Compendium of Current Single Event Effects Results for Candidate Spacecraft Electronics for NASA

Martha V. O'Bryan, Christian Poivey, Kenneth A. LaBel, Stephen P. Buchner, Ray L. Ladbury, Timothy R. Oldham, James W. Howard, Jr., Anthony Sanders, Melanie Berg and Jeffrey L. Titus

***Abstract*— Sensitivity of a variety of candidate spacecraft electronics to proton and heavy ion induced single event effects is presented. Devices tested include digital, linear, and hybrid devices.**

***Index Terms*—Single Event Effects, spacecraft electronics, digital, linear bipolar, and hybrid devices.**

I. INTRODUCTION

In order to meet the demands of reduced cost, higher performance and more rapid delivery schedules imposed by the space flight community, commercial and emerging technology devices have assumed a prominent role in meeting these needs. The importance of ground-based testing of such devices for susceptibility to single event effects (SEE) has assumed greater importance. The novel ways in which some of these devices are used also highlights the need for application specific testing to ensure their proper operation and ability to meet mission goals.

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The studies discussed here were undertaken to establish the sensitivities of candidate spacecraft electronics to heavy ion and proton-induced single event upset (SEU), single event latchup (SEL), and single event transient (SET). For proton displacement damage (DD) and total ionizing dose (TID) results, see a companion paper submitted to the 2007 IEEE NSREC Radiation Effects Data Workshop entitled: "Compendium of Current Total Ionizing Dose Results and Displacement Damage Results for Candidate Spacecraft Electronics for NASA" by D. Cochran, et al. [1].

II. TEST TECHNIQUES AND SETUP

A. Test Facilities

All SEE tests were performed between February 2006 and February 2007. Heavy ion experiments were conducted at Lawrence Berkeley National Laboratory (LBNL) [2], at Texas A&M University Cyclotron (TAMU) [3], and at the Single Event Effects Test Facility (SEETF) at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) [4]. The LBNL and TAMU facilities use an 88" cyclotron. The NSCL MSU facility uses tandem K500 and K1200 cyclotrons to deliver on target ions with energies up to 125 MeV/n. All these facilities are suitable for providing a variety of ions over a range of energies for testing. The DUT was irradiated with heavy ions having linear energy transfers (LETs) ranging from 0.59 to 120 MeV•cm^2/mg. Fluxes ranged from $1x10^3$ to $1x10^7$ particles/cm^2 per second, depending on the device sensitivity. Representative ions used are listed in Table I. LETs between the values listed were obtained by changing the angle of incidence of the ion beam with respect to the DUT, thus changing the path length of the ion through the DUT and the "effective LET" of the ion [5]. Energies and LETs available varied slightly from one test date to another.

Proton SEE tests were performed at two facilities: the University of California at Davis (UCD) Crocker Nuclear Laboratory (CNL) [6], and at the Indiana University Cyclotron Facility (IUCF) [7]. Proton test energies incident on the DUT are listed in Table II. Proton SEE tests were performed in a manner similar to heavy ion exposures. However, because protons cause SEE via indirect ionization of recoil particles, results are parameterized in terms of proton energy rather than LET. Because such proton-induced nuclear interactions are rare, proton tests also feature higher cumulative fluence and particle flux rates than do heavy ion experiments.

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TABLE I: HEAVY ION TEST FACILITIES AND TEST HEAVY IONS

	Ion	Energy (MeV)	Surface LET in Si, MeV•cm^2/mg (Normal Incidence)	Range in Si (μm)
LBNL	O^{18}	184	2.2	227
	Ne^{22}	216	3.5	175
	Ar^{40}	400	9.7	130
	Cu^{65}	659	21	110
	Kr^{86}	886	31	110
	Xe^{136}	1330	59	97
	10 MeV per AMU tune			
MSU	Xe^{124}	17360	14.1	~ 3300
TAMU	Ne^{20}	300	2.5	316
	Ar^{40}	599	7.7	229
	Cu^{63}	944	17.8	172
	Kr^{84}	1259	25.4	170
	Xe^{29}	1934	47.3	156
	15 MeV per AMU tune			
	Ne^{20}	800	1.2	1655
	Ar^{40}	1598	3.8	1079
	40 MeV per AMU tune			

TABLE II: PROTON TEST FACILITIES

University of California at Davis (UCD) Crocker Nuclear Laboratory (CNL), energy 63 MeV, flux ranged from 8x10^7 to 1x10^9 particles/cm^2/s.
Indiana University Cyclotron Facility (IUCF), energy ranged from 50 to 200 MeV, flux ranged from 1x10^7 to 8x10^8 particles/cm^2/s.

B. Test Method

Unless otherwise noted, all tests were performed at room temperature and with nominal power supply voltages. We recognize that high-temperature and worst-case power supply conditions are recommended for single event latchup (SEL) device qualification.

