ESA-QCA9903TS-C

PROJECT

Radiation Evaluation of Actel FPGA's A1280XL, A32140DX, RH1280

ESA Contract No 11407/95/NL/CN

TITLE

Summary Report 2

EUROPEAN SPACE AGENCY
CONTRACT REPORT

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SUMMARY

This document form the Summary Report 2 of the ESTEC/Contract No 1407/95/NL/CN.
The objective of the present study has been to perform Heavy Ion Tests , Proton Tests and Total Dose Tests of the two types A1280XL and A32140DX Field Programmable Gate Arrays (FPGA) from Actel Corporation Inc. Also, SEU sensitivity of different macros available in the Actel standard library was investigated using the RH1280 device as test vehicle.

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1. ABSTRACT

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The objective of the present study has been to perform Heavy Ion Tests , Proton Tests and Total Dose Tests of the two types A1280XL and A32140DX Field Programmable Gate Arrays (FPGA) from Actel Corporation Inc. Also, SEU sensitivity of different macros available in the Actel standard library was investigated using the RH1280 device as test vehicle.

2. INTRODUCTION

Field Programmable Gate Arrays (FPGAs) are attractive for space application because of there quick turn-around time. FPGA devices from Actel Corp. have been frequently investigated for space application due to their anti-fuse technology which make them particular suitable for the space radiation environment. However, these devices are mainly targeted for commercial and military markets and generally no guarantee of radiation hardness is provided by the manufacturer. The Total dose results show large variation in tolerance for various types of FPGA's, while the Heavy Ion results indicate about the same sensitivity for the different FPGA types, but large difference in sensitivity between C and S, I/O modules. Very few types indicate single event latch-up problems.

The Actel devices are programmed by "burning" one or more anti-fuses providing a low resistance path between nodes, which otherwise have a very high electrical resistance and act to separate electrical nodes.
The present radiation evaluation studies have comprised the two commercial device types in the Integrator Series, A1280XL and A32140DX , both manufactured at Chartered in 0.6 micron CMOS technology. Further investigation of the RH1280 has been performed by studies of the different SEU susceptibility of various macros available from the standard library.

3. APPLICABLE DOCUMENTS

ESTEC/Contract No 11407/95/NL/CN "Radiation Pre-Evaluation of Field Programmable Gate Array (FPGA)"

ESA/SCC Basic Specification No 25100 Single Event Effects Test Method and Guidelines

ESA/SCC Basic Specification No 22900 Total Dose Steady-State Irradiation Test Method.

Radiation Pre-Evaluation of A1280A, RH1280 , A1460
Summary Report 1 , Saab Ericsson Space SE/REP/0042/K

4. SAMPLE SELECTION

The following types of Actel FPGA's have been tested during this Radiation Pre-Evaluation Programme.

4.1. Actel A1280XL

The A1280XL is a second generation FPGA, "intergrator series" (ACT2), from Actel. The tested devices were manufactured by Chartered. The devices employ antifuse technology implemented in ONO gate, 0.6 μm, two-level metal CMOS. This device is a 8000-gate FPGA with 1232 dedicated flip-flops (624 S- and 608 C-modules) and a maximum of 140 I/O's.

Screening level:	Commercial
Date code:	9709
Chip manufacturer:	Chartered
Package:	Plastic 208 - PQFP

Marking / *Top side*	Marking / *Bottom side*
Actel logo A1280XL PQ208C 9709	ACQ04533.1

Chip Marking
1992 Actel logo 21280.1M © Ⓜ

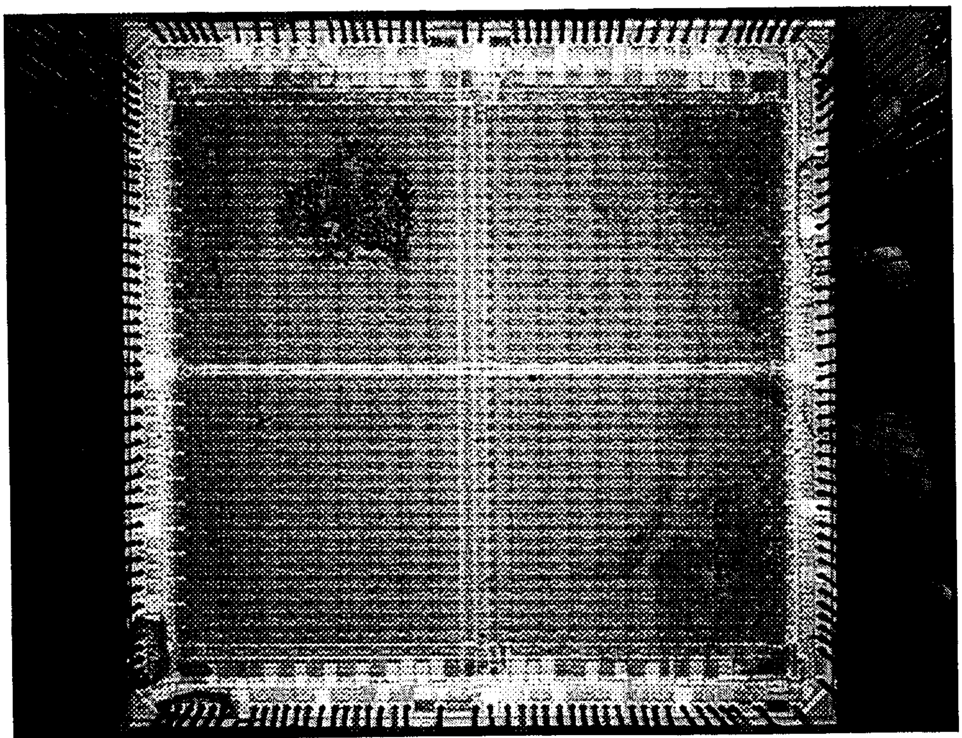


Fig 4.1.1 View of chip A1280XL, Magnification 11,0 X

4.2. Actel A32140DX

The A32140DX belong to the "intergrator series" (ACT2). The devices employ antifuse technology implemented in ONO gate, 0.6 µm, two-level metal CMOS process. This device contain 1250000 antifuses in 14000 equivalent gates with 954 S- modules, 912 C-modules and 176 I/O's.

Screening level:	Commercial
Date code:	9703
Chip manufacturer:	Chartered
Package:	Plastic 208-pin PQFP

Marking / *Top side*	Marking / *Bottom side*
Actel logo	ACQ06716.1
A32140DX	504273
PQ208C 9703	HONG KONG

Chip Marking
1995 Actel logo
232140_A6C © Ⓜ

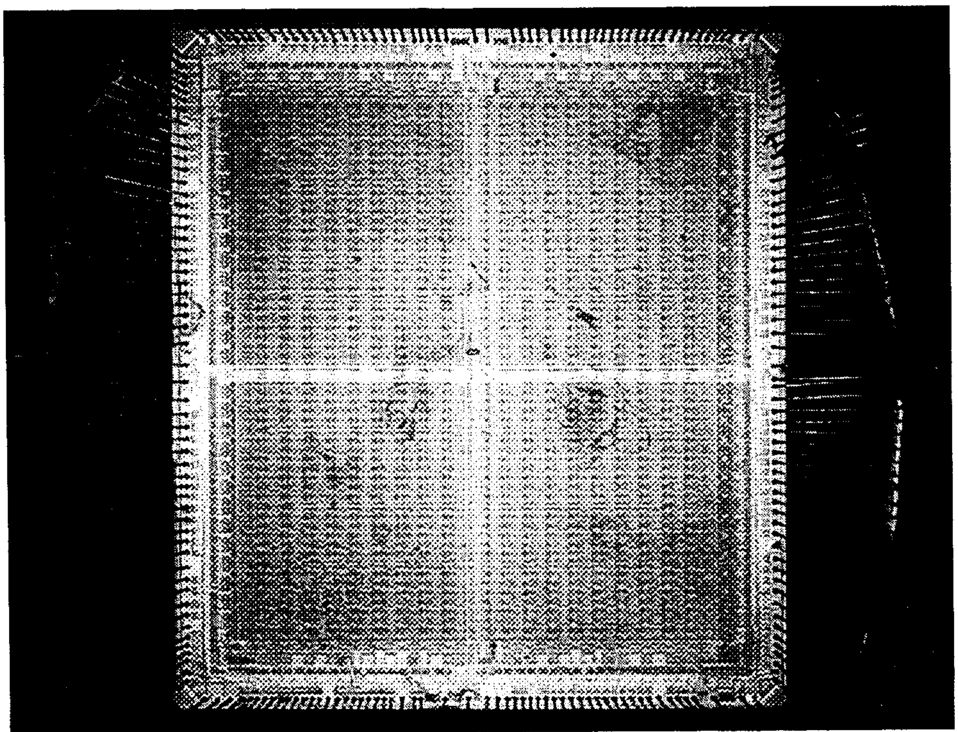


Fig 4.2.1 View of chip layout A32140DX, Magnification 8,5 X

4.3. Actel RH1280

The RH1280 is manufactured by Lockheed Martin Federal Systems , Manassas, Virginia, USA in a RHCMOS-4 process (0.8 μm rad hard antifuse 5 μm epi CMOS 2-poly 2 metal technology). Basically, the device resembles the A1280XL in structure and timing. The A1280XL could be used for prototyping and be replaced by the rad hard version without any changes. The devices have been delivered by Actel free of charge.

