Single-Event Latchup Measurements on COTS Electronic Devices for Use in ISS Payloads

Farokh Irom, Gregory R. Allen, member IEEE and Sergeh Vartanian

***Abstract*-- This paper reports recent single-event latchup results for a variety of microelectronic devices that include an ADC, OpAmp, EEPROM, CPLD, PWM, transceiver, voltage regulator, digital signal processor, step-down converter, buck controller and supervisory circuits. The data were collected to evaluate these devices for possible use in NASA ISS payloads.**

I. Introduction

At the present time there has been increased interest in the possible use of unhardened commercial-off-the-shelf (COTS) electronic devices for International Space Station (ISS) missions. These devices offer cutting-edge technology in terms of speed and performance as compared to hardened devices. However, unhardened COTS devices might be susceptible to Single-Event Latchup (SEL) and degradation from radiation effects. Therefore, more information is needed on how COTS parts respond to radiation exposure before they can be safely used in ISS missions. SEL results for space applications have been published previously [1-6].

The studies discussed in this paper were undertaken to establish the sensitivity of the COTS electronic devices to single-event latchup. SEL measurements were performed on 30 different types of CMOS and BiCMOS devices including analog-to-digital converters (ADCs), an operational amplifier, transceivers, an Electrically Erasable PROM (EEPROM), an oscillator, voltage regulators, complex programmable logic devices (CPLDs), digital signal processors, a synchronous step-down converter and supervisory circuits, as well as a buck controller and pulse width modulator.

For the heavy ion SEL measurements, the device under test (DUT) was tested for destructive latchup. If the DUT showed non-destructive SEL, the device cross-section was measured as a function LET (Linear Energy Transfer), in order to calculate SEL rates.

Some of the SEL data in this compendium was obtained with ions that have short range, in some cases < 30 μm. For devices on bulk substrates, the limited range will reduce collected charge by as much as a factor of three compared to ions with longer range. The effective LET is reduced by the same factor. There are cases where devices have not latched with ions that have shorter range, but were found to exhibit latchup when subsequent tests were done with longer range ions. The recommended ion range for SEL measurements is 70 μm or more [7]; results with short-range ions should be treated with caution.

SEL heavy-ion rates for the DUTs were calculated for the ISS Galactic Cosmic Rays (GCR) environment. The environment was modeled with CREME96 and was a time-average (averaged over many orbital passes) that includes the protection from geomagnetic shielding for the ISS (435 km, 51.6° inclination angle). The "quiet" magnetic field option was selected to model the orbit average environment. Mass shielding was taken to be 100 mils of aluminum.

Heavy-ion rate estimates require a model describing the directional dependence of device susceptibility. This dependence is rarely measured, so two models are typically used to produce two rate estimates. One is the "Best Estimate Model", which is probably close to reality but is not guaranteed. The other is the "Worst Case Model", which is recommended for design purposes. In this paper we presents heavy-ion rates for both the Best Estimate and Worst Case Models.

The Best Estimate directional model is based on a Rectangular Parallelepiped (RPP) calculation with a RPP depth (Z) equal to one-fifth of the lateral (X, Y) dimensions of the device. This estimate represents a case in which the cosine law applies to tilt angles up to about 60°, with progressively larger deviations from the cosine law at larger angles. The Worst Case directional model is an RPP calculation with RPP thickness selected for a maximum calculated rate, and is almost always equivalent to the unrestricted cosine law [8].

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II. EXPERIMENTAL PROCEDURE

A. *Test Facilities*

Heavy ion measurements were performed at two facilities: the SEU Test Facility located at Brookhaven National Laboratory (BNL) and the Radiation Effects Facility located at the Cyclotron Institute Texas A&M University (TAMU). The BNL facility uses a twin Tandem Van De Graaff accelerator while the TAMU facility uses an 88" cyclotron. Both facilities provide a variety of ion beams over a range of energies for testing. The ion beams used for our measurements are listed in Table I (for BNL) and Table II (for TAMU). The LET and range values provided are for ion beams at normal incidence.

At both facilities, test boards containing the device under test (DUT) were mounted to the facility test frame. Tests at BNL were done in vacuum with ion beams at normal incidence. Tests at the TAMU facility were performed in air at normal incidence. Some of the parts were tested at both facilities. The tests at the TAMU facility were done in air because of the higher energy ions available at this facility. The beam flux ranged from $1x10^3$ to $2x10^4$ ions/cm^2-sec.

