Compendium of Recent Test Results of Single Event Effects Conducted by the Jet Propulsion Laboratory

Gregory R. Allen, *Member, IEEE,* Steven M. Guertin, Leif Z. Scheick, *Member, IEEE,* Farokh Irom, and Stephanie Zajac

***Abstract*-- This paper reports heavy ion, proton, and laser induced single event effects results for a variety of microelectronic devices targeted for possible use in NASA spacecrafts. The compendium covers devices tested within the years of 2010 through 2012.**

I. Introduction

SPACECRAFT and satellites are constantly driven to reduce power, weight, and cost while simultaneously increasing computational power. Emerging state of the art microelectronic technologies are typically targeted for such applications, yet are often susceptible to Single Event Effects (SEE). To ensure both the reliability and the functionality of these devices, ground based testing to define microelectronic susceptibility to single event effects (SEE) remains important. The data presented in this paper were acquired to characterize the susceptibility of potential spacecraft microelectronics to single event latchup (SEL), single event upset (SEU), single event functional interrupt (SEFI), and single event transient (SET). This compendium represents SEE data acquired from August 2010 to the February 2012.

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G. R. Allen is with the California Institute of Technology/Jet Propulsion Laboratory, Pasadena, CA, 91109, USA (telephone: 818-393-7558, e-mail: grallen@jpl.nasa.gov).

S. M. Guertin is with the California Institute of Technology/Jet Propulsion Laboratory, Pasadena, CA, 91109, USA (telephone: 818-393-6895, e-mail: steven.m.guertin@jpl.nasa.gov).

L. Z. Scheick is with the California Institute of Technology/Jet Propulsion Laboratory, Pasadena, CA, 91109, USA (telephone: 818-354-3272, e-mail: leif.z.scheick@jpl.nasa.gov).

F. Irom is with the California Institute of Technology/Jet Propulsion Laboratory, Pasadena, CA, 91109, USA (telephone: 818-354-7463, e-mail: farokh.irom@jpl.nasa.gov).

S. Zajac is an intern with the Jet Propulsion Lab, Pasadena, CA 91109 USA and an graduate student of physics at Stoney Brook University, Stoney Brook, NY 11794 USA (telephone: 626-675-4020, email: Stephanie.zajac@stoneybrook.edu)

II. Experimental Procedure

A. Test Facilities

A variety of SEE facilities are available for experimental use. The criterion to select a test facility may include: scheduling, ion range, and/or programmatic expense. A high level view of the facilities used is outlined below. The facility websites [1]-[6] provide a detailed view of available ions, energies, and facility capabilities that are beyond the scope of this paper.

1) Heavy Ion Facilites

Heavy ion measurements were performed at either Brookhaven National Laboratory (BNL) or at the Texas A&M University Cyclotron (TAM). The BNL facility uses a twin Tandem Van De Graaff accelerator and TAM uses an 88" cyclotron. Both of these facilities are capable of diverse range of particle beams and energies for radiation effects testing. The longer-range ions at TAM allow much of the irradiations to be performed in air, whereas all testing at BNL took place in vacuum. Intermediate LETs were acquired either through the use of degrader (TAM only) or by changing the angle of incidence of the ion relative to the device under test (DUT), providing an effective LET.

2) Proton Facilities

Proton tests were performed at the University of California, Davis (UCD) Crocker Nuclear Laboratory (CNL) or at the Indiana University Cyclotron Facility (IUCF). Much of the work associated with recent proton testing has been associated with displacement damage effects, and have not been included here. The majority of the representative proton data in this compendium has complimentary heavy ion data, and was acquired to achieve rates for particular environments.

3) Laser Facilities

Laser SEE tests were performed at the Jet Propulsion Laboratory's Picosecond Laser Lab or at the Naval Research Laboratory. JPL's laser typically operated at a wavelength of 800 nm whereas NRLs operated at 590 nm.

B. Experimental Methods

Details concerning experimental methodology including data acquisition, ion selection, biasing conditions, etc. vary from experimenter to experimenter and device to device. In many instances devices were tested both at room temperature and at elevated temperature; results are shown for both instances. Generally speaking, approaches used by experimenters followed the procedures documented in the ASTM F1192 or JEDEC JESD57 standards for single event testing [6], [7].

