HEAVY IONS RADIATION
TEST REPORT

Part Type : AD9243

Package : 44-Pin MQFP

14-Bit, 3.0 MSPS A/D Converter

Analog Devices

Report Reference : ESA_QCA991201S_C

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The work described in this report was done under ESA contract.
Responsibility for the contents resides in the author or organization that prepared it

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HEAVY IONS RADIATION TEST REPORT
on
Analog Devices AD9243 14-Bit A/D Converter.

TABLE OF CONTENTS

1 ABSTRACT **3**

2 INTRODUCTION **4**

3 DOCUMENTS **4**

3.1 APPLICABLE DOCUMENTS 4
3.2 REFERENCE DOCUMENTS 4

4 DEVICE INFORMATION **5**

4.1 DEVICE DESCRIPTION 5
4.2 PROCUREMENT OF TEST SAMPLES 5
4.3 PREPARATION OF SAMPLES 5
4.4 FUNCTIONAL TEST OF SAMPLES 5
4.5 DEVICE DESCRIPTION 5

5 DEVICE TEST PATTERN DEFINITION **7**

5.1 PREPARATION OF TEST HARDWARE AND PROGRAM 7
5.2 GENERIC TEST SET-UP 7
5.2.1 Mother board description (ref. IL170A) 7
5.2.2 DUT Test board description 9
5.3 TEST CONFIGURATION 10

6 TEST FACILITIES **11**

6.1 HEAVY IONS 11
6.1.1 Beam Source 11
6.1.2 Beam Set-up 11
6.1.2.1 Ion Beam Selection 11
6.1.2.2 Flux Range 11
6.1.2.3 Particle Fluence Levels 11
6.1.2.4 Dosimetry 11
6.1.2.5 Accumulated Total Dose 11
6.1.2.6 Test Temperature Range 11

7 HEAVY IONS RESULTS **12**

8 CONCLUSION **15**

List of tables:

Table 1 – Detailed results per run on AD9243 14
Table 2 – SEU errors characterization summary 15

List of Figures:

Figure 1 – AD9243 External and Internal Photos 6
Figure 2 – DUT Adapter Board 6
Figure 3 - Generic Device Test Set-up 8
Figure 4 - Mother board synoptic 9
Figure 5 – AD9243 SEU error cross-section versus LET 12
Figure 6 – Scope observation of SEU error waveform 12
Figure 7 – AD9243 latch-up error cross-section versus LET 13
Figure 8 – Scope observation during a latch-up (below the threshold detection value) 13

1 Abstract

Under ESA/ESTEC contract n° 13602/99/NL/GD dated 18/06/99 covering "Radiation Pre-screening of High-resolution High-speed ADC's", three different 14-bit Analog to Digital converters were radiation assessed. Results from these assessments, primarily focused on the radiation sensitivity of the ADC's to Total Ionizing Dose (TID) and Single Event Effects (SEE), are reported in individual TID and SEE reports. Below summary table lists manufacturer and evaluated types, and gives references to the various reports issued.

Manufacturer	**Type**	**TID Report**	**SEE Report**
Analog Devices	AD9243	ESA_QCA991201T_C	ESA_QCA991201S_C
Linear Technology	LTC1414	ESA_QCA991202T_C	ESA_QCA991202S_C
National Semiconductor	ADC14161	ESA_QCA991203T_C	ESA_QCA991203S_C

2 Introduction

This report presents the results of a heavy ion Single Event Effects (SEE) test program carried out on Analog Devices AD9243 Complete 14-bit, 3.0 MSPS, Monolithic A/D Converter.

Standard devices were tested at the European Heavy Ion Irradiation Facility (HIF) at Cyclone, Université Catholique de Louvain, Belgium.

Test set-up allowed for the detection of both Single Event Latch-up (SEL) errors and Single Event Upset errors (SEU)

This work was performed for ESA/ESTEC under ESA Contract No 13602/99/NL/GD dated 18/06/99

3 Documents

3.1 Applicable documents

AD1. SOW Radiation Pre-screening of High-resolution High-Speed ADC's
Ref. APP-JP/99-02-057/PS/ps

3.2 Reference documents

RD1. Analog devices, AD9243 data sheet (Rev. A)
RD2. Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100
RD3. The Heavy Ion Irradiation Facility at CYCLONE, UCL document, Centre de Recherches du Cyclotron (IEEE NSREC'96, Workshop Record, Indian Wells, California, 1996)

4 DEVICE INFORMATION

4.1 Device Description

Complete 14-bit, 3.0 MSPS, Monolithic A/D Converter

4.2 Procurement of test samples

12 free samples have been delivered to Hirex by Analog Devices.

