THE SINGLE EVENT UPSET RESPONSE OF THE ANALOG DEVICES, ADSP2100A, DIGITAL SIGNAL PROCESSOR.

by

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ABSTRACT

This paper presents the results of a radiation evaluation program carried out by ESTEC on the Analog Devices, ADSP2100A, which is a single chip microprocessor optimized for 12.5 Mips Digital Signal Processing (DSP). Single Event Upset/Latch-up (SEU/SEL) testing using Californium-252 was the primary aim of this program, however, accelerator heavy ion and proton SEU/SEL data as well as total ionising dose data are also presented.

In order to perform these tests, in particular the SEU tests, a dedicated test system was required. Special test hardware and software was developed. The hardware was optimized for use in standard Cf-252 and accelerator vacuum chambers, in a proton environment and for easy Cobalt-60 testing. The software was developed to cover reliable and transparent SEU testing of a known number of register bits while running the processor in a simple self-test mode. A watch-dog/latch-up board and a PC completed the design. The final version of this test set-up covered testing of 531 register bits.

Californium-252 SEU testing covered both 12.5 micron and 21.3 micron epitaxial layer DSP's whereas only the 12.5 micron type was tested with heavy ions and protons. Heavy ion SEU testing at IPN covered the LET range of 3.4 to 79.2 MeV/(mg/cm2) and SEU testing at SATURNE the proton energies of 200, 500 and 800 MeV. A total ionising dose rate of 64.0 rad(Si)/min was used for the ESTEC cobalt-60 testing.

The hardware design and software used will be described and details of the various tests and test facilities will be given. Finally, we report on the use of the SEU data for the calculation of expected in-orbit upset rates using the CREME suite of programs.

I. INTRODUCTION

In recent years an increased interest for using Digital Signal Processors in space projects has led to various evaluations and assessments of available DSPs [1]. In the frame of the SILEX program, the Fine Pointing Sequencing Control Electronics (FPSCE) has identified the Analog Devices DSP, the ADSP2100A, as a suitable candidate. However, before using this type of DSP in space, a number of space related criteria have to be satisfied, in particular the radiation evaluation.

From the start of this radiation prescreening program, Analog Devices (NL) offered the use of a ADSP2100A evaluation board, gave software support and provided devices for testing. However, the evaluation board was considered too large for the various vacuum chambers, so a smaller and more convenient test system was designed by ESTEC. This design was optimised for both reliable and easy SEU/latch-up and Co-60 testing. Having tight time constraints for the completion of the hardware and software, the Single Board Computer (SBC) approach, running the ADSP2100A in a self-test mode was used. Testing was concentrated on the registers where eventually a total of 531 bits could be 100 % tested with a random or known pattern.

The ADSP devices provided for testing were two times six devices, fabricated in low-power CMOS, 1.0 micron double metal-layer technology. ESTEC Destructive Physical Analysis (DPA) identified the first set of devices to have epitaxial (EPI) layer thickness of 21.3 micron whereas the second set had EPI layer thickness of 12.5 micron. Extensive Californium-252 "CASE" testing was carried out on both EPI layer types for debugging of the software and comparison of the results. Only the 12.5 micron type was later SEU tested using accelerator heavy ions and protons, and total dose Cobalt-60 tested . In order to complete the radiation pre-screening of the ADSP2100A, the heavy ion and proton SEU sensitivities established for the registers were used in conjunction with the CREME suite of programs, for the calculation of expected in-orbit upset rates.

II. TEST HARDWARE AND SOFTWARE

The design of the ADSP2100A SEU/latch-up test system followed the standard test configuration as adopted by ESTEC [2]. The Single Board Computer with the Device Under Test (DUT) was placed in the vacuum chamber, the watch-dog/latch-up board was placed just outside the vacuum chamber and the PC, remotely controlled all commands and data collection acquisition. The wire-wrapped SBC was designed so that the ADSP2100A zero force extraction socket was placed at one end of the board to facilitate the various radiation tests. The watch-dog/latch-up board (also wire-wrapped), connected via a 40 pin flat cable, contained the various circuits to ensure continuous testing even if crashes or latch-ups occured. Figure 1 shows the SBC lay-out and Figure 2 the ADSP2100A test set-up.

