# Radiation Test Results on COTS & non-COTS Electronic Devices for NASA-JSC Spaceflight 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 guickly 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 IUCE.

#### 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 K K Allums Phr

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



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 served laptop 1) Results of the Lenovo Laptop Testina

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



Spece Application	Fight Propert	Test Article Description	Device Part Number	Manuf	# Bears Posttone Used	Observed Results
155	Cabin An Separator for EVA Daugen	Oxigraft Board, CPU Boards, Digital and Serial 1/O Boards	hçin.	4/4	25	17 MP4 in 1 00010
(55	Air Quality Monitor	Power Supply and Battery molder Handware	N/A	N/A	15	0 0 mprs 14 1 00033
155	Annonia Measurement 63	Orager Chip Messurement		Drager		D Briers In 2,00830
155	Improved Payload Ethernet Hulls and Galeway	Modified Othernet Hub & Galaway	AN64343	Geodrich	44	32 58%4 in 1 00(10
155	EUC Writeless Communications System	0075 Writeles Access Point - Sel-Air 200n		Bel-61 3001	19	3250% in 25032
195	Eackbone Othernet Router	48 portmenetiwith	MACH4002	HIS COMMON	18	27 56h H 1 00610
155	Power investers	120v Power Inventor XP	1100 walt IP Serves	Lost Sech	14	0 Briers in 1,00(10
155	Power Inventers	28V Power Inventer XP Sector	1300 wate KP Series	Boat Tach	18	0 Strors in 1.00010
155	Oxygen Monitor	Improved Portable Oxygen Monitor	OWT355	Veisela	29	201011=1.00610
155	ELC Wineless Communications System	Wirefess USB Adapter -	5471	LEiquiti	1	0 8 yers in 2 5438
155	Oscillascopei	Portable Oscillascope and shave form Generator	MSO 19	Link Instruments	3	3 5871 +2 58Ve in 1.00
-55	Oscillascopes	Portable Oscilloscope and Wave form Generator	Model #4227	Picelcope	1	7 501 + 3 58in in 1.0
155	Hardware Svaluation	Apple IPAD 6408	MEZHUUA	Apple	9 of 11 beched	9 SEPta in 1.00610
-55	Hardware Svaluation	Apple IPAD 1808	MEDELLUK	Apple	1	3 SEPis in 3 positions
155	GPS Anothena	DC-DC Converter		MO	1	0 Errors in 1.00E20
	OVA	FLASH KDR		Convergent Design	34	23 56Fs in 1.00E10
155	Extravelicular Mobility Civit	USB AS485 Converse	SPERCA	Starts Son	3	\$ 56PL IN 1-00630
155	Extraveli cular Mobility	Plaw Meter	1A-10C	Flocat	1	0 6 more in 1.0063.8