III. DATA ORGANIZATION

This compendium is intended to serve as a reference list for tested devices. The data tables contain abbreviated information mainly due to spatial constraints. It is highly recommended that the reader review the referenced article or contact the PI to acquire details concerning the data and test methodologies.

When possible LET thresholds were shown to be lie between a set of tested energies, otherwise they are simply shown to be at or below a certain value or not seen at the highest tested LET. SEE results have been combined on a single line. For SEL results, only the thresholds have been provided. Saturated cross-sections and thresholds are provided for SEFI, SEU, and SET where available. Unless otherwise noted, all LET values are in MeV•cm^2/mg and all cross-sections in cm^2/device.

Abbreviations for principal investigators are shown in Table I, Table II provides a list of abbreviations.

TABLE I
LIST OF PRINCIPLE INVESTIGATORS

Principal Investigator	Abbreviations
Greg Allen	GA
Steve Guertun	SG
Farokh Irom	FI
Leif Scheick	LS

TABLE I
ACRONYMS, ABBREVIATIONS, AND CONVENTIONAL SYMBOLS

ABBREVIATION	DEFINITION
ADC	ANALOG TO DIGITAL CONVERTER
ADI	ANALOG DEVICES, INC.
CMOS	COMPLEMENTARY METAL OXIDE SEMICONDUCTOR
DAC	DIGITAL TO ANALOG CONVERTER
DUT	DEVICE UNDER TEST
EPC	EFFICIENT POWER CONVERSION CORP
FPGA	FIELD PROGRAMMABLE GATE ARRAY
GAN	GALIUM NITRIDE
H	HEAVY ION TEST
I	INTERNAL DOCUMENT (CONTACT PI FOR SOURCE DATA)
IR	INTERNATIONAL RECTIFIER
LET	LINEAR ENERGY TRANSFER (MEV•CM^2/MG)
LET_{TH}	LINEAR ENERGY TRANSFER THRESHOLD
LTN	LINEAR TECHNOLOGY
MOSFET	METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR
MSK	MS KENNEDY
NAND	NOT AND LOGICAL OPERATION
NSC	NATIONAL SEMICONDUCTOR
OP AMP	OPERATIONAL AMPLIFIER
P	PROTON TEST
PI	PRINCIPLE INVESTIGATOR
σ	CROSS-SECTION
σ_{SAT}	SATURATED CROSS-SECTION
SDRAM	SYNCHRONOUS DYNAMIC RANDOM ACCESS MEMORY
SEB	SINGLE EVENT BURNOUT
SEGR	SINGLE EVENT GATE RUPTURE
SEE	SINGLE EVENT EFFECT
SEFI	SINGLE EVENT FUNCTIONAL INTERRUPT
SEL	SINGLE EVENT LATCHUP
SET	SINGLE EVENT TRANSIENT
SEU	SINGLE EVENT UPSET

IV. TEST RESULTS

A few select, previously unpublished test results are shown here. The remaining details are available in the reference designated in the full results table.

A. LTC1419

SEL testing was performed on the Linear Technology LTC1419 on two separate flight lots. The LTC1419 is an 800ksps, 14-bit sampling A/D converter that draws only 150mW from ±5V supplies. This easy-to-use device includes a high dynamic range sample-and-hold and a precision reference. Two digitally selectable power shutdown modes provide flexibility for low power systems. The LTC1419 has a full-scale input range of ±2.5V. Outstanding AC performance includes 81.5dB S/(N + D) and 93dB THD with a 100kHz input; 80dB S/(N + D) and 86dB THD at the Nyquist input frequency of 400kHz.

The devices were irradiated in air at various temperatures at Texas A&M and also at JPL's pulsed laser facility. An HP 6629 quad power supply was used to power the LTC1419. Three of the four available supplies on the HP6629 were used. One supply for AV_{DD}, one supply for V_{ss}, and one supply for DV_{dd}. All three supplies were set to +5.25V. The power supply clamp currents were set to 50, 100 and 40 mA and threshold currents were set to 25, 50 and 20 mA for AV_{DD}, V_{ss}, and DV_{DD} supplies respectively. SELs were detected via the test system software. The software controls the power supply voltage, and monitors the supply current and voltage to the Device Under Test (DUT). The software also provides automatic latchup detection, latchup counting, DUT protection, and records a strip chart of power supply currents and voltages to disk. At TAM, the LTC1419 was tested at room temperature, application temperatures of 40, 45, 50, 60, and 70 and at 85°C, at JPL's pulse laser facility, the device was only tested at room temperature.