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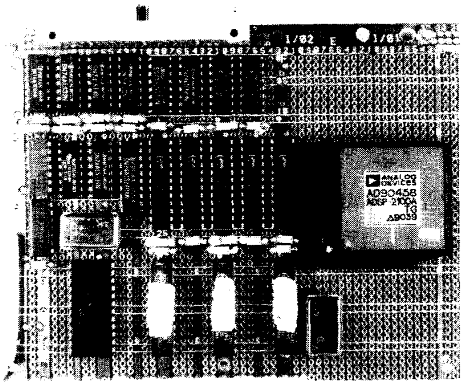


FIGURE 1, ADSP2100A SBC LAY-OUT, BOARD SIZE 15.5 x 12.0 cm.

The software used can be divided into the machine code program and the PC test information software. The test program consisted of filling accessible registers in the Computational Unit (CU) and in the Data Address Generators (DAG) with a known pattern. After a fixed delay loop, a memory image of the registers is created and compared with the initial values via the PC. The PC software also counts the elapsed time, collects the register contents, increments and displays the number of SEUs and latch-ups, and stores the results on disk.

The three Computationnal Units, the Arithmetic Logic Unit (ALU), the Multiplier Accuumulator Unit (MAC) and the Shift Unit (SU), contain duplicate banks of registers called either the "primary" or behind them the "shadow" registers, each representing 14 registers of 16 bits, 2 of 8 bits and 1 of 5 bits. The selection of a bank is controlled by a bit in the processor Mode Address Generators (MSTAT). The ADSP2100A contains two independent Data Address Generators (DAG), each of 24 registers of 14 bits. Five registers maintain internally the status and mode bits (ASTAT, SSTAT, MSSTAT, ICNTL and IMASK) and with the down counter register (CNTR) provide the processor with a powerful looping mechanism, so out of all these registers the following 531 bits are tested 100 % of the time.

	REGISTER BITS TOTAL	TESTED
"SHADOW"		
ALU	80 bits	80 bits
MAC	104 bits	104 bits
SU	61 bits	45 bits
PX (PM vs. DM)	8 bits	8 bits
"PRIMARY"		
DAG	336 bits	294 bits
TESTED		531 bits

III. TEST CONDITIONS AND TEST FACILITIES

All ADSP2100A tests were carried out using VDD = 5.0 V and test patterns of either "5555" or "AAAA" (hex). Co-60 and SEU proton testing were carried out in air on lidded devices, while "CASE" and SEU heavy ion testing on delidded devices in vacuum. Co-60, proton and "CASE" data were created with the incident beam normal to the die surface whereas heavy ion data also used tilting of the ADSP2100A at 48 and 60 degrees.

ESTEC source III, 1.37 microcuries of Cf-252, was used during all "CASE" tests. The average Linear Energy Transfer (LET) of Cf-252 is 43.0 MeV/(Mg/cm2). Irradiation at working distances of 1, 2, 3, and 4 cm produced fission fragment fluxes of 2731 to 222 ions/cm2/min. In order to validate the test system and create reliable test data at different fluxes, test times ranging from a few hours to several weeks were used.

SEU heavy ion testing was carried out at the 14 MeV Tandem van de Graaff at the Institut de Physique Nucleaire (IPN), Orsay, France. The Centre National d'Etudes Spatiales (CNES) beam line, calibration and beam counting set-up was used [3]. Support by CNES was given during the whole test campaign which covered testing with the following ions :

ION	ENERGY	LET in Si	RANGE in Si
127 I	217 MeV	53.0 MeV/(mg/cm2)	26.0 um
58 Ni	182 MeV	27.2 MeV/(mg/cm2)	31.5 um
35 Cl	153 MeV	12.7 MeV/(mg/cm2)	45.0 um
19 F	112 MeV	4.0 MeV/(mg/cm2)	77.0 um
12 C	84 MeV	1.7 MeV/(mg/cm2)	135.0 um

SEU proton testing was carried out at the SATURNE synchrotron at the Commissariat a l'Energie Atomique (CEA) facility, Saclay, France. The Departement d'Electronique et d'Instrumentation Nucleaire (DEIN) beam line 4, calibration and beam counting set-up was used [4]. Support by DEIN was given during the whole test campaign which covered proton testing with 200, 500 and 800 MeV to fluences of 5.3E11, 5.6E10 and 2.0E10 protons/cm2 respectively.

Total ionising dose tests were carried out using the ESTEC GAMMABEAM 150C Cobalt-60 facility (2040 Curies) at a dose rate of 64 rad(Si)/min.