Number of test samples:	2
Screening level:	QML
Date code:	9617 (?)
Chip manufacturer:	Lockheed Martin
Package:	172-pin CQFP

Marking / *Top side*	Marking / *Bottom side*
"None"	"None"

Chip Marking

1994 Actel logo
21280_C6C © Ⓜ

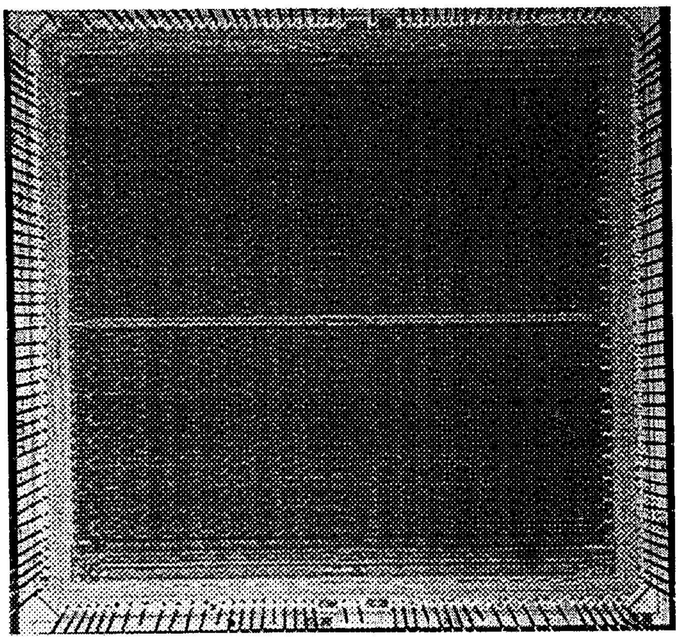


Fig 4.3.1 Overview of RH1280 chip, magnification 10X.

5. TEST TECHNIQUES

5.1. General

The general concept is to load data into the DUT's, pause for a pre-set time and thereafter read data and check for errors. A schematic picture is shown in Fig 5.1.1.

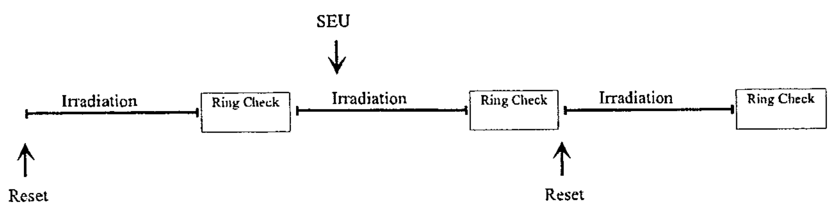


Fig 5.1.1 Schematic view of test sequence.

A flow chart of the test sequence is given in the Fig 5.1.2. Any detected errors will be store in memory, the DUT will be reseted and new data will be loaded again. The cycle will then be repeated. Failing read/write operations from/to the DUT will determine the functionality criteria. The clock speed will be 50 kHz. For each DUT errors can be traced down to logic module, logic value and position.

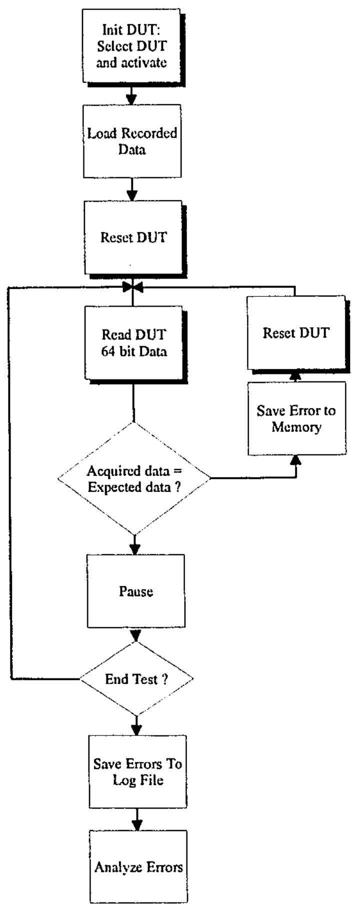


Fig 5.1.2 Flow chart of the test sequence.

5.2. Test Boards

Three different types of printed circuit board, one for each FPGA type, were designed and manufactured. Each test board can house three Device Under Test (DUT). Illustration of the RH1280 test board is given in Fig 5.2.1. The design and lay-out are the same as used in previous tests [SE/REP/0042/K]. To verify functionality of the programmed DUT's, test boards and software monitoring system, one board of each type were subjected to irradiation by ^{252}Cf.
The DUT's are tested using a "virtual golden chip" test method. The principal of the measuring technique is to compare each output from the DUT with the correct data controlled via a PC. The general concept of the error detection and test sequence is shown in Fig 5.1.2. The DUT is continually cycled while the outputs of selected ring counters are compared by the "golden chip" with three times over sampling. When an error is found (when outputs do not match), the state of all outputs and position in cycle of the failing ring counter will be temporarily stored in the memory. The ring counters (DUT) are then reseted. After each test run the data are analysed and stored in a database by the controlling PC. The PC can be remote controlled via thin Ethernet network in order to cope with the long distance transmission as required at the proton facility. For all tests, the devices will be clocked at frequency of 50 kHz.

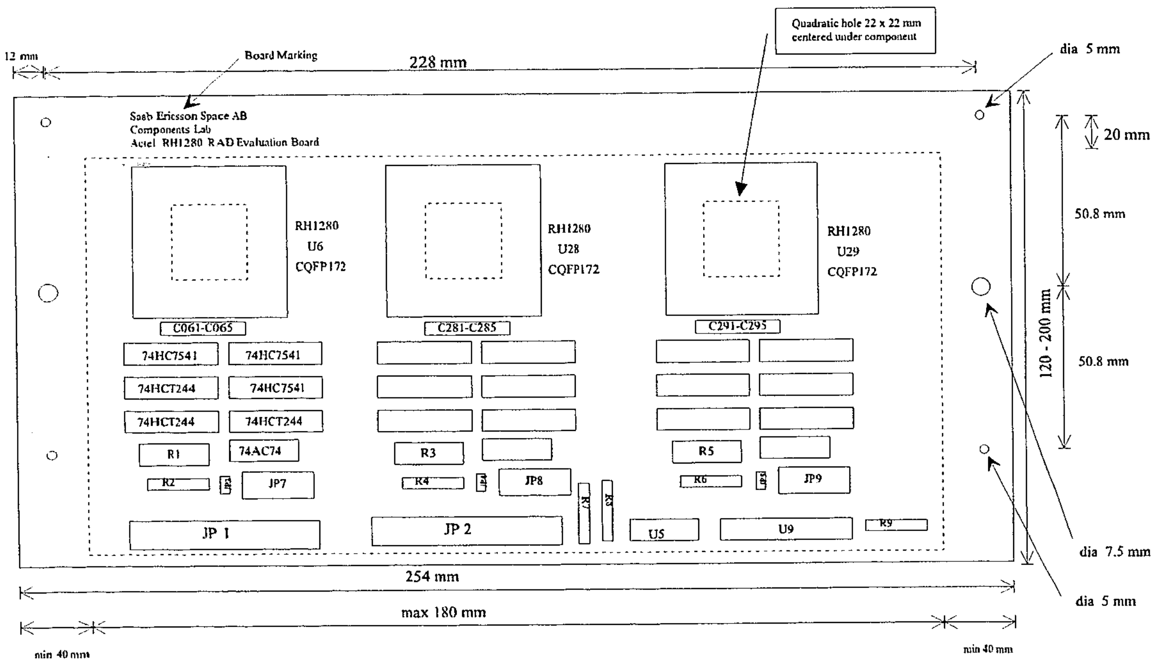


Fig 5.2.1 Lay-out of the RH1280 test board. The test boards for all three FPGA types have simular lay-out and are prepared for both 5V and 3.3 V power on the DUT's

6. HEAVY ION TEST

6.1. Equipment & Facility

Heavy ion test was performed at the CYClotron of LOuvain la NEuve (CYCLONE) ,Belgium. This accelerator can cover an energy range of 0.6 to 27.5 MeV/AMU for heavy ions produced in an double stage ECR source. The use of an ECR source allow the acceleration of an ion "cocktail" composed of ions with very close mass over charge ratio. The preferred ion is selected by fine tuning of the magnetic field or a slight change of the RF frequency. Within the same cocktail it takes only a few minutes to change ion species.

The facility provides beam diagnostic and control with continuous monitoring of beam fluence and flux via plastic scintillators.
The irradiations were performed in a large vacuum chamber with one test board mounted at the same time on a movable frame.
Three samples of each device type were delidded and mounted on the three boards and serialised as S/N #1, S/N #2 and S/N #3 for each device type. Each device were individually biased. During irradiation the samples were monitored for latch-up.

Table 6.1.1 Ion Beam Data

Ion Specie	Energy (MeV)	Tilt Angle (Degree)	LET (MeV/mg/cm2)	Range (µm)
Ne-20	78	0	5.8	45
		45	8.3	
		60	11.7	
Ar-40	150	0	14.1	42
		45	20	
		60	28.2	
Kr-84	316	0	34	43
		45	48	
		60	68	
Xe-132	459	0	55.9	43
		30	79	
		45	112	

6.2. Results

The results are presented individually for each device type in a graphical form showing the SEU cross section per cm^2 per bit versus the LET values. The LET range was obtained by changing the ion species and the angle of incidence between the beam and the chip. Table 6.1.1 provide the data of the ions used. Cross sections given in the figure captions is taken to be the average value of logical "0" and "1" at ^{132}Xe, 0° LET= 55.9 MeV/mg/cm^2. The threshold value is taken to be the value at 1 % of the cross section value. A summary of the data are given in the conclusion, section 9.

6.2.1. A1280XL

The layout of the devices under tests have been a bit pattern consisting of consecutive 0 1 0 1 etc in individually controlled 64-bit ring counters (shift registers) for each logical module C, S and I/O. The C- and S- module rings have been designed using the two macros, DFPC and DFC1B, respectively. I/O modules has been designed with macros IR and ORH for input and output, respectively. The device design of all shift registers has been auto place & route using Actel Designer software.
The number of bits subjected for tests are summarized in Table 6.2.1.1 below.