1) SEE Testing - Heavy Ion:

Depending on the DUT and the test objectives, one or more of three SEE test methods were typically used:

Dynamic – the DUT was exercised continually while being exposed to the beam. The events and/or bit errors were counted, generally by comparing DUT output to an unirradiated reference device or other expected output (Golden chip or virtual Golden chip methods). In some cases, the effects of clock speed or device operating modes were investigated. Results of such tests should be applied with caution due to the application-specific nature of the results.

Static – the DUT was loaded prior to irradiation; data were retrieved and errors were counted after irradiation.

Biased – the DUT was biased and clocked while I_{CC} (power consumption) was monitored for SEL or other destructive effects. In most SEL tests, functionality was also monitored.

In SEE experiments, DUTs were monitored for soft errors, such as SEUs and for hard errors, such as SEL. Detailed descriptions of the types of errors observed are noted in the individual test results. [8]

SET testing was performed using a high-speed oscilloscope. Individual criteria for SETs are specific to the device being tested. Please see the individual test reports for details. [8]

Heavy ion SEE sensitivity experiments include measurement of the Linear Energy Transfer threshold (LET_{th}) and saturation cross section at maximum measured LET. The LET_{th} is defined as the maximum LET value at which no effect was observed at an effective fluence of 1x10^7 particles/cm^2. In the case where events are observed at lower fluences for the smallest LET tested, LET_{th} will either be reported as less than the lowest measured LET or determined approximately as the LET_{th} parameter from a Weibull fit.

2) SEE Testing - Proton

Proton SEE tests were performed in a manner similar to heavy ion exposures. However, because protons cause SEE via indirect ionization of recoil particles, results are parameterized in terms of proton energy rather than LET. Because such proton-induced nuclear interactions are rare, proton tests also feature higher cumulative fluences and particle flux rates than do heavy ion experiments.

III. TEST RESULTS OVERVIEW

Abbreviations and conventions are listed in Table III. Abbreviations for principal investigators (PIs) are listed in Table IV, and SEE results are summarized in Table V. Unless otherwise noted, all LETs are in MeV•cm^2/mg and all cross sections are in cm^2/device. This paper is a summary of results. Complete test reports are available online at http://radhome.gsfc.nasa.gov [8].

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TABLE III: ABBREVIATIONS AND CONVENTIONS:

H = heavy ion test
P = proton test (SEE)
Samp = sample
P.I. = principal investigator
LDC = lot date code
DUT = device under test
LET = linear energy transfer (MeV•cm^2/mg)
LET$_{th}$ = linear energy transfer threshold (the minimum LET value for which a given effect is observed for a fluence of 1x10^7 particles/cm^2 – in MeV•cm^2/mg)
< = SEE observed at lowest tested LET
> = No SEE observed at highest tested LET
σ = cross section (cm^2/device, unless specified as cm^2/bit)
$\sigma_{max\ measured}$ = cross section at maximum measured LET (cm^2/device, unless specified as cm^2/bit)
App. Spec. = application specific
Aux = auxiliary
CMOS = complementary metal oxide semiconductor
DDR = double data rate
FPGA = field programmable gate array
I/O = input/output
LVDO = low voltage drop out
MMIC = monolithic microwave integrated circuit
MOSFET = metal oxide semiconductor field effect transistor
N/A = not applicably
NAND = not and (electronic logic gate)
Op Amp = operational amplifier
PAL = programmable array logic
pHEMT = p-type high electron mobility transistor
PPC = power PC
SDRAM = synchronous dynamic random access memory
SEBE = single event burst error
SEE = single event effect
SEFI = single event functional interrupt
SEGR = single event gate rupture
SEL = single event latchup
SET = single event transient
SEU = single event upset
VIN or VOUT = input voltage or output voltage

TABLE IV: LIST OF PRINCIPAL INVESTIGATORS

Principal Investigator (PI)	Abbreviation
Steve Buchner	SB
Melanie Berg	MB
Jim Howard	JH
Ray Ladbury	RL
Timothy Oldham	TO
Christian Poivey	CP
Anthony (Tony) Sanders	TS

