Recent Total Ionizing Dose and Displacement Damage Compendium of Candidate Electronics for NASA Space Systems

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Abstract-- **Vulnerability of a variety of candidate spacecraft electronics to total ionizing dose and displacement damage is studied. Devices tested include optoelectronics, digital, analog, linear bipolar devices, and hybrid devices.**

Index Terms- Displacement Damage, Optoelectronics, Proton Damage, Single Event Effects, and Total Ionizing Dose.

I. Introduction

NASA spacecraft are subjected to a harsh space environment that includes exposure to various types of ionizing radiation. Long-term exposure to radiation has been known to affect the function of the spacecraft electronics. As a result flight parts must be tolerant to radiation-induced Total Ionizing Dose (TID) and displacement damage (DD) effects for space approval or parts must be mitigated by shielding or other methods to reduce TID effects. Hence, the effects of TID and proton DD need to be evaluated by test in order to determine risk to space projects.

The test results presented here were gathered to establish the sensitivity of candidate spacecraft electronics to TID and/or proton damage. For similar results on single event effects (SEE), a companion paper has also been submitted to the 2011 IEEE NSREC Radiation Effects Data Workshop entitled: "Recent Single Event Effects Compendium of Candidate Electronics for NASA Space Systems" by M. O'Bryan, et al. [1]

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II. Test Techniques and Setup

Unless otherwise noted, all tests were performed at room temperature and with nominal power supply voltages.

A. Test Methods – TID

TID testing was performed using a Co-60 source. Dose rates used for testing were between 0.0005 and 50 rads(Si)/s.

B. Test Methods – Proton

Proton DD/TID tests were performed at the University of California at Davis - Crocker Nuclear Laboratory (UCD-CNL) using a 76" cyclotron (maximum energy of 63 MeV) and the Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE). Table I lists the proton damage test facilities and energies used on the devices.

TABLE I
PROTON TEST FACILITIES

Facility	Proton Energy, (MeV)
University of California at Davis - Crocker Nuclear Laboratory (UCD-CNL)	6.5-63
Lawrence Berkeley National Laboratory Berkeley Accelerator Space Effects (LBNL BASE)	50

C. Test Methods – Electron

Electron DD/TID tests were performed at Rensselaer Polytechnic Institute's (RPI) Gaerttner Linear Accelerator Laboratory. The electron energies used were between 5 and 50 MeV.

III. Test Results Overview

Abbreviations for principal investigators (PIs) are listed in Table II. Abbreviations and conventions are listed in Table III. Please note that these test results can depend on operational conditions. Complete test reports are available online at http://radhome.gsfc.nasa.gov [3].

TABLE II
LIST OF PRINCIPAL INVESTIGATORS

Abbreviation	Principal Investigator (PI)
MiC	Michael Campola
MaC	Martin Carts
MeC	Megan Casey
DC	Dakai Chen
RL	Raymond Ladbury
JML	Jean-Marie Lauenstein
CM	Cheryl Marshall
TO	Timothy Oldham
JP	Jonathan Pellish
AS	Anthony (Tony) Sanders
MX	Michael Xapsos

TABLE III
ABBREVIATIONS AND CONVENTIONS

ACRONYM/ DEFINITION	ACRONYM/ DEFINITION
A = Amp BiCMOS = Bipolar – Complementary Metal Oxide Semiconductor BJT = Bipolar Junction Transistor CERDIP = Ceramic Dip CMOS = Complementary Metal Oxide Semiconductor CTR = Current Transfer Ratio DAC = Digital to Analog Converter DC-DC = Direct Current to Direct Current DD = Displacement Damage DNL = Differential Non-Linearity DTRA = Defense Threat Reduction Agency DUT = Device Under Test DV_{out}/DI_{out} = Output Voltage Load Regulation E = Electron ELDRS = Enhanced Low Dose Rate Sensitivity FET = Field Effect Transistor G = Gamma GaAlAs = Gallium-Aluminum-Arsenide GaAsP = Gallium-Arsenide-Phosphide HBT = Heterojunction Bipolar Transistor H_{FE} = Forward Current Transfer Ratio I_b = Input Base I_{bias} = Input bias Current I_c = Collector Current I_{ce} = Output Current IDD = Supply Current I_f = Input Forward Current I_{GSS} = Gate Reverse Current I_{os} = Offset Current InGaP = Indium Gallium Phosphide I_{OUT} = Output Current IUCF = Indiana University Cyclotron Facility JFET = Junction Field Effect Transistor LBNL BASE = Lawrence Berkeley National Laboratory/Berkeley Accelerator Space Effects LCC = Leadless Chip Carrier LDC = Lot Date Code LDO = Low Dropout LED = Light Emitting Diode	LDR = Low Dose Rate MeV = Mega Electron Volt mA = milliamp MOSFET = Metal Oxide Semiconductor Field Effect N/A = Not Available Op-Amp = Operational Amplifier P = Proton PI = Principal Investigator REAG = Radiation Effects & Analysis Group RPI = Rensselaer Polytechnic Institute Gaerttner Linear Accelerator Laboratory SEE - Single Event Effects Spec = Specification(s) TID = Total Ionizing Dose UCD-CNL = University of California at Davis – Crocker Nuclear Laboratory V_{bias} = Bias Voltage V_{ce} = Collector Emitter Voltage V_{CEsat} = Collector-Emitter Saturation Voltage V_{IH} = High Level Input Voltage V_{in} = Voltage In V_{os} = Offset Voltage V_{out} = Output Voltage V_{ref} = Reference Voltage V_{th} = Threshold Voltage V_z = Reverse Breakdown Voltage

