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TITLE

Radiation Pre-Evaluation of Actel FPGA RT54SX16 and A14100A

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SUMMARY

Total dose and Heavy ion tests have been performed on Actel FPGA RT54SX16 devices manufactured by Matshushita (MEC). The Total dose tolerance is much higher for this device type then for A14100A, while the heavy ion respone is about the same. No latch-up was detected up to LET=80 MeV/mg/cm2. No proton tests have been performed.

Total dose irradiation tests have been performed on samples of Actel FPGA's A14100A in order to investigate the impact of burn-in / non burn-in. From samples used in these tests, no significant difference on average radiation response could be detected. The spread in supply current between test samples were less on devices subjected to burn-in.

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1. ABSTRACT

Total dose and Heavy ion tests have been performed on Actel FPGA RT54SX16 devices manufactured by Matshushita (MEC). The Total dose tolerance is much higher for this device type then for A14100A, while the heavy ion response is about the same. No latch-up was detected up to LET=80 MeV/mg/cm2. No proton tests have been performed.

Total dose irradiation tests have been performed on samples of Actel FPGA's A14100A in order to investigate the impact of burn-in / non burn-in. From samples used in these tests, no significant difference on average radiation response could be detected. The spread in supply current between test samples were less on devices subjected to burn-in.

2. INTRODUCTION

In continuation of the Radiation pre-screening programme, the present study presents the radiation tests of Actel FPGA RT54SX16 and total dose re-testing of earlier tested Actel A14100A using a modified test method.
The devices have been functionally tested in-situ at 20 MHz and operated at the same frequency for 50% of the total irradiation time. In the other 50% of the irradiation time, the devices have been un-clocked in steady state. With respect to the increase in standby current, this test method indicates higher total dose tolerances [1].

3. TEST SAMPLES

The A14100A is a third generation FPGA from Actel. The tested devices were manufactured by Matshushita. The devices employ antifuse technology implemented in ONO gate, 0,8 um, two level metal CMOS. This device is a 10000 gate FPGA with 697 S-modules and 680 C-modules. No manufacturer screening has been performed on the devices prior to irradiation tests. The samples have not been subjected to burn-in. The samples originate from a MIL-STD-883 batch, which explains the 'B' on the marking.

	Marking / *Top side*	Marking / *Bottom Side*
A14100A	Actel Logo A14100A CQ256B 9818	UCL054 005 USA

The RT54SX16 are the new generation FPGA from Actel. The die of the tested devices were manufactured by MEC in 0.6u 3-metal CMOS technology. The devices employ antifuse technology implemented in metal-to-metal programmable elements embedded between metal layers M2 and M3. The devices support 3,3V operation and are designed to tolerate 5 V inputs. This device type is a 16000 gate FPGA with 528 dedicated register logic modules (R-cells). The R-cell is the equivalent S-logic module increased with more control signals.
Marking of the tested devices is shown below. The package was Ceramic Quad Flat Pack with 256 leads. No screening has been performed on the devices prior to irradiation tests. The samples have not been subjected to burn-in. The samples originate from a MIL-STD-883 batch, which explains the ‘B’ on the marking.

RT54SX16	Marking / *Top side*	Marking / *Bottom Side*
	Actel Logo	P04
	RT54SX16	001
	CQ256B 9832	USA

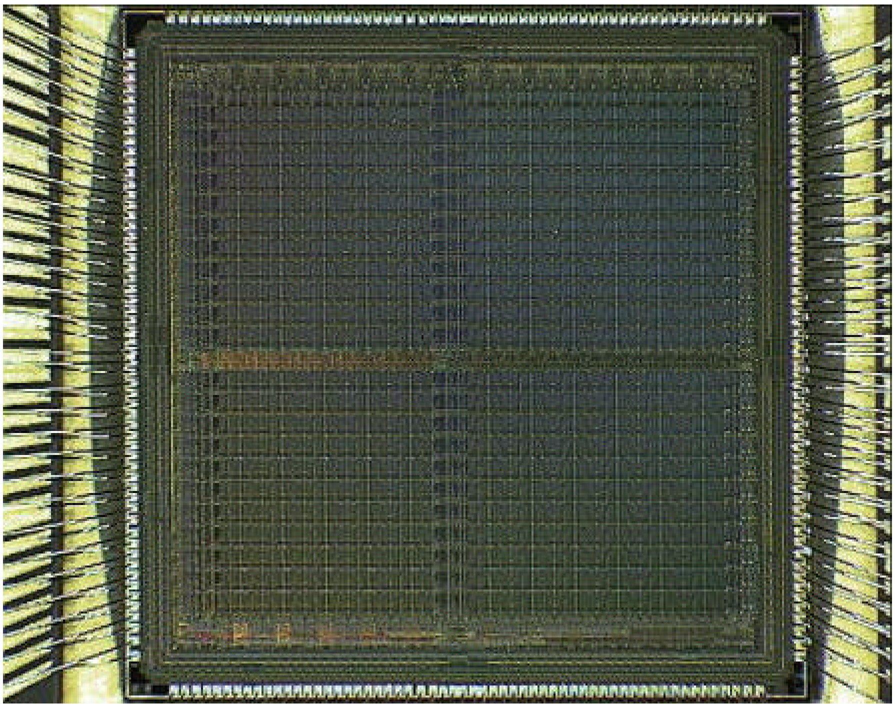


Fig 3.1 Picture of the RT54SX16 chip, magnification x11,7. The chip size is 77x77 mm^2.

4. Test Techniques

4.1 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. New data is loaded into the DUT's at the same time as old is read out.

A flow chart of the test sequence is given in Fig 4.1.1. Any detected errors will be stored in FIFO's, and the DUT will be loaded with new data again. The cycle will then be repeated. Failing read/write operations from/to the DUT will determine the functionality. The clock speed is variable up to 20 MHz. Error Data are serially transferred from the FIFO to a PC where data are analyzed. For each DUT, errors can be traced down to logic module, logic value and position.