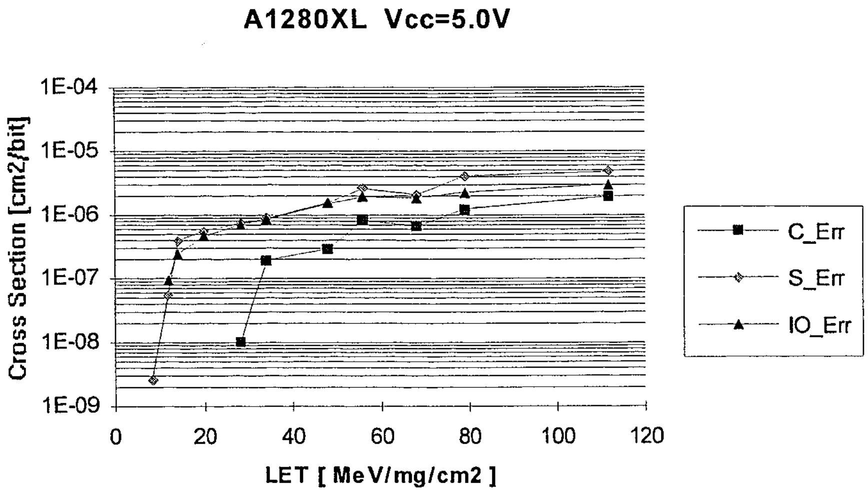
Graphical illustration of the upset probabilities for all modules are given in Figure 6.2.1.1, whereas Fig 6.2.1.2 to Fig 6.2.1.4 show the sensitivity for S, C and I/O modules, respectively.

For S-modules, the high SEU sensitivity resulted in good statistical accuracy. Good homogeneity in the data between the sample were observed. The SEU sensitivity for I/O is very similar to the S-module. The logical "1" (high) SEU cross sections are a factor 4-5 higher than the logical "0" (low) cross sections. The average values for 3.3 V are about a factor 2 higher than the 5 volt values.

For C modules, the SEU sensitivity are lower which results in limited statistics particular for the lower LET values.

Table 6.2.1.1 Number of bit tested

	C-Module	S-Module	I/O-Module
A1280XL	384 (6 ring counters)	256 (4 ring counters)	64 (1 ring counters)



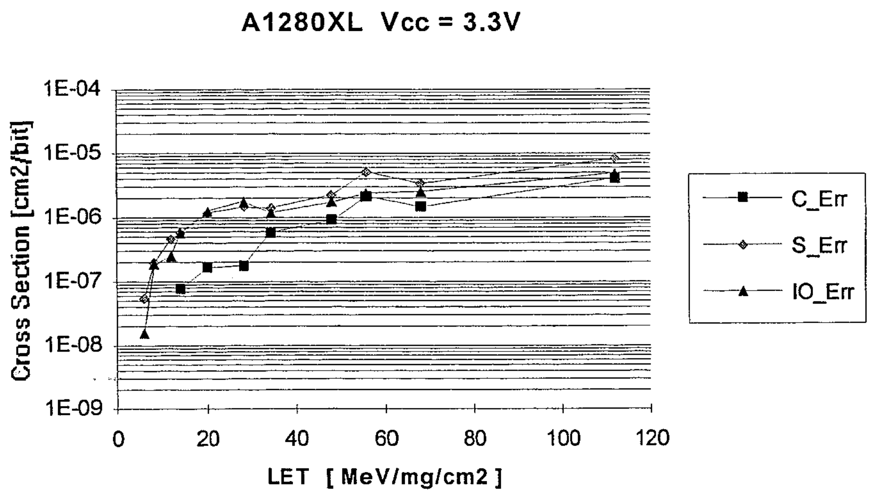
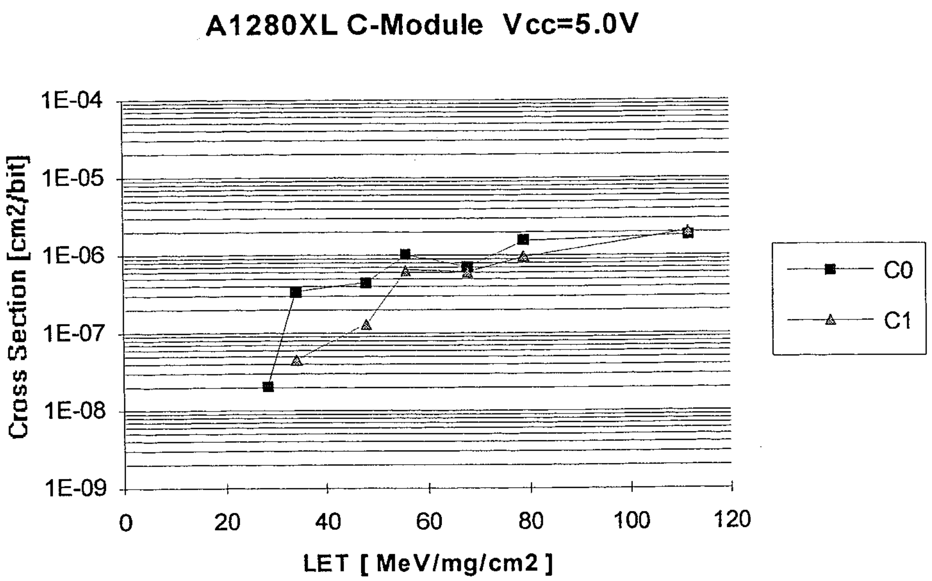


Fig 6.2.1.1 : Average SEU Cross Section for Actel A1280XL C, S and I/O-Modules

Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A1280XL, 208-pin PQFP, S/N #1, #2, #3
C-Module , Cross Section (σ) :	5V 8 E-7 cm^2 /bit 3.3V 2 E-6 cm^2 /bit
Threshold :	5V 28 MeV/mg/cm^2 3.3V 20 MeV/mg/cm^2
S-Module , Cross Section (σ) :	5V 2.5 E-7 cm^2 /bit 3.3V 3.5 E-6 cm^2 /bit
Threshold :	5V 10 MeV/mg/cm^2 3.3V 5 MeV/mg/cm^2
I/O-Module , Cross Section (σ) :	5V 2 E-7 cm^2 /bit 3.3V 2.5 E-6 cm^2 /bit
Threshold :	5V 10 MeV/mg/cm^2 3.3V 5 MeV/mg/cm^2



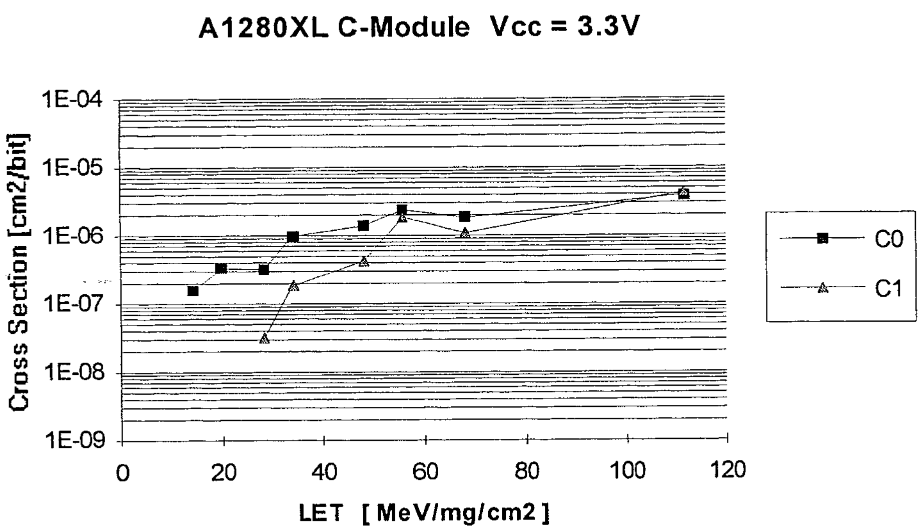
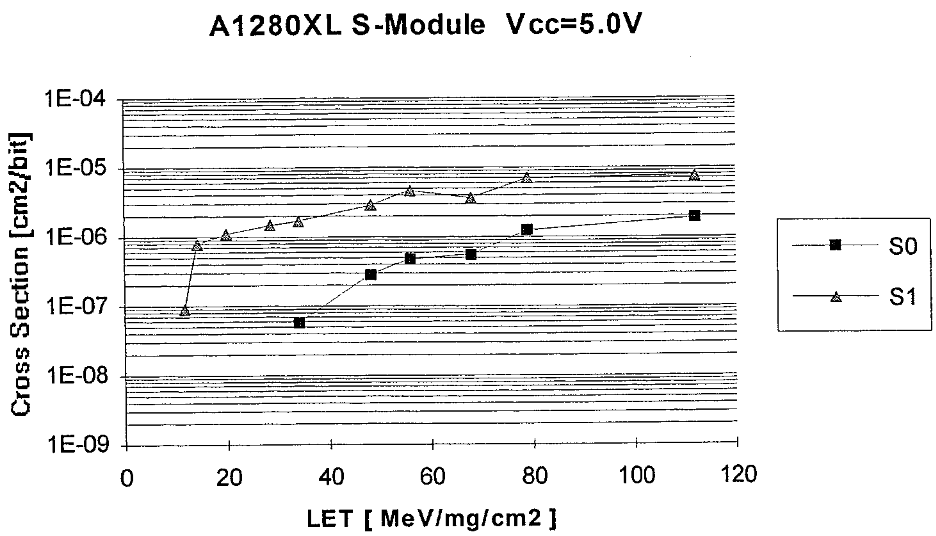


Fig 6.2.1.2 : SEU Cross Section for Actel A1280XL C-Modules

S/W Macro :	DFPC
Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A1280XL, 208-pin PQFP, S/N #1, #2, #3
C-Module Comments :	The differences in sensitivity between "1" and "0" are very small and only evident at low LET values. The C-module has reversed sensitivity of the "1" and "0" compared to S and I/O modules.



