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

Alvin J. Boutte, Donna J. Cochran, Dakai Chen, Michael J. Campola, Jonathan A. Pellish, Raymond L. Ladbury, Edward P. Wilcox, Jean-Marie Lauenstein, Robert A. Gigliuto, Kenneth A. LaBel, and Martha V. O'Bryan

***Abstract*—We present the radiation response of a variety of candidate spacecraft electronics to total ionizing dose and displacement damage. Devices tested include digital, analog, linear, and hybrid micro- and optoelectronics.**

***Index Terms*—Displacement Damage, Optoelectronics, Radiation Effects, and Total Ionizing Dose.**

I. INTRODUCTION

NASA spacecraft are subjected to a harsh space environment that includes exposure to various types of radiation. Long-term exposure to radiation has been shown to affect the function of spacecraft electronics. As a result, space flight parts must be tolerant to radiation-induced total ionizing dose (TID) and displacement damage (DD) effects, or be mitigated by shielding and other methods. Therefore, the effects of TID and DD need to be evaluated through ground-based testing in order to determine risk to spaceflight applications.

The test results presented here were gathered to establish the sensitivity of candidate spacecraft electronics to TID and/or DD. Proton-induced degradation, dominant for most NASA missions, is a mix of ionizing (TID) and non-ionizing damage. The non-ionizing damage is commonly referred to as displacement damage (DD). For similar results on single-event effects (SEE), a companion paper has also been submitted to the 2013 Institute of Electrical and Electronics Engineers (IEEE) Nuclear and Space Radiation Effects Conference (NSREC) Radiation Effects Data Workshop entitled: "Compendium of Single Event Effects for Candidate Spacecraft Electronics for NASA," by M. O'Bryan, *et al.* [1].

This work was supported in part by the NASA Electronic Parts and Packaging Program (NEPP), NASA flight projects, and the Defense Threat Reduction Agency (DTRA) under IACRO# 11-4395I to NASA.

A. J. Boutte, D. Chen, M. J. Campola, J. A. Pellish, R. L. Ladbury, M. C. Casey, J.-M. Lauenstein, M. A. Carts, K. A. LaBel, C. J. Marshall, and M. A. Xapsos are with the NASA Goddard Space Flight Center, Mail Stop 561.4, 8800 Greenbelt RD, Greenbelt, MD 20771 USA; corresponding author (A. J. Boutte) phone: 301-286-2128, fax: 301-286-4699, and email: alvin.j.boutte@nasa.gov.

D. J. Cochran, E. P. (Ted) Wilcox, R. A. Gigliuto, and M. V. O'Bryan are with MEI Technologies, Inc.; work performed for the NASA Goddard Space Flight Center under the Electrical Systems Engineering Services Interim contract; Mail Stop 561.4, 8800 Greenbelt RD, Greenbelt, MD 20771 USA.

II. TEST TECHNIQUES AND SETUP

A. Test Methods – TID

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

B. Test Methods – Proton

Proton DD/TID tests were performed at the Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE) facility using their 88-inch cyclotron, which for protons has a maximum useable energy delivered to the test area of 55 MeV. Table I lists the proton damage test facility and energy used on the device in this presentation. Unless otherwise noted, all tests were performed at room temperature and with nominal power supply voltages.

TABLE I: PROTON TEST FACILITIES

Facility	Incident Proton Energy, (MeV)
Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE) Facility	55

III. TEST RESULTS OVERVIEW

Abbreviations for principal investigators (PIs) are listed in Table II. Abbreviations and conventions are listed in Table III. A summary of TID and DD test results are listed in Table IV.

