Radiation Test Results on COTS & non-COTS Electronic Devices for NASA-JSC Spaceflight Projects

Kimberly K. Allums PhD, Patrick M. O'Neill PhD, Brandon D. Reddell PhD, Charles R. Bailey, Kyson V. Nguyen
NASA Johnson Space Center, Avionics Systems Division, Radiation Effects Group

ABSTRACT

This presentation reports the results of recent proton and heavy ion Single Event Effect (SEE) testing on a variety of COTS and non-COTs electronic devices and assemblies tested for the Space Shuttle, International Space Station (ISS) and Multi-Purpose Crew Vehicle (MPCV).

INTRODUCTION

NASA JSC has supported 3 programs (Shuttle , ISS, and MPCV)and must test electronic devices in a method that will meet the applicable program requirements.

LEO - Space Shuttle and ISS are Low Earth Orbit (LEO) applications and are tested using 200MeV protons as documented by Dr. O'Neill [1] The 200MeV beam has been used for over a decade with positive results and this method is especially valuable for testing board level assemblies and COTS units are commonly tested using this method.

Deep Space – Multi-Purpose Crew Vehicle (MPCV) or Orion 2 is a deep space mission profile and generally all hardware used for Orion-2 requires heavy ion characterization but Proton Testing has also been used to quickly screen out "soft" hardware and select the best candidate device when hardware was available from multiple vendors.

In 2008 through 2011 the Specialty Engineering Branch of the Avionics Division of the JSC Engineering Directorate tested at the Indiana University Cyclotron Facility (IUCF), Texas A&M University Cyclotron (TAMU), Lawrence Berkeley National Laboratory (LNBL), and NASA Space Radiation Laboratory (NSRL) at Brookhaven National Laboratory. A wide variety of COTS parts such as FPGAs, memories, wireless routers and processors were tested at board level using the high energy protons at IUCF.

TESTING & EXPERIMENTAL METHODS

A. PROTON TESTING

The majority of JSC hardware used for Shuttle and ISS is tested using 200MeV protons, at IUCF. The proton beam passes through the device losing less than 10% of the initial energy. While the incident protons themselves usually do not cause direct device upsets, they do collide with the nucleus of atoms inside the target device. This collision can fragment the nucleus and then generate a shower of high-energy secondary particles that can cause direct ionization with surrounding atomic nuclei [2]. It is these secondary particles that cause an electronic device to upset, if enough recoil energy is deposited in the sensitive volume. These reactions are rare, with approximately one nuclear collision in every 1E+6 incident protons. However, the primary drawback of proton testing is that the effective linear-energy-transfer (LET) of the secondary particles are limited to less than 14 MeV cm2/mg and have a short range [2]. Protons do not fully characterize the device's response to radiation compared to heavy ions with the same effective LET.

In preparation for proton testing an initial meeting is held with the potential project to understand the hardware and its application, as well as specific radiation success criteria. The hardware criticality, mission duration, and any mitigation methods are taken into account when planning the radiation test. A parts list of the hardware is generated and a sequence of beam positions or target areas is mapped out for the candidate hardware. The general project information, parts lists, beam positions and hardware setup and configuration is captured in the project test plans and procedures for documentation.

ANALYSIS METHODS

A. PROTON ANALYSIS

To analyze the proton data, the SEEs are grouped by type, frequency and severity. The errors are counted and inputted into a program called PROTEST [3]. PROTEST derives the equivalent 10 year MTBF for the hardware. This software integrates the test data with the LEO radiation environment defined above. It typically assumes worst-case environmental conditions, with 0.1 inch shielding around the device to give a conservative result. The output of PROTEST is the calculated Mean-Time-Between-Failure (MTBF) rate expected for operating the hardware in LEO orbits (expressed in terms of days between failures). An MTBF is calculated for each beam position, as well as a final box-level composite rate. These estimates assume the hardware is operating continuously on-orbit and does not take into account the actual mission timeline in which it will be used. For those devices that show no SEE failures in a typical 1E+10 exposure, we estimate the LEO on-orbit MTBF to be greater than 10 years. This is the same methodology that has been used at JSC for more than 15 years to evaluate the radiation hardness of mostly COTS hardware.

SUMMARY OF RADIATION TESTING

The following section will summarize Proton radiation testing on select COTs, Non-COTS hardware and individual electronic parts in a series of summary tables. Also a summary of the ISS Laptop testing will also be shown in this section along with a summarized table of the hardware tested.