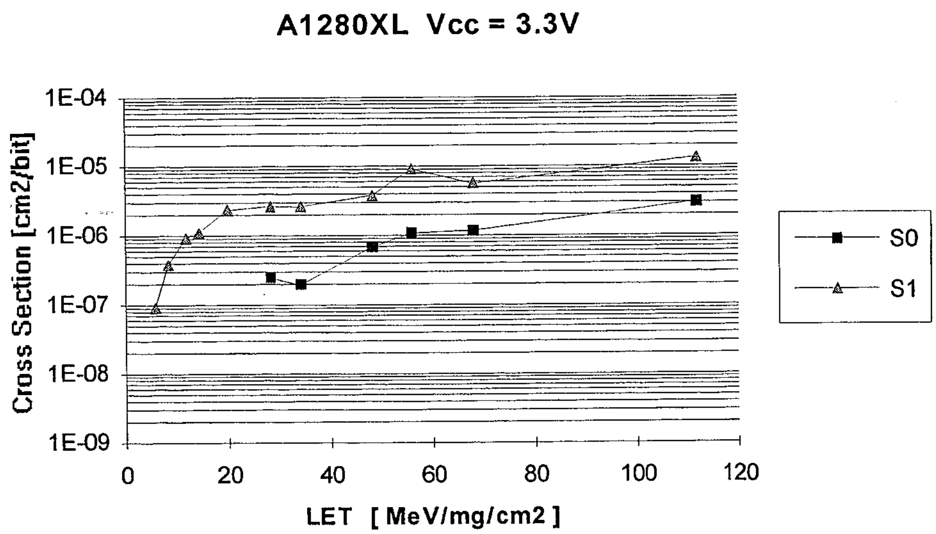
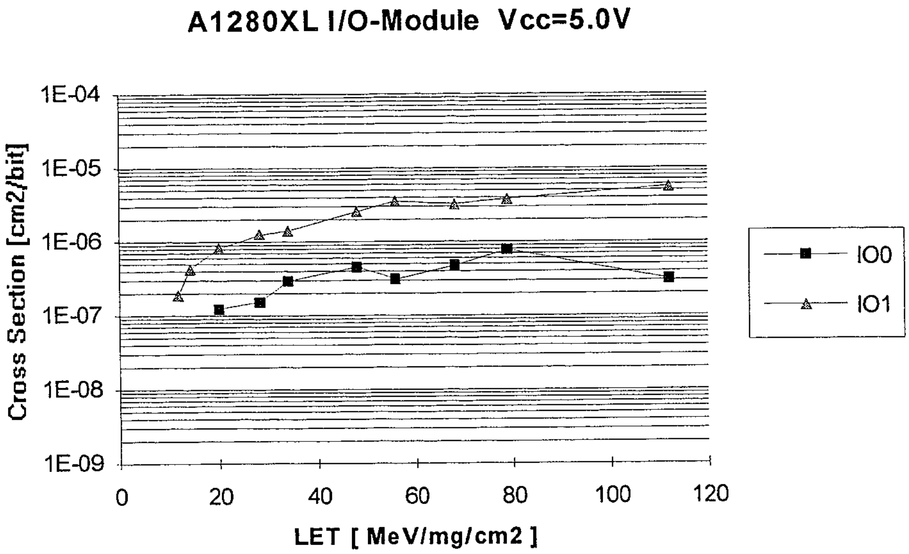


Fig 6.2.1.3 : SEU Cross Section for Actel A1280XL S-Modules

S/W Macro :	DFC1B
Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A1280XL, 208-pin PQFP, S/N #1, #2, #3
S-Module Comments :	The differences in sensitivity between "1" and "0" are about a factor 5 for both 5V and 3.3 V at large LET. The number of detected errors for "0" at low LET are very small which give statistical uncertain values for the lowest LET.



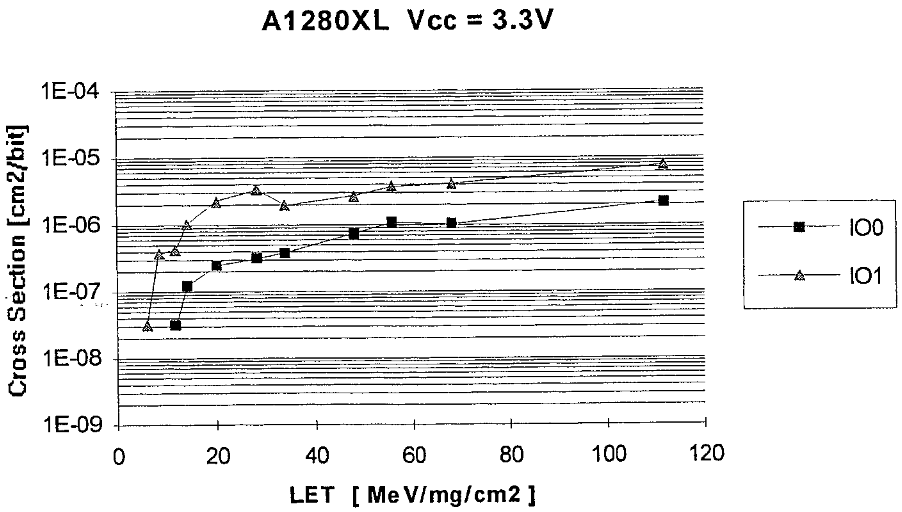


Fig 6.2.1.4 : SEU Cross Section for Actel A1280XL I/O-Modules

S/W Macro :	ORH for logic "1" , IR for logic "0"
Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A1280XL, 208-pin PQFP, S/N #1, #2, #3
I/O-Module Comments :	Data for the I/O-modules resembles very much the S-modules. Both modules utilise the sensitive D latch.

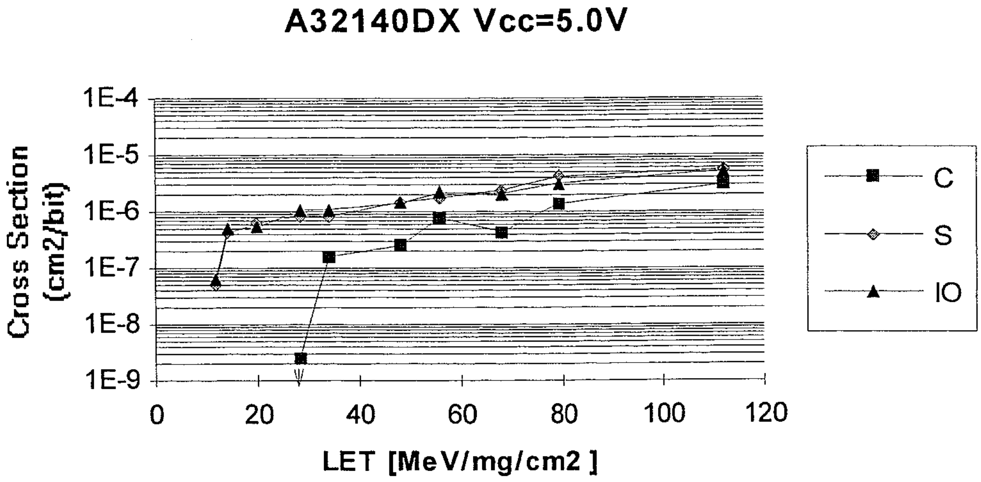
6.2.2. A32140DX

Graphical illustration of the upset probabilities for all modules are given in Figure 6.2.2.1, whereas Fig 6.2.2.2 to Fig 6.2.2.4 show the sensitivity for S, C and I/O modules, respectively. The number of bits subjected for tests are summarized in Table 6.2.2.1 below.

A32140DX resembles the results for A1280XL very much. Both device types belongs to the Actel Integrator Series and are manufactured in the same technology by the same manufacturer.

Table 6.2.2.1 Number of bit tested

	C-Module	S-Module	I/O-Module
A32140DX	512 (8 ring counters)	256 (4 ring counters)	64 (1 ring counters)



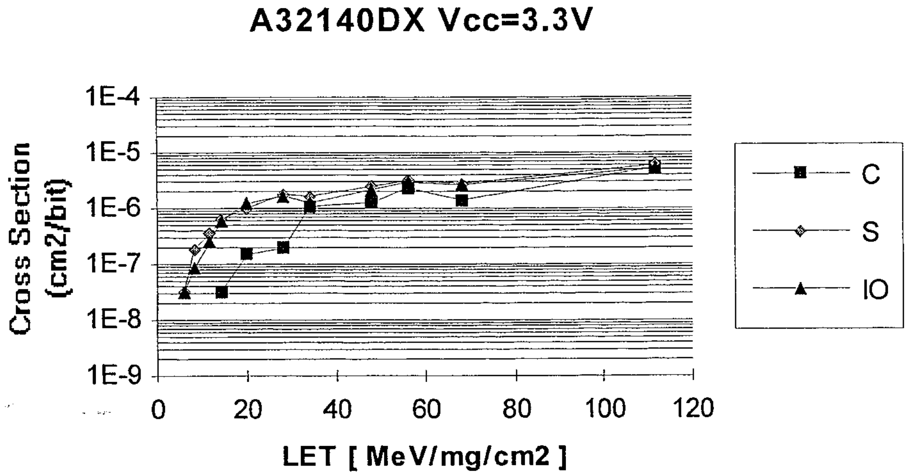
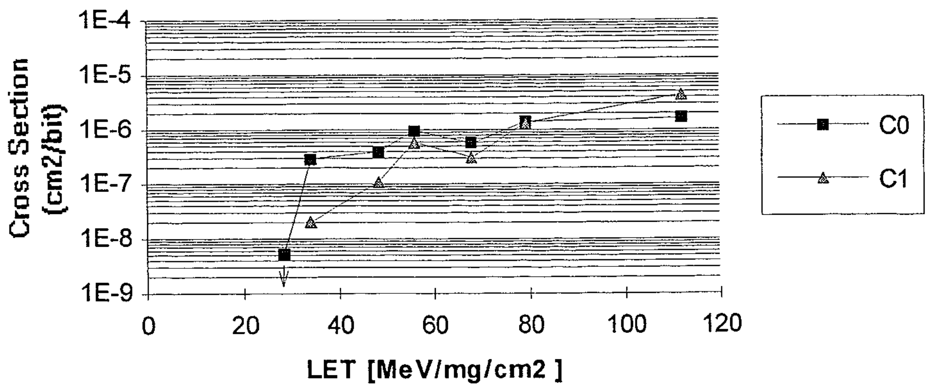