1. TABLE I

1. LIST OF ION BEAMS USED FOR MEASUREMENTS AT BNL

2.

Ion	LET (MeV-cm^2/mg)	Range (μm)
^{19}F	3.4	122
^{28}Si	8.0	74
^{35}Cl	11.7	59
^{48}Ti	19.8	40
^{58}Ni	26.6	42
^{81}Br	37.5	36
^{127}I	59.7	31

1. TABLE II

1. LIST OF ION BEAMS USED FOR MEASUREMENTS AT BNL

2.

Ion	LET (MeV-cm^2/mg)	Range (μm)
^{40}Ar	8.5	186
^{63}Cu	19.9	129
^{84}Kr	20.4	290
^{109}Ag	42.8	113

1.

B. *Experimental Methods*

In general, the SEL test setup consisted of a computer, power supplies, and test boards specially designed for the device to be tested. A computer-controlled Keysight N6700B power supply provides precision voltage control, current monitoring and latchup protection. SELs were detected via the test system software. The software controls the power supply voltage, and monitors the supply current. The software also provides a strip chart of power supply measurements. In some cases, a separate computer was used to monitor the functionality of the test device.

The DUTs were tested at room temperature as well as at an elevated temperature. To determine each cross-section point, either a minimum of fifty latchup events were recorded or a beam fluence of 10^7ions/cm^2 was accumulated.

The SEL evaluation included measurements of the saturation cross-section and the Linear Energy Transfer threshold (LET_{th}) for each device. The LET_{th} is the minimum LET value necessary to cause a SEL at a fluence of $1x10^7$ ions/cm^2.

Section III provides an in-depth discussion on the SEL measurement results of four different part types. The results for the remaining devices that were tested are summarized in Table VIII of Section IV.

III. TEST RESULTS AND DISCUSSION

1) LTC3708

The Linear Technology LTC3708 is a dual, 2-phase synchronous step-down switching regulator with output voltage up/down tracking capability.

Three devices were tested at room temperature and at 85ºC at BNL. At room temperature, SELs were observed at a LET of 19.8 MeV-cm^2/mg but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET threshold is between 19.8 and 11.7 MeV-cm^2/mg at room temperature.

Figure 1 compares the results of the room temperature measurements with that of the heated measurements. There was a factor of 1.2 -1.5 increase in the latchup cross-section for the heated device.

The LTC3708 was tested for destructive latchup by turning off the latchup protection. When the device went into a latchup state, the supply current increased to 200 mA. The lack of an output signal from the device indicated that the device was not functioning in this high current state. To determine if this condition was recoverable, the beam was turned off and the device was power cycled. The device did recover after power cycling, indicating the device did not destructively fail.

The heavy-ion GCR rate estimates for LTC3708 are presented in Table III.

2. TABLE III

3. LTC3708 GALACTIC COSMIC RAY (GCR) SEL RATES (PER DEVICE).

4.

Environment	Best Estimate Rate	Worst Case Rate
ISS	1.4×10^{-4}/year	6.3×10^{-4}/year

2) TPS51200

The Texas Instruments TPS51200 is a sink and source double data rate (DDR) termination regulator, specifically designed for low input voltage.

An evaluation board manufactured by Texas Instruments was used for the test. The SEL measurements were performed at BNL.

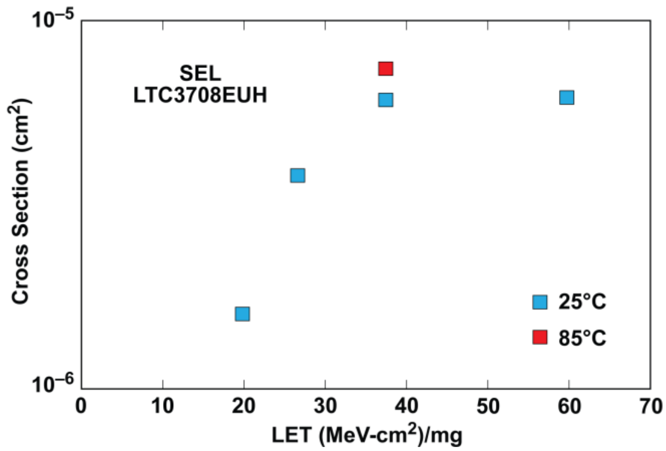

Figure 1. Comparison of latchup cross-sections at room temperature and 85ºC for LTC3708EUH.

