Single Event Effect Proton and Heavy Ion Test Results for Candidate Spacecraft Electronics

Kenneth A. LaBel, Amy K. Moran, Donald K. Hawkins, James A. Cooley
NASA/GSFC
Code 735.1
Greenbelt, MD 20771

Christina M. Seidleck
Hughes/ST Systems Corporation
Code 735.1, NASA/GSFC
Greenbelt, MD 20771

Michele M. Gates
Jackson and Tull
NASA/GSFC, Code 735.1
Greenbelt, MD 20771

Brian S. Smith
NASA/GSFC
Code 735.2
Greenbelt, MD 20771

E.G. Stassinopoulos
Code 900.0, NASA/GSFC
Greenbelt, MD 20771

Paul Marshall
NRL/SFA, Washington, D.C.

Cheryl Dale
NRL, Washington, D.C.

Abstract

We present proton and heavy ion single event effect (SEE) ground test results for candidate spacecraft electronics. Device types include digital and analog components, MIL-STD-1553B transceivers, ADCs, FPGAs, SRAMs, optoelectronics, and a microprocessors.

Summary

INTRODUCTION

As spacecraft and spacecraft designers increasingly utilize increasing number of commercial technology devices versus the more traditional radiation hardened (RH) components in order to meet stringent spacecraft requirements in such areas as volume, weight, power, cost and schedule, SEE ground testing has become a key in many spaceflight programs. Amongst NASA's projects that understand the need for SEE tests is Goddard Space Flight Center's (GSFC) Far Ultraviolet Spectroscopic Explorer (FUSE).

The objective of this study was to determine the Linear Energy Transfer (LET) threshold (the minimum LET value to cause an effect at a fluence of 1E7 particles/cm^2) and saturation cross section of candidate spacecraft electronics (FUSE and other GSFC programs) for Single Event Upset (SEU) and latchup (SEL) due to protons and heavy ions.

TEST TECHNIQUES AND SETUP

--- *FACILITY USAGE 1*

The test facility used for heavy ion experiments was the Brookhaven National Laboratories (BNL) Single Event Upset Test Facility (SEUTF). The SEUTF utilizes a tandem Tandem Van De Graaff accelerator suitable for providing various ions and energies. Test boards containing the device under test (DUT) are mounted inside a vacuum chamber.

Ions used are listed below. Intermediate LETs were obtained by changing the angle of incidence of the DUT to the ion beam, thus changing the path length of the ion through the DUT.

ION	ENERGY in MeV	LET at Normal Incidence in MeV*cm/mg
C-12	98	1.45
F-19	140	3.45
Cl-35	211	11.5
Ni-58	263	26.7
I-127	320	59.7
Au-197	341	81.9

Energies and LETs are nominal due to slight variances in the beam at multiple test dates during the calendar year.

--- FACILITY USAGE 2

The test facility utilized for proton SEE testing was the University of California at Davis (UCD) cyclotron facility. Proton energies and fluxes were measured as those incident on the DUT package. Test energies ranged from 22 to 63 MeV incident upon the test device.

--- TEST METHOD

Three modes of testing are used depending on the DUT. They are as follows:

static **-** load device prior to beam irradiation, then retrieve data post-test run counting errors (either transients or bit flips)

dynamic **-** actively exercise a DUT during beam exposure while counting errors

and for SEL only,

biased **-** DUT is biased and clocked while lcc (power consumption) is monitored for SEL conditions.

All tests were performed at room temperature.

TEST RESULTS

The parts and partial test data information is as follows: (HI=Heavy Ion, P=Proton, SEU=SEU LET_{th}, SEL=SEL LET_{th}, All LETs in MeV*cm^2/mg, all cross sections in cm^2/device).

