Single Event Effects

Heavy Ions Test Report

Test type	Single Event Latchup
Part Reference	AD7961
Tested function	16-Bit, 5 MSPS PulSAR Differential ADC
Chip manufacturer	Analog Devices
Test Facility	UCL-HIF, Louvain-La-Neuve Belgium JYFL-RADEF, Jyväskylä, Finland
Test Date	October 2017, November 2017
Customer	ESA

Call-of order No6 "Radiation testing for Plato and other ESA missions"

BCE 7441

Hirex reference :	HRX/SEE/00629	Issue : 01	Date :	27/03/2018
Written by:	Benjamin Crouzat	SEE Engineer		
Authorized by:	F.X. Guerre	Study Manager		

DOCUMENTATION CHANGE NOTICE

Issue	Date	Page	Change Item	
01	23/11/2017	All	Original issue	

Contributors to this work:

Bendy Tanios Hirex Engineering

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 Introduction

This report presents results of SEE test campaign for the Analog Devices 16-Bit, 5 MSPS PulSAR Differential ADC AD7961. The test campaign took place at UCL-HIF, Louvain-La-Neuve Belgium in October 2017 and in JYFL-RADEF Jyvaskyla Finland in . Components were tested for SEL.

2 Applicable and Reference Documents

2.1 Applicable Documents

AD-1 AD7961 datasheet rev. D

AD-2 SEE AD7961 test specification ref. HRX/SEP/00112 issue 1 dated 03/10/2017

2.2 Reference Documents

RD-1. Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100

3 Device Information

3.1 Device description

The AD7961, from Analog Devices, is a 16-Bit, 5 MSPS PulSAR Differential ADC using CMOS technology.

Manufacturer:	Analog Devices
Package:	LFCSP-32
Datecode:	1520
Marking:	. AD7961 BCPZ #1520 3150203.1 CHINA
Part number:	AD7961BCPZ-RL7CT-ND
Mnfr lot number:	AL99257.7
Technology:	CMOS
Die dimensions:	2031 µm x 2639 µm

3.2 Device and die identification

Figure 1: Package, top.

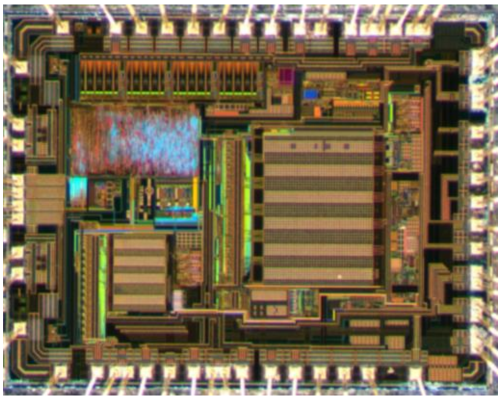


Figure 2: Component die.

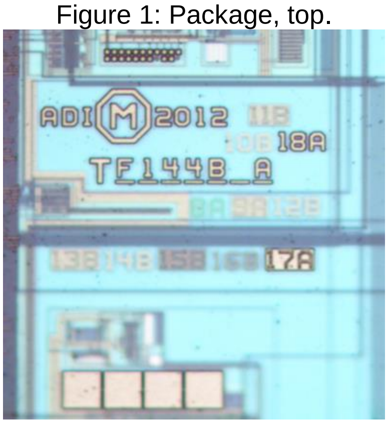


Figure 3: Die marking #1.

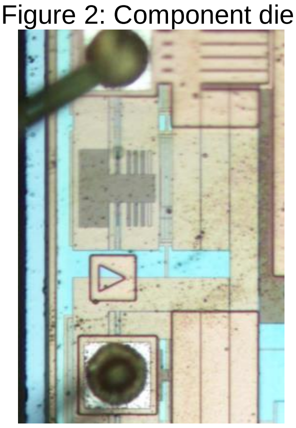


Figure 4: Die marking #2.

3.3 Samples preparation

Four samples have been chemically opened from the top and tested for their functionality before the test campaign.

Four samples are used as Device Under Test (DUT) for SEL test.

Board number	DUT number	Test performed		
		SEU	SET	SEL
1	1	-	-	X
1	2	-	-	X
1	3	-	-	X
1	4	-	-	X

Table 1: DUT distribution for the test campaign.

4 Test Setup

4.1 Irradiation board

4 independent DUTs are mounted on the DIB331A daughter board and bias schematic is given in Figure 5.
A photo of the top side of the board is shown in Figure 6.
Bias setup is in accordance with the SEE AD7961 test specification (AD-2)