TABLE V: SUMMARY OF SEE TEST RESULTS

Part Number	Manufacturer	LDC	Technology/ Device Function	Process	Particle: (Facility/Date) P.I.,	Test Results LET in MeV•cm^2/mg σ in cm^2/device, unless otherwise specified	App. Spec. Test (Y/N)	Supply Voltage	Samp. Size	Test Report
Programmable Logic/FPGA										
Eclipse FPGA	Aeroflex	1059 and 1082	0.25µm CMOS shift register	CMOS	H: (TAMU06MAY) MB; H: (TAMU06NOV) MB; H: (LBNL07JAN) MB; P: (IU06MAR) MB	H: 8.5<SEU LET_{th} <12; P: SEU LET_{th} <5x10^{-16} with 195 MeV Protons. No errors observed at lower energies.	N	Core 2.5V; I/O 3.3V	10	T022205_Aeroflex_Eclipse_v2
RTAX-S	Actel	0506 and 0543	0.15µm CMOS FPGA	CMOS	H: (TAMU06MAY) MB; P: (IU06MAR) MB	H: SEU LET_{th} <8.5 (will be higher if running at a slower frequency); P: SEU σ~8.5x10^{-16} with 195 MeV; 6.6x10^{-16} with 63 MeV Protons at 150 MHz; No SEUs observed at 15 MHz at both 63 and 195 MeV Protons.	N	Core: 1.5 V, I/O: 3.3 V	10	T110405_RTAX_v2
LX25	Xilinx	0553	Virtex IV FPGA 90nm CMOS flip chip	CMOS	H: (TAMU06MAY) MB; H: (TAMU06JUN) MB; H: (TAMU06AUG) MB; P: (IU06MAR) MB; P: (IU06JUL) MB	H: SEL LET_{th} >75; SEFI LETth<5.7; P: No SEL observed at both 93 and 195 MeV Protons.	N	Core 1.2V; I/O 3.3V	1	[I032706_LX25
XC4VFX60	Xilinx	0629(MSU), 0609(TAMU)	Virtex IV FPGA 90µm CMOS	CMOS	H: (MSU06OCT) CP; H: (TAMU07FEB) CP	SEL LET_{th}>58; SEFI LET_{th}<5.7; SEFI σ_{SAT}=1x10^{-2} with embedded PPC.	Y	Core 12V; I/O 3.3V; Aux 2.5V	2(MSU), 3(TAMU)	M102606_ XC4VFX60, and T021607_XC4VFX60
AT22V10	Cypress	0437A	PAL	1nm BiCMOS	H: (TAMU06AUG) CP	1 failure at LET 106; 2 failures at LET 53; SEU LET_{th}<2.8; SEU σ >1x10^{-3}	N	5V	4	T082606_AT22V10
Linear Devices										
RH137H	Linear Technology	0235	Negative Adjustable Regulator	Bipolar	H: (TAMU06MAY) CP	SET LET_{th} >76 with the 33µF output capacitor; SET LET_{th} ~20 without output capacitor; Positive and negative transients observed; SET σ >3x10^{-3}	Y	Vin –15; Vout -12V	2	T052306_RH137
TPS76701	Texas Instruments	LDC unknown – no package markings	Voltage Regulator	BiCMOS	H: (LBNL06JUN) CP	SEL LET_{th} >83; SET LET_{th} <3.45; SET σ ~2x10^{-3}	N	Vin 3.3; Vout 1.5V	3	L061606_TPS76701, [13]
TPS73601	Texas Instruments	LDC not indicated	Low dropout linear adjustable voltage regulator	BiCMOS	H: (LBNL06JUN) CP	SEL LETth >59; SET LET_{th} <2 at highest load current (I_{out}=250mA), SET sensitivity increased with load current; SET σ ~1x10^{-3} (worst case)	N	Vin 3.3; Vout 1.5V	2	L061806_TPS73601, [13]
SAT8605R	SatCon Electronics	LDC unknown – no package markings	2.5 linear voltage regulator	Hybrid	H: (LBNL06JUN) CP	SEL LET_{th}>59; SET LET_{th} <21; SET σ ~8x10^{-4}	N	Vin 3.3; Vout 1.5V	2	L061606_SAT8605R, [13]
RH1013	Linear Technology	0343A	Op Amp	Bipolar	H: (TAMU06NOV) CP	SEU LET_{th}~76; SET LET_{th}~10; SET σ ~3x10^{-4}	Y	+/-15V	2	T111606_RH1013
MAX997	Maxim	0531	Voltage Comparator	Bipolar	H: (TAMU06NOV) AS	SEL LET_{th}>76; SEU LET_{th}<2.8	Y	4.3V and 5V	2	T111906_MAX997ESA
RHFL4913	ST Microelectronics	0510A	Bipolar LVDO Regulator	Bipolar	H: (TAMU06NOV) AS	SEL LET_{th}>76 (full loading); SEU LET_{th}<12.3 (no load) and >4 (300mA and 600mA loading); SEU $\sigma_{max\ measured}$ ~2.9x10^{-5} (no load); ~1.26x10^{-4} (300mA loading); and ~5.3x10^{-5} 600mA loading)	Y	3.3V and 5V	2	T111806_RHFL4913
ACT8601	Aeroflex	No LDC (hybrid)	Dual voltage regulator RH117 and RH137	Bipolar	H: (LBNL06JUN) SB	SEL LET_{th}>59; SET LET_{th}>59	Y	+/-12V inputs; +/- 9V outputs	1	L061806_ACT8601
TL431	Texas Instruments	No LDC; die pkg at GSFC	Programmable Shunt Regulator	Bipolar	H: (LBNL06JUN) SB	SEL LET_{th}>59; SET LET_{th}<3.3; SET $\sigma_{max\ measured}$~3x10^{-3} at LET 59	Y	3.67V	2	L061806_TL431
LMH6702	National Semiconductor	No LDC Info on package	High Speed Op Amp	Bipolar	H: (LBNL06JUN) SB	SEL LET_{th}>81; SET LET_{th}~10; SET $\sigma_{max\ measured}$~7x10^{-6} at LET 81	Y	3.8V	1	L061806_LMH6702
RH1499	Linear Technology	0220	Op Amp	Bipolar	H: (LBNL06JUN) SB	SEL LET_{th}>58.7; SET LET_{th}<3; SET σ_{SAT}~4x10^{-3} at LET 58.7	N	+/-15V	2	L061806_RH1499
AD549	Analog Devices	0535	Ultralow Input-Bias Current Operational Amplifier	Bipolar	H: (LBNL06SEP) AS	SEL LET_{th} >83; SET LET_{th} <58.7	Y	15V	3	L091906_AD549