Summary of Test Results

PART #	MANUFACTURER	FUNCTION	PROCESS	TEST DATA	MISC.
Mongoose	LSI Logic	Microprocessor	1.0 µm HCMOS on EPI	HI: SEU=23-26 SEL>85	Hardened version of R3000-based "Cobra"
AD1671	Analog Devices	12-bit ADC	BiCMOS	HI: SEL>90	SEL only
HS26C31	Harris	Differential Driver	1.2 µm HCMOS	HI: SEU>80 SEL>80	~
HS26C32	Harris	Differential Receiver	1.2 µm HCMOS	HI: SEU>80 SEL>80	~
HS2420	Harris	Sample-and-Hold	1.2 µm HCMOS	HI: SEU=20 SEL>80	~
ODL200 TX	ATT/CTS	200 Mbps Fiber optic TX	GaAlAs diode/bipolar	P: No SEUs	
HI on IC: SEU>45 SEL>82	IC and separate diode in each device				
ODL200 REC	ATT/CTS	200 Mbps Fiber optic REC	GaAlAs diode/bipolar	P: data varies with clock rate	
HI on IC: SEU~3 SEL>82	IC and separate diode in each device				
Hot Rod TX	Gazelle	High speed comm. protocol IC	GaAs	P: 1.5E-8	
HI: SEU<1.5 SEL>120	~				
Hot Rod REC	Gazelle	High speed comm. protocol IC	GaAs	P: 1.5E-8	
HI: SEU<1.5 SEL>120	~				
HM68512	Hitachi	4 Mbit SRAM	CMOS on EPI	P: 1.6E-6(static) 2.2E-5(dynamic)	Heavy Ion results previously reported
HM68128	Hitachi	1 Mbit SRAM	CMOS on EPI	HI: SEU<1.4 SEL>110	~
EL2243	Hitachi	Analog op-amp	Bipolar	HI: SEU=5 SEL>110	~
HS508RH	Harris	Analog MUX	HCMOS	HI: SEU=110 SEL>110	~
AD676	Analog Devices	16-bit ADC	CMOS and BIMOS II	HI: SEU<3.4 SEL-25	Hybrid
UT63M125	UTMC	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	15V supply
63125	ILC Data Devices Corp	MIL-STD-1553B Transceiver	Bipolar	HI: SEU=14 SEL>80	15V supply

PART #	MANUFACTURER	FUNCTION	PROCESS	TEST DATA	MISC.
AX3411	Aeroflex	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	15V supply
CT1487D	Marconi/CTI	MIL-STD-1553B Transceiver	Bipolar	HI: SEU=11.5 SEL>80	15V supply
NHI1500	National Hybrids	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	15V supply
FC1553921	STC	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	5V supply
63147	UTMC/Microrel	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	5V supply
CT2521	Marconi/CTI	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<26.5 SEL>80	5V supply
AX3453	Aeroflex	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	5V supply
NHI1529	National Hybrids	MIL-STD-1553B Transceiver	Bipolar	HI: SEU<11.5 SEL>80	5V supply
AT22V10	Atmel	PAL	CMOS	HI: SEU<11.5 SEL>80	~
IDA07318	Hewlett Packard	Laser Driver	ECL	HI: SEL>80	SEL only
LM108	NSC	Op-amp	Bipolar	HI: TID degradation at ~2.5krad(Si)	~
LM139	NSC	Analog comparator	Bipolar	HI: TID degradation at ~2.5krad(Si)	~
TSC4429	Teledyne	Mosfet driver	Bipolar	HI: SEU>120 SEL>120	~
CP20420	Crosspoint	FPGA	CMOS	HI: SEU~12.5 SEL 15-26.6	~
88C20	NSC	Driver	CMOS	HI: SEU~11.3 SEL>120	~
88C30	NSC	Receiver	CMOS	HI: SEU>120 SEL>120	~
SPT7922	Signal Processing Technologies	16-bit ADC	Bipolar	HI: SEU<3.4 SEL>120	~

Discussion

LM108, LM139

These devices are bipolar operational amplifier (LM108) and an analog comparator (LM139) respectively manufactured by NSC. The test method used for both devices was straightforward. The DUT was operated in-step with a reference device. The outputs from both devices (both the DUT and the reference) were then compared. A noncompare in the outputs was logged as an SEU.

During heavy ion irradiation, the LM108 showed a permanent increase in current while the LM139 showed a permanent decrease in current both after exposure to several (< 5) kRads at lower LET values (< 30). These discrepancies persisted after power was cycled to the device, however, the devices were still fully operational. In addition, this current phenomena was accompanied by ever increasing SEU counts from run to run at the same LET value.