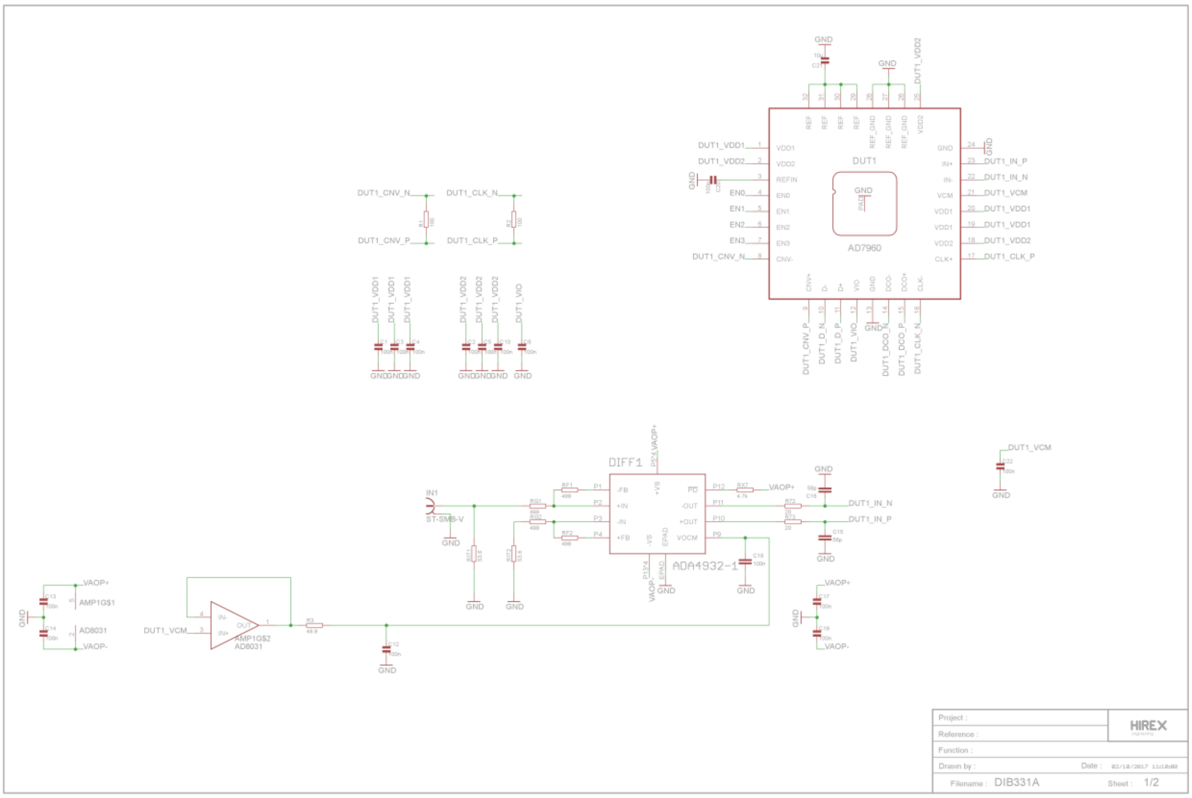


Figure 5: Part biasing.

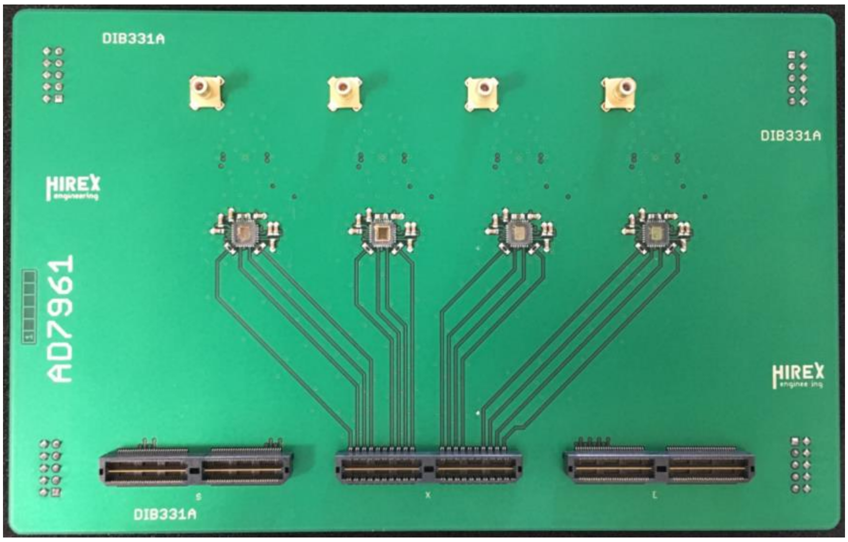


Figure 6: Top side DIB331A photo

4.2 Bias configuration

The input signal feeding the DUT will be a ±4.96V amplitude differential sinus with a frequency of 100 kHz.
The supply voltages will be set to:

Test mode	VDD1	VDD2	VIO
SEL	+6V	+2.1V	+2.1V

Clk input signal will be LVDS running at 300MHz.
Cnv input signal will be LVDS running at 5MHz to get an analog to digital conversion rate at 5MSPS.

4.3 Hirex test setup

Figure 7 shows the principle of the single event test system.
The test system is based on a Virtex4 FPGA (Xilinx). It runs at 50 MHz. The test board has 271 I/Os which can be configured using several I/O standards.
The test board includes the voltage/current monitoring and the latch-up management of the DUT power supplies with up to 24 independent channels.
The communication between the test chamber and the controlling computer is done by a 100 Mbit/s Ethernet link which safely enables high speed data transfer.
SEL event is detected when the supply current is over a configurable threshold. Once detected, SEL state is maintained and power supplies are cut off during configurable times. Each power supply under supervision is monitored independently for SEL detection and processing but subsequent cut off is performed on all power supplies.