TABLE II
LIST OF PRINCIPAL INVESTIGATORS

Abbreviation	Principal Investigator (PI)
AB	Alvin Boutte
MiC	Michael Campola
DC	Dakai Chen
RG	Robert Gigliuto
RL	Raymond Ladbury
JML	Jean-Marie Lauenstein
JP	Jonathan Pellish
EW	Edward (Ted) Wilcox

TABLE III
ABBREVIATIONS AND CONVENTIONS

Al/Pb = aluminum/lead	LDR = low dose rate
AMD = Advanced Micro Devices, Inc.	LDR EF = low dose rate enhancement factor
App. Spec. = application specific	MOSFET = metal oxide semiconductor field effect transistor
A_{VO} = large signal gain	NEPP = NASA Electronic Parts and Packaging Program
BASE = Berkeley Accelerator Space Effects	N/A = not available
BiCMOS = bipolar – complementary metal oxide semiconductor	ONFI = open NAND flash interface
CB = complimentary bipolar	PCB = printed circuit board
CMOS = complementary metal oxide semiconductor	PI = Principal Investigator
CMRR = common mode rejection ratio	PSRR = power supply rejection ratio
DD = displacement damage	REAG = GSFC Radiation Effects & Analysis Group
DDR2 = double data rate, generation 2	R_{OO} = output on resistance
DIMM = dual in-line memory module	SDRAM = synchronous dynamic random access memory
DTRA = Defense Threat Reduction Agency	SSDI = Solid State Devices, Inc.
DUT = device under test	SEE = single-event effects
ECC = error correction code	SiGe = silicon germanium
ELDRS = enhanced low dose rate sensitivity	SLC = single level cell
FPGA = field programmable gate array	SOI = silicon-on-insulator
GSFC = Goddard Space Flight Center	TI = Texas Instruments
Gbps = gigabit per second	TID = total ionizing dose
h_{FE} = forward current gain	$V_{GS(th)}$ = gate-source threshold voltage
I_{bias} = input bias current	V_{out} = output voltage
I_{DSS} = zero gate voltage drain current	V_{rd} = voltage range differential
I_{IO} = input offset current	V_{ref} = reference voltage
LBNL = Lawrence Berkeley National Laboratory	100 rad(Si) = 1 Gy(Si)
LDC = lot date code	
LED = light emitting diode	

TABLE IV
SUMMARY OF TID AND DD TEST RESULTS

Part Number	Manufacturer	LDC	Device Function	Technology	PI	Results	App. Spec. (Y/N)	Dose rate (mrad(Si)/s) or Proton Energy (MeV)	Degradation Level (krad(Si)) or Proton Fluence
Flash Memory									
MT8HTF12864AZ	Micron	N/A	DDR2 SDRAM DIMM	CMOS	RL	Parts failed functionally at about 800 krad(Si); DC parameters remained within specification.	N	5-10 rad(Si)/s	> 800 for both biased and unbiased parts
Miscellaneous									
AD8212	Analog Devices	1016B	Current Shunt Monitor	Bipolar	MiC	Voltage range differential (V_{rd}) showed parametric degradation	Y	10	$15 < V_{rd} \leq 17.5$
A4 3300	AMD	n/a	Processor	32 nm CMOS SOI	RG	Parts remained functional and within specification to 17 Mrad(Si). Temperature sensing diodes were degraded and reporting false values.	N	9.15 rad(Si)/s	> 1700
OMH3075S	OPTEK	M0904	Hall Effect Sensor	Bipolar	JP	All parts functional to 20 krad(Si).	N	10	>20
UC1524A	Unitrode/TI	0620A	Pulse Width Modulator	Bipolar	AB	All parameters within specification up to 20 krad(Si).	Y	10	> 20
LM139AWRQMLV	National Semiconductor	JM046X13	Comparator	Bipolar	DC	Parameters within specification.	Y	0.5	> 27
NBSG53AMN	ON Semiconductor	G5ERY	D Flip Flop	SiGe	MiC/ EW	All parameters showed no change after radiation up to and including 20 krad(Si).	N	10	> 20
53124	Micropac	1108	Solid State Relay	CMOS	MiC	Output on resistance exceeded maximum specification between $8x10^{11}$ and $8.5x10^{11}$ protons/cm^2.	Y	55 MeV	$8.0x10^{11} < R_{OO} \leq 8.5x10^{11}$ protons/cm^2
Operational Amplifiers									
OP200A	Analog Devices	0302	Operational Amplifier	Bipolar	DC	Parts showed parametric degradation to $I_{bias.}$	Y	10	$9 < I_{bias} \leq 13.5$
OP271	Analog Devices	9917	Operational Amplifier	Bipolar	DC	Parts showed parametric degradation to A_{vo} and I_{IO}, but remained functional up to 27 krad(Si)	Y	10	$6 < A_{VO} \leq 9$ $22.5 < I_{IO} \leq 27$
AD847	Analog Devices	0937B	Operational Amplifier	Bipolar	AB	Parts showed parametric degradation to PSRR.	N	10	$2.5 < PSRR \leq 5$
LM124 (Ceramic DIP-14)	National Semiconductor	JM0591182	Operational Amplifier	Bipolar	DC	Parameters within specification.	Y	1	> 100
								0.5	> 60