These devices were later tested by NASA's code 300 and found to have total dose failure at ~2.5kRad(Si). It is believed that the current anomalies as well as the creeping SEU counts observed were due to total dose degradation (parametrically) of the devices. It should be noted that these were strictly commercial devices with no upscreening to MIL-883.

Mongoose

The Mongoose is a 1.0µm HCMOS on EPI radiation hardened version of the R3000-based "Cobra" microprocessor manufactured by LSI Logic.

Testing of this device exercised all accessible core and peripheral register sets, along with the arithmetic logic unit (ALU). A watchdog timer and comparator monitored Mongoose operation during irradiation. The DUT sent an "OK" pulse to the timer, while the software surveyed outputs and also sent the timer a pulse provided the output was correct. If the watchdog timer failed to receive either signal, the error (or SEU) counter was incremented and the DUT reset.

The test system could capture a maximum of 1 error/second. On some test runs errors may have been missed, for example, those occurring during reset or other processor operations.

Heavy ion test results for this device were very encouraging. Shown in figure 1, the SEU LET_{th} was experimentally found to be 23-26 while the SEL LET_{th} was > 85 making this device more than an order of magnitude harder than the Intel 386. The Mongoose is the first known rad-hard commercially compatible 32-bit microprocessor.

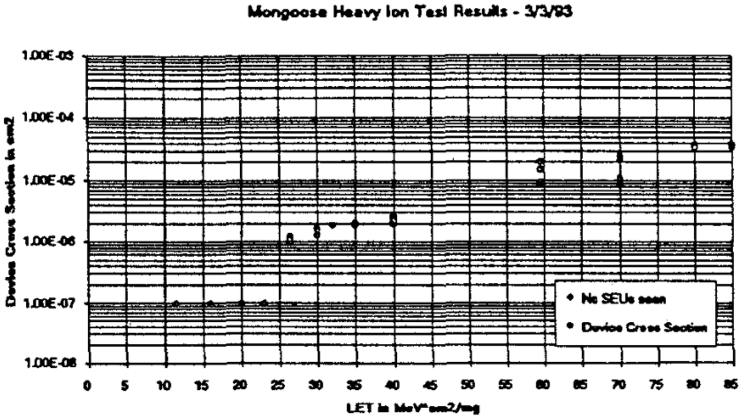

Figure 1: Mongoose Heavy Ion test results.

1553 Transceivers

Ten device types of MIL-STD-1553B transceivers from multiple manufacturers were tested. Both +5V and +15V bipolar device samples were used.

During irradiation, known data was sent from the BC or bus controller (inside of a PC) on one side of the 1553 bus to one of the DUTs (aka remote terminal or RT). The 1553 protocol performed the message error checking on the transfers (parity errors, incorrect addresses). The data inside the receiving RT was then transferred to its other side and transmitted back to the PC. Protocol error checking was performed here as well. All errors were logged as SEUs by the PC.

A message error cross section was determined per test run (# message errors/fluence). Data was transmitted by both BC and RT at 471 kbit/second creating an effective bus utilization of 94% which is a "worst case" bus scenario.

As seen in figure 2, the results from these devices varied from vendor to vendor.