No SELs were observed at room temperature for LDC 0612 at LET 86.2 MeV-cm^2/mg nor at 40°C temperature at LET 78.0 MeV-cm^2/mg. At an evaluated temperature of 50°C SELs were observed at LET of 78.0 MeV-cm^2/mg. At evaluated temperature of 60°C SELs were observed at LET of 59.0 MeV-cm^2/mg for one sample, but no SEL was observed for other two samples. We estimate the SEL threshold at the elevated temperature of 60°C is between an LET of 50.0 MeV-cm^2/mg and an LET of 55.0 MeV-cm^2/mg for MSL flight lots. We also performed limited SEL measurements at 70 and 45 °C.

No SELs were observed at room temperature for LDC 1034 at LET 78.0 MeV-cm^2/mg. SELs were observed at 40°C temperature at an LET of 78.0 MeV-cm^2/mg, but no SELs were observed at LET 73.5 MeV-cm^2/mg. At evaluated temperature of 60°C, SELs were observed at LET of 59.0 MeV-cm^2/mg for one sample, but no SELs were observed for other two samples. We estimate the SEL threshold at the elevated temperature of 60°C is between an LET of 50.0 MeV-cm^2/mg and an LET of 55.0 MeV-cm^2/mg for this flight lot. Fig. 1 below shows a plot for SEL at 60°C for the two flight lots.

In order to determine if latchup for these devices could be destructive, we removed the latchup protection by increasing the current clamps to 1.9A and current threshold to 2.0 A. This current setting effectively removes latchup protection by keeping the latchup protection software from shutting down the power supply when a latchup is detected. During the irradiation, the supply current increased to ~450mA and the lack of output signal from the device indicated that the device was no longer functioning. To determine if this condition was recoverable, the beam was turned off and the device power cycled (power supply was turned off and back on again). The current after power cycling was down to about 0.5mA and there was no output signal (the device was no longer functioning). This device therefore is subject to destructive SEL at elevated temperature above 40°C.

Laser testing was performed at JPL's pulsed laser facility in order to determine the effectiveness of a current limiting resistor on destructive SEL. The laser operated at 800nm with 1.2ps pulses injected at a frequency of 800kHz. The laser Fig. 2 shows the regions on the die that when subjected to laser pulses, induced destructive SEL.

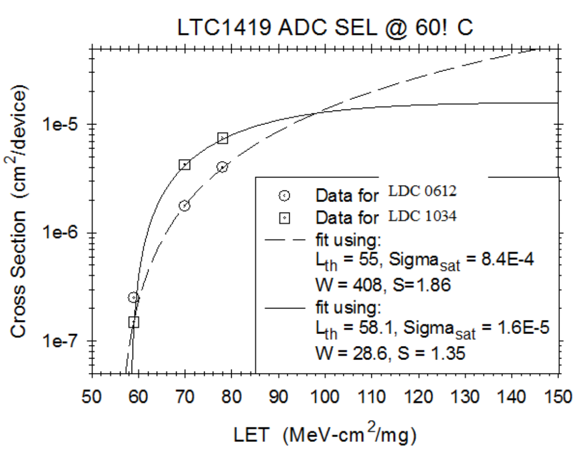

Fig. 1. Heavy ion SEL data for both lots at 60°C.

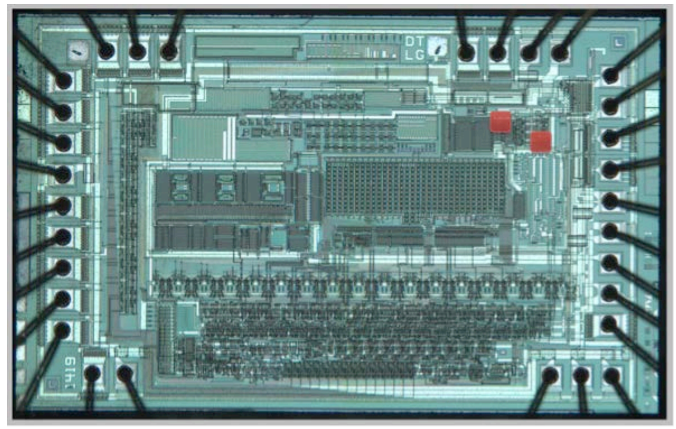

Fig. 2. Illustrates the areas (red squares) where the destructive SEL occurred during the pulsed laser testing.