## Table I: Summary of Laptop Hardware using Proton Radiation Testing

ey i	FartNorber	Device Calegory	Part Description	Manufacturer	Beam Proition #	MTSP Estimate	Observed Radiation Tvents
Screen	243-41	SC0 Screen	Ceptos GCD Screen	lahove	Screen 3 thru 12	>30 Years	NONE
110	A(3-8)	Powerics	CPU Power Chips	A/A	1	1790 Days	15EU + 171 In 1E30 F1+ Laptop crash veg's Hard per Cycle to restore. SEU rulate verification error
rtog	Av3-#1	Ethernet ics	Etherhet Chips	204	2	HID Years	1502 in 1510 MU in three writing to an external IND and creating a New Registion poor cyclic to clean error.
100	8/3-81	Memory	Graphic Memory	A(A	1.2	20278919	1F1 in 1E10 F11 Lectro crash reg/d. Herd per, Cocie to restore
110	4/3-81	Power ICs	Prover for SORAM DIMM	NA	4	100 Years	NOM
1.0	A/3-#1	3/8	Docking Station Connector and Modem Connector Daughter Card	N/8	3	+20 Years	2F1 in 1810 F1+ Leptop crash reg/d. Hand pur. Cpcle to restore.
1106	843-81	R/A	USB Cable Connection	Alla		200 Years	NOME
104	#43-#1	A/A	Additional ics	ALM .		1790 Devb	NONE
100	AV3-#1	Ethernet kis	Ethernet Chips	ALA .		1790 Days	NOM
116	443.41	Power 1Ca	1.54 Williage Regulator	A(A		100 19979	NOME
rha	10/3-81	Various	PCMC/A& Other Electronic Chips	Alla	10	10078816	NONE
100	413-01	Various	POACUL& Other Electronic Drips	A(A	13	10078418	NOM
104	812-81	Through	PCMCIA& Other Electronic Draw	202	12	1007ber4	nond .
the last	A/3-#1	Various	PCMCIA& Other Electronic Chips	Alla	18	396 Oeve	NOM
rtop .	AV3-81	Core Logic	North Bridge - Mobile Intel GM965 Express Chipset	intel	54	196 Days	3 5071 1 in 1810 5871 1r Laptop crash reg'il. Hard pwr. Cycle to resilore.
114	813-81	Core Lagie	South Bridge - Mobile Intel GM965 Express Chipset	(red)	15	357 Days	8F1 in 1E10 F1+ Leptop cresh req. Hard pur, Cycle to restore.
-	A/3-#1	Optical Drive	0V0 R041 - F/N 3972829 Sept. 2007	laneve			3582 + 15871 1 + 15871 5 in 1810
tos	A/2-#1	Optical Drive	0VD ROM - P/N 3972829 Sept. 2007	Serovo	164.184	150 0000	SEFI 1+ Leptop crash-regid. Hand pur, Cycle to restore.
rios	AV3-#1	Optical Drive	DVD ROM - P/N 3972829 Sept. 2007	Lanova	104 104		SET ( 5 + DVD Read Error
114	#43-#1	Optical Drive	OVD ROM - P/N 3972829 Sept. 2007	Lenovo			SEU + Error Reading the CO, required a software restart to clear.
100	443-81	Optical Online	OVD ROM - #/N 3972850 July 2007	Lenove			1 582 H 1810
100	418-05	Optical Online	DVD ROM - P/N 3972850 July 2007	Langua	168-159	1790 Devis	SEX + Data error locating files. Aug'd, a software restart to clear.
100	443-45	Optical Drive	DVD 8044 - P/N 3972850 July 2007	Lenovo			
14	413-41	Optical Drive	DVD RDM - P/N 3972850 July 2007	Lanovo			
100	4/3-41	Graphic PROC	Video Graphics Processor	NA	20	298 Dect	5589 1 + 1589 4 in 1630 589 1 × Laptop Crash required Hard Pur Cycle to restore, 1891 4 + Cost of video to on Laptop under test but