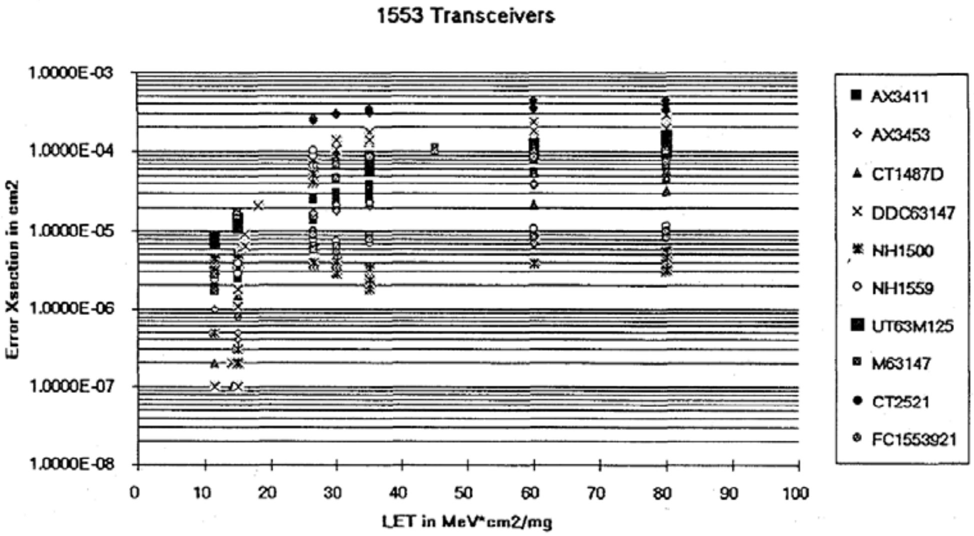

Figure 2: 1553 Transceivers test results.

HS26C31, HS26C32

These devices are 1.2µm HCMOS differential driver (HS26C31) and receiver (HS26C32) pair manufactured by Harris. In this test, the driver and receiver were irradiated separately using the same test procedure for both.

A signal was sent to the driver and then through the receiver. The receiver outputs were multiplexed together and then compared to the original signal to detect errors at a rate of 0.9216Mhz.

These devices were virtually immune to heavy ion SEU and SEL for LETs up to 80.

SPT7922

The SPT7922 is a 16-bit ADC manufactured by Signal Processing Technologies. During irradiation, the device (DUT) was operated in-step with a reference device.

An SEU was defined as ¦Vd-Vr¦ > 55mV where Vd=device output voltage and Vr=reference output voltage, ± 4V sine wave (peak to peak).

Figure 3 shows the SEU LET$_{th}$ to be < 3.4 with a maximum device cross section of ~1.5E-03cm^2. The SEL LET$_{th}$ was > 120 at a cross section of 1E-07cm^2.

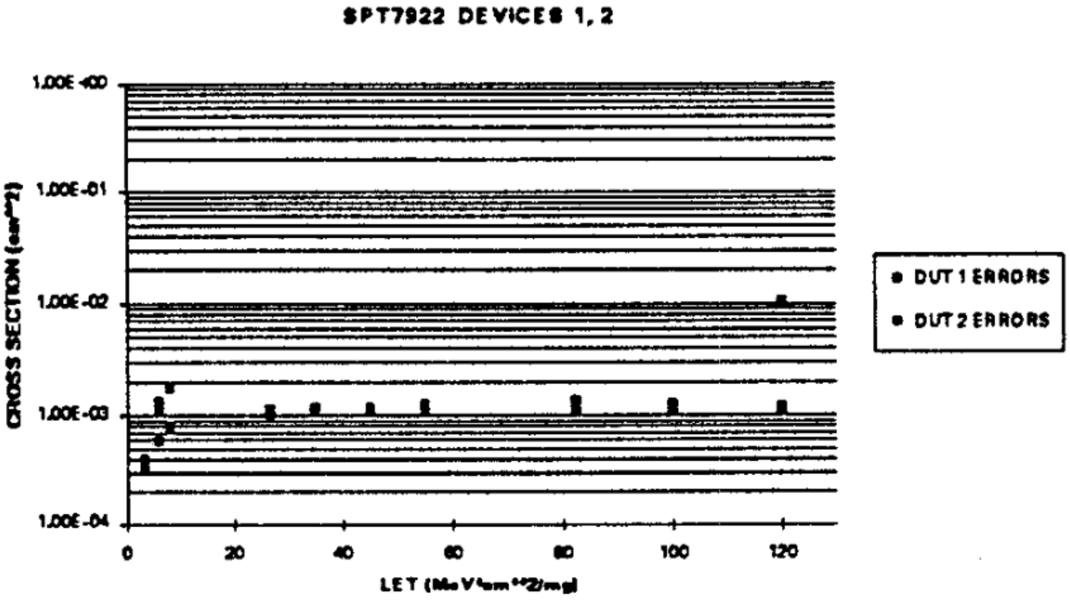

Figure 3: SPT7922 test results.

CP20420

The CP20420 is a CMOS field programmable gate array (FPGA) from Crosspoint. For test purposes, this device was programmed with a two-part design. A FIFO was used to test memory applications and a ring counter to test the sequential logic applications.