Part Number	Manufacturer	LDC	Device Function	Technology	PI	Results	App. Spec. (Y/N)	Dose rate (mrad(Si)/s) or Proton Energy (MeV)	Degradation Level (krad(Si)) or Proton Fluence
LM158AJRQMLV (Ceramic DIP-8)	National Semiconductor	JM084X27	Operational Amplifier	Bipolar	DC	Input bias current degradation shows dose rate sensitivity below 10 mrad(Si)/s. However parameters are within specification for all dose rates.	N	5, 1	> 100
								0.5	> 60
RH1013MH (TO-5 Metal Can)	Linear Technology	0329A	Operational Amplifier	Bipolar	DC	Small levels of dose rate sensitivity in the input bias current degradation. Parameters within specification.	Y	5, 1	> 100
								0.5	> 50
RH1013MJ8 (Ceramic DIP)	Linear Technology	0305A	Operational Amplifier	Bipolar	DC	Small levels of dose rate sensitivity in the input bias current degradation. Parameters within specification.	Y	5, 1	> 100
								0.5	> 50
RH1078MH (TO-5 Metal Can)	Linear Technology	0741A	Operational Amplifier	Bipolar	DC	Parameters within post-irradiation specification.	Y	1	> 20
								0.5	> 25
RH1078W (Flatpack)	Linear Technology	0325A	Operational Amplifier	Bipolar	DC	1 mrad(Si)/s: two biased and two unbiased parts exceed specification for V_{os} at 20 krad(Si) step. 0.5 mrad(Si)/s: three biased and two unbiased parts exceeded specifications for V_{os} at 25 krad(Si) step. Test in progress.	Y	1	$10 < V_{os} \leq 20$
								0.5	$15 < V_{os} \leq 25$
RHF310 (Ceramic Flat-8)	ST Microelectronics	30849A	Operational Amplifier	Bipolar	DC	Input bias current and input offset voltage within specification.	N	5	> 100
								1	> 50
								0.5	> 45
RHF43B (Ceramic Flat-8)	ST Microelectronics	30820A	Operational Amplifier	Bipolar	DC	Minimal dose rate sensitivity. Parameters within specification.	N	10	> 100
								1	> 50
								0.5	> 37
Power MOSFETs									
BUY25CS54A	Infineon	1146.50	Power MOSFET	n-type Superjunction	JML	Parametric degradation of $V_{GS(th)}$ and I_{DSS} in all samples. $V_{GS(th)}$ fell below specification after 400 krad(Si) in samples biased in the on state.	N	0.44 – 16 rad(Si)/s	On-state bias: $400 < V_{GS(th)} \leq 500$; $I_{DSS} \geq 500$; Off-state, Grounded biases: $V_{GS(th)} \geq 500$; $I_{DSS} > 500$
Transistors									
SFT5094-4	SSDI	1007	PNP Transistor	Bipolar	AB	Parts showed slight parametric degradation with respect to dose for h_{FE}.	N	0.02	> 25