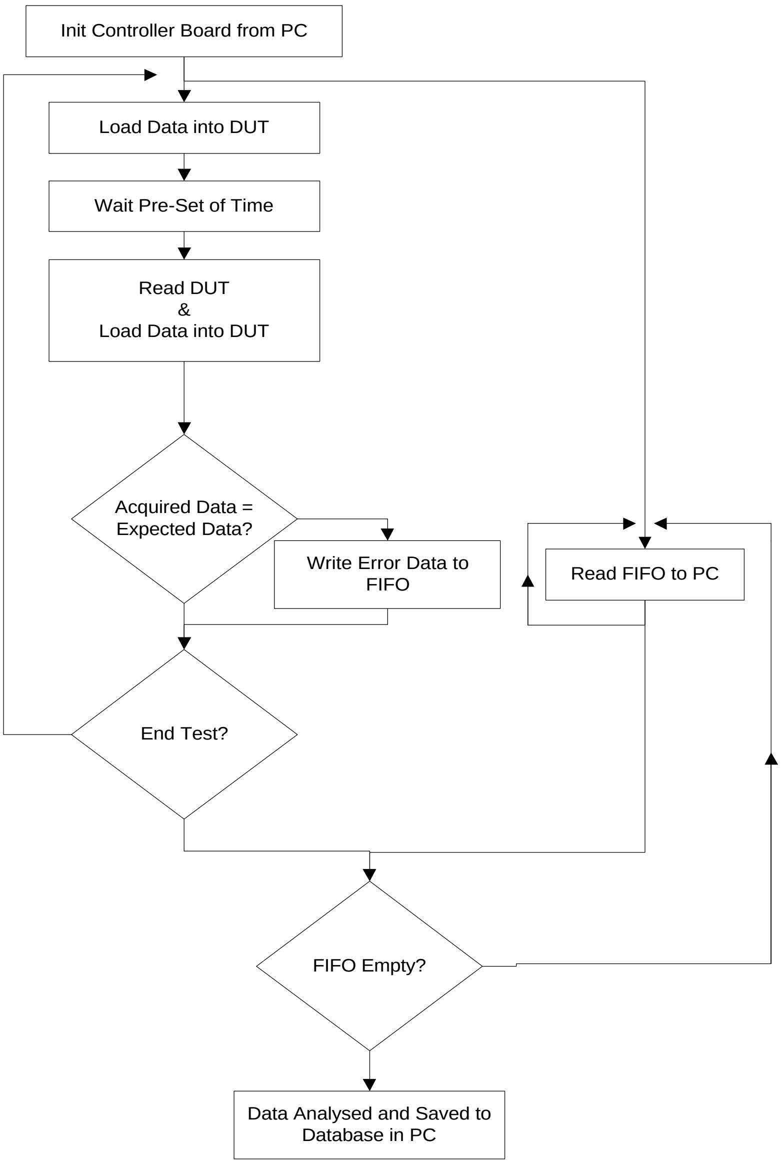


Fig 4.1.1 Flow chart of the test sequence.

4.2 Test Boards

The test system consist of two boards, one Controller board managing the test sequence and the serial interface to the PC and one DUT board housing two Devices Under Test (DUT). A principal drawing is given in Fig 4.2.1 and a picture of the boards is shown in Fig 4.2.2.

The Controller board tests one DUT at a time 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 stored in SRAM’s. The general concept of the error detection and test sequence is shown in Fig 4.1.1. The DUT is continually cycled while the outputs of selected ring counters are compared with the "golden chip". When an error is detected (when outputs do not match), the state of all outputs and position in cycle of the failing ring counter will be temporarily stored in FIFO's. Data in the FIFO's is continually send to a PC through a RS232 serial interface. After each test run the data are analyzed and stored in a database by the controlling PC.

The controller board also control the power supply for the DUT's by relays and send status signals to a Data Logger connected to the board.

