. Testing

Testing was completed in three phases consisting of structural, radiation, and environmental testing. Structural testing was completed without any electronics as to not risk damage. Instead the electronics were represented with foam of equal weight. Radiation testing was done by utilizing a source of Cesium 137 on the CSU campus to ensure our Geiger Muller circuit was calibrated properly. Environmental testing was done with electronics attached and simulated the worst-case scenario environments that the payload could experience during flight. Lastly, the payload was put through functionality testing to ensure proper function through the duration of the flight.

4.1. Structural Testing

To determine the structural integrity of the payload a drop test was performed. The payload was dropped from a height of 15 feet and three inches onto a hard dirt surface. The inside of the payload shell was fitted with foam to simulate the weight of all of the electronics as to not risk damage. Upon impact the payload was in an upright orientation, thus putting the majority of the impact force on the bottom. This energy then transferred through the bottom of the payload, to the nylon rods, and finally to the top plate. This caused the acrylic lid to fracture into multiple pieces upon impact. Overall, the test was a success in that the payload remained structurally intact during a simulated worst-case scenario landing.

A stair pitch test was done to determine the structural integrity of the payload upon possible re-inflation of the parachute after landing. The payload was pushed down a flight of 24 steel steps that were six and three quarter inches high and 44 inches wide. After tumbling down the stairs the only visible damage was a piece of the acrylic lid fractured off. This instills confidence in us that if the parachute re-inflates all internal components will remain intact.

A whip test was performed to determine if the payload would securely attach to the flight string. This was done by swinging the payload above ones head with a six and a half foot piece of attached flight string. The process continued for approximately 30 seconds at which point a jerk motion was induced to simulate close to worst case scenario acceleration. No visible damage occurred and the payload remained securely attached to the flight string.

A second version of the whip test was done to impart a more drastic directional change than during the overhead

whip test. This was done by attaching the payload to an eight-foot long flight string and then dropping it from an elevated surface. Once the payload was about to hit the bottom of the eight foot drop the tester pulled up to simulate a jerk. Upon completion of the test no substantial damage to the payload was observed. A small indentation was seen in the foam on the bottom of the payload due to the washer used to secure the payload to the flight string. This indentation was deemed insignificant and thus did not pose a threat to the structural integrity of the payload.

4.2. Radiation Testing

In order to ensure the Geiger Muller circuit was counting radiation hits properly, a calibration test was performed using a known amount of Cesium 137. The circuit was placed two meters away from the Cesium 137 and was exposed for three minutes. During this time the counts per minute were recorded onto a micro SD card. The recorded counts per minute were then compared to the calibration data sheet provided by the lab manager. The SD card recorded an average of 21,320 counts per minute which converts to approximately 17.5 milli Rems per hour. The calibration data sheet had an actual exposure rate of approximately 18 milli Rems per hour showing that the Geiger Circuit is properly calibrated.

4.3. Environmental Testing

Due to the Geiger Muller circuit being a high voltage device, a vacuum test was done to ensure proper operation in a low-pressure environment. The payload was turned on and placed inside a bell jar vacuum at CU Boulder, where the pressure was brought down to 603 Pascals. At this point the pressure was maintained for five minutes to represent an extended period of time at the lowest pressure the payload will encounter. Upon bringing the bell jar back to room pressure the Geiger Muller circuit was inspected and the SD card was read to ensure proper recordings. The circuit and data were proper upon inspection.

A cold test was completed to ensure the components of the payload would remain functional through the Tropopause where temperatures can reach – 80 degrees Celsius. The completed payload was placed in an ice chest with approximately 15 pounds of dry ice where a temperature of – 69.6 degrees Celsius was achieved. The payload was turned on and placed in the cooler with a Doric Trendicator mounted near the Geiger counter to monitor the temperature in real time. This was necessary as the Geiger counter was the most temperature sensitive component and was not recommended for use below freezing. The test was initially run with the battery powered film heaters but was run a second time with

chemical hand warmers to determine which system was more effective. The internal temperature as well as the Trendicator readings versus time for the two tests is shown in Figure 5. From this test it was concluded that the battery powered film heaters performed more effectively than the chemical hand warmers and were thus selected for use on launch day.