Part Number	Manufacturer	LDC	Device Function	Technology	PI	Results	App. Spec. (Y/N)	Dose rate (mrad(Si)/s) or Proton Energy (MeV)	Degradation Level (krad(Si)) or Proton Fluence
2N2222	Microsemi	0951	NPN Transistor	Bipolar	JP	DC current gain began testing out of specification between 5 and 7.5 krad(Si) for multiple collector currents.	N	10	$5 < h_{FE} \leq 7.5$
2N2369	Semicoa	1934	NPN Transistor	Bipolar	DC	All parameters within specification up to 100 krad(Si). Minimal LDR sensitivity.	N	50 rad(Si)/s, 10	> 100
2N2857	Semicoa	1523	NPN Transistor	Bipolar	DC	All parameters within specification up to 100 krad(Si). Minimal LDR sensitivity.	N	50 rad(Si)/s, 10	>100
2N2907	Microsemi	1020	PNP Transistor	Bipolar	JP	All parameters within specification up to 20 krad(Si).	N	10	> 20
2N3700	Semicoa	0702	NPN Transistor	Bipolar	DC	Device parameters remained in specification.	N	10	>100
2N2222AJSR	Semicoa	1364	NPN Transistor	Bipolar	DC	At 10 mrad(Si)/s, current gain at low injection levels (IC = 1 and 0.1 mA) failed parametrically between 35 and 40 krad(Si). The LDR EF = 3.9 after 100 krad(Si).	N	10	$35 < h_{FE} \leq 40$
2N2369	Semicoa	1934	NPN Transistor	Bipolar	DC	All parameters are within specification up to 100 krad(Si). Minimal LDR EF.	N	50 rad(Si)/s, 10	> 100
2N2857	Semicoa	1523	NPN Transistor	Bipolar	DC	At high dose rate, all parameters within specification up to 100 krad(Si). Low dose rate testing in progress.	N	50	>100
								10	> 17
2N2907	Semicoa	1324	PNP Transistor	Bipolar	DC	Low dose rate testing in progress. LDR EF = 1.78 after 100 krad(Si).	N	10	$40 < h_{FE} \leq 50$
2N5153	Semicoa	1013	PNP Transistor	Bipolar	DC	All parameters are within specification up to 100 krad(Si). Minimal LDR EF.	N	50 rad(Si)/s, 10	> 100
2N5154	Semicoa	1023	NPN Transistor	Bipolar	DC	All parameters are within specification up to 100 krad(Si). LDR EF = 4.2 after 100 krad(Si).	N	50 rad(Si)/s, 10	> 100
Voltage References / Voltage Regulators									
AD581	Analog Devices	0020	Precision Voltage Reference	Bipolar	DC	Parts showed parametric degradation to $V_{out.}$	Y	10	$4.5 < V_{out} \leq 9$
LM117HRQMLV (TO-39 metal can)	National Semiconductor	7D5867L019	Adjustable Voltage Regulator	Bipolar	DC	Observed LDR sensitivity for V_{ref} degradation.	N	5	> 100
								1	$50 < V_{ref} \leq 60$
								0.5	$30 < V_{ref} \leq 40$
LM136AH2.5QMLV (3-lead TO-46)	National Semiconductor	200746K019	Voltage Reference	Bipolar	DC	Exhibits no LDR enhancement.	N	5, 1	> 100
								0.5	> 60