B. SG1524BJ

The Microsemi SG1524BJ regulating pulse width modulator was tested for Singe Event Transient. A preliminary SEE evaluation was performed on a total of three samples. The purpose of this test was to evaluate the response of these devices against heavy ion irradiation under worst-case operational condition up to an LET of at least 80 MeV cm^2/mg using ASTM F 1192-00. Two devices were tested under worst-case bias conditions, the third was held as a control device. The output response was recorded for each selected heavy ion with its associated LET (in MeV.cm^2/mg). Only Au ions were used for characterization. Figure 3 below shows the electrical configuration for the SEE test.

The failure criteria for the test are not defined per se as the circuit requirements for the project were not defined at the time of the test. Any positive or negative transient with a magnitude over 100mV was recorded for analysis. Two configurations were available on the PWM daughter card: with and without SD feedback (see the switch on Figure 3). The feedback configuration emulates the application more accurately; however no difference was seen between the two operational modes. The PWM was configured to produce a 300 kHz output. The scope was configured to trigger upon any change in duty cycle greater than 5%. The devices were subsequently characterized for any SEE modes that changed the output as described above.

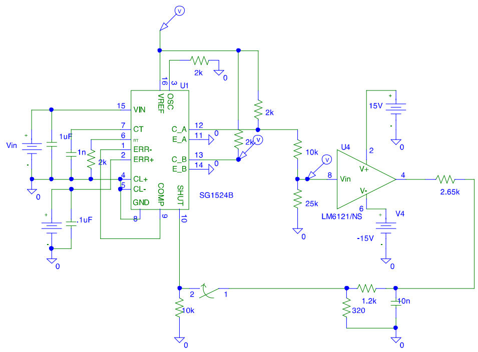

Fig. 3. SEE test schematic for the SG1524BJ.

Testing was performed at TAM cyclotron facilities using the 15MeV/amu beam. The 15 MeV/amu set of ions was used for SET characterization due to its wide selection of LETs and sufficient range to properly evaluate the single event transient sensitivity of these device types. Two devices were subjected to a total fluence of $1x10^7$ ions/cm^2 each with 15 MeV/amu Au (effective LET 84.6 MeV-cm^2/mg) at room temperature; no SEL/SEB/SEDR were observed. The following types of SEE events were observed and counted during irradiation: decreased duty cycles, increased duty cycles, and SET. Figures 4 through 6 depict these events. In addition to the PWM output A, VREF and PWM Output B were captured on the oscilloscope as well. The VREF is shown in red, and the soft start output in blue. The testing performed was exploratory in nature, as such full LET sweeps were not performed and therefore no rates are available. No destructive events were observed, nor were any events observed that could lead to an increase in the power supply's voltage that this PWM is a component of (e.g. a continuous increase in the output signal's frequency or duty cycle).

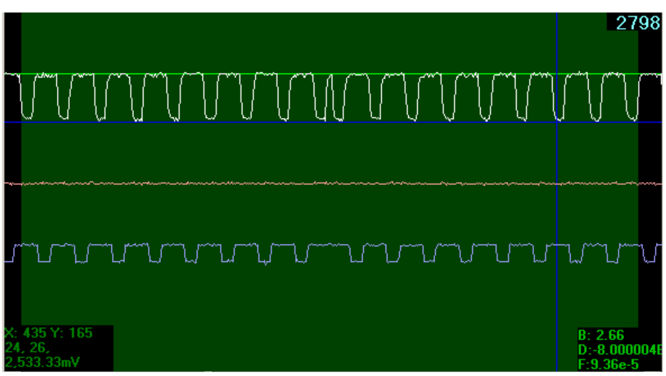

Fig. 4. An example of an SEE induced shortened pulse.