Operated at 1Mhz, 5V, the FIFO cycled through a read/write sequence and an SEU occurred when either a mismatch in data was read or an invalid FIFO address was encountered. The ring counter sent 1 pulse through 32 stages with an SEU occurring during either missing or extra pulses.

Figure 4 shows the SEU LET_{th} to be ~12.5. All samples tested of this device latched up at an LET of 26.6. Since no LET values between 15 and 26.6 could be attained due to mounting constraints, the latchup threshold lies between those two values.

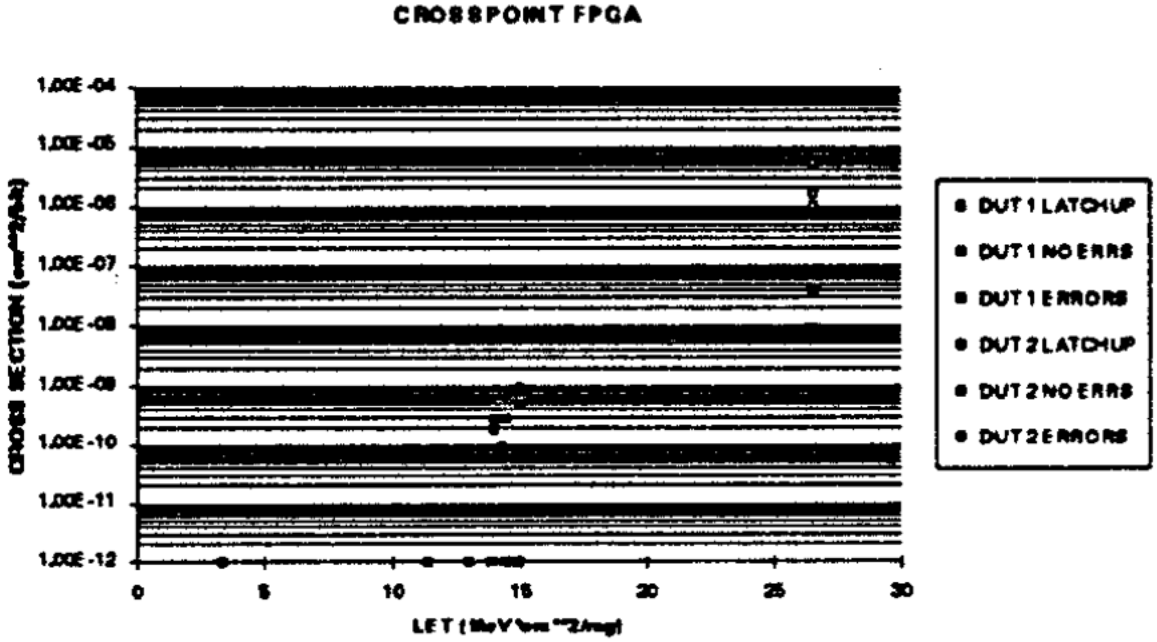

Figure 4: CP20420 FPGA test results.

HS508

The HS508 is an 8 to 1 multiplexor manufactured by Harris. Samples tested were the RH version.

For this test, the DUT was again operated in-step with a reference and compared. Step analog signals of 9.7V, 7.5V, and 5.0V were continuously applied to input channels of both the DUT and the reference. The signal was applied to only one input channel of the HS508 at a time to maintain channel-to-channel comparison. Output from the DUT and reference were fed to ADCs and digital output were then compared. Several bits of the ADC were masked to accommodate circuit noise. An error (SEU) was logged if the difference exceeded 5V.

The SEU LET_{th} was experimentally found to be 110. No latchup was seen for LETs up to 110.

AT22V10

The AT22V10 is a CMOS programmable array logic (PAL) device manufactured by Atmel. During irradiation, the DUT was operated in-step with a reference AT22V10 and compared at 1.0Mhz.

Figure 5 shows the SEU cross section data for the AT22V10 PAL. LET_{th} is between 9 and 11.5 with a maximum cross section < 3E-04cm^2/device.