Part Number	Manufacturer	LDC	Device Function	Technology	PI	Results	App. Spec. (Y/N)	Dose rate (mrad(Si)/s) or Proton Energy (MeV)	Degradation Level (krad(Si)) or Proton Fluence
LM317KTTR	Texas Instruments	0608	Positive Voltage Regulator	Bipolar	DC	Parameters within specification. Observed LDR sensitivity for parts irradiated at 0.5 and 1 mrad(Si)/s after 20 krad(Si).	N	5, 1	> 100
								0.5	> 60
LT1009IDR	Texas Instruments	0606	Internal Reference	Bipolar	DC	Parameters within specification. Parts exhibit minimal LDR enhancement.	N	5, 1	> 100
								0.5	> 60
RH1009MH (TO-46 can)	Linear Technology	0829H	Voltage Reference	Bipolar	DC	Begins to exhibit LDR sensitivity after 20 krad(Si).	N	5	$80 < V_{ref} \leq 90$
								1	$60 < V_{ref} \leq 70$
								0.5	$50 < V_{ref} \leq 60$
RH1009MW (Flatpack)	Linear Technology	0649A	Voltage Reference	Bipolar	DC	Begins to exhibit LDR sensitivity after 15 krad(Si) for devices irradiated at 5 and 1 mrad(Si)/s.	N	5	$100 < V_{ref} \leq 120$
								1	$60 < V_{ref} \leq 70$
								0.5	$35 < V_{ref} \leq 40$
RH1021CMW-5 (TO-5 can)	Linear Technology	9783A	Precision Voltage Reference	Bipolar	DC	Exhibits slight LDR sensitivity.	N	5	$80 < V_{out} \leq 90$
								1	$20 < V_{out} \leq 30$
								0.5	$20 < V_{out} \leq 30$
RH1021CMW-5 (Flatpack)	Linear Technology	0123A	Precision Voltage Reference	Bipolar	DC	Exhibits slight LDR sensitivity. One part at 1 mrad(Si)/s exceeded specification after 20 krad(Si). Four parts exceeded specifications after 50 krad(Si).	N	5	>100
								1	$15 < V_{out} \leq 20$
								0.5	$20 < V_{out} \leq 30$
RHFL4913ESY332 (TO257)	ST Microelectronics	30828A	Voltage Regulator	Bipolar	DC	All parameters within specification. Minimal dose rate sensitivity.	N	10, 5, 1	>100
								0.5	> 40
RHFL4913KP332 (Flat-16)	ST Microelectronics	30814B	Voltage Regulator	Bipolar	DC	All parameters within specification. Minimal dose rate sensitivity.	N	10, 5, 1	> 100
								0.5	> 40
TL750L05CDR	Texas Instruments	0605	LDO Positive Voltage Regulator	Bipolar	DC	Exhibits LDR EF for functional failures.	N	10	$50 < V_{out} \leq 60$
								5	$35 < V_{out} \leq 40$
								1	$10 < V_{out} \leq 15$
								0.5	$7.5 < V_{out} \leq 10$
TL750M05CKTRR (TO263-3)	Texas Instruments	0707	LDO Positive Voltage Regulator	Bipolar	DC	One part irradiated at 1 mrad(Si) exceeded specification at 40 krad(Si). V_{out} specification for full temperature range. (Characterization performed in DC mode.) Minimal dose rate sensitivity.	N	5	> 100
								1	$30 < V_{out} \leq 40$
								0.5	> 50

IV. Test Results and Discussion

As in our past workshop compendia of GSFC TID and DD test results, each DUT has a detailed test report available online at http://radhome.gsfc.nasa.gov [2] describing test methods in further detail, TID conditions and parameters, test results, and as well as graphs and tables of the gathered data. The following sections cover featured parts from this year's compendium report.

A. OP200A / Operational Amplifier / Analog Devices

The OP200A is an operational amplifier (op amp) manufactured by Analog Devices. We performed irradiations with ^{60}Co gamma rays in air at room temperature. The devices were placed inside Al/Pb shielding boxes to minimize dose enhancement effects from scattered photons. The dose rate was 10 mrad(Si)/s.

All parts were functional after 27 krad(Si). We found that the input bias current (I_{bias}) was the most sensitive parameter. Fig. 1 shows I_{bias} as a function of total dose for parts irradiated under bias and with pins grounded. We observed a monotonic increase in I_{bias} with increasing TID. The parts irradiated with pins grounded showed higher degradation levels relative to the parts irradiated under bias. Five parts irradiated with pins grounded exceeded specification limits after 13.5 krad(Si). The parts irradiated under bias did not show parametric failure until after 27 krad(Si). The data points in all plots are the mean values for all operational amplifier devices for each irradiation condition. There are two devices per part (dual op amp) and 10 parts per bias condition. The error bars are the standard deviation due to part-to-part variability. The error bars on the control device represent device-to-device variability within the package.