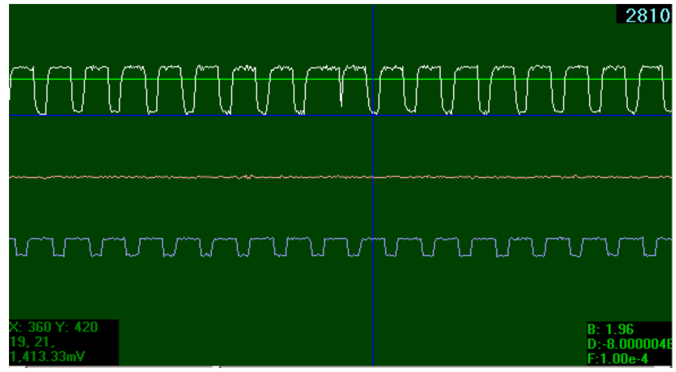

Fig. 5. An example of an SEE induced elongated pulse.

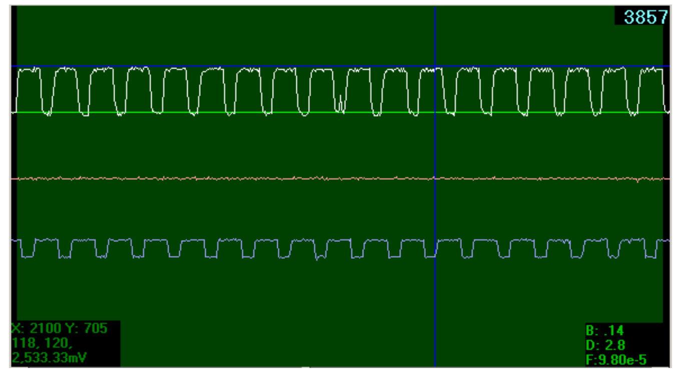

Fig. 6. An example of an SEE induced transient in the middle of a pulse.

C. *MAX2112*

Maxim's MAX2112 was tested for functional SEU and SEL. Six (6) parts were prepared for test. These parts were a QFN with a copper lead frame, so they resisted the acid etching process typical used to de-lid the devices. Any acid that contacted the die jeopardized the lead frame. Bare dice were not available at the time of the test for re-bonding, so the test moved forward by thinning the plastics on the die to depth that the ions could penetrate and still traverse the active area of the die. As the die area was very thin, ions that penetrate the plastics should have uniform charge deposition in the active areas of the device. Twenty (20) parts were prepared by partial chemical etching of the plastic package. After this process, 111.794 microns +/- 7.406 microns of plastic remained. Therefore, all of the ions at TAM were available for this test with the following caveat: Some of the ions at 15 MeV/amu were on the "wrong side of the Bragg peak." That was, the ions were dropping in LET very quickly when they traverse the active area so the estimate of the LET uncertainty were amplified. Use of these ions was limited.

Failure criteria were classified as an SEL being a stable increase in current that causes device functional interrupt, sustained until a power cycle. SEU was a change in the registers. SEFI (reset error) was defined as loss of the output signal from the device, i.e., flat line. Two types of SEU/SEFI test were performed. One was an observational study in which the fluence required to cause the output sine wave of the device to drop to flat-line. The cross section of these events is plotted as a function of LET in Figure 7 as a "reset error." Also in the Figure 7 is the cross section of the register errors as a function of fluence. No SELs were observed at for three parts during irradiation of $1x10^7$ cm^2 gold ions (83.2 MeV-cm^2/mg).

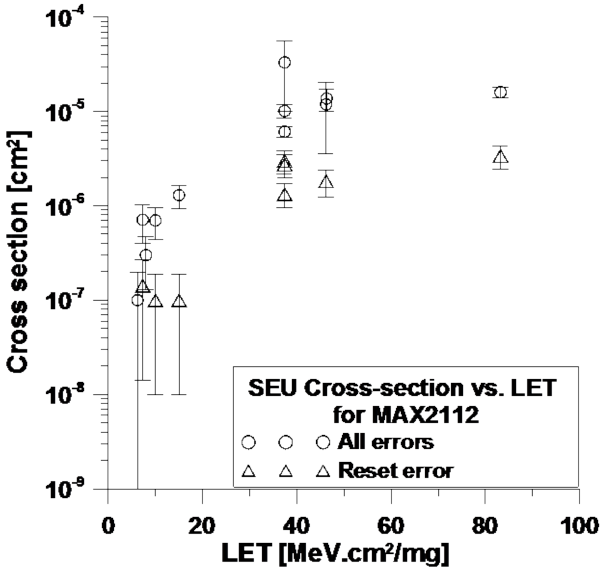

Fig. 7. Cross-section of events on the MAX2112 as a function of LET. The LETs in this figure account for the 111um of potting on the device during irradiation.