Fig 6.2.2.1 : Average SEU Cross Section for Actel A32140DX C, S and I/O-Modules

Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A32140DX, 256-pin PQFP, S/N #1, #2, #3
C-Module , Cross Section (σ) :	5V 8 E-7 cm^2 /bit 3.3V 2 E-6 cm^2 /bit
Threshold :	5V 30 $MeV/mg/cm^2$ 3.3V 15 $MeV/mg/cm^2$
S-Module , Cross Section (σ) :	5V 2 E-6 cm^2 /bit 3.3V 3 E-6 cm^2 /bit
Threshold :	5V 10 $MeV/mg/cm^2$ 3.3V 5 $MeV/mg/cm^2$
I/O-Module , Cross Section (σ) :	5V 2 E-6 cm^2 /bit 3.3V 2.5 E-6 cm^2 /bit
Threshold :	5V 10 $MeV/mg/cm^2$ 3.3V 5 $MeV/mg/cm^2$

A32140DX C-module Vcc=5.0V



A32140DX C-module Vcc=3.3V

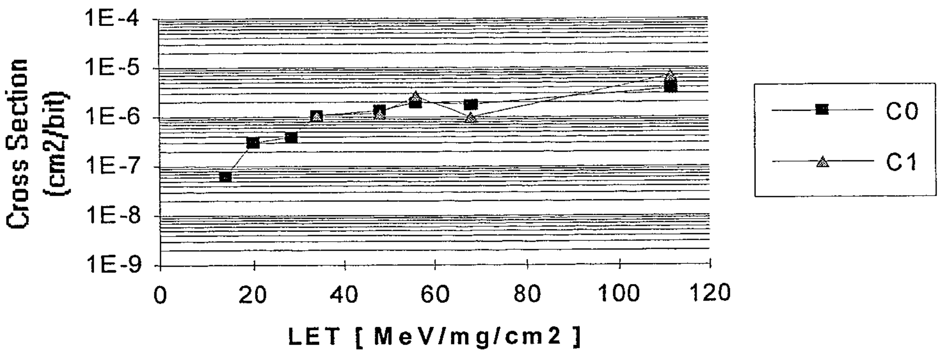
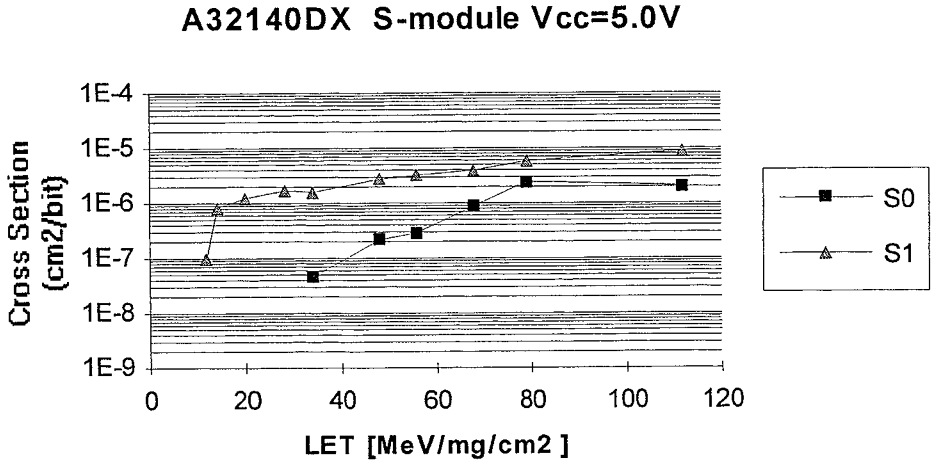


Fig 6.2.2.2 : SEU Cross Section for Actel A32140DX C-Modules

S/W Macro :	DFPC
Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A32140DX, 256-pin PQFP, S/N #1, #2, #3
C-Module Comments :	The differences in sensitivity between "1" and "0" are very small and only evident at low LET values for 5V. The C-module has reversed sensitivity of the "1" and "0" compared to S and I/O modules.



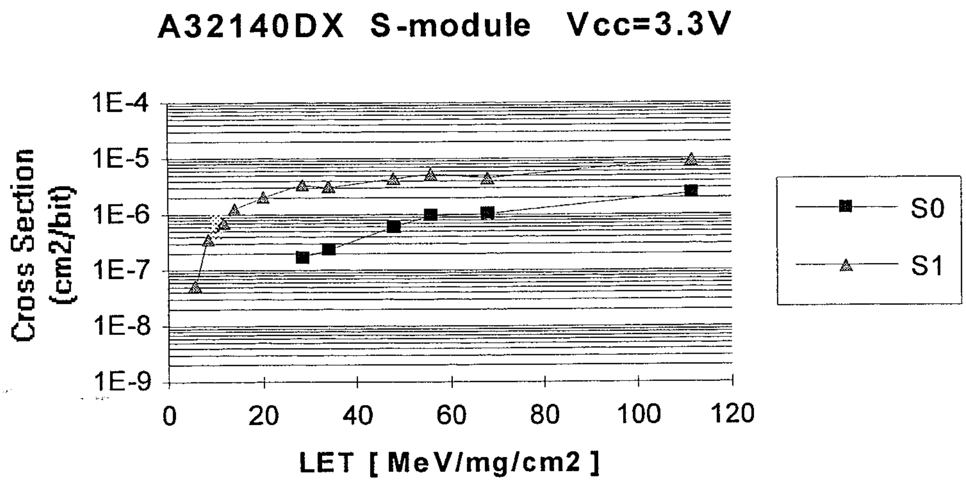
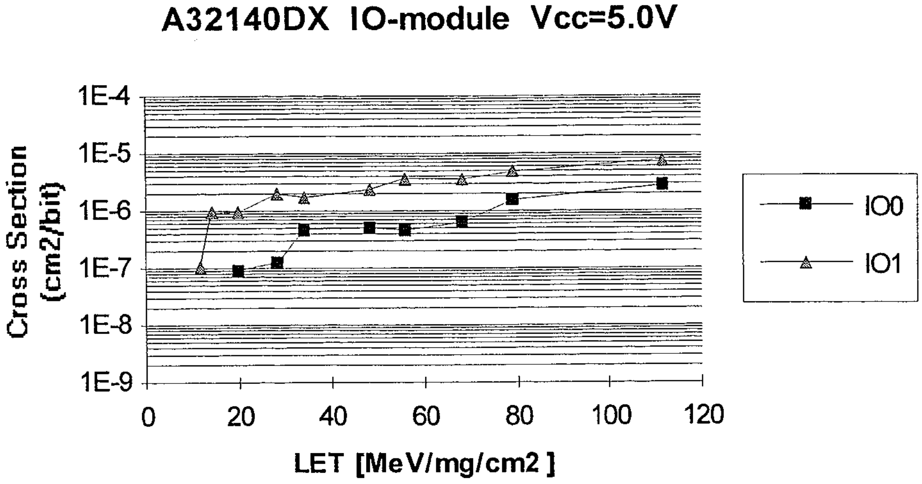


Fig 6.2.2.3 : SEU Cross Section for Actel A32140DX S-Modules

S/W Macro :	DFC1B
Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A32140DX, 256-pin PQFP, S/N #1, #2, #3
S-Module Comments :	The differences in sensitivity between "1" and "0" are about a factor 5 for both 5V and 3.3 V at large LET. The number of detected errors for "0" at low LET are very small which give statistical uncertain values for the lowest LET.



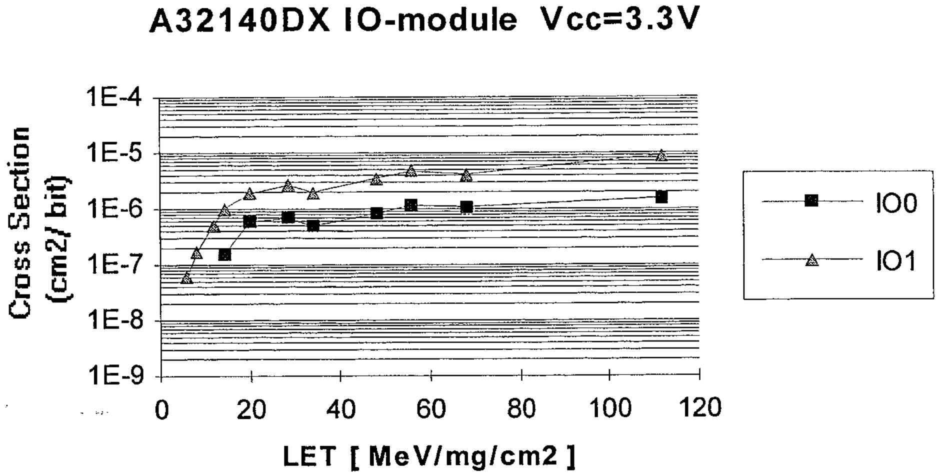


Fig 6.2.2.4 : SEU Cross Section for Actel A32140DX I/O-Modules

S/W Macro :	ORH for logic "1" , IR for logic "0"
Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	A32140DX, 256-pin PQFP, S/N #1, #2, #3
I/O-Module Comments :	Data for the I/O-modules resembles very much the S-modules.