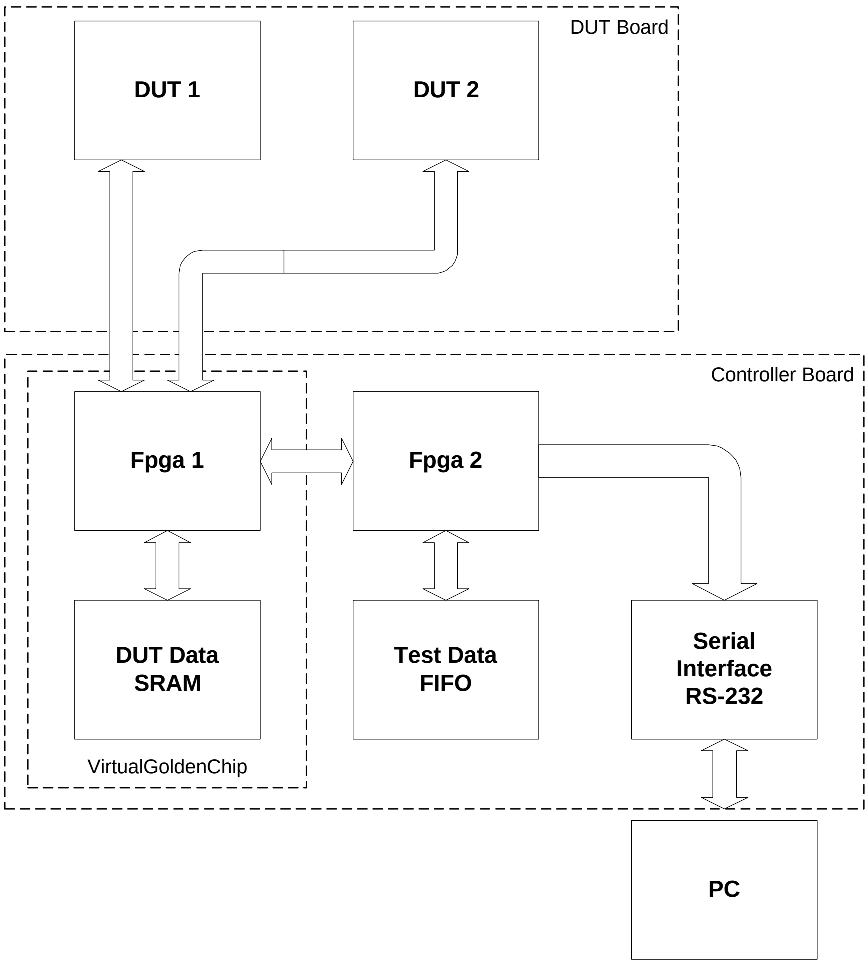


Fig 4.2.1 Principal drawing of DUT board and Controller Board

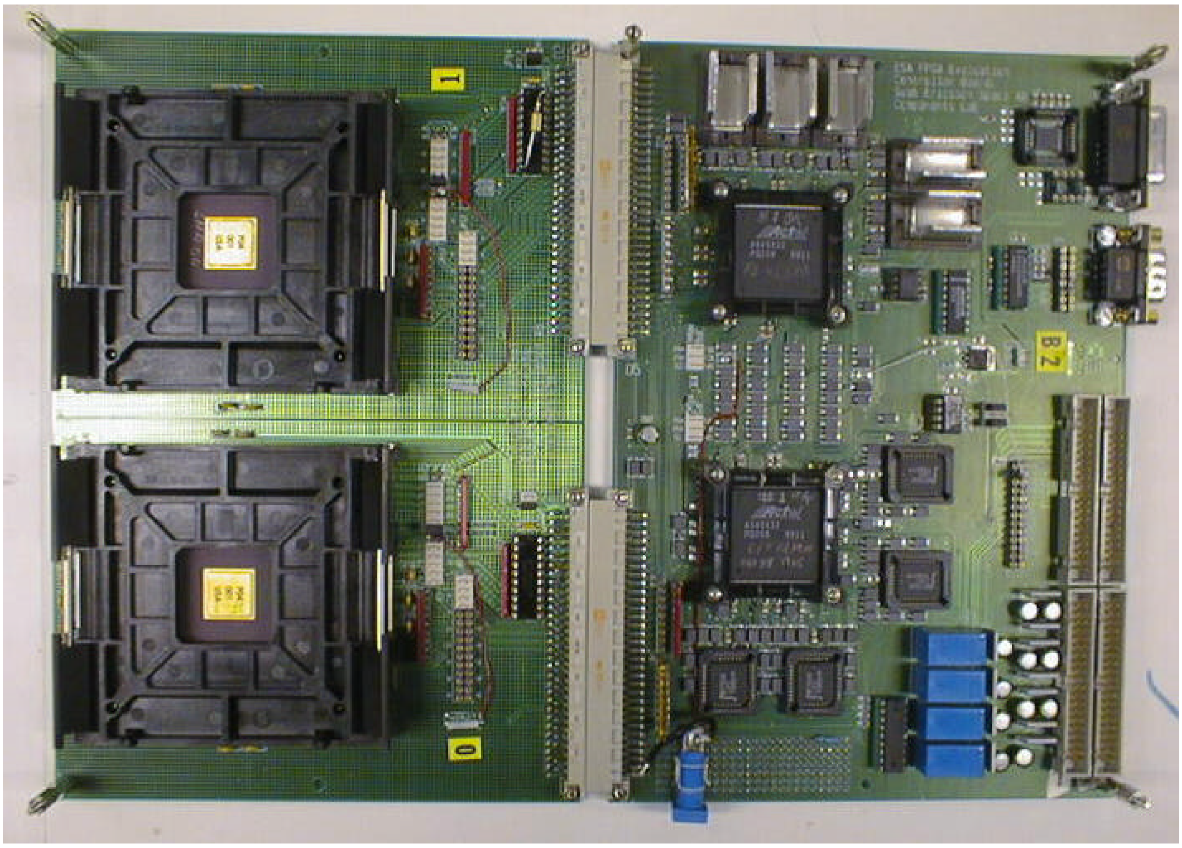


Fig 4.2.2 Photo of the test board. On right side is the controller board connected via two 64 pin connectors to the DUT board on the left. All control logics are implemented in two FPGA's.

4.3 Test Methods

Total dose tests have been performed by loading data into the DUT's, pause for a pre-set of time and check for errors. To test for start-up problems, the bias to the DUT's was always turned off/on before function test. The supply current to the DUT was monitored continuously. The following test cycle was performed:

1) DUT turned off during 10 seconds
2) DUT turned on
3) DUT tested for functionality at 20 MHz
4) DUT biased for 45 minutes for A14100A and 120 minutes for RT54SX16
5) DUT biased for 1 minute in static mode for measurements of standby current

During step 4, the test samples have been left in bias conditions toggled in a un-clock / clock sequence for equivalent 64 clock pulses at 20 MHz. The supply current and the bottom case temperature were monitored throughout the tests.

The DUT's are tested using a "virtual golden chip" test method. The principal of the technique is to compare each output from the DUT with the correct data stored and controlled by the monitor board closely connected to the DUT-board.
The layout of the DUT's have been a bit pattern consisting of consecutive 0 1 0 1 etc in individually controlled 64-bit ring counters.

4.4 Test Conditions

4.4.1 RT54SX16

Four non burn-in samples have been tested at a dose rate of 750 rad (Si)/h to accumulated dose of 100 krad (Si). The devices have been biased at 3,3 V supply voltage for I/O's and array. A 5V supply voltage is also required for input tolerance of internal biasing. The dynamic supply current has been around 50 mA.

During irradiation, ambient temperature has been around 22 ºC and the outer case temperature on the bottom lid for chip attachment has been around 25ºC. The package has a metal "lid" on the backside of the package where the temperature has been measured.

The DUT's have been programmed with eight "64 bit" R-cell shift registers.

The I/O output pins used for test have been loaded with an RC-load equivalent to 100Ω&100 nF serial connected to ground.
Pre- and post irradiation electrical measurements have been performed according to Table 4.4.1. These parameters have been measured at I/O pins connected to a specially programmed test area stimulated similarly as the main array area.
The AC parameters have been measured with oscilloscope and the DC parameters with SE's component tester, SZ M3000.

Table 4.4.1 Electrical parameters and conditions for RT54SX16

TEST PARAMETER	TEST CONDITIONS	LIMITS from Actel	
		Min	Max
I_{CC}	V_{CCR} = 5,0 V V_{CCI} & V_{CCA} =3,3 V		4 mA
Functionality	f_{CLK} =20 MHz		
Input current low , I_{IL}	V_I = 0,3 V	*	*
Input current high , I_{IH}	V_I = 5,0 V	*	*
Voltage output low, $V_{OL\ (CMOS)}$ [1]	V_{CC} = 3,3 V Output current = 6.0 mA		0.5 V
Voltage output high, $V_{OH\ (CMOS)}$ [2]	V_{CC} = 3,3 V Output current = -4.0 mA	2.4 V	
Output Tristate Current High, I_{OZH}	V_{CC} = 3,3 V V_O = 3,3 V	*	*
Output Tristate Current Low, I_{OZL}	V_{CC} = 3,3 V V_O = 0 V	*	*
Timing = delay of signal between two I/O pins	V_{CC} = 3,3 V, Threshold = 1,5 V		

* Limits not specified by Actel
[1] Limits is specified with Output current = 8.0 mA
[2] Limits is specified with Output current = -12 mA

4.4.2 A14100A

Four non burn-in samples and four burn-in samples biased at 5V have been tested at a dose rate of 1300 rad (Si)/h to a cumulated dose of 30 krad (Si). During irradiation, ambient temperature has been around 22 ºC and the outer case temperature on the side for chip attachment has been around 60ºC. Pre-irradiation dynamic supply current was around 300 mA.

The DUT's have been programmed with eight "64 bit" C-module shift registers, four "64 bit" S-module shift registers and one "64 bit" I/O module shift register.

Burn-in has been performed on blank devices at 125ºC for 168h. On the SE manufactured burn-in board, all I/O's were pulled up with 3.3 kohm, five clock signals were connected to 500 kHz via 1.2 kohm. The devices were connected to a supply voltage of 5.5V.

The I/O output pins used for test have been loaded with a RC-load equivalent to 100 Ω&100nF serial connected to ground.
Pre- and post irradiation electrical measurements have been performed according to Table 4.4.2. The AC parameters have been measured with oscilloscope and the DC parameters with SE's component tester, SZ M3000.

Table 4.4.2 Electrical parameters and conditions for A14100a

TEST PARAMETER	**TEST CONDITIONS**	**LIMITS from Actel**	
		Min	**Max**
I_{CC}	V_{CC} = 5,0 V		2 mA
Functionality	f_{CLK} =20 MHz		
Input current low , I_{il} [1]	V_I = 0,3 V	-10µA	+10µA
Input current high , I_{ih}	V_I = 4.5 V	-10 µA	+10 µA
Voltage output low, $V_{OL\ (CMOS)}$ [2]	V_{CC} = 5,0 V Output current = 8.0 mA		0.33 V
Voltage output high, $V_{OH\ (CMOS)}$ [3]	V_{CC} = 5,0 V Output current = -6.0 mA	3.84V	
Output Tristate Current High, I_{OZH} [4]	Vcc = 5,0 V, Vo = 4,5 V	-10 µA	+10 µA
Output Tristate Current Low, I_{OZL}	Vcc = 5,0 V, Vo =0 V	-10 µA	+10 µA
Timing = delay of signal between two I/O pins	V_{CC} = 5,0 V Threshold = 1,5 V		

[1] Limits is specified with V_I = GND
[2] Limits is specified with VCC = min (4.75V) and Output current = 6 mA
[3] Limits is specified with VCC = min (4.75V)
[4] Limits is specified with V_I = VCC

4.5 Facility

The total dose tests were performed at the hospital of Borås. This facility has a Cobalt-60 source suitable for low dose rate testing.
The exposition rate was calibrated by staff from Department of Sjukhusfysik at Borås hospital. The source is calibrated for dose rate to water and then calculated for expected dose rate to Silicon. The determined dose is correct within 10%.

Heavy ion tests were performed at the heavy ion facility at UCL/Belgium. The test conditions from the SEE tests are given in Table 6.1 together with the results.

