Single-Event Latchup Measurements on Wireless and Powerline Network Communication Devices for Use in Mars Missions

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Abstract**-- This paper reports recent single-event latchup results for a variety of microelectronic devices that include Wireless and Powerline Network Communication devices. The data were collected to evaluate these devices for possible use in NASA Mars missions.**

I. Introduction

AT the present time, there has been increased interest in the possible use of commercial-off-the-shelf (COTS) electronic devices for space missions. These devices offer cutting-edge technology in terms of speed and performance 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 space missions. SEL results for space applications have been published previously [1]-[7].

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 tweleve different types of CMOS and BiCMOS devices including wireless, Programmable Powerline Communication (PLC), Powerline Transceiver, and Multiprotocol System on Chip (SoC).

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

Some of the SEL data in this report were obtained with ions that have short range, in some cases < 40 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 are 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 Galactic Cosmic Rays (GCR) interplanetary space environment. Mass shielding was taken to be 100 mils of aluminum. In addition, SEL heavy-ion rates for the surface of Mars were calculated. The Martian environment is affected by atmospheric shielding, but has not yet been accurately modeled. The algorithm for heavy ions starts with the interplanetary space solar maximum GCR environment. This is the environment that remains after many of the lower energy particles are removed from the solar minimum environment, i.e., the solar maximum environment is less intense but more skewed towards the higher energies. Roughly, half of these particles make it through the Martian atmosphere; divide by another factor of two for shielding by the planet below. The heavy-ion rates on Mars are then estimated by calculating the heavy-ion rates in interplanetary space solar maximum GCR and then dividing by four.

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.

The Best Estimate directional model is based on a rectangular parallelepiped (RPP) calculation, with an 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

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calculated rate, and is usually equivalent to the unrestricted cosine law [8].

In this paper, we present heavy-ion rates for the Worst Case Model.

II. EXPERIMENTAL PROCEDURE

A. *Test Facilities*

Heavy ion measurements were performed at the SEU Test Facility located at Brookhaven National Laboratory (BNL) The BNL facility uses a Tandem Van De Graaff accelerator. This facility provide a variety of ion beams over a wide range of energies for testing. The ion beams used for our measurements are listed in Table I. The LET and range values provided are for ion beams at normal incidence.

At BNL, facility test boards containing the DUT were mounted onto the facility test frame. Tests were done in vacuum. The beam flux ranged from 1×10^3 to 2×10^4 ions/cm^2-sec.

TABLE I
LIST OF ION BEAMS USED FOR MEASUREMENTS AT BNL

Ion	**LET** (MeV-cm^2/mg)	**Range** (µm)
^{19}F	3.4	122
^{28}Si	7.9	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

B. *Experimental Methods*

In general, the SEL test setup consists of a computer, power supply with multiple output channels, and test boards specially designed for the DUT. A computer-controlled Keysight N6700B power supply provides precise voltage control, current monitoring, and latchup protection. SELs were detected via the custom test software. The software controls the power supply voltage, monitors, and records the supply current. The software also provides a strip chart of power supply measurements. In some cases, a separate computer is 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 10^7 ions/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 an SEL at a fluence of 1×10^7 ions/cm^2.

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

III. TEST RESULTS AND DISCUSSION

1) MAX79356

The Maxim MAX79356 is a programmable, narrowband PLC modem and an integrated SoC device that provides standards compliant, high performance, and secured power line communication in a small package.

Three devices were tested at room temperature and at 85ºC at BNL. DV_{dd} and AV_{dd} were set to 3.3 V. The SEL threshold current was set to 100 mA for DV_{dd} channel and 50 mA for AV_{dd} channel. We observed latchup events on DV_{dd} channel for both room and elevated temperature measurements at LET of 37.5 MeV-cm^2/mg. SELs were observed at a LET of 11.7 MeV-cm^2/mg, but no latchups were observed at a LET of 19.8 MeV-cm^2/mg at both room and 85ºC. The latchup LET_{th} is between 19.8 and 11.7 MeV-cm^2/mg for both room and 85ºC.

The MAX79356 was tested for destructive latchup by disabling the latchup, current limiting protection. When the device went into a latchup state, the supply current increased to 280 mA. Before a latchup event, the nominal current was about 40 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 exhibit destructive failure.

SEL heavy-ion rates for the DUTs were calculated for the interplanetary GCR and surface of Mars environments. The environment was modeled with CREME96. Table II summarizes the rate calculation results.

Table II
MAX79356 Worst Case SEL Rates (per device)

Environment	Rate
GCR	1.4×10^{-4}/year
Surface of Mars	9.2×10^{-6}/year

2) MAX2982

The Maxim MAX2982 is a powerline transceiver that utilizes state-of-the-art CMOS design techniques to deliver the highest level of performance, flexibility, and operational temperature range at reduced cost. This highly integrated design combines the media access control (MAC) and the physical (PHY) layers in a single device.

