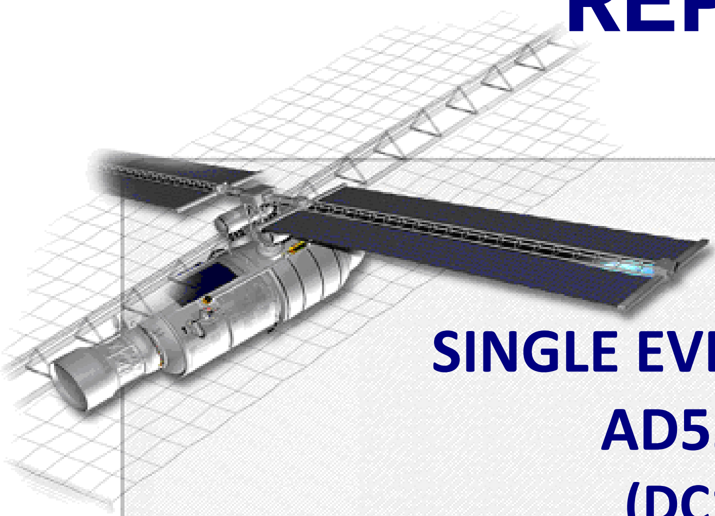
HEAVY IONS TEST REPORT



SINGLE EVENT EFFECTS
AD558JNZ
(DC1116)
Voltage-Output 8-Bit Digital-to-Analog Converter
From
Analog Devices

TRAD/TI/AD558JNZ/1116/ESA/LG/1409		Labège, 09 September, 2015
TRAD Tests & radiations; afaq ISO 9001 Qualité AFNOR CERTIFICATION		TRAD, Bât Gallium 907, Voie l'Occitane - 31670 LABEGE France ☏: 05 61 00 95 60 Fax: 05 61 00 95 61 Email: trad@trad.fr Web Site: www.trad.fr SIRET 397 862 038 00056 - TVA FR59397862038
Written by	Verified by / Quality control	Approved by
B.VANDEVELDE **09/09/2015**	**A. SAMARAS** **21/09/2015**	**A. VAROTSOU** **01/10/2015**
Revision: 1		
To: **ESA** **Marc POIZAT**		Project/Program: TID influence on the SEE sensitivity of active EEE Components Ref: ESTEC Contract No.4000111336

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1. Introduction

This report includes the test results of the heavy ions Single Event Effects (SEEs) test sequence carried out on the **AD558JNZ**, a **Voltage-Output 8-Bit Digital-to-Analog Converter** from **Analog Devices**.

This test was performed for **ESA** at U.C.L (Université Catholique de Louvain, Louvain la Neuve, Belgium) on October 27th and 28th, 2014. Six samples were irradiated.

This test was performed for **ESA** on the **AD558JNZ** susceptible to show Single Event Latchups (SELs) Single Event Transients (SETs) and Single Event Functional Interrupt (SEFIs) induced by heavy ions. This test was performed as a part of a global study to evaluate the potential synergetic effects of TID on SEE sensitivity (ESTEC Contract No.4000111336/14/NL/SW). As a result, the development strategy for this test was not the characterization of the AD558JNZ itself, but the evolution of its SEE sensitivity after submission to TID. The results presented in this report were obtained before TID irradiation (0 krad).

2. Documents

2.1. Applicable documents

Financial and technical proposal: TRAD/P/ESA/AO7751/AV/130214 Rev.0
Irradiation test plan: ITP/TRA/TE/AD558/XXX/AD/240714 issue 2 of 15/10/2014

2.2. Reference documents

Data-sheet: AD558 Datasheet from Analog Devices Rev. A

3. Organization of Activities

The relevant company has performed the following tasks during this evaluation:

1	Procurement of Test Samples	TRAD
2	Preparation of Test Samples (delidding)	TRAD
3	Preparation of Test Hardware and Test Program	TRAD
4	Samples Check	TRAD
5	Accelerator Test	TRAD
6	Heavy Ion Test Report	TRAD

Table 1: Organization of activities

4. Parts information

4.1. Device description

The AD558 DAC is a complete voltage-output 8-bit digital-to-analog converter, including output amplifier, full microprocessor interface and precision voltage reference on a single monolithic chip. No external components or trims are required to interface, with full accuracy, an 8-bit data bus to an analog system.