5. TID RESULTS

5.1 A14100A

This device type was used as test vehicle for burn-in / non burn-in comparison. Four samples of each burn-in / non burn-in were irradiated. Average values of in-situ measurements of the supply current are presented in Fig 5.1.1 below. The average irradiation response seems to be the same for the two groups. However, the spread in the leakage current is less for the samples subjected to burn-in as can be seen in Fig 5.1.2 where the individual supply current measurements are shown. One reference sample for each burn-in / non burn-in group have been used.

Pre- and post electrical measurements indicate very little difference between burn-in and non burn-in devices over the tested cumulated total dose. The results are shown in Figs 5.1.3 to 5.1.6.

The Output Voltage Low (Vol) indicate small changes with cumulated dose in contrast to the A1425A devices [1]. According to Actel, the A14100A should only be an up-scale of A1425A. In such a case they should suffer about the same problems. The leakage current after 30 krad (Si) cumulated dose is about 4 times higher in A14100A. Pre-irradiation dynamic supply current was about 4 times higher leading to a 50% higher case temperature on the A14100A. This may have an annealing effect, which could explain the difference.

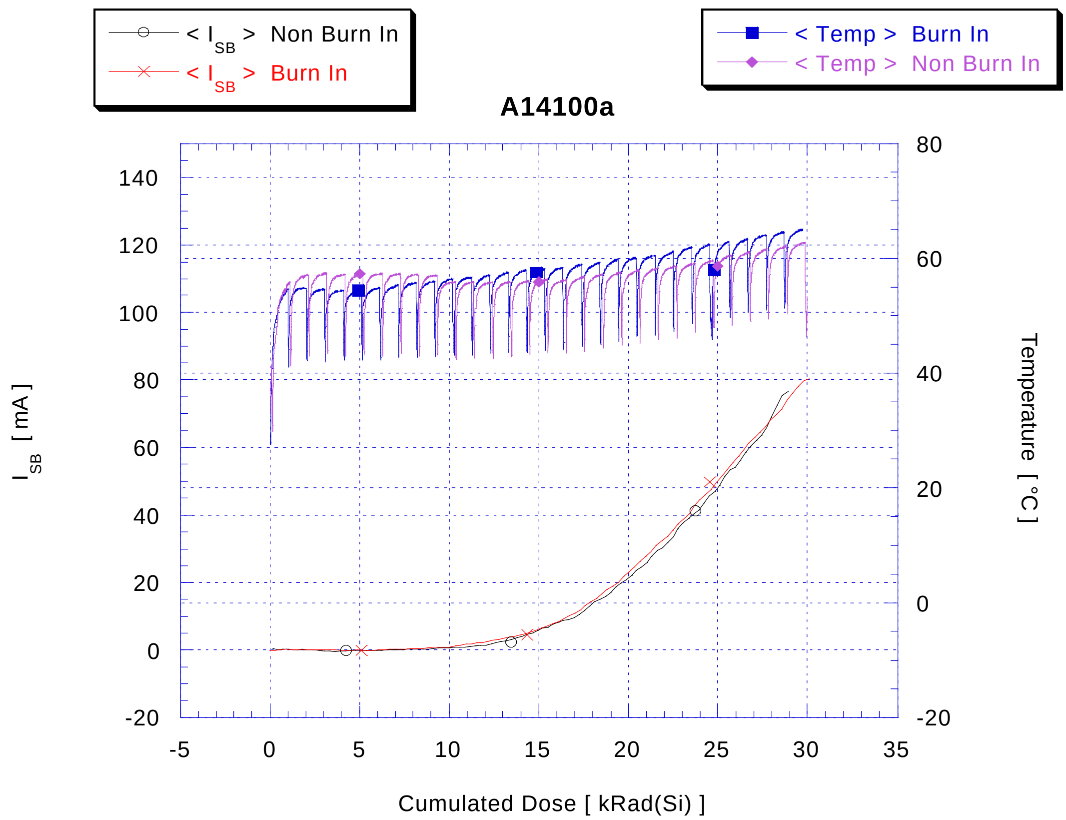


Fig 5.1.1 Average standby current (I_{sb}) as a function of cumulated dose for A14100A. The devices were powered off/on for 10 seconds every 45 minutes. This is seen as "dips" in the temperature curves.

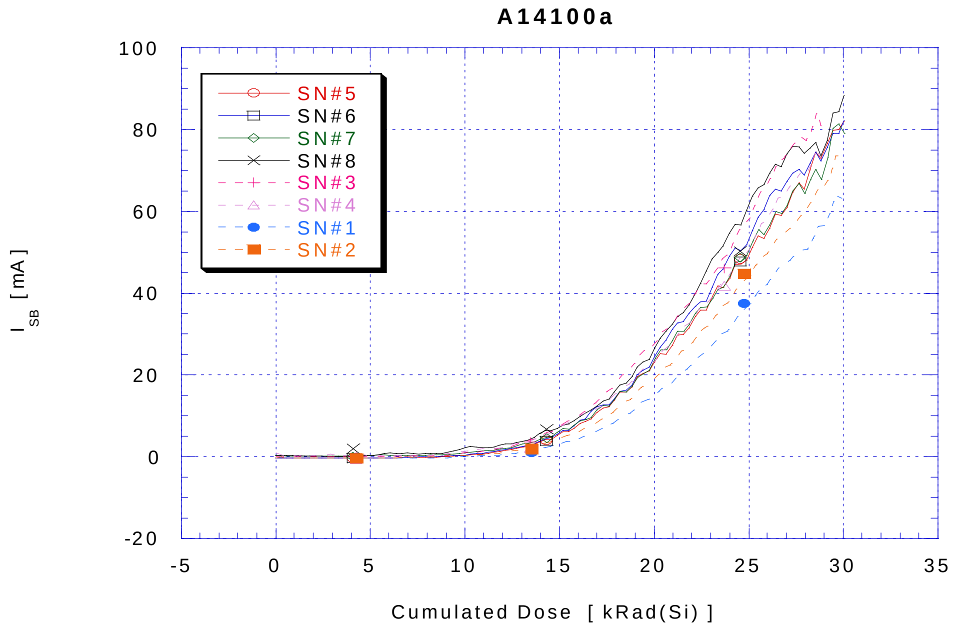


Fig 5.1.2 Standby Current (I_{sb}) as a function of cumulated dose for A14100A, all devices. The dashed lines represent the non burn-in samples, S/N#1-4. The spread in leakage current is much less for samples subjected to burn-in.

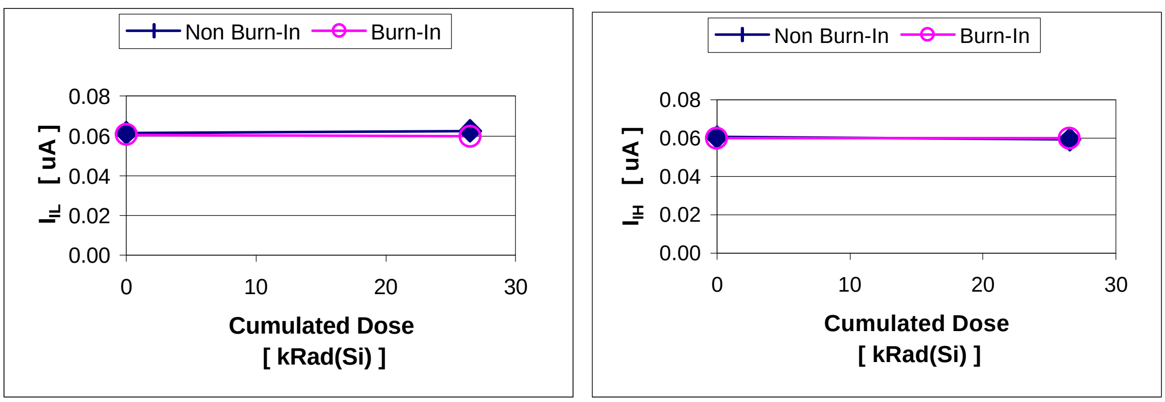


Fig 5.1.3 Input Current Low (left) and High (right) as function of cumulated dose. No spread due to clocking of I/O's could be detected compared to A1425A [1] where large difference was observed. The case temperature for A14100A was about 60°C while the temperature of A1425A was 35° C. Data specification limit is ± 10µA for $V_I = V_{CC}$ or GND.