Three devices were tested at room temperature and at 85ºC at BNL. V_{dd}, AV_{dd}, AV_{dd12} and V_{dd12} were set to 3.3, 3.3, 1.2 and 1.2 V, respectively. The SEL threshold current was set to 30, 10, 500, 500 mA, respectively. During irradiation, the nominal current draw was about 50 mA. SELs were observed at a LET of 7.9 MeV-cm^2/mg, but no latchups were observed at a LET of 3.4 MeV-cm^2/mg. The latchup LET_{th} is between 7.9 and 3.4 MeV-cm^2/mg at both room and 85ºC.

The MAX2982 was tested for destructive latchup by disabling the latchup protection. When the device went into a latchup state, the supply current increased to 600 mA. The device did recover after power cycling, indicating the device did not destructively fail.

Figure 1 shows the results of the room temperature measurements. The heavy-ion GCR and surface of Mars rate estimates for MAX2982 are presented in Table III.

Table III
MAX2982 Worst Case SEL Rates (per device)

Environment	Rate
GCR	2.0×10^{-1}/year
Surface of Mars	1.5×10^{-2}/year

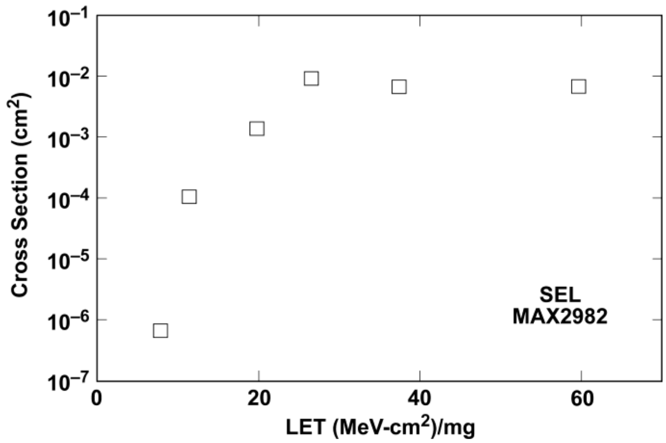

Figure 1. MAX2982 SEL cross section versus LET.

3) MAX2981

The Maxim MAX2981 is a powerline communication analog frontend (AFE) and line-driver IC that delivers high performance at low cost. This highly integrated design combines an analog-to-digital converter (ADC), digital-to-analog converter (DAC), adaptive gain control (AGC), filters, and line driver on a single chip.

Three devices were tested at room temperature and at 85ºC at BNL. V_{dd} was tied to AV_{dd} and was set to 3.3 V. The nominal device current was about 200 mA. The SEL threshold current was set to 400 mA. SELs were observed at a LET of 19.9 MeV-cm^2/mg, but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET_{th} is between 11.7 and 19.9 MeV-cm^2/mg at both room and 85ºC.

The MAX2981 was tested for destructive latchup by disabling the latchup protection. When the device went into a latchup state, the supply current increased to 900 mA. The device did recover after power cycling, indicating the device did not destructively fail.

Figure 2 shows the results of the room temperature measurements. The heavy-ion GCR and surface of Mars rate estimates for MAX2981 are presented in Table IV.

Table IV
MAX2981 Worst Case SEL Rates (per device)

Environment	Rate
GCR	2.6×10^{-5}/year
Surface of Mars	1.6×10^{-6}/year

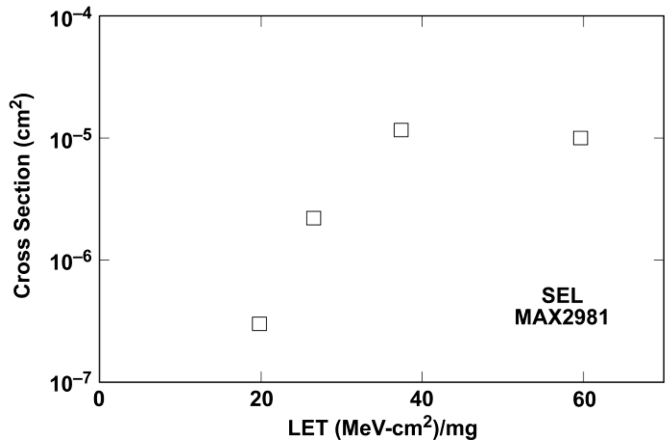

Figure 2. MAX2981 SEL cross section versus LET.

4) SIG60

The YAMAR Electronic SIG60 is a transceiver for digital communication over battery powerline. It allows the powerline to be employed for both power and communication; thus, eliminating the need for special wires for carrying control and data.