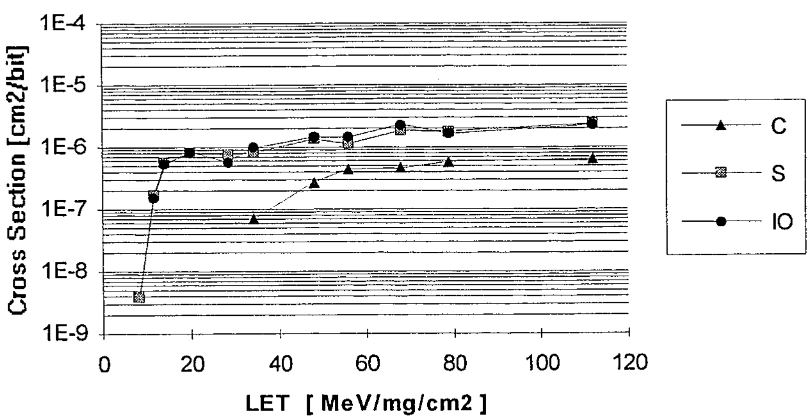
6.2.3. Actel RH1280

The RH1280 is programmed with 7 different S and 2 different C -macros in 9 shift registers, all 64 bit long. I/O modules has been designed with macros IR and ORH for input and output, respectively. The macros used are given in the Table below.
Shift register S0 has been generated using Act-Gen macro builder, which also selected the used macro (DFE3C). Graphical illustration of the upset probabilities for all modules are given in Figure 6.2.3.1, whereas Fig 6.2.3.2 to Fig 6.2.3.4 show the sensitivity for S, C and I/O modules, respectively.

The results of the S-macros are very similar to each other and indicate that there are basically no difference between the various tested macros, see Fig. 6.2.3.3. The majority of the errors within each ring counter are found in the "1" registers. The measured number of errors in the "0" registers will therefore be affected by larger statistical fluctuation.
For the two C-macros tested a small difference could be observed, particularly for the "0" see Fig 6.2.3.2. However, since the statistics for the "0" are pore in comparison with the "1", it is likely that this discrepancy are solely due to statistical fluctuation.
The average results over all tested flip-flops are given in Fig. 6.2.3.1

Table 6.2.3.1 Macros tested in different shift registers

Shift Register #	Macro	Modules C	Modules S
C0	DFPC	2	
C1	DFP1B	2	
S0	DFE3C		1
S1	DF1		1
S2	DFC1B		1
S3	JKF		1
S4	JKF2A		1
S5	DFM6A		1
S6	DFE		1



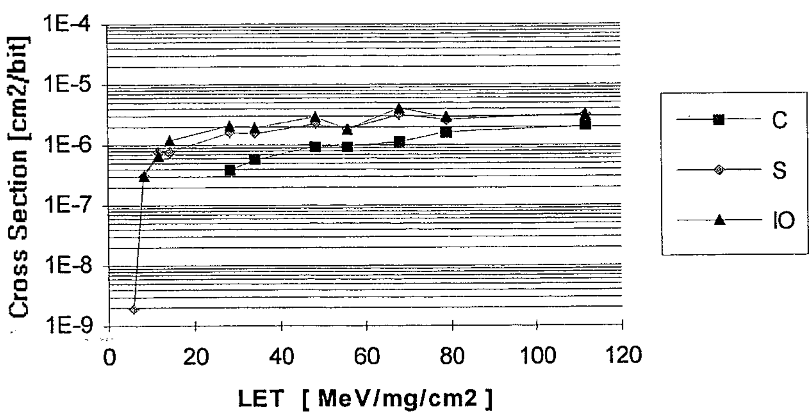
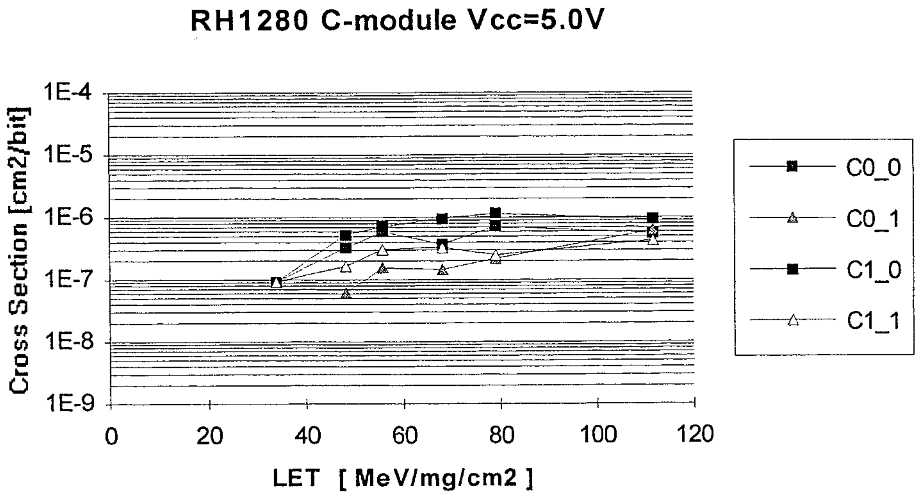


Fig 6.2.3.1 : Average SEU Cross Section for Actel RH1280 C, S and I/O-Modules

Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	RH1280, 172-pin CQFP, S/N #1
C-Module , Cross Section (σ) :	5V 4.5 E-7 cm^2 /bit 3.3V 8 E-7 cm^2 /bit
Threshold :	5V 30 $MeV/mg/cm^2$ 3.3V 25 $MeV/mg/cm^2$
S-Module , Cross Section (σ) :	5V 1.5 E-6 cm^2 /bit 3.3V 2 E-6 cm^2 /bit
Threshold :	5V 10 $MeV/mg/cm^2$ 3.3V 8 $MeV/mg/cm^2$
I/O-Module , Cross Section (σ) :	5V 1.5 E-7 cm^2 /bit 3.3V 2 E-6 cm^2 /bit
Threshold :	5V 10 $MeV/mg/cm^2$ 3.3V 8 $MeV/mg/cm^2$



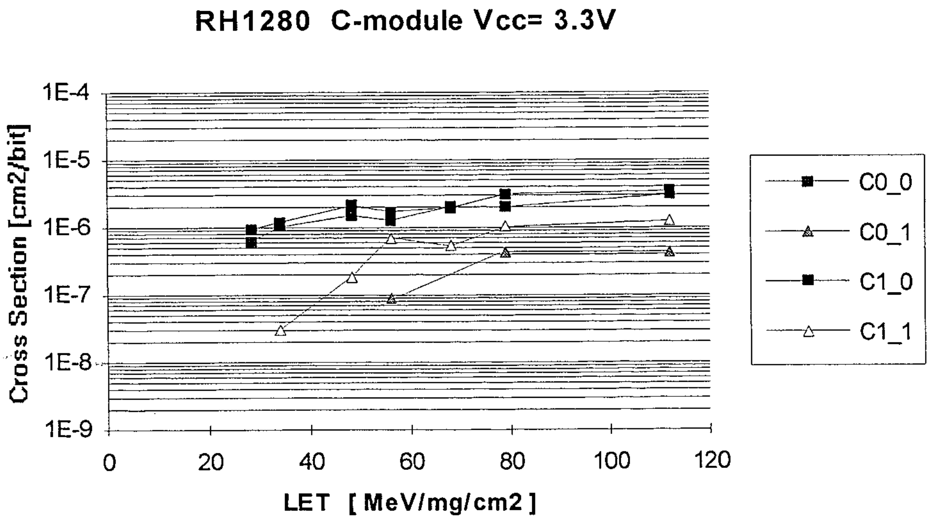
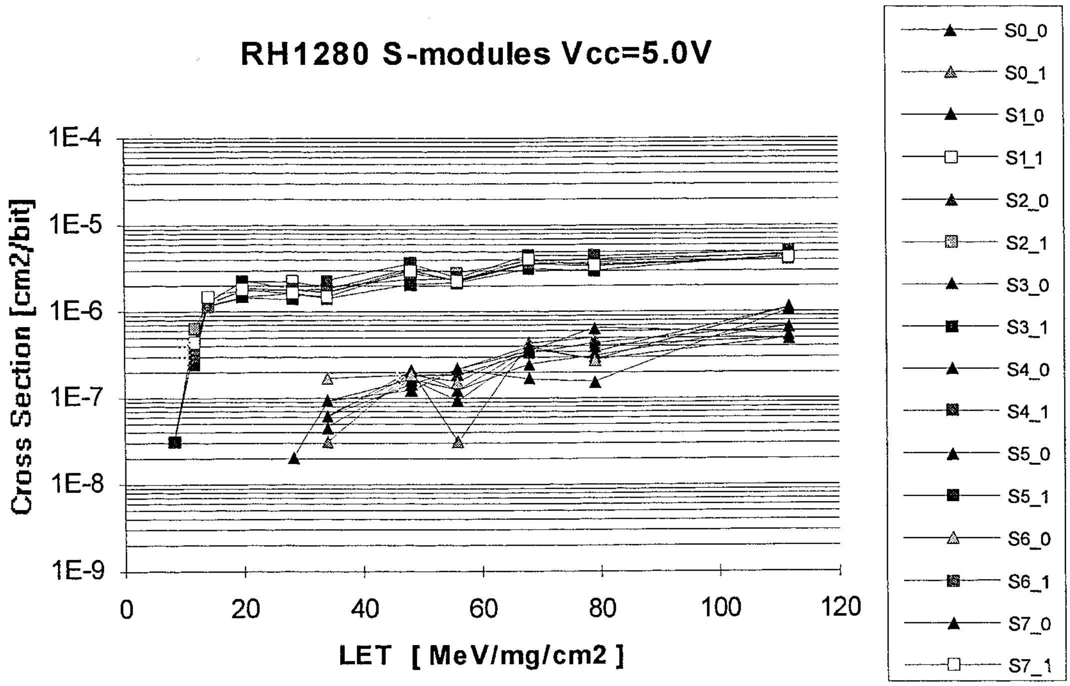


Fig 6.2.3.2 : SEU Cross Section for Actel RH1280 C-Modules

Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	RH1280, 172-pin CQFP, S/N #1
Macros :	CO=DFPC, C1=DFP1B
Comments :	Small differences in sensitivity of the two macros are observed, particularly for the "1" state. The basic differences between the macros are that DFPC have the functions "active low clear ", which is missing in DFP1B.