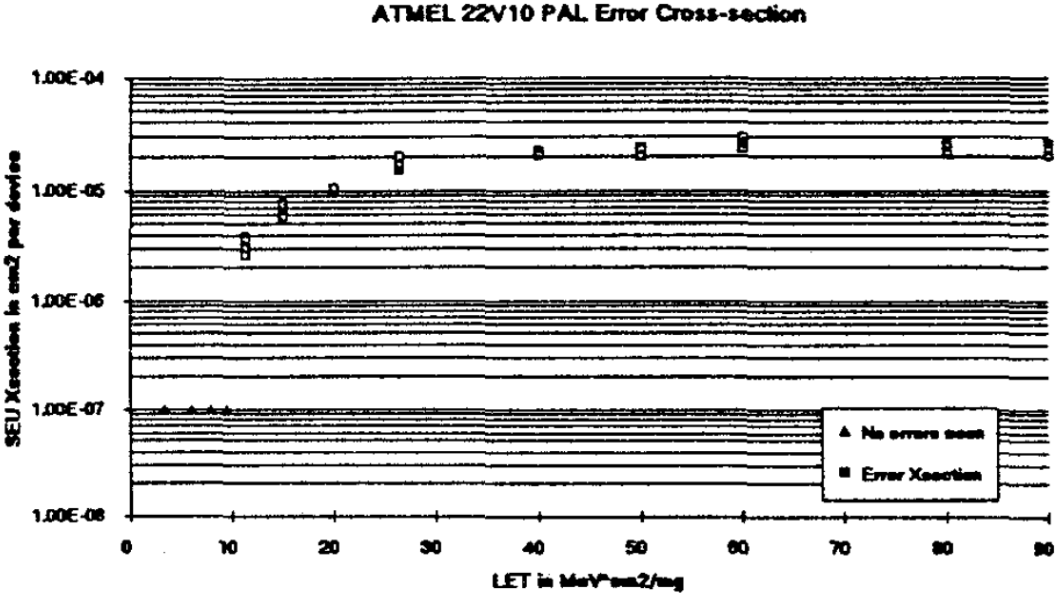

Figure 5: Atmel AT22V10 PAL Error Cross-section.

AD1671

The AD1671 is a 12-bit 1.25MSPS analog-to-digital convertor manufactured by Analog Devices and constructed with a bipolar/CMOS process. This device was tested for latchup only.

The DUT was biased and operated with a checkerboard input alternating between 0 and +5V. The currents from both analog and digital sections of the device were monitored for latchup.

The AD1671 was found to be virtually immune to latchup for the LET range 11.5 to 90.

HM68512

The HM68512 is a 4Mbit SRAM (CMOS on EPI) manufactured by Hitachi.

This device was proton tested in two modes: dynamic and static. In dynamic mode, a read/write was performed on the first 32k memory locations at 1.3077Mhz while the device was being irradiated. For static mode, the device was loaded (again, the first 32k memory locations), then irradiated. The read and compare were performed post-beam. In both modes the device was tested with checkerboard, all 1s and all 0s patterns.

Figure 6 shows SRAM cross section per device versus proton energy for both operating modes. Little energy dependence was seen. However, the maximum cross section for static mode was approximately > 1 order of magnitude less than for dynamic mode (1E-06cm^2/device vs. 2.2E-05 cm^2/device).

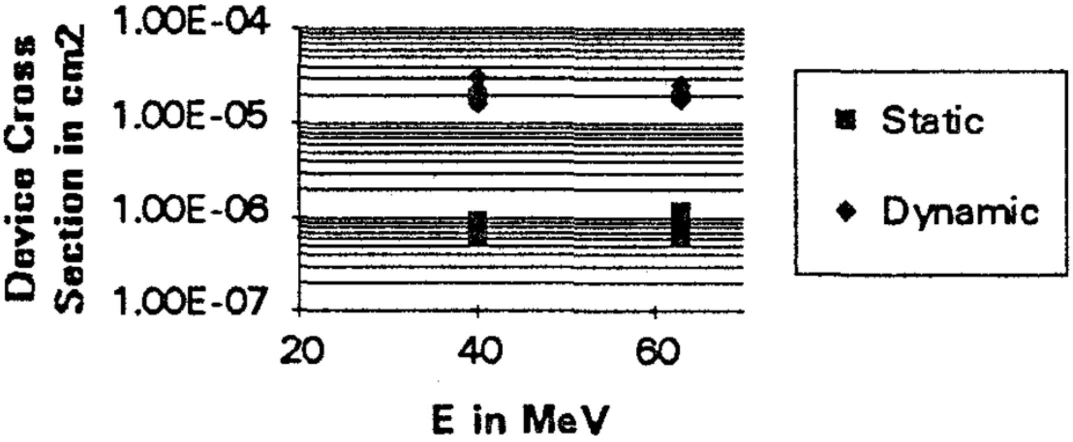

Figure 6: Hitachi HM68512 4 Mbit SRAM Device Cross Section for each operating mode versus Proton energy.