Three devices were tested at room temperature and at 70ºC at BNL. V_{dd} was set to 3.3V. The SEL threshold current was set to 400 mA. SELs were observed at a LET of 19.9 MeV-cm^2/mg, but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET_{th} is between 11.7 and 19.9 MeV-cm^2/mg at both room temperature and elevated temperature of 70ºC.

The SIG60 was tested for destructive latchup by disabling the latchup protection. When the device went into a latchup state, the supply current increased to 430 mA. The device did recover after power cycling, indicating the device did not display destructive failure.

Figure 3 shows the results of the room temperature measurements. The heavy-ion GCR and surface of Mars rate estimates for SIG60 are presented in Table V.

Table V
SIG60 Worst Case SEL Rates (per device)

Environment	Rate
GCR	2.5×10^{-3}/year
Surface of Mars	1.6×10^{-4}/year

5) AFE031

The Texas Instruments AFE031 is an integrated, powerline communications analog front-end device that is capable of capacitive- or transformer-coupled connections to the powerline while under the control of a DSP or a microcontroller.

Three devices were tested at room temperature and at 85ºC at BNL. DVdd and AVdd was set to 3.3 V. Supply voltage was set to 15V. The SEL threshold currents were set to 20 and 250 mA, respectively. No SEL events were observed up to LET of 59.7 MeV-cm^2/mg.

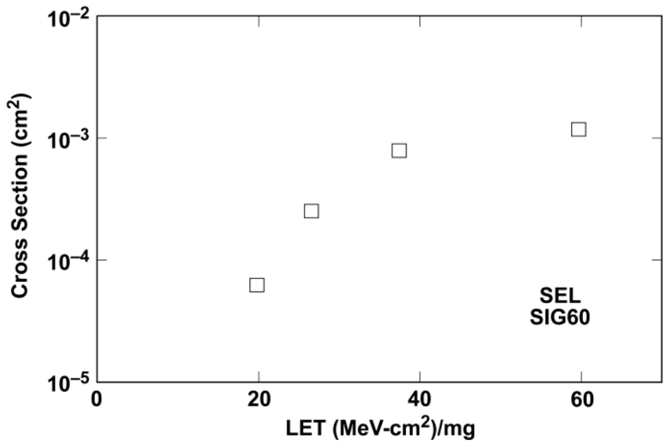

Figure 3. SIG60 SEL cross section versus LET.

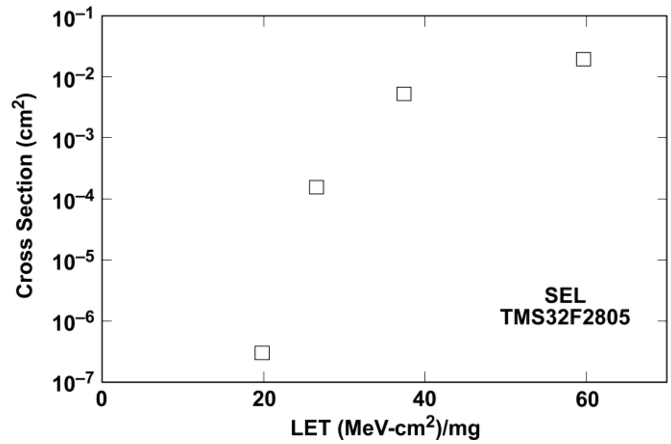

Figure 4. TMS320F2806 SEL cross section versus LET.

6) TMS320F2805

The Texas Instruments TMS320F2805 is a highly integrated and high-performance DSP solution for demanding control and network applications.

Three devices were tested at room temperature and at 85ºC at BNL. V_{ADC}, V_{dd}, and V_{IO} were set to 1.8, 1.8 and 3.3V, respectively. The SEL threshold currents were set to 100, 1000 and 200 mA, respectively. SELs were observed at a LET of 19.9 MeV-cm^2/mg, but no latchups were observed at a LET of 11.7 MeV-cm^2/mg. The latchup LET_{th} is between 11.7 and 19.9 MeV-cm^2/mg at both room temperature and 85ºC.

The TMS32F2805 was tested for destructive latchup by disabling the latchup, current limiting protection. When the device went into a latchup state, the supply current increased to 1.3A. The device did recover after power cycling, indicating the device did not destructively fail.

Figure 4 shows the results of the room temperature measurements. The heavy-ion GCR and surface of Mars rate estimates for TMS32F2805 are presented in Table VI.

Table VI
TMS32F28050 Worst Case SEL Rates (per device)

Environment	Rate
GCR	2.1×10^{-2}/year
Surface of Mars	3.0×10^{-3}/year

7) AD9361

The Analog Devices AD9361 is a high performance, highly integrated radio frequency (RF) Agile Transceiver™ designed for use in 3G and 4G base station applications.