4.2. Identification

Type:	AD558JNZ
Manufacturer:	Analog Devices
Function:	Voltage-Output 8-Bit Digital-to-Analog Converter

4.3. Procurement information

Package	DIL-16
Date code	1116
Sample size:	10 parts procured by TRAD

4.4. Sample Preparation

All parts were delidded by TRAD.
No sample was damaged during this operation.
A functional test sequence was performed on delidded samples to check that devices were not degraded by the delidding operation.
Among the 10 delidded samples available for the test campaign, 6 were irradiated and 4 were not used.

4.5. Sample pictures

4.5.1. External view

No marking was observed at the bottom of the package.

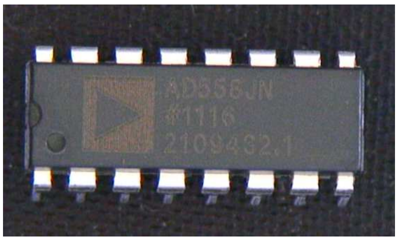


Figure 1: Package marking

4.5.2. Internal view

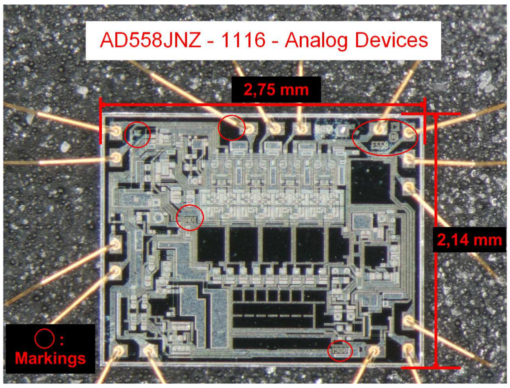


Figure 2: Overall internal view

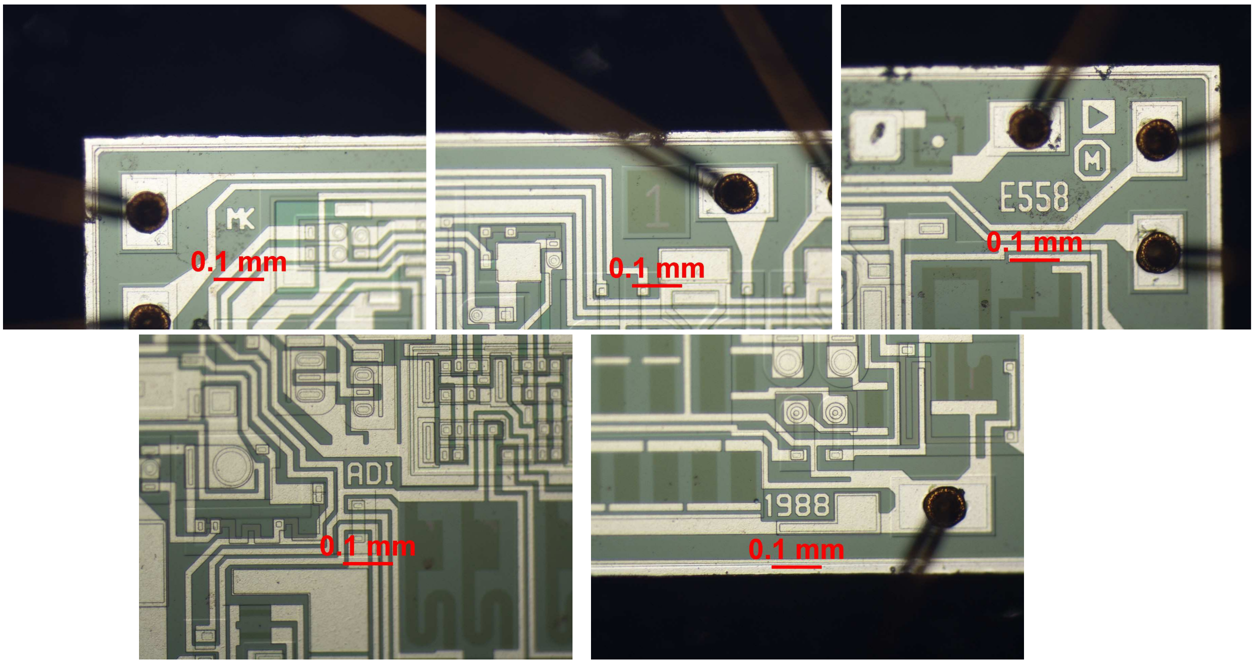


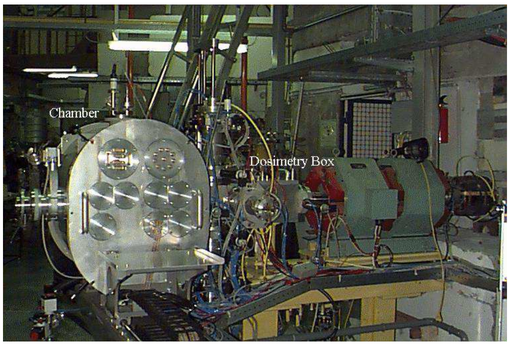
Figure 3: Die marking

5. Dosimetry and Irradiation Facilities

The test performed at U.C.L (Université Catholique de Louvain) on October 27th and 28th, 2014. 6 delidded samples were irradiated.

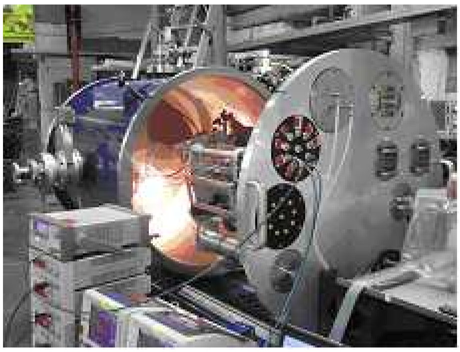
5.1. UCL Heavy Ion Test Facility (Université Catholique de Louvain - Belgique)

The CYClotron of LOuvain la NEuve (CYCLONE) is a multi-particle, variable energy, cyclotron capable of accelerating protons (up to 85 MeV), alpha particles and heavy ions.
For the heavy ions, the covered LET range is between 1.2 MeV.cm².mg^{-1} and 67.7 MeV.cm².mg^{-1}. Heavy ions available are separated in two "Ion Cocktails" named M/Q=5 and M/Q=3.3.



One of the main advantages of the UCL Heavy Ion Test Facility is the fast changing of ion species. Within the same cocktail, it takes only a few minutes to change from one ion to another.