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

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

0 Dual Care Processor 0 Dual Care Processor 0 Dual Care Processor 10 Dual Care Procesor 10 Dual Care Procesor 10 Dual Care Procesor 10 Dual Care	intel Intel Intel IntelN Hachi Hachi Seepte Intel Seepte Intel Int	21 23 23 23 23 24 23 24 23 24 23 24 24	34.2 Deps 38 Deps 24.9 Deps 40 Years 569-74.1 Deps 560-74.1 Deps 560-74.1 Deps 560-74.1 Deps 560-74.1 Deps 560-74.1 Deps	Litter: 1 - A start SMM - Legging start Area (2) - Marging Control (2)     To 2 - SMM
6 Dual Care Processor (ph) Card Processor (ph) Card Reader and Processor 2000 Full Instructure 2000 Full Instructure 2000 Full Instructure 2000 Full Sectors 2	inal inal intuchi intuchi Seapte Seapte Seapte	23 23 24 24 23 24 23 24 24	18 Deys 26.9 Deys 40 Years 58%-11 Deys 58%-225 Deys 58%-74.1 Deys 58%-688 Deys 228 deys	Listy: In 2383 589 - Lappa outs well find pur Cpains     more     the second outside outside outside outside outside outside     Listy: In 2385 589 - Lappa outside well well pur Cpains     Model     Dirth 2587 1997 1 to 1233 589 - Data Second 587 1 to 1 september 2006     Second 2006     Second 2007 1 to 1233 589 - Data Second 597 100 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 100 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 100 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 100 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 100 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 589 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 587 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 587 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 587 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 587 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1233 587 - Data Second 597 1 to 1 - Lappa outside     Second 2009 1 to 1234 597 100 1 to 1234 597 100 1 to 1244 59
6 Dual Care Processor ppie Carl Reader and . 	ingel mitachi mitachi Seegote seegote myrra myrra	21 23 24 25 24 25 24 25	26.9 Deys 100 Years 109-111 Deys 553x-225 Deys 553x-225 Deys 553x-428 Deys 223 days	Litter: In Letter Sim: In Laplace oracle need an end and content and the end and content and the end of the end
ppi (2x4) Reader and 28 28 - Intervol. 20008 full - Intervol. 20008 full - Intervol. 20008 full - Intervol. 20008 full - Segarar 10008 mO hyte - Segara 1008 mO hyte - Segara	mtachi mtachi Seagate Seagate myrca	23 24 23 24 23 24 24	-00 Years 50%-111 Days; 50%-223 Days 50%-74.1 Days; 50%-680 Days 223 days	MONE 1910 - SAMP 1 in SELS 507 - Data Shur SAM 1 - Laptop crash. Ref SamP alware cipile to motion 6100 - 1100 1 in 1023 500 - done form 507 1 - Laptop crash. 8200 - 1100 1 in 1023 500 - done form 507 1 - Laptop crash. Ref 3 hard paser cipile to motion 8400 - 1100 1 in 1103 500 - done form 507 1 - Laptop crash. 8400 - 1100 1 in 1103 500 - bottom control (1) - Laptop crash. 8400 - 1100 1 in 1103 500 - bottom control (1) - Laptop crash. 8400 - 1100 1 in 1103 500 - bottom control (1) - Laptop crash. 8400 - 1100 1 in 1103 500 - bottom control (1) - Laptop crash.
	ntachi Intachi Seagate Seagate Myrca	23 34 23 34 23 24	1691-211 Days; SELL-225 Days SELL-225 Days SELL-225 Days SELL-225 Days SELL-225 Days	$\begin{split} & 1240 + 1240 + 1242 + 5240 - 4046 + driver $10^{14}$ 1 - isophete crash, $$ field $hard $hard$ are crash, $$ field $hard$ $$
<ul> <li>Historik 20008 Hull</li> <li>Hill C. P./NC 5455580</li> <li>Hangure 18008 Holl Pr/NC 01</li> <li>Sampare 18008 Hol Pr/NC 02</li> <li>Hangure 18008 Holl Pr/NC 03</li> <li>Hangure 18008 Holl Pr/NC 048 Holl Pr/NC 048</li></ul>	Historia Seegate Seegate Myrca	24 23 24 25A	SELA-223 Davs SELA-223 Davs SELA-223 Davs SELA-223 Davs SELA-223 Davs	ESD(+ 11109) 1 in 1233 500+ Data Dras 5091 1 + Laptin crash. Negl Data Speech (yin b) mittan. 2150+ 13309 1 in 1233 500+ Data Dras 5091 1 + Lapting crash. Negl Data Speec cyclick in relation 2160+ 333091 1 + 1213 500+ Data Dras 5091 1 + Lapting crash. Negl March passes cyclick in relation
4 - Saugara 19008 HD H/H 01 4 - Saugara 19008 HD H/H 02 minix 208 P/N 9404029 - 15 - 48 - A 8 PC3 3305 555 - 12 minix 208 P/N 9404078 - 15 - 48 - A 8 PC3 3305 555 - 12 manuag 208 P/N 94040 P/N 94040 P/N	Seagate Seagate myrca myrca	23 24 25A	SEPI-74.3 Days; SED-668 Days 223 days	$\label{eq:2.1} 2500 + 1300 f(1 + 120 500 + Data Drive S01 1 + Laping crack. And 0 hard power cycle to restore 2500 + 1300 f(1 + 120 500 + Data Drive S01 1 + Laping crack. And 0 hard power cycle to restore$
- Seagarte 18005 HD F/H 03 weix 200 F/H 56440792 - 15 - 88 - A III F/2 53005-555-12 min 200 F/H 56440792 - 15 - 82 - A III F/2 53005-555-12 seal-ang 200 F/H 68403 - CCC 0625 2Hub	Seagute myrca myrca	24 25A	SAU-HAR Days	250 + 1150* 1 + 1150 50 + beta first 50* 1 + Gategi crash. Regil hard power cycle to restore
4443 208 7/N 5444078 - 15 - 48 - A 8742 5100 - 555 - 12 1474 208 7/N 5444078 - 15 - 48 - A 8742 5100 - 555 - 12 4744 208 7/N 6442 - 208 7/N 6442 - 208 7/N 6442 - 208 7/N	7973 7973	25A	223 days	
5014 208 P/N 54440PE - 15 - AB - A 8 PC2 53005-555-12 amilung 208 P/N 68420 - CEC 0625 2Pv8	19,000	1000		# Bit engrs in 1810
amaung 208 P/N 68A30 - 006-0635 2Rx8		101	83.4 Days	28 bit even in 1510
> > > + + + + + + + + + + + + + + + + +	Sensorg	250	52.2 Days	34 bit errors in 1830
iamsung 208 P/N 68A20 - CE8 0825 2848 5-055-22	Samoung	250	8/7 5+945 - 88.7 Deys: 50%s - 895 Deys	18 bit errors + 250% 1 in 1810
O Dual Core Processor	intel	п	28.5 Days	10 SEH 1 + 13EH 2 in 1.77EH SEH 1+ Lapter crashing. Kand per Cycle to restors. SEH 2 + Current to laptop dropped SA and system from Reg 3 Hard Per. Cycle to restore.
O Dual Core Processor	intel	21	27 Desn	11509 1 (+ L&BEB 509 1+ Laptog crash reg. Hard per, Cycle to restore.
O Dual Core Processor	intel	n	15.6 Deyn	11507 1 in 22509 50% 2+ Laptop crashing, Hand pur, Cycle to report
Sge - Mobile Intel GMIIGS Napoet	1.1M	14	647 Orys	1587 1 • 1587 3 in 1530 587 1 • Laples Crash regid hand part Cycle to restore. 587 3 • Last of ethernet connection regid power cycle to restore attended connection.
fge - Mobile Intel GARDES Naset	intel	15	897 Oave	458% 1 in 1850 58% 1 + laptop crack reg's hard per cycle.
phils Pricesor	N/A	20	897 Deut	1589 1 + 15891 4 in 3520 5891 1 + Laptitis chash negʻil power cycli to restore, 5891 4 + Last af Video output on the DutTaphop negʻil part cyclin
O Dual Com Processor	intel	n	25.5 Orys	325071 2 In 3.7509 5071 3+ Lapling crash reg. Hand per, Cycle to INNER
O Dual Core Processor	ined.	23	19.6 Days	115071 Lin 3.2209 5071 2+ Lapitop crack res. Hand pwr. Cycle to restore.
	ge - Nobel a Intel GARRES ge - Mobel a Intel GARRES gett Miles Processor Duel Come Processor D'Duel Come Processor	ge - Moles tall COMIS gen (Moles tall COMIS) (244) Mels Processer (MA Oual Com Processer (MA Oual Com Processer (MA)	Al-ADDER SING DARKS Used 24 argument (SANSES) Used 24 Angen Anderson (SANSES) Used 25 Angen Angen Ang Angen Angen Ange Angen Angen A	and an and a set of the set of th