This device was tested for SEL at V_{ip3A}= 1.3 V, V_{DDA}= 3.3 V, ViP3B= 1.3 V, V_{DDA}= 1.8 V. Current threshold was set to 1 A. The measurements were performed at BNL. Two devices were tested at room temperature. The nominal device current was about 550 mA on channel V_{ip3A}. No latchup events were observed at LET of 37.5 MeV-cm^2/mg at room temperature.

8) CC3200

The Texas Instruments CC3200 is a Wi-Fi integrated single-chip ARM microcontroller unit with built-in network processor and power management subsystems.

This device was tested for SEL at 3.3V, current threshold was set to 50 mA. The measurements were performed at BNL. Two devices were tested at room temperature. The part current before irradiation was about 17 mA. No latchup events were observed at LET of 37.5 MeV-cm^2/mg at room temperature.

9) *NRF52832*

The NORDIC Semiconductor NRF52832 is a powerful, highly flexible, ultra-low power multiprotocol SoC ideally suited for low power Bluetooth®, ANT network, and 2.4GHz ultra low-power wireless applications. The NRF52832 SoC is built around a 32-bit ARM® Cortex™-M4F CPU with 512kB + 64kB RAM.

This device was tested for SEL at 3.3V, current threshold was set to 20 mA. The measurements were performed at BNL. Two devices were tested at room temperature. The device current before irradiation was about 17 mA. During irradiation, it went up close to 50 mA. No latchup events were observed at LET of 37.5 MeV-cm^2/mg at room temperature; however, the part was not functional after irradiation due to corruption of non-volatile flash memory. It was necessary to reprogram the flash memory after irradiation to regain functionality.

10) QCA7000

The Qualcomm QCA7000 is a highly integrated processor and transceiver SoC device providing powerline communication. It is fully compliant with the HomePlug Green PHY (HPGP) specification.

This device was tested for SEL at V_{cc}= 3.3 V, current threshold was set to 300 mA. The measurements were performed at BNL. Two devices were tested at room temperature. Destructive latchup events were observed at LET of 37.5 MeV-cm^2/mg at room temperature.

11) ZigBee XBEE S1D

The Digi XBEE SID is a RF module that provides wireless connectivity to electronic devices through Zigbee application.

This device was tested for SEL at 3.3 V, current threshold was set to 120 mA. The measurements were performed at BNL. Two devices were tested at LET 37.5 MeV-cm^2/mg room temperature. Destructive latchup events were observed at LET of 37.5 MeV-cm^2/mg at room temperature.

12) ZigBee XBEE S2D

The Digi XBEE S2D is a RF module that provide wireless connectivity to electronic devices through Zigbee application.

This device was tested for SEL at 3.3 V; current threshold was set to 100 mA. The measurements were performed at BNL. Two devices were tested at LET 37.5 MeV-cm^2/mg at room temperature. Nondestructive radiation induced events resulted in functional failure. This could be explained as possibly corruption in the non-volatile flash memory, however we could not reprogram the flash memory, so we cannot be certain.

IV. Summary of Results

SEL test results for all the devices included in this paper are summarized in Table VII.

TABLE VII
SUMMARY OF SEL RESULTS FOR THE DEVICES INCLUDED IN THIS PAPER

Part Number	Manufacturer	Device Function	Test Results
MAX79356	Maxim	16-Bit, Low Noise Dual ADC	Non-destructive SEL, LET_{th} 11.7 MeV-cm^2/mg
MAX2982	Maxim	18-Bit, SAR ADC	Non-destructive SEL, LET_{th} 7.9 MeV-cm^2/mg
MAX2981	Maxim	CoolRunner-II CPLD	Non-destructive SEL, LET_{th} 11.7 MeV-cm^2/mg
SIG60	YAMAR Electronic	+5 V RS-232/RS-422 Transceiver	Non-destructive SEL, LET_{th} 11.7 MeV-cm^2/mg
AFE031	Texas Instruments	RS232/RS485 Dual Transceiver	SEL immune up to LET 59.7 MeV-cm^2/mg
TMS320F2805	Texas Instruments	1.8V to 3.3V RS-485/RS-422 Transceivers	Non-destructive SEL, LET_{th} 11.7 MeV-cm^2/mg
AD9361	Analog Devices	Microstepping Driver with Translator	SEL immune up to LET 37.7 MeV-cm^2/mg
CC3200	Texas Instruments	3.0-5.5V RS-232 Line Driver and Receiver	SEL immune up to LET 37.7 MeV-cm^2/mg
NRF52832	NORDIC Semiconductor	Multiprotocol SoC	SEL immune up to LET 37.7 MeV-cm^2/mg
QCA7000	Qualcomm	Operational Amplifiers	Destructive SEL
ZigBee XBEE S1D	Digi	. Dual-Output LDO Voltage Regulators	Destructive SEL
ZigBee XBEE S2D	Digi	Digital Signal Processors	Non-destructive SEL

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