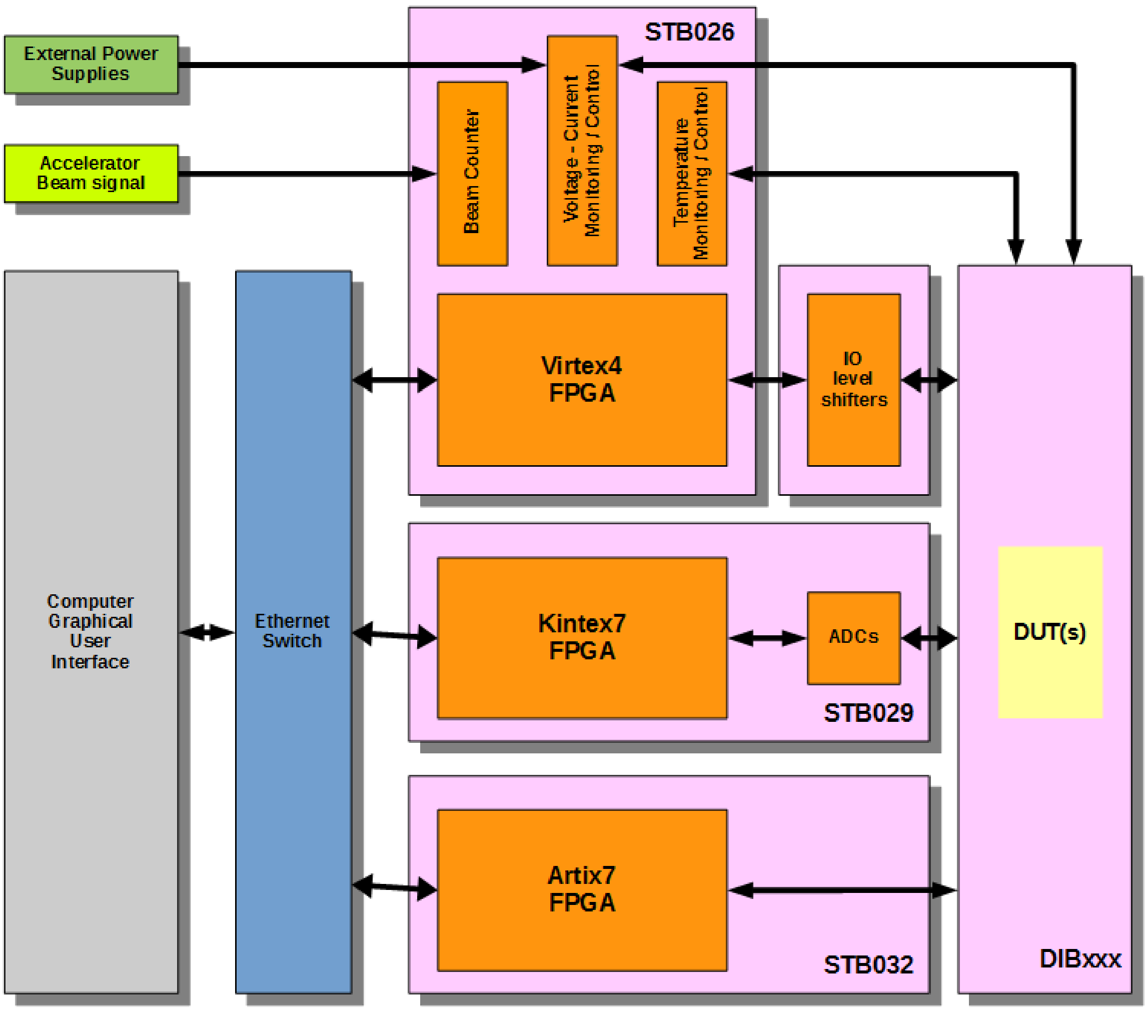


Figure 7: Hirex test setup

5 HIF facility

Test at the cyclotron accelerator was performed at Université Catholique de Louvain (UCL) in Louvain-La-Neuve (Belgium) under HIREX Engineering responsibility.

In collaboration with the European Space Agency (ESA), the needed equipment for single events studies using heavy ions was 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:

$$110\frac{Q^2}{M}$$

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 producing 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.

5.1 Dosimetry

The current UCL Cyclotron dosimetry system and procedures were used.

5.2 Used ions

UCL cocktail ions used for the test campaign are listed in the table below.

M/Q	Ion	DUT energy [MeV]	Range [µm Si]	LET [MeV/mg/cm²]
3.33	$^{40}Ar^{12+}$	379	120.5	10.0
3.31	$^{53}Cr^{16+}$	513	107.6	16.0
3.22	$^{58}Ni^{18+}$	582	100.5	20.4
3.35	$^{84}Kr^{25+}$	769	94.2	32.4
3.32	$^{103}Rh^{31+}$	972	88.7	45.8
3.54	$^{124}Xe^{35+}$	995	73.1	62.5

Table 2: Ion beam setting

6 RADEF facility

The facility includes a special beam line dedicated to irradiation studies of semiconductor components and devices. It consists of a vacuum chamber including component movement apparatus and the necessary diagnostic equipment required for the beam quality and intensity analysis.
The cyclotron is a versatile, sector-focused accelerator of beams from hydrogen to xenon equipped with three external ion sources: two electron cyclotron resonance (ECR) ion sources designed for high-charge-state heavy ions, and a multicusp ion source for intense beams of protons. The ECR's are especially valuable in the study of single event effects (SEE) in semiconductor devices. For heavy ions, the maximum energy attainable can be determined using the formula,

$$130\ Q^2/M,$$

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

6.1 Test chamber

Irradiation of components is performed in a vacuum chamber with an inside diameter of 75 cm and a height of 81 cm.
The vacuum in the chamber is achieved after 15 minutes of pumping, and the inflation takes only a few minutes. The position of the components installed in the linear movement apparatus inside the chamber can be adjusted in the X, Y and Z directions. The possibility of rotation around the Y-axis is provided by a round table. The free movement area reserved for the components is 25 cm x 25 cm, which allows one to perform several consecutive irradiations for several different components without breaking the vacuum.
The assembly is equipped with a standard mounting fixture. The adapters required to accommodate the special board configurations and the vacuum feed-throughs can also be made in the laboratory’s workshops. The chamber has an entrance door, which allows rapid changing of the circuit board or individual components.
A CCD camera with a magnifying telescope is located at the other end of the beam line to determine accurate positioning of the components. The coordinates are stored in the computer’s memory allowing fast positioning of various targets during the test.

6.2 Beam quality and dosimetry control

For measuring beam uniformity, flux and fluence, four plastic scintillators combined with photomultiplier tubes are located edges of the adjustable beam entrance collimator, about one meter upstream from the component. The detector-collimator combinations are operated with linear motors and are located at 90 degrees with respect to each other. The uniformity and flux of the beam is measured before component irradiation in the front of the component. During the irradiation, detectors are set to the outer edge of the beam in order to monitor the stability of the homogeneity and flux.
Two elector magnetic beam wobblers with vibration frequencies of 82Hz and 92Hz creating Lissajous curve are located perpendicular of each other about 7 meters upstream from the component to achieve good beam homogeneity. The proper sweeping area is attained with the adjustable coil-currents.
Beam current is adjusted using magnets and collimator in the injection line between the ECR ion source and accelerator.
There is beam only about 10% of the time, and the rest is empty. In the cocktail case the frequency of the cyclotron is about 14MHz, which means that the beam cycle is about 70ns and 10% of it is the time the beam particles can hit the device. For example, if flux is 10^4ions.cm^{-2}.s^{-1} in average you get one ion to 1cm^2 area after every 1400 beam cycles.