A. Lenovo T61P Laptop Testing

The T61P 15.4" Wide Screen Lenovo Thinkpad Laptop is a commercial off-the-shelf (COTS) device that was tested in 2008. A series of selected hardware which consisted of SDRAMs, Intel Dual Core Processors, and Hard Drives from different vendors was tested to determine the best hardware for a final flight laptop configuration. The T61P laptop was an upgrade to the A31P IBM Thinkpad laptops on ISS, which has been in use for the last 10 years on orbit. In preparation for testing the candidate laptop was completely dissembled down to the motherboard in order to create a detailed parts list of the components of the laptop and to determine the beam positions for testing. Figure 1 shows the beam positions of the laptop on the motherboard. The major components (processor, SDRAM, hard drive, north and south bridge processors, graphics processor, wireless Communication chips and the power chips) of the laptop were isolated in single beam positions to evaluate their potential SEE without multiple active parts being considered as well.

Passmark's Burn In Test software was used to exercise the full capabilities of the laptop and external hardware of the laptop and custom Read/Write software, RWTEST.EXE, was used to test the SDRAM located in the laptop.


K.K. Allums,PhD


P.M. O'Neill, PhD


B.D. Reddell,PhD


K.V. Nguyen

The T61P Laptop was powered using a modified AC adapter cord that was connected to a Sorensen power supply, with the operating parameters set at 16V out and max current at 4.5A. With this modified AC adapter we were able to monitor current to the laptop and voltage at the power supply and going to the laptop.

1) Results of the Lenovo Laptop Testing

Each position was irradiated with a total 600rads (Si) and SEEs were recorded in the data log for each position. For the positions where the hardware could be removed and switched to another vendor supplied component, these positions were retested based on the number of varied vendors for the SDRAM, Hard Drives, and Processors. Figure 2 show the laptop in the test cave at IUCF.

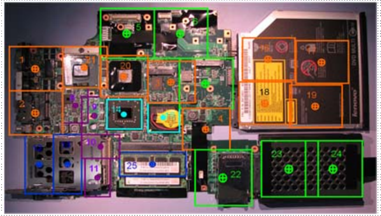

Fig. 1. Beam Position Layout of the Lenovo Laptop

Table II: Summary of COTS & GFE Hardware Tested with Proton Radiation

Device Category	Space Application	Flight Project	Test Article Description	Device Part Number	Manuf	# Beam Positions Used	Observed Results
SPE	ISS	Cabin Air Separator for EVA Oxygen	Oxigraft Board, CPU Boards, Digital and Serial I/O Boards	N/A	N/A	35	37 SEFIs in 1.00E10
SPE	ISS	Air Quality Monitor	Power Supply and Battery Holder Hardware	N/A	N/A	15	0 Errors in 1.00E10
COTS	ISS	Ammonia Measurement Kit	Drager Chip Measurement Unit		Drager	6	0 Errors in 1.00E10
COTS/Modified	ISS	Improved Payload Ethernet Hub and Gateway	Modified Ethernet Hub & Gateway	ANK4561	Goodrich	46	32 SEFIs in 1.00E10
COTS	ISS	ELC Wireless Communications System	COTS Wireless Access Point - Bel-Air 100n		Bel-Air 100n	19	12 SEFIs in 2.5E10
COTS	ISS	Backbone Ethernet Router	48 port Ethernet Switch	MACH4002	Hirschmann	18	27 SEFIs in 1.00E10
COTS	ISS	Power Inverters	120V Power Inverter KP Series	1100 Watt KP Series	ExelTech	18	0 Errors in 1.00E10
COTS	ISS	Power Inverters	28V Power Inverter XP Series	1100 Watt XP Series	ExelTech	16	0 Errors in 1.00E10
COTS	ISS	Oxygen Monitor	Improved Portable Oxygen Monitor	OMT355	Vaisala	23	20 SEFIs in 1.00E10
COTS	ISS	ELC Wireless Communications System	Wireless USB Adapter	SR71	Ubiquiti	1	0 Errors in 2.5E10
COTS	ISS	Oscilloscopes	Portable Oscilloscope and Wave Form Generator	MSO-19	Link Instruments	2	3 SEFIs [illegible] in 1.00E10
COTS	ISS	Oscilloscopes	Portable Oscilloscope and Wave Form Generator	Model #4227	PicoScope	6	7 SEFIs [illegible] in 1.00E10
COTS	ISS	Hardware Evaluation	Apple IPAD 64GB	MB294LL/A	Apple	9 of 11 tested	9 SEFIs in 1.00E10
COTS	ISS	Hardware Evaluation	Apple IPAD 64GB	MB292LL/A	Apple	3	3 SEFIs in 3 positions
COTS	ISS	GPS Antenna	DC-DC Converter		MDI	1	0 Errors in 1.00E10
COTS	ISS	DVR	FLASH XDR		Convergent Design	10	23 SEFIs in 1.00E10
COTS	ISS	Extravehicular Mobility Unit	USB RS485 Converter	SP390A	Black Box	2	3 SEFI in 1.00E10
COTS	ISS	Extravehicular Mobility Unit	Flow Meter	LA-10C	Flocat	2	0 Errors in 1.00E10