TABLE IV
SUMMARY OF TID AND DD TEST RESULTS

Part Number	Manufacturer	LDC	Technology/ Device Function	PI	Summary of Results	Radiation Source	Dose rate (rad(Si)/s)	Deg. Level (krad(Si))
Analog Digital Converter/Digital Analog Converter								
AD5544ARS	Analog Devices	0332, 0409, 0827, & 1028	CMOS / Quad 16-bit DAC (0827 & 1028); BiCMOS/Quad 16-bit DAC (0332 & 0409)	JP	0827: Functional failure was observed in one DUT at 2 krad(Si). 1028: Functional failure observed in one DUT at 10 krad(Si). Both 0827 & 1028 show TID sensitivities to IDD, output leakage, & DNL errors – biased irradiation is worst case. 0332 & 0409 passed all tests through 15 krad(Si) at which point the biased samples' IDD went out of spec. Both date codes showed no functional failures through 20 krad(Si).	G	0.01 (0827), 2 (1028), 0.01 (0332 & 0409)	$0 \leq x \leq 2$ (0827); $7 \leq x \leq 10$ (1028); $10 \leq x \leq 15$ (0332 & 0409)
AD585	Analog Devices	8440	Bipolar / Sample & Hold Amp	MX	Droop rate out of spec at 15 krad; V_{os} at 40 krad(Si).	G	0.01	10 < droop rate < 15 30 < offset V < 40
Flash								
MT29F8G0AAAWP	Micron	0948	CMOS/8G NAND Flash	TO	50 krad(Si). <Fail<75 krad(Si); loss of erase/write function.	G	50	75
K9F8G08U0M	Samsung	1031	CMOS/8G NAND Flash	TO	400 krad(Si)< Fail<500 krad(Si); partial loss of Erase/Write functions.	G	50	500
Miscellaneous								
LM139AWRQMLV (14-lead CERDIP)	Natl Semi	JM046X13	Bipolar / Analog Comparator	DC	Parameters within spec after 10 krad(Si) for devices irradiated at 0.5 mrad(Si)/s.	G	0.0005	>10
HS-1840ARH	Intersil	X0902ABB8	CMOS/ Analog Multiplexer	MX	Outputs & reference voltage held at application specific +3.3V.	G	16.7	>100
Ram - 6+	Mini-Circuits	N/A	Bipolar / RF Amplifier	MX	For 2 lots of 8 parts each worst-case gain degradation at 50 krad was 15%.	G	0.02	>50
ISL74422ARH/ISL4422BRH	Intersil	0948	BiCMOS/ MOSFET Driver	RL	Minor degradation. All parts within spec to >100 krad(Si).	G	0.01	>100
MCM2760-4M	QTech	0135	Hybrid / Crystal Oscillator	MeC	All parameters stayed within spec limits to 3 Mrad(Si).	G	74	>3000
Operational Amplifier/Amplifier								
LM158AJRLQMLV (8-lead CERDIP)	Natl Semi	7W4453G019	Bipolar/ Op-Amp	DC	Parameters within spec after 100, 70, 50, & 30 krad(Si) for devices irradiated. at 10, 5, 1, & 0.5 mrad(Si), with the exception of 1 part at 5 mrad(Si)/s, which parametrically failed after 70 krad(Si). 5 mrad(Si)/s (1 part): 60 < I_b < 70 krad(Si). Devices Exhibit dose rate enhancement after 50 krad(Si).	G	0.01 0.0005 0.001 0.0005	>100 $60<I_b<70$ >50 >30

Part Number	Manufacturer	LDC	Technology/ Device Function	PI	Summary of Results	Radiation Source	Dose rate (rad(Si)/s)	Deg. Level (krad(Si))
LM124AJRQMLV (14-lead CERDIP)	Natl Semi	9R5469G019	Bipolar/ Op-Amp	DC	Exhibits no dose rate enhancement. Parameters within spec after 10 & 13 krad(Si) for devices irradiated at 10 & 0.5 mrad(Si)/s.	G	0.01	>13
							0.0005	>10
RH1013MH (TO5 metal can)	Linear Technology	0329A/9513A	Bipolar/ Dual Precision Op-Amp	DC	Parameters within spec after 100, 20, & 10 krad(Si) for 5, 1, & 0.5 mrad(Si)/s.	G	0.005	>100
							0.001	>20
							0.0005	>10
RH1013MJ8 (CERDIP)	Linear Technology	0305A/0337A	Bipolar/ Op-Amp	DC	Parameters within spec after 100, 20, & 10 krad(Si) for 5, 1, & 0.5 mrad(Si)/s.	G	0.005	>100
							0.001	>20
							0.0005	>10
RH310 (Ceramic Flat-8)	ST Micro-electronics	30849A	Bipolar/ Op-Amp	DC	Parameters within spec for parts irradiated at 5 mrad(Si)/s after 5 krad(Si). 1 mrad(Si)/s irradiation currently in progress.	G	0.0005	>5
OP497BRC	Analog Devices	0946A	Precision Picoampere Input Current Quad/ Op-Amp	JP	Significant degradation of all measured parameters after 10 krad(Si). I_{bias} & I_{os} & voltage parametric means out of spec by 4 krad(Si), but may be tolerable in a given application. Co-60 low dose rate testing only.	G	0.01	$2.5 \leq x \leq 5$
AD648	Analog Devices	9643	Bipolar/ Op-Amp	MeC	The spec for I_{bias} & I_{os} was exceeded by one biased part at 2 krad(Si).	G	0.01	$0 < I_{os} < 2$, $0 < I_{bias} < 2$
PA10	Apex	0936	Bipolar / Op-Amp	MiC	All devices stayed within spec up to 50 krad(Si).	G	0.01	x >50
RH1056A	Linear Technology	0921A	Bipolar/ JFET Input Op-Amp	MX	4 parts tested all within specs at 50 krad(Si).	G	0.02	>50
AD524	Analog Devices	0939A	Bipolar / Instrumentation Amp	MX	I_{bias} out of specs at 10 krad(Si).	G	0.02	$5 < I_{bias}$ I < 10
OP400	Analog Devices	0204	Bipolar/ Quad Op-Amp	RL	I_b is most sensitive parameter; V_{IO} second; all other parameters in specification to > 60 krad(Si).	G	0.01	$9<I_b<11.5, 15<V_{IO}<20$
Power Mosfet/Misc. Power/DC-DC								
SiB455EDK	Vishay	BKW 9QZ	Power p-type TrenchFET	JML	V_{th} degrades with TID. Parameters remained within spec.	G	4-17	>150
SPT6235MS	SSDI	0624	General Purpose High Voltage/Power NPN BJT	JP	Tested with I_c of 0.25 & 0.51 A, V_b = 5 V, & V_{ce} = 155.6 V. Mean h_{FE} stayed within application spec for the duration of the test.	G	2-20	$>2x10^6$
LS2805	Intl Rectifier	0536	Hybrid /High Reliability Radiation Hardened DC/DC Converter	MeC	V_{out} decreased below the specified limit between 100 & 300 krad(Si) for one part.	G	67.6	$100 < V_{out} < 300$