TABLE V: SUMMARY OF SEE TEST RESULTS (CONT.)

Part Number	Manufacturer	LDC	Technology/ Device Function	Process	Particle: (Facility) P.I.,	Test Results LET in MeV•cm^2/mg σ in cm^2/device, unless otherwise specified	App. Spec. Test (Y/N)	Supply Voltage	Samp. Size	Test Report
Optocouplers										
HCPL625K	Agilent Technologies	0534	Optocoupler; 4 channels logic gate	AlGaAs LED	P: (IU06MAR) CP	SET σ =1x10^{-7} cm^2/channel; Proton energy threshold <100	Y	5V	4	I032706_HCPL625K
HCPL-6751	Agilent Technologies	0251	Power MOSFET Optocouplers	Hybrid	P: (UCD06OCT) JH	P: No SETs observed up to a fluence of 1x10^{12} with 63 MeV protons	N	5V	3	D102506_HCPL6751 I111606_HCPL6751
Memories										
NAND01GW3B2ANGE	ST Microelectronics	0604	1 Gb Micro Flash	CMOS	H: (LBNL07JAN) TO; P: (IU06JUL) TO/MF/RL	H: SEL LET$_{th}$<55; SEU LET$_{th}$>3; SEU $\sigma_{max\ measured}$=1.1x10^{-11} cm^2/bit at LET 58.7 (static) P: No SEL observed with 200 MeV Protons; SEU σ ~1 to 3x10^{-10} up to a fluence of 1x10^{11} with 200 MeV Protons;	N*	3.3V	1	I072706_NAND01GW3B2ANGE L012707_NAND01GW3B2ANGE
K9F4G08U0A	Samsung	0625	4 Gb Flash	CMOS	H: (LBNL07JAN) TO	SEL LET$_{th}$>55; SEU LETth~3.4; SEU $\sigma_{max\ measured}$=5x10^{-11}cm^2/bit (static); SEU $\sigma_{max\ measured}$= 7.5x10^{-11}cm^2/bit (dynamic)	N*	SEL: 3.3V SEU: 3.0V	3	L012607_K9F4G08U0A [9]
KH41G0X38	Samsung	0546	1 Gbit DDR SDRAM	90 nm minimum feature size CMOS	H: (TAMU06JUN) RL; P: (IU06JUL) RL	H: SEL 45<LETth<108; SEU LETth~1 P: σ~4x10^{-19} cm^2/bit at 200 MeV	N*	2.5V	2	T062806_I072806_KH41G0X38
Communication Devices										
TLK2711	Texas Instrument	0545	Transceiver	CMOS	H: (LBNL06SEP) JH	SEL LET$_{th}$ >58.8; SEU LET$_{th}$ =1.5 transmit and 1.1 receive, $\sigma_{max\ measured}$ 5.4x10^{-5} transmit and 3.75x10^{-5} receive; SEBE LET$_{th}$ = 2.2; $\sigma_{max\ measured}$ 5.4x10^{-5} for both transmit and receive; Loss of sync LET$_{th}$ = 1.5; $\sigma_{max\ measured}$ 1.5x10^{-5} for both transmit and receive;	Y	2.5V	2	L092106_TLK2711
Power Devices										
SHD85202	Sensitron	0321	Dual power MOSFET driver	Bipolar/ CMOS/ DMOS	H: (LBNL06JUN) JH	SEL LET$_{th}$ >58.8; SET LETth <20 at room temp. and <10 at 100 degrees Celsius.	Y	12V	3	L061706_SHD85202
53111	Micropac	0103	Power MOSFET Optocouplers	Hybrid	H: (TAMU06NOV) JH; P: (UCD06OCT) JH	H: SEL LET$_{th}$ <83.4; SEGR LET$_{th}$ <83.4 MOSFET; No SET testing of opto due to device construction P: No SETs observed up to a fluence of 1x10^{12} with 63 MeV protons	Y	0V, 28V, and 34V	P: 3; H: 2;	D102506_T111606_53111
MSAFX11P50A	Microsemi	0644	Power MOSFET	MOSFET	H: (TAMU07FEB) CP	No SEGR at 0V and -425V at LET 20.6	N	N/A	10	T021907_MSAFX11P50A
Special Devices										
OMH3075S	Optek Technology	SN0011, SN0137, and SN0136	Hallogic Hall Effect Sensor	Bipolar	H: (LBNL06SEP) AS	SEL LET$_{th}$>83; SET LET$_{th}$<58.7; SET $\sigma_{max\ measured}$~4.6x10^{-4} (5V), and 2.1x10^{-4} (24V) at LET 83	Y	5V and 24V	3	L091906_OMH3075B
TGL4302	Triquint	No LDC; die pkg at GSFC	MMIC voltage variable attenuator	pHEMT MMIC	H: (TAMU06AUG) SB	SEL LET$_{th}$>78.4; SET LET$_{th}$>78.4	Y	10V	1	T082806_TGL4302
Discrete Devices										
2N2222	Microsemi	0315	Transistor	Bipolar	H: (LBNL06JUN) SB	SEL LET$_{th}$>58.72; SET LET$_{th}$~20; SET $\sigma_{max\ measured}$~2.1x10^{-4} at LET 58.72	N	8V	1	L061806_2N2222
N* = Test data taken in limited operating modes. It is recommended that application specific tests be performed.										