4.3 Preparation of samples

5 devices were selected for the SEE testing and serialized from #1 to #5.
#1 was used as the golden chip.
#2 as control sample.
#3 and #4, and #5 were chemically opened (by Hirex Lab).
Further each test sample was then mounted on individual adapter boards.

4.4 Functional Test of samples

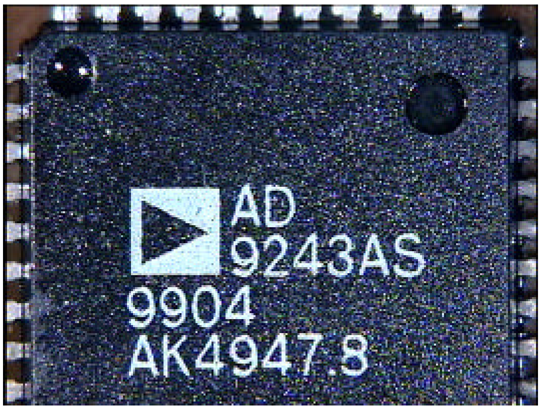
All opened samples were functional tested before use.

4.5 Device description

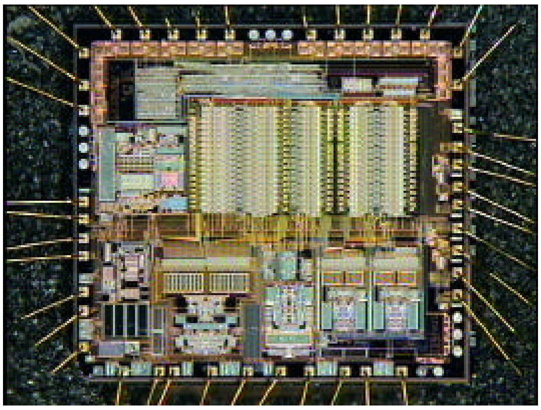
Description of the devices is as follows:

Part type :	AD9243AS
Manufacturer :	Analog devices
Package :	44-Lead Plastic Quad Flatpack
Quality Level :	Standard
Date Code :	9904
Serial Number :	#001, #002, #003, #004, #005
Die Technology :	CMOS
Top Marking:	AD 9243AS 9904 AK4947.8
Die Size :	4.2 mm x 3.8 mm approximately
Die Marking :	See Figure 1
Heavy ion test samples (delidded) :	3, #003, #004,#005

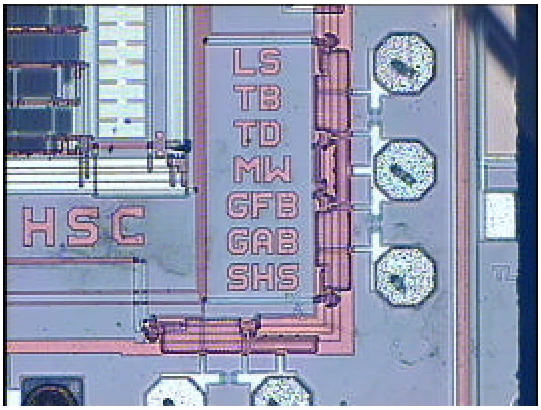
External and Internal Photos are shown in Figure 1.



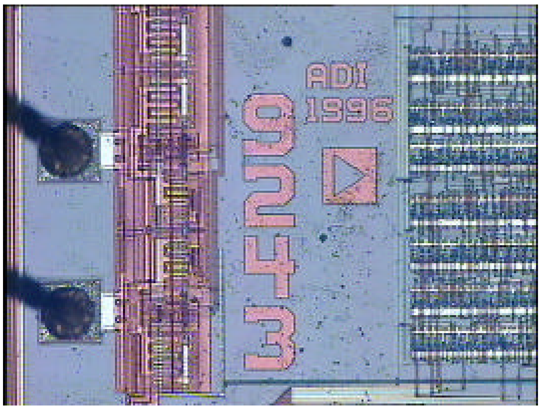
(x 10)
Top view



(x 20)
Die, Full view



(x 100)
Die, Marking, Detail 1



(x 100)
Die, Marking, Detail 2

Figure 1 – AD9243 External and Internal Photos

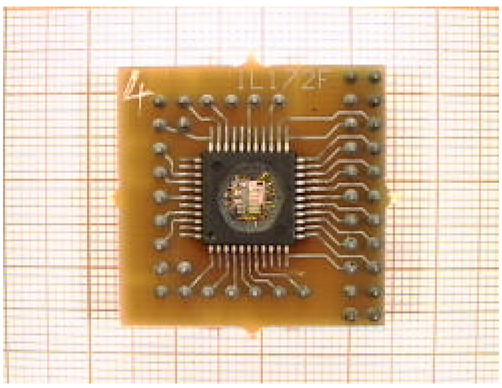


Figure 2 – DUT Adapter Board

5 Device TEST PATTERN DEFINITION

5.1 Preparation of Test Hardware and Program

Overall device operation, SEU and Latch-up detection, data storage and processing were implemented using an in-house test hardware and application specific test boards.