Three devices were tested at room temperature and at 85˚C. At room temperature SELs were observed at a LET of 19.8 MeV-cm^2/mg but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET threshold is between 19.8 and 11.7 MeV-cm^2/mg at room temperature.

In figure 2, we compare the results of the room temperature measurements with that of the heated measurements. As one might expect, the latchup cross-section is higher for the heated device.

The TPS51200 was tested for destructive latchup by turning off the current limit on the power supply. When the device went into a latchup state, the supply current increased to 60 mA. The lack of an output signal from the device indicated that the device was not functioning in this high current state. To determine if this condition was recoverable, the beam was turned off and the device was power cycled. The device did recover after power cycling, indicating non-destructive SEL.

The heavy-ion GCR rate estimates for TPS51200 are presented in Table IV.

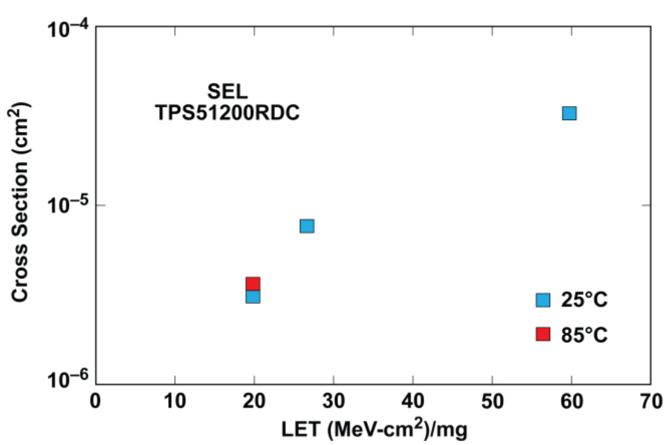

Figure 2. Comparison of latchup cross-sections at room temperature and 85ºC for TPS51200.

5. TABLE IV

6. TPS51200 GCR SEL RATES (PER DEVICE)

7.

Environment	Best Estimate Rate	Worst Case Rate
ISS	7.2×10^{-4}/year	3.3×10^{-3}/year

3) ADS8320

The Texas Instruments ADS8320 is a 16-bit, sampling analog-to-digital (ADC) converter with ensured specifications over a 2.7V to 5.25V supply range.

An evaluation board provided by the manufacturer was used to test the device. The evaluation board required four power supplies and an analog input signal. A parallel digital-to-analog converter (DAC) was used to convert the parallel output to an analog signal that was monitored with an oscilloscope.

The ADS8320 ADC was tested for SEL at BNL. Three devices were tested at room temperature and one device was tested at both room temperature as well as an elevated temperature of 85ºC. At room temperature, SELs were observed at a LET of 19.8 MeV-cm^2/mg but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET threshold is between 19.8 and 11.7 MeV-cm^2/mg at room temperature.

In figure 3, we compare the results of the room temperature measurements with that of the heated measurements. As one might expect, the latchup cross-section is higher for the heated device.

The ADS8320 was tested for destructive latchup by turning off the current limit on the power supply. When the device went into a latchup state, the supply current increased to 200 mA. The lack of an output signal from the device indicated that the device was not functioning in this high current state. To determine if this condition was recoverable, the beam was turned off and the device was power cycled. The device did recover after power cycling, indicating non-destructive SEL.

The heavy-ion GCR rate estimates for ADS8320 are presented in in Table V.

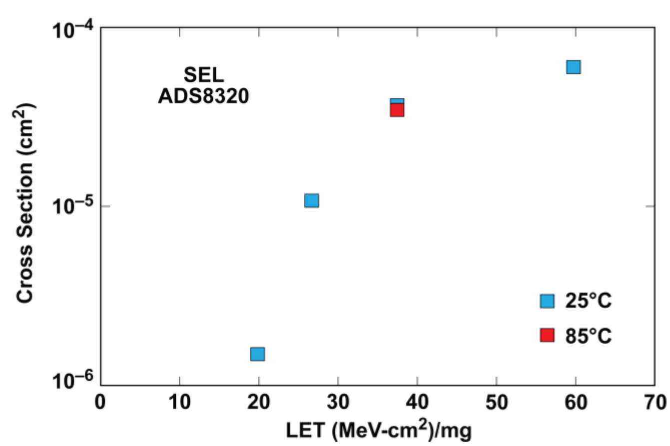

Figure 3. Comparison of latchup cross-sections at room temperature and 85ºC for ADS8320.