Part Number	Manufacturer	LDC	Technology/ Device Function	PI	Summary of Results	Radiation Source	Dose rate (rad(Si)/s)	Deg. Level (krad(Si))
Transistors/BJTs/FETs								
JANS2N3866	Semicoa	0721	General Purpose NPN BJT	JP	Tested with I_c of 0.25 & 0.51 A with a pulsed base current & V_{ce} = 4.4 V. Mean h_{FE} stayed within application spec for the duration of the test.	G	2-20	$>2x10^6$
2N5116	Vishay	S0618	JFET / P-Channel Analog Switch	MeC	I_{GSS} exceeded the specified limits at the first datapoint of 10 krad(Si).	G	31.3	$0 < I_{GSS} < 10$
2N2222A	SSDI	0686	Bipolar/ Discrete Transistors	MX	DC h_{FE} out of specs at 40 krad(Si).	G	16.7	$30 < h_{FE} < 40$
2N2907A	Semicoa	0807	Bipolar/Switching & Small Signal Transistors	MX	DC current gain out of specs at 40 krad(Si).	G	16.7	$30 < h_{FE} < 40$
2N2907	Micro Semi	0513	Bipolar / PNP Silicon Switching Transistor	MeC	h_{FE} for a I_C of 0.1 mA exceeded the spec between 30 & 50 krad(Si).	G	95	$30 < h_{FE} < 50$
Voltage Reference/Voltage Regulator								
LT1009IDR	Texas Instruments	0606	Bipolar/ 2.5V Internal Reference	DC	Exhibits no dose rate enhancement. Parameters within spec after 100, 30, & 15 krad(Si) for the 5, 1, & 0.5 mrad(Si) parts.	G	0.005	>100
							0.001	>30
							0.0005	>15
LM317KTTR	Texas Instruments	0608	Bipolar/ Positive Voltage Regulator 3-terminal	DC	Parameters within spec after 80, 20, & 15 krad(Si) for the 5, 1, & 0.5 mrad(Si) parts. LDR enhancement observed for parts irradiated at 0.5 & 1 mrad(Si)/s after 20 krad(Si).	G	0.005	>80
							0.001	>20
							0.0005	>15
TL750L05CDR	Texas Instruments	0605	Bipolar/ LDO Positive Voltage Regulator 5V	DC	Exhibits LDR enhancement for functional failures. Degradation level shows initial failure dose levels.	G	0.01	$50<V_{out}<60$
							0.005	$35<V_{out}<40$
							0.001	$10<V_{out}<15$
							0.0005	$7.5<V_{out}<10$
TL750M05CKTRR (TO263-3)	Texas Instruments	0707	Bipolar / LDO positive Voltage Regulator 5V	DC	V_{out} failure levels (I_O = 10 mA): 5 mrad(Si)/s: 70 < V_{out} < 80 krad(Si). 1 mrad(Si)/s: > 20 krad(Si) 0.5 mrad(Si)/s: > 15 krad(Si).	G	0.005	$70<V_{out}<80$
							0.001	>20
							0.0005	>15
LM117HRQMLV (TO-39 metal can)	Natl Semi	7D5867L019	Bipolar / Adjustable Voltage Regulator	DC	LDR enhancement observed for V_{ref} degradation. Parameters within spec after 90, 20, & 15 krad(Si) for the 5, 1, & 0.5 mrad(Si)/s parts.	G	0.005	> 90
							0.001	> 20
							0.0005	> 15
LM136AH2.5QMLV (3-lead TO-46)	Natl Semi	200746K019	Bipolar / 2.5V Reference	DC	Exhibits no dose rate enhancement. Parameters w/in spec after 100, 20, & 10 krad(Si) for the 5, 1, & 0.5 mrad(Si) devices.	G	0.005	>100
							0.001	>20
							0.0005	>10