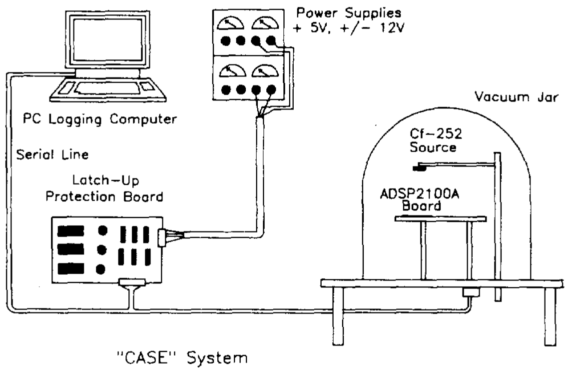


FIGURE 2, ADSP2100A SEU TEST SET-UP

IV. TEST RESULTS

Table 1 shows the test matrix of device numbers and marking exposed to the different tests. Identical die marking (ADSP D0002A *m*ADI) and die size (6.6 mm x 5.3 mm = 35.0 mm2) was found on the two types tested, however, our DPA identified epitaxial layer differences. The EPI layer on the commercial ADSP2100A, date code 9008, was measured to be 21.3 micron and the experimental device, date code 9039, to be 12.5 micron. The depth of the n-well for 9008 was measured to be between 4 to 5 micron and for 9039 to be between 3 to 4 micron. AD information identifies the 041XX series of experimental devices to have 13.0 micron EPI and 4.4 micron n-wells. Experimental devices with 13.0 micron EPI and 3.3 micron n-wells were also manufactured [5].

During a test, a data file collects all information received from the test board together with the general information related to the test. A second file which can be displayed on the PC screen at any time during the test, gives test progress and the number of SEU/Latch-ups. A copy of this page, showing the format and typical values is presented in Figure 3. The upper part of Figure 3 gives test details and conditions, and the total number of SEUs and latch-ups. The lower part provides a register bit map showing the number and location of upsets. So, for each test, a detailed test file together with the summary file is generated. However, in the following, only the summary data will be presented. Note, that for each test summary there is also a crash duration defined, which is the time when the DSP crashed, created spurious data or invalid test results due to upsets in the unmonitored circuitry.

TABLE 1, TEST MATRIX SHOWING DEVICE MARKING AND NUMBER OF DEVICES TESTED. ESTEC DPA IDENTIFIED THE EPI LAYER TO BE - 1) = 12.5 MICRON and 2) = 21.3 MICRON

A N A L O G D E V I C E S - ADSP2100A												
MARKING	AD90458 9039 TG						9008 JG					
TEST	56	58	59	60	61	62	00	01	02	03	04	05
"CASE"	+		+	+			+	+	+			
IPN I			+									
Ni	+	+										
HEAVY Cl	+	+										
ION F			+									
C			+									
PRO- 200 M					+	+						
TON 500 e					+	+						
800 V						+						
Co-60	+			+						(+)	(+)	+
DPA	1)						2)					

"CASE"

After "CASE" validation of the test system over a long period of time, test results on three commercial devices were obtained. A total of 1Ø tests at various fluxes were carried out. A summary of these tests are given per device in Table 2A. If we look at the average SEU values, then we see that 2.1EØ7 particles/cm2 produced 8268 upsets and 412 latch-ups equivalent to cross section device values of 3.9E-Ø4 cm2 (7.4E-Ø7 cm2 per bit) and 1.9E-Ø5 cm2 respectively. The 8268 upsets consist of 24 % Ø to 1 and 76 % 1 to Ø transitions. The distribution of upsets among the various types of register tested are also given as well as the device and per bit cross section values and the Ø to 1/1 to Ø transitions in %. Note, that the same sensitivity was measured between the ALU, MAC and SHIFT registers, whereas the PX and ADD. registers are different.

Three 12.5 micron devices were "CASE" tested over 1Ø tests at various fluxes. The summary is given in Table 2B. Here we see that 5.6EØ7 particles/cm2 produced 24584 upsets and 116 latch-ups equivalent to cross section device values of 4.3E-Ø4 cm2 (8.2E-Ø7 cm2 per bit) and 2.1E-Ø6 cm2 respectively. The transitions are measured to be 28 % Ø to 1 and 72 % 1 to Ø. The distribution of upsets, cross section values and percentage transition compare closely with the data in Table 2A. The only noticeable difference between the two device types is the latch-up behaviour which has improved from 1.9E-Ø5 cm2 to 2.1E-Ø6 cm2, for the experimental type using 12.5 micron EPI.