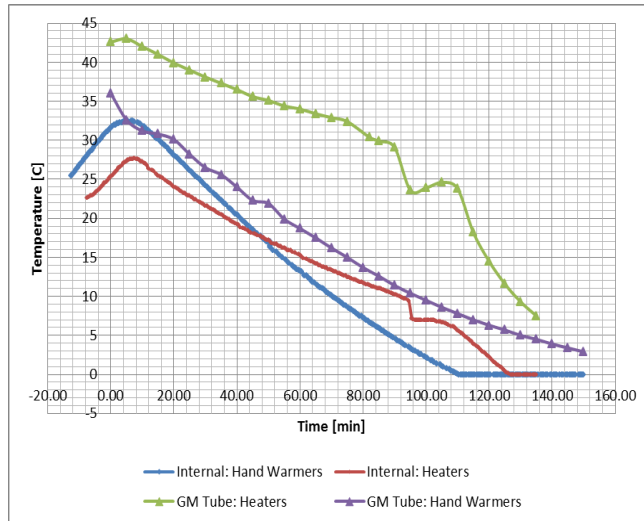


Figure 5. Cold Test Data - Temperatures

4.4. Functional Testing

The fully functional payload was turned on for two and a half hours to simulate the entirety of the flight. This allowed us to see if all systems will function properly. During the test the payload was taken three stories up an elevator to activate the device into active mode. It was then placed indoors, outdoors, and in a fridge to see variation in the thermocouples recordings. At one point during the test an americium core was placed on top of the device to ensure the Geiger Muller tube was counting radiation hits. Afterwards the data was analyzed and it was determined that all components were functioning properly. This test was repeated three times to ensure mission success.

5. Results

The results from launches one and two were inconclusive for the memory error data. During launch one a communication error in the Arduino-Arduino interface occurred. The slave Arduino, which continually reads and writes to the memory modules, sends the number of loop errors and total errors for each memory type to the master Arduino via a serial interface once every minute. This data was not sent correctly and as such is unusable. However, many of the environmental parameter sensors successfully logged data during this

time. Launch two yielded similar results in that the Arduino interface to the memory modules failed to record any loop errors. As with launch one, the environmental parameter sensors recorded successfully.

5.1. Pressure

Despite this error it is still interesting to look at the data that was collected. First, it can be seen in Figure 6 and Figure 7 that the pressure dropped at the same rate for both launches. Figure 7 shows that altitude data stopped being recorded around 10,000 meters on flight number 2.

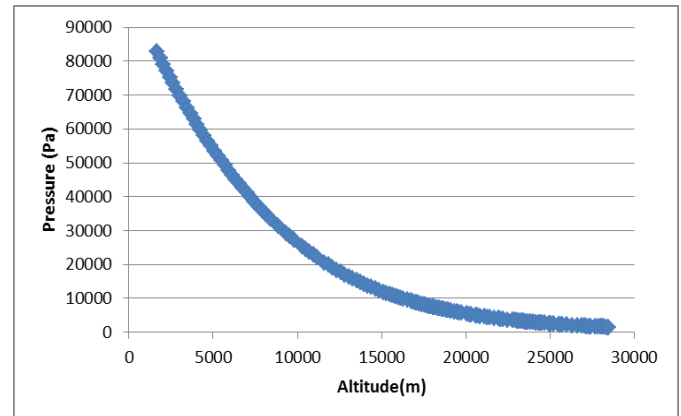


Figure 6. Launch One Pressure Data

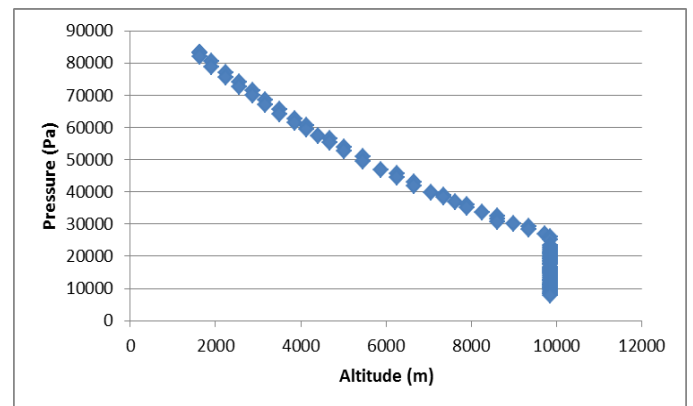


Figure 7. Launch Two Pressure Data

5.2. Magnetic Field

Magnetic field data showed very similar results from both launches. The magnetic field stayed steady throughout the flights. This appears because the magnetic field of the earth is relatively constant with altitude at nearly constant latitude. Figure 8 and Figure 9 show both magnetic field readings. Both are plotted versus pressure as the altimeter stopped recording on the second launch. Keep in mind pressure decreases with an increase in altitude.