The generic in-house test equipment is driven by a PC computer through a RS232 line. All power supplies and input signals are delivered and monitored by the in-house equipment which also stores in its memory the output data from the device under test.

The application specific test board allowed to interface the standard test hardware with the device under test, in order to correctly test the relevant part, to record all the different type of errors during the irradiation and to set output signal for processing and storage by the standard test equipment.

At the end of each test run, data are transferred to the PC computer through the RS232 link for storage on hard disk or floppies.

5.2 Generic Test Set-up

Generic device test set-up is presented in Figure 3 and is constituted of the following equipment units :

- A PC computer (to configure and interface with the test system and store the data),
- An electronic rack with the instrumentation functions provided by a set of electronic modules,
- A mother board under vacuum. This board provides the electronics needed for each test sequence, calibration, simulation and test.
- A digital oscilloscope to store analog upset waveform

5.2.1 Mother board description (ref. IL170A)

Main board characteristics are :

- Specially designed to test up to 16-bit ADC at a sampling frequency of 20 Mhz,
- Based on a golden chip approach.
- On-board analog pattern generator
- A common analog signal (linear ramp for calibration, sinus during test) is applied to both DUT and reference device inputs.
- Possibility to calibrate the DUT with the reference device by recording the errors values for each output word.
- Possibility to adjust a programmable voltage Vref to compensate for gain dispersion between DUT and ref. device.
- Both outputs are compared numerically thanks to the use of on-board CPLDs. For each comparison, the error value previously recorded for the output Ref. device word is substracted.
- DUT output and comparison signals are converted with high-speed 8-bit DACs to allow for scope observation.
- Three on-board counters are used to sort the errors in the following categories, small, medium and large (A medium error is also counted as a small, a large error is also counted as a medium and a small error)

Mother board synoptic is shown in Figure 4.