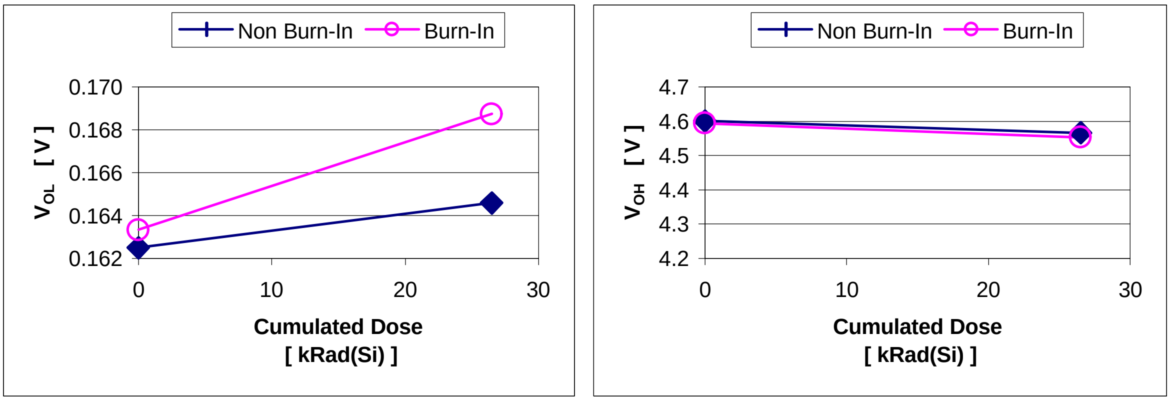


Fig 5.1.4 Output Voltage Low (left) and High (right) as function of cumulated dose. Data specification limit is 0,33 V for V_{OL} and 3.84 V for V_{OH} at I_O= ± 6 mA.

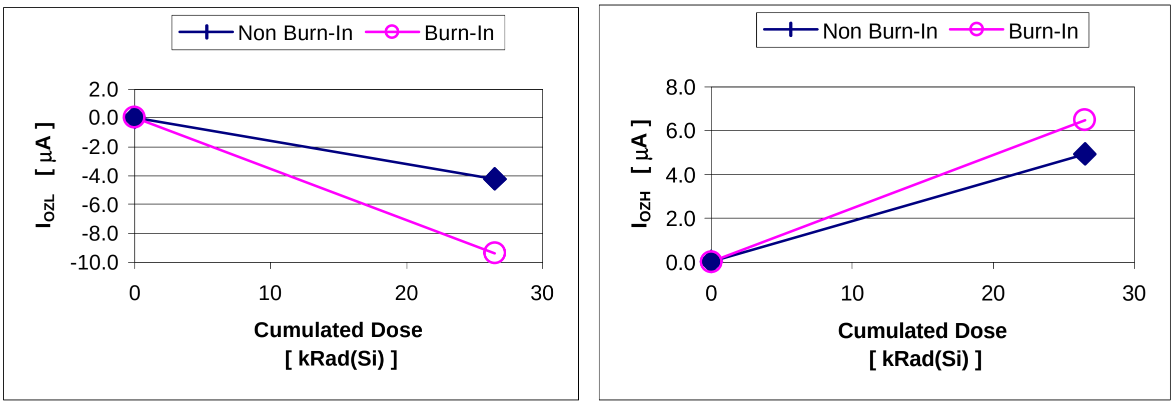


Fig 5.1.5 Output Tristate Current Low (left) and High (right) as function of cumulated dose. Data specification limit is ± 10 µA for V_I = V_{CC} or GND.

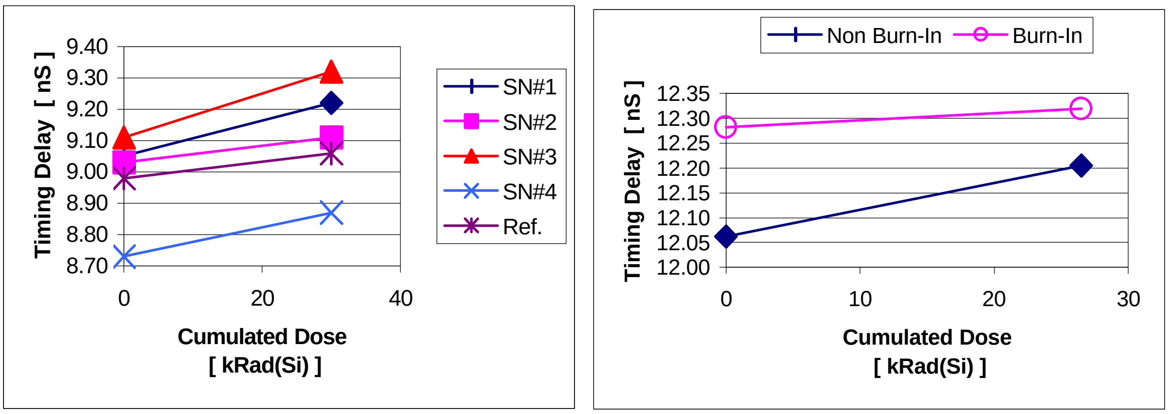


Fig 5.1.6 I/O Timing delay as a function of cumulated dose. The left figure shows the timing delay measured from I/O-to-I/O for all non burn-in samples measured. The right figure shows the average results for burn-in and non burn-in devices where the timing has been measured I/O to I/O via a C-module. These measurements are very sensitive to power supply value and temperature values.

5.2 RT54SX16

The standby current as a function of cumulated dose is shown in Fig 5.2.1. Compared to A14100A, this device type seems to have a much higher total dose tolerance. At 30 krad (Si) total dose, hardly any indication of leakage could be detected while the leakage for A14100A was about 80 mA. The tested devices were functioning at 100 krad (Si) cumulated dose.
The case temperatures of RT54SX16 were low compared to A14100A.

Pre- and post irradiation parameter measurements have been performed. The results are shown in Figs 5.2.3 to 5.2.7 Avialable specification limits given by Actel preliminary specification “54SX Family FPGAs RadTolerant and HiRel” v1.4 are indicated in Table 4.4.1 and below each applicable figure.