HEAVY ION

Three 12.5 micron devices were tested using heavy ions at IPN. The results of these tests are given in Table 2C. Again the results are presented in a summary form resembling the "CASE" data, however, now based on LET values. The same test results are also given in graphical form in Figure 4. This graph shows, as a function of LET, the upset cross section per bit (cm2/bit) and latch-up cross section per device. Three upset curves and one latch-up curve are presented. The upset curves cover the average of all tested register bits, the average of ADD. register bits and the average of ALU register bits. Test levels (1/fluence) where no upset or latch-up is seen, and "CASE" reference points are also included on the plot. Very little upset variation can be seen between these curves, so for these tests a threshold cross section value of about 8.Ø MeV/(mg/cm2) and a saturated cross section sensitivity of about 2-3E-Ø6 cm2/bit can be quoted.

Device type:	ADSP 21ØØA s/n Ø4159
Test number:	3Ø
Test date:	Ø5/11/199Ø
Start time:	ØØ:56:43
Test duration:	7Ø:38:Ø7
Crash duration:	ØØ:Ø5:47
Effective duration:	7Ø:32:2Ø (4232,3 min.)
Register test pattern:	5555
Total number of register bit upsets:	45ØØ
Number of Ø to 1 transition:	1298
Number of 1 to Ø transition:	32Ø2
Number of cycles:	52859Ø
Number of latchup:	21
CASE/dist/fluence:	1 cm, (2615), 11Ø67464 f.p.cm2

Register bit map of upsets:

BIT	15	14	13	12	11	1Ø	9	8	7	6	5	4	3	2	1	Ø	total
REGIS	Ø	1	Ø	1	Ø	1	Ø	1	Ø	1	Ø	1	Ø	1	Ø	1	
AXØ	7	16	4	15	7	18	6	14	1Ø	15	7	8	3	17	6	18	171
AX1	6	11	2	2Ø	1	17	8	9	1Ø	13	9	14	11	15	8	1Ø	164
AYØ	4	17	7	12	5	23	2	8	5	22	2	1Ø	4	14	3	18	156
AY1	8	13	8	13	7	15	1Ø	1Ø	7	13	4	16	8	9	5	12	158
AR	15	18	16	13	15	22	13	12	18	17	23	18	13	11	18	2Ø	262
MXØ	15	9	5	15	1Ø	1Ø	7	14	7	14	9	9	23	12	5	7	171
MX1	11	9	1Ø	12	11	1Ø	11	5	8	9	11	14	13	11	14	7	166
MYØ	6	11	7	11	7	1Ø	9	1Ø	13	13	7	9	9	8	4	1Ø	144
MY1	11	14	14	8	1Ø	16	1Ø	8	7	1Ø	9	5	1Ø	8	7	7	154
MRØ	7	29	9	16	7	18	6	16	6	2Ø	7	2Ø	2	22	12	21	218
MR1	5	2Ø	2	19	4	22	6	18	6	16	4	19	7	19	8	12	187
MR2									6	23	8	19	2	19	6	21	1Ø4
SE									2	14	6	9	8	15	3	7	64
SRØ	11	13	12	13	11	1Ø	5	8	12	1Ø	9	11	12	8	1Ø	19	174
SR1	7	15	3	8	6	12	11	11	9	9	4	17	9	16	6	13	156
SB												1Ø	6	16	14	13	59
PX									8	1Ø	1	9	5	4	5	1Ø	52
LØ			5	14	2	5	2	1Ø	1	11	4	19	2	15	2	11	1Ø3
L1			1	12	7	6	3	11	6	8	5	1[illegible]	7	5	7	22	113
L2			5	14	4	16	Ø	1Ø	2	7	2	11	5	12	7	13	1Ø8
L4			1	13	2	2	1	12	1	15	2	7	6	14	1	15	92
L5			6	13	4	1Ø	3	14	4	11	4	17	3	15	4	12	12Ø
L6			7	11	1	11	7	14	4	13	3	11	5	12	3	15	117
L7			6	13	4	12	2	15	6	9	5	5	12	12	4	1Ø	115
MØ			1	17	Ø	9	2	15	Ø	9	1	11	2	8	Ø	19	94
M1			1	8	1	13	3	1Ø	Ø	5	1	1Ø	Ø	16	2	13	83
M2			3	7	1	1Ø	Ø	2	1	9	1	11	2	14	1	7	69
M4			Ø	8	2	8	Ø	9	Ø	9	1	8	1	7	1	1Ø	64
M5			1	9	Ø	1Ø	Ø	12	2	6	Ø	9	2	14	1	7	73
M6			1	14	1	11	2	13	1	14	1	1Ø	3	9	2	8	9Ø
M7			2	13	2	11	1	4	1	9	1	9	1	4	1	6	65
IØ			Ø	12	Ø	14	2	17	Ø	1Ø	Ø	8	3	9	2	5	82
I1			1	14	5	15	3	8	4	13	2	1Ø	1	9	5	4	94
I2			6	9	4	12	Ø	13	1	18	5	1Ø	2	6	2	11	99
I4			2	12	1	14	Ø	5	Ø	6	1	14	1	12	1	11	8Ø
I5			2	16	2	12	1	8	1	9	3	12	1	7	3	13	9Ø
I6			5	15	1	1Ø	1	5	3	11	1	6	3	17	4	14	96
I7			3	7	3	1Ø	2	1Ø	Ø	11	3	8	4	11	4	17	93
total	113	195	158	426	148	424	139	36Ø	172	441	166	436	211	452	191	468	45ØØ