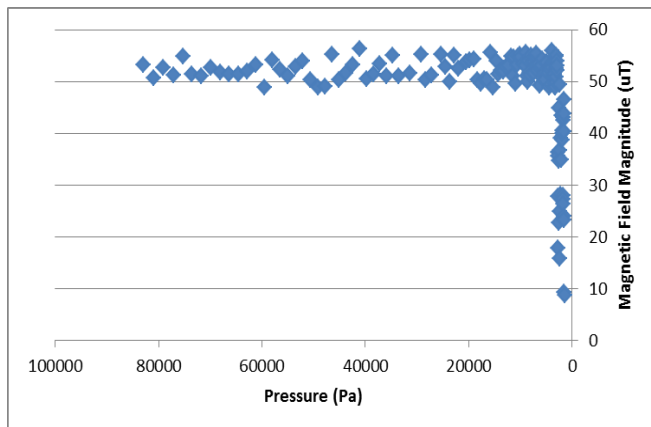


Figure 8. Launch One Magnetic Field Data

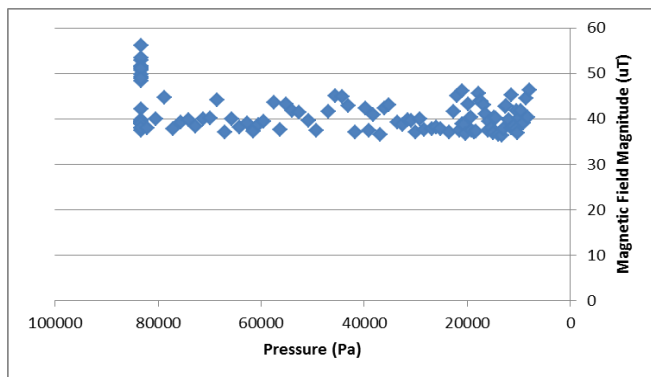


Figure 9. Launch Two Magnetic Field Data

5.3. Radiation

Both radiation readings from the Geiger tube showed the expected trends. First, the incident ionizing radiation versus altitude until around 50,000 feet, where the rate then slows and ultimately decreases slightly. This is in accordance with the ideas presented earlier, namely that the detectable secondary particles reach their maximum levels at around 65,000 feet. After this, the radiation is present in its 'pure' galactic form as mostly protons, neutrons, and high energy nuclei. The slightly smaller radiation hits from launch two may have been because of cloud cover that day as well as colder temperatures. Both launches are plotted versus temperature in Figure 10 and Figure 11.

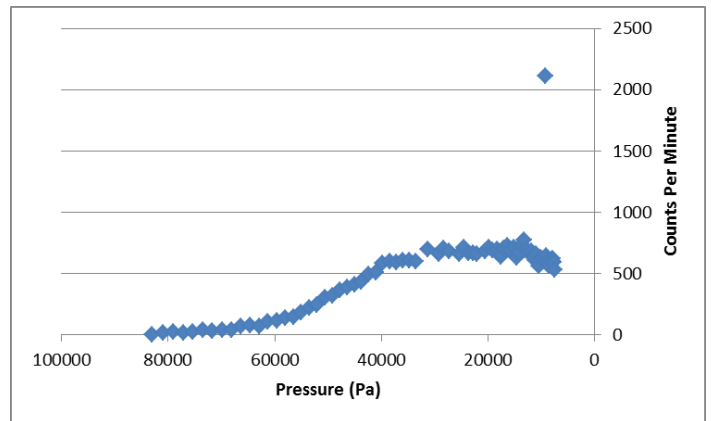


Figure 10. Launch One Radiation Data

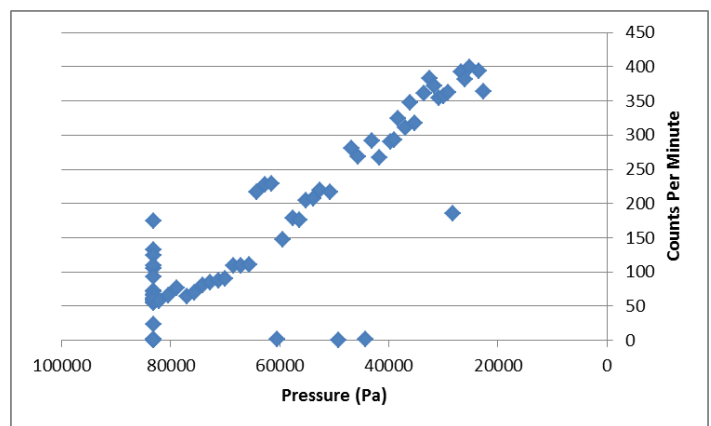


Figure 11. Launch Two Radiation Data

6. Conclusion

From the collected data it is shown that the incident ionizing radiation does in fact increase with altitude. The temperature minima expected in the tropopause was also readily observed from the internal temperature data. The magnetic field of the earth is relatively constant with altitude at nearly constant latitude. The payload used demonstrated that it is a robust design that can be used for multiple launches and is capable of protecting sensitive electronic components from both extreme temperatures as well as mechanical shock endured during launch, balloon burst, and landing. The most important lesson learned was to test the device as thoroughly as possible. Special focus should be paid to communication architecture, especially that for which the most critical data will pass.

7. References

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