V. APPENDIX

P.I.	Date	Device	LDC/Alt PN	Function	Mfr.	Technology	Test Type	Test Facility	Test Results	Test Report
ADC/DAC										
FI	April, 2011	LTC1419AIG	0612, 1034	14-bit ADC	LTN	CMOS	SEL	TAM (HI)	LET_{TH}>86.2 @ 20°C LET_{TH}>78.0 @ 40°C 50<LET_{TH}<86.2 @ 60°C	I
GA	Decmeber, 2011	LTC1419AIG	0612, 1034	14-bit ADC	LTN	CMOS	SEL	JPL (L)	Destructive SEL observed at room temperature with equivalent LET > 100.	I
FPGAs										
GA	July, 2011	XQR5VFX130	-	Reprogrammable FPGA	Xilinx	CMOS	SEL, SEFI, SEU	TAM (HI)	SEL LET_{TH}>145@125°C SEFI LET_{TH}<1 SEFI σ_{SAT}~1x10^{-6} BRAM SEU LET_{TH}<1.3 BRAM SEU σ_{SAT}~2x10^{-8}/bit See reports for details concerning other test results	8
GA	July, 2011	iCE65L04VF-LCB284C	0852	Reprogrammable FPGA	SiliconBlue	CMOS	SEL	TAH (HI)	LET_{TH}>83@25°C	8
GA	July, 2011	EP4SGX230KF40	-	Reprogrammable FPGA	Altera	CMOS	SEL	TAM (HI)	LET_{TH}>112@85°C	8
Logic Devices										
LS	July, 2010	BUF634	BUF634U	Buffer	Burr-Brown	CMOS	SET	NRL(L)	Laser, LET ~ 120, worst case SET observed: amplitude 2V, 0.1us duration	RC
Microprocessor (32-bit)										
SG	July, 2011	Maestro	-	MultiCore Processor	Boeing	CMOS	SEL, SEU	TAM (HI)	Cache(unprotected) LET_{TH}<2 Cache(unprotected) σSAT~8x10^{-8}/bit SEE response of this device is extremely complicated, see report for details.	I
SG	May, 2012	P5020	P5020PSE 10Z A	Processor	Freescale	CMOS	SEL, SEU	TAM (HI)	Cache(unprotected) LET_{TH}<1.8 Cache(unprotected) σSAT~1x10^{-9}/bit See report for further details	I
SG	August, 2011	P2020	-	Processor	Freescale	CMOS	SEL, SEU	TAM (HI)	Cache(unprotected) LET_{TH}<1.8 Cache(unprotected) σSAT~2x10^{-9}/bit See report for further details	I
Miscellaneous										
GA	October, 2010	SG1524BJ	0824	PWM	MSC	Bipolar	SEL,SEGR,SEB	TAM (HI)	SEL/SEGR/SEB LET_{TH}>84.6 @25°C	RC
LS	October, 2010	MAX2112	-	Tuner	Maxim	CMOS	SEL, SEU	TAM (HI)	SEL LET_{TH}>83.2 @ 25°C SEU LET_{TH}<6.3 SEU σ_{SAT}~2x10^{-5}	RC