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 [8] describing in further detail, test method, SEE conditions/parameters, test results, and graphs of data.

This section contains a summary of testing performed on a selection of featured parts.

1) Agilent Technologies HCPL625K Four Channels Logic Gate Optocoupler

HCPL625K four-channel logic gate optocoupler was tested for proton-induced SET susceptibility at IUCF. HCPL625K optocoupler has a 5MHz bandwidth. Previous data [10] shows that fast optocouplers (>10 MHz bandwidth) are sensitive to proton-induced SET, but that slow optocouplers (about 400 KHz bandwidth) are not sensitive to proton-induced SET. In the latter case, optocoupler bandwidth is too low to propagate SETs to the device output. No data were available for optocouplers with bandwidth in between these two ranges. Test data show that HCPL is sensitive to proton-induced SETs. SET cross-section curves are shown in Fig. 1. Generally, we see one type of transient where the phototransistor is in the off state and is turned on. This is the case shown in Fig. 1 where the optocoupler is on and its output is high. In this bias condition, measured cross-section is $1x10^{-7}$ cm^2/channel. A typical SET when device is on is shown in Fig. 2. HCPL 625K is also susceptible to SET when the phototransistor is on and the device is in the off state (low output). In that case the SET probably occurs in device logic gate output. SET sensitivity is significantly lower in this configuration. Maximum measured cross-section is about $2x10^{-9}$ cm^2/channel. A typical SET when device is off is shown in Fig. 3. [11]

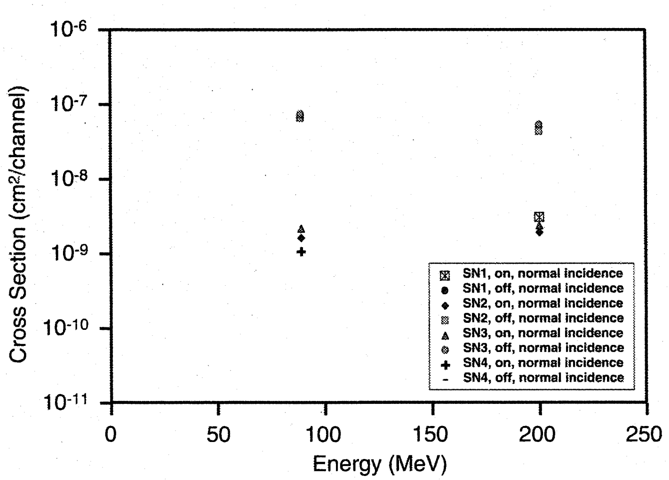

Fig. 1. HCPL625K SET cross-section curves. Cross-section is given for one channel.