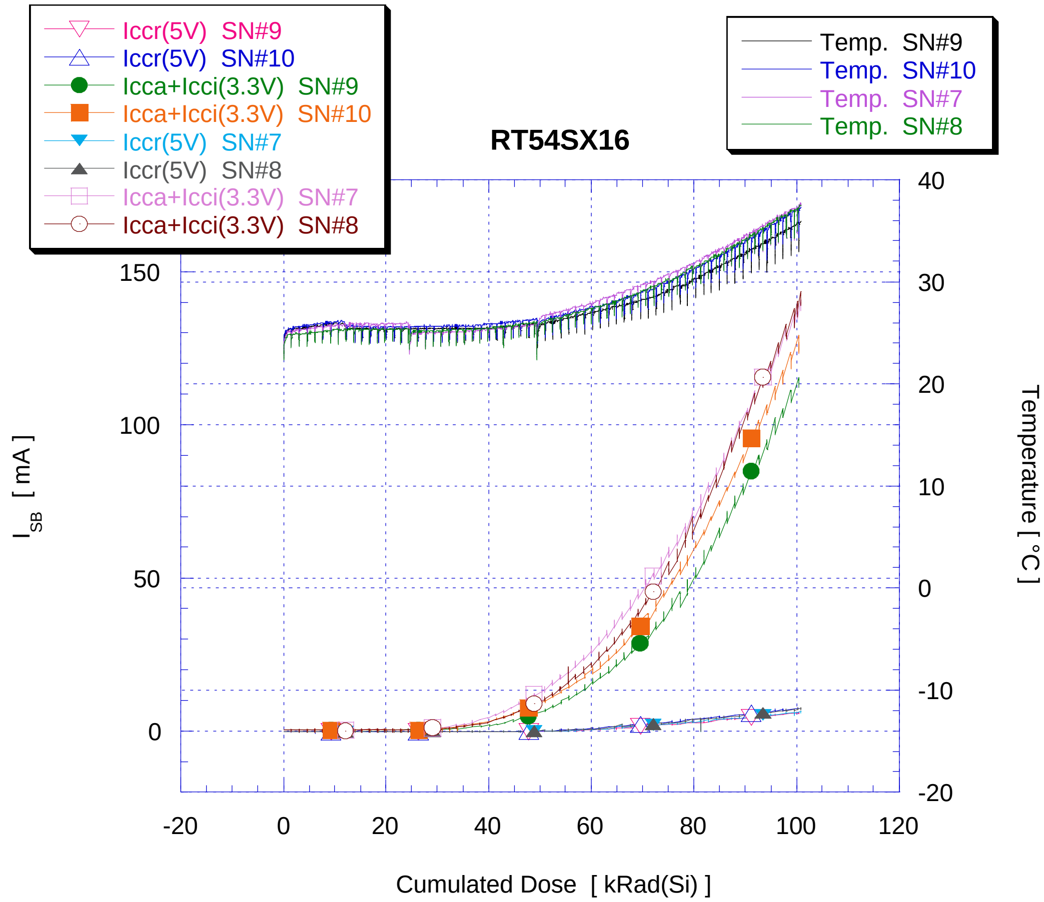


Fig 5.2.1 Standby current (I_{sb}) as a function of cumulated dose for the four tested devices. Supply voltage for I/O’s and array has been 3,3V. The 5V supply voltage is required for input tolerance of internal biasing. The devices were powered off/on for 10 second every 30 minutes. This is seen as “dips” in the temperature curves.

The RT54SX16 samples have been subjected to biased annealing at room temperature. The samples have been conditioned in the test board in the same way as they were irradiated. The results are shown in Fig. 5.2.2. This device type does not show the same fast annealing as A14100A.

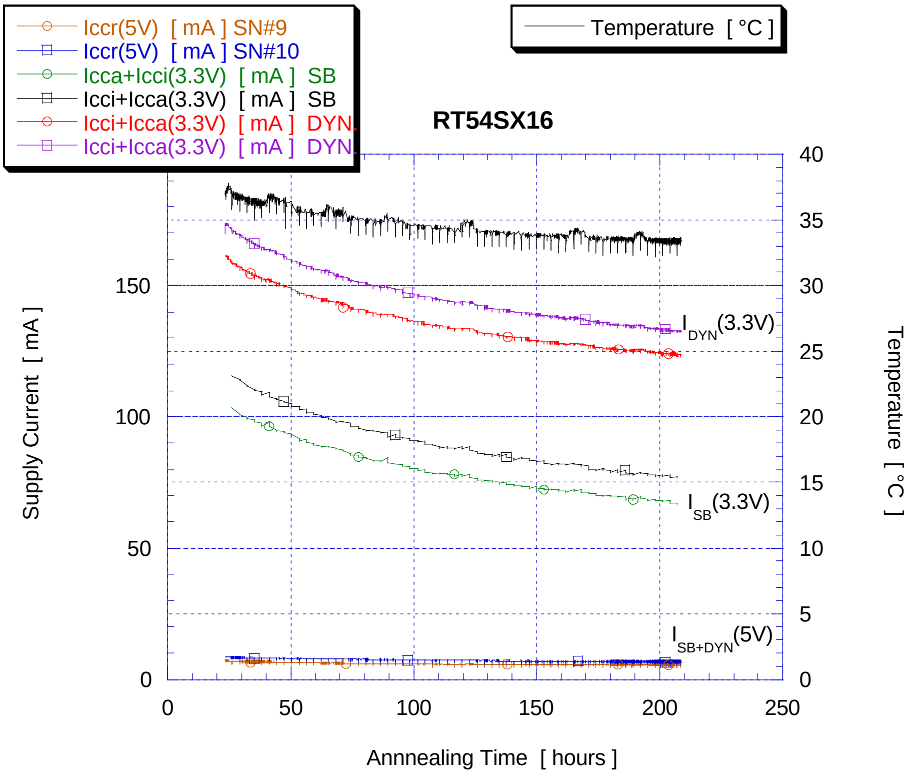
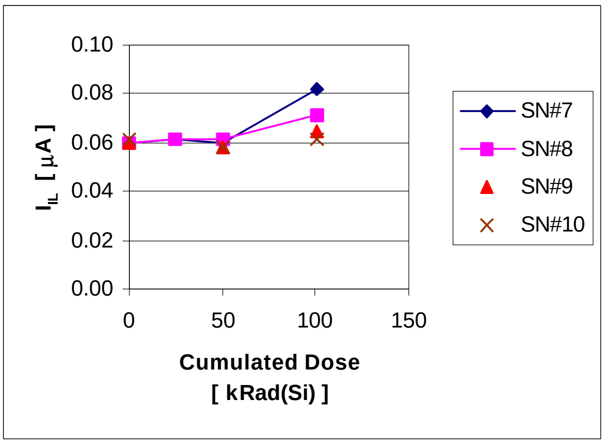


Fig 5.2.2 Dynamic supply current (second from top) and Standby supply current (third from top) as function of annealing time at room temperature. The bottom graph shows the 5V supply current. The top graph shows the case temperature.



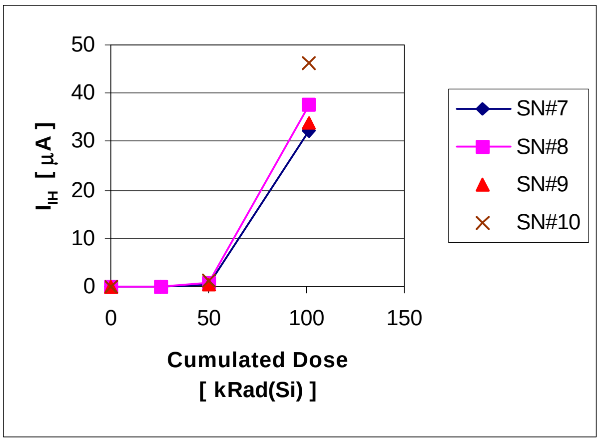


Fig 5.2.3 Input Current Low (left) and High (right) as function of cumulated dose. For each device, average values for the different type of IO's are shown. Up to 30 krad (Si) cumulated dose, no changes in the parameter values could be observed. For measurements of I_{IL}, the lower limit for the SZ3000 tester is 0.3V.