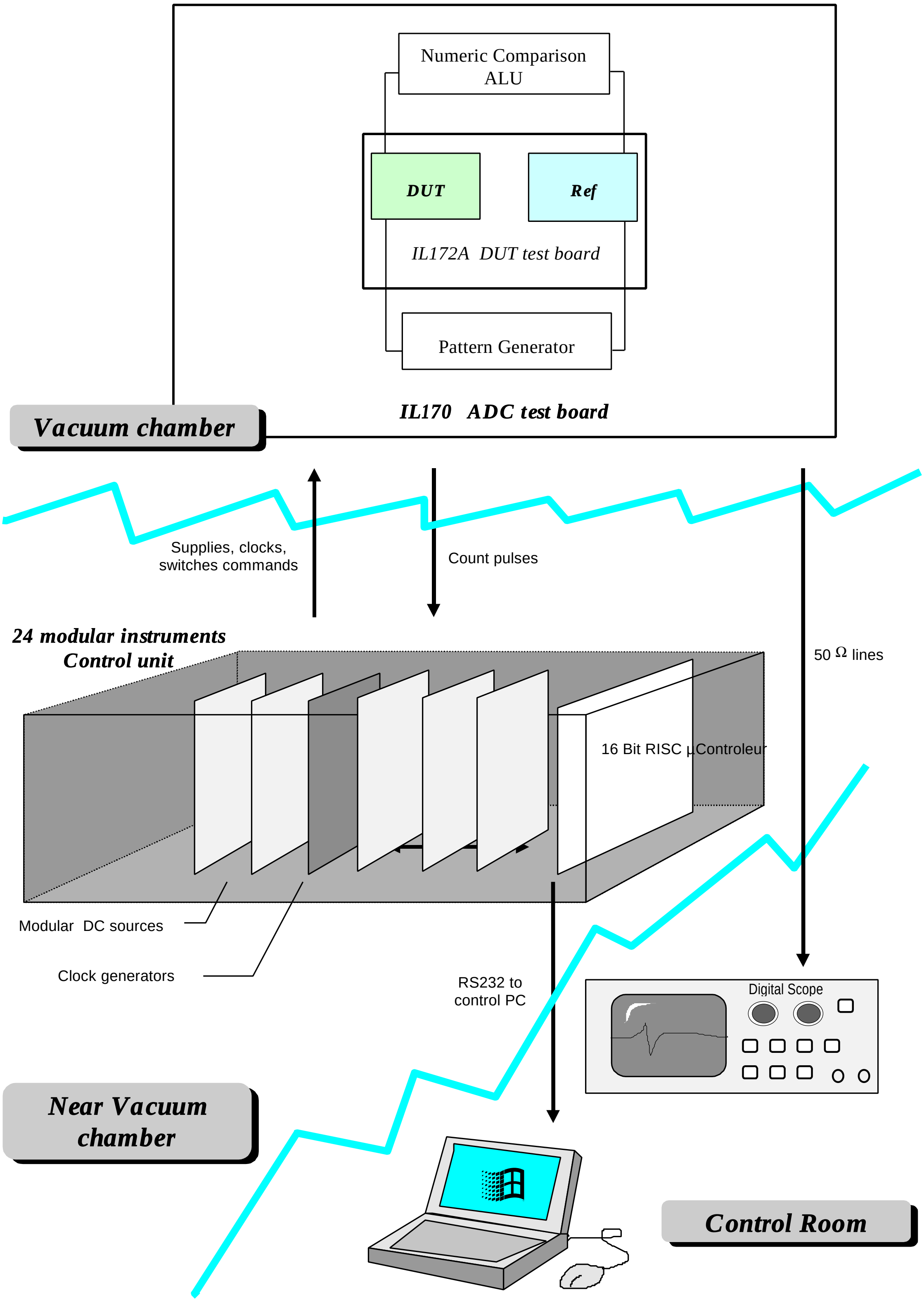


Figure 3 - Generic Device Test Set-up

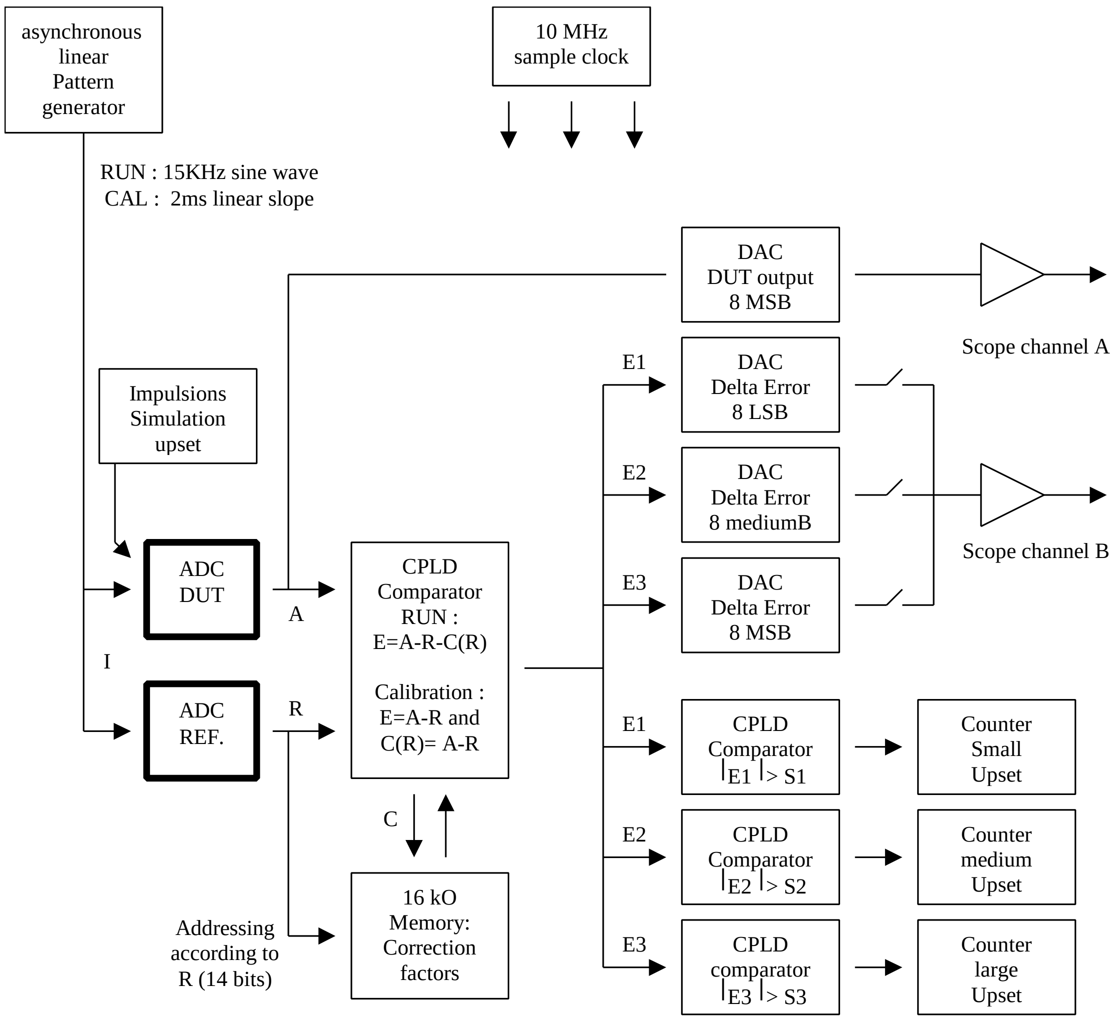


Figure 4 - Mother board synoptic

5.2.2 DUT Test board description

Both the DUT and the reference device (golden chip) are mounted on adapters PCBs for easy interchangeable motherboard set-up.