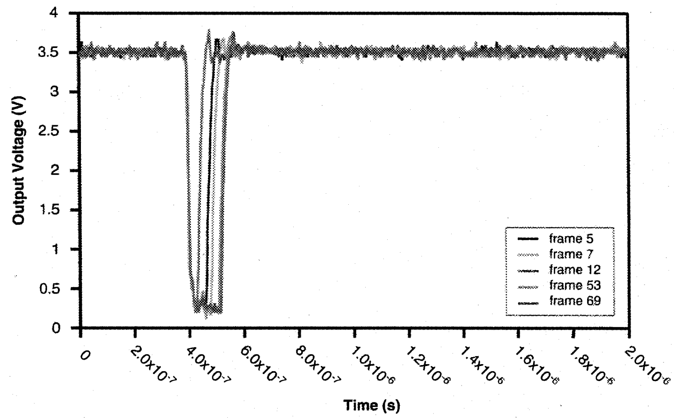

Fig. 2. HCPL625K Typical SET waveforms when optocoupler is on.

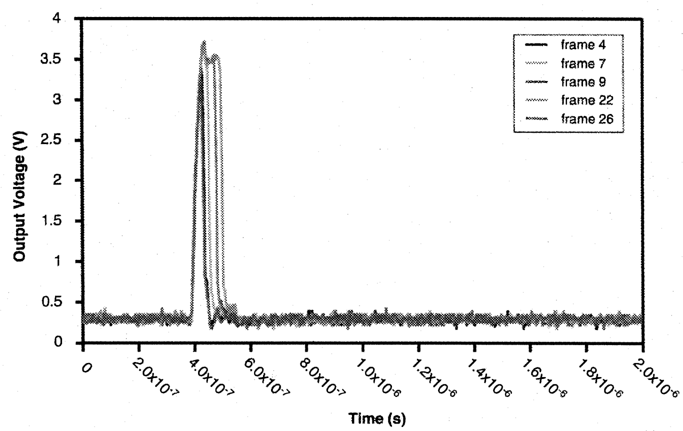

Fig. 3. HCPL625K Typical SET waveform when optocoupler is off.

2) Recent LDO SEE Results

As with other bipolar analog devices, voltage regulators are known to be sensitive to single event transients (SET). In typical applications large output capacitors are used to provide noise immunity. Therefore, SET amplitude and duration are generally small, and are often of secondary importance. However, even small SETs are a concern for low voltage applications. Over-voltages may cause destructive conditions. Under-voltage may cause functional interrupt and may also trigger electrical latchup conditions. In addition, internal protection circuits which are affected by load as well as internal thermal effects can also be triggered from heavy ions, causing dropouts or shutdown ranging from milliseconds to seconds.

Tested devices are presented in the table to the right. Satcon device is an hybrid developed for the space market. TI devices are commercial parts. All parts have internal protection circuitries for thermal and over current effects.

The parts were tested at LBL with a 10 MeV/amu beam. Devices under test (DUT) were biased with an input voltage of 3.3V and an output voltage of 1.5V under different load conditions. Output capacitor values were those recommended in manufacturer data sheets. More detailed results are available in [12].

Figure 4 shows SAT8605R SET cross sections with a 1000 μF output capacitor. We can't see a significant effect of output current on SAT8605R sensitivity. However, SAT8605R is not sensitive for an output current lower than 100 mA.

Only one transient waveform was observed. Figure 5 shows typical transients. Maximum SET amplitude is 450 mV. Worst case transient duration is 6 µs.

Figure 6 shows TPS76701 SET cross sections for a 10 µF output capacitor. We can't see a significant effect of output current on device SET sensitivity. However, for high output current values, heavy ions trigger device internal protection circuitries.

Figure 7 shows worst case SET. Device output goes down from 1.5V to 0V. In some cases protection circuitries are triggered and the device output is off for several milliseconds. About 20% of SET are long duration transients.

Figure 8 shows the SET cross sections for a 10 µF output capacitor. SET sensitivity is higher for high output current values. SET sensitivity is negligible for 10 mA output current. As for TPS76701, for high output currents (> 100 mA), heavy ions trigger device internal protection circuitries.

Figure 9 shows the worst-case transients. Device is shutdown for up to 100 ms. All SET are long duration transients.

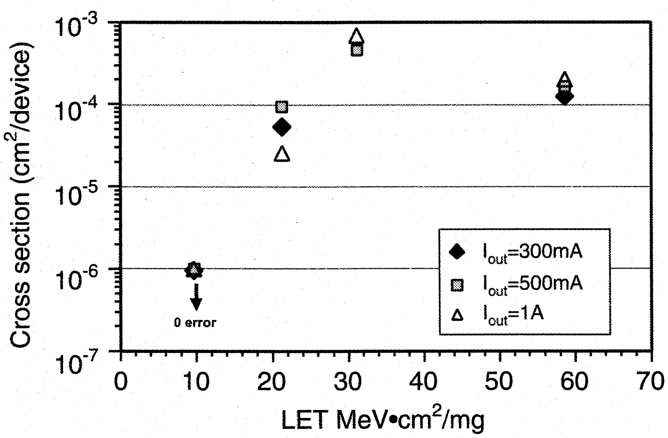

Fig. 4. SAT8605R SET cross-section.