Part Number	Manufacturer	LDC	Technology/ Device Function	PI	Summary of Results	Radiation Source	Dose rate (rad(Si)/s)	Deg. Level (krad(Si))
RH1021CMW-5 (Flatpack)	Linear Technology	0123A	Bipolar / Precision 5V Reference	DC	Parameters within spec after 100, 20, & 10 krad(Si) for 5, 1, & 0.5 mrad(Si)/s.	G	0.005	>100
							0.001	>20
							0.0005	>10
RH1021CMH-5 (TO-5 can)	Linear Technology	9783A	Bipolar/ Precision 5V Reference	DC	LDR enhancement observed for parts irradiated at 5 mrad(Si)/s after 30 krad(Si). 5 mrad(Si) (TO-5): $90 < V_z < 100$ krad(Si).	G	0.01	>50
							0.005	$80 < V_z < 90$
							0.001	>20
							0.0005	>10
RH1009MW (Flatpack)	Linear Technology	0649A	Bipolar / 2.5V Reference	DC	Exhibits dose rate enhancement after 15 krad(Si) for devices irradiated at 5 & 1 mrad(Si)/s. 5 mrad(Si)/s Flatpacks: $100 < V_z < 120$ krad(Si).	G	0.005	$100 < V_z < 120$
							0.001	>20
							0.0005	>10
RH1009MH (TO-46 can)	Linear Technology	0829H	Bipolar / 2.5V Reference	DC	Exhibits dose rate enhancement after 20 krad(Si) for devices irradiated at 5 & 1 mrad(Si)/s. 5 mrad(Si)/s TO-46 cans: $80 < V_z < 90$ krad(Si).	G	0.005	$80 < V_z < 90$
							0.001	>20
							0.0005	>10
RHFL4913ESY332 (TO257)	ST Micro-electronics	30828A	Bipolar / Voltage Regulator	DC	Parameters within spec for parts irradiated at 10, 5 & 1 mrad(Si)/s after 100, 30 & 20 krad(Si).	G	0.001	>100
							0.005	>30
							0.001	>20
RHFL4913KP332 (Flat-16)	ST Micro-electronics	30814B	Bipolar / Voltage Regulator	DC	Parameters within spec for parts irradiated at 10, 5 & 1 mrad(Si)/s after 100, 30 & 20 krad(Si).	G	0.01	>100
							0.005	>30
							0.001	>20
RHF43B (Ceramic Flat-8)	ST Micro-electronics	30820A	Bipolar / Voltage Regulator	DC	Parameters within spec for parts irradiated at 0.5 mrad(Si)/s after 10 krad(Si).	G	0.0005	> 10
RH1021	Linear Technology	0940A	Bipolar/ 5V Voltage Reference	MeC	V_{out} exceeded the specified limits between 10 & 30 krad(Si).	G	55.6	$10 < V_{out} < 30$

Displacement Damage

Part Number	Manufacturer	LDC	Technology/ Device Function	PI	Summary of Results	Radiation Source	Dose rate (rad(Si)/s)	Deg. Level (e-/cm^2 or p/cm^2)
66212	Micropac	1014	GaAIAs/Optocoupler	JP	Parts remained functional through 2e^{12} cm^2. The device CTR dropped out of datasheet specifications between 4x10^{11} cm^{-2} & 8x10^{11} cm^{-2} at a V_{ce} of 1 V & between 8x10^{11} cm^{-2} & 1.2x10^{12} cm^{-2} at a V_{ce} of 5 V. Tested with 50 MeV protons.	P	N/A	$4\times10^{11} \leq x \leq 8\times10^{11}$ (V_{CE} = 1 V); $8\times10^{11} \leq x \leq 1.2\times10^{12}$ (V_{CE} = 5 V)
HCPL-573K	Avago	0937	GaAsP/Optocoupler	JP	Parts remained functional through 2x10^{12} cm^{-2}. CTR within spec at a V_{ce} of 0.4 V for all fluences tested. CTR out of specification at a V_{ce} of 0.1 V at 2x10^{12} cm^{-2}. Tested with 50 MeV protons.	P	N/A	$1.2\times10^{12} \leq x \leq 2\times10^{12}$ (V_{CE} = 0.1 V); $> 2\times10^{12}$ (V_{CE} = 0.4 V);
RAM-3+	Mini-Circuits	0918	InGaP/MMIC RF Amp	JP	Parts remained functional & in spec through 2x10^{12} cm^{-2}. Mini-Circuits evaluation board used for testing. Tested with 50 MeV protons.	P	N/A	$> 2\times10^{12}$
UT54LVDS031LV/E	Aeroflex	0946	CMOS / Low Voltage Quad Driver	MeC	Within the measurement resolution & noise threshold, all parameters stayed in spec to a 17 MeV electron fluence of 8 x 10^{13} cm^{-2}.	E	N/A	$> 8\times10^{13}$
MCM2760-4M	QTech	0135	Hybrid / Crystal Oscillator	MeC	All parameters stayed within spec limits to a 17 MeV electron fluence of 1.5 x 10^{14} cm^{-2}.	E	N/A	$> 1.5 \times 10^{14}$
UT54ACS08	Aeroflex	0907	CMOS / Radiation-Hardened Quadruple 2-Input AND Gates	MeC	V_{IH} decreased below the spec between 17 MeV electron fluences of 8 x 10^{13} and 1.6 x 10^{14} cm^{-2}.	E	N/A	$8\times10^{13} \leq x \leq 1.6\times10^{14}$
LS2805	Intl Rectifier	0536	Hybrid /High Reliability Radiation Hardened DC/DC Converter	MeC	V_{out} decreased below the specified limit between 17 MeV electron fluences of 2.7 and 5.3 x 10^{13} cm^{-2}.	E	N/A	$2.7\times10^{13} \leq x \leq 5.3\times10^{13}$
2N5116	Vishay	S0618	JFET / P-Channel Analog Switch	MeC	Within the measurement resolution & noise threshold, all parameters stayed in spec to a 17 MeV electron fluence of 2.7 x 10^{14} cm^{-2}.	E	N/A	$> 2.7\times10^{14}$
2N2222	Semicoa	0743	Bipolar / Silicon NPN Transistor	MeC	h_{FE} for I_C of 0.1, 1.0, & 10 mA exceeded the spec between 5 MeV electron fluences of 1.1 and 3.6 x 10^{13} cm^{-2} for all three parts.	E	N/A	$1.1\times10^{13} \leq x \leq 3.6\times10^{13}$
					h_{FE} for I_C of 0.1, 1.0, & 10 mA exceeded the spec between 17 MeV electron fluences of 8 x 10^{12} and 2.7 x 10^{13} cm^{-2} for all three parts.	E	N/A	$8\times10^{12} \leq x \leq 2.7\times10^{13}$
					h_{FE} for I_C of 0.1, 1.0, & 10 mA exceeded the spec between 25 MeV electron fluences of 7 x 10^{12} and 2.3 x 10^{13} cm^{-2} for all three parts.	E	N/A	$7\times10^{12} \leq x \leq 2.3\times10^{13}$