Group has tested over the past years. We free test many commercial microelectronic devices. and assemblies for short-term use in LEO applic Actual on-orbit radiation performance obtain 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 utilizat 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 auton The JSC Radiation Effects Team has impler changes to our current test philosophy and a methods in order to meet this challenge.

CONCLUSIONS

Presented in this body of work is a small su

of the ongoing testing the NASA-JSC Radiation

## REFERENCES

I Badhwar, G. D. and P.M. O'Neill, "Galactic Cosmic Ra Model and Its Applications". Advances in Space Resea 17 No 2 1996 [2] O'Neill P M G D Badhwar and W X Cu "Internuclear Cascade - Evaporation Model for LET Spe 200 MeV Protons Used for Parts Testing \* IEEE Trans Science. (Dec. 1998) [3] O'Neill, P. M., "Computer Code for Calculating ( Single Event Effect (SEE) Rates Based on Proton Test NASA Internal Memo FA44-98-28 (Nov. 1998) Additional References: (4) Badhwar, G. D. and P.M. O'Neill, "Time Lag of Twei 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 Rev (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.go K.V.Nauven, ESCG-Jacobs Engineering, kyson, v.nauven@n C.R. Bailey, NASA JSC, charles.r.bailey@nasa.gov

Metadata citation ano



Ë	Ň	ï	ć	3	ĕ	Ŕ	1	e	à	Ì	ï		Ē	ij	ĥ	i	5							I	3	É	į	í	Ŕ	é	d	c	ŝ	ë	Ë	ŧ		
1	 :					:						1				1									:				1	:		1	1			ŝ	f	