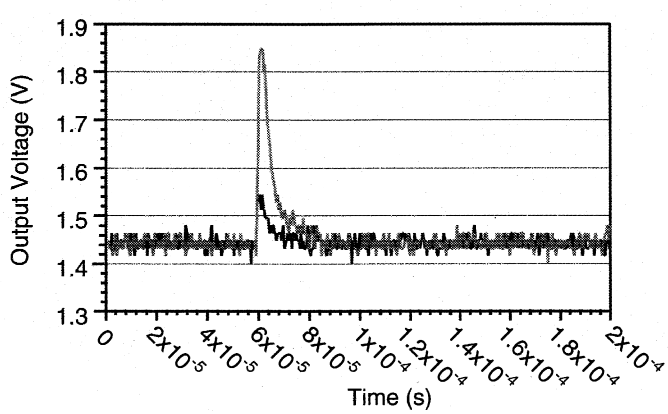

Fig. 5. SAT8605R typical SET.

Fig. 6. TPS76701 SET cross-section.

Fig. 7. TPS76701 SET waveforms, I_{out}=1A, at LET=83 MeV•cm²/mg.

Fig. 8. TPS73601 SET cross-section curves.

Fig. 9. TPS73601 worst case SETs, I_{out}=250mA, at LET=2.2 MeV•cm²/mg.

3) Samsung K9F4G08U0A 4 Gb Flash

The results in Figure 11 were fitted with Weibull parameters, threshold LET=3.5, saturation cross section=$5x10^{-11}$ cm²/bit, width=27, exponent=5, and Creme96 was used to calculate the bit error rate for geosynchronous orbit at solar minimum. The result was $1x10^{-12}$ errors/bit-day, which is equivalent to about 1.5 bit errors per year for a 4G. The data in Figure 11, is normalized per device (instead of per bit) so that the SEFI and destructive effects can be shown on the same scale as the bit errors. Obviously, the SEFI and destructive error cross sections are much less than the bit upset cross section, and the error rate expected in space will scale with the cross section.

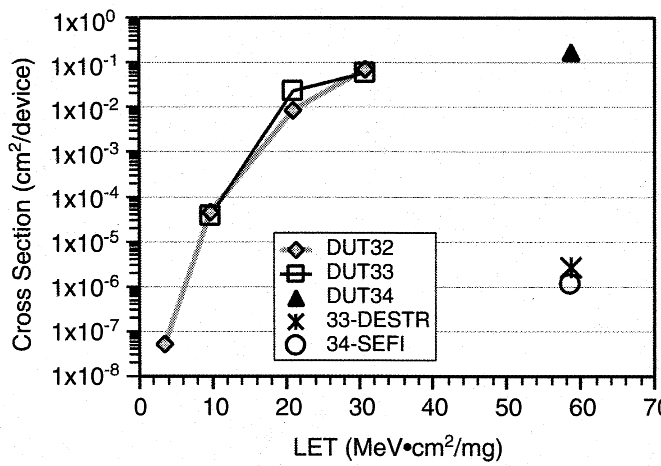

Fig. 11. Samsung K9F4G08U0A static upset cross sections.

4) Microsemi MSAFX11P50A P channel MOSFET

Radiation performance of the 500V, 11A, P channel MOSFET MSAFX11P50A from Microsemi was measured at TAMU. 10 parts were irradiated. 5 out of 10 were irradiated using 1858 MeV Krypton (LET=20.6 MeVcm²/mg and Range=284 µm). Fig. 10 shows the last passing value and the first failing value on the 5 parts tested with this ion at this energy. Safe operating area is based on this condition.

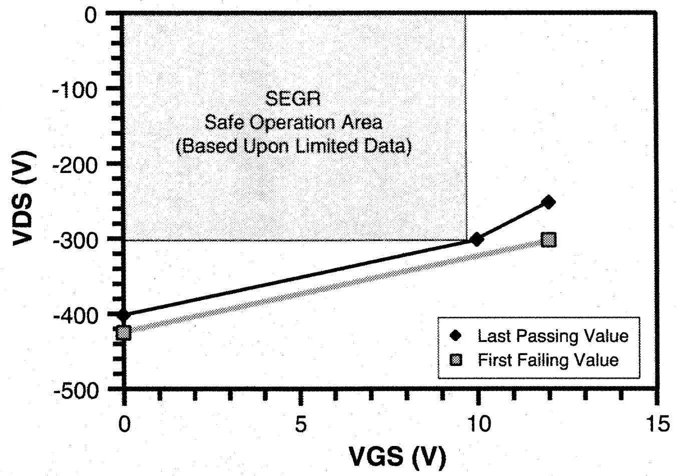

Fig. 10. MSAFX11P50A Krypton test results showing last passing and first failing value. Safe operating area is based upon this condition.