Part Number	Manufacturer	LDC	Technology/ Device Function	PI	Summary of Results	Radiation Source	Dose rate (rad(Si)/s)	Deg. Level (e-/cm^2 or p/cm^2)
2N2907	Micro Semi	0513	Bipolar / PNP Silicon Switching Transistor	MeC	h_{FE} for a I_C of 0.1 mA exceeded the spec at a 17 MeV electron fluence of 2.7 x 10^{11} cm^{-2}, the first irradiation step.	E	N/A	$0 \leq x \leq 2.7x10^{11}$
RH1021	Linear Technology	0940A	Bipolar / 5V Voltage Reference	MeC	V_{out} exceeded the specified limits at a 17 MeV electron fluence of 2.7 x 10^{11} cm^{-2}, the first irradiation step.	E	N/A	$0 \leq x \leq 2.7x10^{11}$
SPT6235MS	SSDI	0624	General Purpose High Voltage/Power NPN BJT	JP	Tested with I_c of 0.25 & 0.51 A, V_b = 5 V, & V_{ce} = 155.6 V. Mean h_{FE} stayed within application spec for the duration of the 17 MeV electron exposures. Biased parts were tested to an electron fluence of $3.3x10^{13}$ cm^{-2} and the unbiased parts to $7.1x10^{13}$ cm^{-2}.	E	N/A	> $3.3x10^{13}$ (biased) > $7.1x10^{13}$ (unbiased)
JANS2N3866	Semicoa	0721	General Purpose NPN BJT	JP	Tested with I_c of 0.25 & 0.51 A with a pulsed base current & V_{ce} = 4.4 V. Mean h_{FE} stayed within application spec for the duration of the 17 MeV electron exposures. Biased parts were tested to an electron fluence of $3.3x10^{13}$ cm^{-2} and the unbiased parts to $7.1x10^{13}$ cm^{-2}.	E	N/A	> $3.3x10^{13}$ (biased) > $7.1x10^{13}$ (unbiased)

IV. Test Results and Discussion

As in our past workshop compendia of GSFC test results, each DUT has a detailed test report available online at http://radhome.gsfc.nasa.gov [3] describing in further detail, test method, TID conditions/parameters, test results, and graphs of data.

A. 66212/Optocoupler (Displacement Damage)/ Micropac

We tested five pieces of the 66212 850 nm optocoupler from Micropac Industries, Inc. for DD dose degradation using the accelerated proton beam at the LBNL BASE facility during June 2010. The CTR of the amplifier was monitored as a function of proton fluence by measuring the I_{CE} as a function of the I_F. The parts were irradiated under bias.