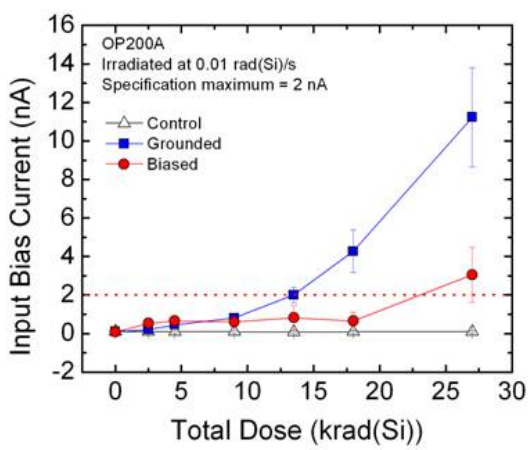

Fig. 1. I_{bias} vs. total dose for OP200A devices irradiated at a dose rate of 10 mrad(Si)/s in a biased configuration and with pins grounded.

B. MT29F32G08ABAAAWP / NAND Flash Memory / Micron

This Micron NAND Flash Memory is a non-volatile memory that uses a floating gate NAND cell, implemented in 34 nm CMOS technology. The device features open NAND Flash Interface (ONFI) 2.1 compliant specifications. The device is designed with single-level cell (SLC) technology. The device is organized with 4320 bytes per page, 128 pages per block, 2048 blocks per plane, and 2 planes per device. This particular part number only supports asynchronous operation.

We irradiated 10 parts with ^{60}Co gamma rays in air at a dose rate of approximately 30 rad(Si)/s under ambient conditions. The DUTs were initially programmed with a physical checkerboard pattern. All DUTs were biased with a supply voltage of 3.6 V (110% of 3.3 V nominal supply voltage). Five parts were read-only during the exposures. Five parts were exercised between exposures—read, erased, and written into four different patterns. The patterns are checkerboard (xAA – hexadecimal), checkerboard complement (x55 – hexadecimal), all ones, and all zeroes. The parts were annealed under bias at room temperature for 1 week following the irradiation.

The number of bit errors at each address increased monotonically with increasing dose up to 20 krad(Si). The bit error count increased significantly in both the cycled and read-only DUTs after 50 krad(Si). One cycled DUT and two read-only DUTs failed to erase. The other DUTs were erased and reprogrammed for the next exposure. Four additional DUTs failed to erase after 70 krad(Si). The three remaining DUTs were erased and reprogrammed for the next exposure. All DUTs failed functionally after 100 krad(Si). The functional failures are characterized by block erase failures. The parts remained nonfunctional after a 168 hr room temperature anneal under bias.

The error signatures can be grouped into three different categories: 1) single-bit errors, where 1 bit in a byte showed a bit flip, usually from logic 0 to logic 1; 2) multiple-bit errors, where several bits in a byte showed bit flips of both 0 to 1 and 1 to 0; and 3) erase errors, where usually the entire block failed to erase.

Fig. 2 shows the number of single-bit, multiple-bit and erase errors for each DUT as a function of dose. The multiple-bit errors are not present until after 50 krad(Si). The initial functional failures occurred after 50 krad(Si). All DUTs failed to erase after 100 krad(Si).

We performed the test without error correction code (ECC) implementation. We expect that ECC will be able to correct the single-bit errors. However, the control errors, including most of the multiple-bit errors and block erase errors, will not be correctable by ECC. Therefore, the susceptibility to these errors will determine the total dose hardness of the flash memory under investigation.