This approach allows cost effective SEE testing of different ADC devices and types at the same time. Figure 2 show the DUT arrangement for AD9243 #4

Note : Beam focus diameter is limited to maximum 25 mm, to prevent the exposure of others devices which might be sensitive.

5.3 Test configuration

The test configuration is as follows :

Sampling frequency is set to 2 MHz

Prior to the irradiation, a calibration run is performed which allows to record into the on-board memory the error value found for each output reference device word. This is done with a slow linear ramp (2ms period) applied to the inputs of both DUT and reference devices.
Calibration duration is such that, for each word, corresponding error is averaged on more than 20 values.
Eventually, DUT Vref is adjusted to minimize the error range.
With this approach, it is possible to match both output devices with a precision of ± 5 LSBs.

Each irradiation run is performed with a 15 kHz sine waveform applied at both DUT and ref. inputs.

The different errors which can be detected are :

- Single errors which can be classified as small (threshold = +/- 6 LSBs), medium (threshold = +/- 96 LSBs) or large (threshold = +/-768 LSBs).
- Permanent errors : This was not considered for this device which does not present an internal calibration.
- Latch-up errors : each power supply (Analog + and Logic) is monitored separately.

6 TEST FACILITIES

6.1 Heavy Ions

Test at the cyclotron accelerator was performed at Université de Louvain (UCL) in Louvain la neuve (Belgium) under HIREX Engineering responsibility.

6.1.1 Beam Source

In collaboration with the European Space Agency (ESA), the needed equipment for single events studies using heavy ions has been built and installed on the HIF beam line in the experimental hall of Louvain-la-Neuve cyclotron.
CYCLONE is a multi particle, variable energy, cyclotron capable of accelerating protons (up to 75 MeV), alpha particles and heavy ions. For the heavy ions, the covered energy range is between 0.6 MeV/AMU and 27.5 MeV/AMU. For these ions, the maximal energy can be determined by the formula :

$$110\ Q^2/M$$

where Q is the ion charge state, and M is the mass in Atomic Mass Units.

The heavy ions are produced in a double stage Electron Cyclotron Resonance (ECR) source. Such a source allows to produce highly charged ions and ion "cocktails". These are composed of ions with the same or very close M/Q ratios. The cocktail ions are injected in the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency. This method is very convenient for a quick change of ion (in a few minutes) which is equivalent to a LET variation.

6.1.2 Beam Set-up

6.1.2.1 Ion Beam Selection

The LET range was obtained by changing the ion species and incident energy and changing the angle of incidence between the beam and the chip.
For each run, information is provided on the beam characteristics in the detailed results table provided in paragraph 7.

6.1.2.2 Flux Range

For each run, the averaged flux value is provided in the detailed results table of paragraph 7.

6.1.2.3 Particle Fluence Levels

Target fluence level was set to 1 x10E6 ions/cm²

6.1.2.4 Dosimetry

The current UCL Cyclotron dosimetry system and procedures were used.

6.1.2.5 Accumulated Total Dose

For each run, the computed equivalent cumulated doses received by the DUT sample, are provided in the detailed results table of paragraph 7.

6.1.2.6 Test Temperature Range

All the tests performed were conducted at ambient temperature.

7 Heavy ions Results

The detailed results per run are presented in Table 1.

This device has been found to be both sensitive to SEUs and SELs..

Figure 5 gives the plot of the different SEU errors cross-sections (small, medium and large) versus LET for the two samples tested.