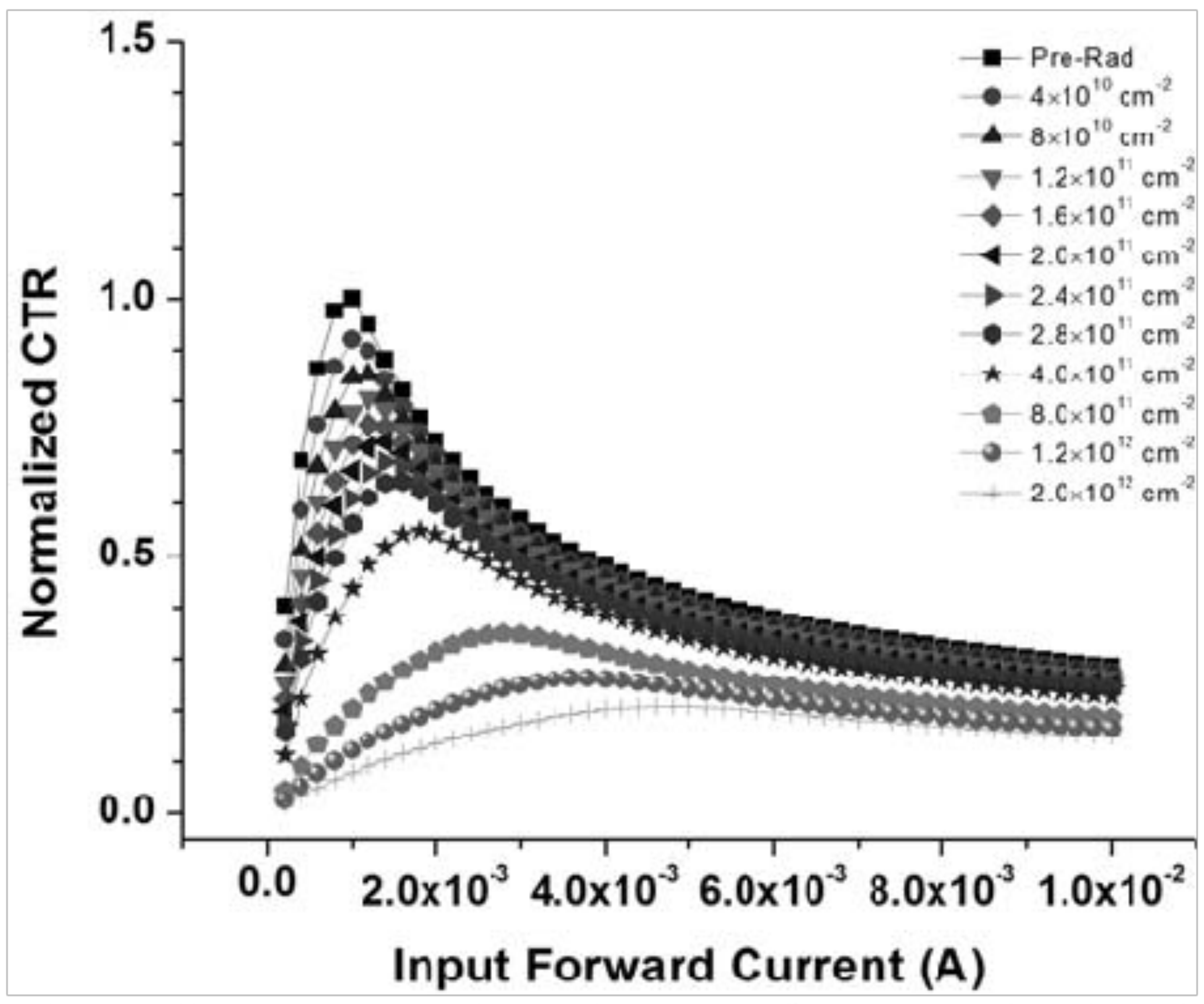

Fig. 1. Mii 66212 CTRs at increasing proton fluences as a function of input forward current. The CTRs shown here are an average of all the pieces tested. For all data, V_{CE} = 1 V.

The 66212 optocoupler consists of an 850 nm GaAlAs LED optically coupled to a phototransistor detector all mounted in a hermetic 4-pin LCC package. Following irradiation to 2×10^{12} p/cm^2 with 50 MeV protons, degradation was observed in all devices tested. 99/90 bounds were computed based on the sample standard deviation and one-sided tolerance limits. The device CTR dropped out of datasheet specifications between 4×10^{11} cm^{-2} and 8×10^{11} cm^{-2} at a V_{CE} of 1 V. The measured CTR's at a V_{CE} of 1 V are shown in Fig. 1. The CTR was normalized to the peak average CTR pre-irradiation; at a V_{CE} of 1 V this was 8.9.

B. AD648/Operational Amplifier/Analog Devices

The AD648 is a pair of low-power, precision op amps with JFET inputs manufactured by Analog Devices. The parts were tested for ELDRS using a Co-60 source, at a dose rate of 10 mrad/s to a total dose of 20 krad(Si). A total of ten parts (20 op amps) were irradiated, with five parts irradiated under biased and five parts with all pins grounded, and an additional two parts were used as controls. Fig. 2 shows the average Ib for the control samples, the parts biased during irradiation, and the parts with all pins grounded during irradiation as a function of dose. At the 10 krad(Si) dose, all biased parts exceeded the specification of I_{bias} and I_{os}, but some parts exceeded the specifications as early as 2 krad(Si). In the case of the unbiased parts, the average I_{bias} also exceeded the specification for I_{bias} at 10 krad(Si), but all other parameters remained within specification to the 20 krad(Si) dose.