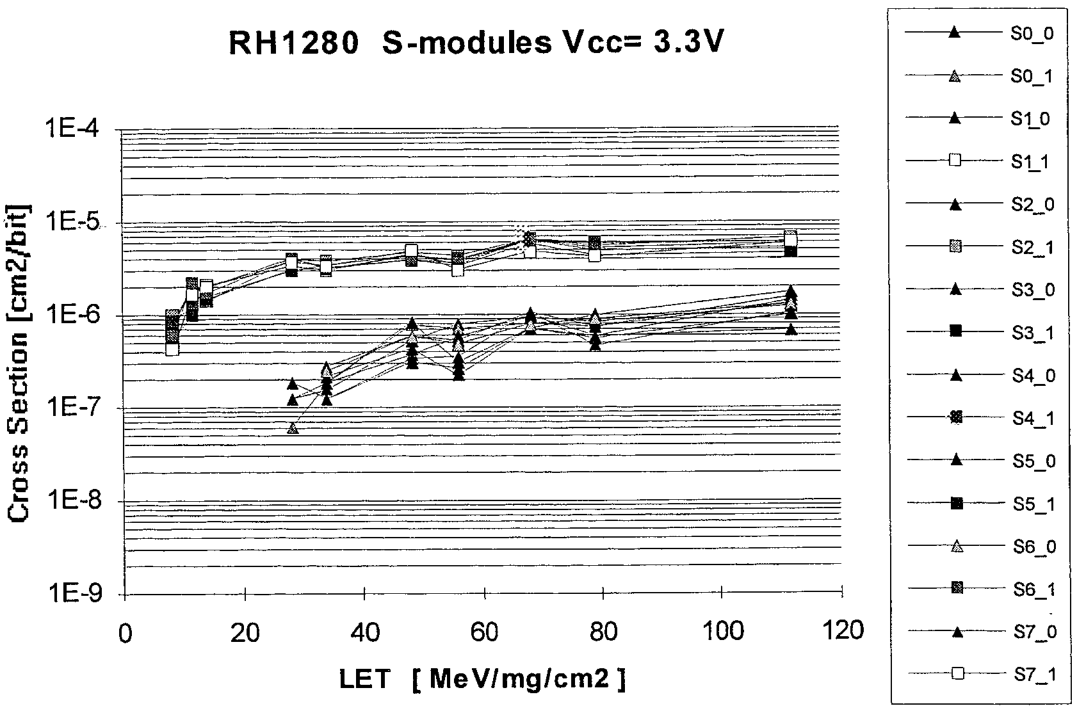
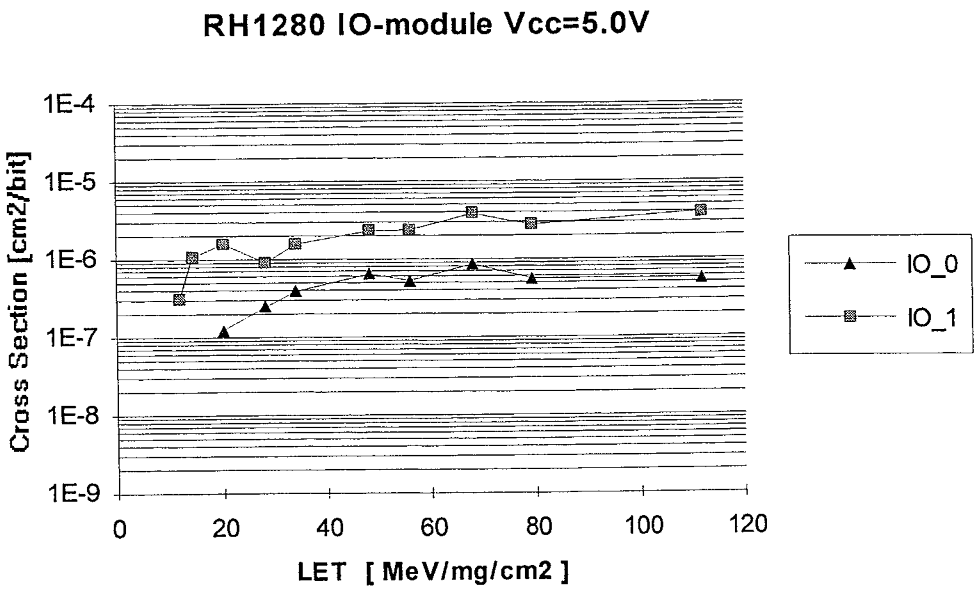


Fig 6.2.3.3 : SEU Cross Section for Actel RH1280 S-Modules

Comments :	No differences in SEU sensitivity of the 7 macros are evident. The spread in data points are due to statistical uncertainties.



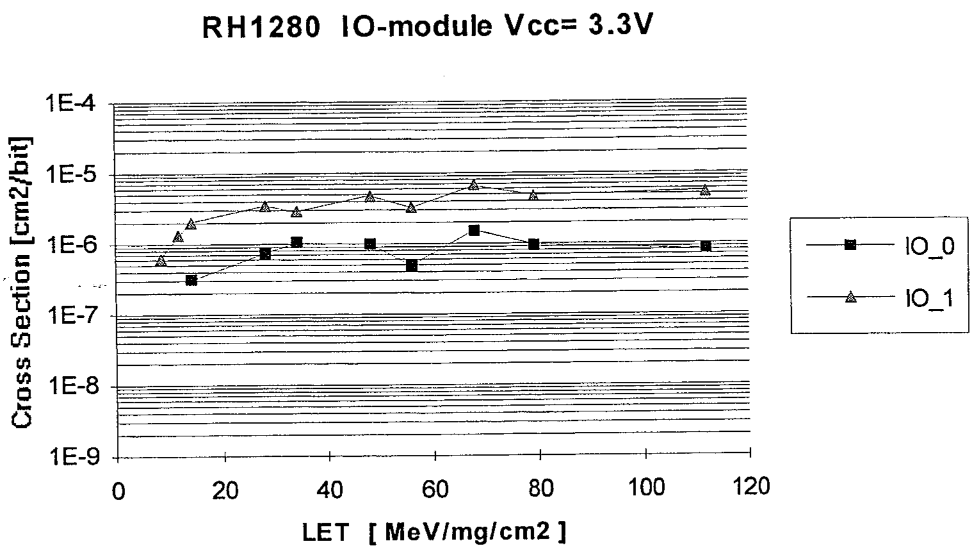


Fig 6.2.3.4 : SEU Cross Section for Actel RH1280 I/O-Modules

Test Condition :	Static, Vcc = 5V & 3.3V, T_{amb}= Room Temp
Test Samples :	RH1280, 172-pin CQFP, S/N #1
Macros :	IO_0=IR, IO_1=ORH
Comments :	I/O modules resembles the S-module in both sensitivity and the fact that high states are about 4-5 times more sensitive than the low state.

7. PROTON TESTS

7.1. Equipment & Facility

Proton test was performed at the Proton Irradiation Facility (PIF) at Paul Scherrer Institute, Villigen, Switzerland. Proton energy of 300 MeV can be achieved in a flux of maximum 10^8 protons/s / cm^2. The ion energy on target can instantly and continuously be attenuated by Aluminium slides from maximum energy down to about 30 MeV. Energy attenuation of the proton beam results in strongly reduced flux.

Two samples of each type A1280XL and A32140DX were dedicated for the proton test. The test board for one type at the time was mounted on a movable frame in front of the beam just behind the proton energy degrader system. The DUT is irradiated in air at normal incident angle. The facility provides beam diagnostic and control with continuous monitoring of beam fluence and flux via plastic scintillators.
The irradiation cave is prohibited area during "beam on", which require controlling equipment to be placed about 50 meters away from the DUT. The PC monitoring system was placed close to the DUT in the irradiation area and remote controlled by a second computer in the control room using thin Ethernet network.

7.2. A1280XL and A32140DX Results

Four samples of A32140DX and two samples of A1280XL were tested with 300 MeV protons at 3.3 V and 5 V. Proton upsets could not be confirmed before the samples fail to function from total dose damage. All samples failed around 7 - 10 10^{10} protons/cm^2 of 300 MeV protons equivalent to about 3- 4 krad(Si) total dose. Two of the four samples of A32140DX were back-up samples aimed and prepared for the total dose test, but due to the fast functional failure these were irradiated to further verify the results.

Table 8.2.1.1 Proton test results of A32140DX and A1280XL. All reults indicate the status of the devices at functional failure.

Device (S/N #)	Vcc (Volt)	Energy (MeV)	Fluence (prot/cm2)	Upsets #	Total Dose krad(Si)
A32140DX					
1	3.3	300	7,1E+10	0*	3,2
4	3.3	300	6,6E+10	0	3.0
2	5.0	300	7,2E+10	0	3,2
3	5.0	300	7,0E+10	0*	3,1
A1280XL					
1	3.3	300	1E+11	0	4,6
2	5	300	5,8E+10	0	2,7

* Indication of proton upset in the S-module preceding functional failure

A limit for the proton cross section of about < 4,4 E-14 cm^2 / bit could be deduced assuming one error and similar sensitivity for both S- and I/O-modules.

8. TOTAL DOSE TEST

8.1. Equipment & Facility

The total dose tests were performed at the hospital Sahlgrenska Sjukhuset, Göteborg. This facility has a ^{60}Co gamma source suitable for low dose rate testing. The dosimetry calibration are taken care of by the local medicine physicist. The dosimetry detectors undergoes calibration to a substandard on regular basis and the determined dose is correct within 5 %.

Three samples of each of the types A1280XL and A32140DX were tested.
Each device type were irradiated under steady state Vcc=5.0 V at a dose rate of 308 rad(Si) per hour. All devices were programmed with the test pattern presented in section 5.
The supply current was measured every 5 minutes. Function of devices were monitored once per minute by clocking in data followed by subsequent read out and comparison. The definition of functional failure is when read data do not match with pre-defined data. Functional tests were performed at 50 kHz with V_{CC}= 5.0 V.
Before each functional test, the devices were powered down for 5 seconds and allowed to stabilised for 2 seconds before the measurement. The test was perused up to a few krad(Si) total dose after first measured functional failure. After irradiation, the devices were subjected to biased room temperature anneal for one week.