Used ions:

Ion	LET^{SRIM} at surface [MeV.cm^2.mg^{-1}]	Range [µm]	Beam energy [MeV]
$^{40}Ar^{12+}$	10.2	118	372
$^{56}Fe^{15+}$	18.5	97	523
$^{82}Kr^{22+}$	32.1	94	768
$^{131}Xe^{35+}$	60.0	89	1217

SRIM-2003.26

Table 3 - Ion beam setting

7 Results

Overall test results are summarized in Table 4.
DUT Tcase was set to about 51°C at UCL and about 66°C at JYFL to achieve a die surface temperature of 85°C measured with an infrared thermometer.

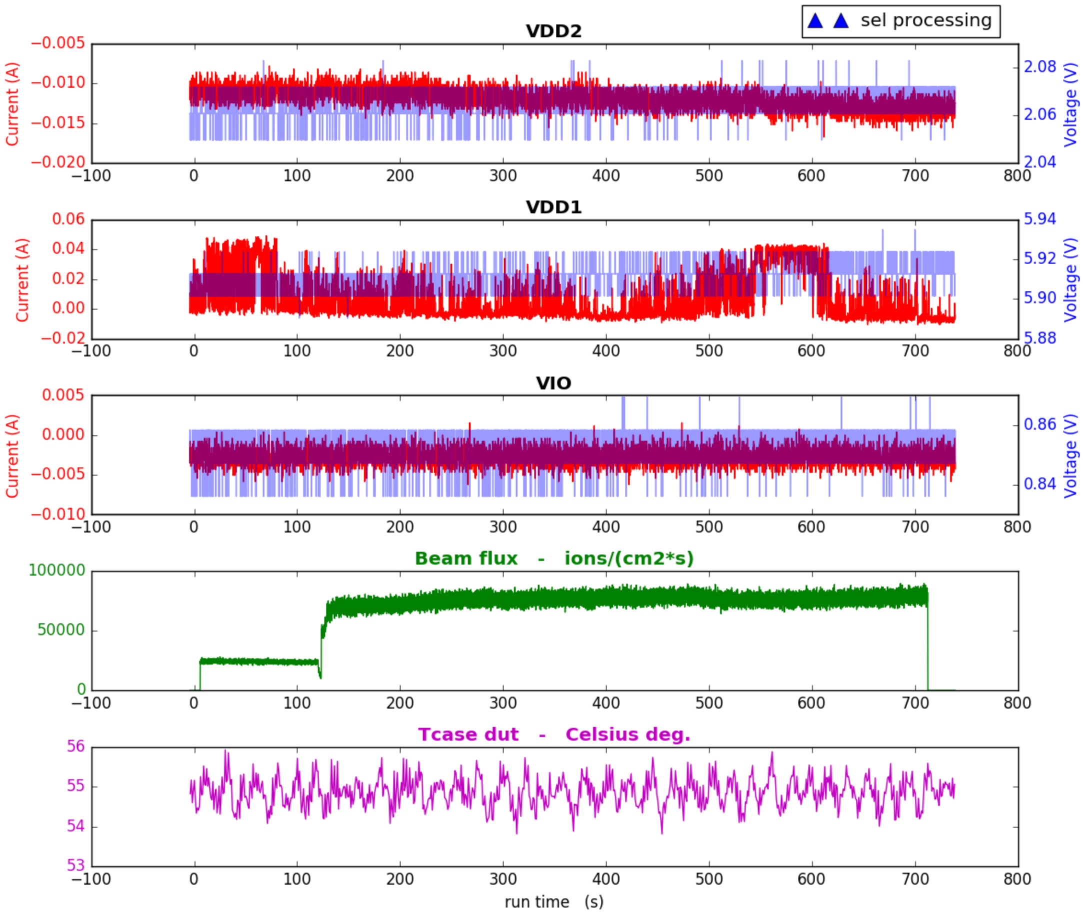
No SEL has been detected with Xenon on three DUTs.

Date	Facility	dut_medium	run_number	Facility_run_number	board_id	DUT_part_id	DUT_partnumber	power_config	test_mode	temperature	Ion	LET MeV/(mg/cm²)	tilt	run_duration	entered_fluence	VDD2 UI channel	VDD1 UI channel	VIO UI channel	VDD2 current limit mA	VDD1 current limit mA	VIO current limit mA	VDD2 SEL	VDD1 SEL	VIO SEL
oct-17	HIF	vacuum	1	150	1	AD7961	2	VMax	SEL	85	Cr	16	0	705	1.00E+07	7	5	20	100	100	100	0	0	0
oct-17	HIF	vacuum	2	151	1	AD7961	3	VMax	SEL	85	Cr	16	0	663	1.00E+07	2	8	6	100	100	100	0	0	0
oct-17	HIF	vacuum	4	152	1	AD7961	3	VMax	SEL	85	Kr	32.4	0	866	1.00E+07	2	8	6	100	100	100	0	0	0
oct-17	HIF	vacuum	5	153	1	AD7961	2	VMax	SEL	85	Kr	32.4	0	629	1.00E+07	7	5	20	100	100	100	0	0	0
nov-17	RADEF	vacuum	2	36	1	AD7961	3	VMax	SEL	85	Xe	60	0	1064	1.00E+07	2	8	6	100	100	100	0	0	0
nov-17	RADEF	vacuum	3	37	1	AD7961	2	VMax	SEL	85	Xe	60	0	871	1.00E+07	7	5	20	100	100	100	0	0	0
nov-17	RADEF	vacuum	4	38	1	AD7961	1	VMax	SEL	85	Xe	60	0	1046	1.00E+07	18	17	16	100	100	100	0	0	0