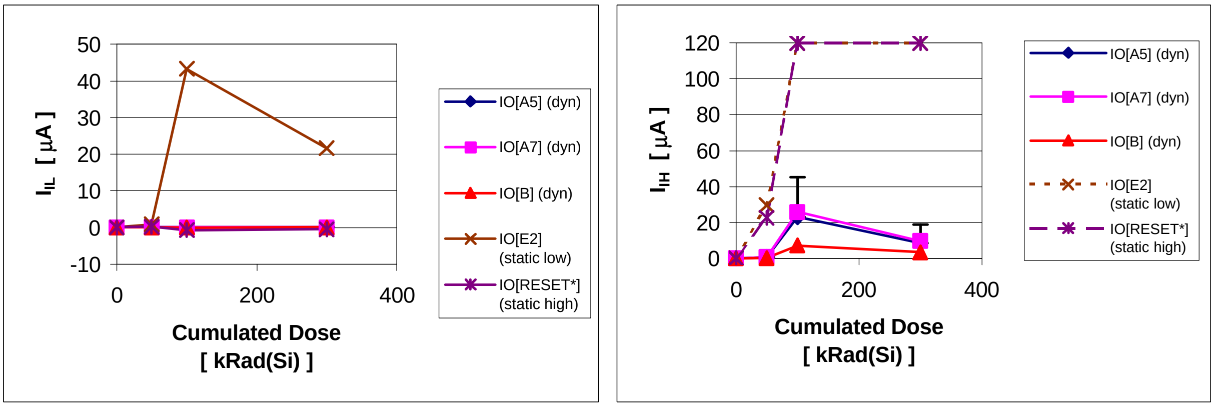


Fig 5.2.4 Pre- and post irradiation measurements of Input current low (Iil) and Input current high (Iih) for different I/O's. Shown in the graphs are 5 different I/O', where the IO (Reset) and IO(E2) have been in static mode during irradiation, while IO(A5), IO(A7) and IO(B) are examples of IO's which have been clocked during irradiation (see Fig 5.2.3). For the IO(Reset) the CLKB pin has been used as an IO. 120 µA was the limit for the measurement. The last points at "300 kRad" are the measurements performed after 200h of annealing at room temperature.

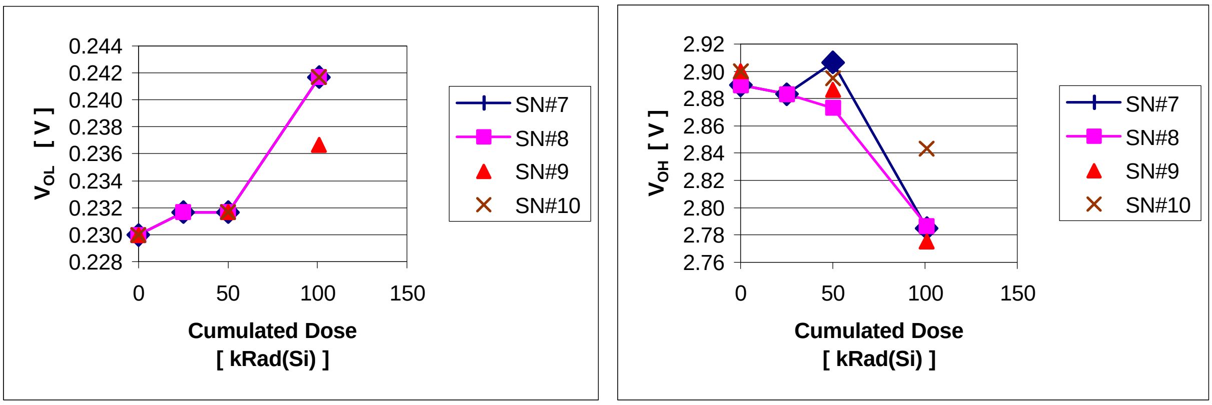


Fig 5.2.5 Output Voltage Low (left) and High (right) as function of cumulated dose. Data specification limit is V_{OL} = 0,5 V at I_O= + 6 mA and V_{OH} = 2.4 V at I_O = -4 mA.

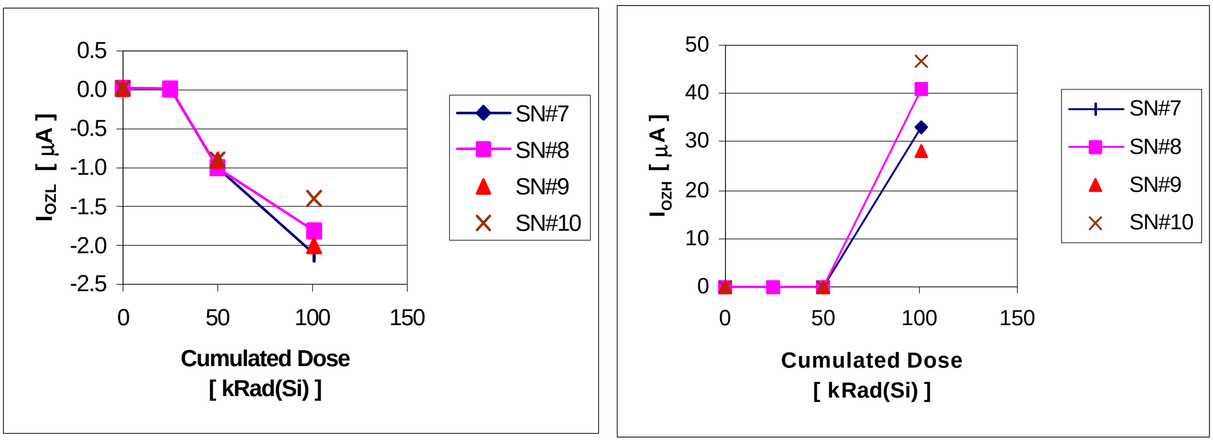
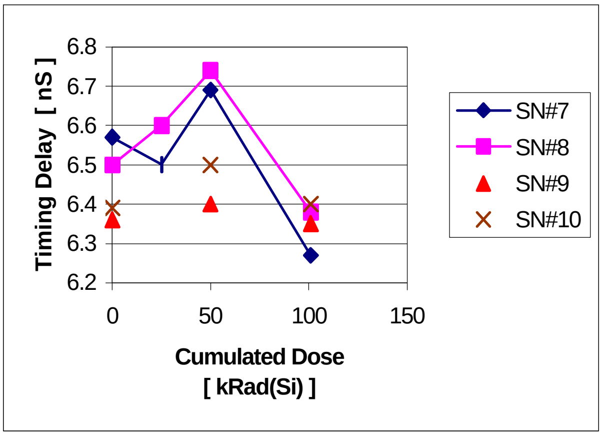


Fig 5.2.6 Output Tristate Current Low (left) and High (right) as function of cumulated dose.