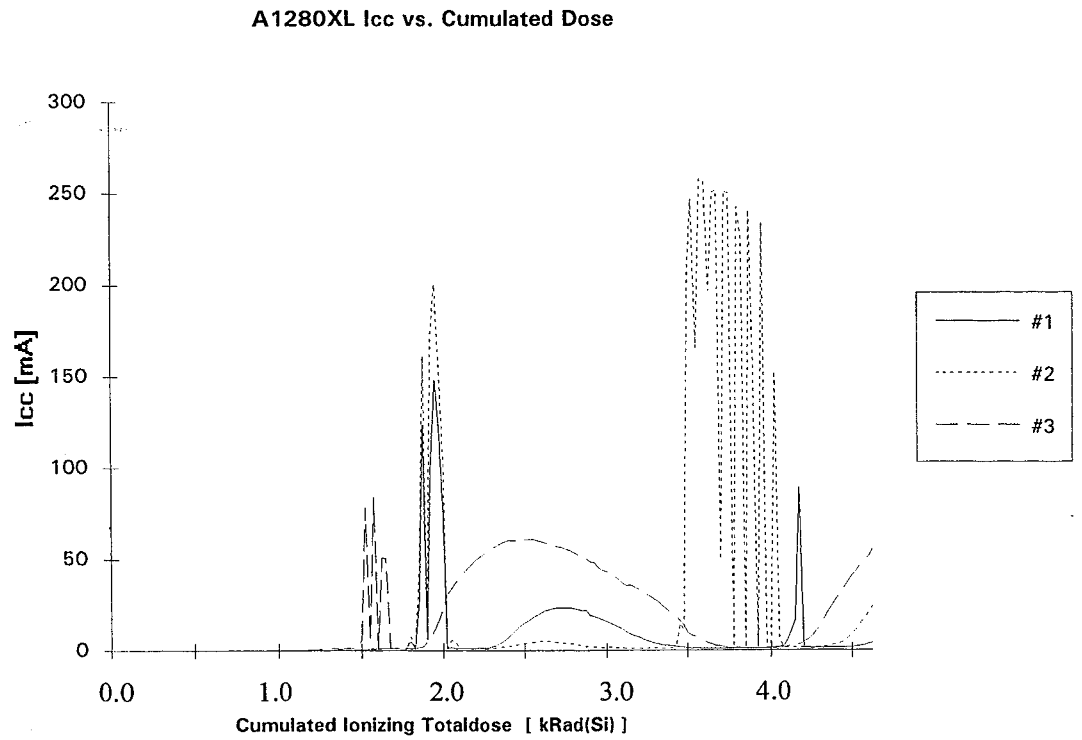


Fig. 8.2.1 *A1280XL supply current as a function of cumulated total dose. The devices were powered off/on for 5 seconds before each functional test. The spikes preceding the general increase of the current are temporarily high current values with functional failures in connection with power off/on of the devices.*

8.2. Total Dose Results

Both device types failed to function in the range of 1.6 - 1.9 krad(Si) cumulated dose when irradiated with ^{60}Co at a dose rate of 308 rad(Si)/hour. Functional failure was first detected after power on/off. Failures of the charge pump or the charge distribution system may cause unpredictable operation and are known to set the total dose limit. Figs 8.2.1 and 8.2.2 show the supply current as a function of cumulated dose. The spikes that occur after 1.5 krad(Si) indicate where functional problems first are observed after power on/off with subsequent functional failures.

Biased room temperature anneal with the devices subjected to the normal functional test each minute indicated still functional failure after one week and very little changes in the supply current. The biased room temperature anneal test is considered to be static.

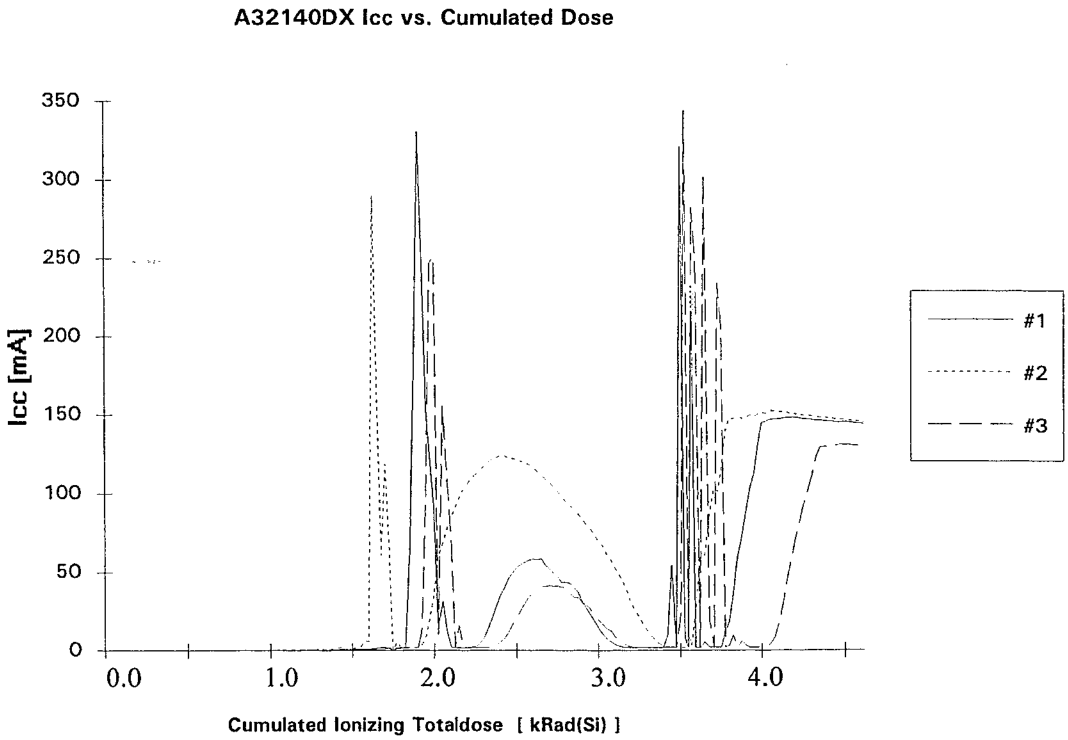


Fig. 8.2.2 A32140DX supply current as a function of cumulated total dose. The spikes preceding the general increase of the current are temporarily high current values with failure in the function test in connection with power off/on of the devices.

9. CONCLUSION

Actel A1280XL and A32140DX are manufactured by Chartered in antifuse ONO gate 0.6 µm, two-level metal CMOS technology. The total dose test indicate functional problems at power-on already before 2 krad(Si) cumulated total dose. In the proton test, no proton upsets could be detected before the devices failed to function at around 2.5-3 krad(Si) generated by 300 MeV protons. These results are consistent with observation by R. Katz, (http://flick.gsfc.nasa.gov/radhome/papers/eeefeb97.htm). Katz has also reported that A1280XL manufactured at Winbond in 0.8 µm technology fail between 2 and 4 krad(Si) cumulated dose. The total dose response for devices manufactured at MEC have shown to be remarkable harder than devices from Chartered and Winbond.

Due to the low total dose tolerance, all test samples indicated functional failure before any upset errors could be observed. In two of the test samples, S-module upset were observed in the same time as functional failure was detected. Wether the upset were real or due to the failure could not be determined. By adding the number of tested bits for the S- and I/O-modules (about the same sensitivity), an upper limit for the proton cross section at 3.3 V was calculated to be about $\sigma_p < 4,4$ E-14 cm^2 /bit for 300 MeV protons.

The results from the heavy ion tests indicate about the same SEU sensitivity for the present devices from Chartered as previously tested MEC manufactured A1280A and A1460.
Large difference in sensitivity between logical "1" and logical "0" are observed, particularly for S and I/O modules for all three device types. For the C-modules, a small difference in sensitivity are observed for A1280XL and A32140DX, while for RH1280 the difference is significant. For all three types logical "1" are the most sensitive for S- and I/O- modules, while it is the reversed for C-module.

A majority of the graphical illustrations exhibit "dips" in the SEU graph. This is likely due to ion penetration limitation in combination with board lay-out, programming features, possible package shadowing effects or beam misalignments. However, the observation of clear curve slopes for all tests, no further investigations have been carried out.

The RH1280 was used as test vehicle for different Actel macros (see Table 6.2.3.1). The SEU results indicated that there are basically no difference in SEU sensitivity between the various macros based on the S-module. For the C-module macros a difference could be observed for logical "1" flip-flops. However, it should be kept in mind that the statistical uncertainties are large. The results shown in Fig 6.2.3.2 for logical "1" are based on around 10 errors per data point for the high LET values.

Flip-flop's made of C-modules are more SEU hard than S and I/O modules when tested at 5 V. In particular, the threshold values for C are much higher. This difference in SEU sensitivity is clearly reduced when the devices are tested at 3.3 Volt.
Average SEU cross section and threshold values over all test samples are summarised in the Table 9.1 below.

Table 9.1 Summary of average cross section and LET threshold values

S-Module	A1280XL		A32140DX		RH1280	
	3.3V	5V	3.3V	5V	3.3V	5V
Cross Section (cm2/bit)	3.5 E-6	2.5 E-6	3.5 E-6	2.5 E-6	2 E-6	1.5 E-6
LET Threshold (MeV/mg/cm2)	5	10	5	10	8	10
C-Module						
Cross Section (cm2/bit)	2 E-6	8 E-7	2 E-6	8 E-7	8 E-7	4.5 E-7
LET Threshold (MeV/mg/cm2)	20	28	15	30	25	30
I/OModule						
Cross Section (cm2/bit)	3.5 E-6	2 E-6	3.5 E-6	2.5 E-6	2 E-6	1.5 E-6
LET Threshold (MeV/mg/cm2)	5	10	5	10	8	10