FUGURE 3, ADSP21ØØA SEU TEST SUMMARY RESULTS

PROTONS

Two 12.5 micron devices were proton tested at SATURNE. The results of these tests are given in Table 3. Due to the very low number of upsets and the comparatively high number of latch-ups, the results are given for all tests performed. Very limited upset data could be measured between the latches, however, the distribution between the various register types can be seen. For each energy the average cross section values per device and per bit have been calculated, but these values should only be taken as reference values with the main conclusion that upsets can occur.

COBALT-6Ø

Initially two commercial devices were Co-6Ø tested using our SBC test system, however, some difficulties with other components on the board (UART) made us change the hardware to the AD ADSP21ØØA evaluation board. Similar programs to the SEU test programs are used to control the DSP during the Co-6Ø irradiation with comprehensive writing and reading operations after each 4 Krad(Si) exposure step. Unfortunately no IDD measurements could be carried out during these tests, however, the Co-6Ø testing was only performed in order to establish a certain functionality level of the experimental DSP. Both 12.5 micron DSPs were fully functional at the end of Co-6Ø testing, 3Ø.Ø and 31.2 Krad(Si) respectively.

TABLE 2A, SUMMARY - "CASE" ADSP2100A (EPI 23.0 um) SINGLE EVENT UPSET RESULTS

S/N ION TEST TILT	FLUENCE (FLUX) p/cm2	UPSET SEU-SEL % 0-1/1-0	CROSS SECTION DEVICE LATCH-UP PER BIT cm2	ALU-80 BITS SEU DEVICE % 0-1 PER BIT	MAC-104 BITS SEU DEVICE % 0-1 PER BIT	SHIFT-45 BITS SEU DEVICE % 0-1 PER BIT	PX-8 BITS SEU DEVICE % 0-1 PER BIT	ADD.-294 BITS SEU DEVICE % 0-1 PER BIT
00 AA Cf 55 00	5185173	1912-118 26/74	3.7E-04 2.3E-05 6.9E-07	370 7.1E-05 34/66 8.9E-07	492 9.5E-05 37/63 9.1E-07	187 3.6E-05 38/62 8.0E-07	25 4.8E-06 16/84 6.0E-07	838 1.6E-04 13/87 5.5E-07
01 55 Cf AA 00	7225413	2942-82 23/77	4.1E-04 1.1E-05 7.7E-07	550 7.6E-05 34/66 9.5E-07	751 1.0E-04 34/66 1.0E-06	257 3.6E-05 38/62 7.9E-07	37 5.1E-06 19/81 6.4E-07	1347 1.9E-04 10/90 6.3E-07
02 AA Cf 55 00	8730906	3414-212 25/75	3.9E-04 2.4E-05 7.4E-07	660 7.6E-05 34/66 9.4E-07	803 9.2E-05 37/63 8.8E-07	367 4.2E-05 37/63 9.3E-07	46 5.3E-06 20/80 6.6E-07	1538 1.8E-04 12/88 6.0E-07
				AVERAGE SEU VALUES - 3 DEVICES				
LET=43.0 MeV/mg/cm2	21141492	8268-412 24/76	3.9E-04 1.9E-05 7.4E-07	1580 7.5E-05 34/66 9.3E-07	2046 9.7E-05 36/64 9.3E-07	811 3.8E-05 37/63 8.5E-07	108 5.1E-06 19/81 6.4E-07	3723 1.8E-04 11/89 6.0E-07