Non-Volatile Memories										
FI	May, 2012	MT29F32G08AB AAA	1202	32 Gb Flash Memory	Micron	CMOS	SEU, SEFI	TAM (HI)	SEU $LET_{TH}<0.1$ SEU $\sigma_{SAT}\sim1x10^{-10}$/bit	12
FI	May, 2012	MT29F64G08CB AAA	1206	64 Gb Flash Memory	Micron	CMOS	SEU, SEFI	TAH (HI)	SEU $LET_{TH}<0.1$ SEU $\sigma_{SAT}\sim1x10^{-9}$/bit	12
FI	May, 2012	MT29F128G08EF AAA	1150	128 Gb Flash Memory	Micron	CMOS	SEU, SEFI	TAM (HI)	SEU $LET_{TH}<0.1$ SEU $\sigma_{SAT}\sim1x10^{-9}$/bit	12
Op Amps										
LS	July, 2010	OP497	5962-9452101M2A	Quad Op-Amp	ADI	Bipolar	SET	TAM (HI)	V_{CC} = ± 15 V, LET_{TH} = 1, σ_{SAT} =1x 10^{-2} V_{CC} = ± 10 V, LET_{TH} = 1, σ_{SAT} = $1x10^{-2}$ V_{CC} = ± 5 V, LET_{TH} = 1, σ_{SAT} = $1x10^{-2}$	RC
LS	July, 2010	AMP01	5962-8863001V3A	Instrument Amp	ADI	Bipolar	SET	NRL(L)	Laser, LET ~ 120, worst case SET observed: amplitude -40mV, 5us duration	RC
LS	July, 2010	LF198	5962-8760801VZA	Sample & Hold Amp	NSC	Bipolar	SET	NRL(L)	Laser, LET ~ 120, worst case SET observed: amplitude 10V, 0.2us duration	RC
LS	July, 2010	OP400	5962-8777101V3A	Quad Op-Amp	ADI	Bipolar	SET	NRL(L)	Laser, LET ~ 120, worst case SET observed: amplitude -400mV, 5us duration	RC
LS	July, 2010	OP470A	5962R8856501V2A	Quad Op-Amp	ADI	Bipolar	SET, SEDR	NRL(L), TAM(HI)	Laser, LET ~ 120, worst case SET observed: amplitude 300mV, 1us duration. SEDR $LET_{TH}<34$ SEDR σ_{SAT} = $1x10^{-2}$	RC
LS	July, 2010	OP484	5962R0051701VDA	Quad Op-Amp	ADI	Bipolar	SET	NRL(L)	Laser, LET ~ 120, worst case SET observed: amplitude 4.4V, 1us duration	RC
Power MOSFETs/GaN										
LS	May, 2012	JANTX2N6790	-	Power MOSFET	IR	nMOS	SEGR, SEB	TAM (HI)	For V_{GS} = 0, Kr @ LET = 37, V_{DS} = 130 Xe @ LET = 50, V_{DS} = 70	RC
LS	May, 2012	IRF5NJ5305	-	Power MOSFET	IR	pMOS	SEGR, SEB	TAM (HI)	Kr @ LET = 36, VGS = 10, VDS = -40	I
LS	March, 2012	2SJ1A03	-	Power MOSFET	FUJI	pMOS	SEGR, SEB	TAM (HI)	For V_{GS} = 0, Kr @ LET = 36, V_{DS} = -100 Br @ LET = 36.1, V_{DS} = -100 Xe @ LET = 61, V_{DS} = -45 Kr @ LET = 27.1, V_{DS} = -100 Xe @ LET = 50.2, V_{DS} = -45	9