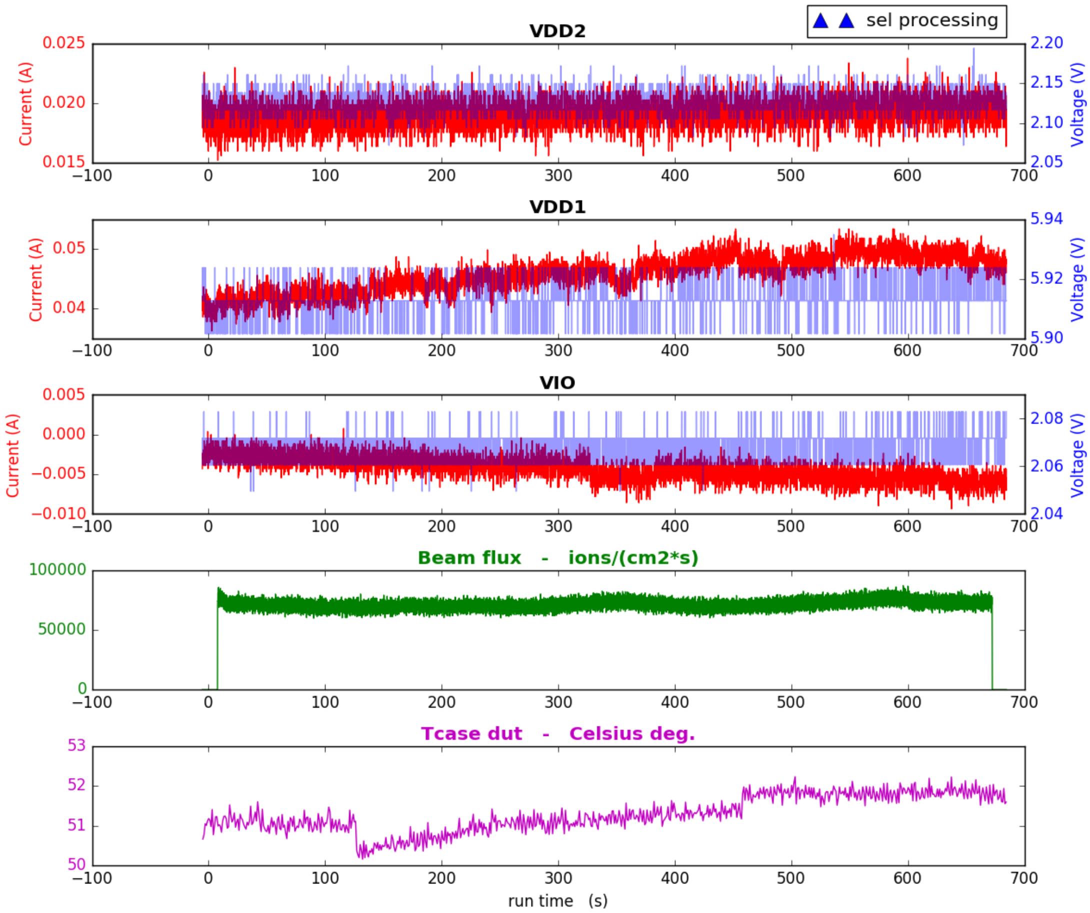
Table 4: AD7961 results for SEL test runs.

Corresponding runs chronograms are provided in following pages.