TABLE 2B, SUMMARY - "CASE" ADSP2100A (EPI 12.5 um) SINGLE EVENT UPSET RESULTS

59 55 Cf AA 00	25336953	10471-53 28/72	4.1E-04 2.1E-06 7.8E-07	2099 8.3E-05 34/66 1.0E-06	2582 1.0E-04 36/64 9.8E-07	1043 4.1E-05 38/62 9.1E-07	143 5.6E-06 27/73 7.1E-07	4604 1.8E-04 17/83 6.2E-07
56 55 Cf AA 00	15872962	6960-28 28/72	4.4E-04 1.8E-06 8.3E-07	1315 8.3E-05 35/65 1.0E-06	1695 1.1E-04 35/65 1.0E-06	725 4.6E-05 39/61 1.0E-06	86 5.4E-06 23/77 6.8E-07	3139 2.0E-04 20/80 6.7E-07
60 55 Cf AA 00	15352651	7153-35 28/72	4.7E-04 2.3E-06 8.8E-07	1306 8.5E-05 38/62 1.1E-06	1743 1.1E-04 37/63 1.1E-06	691 4.5E-05 37/63 1.0E-06	107 7.0E-06 22/78 8.7E-07	3316 2.2E-04 19/81 7.3E-07
				AVERAGE SEU VALUES - 3 DEVICES				
LET=43.0 MeV/mg/cm2	56562566	24584-116 28/72	4.3E-04 2.1E-06 8.2E-07	4720 8.3E-05 36/64 1.0E-06	6020 1.1E-04 36/64 1.0E-06	2459 4.3E-05 38/62 9.7E-07	336 5.9E-06 24/76 7.4E-07	11059 2.0E-04 18/82 6.7E-07

TABLE 2C, SUMMARY - ADSP2100A (EPI 12.5 um) HEAVY ION SEU TEST RESULTS

LET=79.2 MeV/mg/cm2	155622	109-01 38/71	7.0E-04 6.4E-06 1.3E-06	22 1.4E-04 27/73 1.8E-06	15 9.6E-05 27/73 9.3E-07	4 2.6E-05 25/75 5.7E-07	1 6.4E-06 0/100 8.0E-07	67 4.3E-04 40/60 1.5E-06
LET=54.4 MeV/mg/cm2	121409	186-02 32/68	1.5E-03 1.6E-05 2.9E-06	37 3.0E-04 24/76 3.8E-06	35 2.9E-04 29/71 2.8E-06	19 1.6E-04 32/68 3.5E-06	2 1.6E-05 0/100 2.1E-06	93 7.7E-04 36/64 2.6E-06
LET=53.0 MeV/mg/cm2	183468	131-02 41/59	7.1E-04 1.1E-05 1.3E-06	24 1.3E-04 38/62 1.6E-06	22 1.2E-04 46/54 1.2E-06	11 6.0E-05 45/55 1.3E-06	0 <5.5E-06 -/- <6.8E-07	74 4.0E-04 39/61 1.4E-06
LET=40.6 MeV/mg/cm2	146073	171-02 37/63	1.2E-03 1.4E-05 2.2E-06	35 2.4E-04 34/66 3.0E-06	34 2.3E-04 34/66 2.2E-06	12 8.2E-05 17/83 1.8E-06	2 1.4E-05 50/50 1.7E-06	88 6.0E-04 39/61 2.0E-06
LET=27.2 MeV/mg/cm2	433163	316-00 24/76	7.3E-04 <2.3E-06 1.4E-06	52 1.2E-04 33/67 1.5E-06	75 1.7E-04 25/75 1.7E-06	27 6.2E-05 30/70 1.4E-06	4 9.2E-06 25/75 1.2E-06	158 3.6E-04 19/81 1.2E-06
LET=25.4 MeV/mg/cm2	191724	95-00 18/82	5.0E-04 <5.2E-06 9.3E-07	18 9.4E-05 33/67 1.2E-06	28 1.5E-04 32/68 1.4E-06	6 3.1E-05 33/67 7.0E-07	0 <5.2E-06 -/- <6.5E-07	43 2.2E-04 0/100 7.6E-07
LET=19.0 MeV/mg/cm2	282505	93-01 13/87	3.3E-04 3.5E-06 6.2E-07	17 6.0E-05 24/76 7.5E-07	14 5.0E-05 29/71 4.8E-07	13 4.6E-05 31/69 1.0E-06	0 <3.5E-06 -/- <4.4E-07	49 1.7E-04 0/100 5.9E-07
LET=12.7 MeV/mg/cm2	497186	82-00 18/82	1.6E-04 <2.0E-06 3.1E-07	14 2.8E-05 29/71 3.5E-07	17 3.4E-05 53/47 3.3E-07	11 2.2E-05 09/91 4.9E-07	4 8.0E-06 25/75 1.0E-06	36 7.2E-05 0/100 2.5E-07
LET=8.0 MeV/mg/cm2	1370448	1-00	7.3E-07 <7.3E-07 1.4E-09	1 7.3E-07 0/100 9.1E-09	0 <7.3E-07 -/- <7.0E-09	0 <7.3E-07 -/- <1.6E-08	0 <7.3E-07 -/- <9.1E-08	0 <7.3E-07 -/- <2.5E-09
LET=3.4 MeV/mg/cm2	3381770	0-00	<3.0E-07 <3.0E-07 <5.6E-10	0 <3.0E-07 -/- <3.7E-09	0 <3.0E-07 -/- <2.8E-09	0 <3.0E-07 -/- <6.6E-09	0 <3.0E-07 -/- <3.7E-08	0 <3.0E-07 -/- <1.0E-09