One device was irradiated with 860 MeV Krypton (LET=30 MeVcm^2/mg and Range=108 μm). Three parts were irradiated with 2758 MeV Xenon (LET=40.7 MeVcm^2/mg and Range=237 μm). Two devices were irradiated with 929 MeV Argon (LET=5.7 MeVcm^2/mg and Range=445 μm). Table VI shows a summary of all data collected.

Data show that the dominant failure mode is Single Event Gate Rupture (SEGR) and that device operation at V_{GS}<10V and V_{DS}<-300V provides a relatively safe operating region when irradiated with Krypton and Argon. Krypton represents an upper boundary of concern for space applications. There was a significant decrease in the device operational voltages between Kr and Xe with a safe operating region at V_{GS}=-5V and V_{DS}<-100V.[14]

TABLE VI: MICROSEMI MSAFX11P50A SEE TEST SUMMARY

Ion Spec.	Ion Energy (MeV)	Serial Number	Last Passing Value (VGS,VDS)	First Failing Value (VGS,VDS)	SEE Failure Threshold (VGS,VDS)	Failing Nodes
Kr	1858	1	(0V, -425V)	(0V,-450V)	(0V,-437V)	*
Kr	1858	2	(10V, -300V)	(12V, -300V)	(11V, -300V)	(G, D)
Kr	1858	3	(0V, -475V)	(0V, -500V)	(0V, -488V)	(G, D)
Kr	1858	4	(12V, -250V)	NA	NA	NA
Kr	1858	4	(0V, -420V)	(0V, -440V)	(0V, -430V)	(G)
Kr	1858	5	(12V, -250V)	NA	NA	NA
Kr	1858	5	(0V, -420V)	NA	NA	NA
Kr	860	5	(0V, -420V)	NA	NA	NA
Kr	860	5	(12V, -250V)	NA	NA	NA
Kr	860	5	(0V, -480V)	NA	NA	NA
Kr	1858	5	(0V, -460V)	(0V, -480V)	(0V, -470V)	(G)
Xe	2758	6	(0V, -100V)	(0V, -125V)	(0V, -112V)	
Xe	2758	7	(5V, -100V)	(6V, -100V)	(5.5V, -100V)	
Xe	2758	8	(46V, 0V)	(48V, 0V)	(47V, 0V)	(G)
Ar	929	9	(0V, -480V)	(0V, -500V)	(0V, -490V)	(D)
Ar	929	10	(0V, -480V)	(0V, -500V)	(0V, -490V)	

V. SUMMARY

We have presented recent data from SEE tests on a variety of mainly commercial devices. It is the authors' recommendation that this data be used with caution. We also highly recommend that lot testing be performed on any suspect or commercial device.

VI. ACKNOWLEDGMENT

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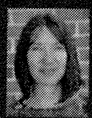
Compendium of Current Single Event Effects Results for Candidate Spacecraft Electronics for NASA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ABSTRACT

Sensitivity of a variety of candidate spacecraft electronics to proton and heavy ion induced single event effects is presented. Devices tested include digital, linear, and hybrid devices.

Introduction

Test Techniques and Setup

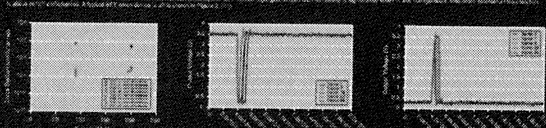
A) Test Facilities

B) Test Method

Summary of SEE Test Results

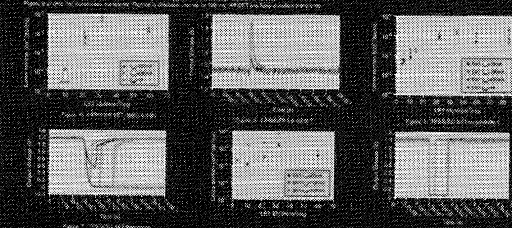
Featured Results

1) Agilent Technologies HCPL625K Four Channels Logic Gate Optocoupler

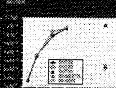


Featured Results (Cont.)

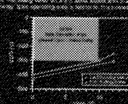
2) Recent LDO SEE Results



3) Samsung K9F4G08U0A 4 Gb Flash



4) Microsemi MSAFX11P50A P channel MOSFET



Summary

Acknowledgment

References

Poster for conference containing the same information as the paper.