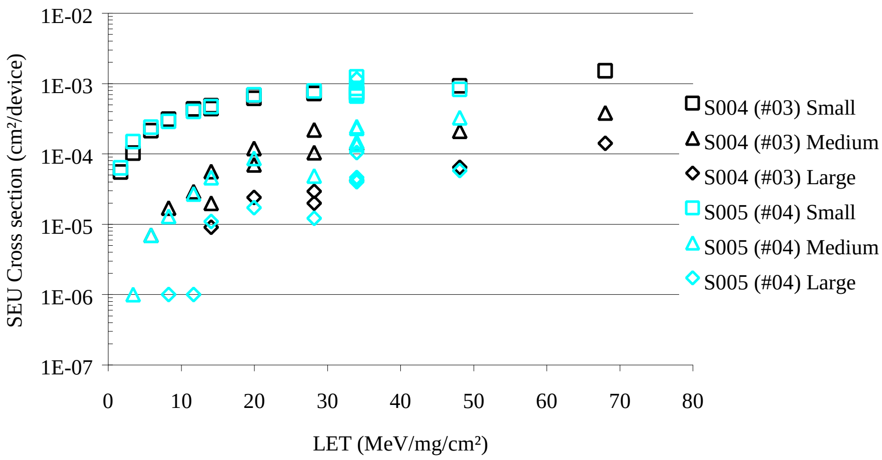
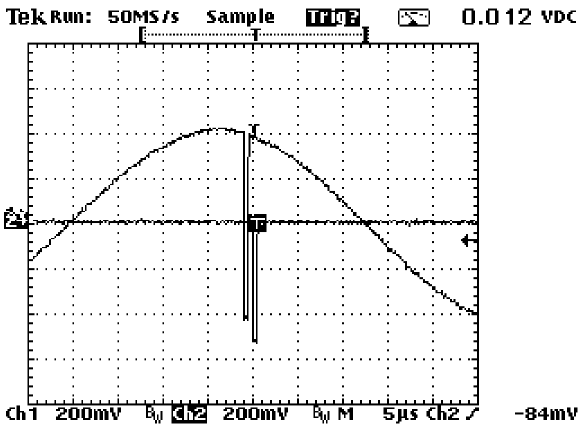


Figure 5 – AD9243 SEU error cross-section versus LET

Observation with a digital scope during the different runs, allowed to visualize the error waveforms. This is illustrated in the Figure 6.



Run 15, large channel

On this scope view, the curve at the top correspond to the DUT output converted with a 8-bits fast DAC (see Figure 4), while the curve at the bottom of the view, represent the large error converted also with a similar fast 8-bit DAC (see Figure 4) :

Verror = Vout(Ref)-Vout (DUT)-V(Calib)

For the error channel, +/- 500 mV corresponds to +/- 7 bits

Figure 6 – Scope observation of SEU error waveform

Figure 7 gives the total latch-up error cross-sections versus LET for the two samples.

For the present set of runs, latch-up detection threshold was set to 80 mA, and further analysis of each run file showed that some non destructive latch-up events with sustaining current between 50 and 80mA were recorded.
In that case, the device was either reset due to a high number of consecutive errors (>20) or stayed in this latch-up state until a new latch-up with a current above the threshold of 80mA triggered the switch off of the device.
When such latch-up events (with sustaining current below 80 mA) were recorded, the corresponding events number have been mentioned in the comment column of Table 1.
All the SEUs which occurred during these non destructive latch-ups have been retrieved in the corresponding recorded runs files and Table 1 has been updated accordingly.
Figure 8 shows a scope record where a latch-up with a latch-up current below the test detection threshold value has been captured : It can be observed that more and more errors are detected, and this process will continue as long as this sustained state will last.

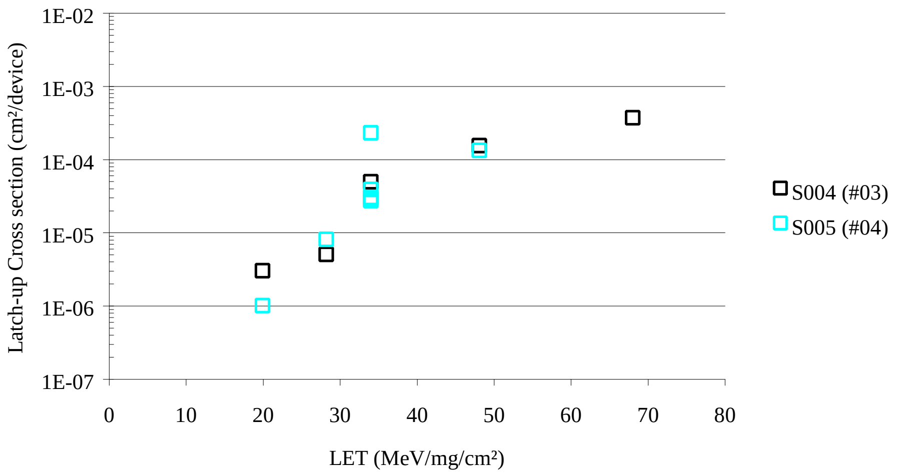
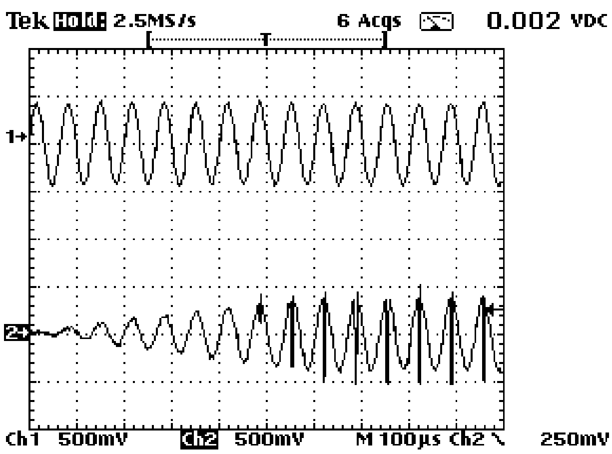