8. TABLE V

9. ADS8320 GCR SEL RATES (PER DEVICE)

10.

Environment	Best Estimate Rate	Worst Case Rate
ISS	1.3×10^{-3}/year	6.2×10^{-3}/year

4) 93LC86BT

The Microchip Technology Inc. 93XX86A/B/C devices are 16K bit, low-voltage serial Electrically Erasable PROMs (EEPROM).

An evaluation board manufactured by Texas Instruments was used for the test. The SEL measurements were performed at BNL.

Three devices were tested at room temperature and at 85°C. At room temperature, SELs were observed at a LET of 11.5 MeV-cm^2/mg but no latchups were observed at a LET of 7.9 MeV-cm^2/mg. The latchup LET threshold is between 11.5 and 7.9 MeV-cm^2/mg at room temperature.

Figure 4, shows the SEL results of the room temperature measurements.

The 93LC86BT-1 was tested for destructive latchup by turning off the current limit on the power supply. When the device went into a latchup state, the supply current increased to 60 mA. The lack of an output signal from the device indicated that the device was not functioning in this high current state. To determine if this condition was recoverable, the beam was turned off and the device was power cycled. The device did recover after power cycling, indicating non-destructive SEL.

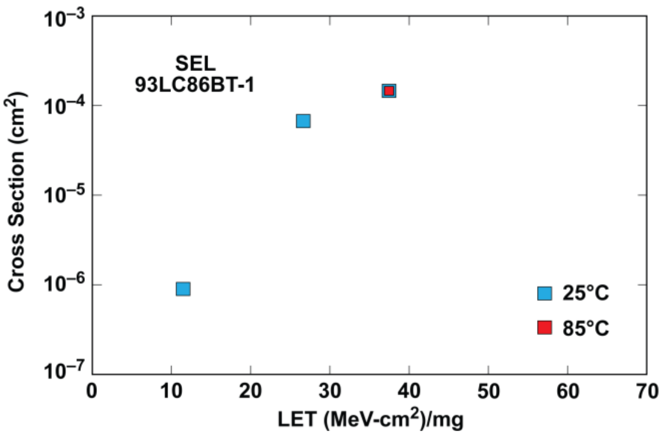

Figure 4. SEL data obtained at room temperature compared to heated measurement for 93LC86BT.

The heavy-ion GCR rate estimates for 93LC86BT are presented in Table VI.

11.

12. TABLE VI

13. 93LC86BT GCR SEL RATES (PER DEVICE)

14.

Environment	Best Estimate Rate	Worst Case Rate
ISS	1.1×10^{-2}/year	3.3×10^{-2}/year

5) LTC2271

The Linear Technology LTC2271 is a 2-channel, simultaneous sampling 16-bit A/D converter designed for digitizing high frequency, wide dynamic range signals.

Three devices were tested at room temperature and at 70°C. At room temperature, SELs were observed at a LET of 19.8 MeV-cm^2/mg but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET threshold is between 19.8 and 11.7 MeV-cm^2/mg at room temperature.

Figure 5 compares the results of the room temperature measurements with that of the heated measurements. There was a factor of 1.1-1.4 increase in the latchup cross-section for the heated device.

The heavy-ion GCR rate estimates for the LTC2271 are presented in Table VII.

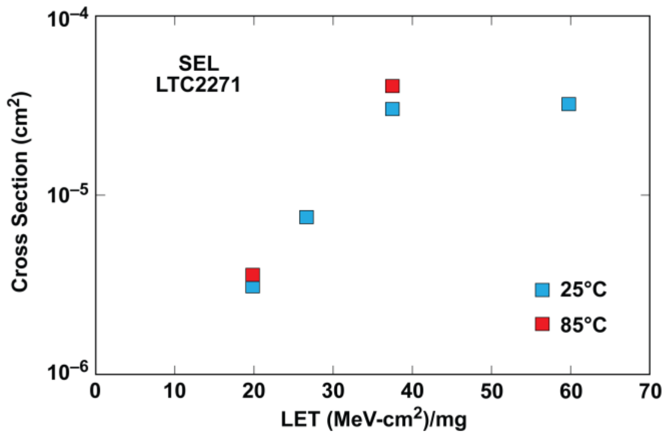

Figure 5. SEL data obtained at room temperature compared to heated measurement for LTC2271.