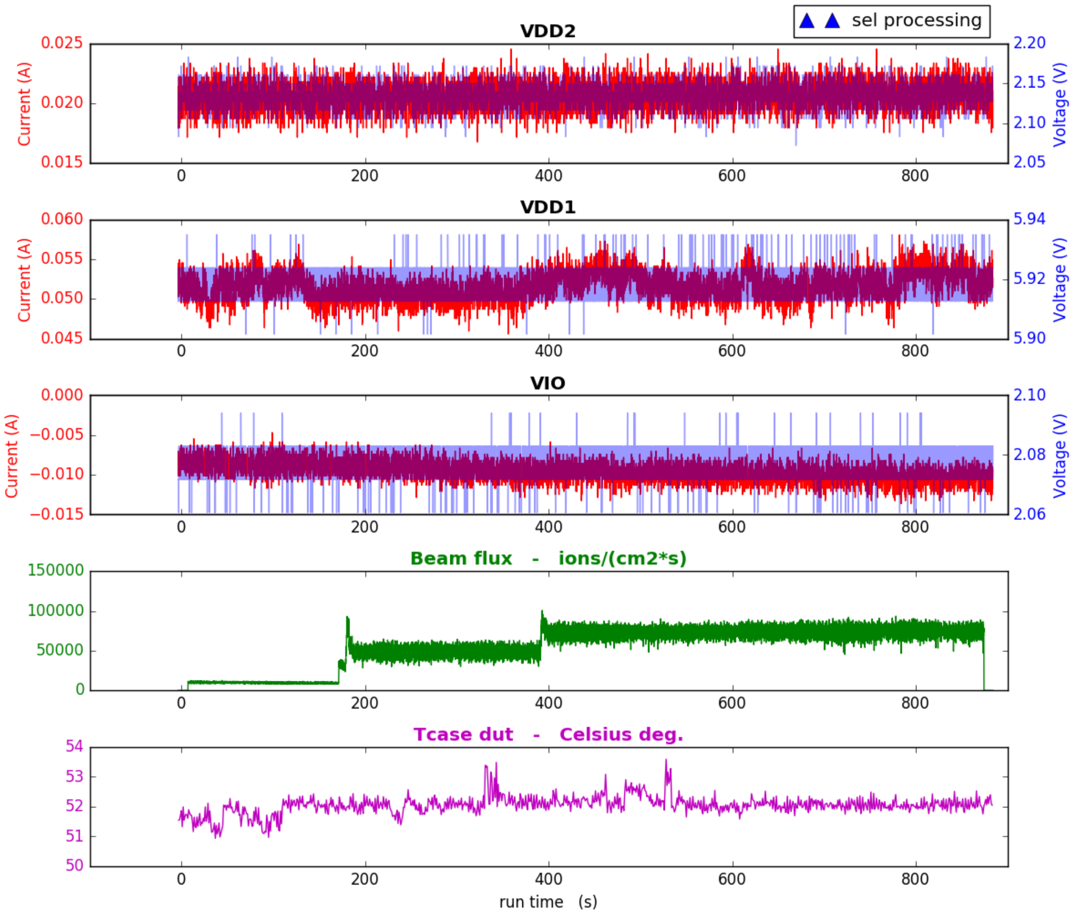
HIF-UCL



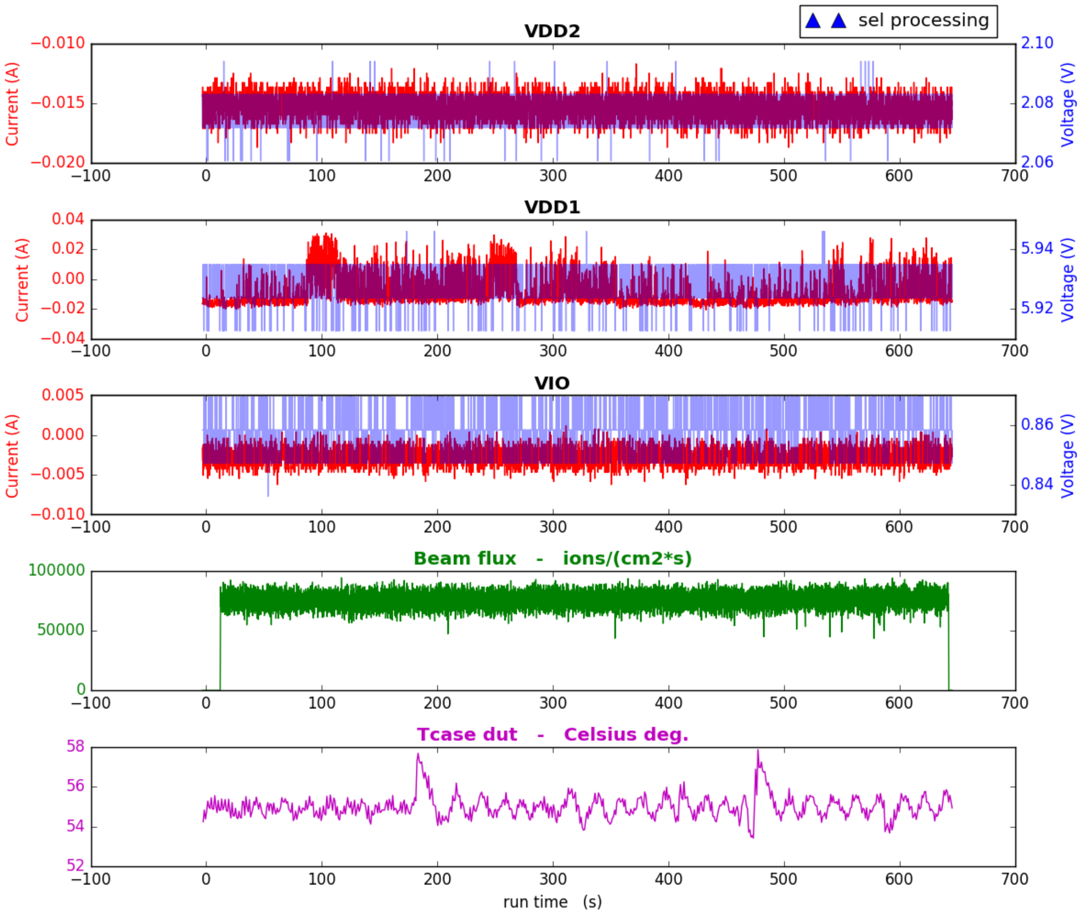
RUN001



RUN002

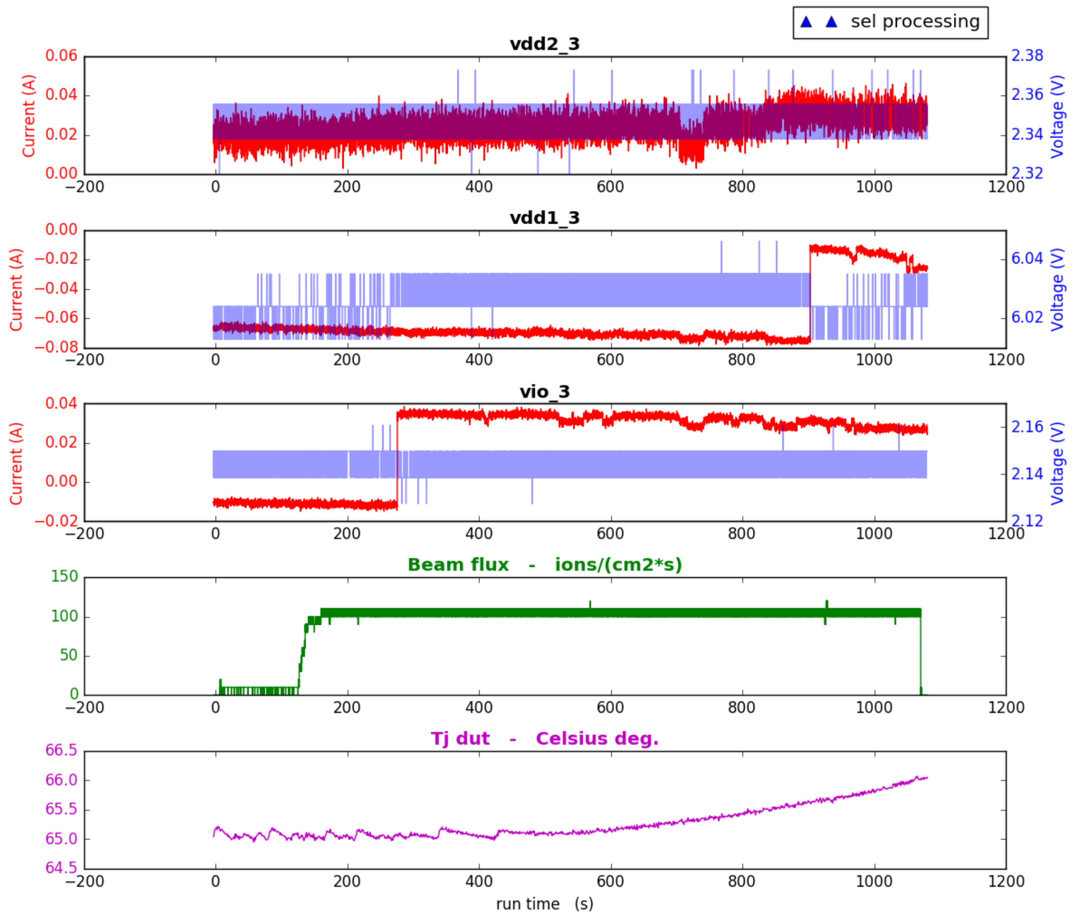


RUN004

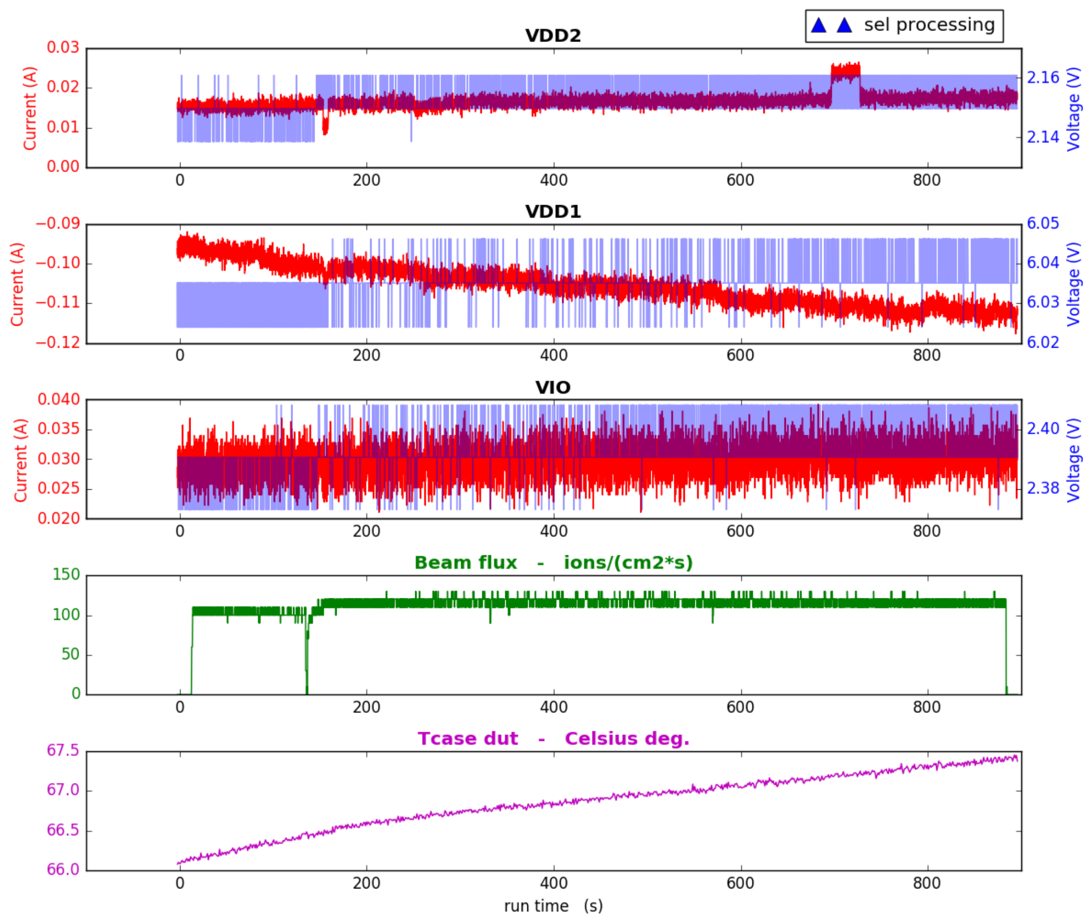


RUN005

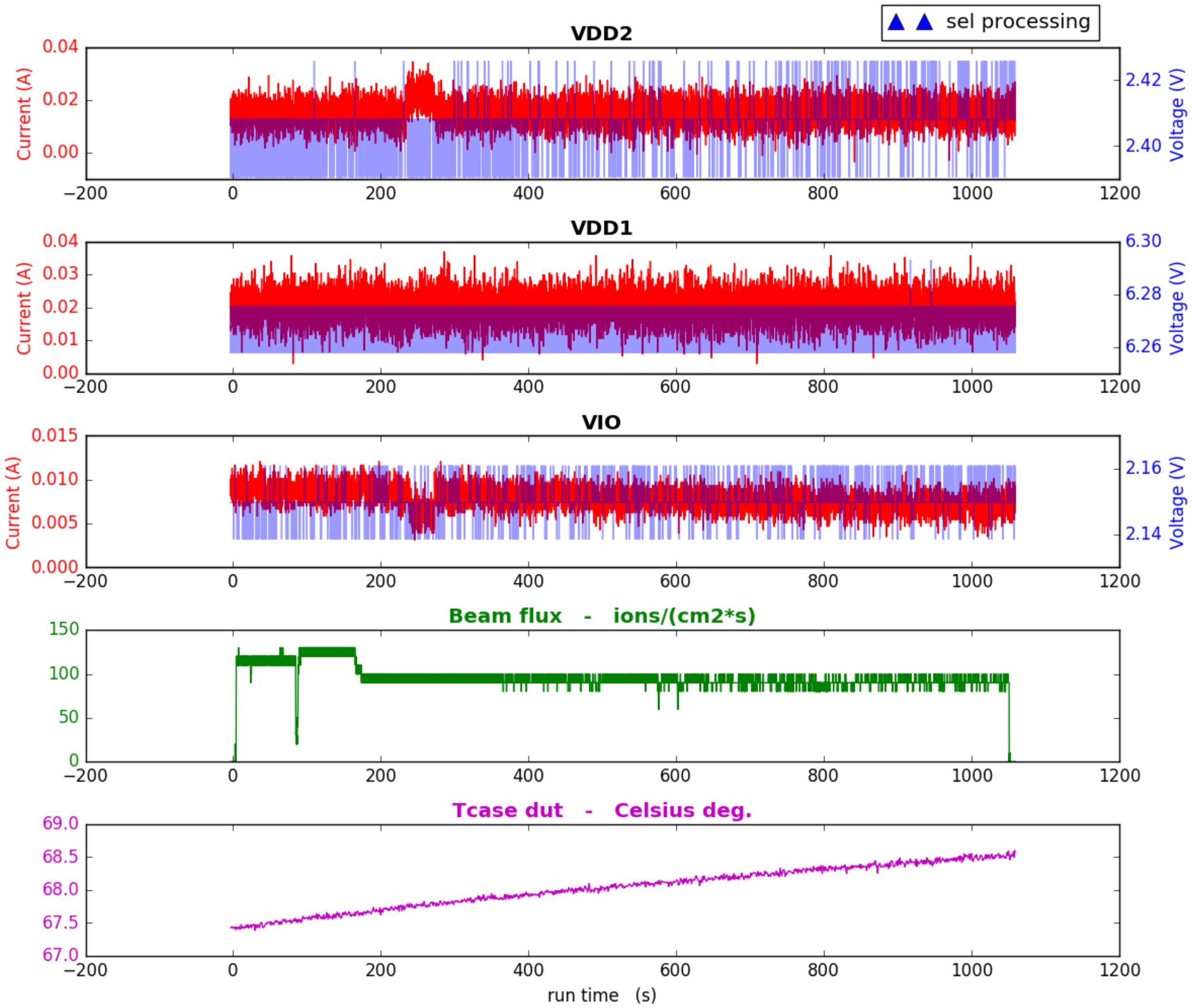
RADEF-JYFL



RUN002



RUN003


sel processing
VDD2
Current (A)
Voltage (V)
VDD1
VIO
Beam flux - ions/(cm2*s)
Tcase dut - Celsius deg.
run time (s)

RUN004

8 Glossary

DUT: Device under test.

Fluence (of particle radiation incident on a surface): The total amount of particle radiant energy incident on a surface in a given period of time, divided by the area of the surface.
In this document, Fluence is expressed in ions per cm².

Flux: The time rate of flow of particle radiant energy incident on a surface, divided by the area of that surface.
In this document, Flux is expressed in ions per cm².s.

Linear Energy Transfer (LET): Amount of energy lost by an ion inside its path in the absorber medium when colliding with atomic electron. In this document, LET is divided by the mass density of the absorber medium and is expressed in MeV.cm²/mg.

Single-Event Effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic particle strike.