TABLE 3,
ADSP2100A (EPI 12.5 um) PROTON SEU TEST RESULTS

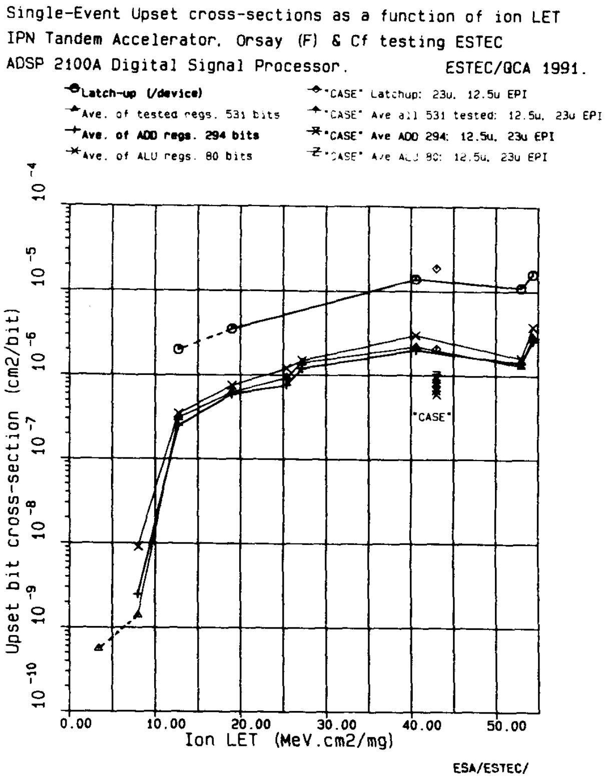
S/N TEST PROTON	FLUENCE P/cm2	SEU SEL	DEVICE PER BIT	REGISTER ERROR DISTRIBUTION ALU	MAC	SHI	PX	ADD
62 AA 70 200 MeV	1.4E11	2 (3)	1.4E-11 2.7E-14	-	1	-	-	1
61 55 71 200 MeV	1.7E11	5 (4)	2.9E-11 5.5E-14	1	2	-	-	2
62 AA 72 200 MeV	8.4E10	3 (4)	3.6E-11 5.7E-14	-	2	-	-	1
62 AA 80 200 MeV	1.9E11	2 (4)	1.1E-11 2.0E-14	1	-	1	-	-
61 55 81 200 MeV	2.1E11	2 (1)	9.5E-12 1.8E-14	-	1	-	-	1
AVERAGE 200 MeV	7.9E11	14 (16)	1.8E-11 3.3E-14	2	6	1	-	5
61 55 82 500 MeV	2.7E10	4 (9)	1.5E-10 2.8E-13	1	1	-	-	2
62 AA 83 500 MeV	2.8E10	5 (9)	1.8E-10 3.4E-13	2	1	-	-	2
62 55 84 500 MeV	2.3E10	2 (8)	8.7E-11 1.6E-13	1	1	-	-	-
AVERAGE 500 MeV	7.8E10	11 (26)	1.4E-10 2.7E-13	4	3	-	-	4
62 AA 85 800 MeV	2.9E10@	10 (3)	3.5E-11@ 6.5E-14@	-	-	-	-	1

@ - DUT latched, data taken at that point.