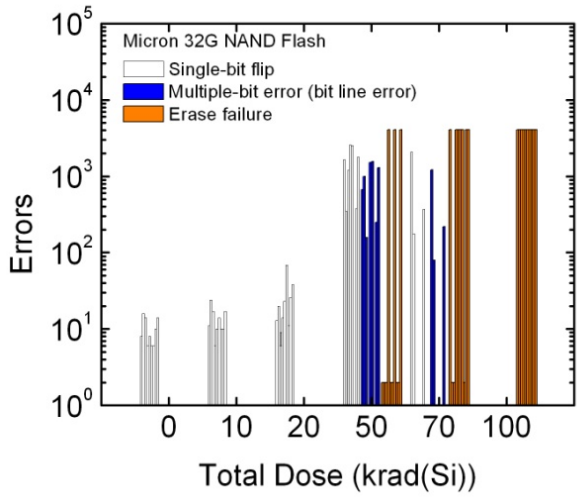

Fig. 2. Total number of single-bit, multiple-bit, and erase errors vs. total dose, for each DUT.

C. NBSG53AMN / SiGe Differential D-Flip Flop / ON Semiconductor

The NBSG53AMN is a commercially-available, high-speed SiGe D-Flip Flop/Clock Divider from ON Semiconductor. It operates from 2.5 V to 3.3 V, has differential clock and data inputs, and operates beyond 8 GHz clock speeds with typical rise and fall times of just 45 ps. Nine parts were mounted on individual PCBs for TID testing with a ^{60}Co gamma ray source and irradiated at 10 mrad(Si)/s with one lot biased during exposure and one lot grounded.

To accurately measure the performance of this device, we designed and fabricated a custom PCB with 50-Ω transmission lines and a high-quality Rogers-4350 dielectric; it is shown in Fig. 3. A 20 GHz Tektronix real-time digital oscilloscope was used to measure the AC parameters, and a 12.5-Gbps Anritsu signal generator provided the fast edge for input and clock signals.

We observed that all parameters remained within manufacturer- specified limits, as illustrated by the supply current data in Fig. 4, or showed no degradation attributable to radiation, after 20 krad(Si).

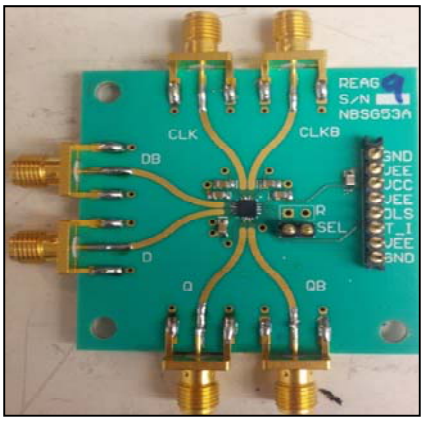

Fig. 3. Custom high-speed PCB required for accurate testing of 8 GHz D-Flip Flop.

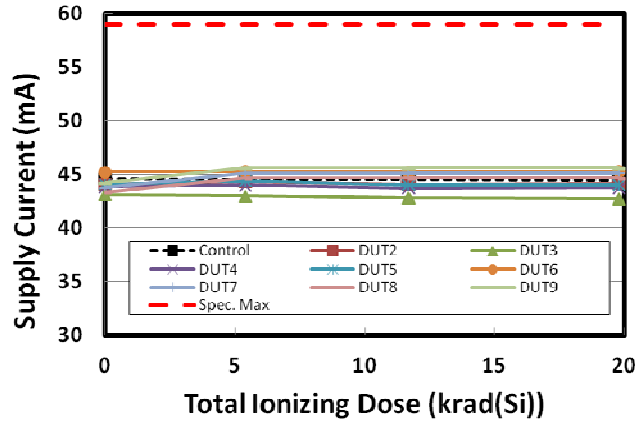

Fig. 4. Supply current did not change during irradiation and remained well below the specified maximum.

D. AD847SQ / Operational Amplifier / Analog Devices

The Analog Devices AD847SQ is a single-channel, high-speed, low-power monolithic operational amplifier that boasts high unity gain bandwidth, low supply current, high slew rate, fast settling time, high open-loop gain and low input offset voltage. It offers a full-power bandwidth of 12.7 MHz as a buffer and is fabricated on Analog Devices' proprietary complementary bipolar process.