Single-event effects include single-event upset (SEU), multiple-bit upset (MBU), multiple-cell upset (MCU), single-event functional interrupt (SEFI), single-event latch-up (SEL).

Single Event Gate Rupture (SEGR) **/ Single Event Dielectric Rupture (**SEDR**):** Destructive rupture of the gate oxide layer or dielectric layer by a single ion strike. This leads to leakage currents under bias and can be observed as stuck bits in digitals devices

Single-Event Upset (SEU)**:** A soft error caused by the transient signal induced by a single energetic particle strike.

Single-Event Transient (SET): A transient signal induced by a single energetic particle strike.

Single-Event Latch-up (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle through sensitive regions of the device structure and resulting in the loss of device functionality.
SEL may cause permanent damage to the device. If the device is not permanently damaged, power cycling of the device (off and back on) is necessary to restore normal operation.
An example of SEL in a CMOS device is when the passage of a single particle induces the creation of parasitic bipolar (p-n-p-n) shorting of power to ground.

Single-Event Functional Interrupt (SEFI): A soft error that causes the component to reset, lock-up, or otherwise malfunction in a detectable way, but does not require power cycling of the device (off and back on) to restore operability, unlike single-event latch-up (SEL), or result in permanent damage as in single-event burnout (SEB).
A SEFI is often associated with an upset in a control bit or register.

Error cross-section: the number of errors per unit fluence. For device error cross-section, the dimensions are cm² per device. For bit error cross-section, the dimensions are cm² per bit.

Tilt angle: tilt angle, rotation axis of the DUT board is perpendicular to the beam axis; roll angle, board rotation axis is parallel to the beam axis

Weibull fit: $F(x) = A\,(1- \exp\{-[(x-x_0)/W]^s\})$ with:

- x = effective LET in MeV/(mg/cm^2);
- $F(x)$ = SEE cross-section in cm^2;
- A = limiting or plateau cross-section;
- x_0 = onset parameter, such that $F(x) = 0$ for $x < x_0$;
- W = width parameter;
- s = a dimensionless exponent.

Error bars: error bars are computed using a confidence level of 95% and a beam flux uncertainty of +/-10% as recommended by Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100.