V. ORBITAL PREDICTION

Using the heavy ion and proton SEU results together with the CREME suite of programs [6], the expected on-orbit upset rates were calculated for a low earth orbit (500 km - 28 degree), polar orbit (800 km - 98 degree) and high altitude/interplanetary. Predictions are made for both Galactic Cosmic Ray (GCR) and Average Solar Flare environments. The upset rates are computed from the experimental cross section versus LET curve. An integration was performed over the experimental curve as previously described in [2]. The results are shown in Table 4 in upsets/bit/day. Three sets of upset rates are given, based on either the average SEU values for all tested registers (ALL), for the average values of the address registers (ADD) and for the average values of the ALU registers.

For the proton predictions, the BENDEL program is used [7]. Orbital proton fluxes due to passage through the radiation belts are computed with the AP8 proton model. Experimental upset cross section versus proton energy are used to derive a threshold parameter "A" describing the cross section shape in the Bendel and Peterson method. Table 4 contains the resulting upset rate predictions for "A" = 26 (200 MeV) and "A" = 29 (500 MeV).



FUGURE 4, ADSP21ØØA SEU TEST RESULTS

It should be noted that the upset rates presented here are based on the sensitivity of a few register types measured. Throughout the ADSP21ØØA design several types of flip-flop have probably been used, each having a different upset sensitivity. A worst case ADSP upset rate may be derived by simply multiplying the total number of bits by the register sensitivity, however, such a sensitivity for a whole ADSP will seriously misrepresent the likely upset rate in a practical application. So the true ADSP21ØØA upset rate would be a function of the number of bistable elements at each sensitivity and their relative importance or percentage use [2]. This however requires a very detailed knowledge of the ADSP21ØØA design, sensitivity and application.

TABLE 4, ORBITAL UPSET RATE (BIT/DAY) PREDICTIONS

ORBIT	GALACTIC COSMIC RAYS REGISTERS- ALL	ADD	ALU	FLARES AVERAGE REGISTERS - ALL	ADD	ALU	PROTONS A=26 ALL	A=29
LEO	6.1E-9	5.0E-9	1.2E-8	-	-	-	2.2E-7	5.0E-8
POLAR	3.4E-7	2.9E-7	4.6E-7	8.0E-6	6.9E-6	1.0E-5	1.5E-6	3.0E-7
INTER.	1.3E-6	1.1E-6	1.8E-6	3.5E-5	3.0E-5	4.5E-5	-	-

VI. DISCUSSIONS AND CONCLUSIONS

ADSP21ØØAs, commercialiy available and experimentally developed 12.5 micron epitaxial types, have been characterised for upset effects using a dedicated SEU test system.

Both types of DSPs were found to latch during the Californium-252 testing. Latch-ups were also experienced during heavy ion and proton testing of the 12.5 micron type. The latch-up LET threshold was found to be between 12.7 and 19.Ø Mev/(mg/cm2), the saturated cross section to be between 1.Ø to 2.ØE-Ø5 cm2. However, ADSP21ØØAs, produced on 13.Ø micron EPI with a 4.4 micron n-well, have been reported not to latch when laser, heavy ion and proton tested [5].

Both types of DSPs showed identical average cross section values when SEU tested using Californium-252. As can be expected, the values are slightly below the heavy ion saturated cross section value of about 2.Ø to 4.ØE-Ø6 cm2. The LET threshold was found to be about 8.Ø MeV/(mg/cm2).

Our attempt to give a preliminary value for the in-orbit upset rate has been based on the measured SEU register data. However, improved and more accurate predictions could be carried out for the whole ADSP21ØØA, if manufacturer details such as number and type of bistable elements were known as well as the practical application.

Co-6Ø total ionising dose testing of two SBC operating DSP's confirmed functional failure levels to be higher than 3Ø Krad(Si).

Finally, in order to provide further test details and results from this work, two ESTEC reports will be issued. The first will describe the tools, hardware and software used whereas the second will give the detailed results of each SEU test. Both reports will be available from ESTEC/QCA on request.

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