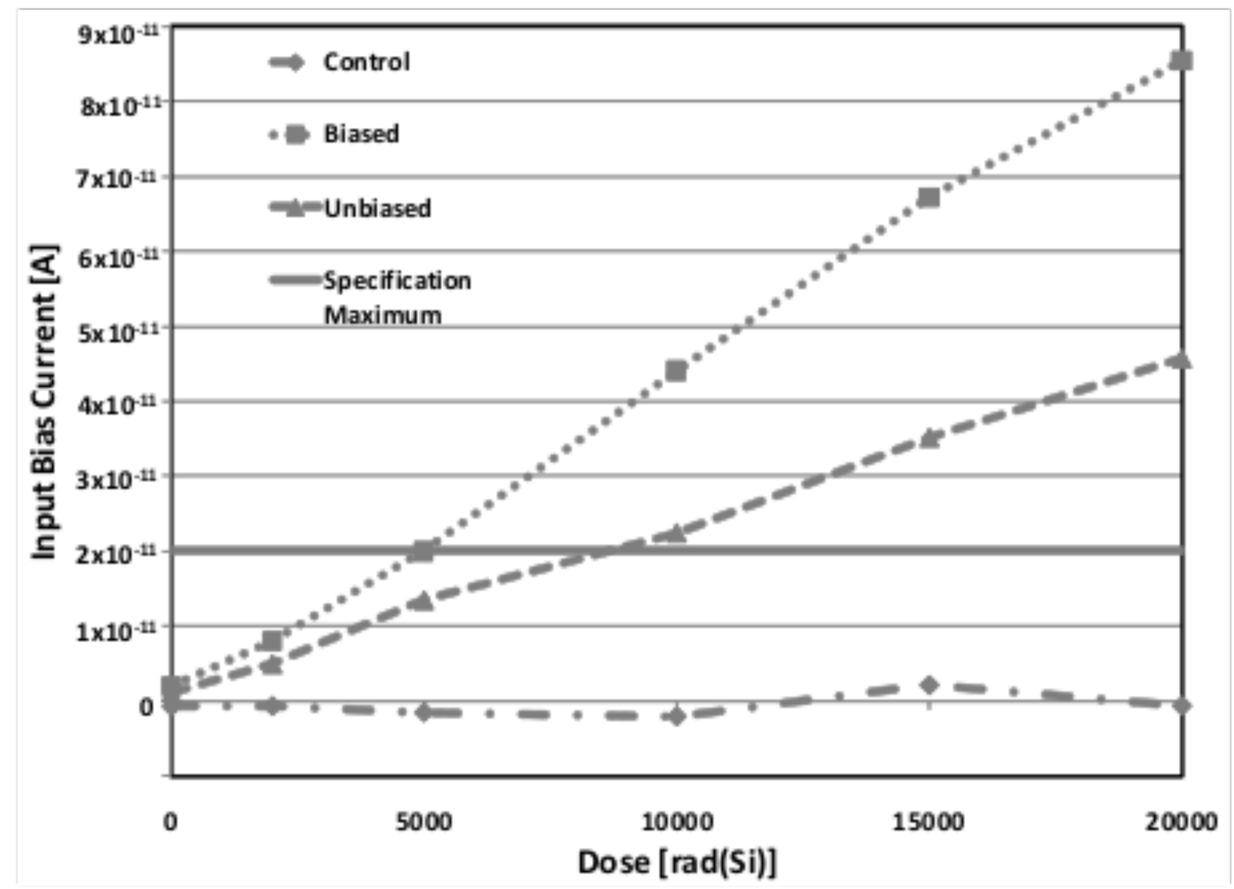

Fig. 2. The average I_{bias} for the AD648 as a function of dose.

C. AD5544/Digital to Analog Converter/Analog Devices

The AD5544 is a quad, 16-bit, current-output digital-to-analog converter manufactured by Analog Devices. Until mid-2008, the device was manufactured in a BiCMOS technology, while after this date the device was migrated to a pure CMOS technology. Testing was carried out for parts in both technologies. The most notable characteristic of the initial tests done on CMOS technology (LDC 0827) was part-to-part variability; one part failed below 2 krad(Si) (DNL) and some parts performed well up to the highest test dose of 50 krad(Si). Moreover, multiple failure modes in DNL were noted for different parts and no obvious correlation was seen for failures in the two sensitive parameters—see Figs. 3 and 4. While not a source of component failure in the intended application, IDD was also sensitive to dose, rising rapidly in the biased parts above 15 krad(Si) and reaching more than 10 mA by 50 krad(Si). IDD was unaffected in the grounded components.

Because of the anomalous nature of the results, an additional 5 parts from date code 0827 were tested, along with 5 parts from another CMOS lot, date code 1028. Because the biased parts in previous testing yielded worst-case results, the second batch of parts was irradiated under bias. The concern here was to ensure that the previous results were not due to a bad lot, mishandling, or electrostatic discharge. These tests yielded two additional failures. One part from date code 1028 failed between 7 and 10 krad(Si), and one part from date code 0827 failed between 20 and 30 krad(Si).

At this stage, the project halted qualification of the CMOS AD5544s and procured older BiCMOS parts (date codes 0332 and 0409). Testing for these parts has been completed but further analysis is underway.