15. TABLE VII

16. LTC2271 GCR SEL RATES (PER DEVICE)

Environment	Best Estimate Rate	Worst Case Rate
ISS	1.1×10^{-2}/year	3.3×10^{-2}/year

IV. SUMMARY

SEL test results for the devices included in this paper are listed in Table VIII.

17.

18. TABLE VII

19. SUMMARY OF SEL RESULTS FOR THE DEVICES INCLUDED IN THIS PAPER
20.

Part Number	Manufacturer	Device Function	Test Results
LTC2271	Linear Technology	16-Bit, Low Noise Dual ADC	Non-destructive SEL, LETth 11.0 MeV-cm^2/mg
LTC2387-18	Linear Technology	18-Bit, SAR ADC	Destructive SEL
XC2C64A	Xilinx	CoolRunner-II CPLD	Non-destructive SEL, LETth 26.6 MeV-cm^2/mg
AD7306	Analog Devices	+5 V RS-232/RS-422 Transceiver	SEL immune up to LET 37.7 MeV-cm^2/mg
LTC2872IUHF	Linear Technology	RS232/RS485 Dual Transceiver	SEL immune up to LET 37.7 MeV-cm^2/mg
ISL32602E	Intersil	1.8V to 3.3V RS-485/RS-422 Transceivers	SEL immune up to LET 37.7 MeV-cm^2/mg
A3967SLB	Allegro MicroSystems	Microstepping Driver with Translator	Destructive SEL
MAX3221EIPW	Texas Instruments	3.0-5.5V RS-232 Line Driver and Receiver	SEL immune up to LET 37.7 MeV-cm^2/mg
93AA86B	Microchip Technology	16K EEPROM	Non-destructive SEL, LETth 7.9 MeV-cm^2/mg
AD8552ARUZ	Analog Devices	Operational Amplifiers	Destructive SEL
TPS767D318	Texas Instruments	Dual-Output LDO Voltage Regulators	SEL immune up to LET 37.7 MeV-cm^2/mg
TMS320F2808PZ	Texas Instruments	Digital Signal Processors	Non-destructive SEL, LETth 8 MeV-cm^2/mg
ADS8320	Texas Instruments	16-Bit, Sampling ADC	Non-destructive SEL, LETth 11 MeV-cm^2/mg
TPS51200DRC	Texas Instruments	Sink and Source DDR Termination Regulator	Non-destructive SEL, LETth 27 MeV-cm^2/mg
TXS02612RTWR	Texas Instruments	SDIO Port Expander with Voltage-Level Translation	SEL immune up to LET 37.7 MeV-cm^2/mg
MAX16043TG	Maxim	Voltage, Capacitor-Adjustable, Supervisory Circuits	SEL immune up to LET 37.7 MeV-cm^2/mg
LTC3428	Linear Technology	Step-Up DC/DC Converter	SEL immune up to LET 37.7 MeV-cm^2/mg
AD5685RTCPZ	Analog Devices	Quad, 16-/14-/12-Bit Nano DAC+ with 2 ppm/°C Reference, SPI Interface	Non-destructive SEL, LETth 3.4 MeV-cm^2/mg
LTC3708	Linear Technology	Fast 2-Phase, No Sense Buck Controller	Non-destructive SEL, LETth 11 MeV-cm^2/mg
EN6347QI	Altera	4A Power SoC	SEL immune up to LET

		Voltage Mode Synchronous PWM Buck with Integrated Inductor	42.8 MeV-cm^2/mg
TPS22921YZPR	Texas Instruments	3.6V, 2A On-Resistance Load Switch with Controlled Turn on	SEL immune up to LET 42.8 MeV-cm^2/mg
SI5338B	Silicon Labs	I2C-Programable Clock Generator	Destructive SEL
NB6L14SMNG	ON Semiconductor	2.5V differential 1:4 Clock or Data Receiver	SEL immune up to LET 42.8 MeV-cm^2/mg
ADS1178	Texas Instruments	Quad/Octal, Simultaneous Sampling, 16-Bit Analog-to-Digital Converters	Destructive SEL
ISL21080DIH	Intersil	300nA Nano Power Voltage References	Destructive SEL
SHPCIE100	Pericom	3.3V Crystal Clock Oscillator	SEL immune up to LET 42.8 MeV-cm^2/mg
TPS54821	Texas Instruments	4.5V to 17V Input, 8-A Synchronous Step-Down Converter	SEL immune up to LET 42.8 MeV-cm^2/mg

21.

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