Table I: Summary of Laptop Hardware using Proton Radiation Testing

Board / Assembly	Part Number	Device Category	Part Description	Manufacturer	Beam Position #	MTBF Estimate	Observed Radiation Events
15.4" Wide LCD Screen	AV3 -#1	LCD Screen	Laptop LCD Screen	Lenovo	Screen 1 thru 12	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	Power ICs	CPU Power Chips	N/A	1	1790 Days	1SEU + 1F1 in 1E10 F1= Laptop crash req'd. Hard pwr. Cycle to restore. SEU = data verification error
15.4" Wide Laptop	AV3 - #1	Ethernet ics	Ethernet Chips	N/A	2	>10 Years	1SEU in 1E10 SEU = Error writing to an external HD and creating a file. Req'd. a pwr cycle to clear error.
15.4" Wide Laptop	AV3 - #1	Memory	Graphic Memory	N/A	3	>10 Years	1F1 in 1E10 F1= Laptop crash req'd. Hard pwr. Cycle to restore.
15.4" Wide Laptop	AV3 - #1	Power ICs	Power for SDRAM DIMM	N/A	4	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	N/A	Docking Station Connector and Modem Connector Daughter Card	N/A	5	>10 Years	2F1 in 1E10 F1= Laptop crash req'd. Hard pwr. Cycle to restore.
15.4" Wide Laptop	AV3 - #1	N/A	USB Cable Connection	N/A	6	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	N/A	Additional ics	N/A	7	1790 Days	NONE
15.4" Wide Laptop	AV3 - #1	Ethernet ics	Ethernet Chips	N/A	8	1790 Days	NONE
15.4" Wide Laptop	AV3 - #1	Power ICs	1.5V Voltage Regulator	N/A	9	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	Various	PCMCIA & Other Electronic Chips	N/A	10	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	Various	PCMCIA & Other Electronic Chips	N/A	11	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	Various	PCMCIA & Other Electronic Chips	N/A	12	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	Various	PCMCIA & Other Electronic Chips	N/A	13	598 Days	NONE
15.4" Wide Laptop	AV3 - #1	Core Logic	North Bridge - Mobile Intel GM965 Express Chipset	Intel	14	596 Days	3 SEFI 1 in 1E10 SEFI 1= Laptop crash req'd. Hard pwr. Cycle to restore.
15.4" Wide Laptop	AV3 - #1	Core Logic	South Bridge - Mobile Intel GM965 Express Chipset	Intel	15	357 Days	6F1 in 1E10 F1= Laptop crash req. Hard pwr. Cycle to restore.
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2829 Sept. 2007	Lenovo	16A - 19A	359 Days	3SEU + 1SEFI 1 + 1SEFI 5 in 1E10
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2829 Sept. 2007	Lenovo			SEFI 1= Laptop crash req'd. Hard pwr. Cycle to restore.
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2829 Sept. 2007	Lenovo			SEFI 5 = DVD Read Error
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2829 Sept. 2007	Lenovo			SEU = Error Reading the CD, required a software restart to clear.
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2850 July 2007	Lenovo	16B - 19B	1790 Days	1 SEU in 1E10
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2850 July 2007	Lenovo			SEU = Data error locating files. Req'd. a software restart to clear.
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2850 July 2007	Lenovo			
15.4" Wide Laptop	AV3 - #1	Optical Drive	DVD ROM - P/N 39T2850 July 2007	Lenovo			
15.4" Wide Laptop	AV3 - #1	Graphic PROC	Video Graphics Processor	N/A	20	298 Days	5SEFI 1 + 1SEFI 4 in 1E10 SEFI 1 = Laptop Crash required Hard Pwr Cycle to restore. SEFI 4 = Lost of video to on Laptop under test but video feed to control laptop remained.Power cycle to restore.