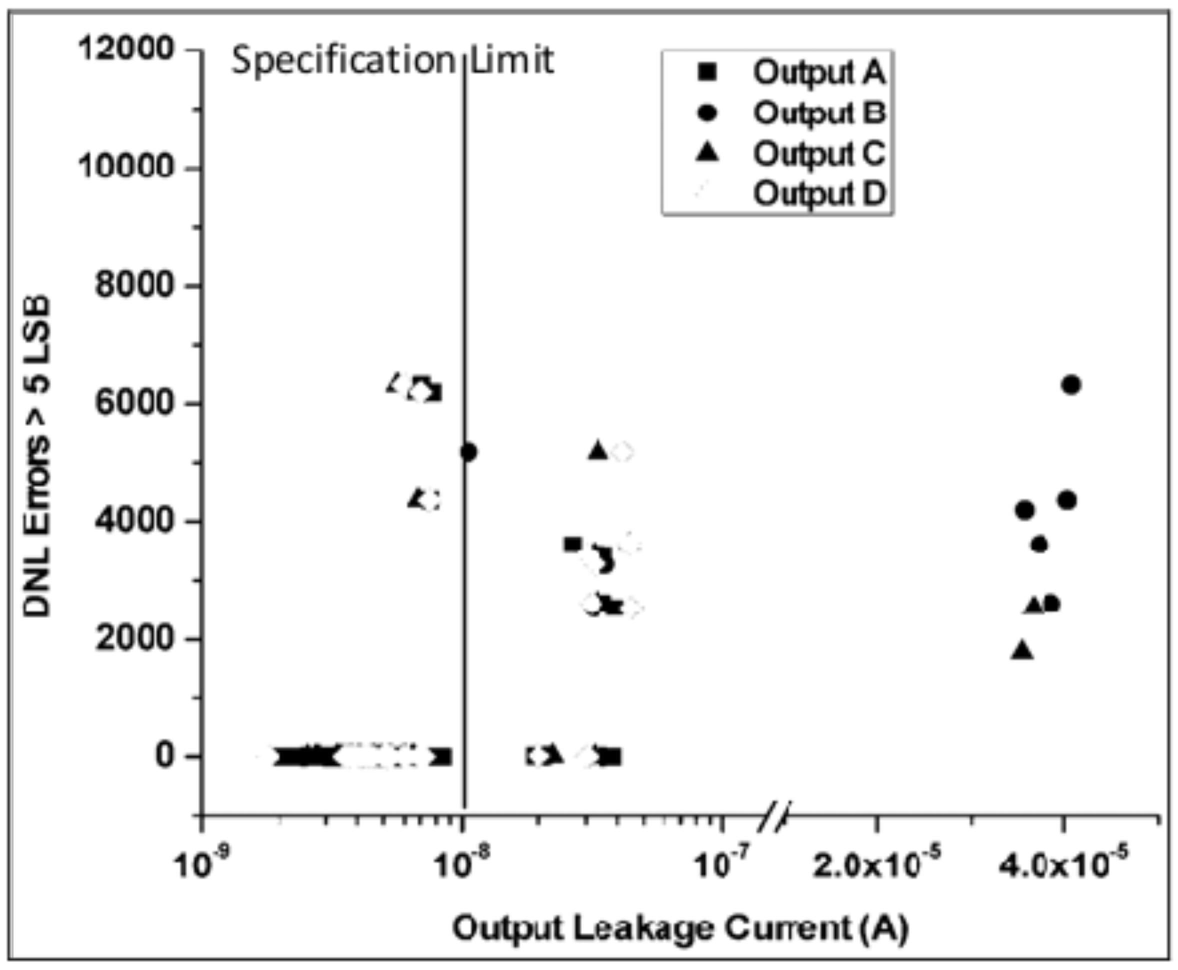

Fig. 3. Biased DNL errors versus output leakage current for all four DACs (A, B, C, & D). LDC 0827 – CMOS Technology.

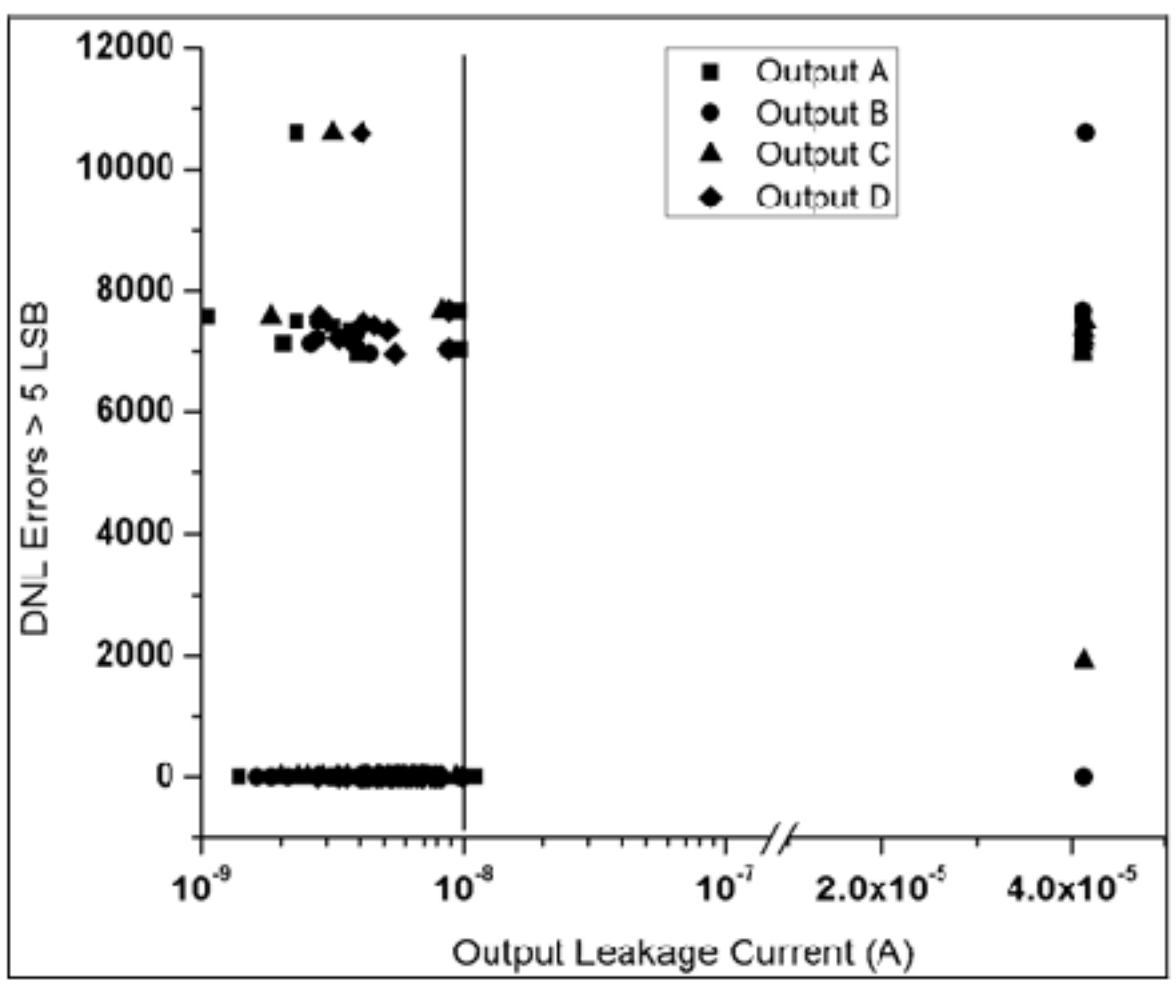

Fig. 4. Unbiased DNL errors versus output leakage current for all four DACs (A, B, C, & D). LDC 0827 – CMOS Technology.

V. Summary

We have presented data from recent TID and proton-induced damage tests on a variety of primarily commercial devices. It is the authors' recommendation that this data be used with caution due to many application/lot-specific issues. We also highly recommend that lot testing be performed on any suspect or commercial device.

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VII. References

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