Figure 7 – AD9243 latch-up error cross-section versus LET



On this scope view, the curve at the top correspond to the DUT output converted with a 8-bits fast DAC (see Figure 4), while the curve at the bottom of the view, represent the small error converted also with a similar fast 8-bit DAC (see Figure 4) :
Verror = Vout(Ref)-Vout (DUT)-V(Calib)
For the error channel, +/- 500 mV corresponds to +/- 7 bits.
The continuous increase of errors is related to the latch-up sustained state

Run 66

Figure 8 – Scope observation during a latch-up (below the threshold detection value)

Run parameters														SEU Errors						SEL Errors				Comments
														Small		Medium		Large		An+	Logic	Total		
Run #	Sample	Ion	LET (MeV/mg/cm²)	Range (µm)	Angle (°)	Time (s)	Eff. Time (s)	Flux (p/cm²s)	Run TID (Rad)	Sample TID (Rad)	Fluence (P/cm²)	Eff. Fluence (p/cm²)	Eff. LET (MeV/mg/cm²)	Nb	Cross-section (cm²)	Nb	Cross-section (cm²)	Nb	Cross-section (cm²)	Nb	Nb	Nb	Cross-section (cm²)	
R00056	S004	10-B	1,7	80	0	125	-	8,00E+03	2,72E+01	5,53E+03	1,00E+06	1,00E+06	1,7	55	5,50E-05									
R00055	S004	10-B	1,7	80	60	341	-	2,93E+03	5,45E+01	5,51E+03	1,00E+06	1,00E+06	3,4	102	1,02E-04									
R00033	S004	20-Ne	5,85	45	0	94	-	1,06E+04	9,37E+01	5,13E+03	1,00E+06	1,00E+06	5,85	213	2,13E-04	7	7,00E-06							
R00034	S004	20-Ne	5,85	45	45	167	-	5,99E+03	1,33E+02	5,27E+03	1,00E+06	1,00E+06	8,273	312	3,12E-04	17	1,70E-05							
R00035	S004	20-Ne	5,85	45	60	305	-	3,28E+03	1,87E+02	5,45E+03	1,00E+06	1,00E+06	11,7	436	4,36E-04	29	2,90E-05							
R00007	S004	40-Ar	14,1	42	0	103	-	4,85E+02	1,13E+01	3,98E+03	5,00E+04	5,00E+04	14,1	22	4,40E-04	1	2,00E-05							
R00012	S004	40-Ar	14,1	42	0	271	-	4,06E+03	2,49E+02	5,04E+03	1,10E+06	1,10E+06	14,1	529	4,81E-04	62	5,64E-05	10	9,09E-06					
R00008	S004	40-Ar	14,1	42	45	198	-	2,53E+02	1,60E+01	4,00E+03	5,00E+04	5,00E+04	19,94	34	6,80E-04	6	1,20E-04							
R00011	S004	40-Ar	14,1	42	45	305	303	3,28E+03	3,19E+02	4,79E+03	1,00E+06	9,94E+05	19,94	608	6,12E-04	70	7,04E-05	24	2,41E-05	1	2	3	3,02E-06	
R00009	S004	40-Ar	14,1	42	60	219	-	2,28E+02	2,26E+01	4,02E+03	5,00E+04	5,00E+04	28,2	36	7,20E-04	11	2,20E-04	1	2,00E-05					
R00010	S004	40-Ar	14,1	42	60	367	363	2,72E+03	4,52E+02	4,47E+03	1,00E+06	9,87E+05	28,2	754	7,64E-04	103	1,04E-04	29	2,94E-05	4	1	5	5,06E-06	
R00065	S004	84-Kr	34	43	0	209	135	4,78E+03	5,45E+02	6,08E+03	1,00E+06	6,45E+05	34	470	7,29E-04	91	1,41E-04	27	4,19E-05	16	16	32(1)	4,96E-05	(1) 2 LUs with I_{LU}< 80mA
R00066	S004	84-Kr	34	43	45	281	143	3,56E+03	7,70E+02	6,85E+03	1,00E+06	5,09E+05	48,08	472	9,27E-04	107	2,10E-04	33	6,48E-05	52	27	79(2)	1,55E-04	(2) 3 LUs with I_{LU}< 80mA
R00067	S004	84-Kr	34	43	60	633	309	1,58E+03	1,09E+03	7,94E+03	1,00E+06	4,88E+05	68	740	1,52E-03	187	3,83E-04	69	1,41E-04	108	73	181(3)	3,71E-04	(3) 20 LUs with I_{LU}< 80mA
R00058	S005	10-B	1,7	80	0	123	-	8,13E+03	2,72E+01	6,32E+03	1,00E+06	1,00E+06	1,7	63	6,30E-05									