Fig. 2. Lenovo Laptop setup in the Test Cave at IUCF

Table I: Summary of Laptop Hardware using Proton Radiation Testing (Cont)

Board / Assembly	Part Number	Device Category	Part Description	Manufacturer	Beam Position #	MTBF Estimate	Observed Radiation Events
15.4" Wide Laptop	AV3 - #1	PROC	Intel T7700 Dual Core Processor	Intel	21	14.2 Days	11SEFI 1 in 8.83E8 SEFI 1= Laptop crash req'd. Hard pwr. Cycle to restore
15.4" Wide Laptop	AV3 - #2	PROC	Intel T7300 Dual Core Processor	Intel	21	38 Days	11SEFI 1 in 2.36E9 SEFI 1= Laptop crash req'd. Hard pwr. Cycle to restore
15.4" Wide Laptop	AV3 - #2	PROC	Intel T7800 Dual Core Processor	Intel	21	26.9 Days	11SEFI 1 in 1.67E9 SEFI 1= Laptop crash req'd. Hard pwr. Cycle to restore
15.4" Wide Laptop	AV3 - #1	Power ics	Secure Digital Card Reader and Power Chips		22	>10 Years	NONE
15.4" Wide Laptop	AV3 - #1	Hard Drives	Hard Drive - Hitachi 200GB Full Encryption HD - P/N: 0A53580	Hitachi	23	SEFI=111 Days; SEUs=225 Days	1SEU + 5SEFI 1 in 1E10 SEU = Data Error SEFI 1 = Laptop crash. Req'd hard power cycle to restore
15.4" Wide Laptop	AV3 - #1	Hard Drives	Hard Drive - Hitachi 200GB Full Encryption HD - P/N: 0A53580	Hitachi	24		6SEU + 11SEFI 1 in 1E10 SEU = Data Error SEFI 1 = Laptop crash. Req'd hard power cycle to restore
15.4" Wide Laptop	AV3 - #1	Hard Drives	Hard Drive - Seagate 160GB HD P/N: 9BS130-901	Seagate	23	SEFI=74.1 Days; SEU=448 Days	2SEU + 13SEFI 1 in 1E10 SEU = Data Error SEFI 1 = Laptop crash. Req'd hard power cycle to restore
15.4" Wide Laptop	AV3 - #1	Hard Drives	Hard Drive - Seagate 160GB HD P/N: 9BS130-901	Seagate	24		2SEU + 11SEFI 1 in 1E10 SEU = Data Error SEFI 1 = Laptop crash. Req'd hard power cycle to restore
15.4" Wide Laptop	AV3 - #1	SDRAM	SDRAM - Hynix 2GB P/N HYMP325S64AMP8 - Y5 - AB - A 0735 2Rx8 PC2 5300S-555-12	Hynix	25A	223 days	8 bit errors in 1E10
15.4" Wide Laptop	AV3 - #1	SDRAM	SDRAM - Hynix 2GB P/N HYMP325S64AMP8 - Y5 - AB - A 0732 2Rx8 PC2 5300S-555-12	Hynix	25B	63.4 Days	28 bit errors in 1E10
15.4" Wide Laptop	AV3 - #1	SDRAM	SDRAM - Samsung 2GB P/N: M470T5669A20 - CE6 0625 2Rx8 PC2 5300S-555-22	Samsung	25C	52.2 Days	34 bit errors in 1E10
15.4" Wide Laptop	AV3 - #1	SDRAM	SDRAM - Samsung 2GB P/N: M470T5669A20 - CE6 0625 2Rx8 PC2 5300S-555-22	Samsung	25D	BIT Errors = 98.7 Days; SEFIs = 895 Days	18 bit errors + 2SEFI 1 in 1E10
14" Standard Laptop	A52 -#1	PROC	Intel T7700 Dual Core Processor	Intel	21	28.3 Days	10 SEFI 1 + 1SEFI 2 in 1.77E9 SEFI 1= Laptop crash req. Hard pwr. Cycle to restore. SEFI 2 = Current to laptop dropped .5A and system froze. Req'd Hard Pwr. Cycle to restore.
14" Standard Laptop	A52 -#1	PROC	Intel T7700 Dual Core Processor	Intel	21	27 Days	11SEFI 1 in 1.68E9 SEFI 1= Laptop crash req. Hard pwr. Cycle to restore.
14" Standard Laptop	A52 -#1	PROC	Intel T7800 Dual Core Processor	Intel	21	35.6 Days	11SEFI 1 in 2.21E9 SEFI 1= Laptop crash req. Hard pwr. Cycle to restore
14" Standard Laptop	A52 -#1	Core Logic	North Bridge - Mobile Intel GM965 Express Chipset	Intel	14	447 Days	1SEFI 1 + 1SEFI 3 in 1E10 SEFI 1 = Laptop Crash req'd hard pwr. Cycle to restore. SEFI 3 = Lost of ethernet connection req'd power cycle to restore ethernet connection.
14" Standard Laptop	A52 -#1	Core Logic	South Bridge - Mobile Intel GM965 Express Chipset	Intel	15	897 Days	4SEFI 1 in 1E10 SEFI 1 = laptop crash req'd hard pwr cycle
14" Standard Laptop	A52 -#1	Graphics PROC	Video Graphics Processor	N/A	20	897 Days	1SEFI 1 + 1SEFI 4 in 1E10 SEFI 1 = Laptop crash req'd power cycle to restore. SEFI 4 = Lost of Video output on the Dut laptop req'd pwr cycle
14" Standard Laptop	A53 - #1	PROC	Intel T7500 Dual Core Processor	Intel	21	25.5 Days	12SEFI 1 in 1.73E9 SEFI 1= Laptop crash req. Hard pwr. Cycle to restore.
14" Standard Laptop	A53 - #2	PROC	Intel T7500 Dual Core Processor	Intel	21	19.6 Days	11SEFI 1 in 1.22E9 SEFI 1= Laptop crash req. Hard pwr. Cycle to restore.