Samples from a lot of AD847SQs with the date code 0937B were tested for total ionizing dose response. A total of ten devices, five in an application-specific bias condition and five unbiased with all pins grounded, were irradiated at a rate of 10 mrad(Si)/s, while two devices were retained as controls.

All ten samples passed functionality testing up to the final dose step of 20 krad(Si), but there were strong signs of degradation of as a result of exposure to ionizing radiation. The parameters that showed the most degradation were the input bias current, input offset current, common mode rejection ratio (CMRR), and power supply rejection ratio (PSRR).

The PSRR of the biased devices was the only parameter that degraded below the datasheet specification of 75 dB, which happened at 5 krad(Si) and is shown in Fig. 5.

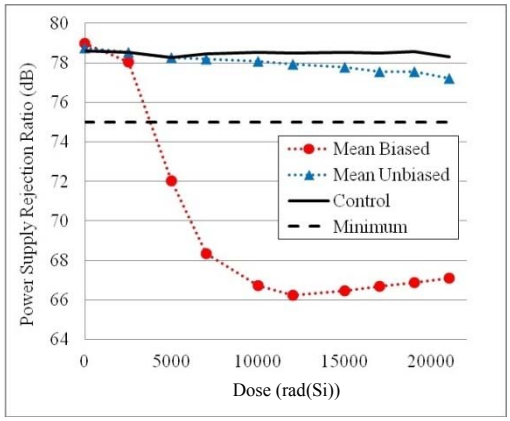

Fig. 5. Mean power supply rejection ratio for biased and unbiased AD847SQ devices.

The CMRR of the biased devices showed clear degradation beginning between 10 and 12.5 krad(Si), while the unbiased devices show little to no change from the controls, which are shown in Fig. 6. Other parameters that showed degradation were consistent for both biased and unbiased configurations.

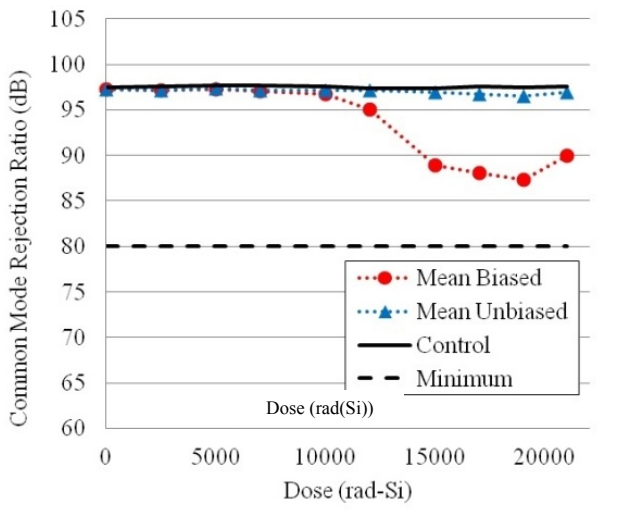

Fig. 6. Mean common mode rejection ratio for biased and unbiased AD847SQ devices.

V. Summary

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

VI. Acknowledgment

The authors would like to acknowledge the sponsors of this effort: the NASA Electronic Parts and Packaging (NEPP) Program [3], NASA flight projects, and the Defense Threat Reduction Agency (DTRA) under IACRO# 11-4395I to NASA. The authors would also like to thank members of the Radiation Effects and Analysis Group (REAG) who contributed to the test results presented here: Melanie D. Berg, Hak S. Kim, Anthony M. Dung-Phan, Donald K. Hawkins, James D. Forney, Christina M. Seidleck, Alyson D. Topper, and Stephen R. Cox.

VII. References

[1] Martha V. O'Bryan, et al., "Compendium of Recent Single Event Effects for Candidate Spacecraft Electronics for NASA" to be submitted for presentation at IEEE NSREC 2013 Radiation Effects Data Workshop, July 2013.

[2] NASA/GSFC Radiation Effects and Analysis home page, http://radhome.gsfc.nasa.gov.

[3] NASA Electronic Parts and Packaging Program home page, http://nepp.nasa.gov.