R00057	S005	10-B	1,7	80	60	243	-	4,12E+03	5,45E+01	6,29E+03	1,00E+06	1,00E+06	3,4	149	1,49E-04	1	1,00E-06							
R00032	S005	20-Ne	5,85	45	0	146	-	6,85E+03	9,37E+01	6,23E+03	1,00E+06	1,00E+06	5,85	240	2,40E-04	7	7,00E-06							
R00031	S005	20-Ne	5,85	45	45	202	-	4,95E+03	1,33E+02	6,14E+03	1,00E+06	1,00E+06	8,273	290	2,90E-04	13	1,30E-05	1	1,00E-06					
R00030	S005	20-Ne	5,85	45	60	277	-	3,61E+03	1,87E+02	6,01E+03	1,00E+06	1,00E+06	11,7	398	3,98E-04	27	2,70E-05	1	1,00E-06					
R00013	S005	40-Ar	14,1	42	0	186	-	5,38E+03	2,26E+02	5,05E+03	1,00E+06	1,00E+06	14,1	466	4,66E-04	46	4,60E-05	11	1,10E-05					
R00014	S005	40-Ar	14,1	42	45	119	118	8,40E+03	3,19E+02	5,37E+03	1,00E+06	9,91E+05	19,94	687	6,93E-04	86	8,68E-05	17	1,72E-05	1		1	1,01E-06	
R00015	S005	40-Ar	14,1	42	60	321	315	3,12E+03	4,52E+02	5,82E+03	1,00E+06	9,83E+05	28,2	765	7,78E-04	48	4,88E-05	12	1,22E-05	7	1	8	8,14E-06	
R00059	S005	84-Kr	34	43	0	233	212	4,29E+03	5,45E+02	6,86E+03	1,00E+06	9,09E+05	34	601	6,61E-04	134	1,47E-04	42	4,62E-05	26		26	2,86E-05	
R00060	S005	84-Kr	34	43	0	215	182	4,65E+03	5,45E+02	7,41E+03	1,00E+06	8,46E+05	34	635	7,50E-04	197	2,33E-04	34	4,02E-05	3	30	33(4)	3,90E-05	(4) 30 LUs with I_{LU}< 80mA
R00061	S005	84-Kr	34	43	0	219	199	4,57E+03	5,45E+02	7,95E+03	1,00E+06	9,09E+05	34	634	6,97E-04	124	1,36E-04	38	4,18E-05	21	4	25	2,75E-05	
R00062	S005	84-Kr	34	43	0	215	170	4,65E+03	5,45E+02	8,50E+03	1,00E+06	7,91E+05	34	675	8,54E-04	118	1,49E-04	919	1,16E-03	11	13	24(5)	3,04E-05	(5) 1 LU with I_{LU}< 80mA
R00064	S005	84-Kr	34	43	0	290	147	2,41E+03	3,81E+02	9,65E+03	7,00E+05	3,54E+05	34	441	1,24E-03	87	2,46E-04	37	1,04E-04	37	45	82(6)	2,31E-04	(6) 3 LUs with I_{LU}< 80mA
R00063	S005	84-Kr	34	43	45	295	214	3,39E+03	7,70E+02	9,27E+03	1,00E+06	7,25E+05	48,08	599	8,26E-04	237	3,27E-04	42	5,79E-05	62	35	97(7)	1,34E-04	(7) 9 LUs with I_{LU}< 80mA

Table 1 – Detailed results per run on AD9243

8 Conclusion

SEU test have been conducted on complete 14-bit, 3.0 MSPS, Monolithic A/D Converter, AD9243 from Analog Devices, using the heavy ions available at the European Heavy Ion Irradiation Facility (HIF) at Cyclone, Université Catholique de Louvain, Belgium.

This device is sensitive to SEL with an LET threshold closed to 20 MeV/mg/cm² and an asymptotic cross-section which, according to the tendency shown in Figure 7, may be higher than 3.7 E-4 cm² (3.7 E-4 cm² @ LET of 68 MeV/mg/cm²)

Heavy ion SEU susceptibility was obtained through the error cross section versus LET curve for three different errors magnitudes.

LET threshold and asymptotic cross-section for each error amplitude, are given in Table 2 here below.

	Error Amplitude (LSBs)	LET Threshold (MeV/mg/cm²)	Asymptotic cross-section (cm²)
Small	+/- 6	1,7	1,5 E-3
Medium	+/- 96	5,9	3,8 E-4
Large	+/- 768	11,7	1,4 E-4

Table 2 – SEU errors characterization summary