CONCLUSIONS

Presented in this body of work is a small su
of the ongoing testing the NASA-JSC Radiation
Group has tested over the past years. We fred
test many commercial microelectronic devices,
and assemblies for short-term use in LEO applic
Actual on-orbit radiation performance obtaine
also been very consistent with our proton
predictions. Caution must be used in interpreting
results as the data we measured is very depend
the part's lot-date code, the host board circuit
DUT setup, and test software used. The duty
input/output signals, and DUT resource utilizati
directly related to the device's SEE performan
NASA continues to develop plans for returning t
space, new radiation-related challenges exist.
durations will be longer and the radiation enviror
are harsher and the avionics used will therefore
to be more reliable, fault-tolerant, and autono
The JSC Radiation Effects Team has implem
changes to our current test philosophy and a
methods in order to meet this challenge.

REFERENCES

[1] Badhwar, G. D. and P.M. O'Neill, "Galactic Cosmic Ra
Model and Its Applications", Advances in Space Researc
17, No. 2,1996.
[2] O'Neill, P. M., G. D. Badhwar, and W. X. Culp
"Internuclear Cascade - Evaporation Model for LET Spe
200 MeV Protons Used for Parts Testing," IEEE Trans. N
Science, (Dec. 1998).
[3] O'Neill, P. M., "Computer Code for Calculating On
Single Event Effect (SEE) Rates Based on Proton Test
NASA Internal Memo EA44-98-28, (Nov. 1998).
Additional References:
[4] Badhwar, G. D. and P.M. O'Neill, "Time Lag of Twen
Year Solar Modulation", Proceedings of the International
Ray Conference,SH 6.21, Calgary, July 19-30, 1993.
[5]Space Station Ionizing Radiation Design Environment,
International Space Station Alpha, NASA SSP30512 Revi
(June 1994).

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the NA
Electronics Parts & Packaging Program, the JSC Engineeri
Directorate & Avionic Systems Division, International Spa
Station Program Offices, and the Indiana University Cyclo
Facility, Lawrence Berkley National Laboratory, and Texa
Cyclotron for their continued support of this work.

Author Affiliations:

K.K. Allums,PhD, ESCG-ERC Inc., kimberly.k.allums@nasa
P.M. O'Neill,PhD, NASA JSC, patrick.m.oneill@nasa.gov
B.D. Reddell,PhD, NASA JSC, brandon.d.reddell@nasa.gov
K.V.Nguyen, ESCG-Jacobs Engineering, kyson.v.nguyen@n
C.R. Bailey, NASA JSC, charles.r.bailey@nasa.gov