LS	March, 2013	2SJ1A09	-	Power MOSFET	FUJI	pMOS	SEGR, SEB	TAM (HI)	For V_{GS} = 0, Au @ LET = 94.4, V_{DS} = -42 Xe @ LET = 31.5, V_{DS} = -110 Xe @ LET = 50.9, V_{DS} = -80 Kr @ LET = 36, V_{DS} = -200 Br @ LET = 36.1, V_{DS} = -190 Kr @ LET = 27.1, V_{DS} = -200	9
LS	March, 2014	NSD1A01	-	Power MOSFET	FUJI		SEGR, SEB	TAM (HI)	For V_{GS} = 0, Au @ LET = 84.7, V_{DS} = 40 Au @ LET = 94.4, V_{DS} = 30 Xe @ LET = 50.9, V_{DS} = 90 Kr @ LET = 34.8, V_{DS} = 600 Kr @ LET = 31, V_{DS} = 600 Xe @ LET = 50.2, V_{DS} = 90	9
LS		CGH40180PP	-	GaN HEMPT	CREE	GaN	SEGR, SEB	TAM (HI)	No SEE observed	I
LS		CGH40120F	-		CREE	GaN	SEGR, SEB	TAM (HI)	No SEE observed	I
LS	July, 2011	SFC9550	-	Power MOSFET	SEMICOA		SEGR, SEB	TAM (HI)	For V_{GS} = 0, Xe @ LET = 39.9, V_{DS} = 180 Xe @ LET = 58, V_{DS} = 150 Kr @ LET = 20.3, V_{DS} = 300 Kr @ LET = 37, V_{DS} = 300	RC
LS	July, 2011	IRHM57260SE	-	Power MOSFET	IR	nMOS	SEGR, SEB	TAM (HI)	For V_{GS} = 0, Xe @ LET = 49, V_{DS} = 115 Xe @ LET = 59.8, V_{DS} = 100	RC
SDRAM										
SG	Jan, 2012	EDS5108ABTA	DC0805BE, DC0629BE	SDRAM	Elpida	CMOS	SEU	BNL (HI),IND (P)	SEU LET_{TH}<2 SEU σ_{SAT}~$2x10^{-9}$/bit SEFI LET_{TH}<2 SEFI σ_{SAT}~$2x10^{-9}$/bit	10
Voltage Comparator										
LS	July, 2010	LM111	5962-8687701Q2A	Voltage Comparator	NSC	Bipolar	SET	TAM(HI)	LET_{TH}<28 σ_{SAT}~$2x10^{-3}$@83	RC
LS	July, 2010	LM119	5962R9679802VXA	Voltage Comparator	NSC	Bipolar	SET	NRL(L)	Contact PI for results	I
Voltage Reference										
LS	July, 2010	AD588	5962-89728022A	Voltage Reference	ADI	BiCMOS	SET	NRL(L)	Laser, LET ~ 120, worst case SET observed: amplitude 2.5V, 1.5ms duration	RC
LS	July, 2010	RH1009	RH1009MH	Voltage Reference	LTC	BiCMOS	SET	TAM(HI)	LET ~ 87 worst case SET observed: amplitude 1V, 1.2us duration	RC
LS	July, 2010	IS1009	5962F0052301VXC	Voltage Reference	Intersil	BiCMOS	SET	TAM(HI)	LET ~ 87 worst case SET observed: amplitude 1V, 1.2us duration	RC

Voltage Regulator										
LS	July, 2010	LM117HV	9562R07229 61VXA	Positive Voltage Regulator	NSC	Bipolar	SET	BNL(HI)	LET ~ 41 worst case SET observed: amplitude 1.6V, 3ms duration	RC
GA	October, 2011	LT1963ES8	1023	LVDO	LTC	Bipolar	SET	JPL (L)	No SET observed to a laser energy of 30pJ	RC
GA	October, 2011	LT1755IS8	0933	LVDO	LTC	Bipolar	SET	JPL (L)	No SET observed to a laser energy of 30pJ	RC
GA	August, 2011	MSK5920-1.5	0635	LVDO	MSK	Bipolar	SET	JPL (L)	Very small amplitude SET (~0.1V) and shutdown mode observed at 14pJ.	RC
GA	August, 2011	MSK5920-2.5	0703	LVDO	MSK	Bipolar	SET	JPL (L)	No SET observed to a laser energy of 15pJ	RC
GA	August, 2011	RH1086	9714	LVDO	LTC	Bipolar	SET	JPL (L)	Small SET (300mV amplitude and 10us duration) observed at 14pJ	RC
GA	August, 2011	LM3940	0W091|0024|6E7033B019-XS	LVDO	NSC	Bipolar	SET	JPL (L)	No SET observed to a laser energy of 16pJ	RC

VI. REFERENCES

[1] Texas A&M Cyclotron webpage, http://cyclotron.tamu.edu .

[2] Brookhaven National Laboratory Tandem Van de Graaff Accelerator Facility webpage, http://www.tvdg.bnl.gov.

[3] Indiana University Cyclotron Facility webpage, http://www.iucf.indiana.edu

[4] UC Davis Crocker Nuclear Laboratory webpage, http://media.cnl.ucdavis.edu/Crocker/Website/default.php.

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[6] ASTM F1192M-95 "Standard Guide for the Measurement of SEP Induced by Heavy Ion Irradiation of Semiconductor Devices," ASTM, 1919 Race St., Philadelphia, PA 19103.

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