AD676

The AD676 is a 16-bit ADC (CMOS/BIMOS II) using a switched-capacitor/charge redistribution architecture. The device is autocalibrating to correct for internal nonlinearities. 100kSPS (samples per second) is the maximum conversion rate of the AD676.

During testing, output from the DUT and a reference were compared for errors after each conversion. Of the 16 bits,the 6 least significant bits were ignored to adjust for noise. An SEU was defined as: ¦Vd-Vr¦ > 150mV with a 10V input range, where Vd=device output voltage and Vr=reference output voltage.

The AD676 was tested with heavy ions in the LET range 3.38 to 28. Upsets were observed at an LET of 3.38. The SEU LET$_{th}$ is < 3.38 as shown in figure 7. The SEL LET$_{th}$ was 25.

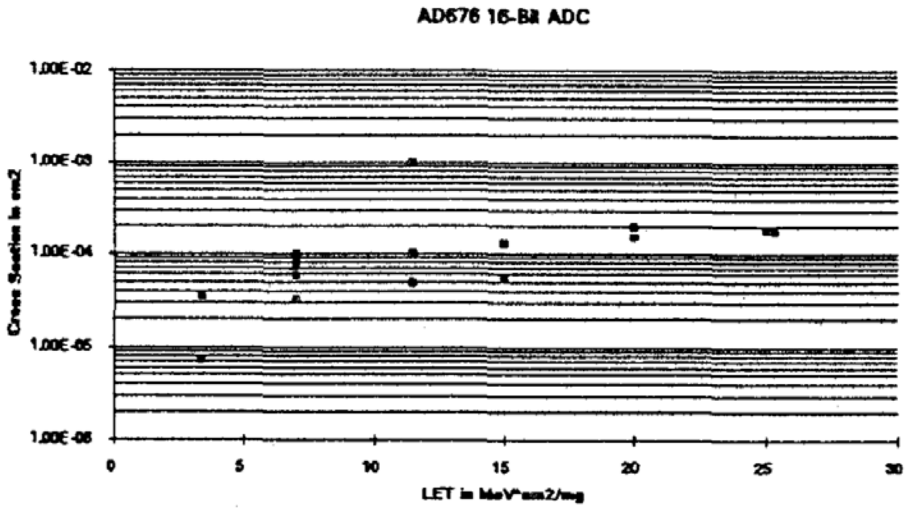

Figure 7: AD676 16-bit ADC heavy ion test results.

Conclusion

Following proton and heavy ion testing, devices generally are categorized into one of four defined categories for recommendation to the flight project of interest.

Devices in the first category are those that are relatively hard or immune to SEEs and are recommended for spaceflight. The HS26C31 and HS26C32 differential driver and receiver pair saw no SEEs for LETs up to 80 and can be judged SEE immune. Also in this category is the HS508 multiplexor. This device has an SEU threshold of 110 making it very hard to SEEs. The AD1671, TSC4429, and IDA07318 (SEL only) are included here as well.

The second category includes devices that are somewhat susceptible to SEEs and may need some error detection and correction (EDAC) when used in an application. Included here are the Mongoose, the 1553 tranceivers, and the HS2420.

Devices in the third category are fairly soft devices that are very susceptible to SEEs. In a space application, these devices should be used with great caution. Intensive EDAC schemes may be necessary as these devices have potentially high error rates. Included here are the ODL200, SPT7922, Hot Rod, HM68128, EL2243 and the HM68512.

The fourth and final category contains those devices that are not recommended for spaceflight. Destructive conditions were seen in these devices at low LETs such as latchup, total dose failure or burnout. Included here are the LM108, LM139, CP20420, and AD676.

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