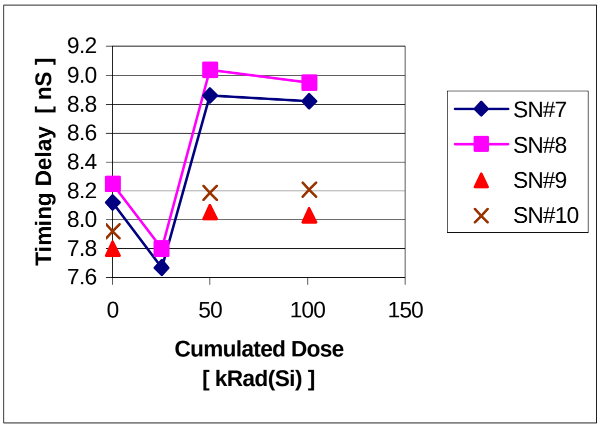


Fig 5.2.7 I/O Timing delay as a function of cumulated dose. The left figure shows the timing delay measured from I/O-to-I/O for all samples measured. The right figure shows the results where the timing has been measured I/O to I/O via a C-module. These measurements are very sensitive to the supply voltage and the temperature. Uncertainties in the measurements are estimated to be in the order of 0.5 ns.

Table 6.1 Heavy ion experimental data on RT54SX16

RUN#	***FLUENCE***	***FLUX***	***ION***	***TILT***	***LET***	***SUM***	***1-0***	***0-1***	***NOTES***
1	1.0E+06	7.8E+03	Kr	0	34	874	529	345	RT54SX16
2	1.0E+06	7.8E+03	Kr	0	34	881	540	341	
3	1.0E+06	5.5E+03	Kr	45	48.1	1462	767	695	
4	1.0E+06	5.5E+03	Kr	45	48.1	1445	781	664	
5	1.0E+06	5.5E+03	Kr	45	48.1	1534	823	711	
6	1.0E+06	5.5E+03	Kr	45	48.1	1469	840	629	
7	1.0E+06	7.8E+03	Kr	0	34	898	540	358	
8	1.0E+06	7.8E+03	Kr	0	34	862	531	331	
9	1.0E+06	6.1E+03	Ar	45	19.94	262	262	1	
10	1.0E+06	6.1E+03	Ar	45	19.94	262	262	1	0-1 was 0
11	5.0E+06	1.1E+04	Ar	0	14.1	316	316	1	0-1 was 0
12	5.0E+06	1.2E+04	Ar	0	14.1	296	296	0	
13	2.0E+06	1.1E+04	Ar	45	19.94	497	497	1	0-1 was 0
14	5.0E+05	9.0E+03	Xe	0	55.9	784	413	371	
15	5.0E+05	1.2E+04	Xe	0	55.9	804	441	363	
16	1.0E+06	8.2E+03	Xe	45	79	2048	1052	996	
17	5.0E+05	8.2E+03	Xe	45	79	1155	596	559	
18	5.0E+05	8.2E+03	Xe	45	79	1159	578	581	
18	1.0E+06	6.2E+03	Xe	0	55.9	2048	1216	832	
20	5.0E+06	1.2E+04	Ne	45	8.27	1	0	0	
21	5.0E+06	1.2E+04	Ne	45	8.27	1	1	0	

6. SEE RESULTS

Single Event Effects tests have been performed using the same test board and control equipment as in the total dose tests. Two samples have been delidded and prepared for SEE tests. The DUT's are individually biased and any latch-up will result in immediate shut down of the power. No latch-up could be detected up to LET = 80 $MeV/mg/cm^2$.
The Single Event Upset results are presented in graphical form in Fig 6.1. Individual results from all measurements including the used ion beam and fluences are given in Table 6.1
The results for the R-cell of RT54SX16 are very similar to earlier observed results for the S-module of A14100A [2] at 3,3 volt bias.

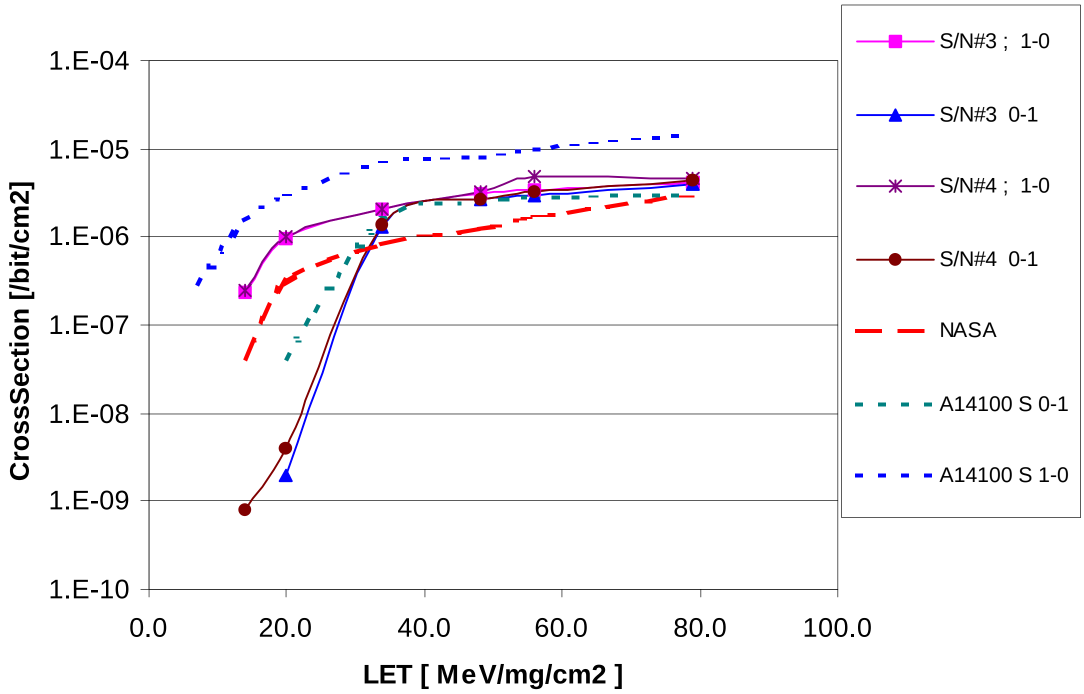


Fig 6.1 Single Event Upset cross section as a function of LET value for RT54SX16. The upset from 0-to-1 indicates a much higher LET threshold than 1-to-0. In the graph are also shown in dashed lines the S-module cross section for A14100A at 3,3V. The results from NASA/GSFC [3] are also given as a dashed curve. This paper only give the average of "0" and "1" upsets.

7. CONCLUSION

The Actel RT54SX16 antifuse metal-to-metal gate devices indicate good total dose irradiation tolerance. The tests have been performed using 50% dynamic operation at 20 MHz and 50% steady state mode. No functional failure at a clock frequency of 20 MHz could be detected up to 100 krad (Si) cumulated dose. The onset of increase of the standby current started around 30 krad (Si) cumulated dose. Once the leakage starts it increases very rapidly similar to what have been observed for other Actel devices.

Post-irradiation electrical measurements indicated small shifts in parameter values. A clear difference could be seen between I/O's subjected to static and dynamic conditioning during irradiation in static parameters degrading more.

The results from heavy ion tests indicated about the same SEU sensitivity as the S-module in Actel A14100A. The R-cell in RT54SX16 shows a similar large difference in sensitivity for 0-to-1 and 1-to-0 as the S-module for A14100A. No latch-up was detected.

The A14100A total dose test indicate very similar results for non burn-in and burn-in samples. The spread in leakage current at higher cumulated doses is seem to be larger for non burn-in samples. Parameter drift measurements indicate very little changes.

8. REFERENCES

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[2] Saab Ericsson Space Report: SE/REP/0084/K, 1997
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[3] NASA Report on NASA Radiation Effects and Analysis homepage
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