The chamber has the shape of a barrel stretched vertically; its internal dimensions are 71 cm in height, 54 cm in width and 76 cm in depth. One side flange is used to support the board frame (25 X 25 cm) and user connectors.
The chamber is equipped with a vacuum system.



5.2. Dosimetry

To control and monitor the beam parameters, a dosimetry box is placed in front of the chamber. It contains a faraday cup, 2 Parallel Plate Avalanche Counters (PPAC).
Two additional surface barrier detectors are placed in the test chamber.
The faraday cup is used during beam preparation at high intensity.
A beam uniformity measurement is performed with a collimated surface barrier detector. This detector is placed on a X and Y movement. The final profile is drawn and the ± 10 % width is calculated. The Homogeneity is ± 10 % on a 25 mm diameter.
During the irradiation, the flux is integrated in order to give the delivered total fluence (particule.cm^{-2}) on the device.

5.3. Beam characteristics

The beam flux is variable between a few particles $s^{-1}cm^{-2}$ and $1.8 \cdot 10^4 s^{-1}cm^{-2}$ depending on the device sensitivity.

Available heavy ion characteristics are listed in the following tables (heavy ions used during the experiment are highlighted in yellow):

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{15}N^{3+}$	60	59	3.3
$^{20}Ne^{4+}$	78	45	6.4
$^{40}Ar^{8+}$	151	40	15.9
$^{84}Kr^{17+}$	305	39	40.4
$^{124}Xe^{25+}$	420	37	67.7

Table 2: UCL cocktail M/Q=5

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{13}C^{4+}$	131	292	1.1
$^{22}Ne^{7+}$	235	216	3
$^{40}Ar^{12+}$	372	117	10.2
$^{58}Ni^{18+}$	567	100	20.4
$^{83}Kr^{25+}$	756	92	32.6

Table 3: UCL cocktail M/Q=3.3

6. Test Procedure and Setup

6.1. Test procedure

6.1.1. Description of the test method

The test was divided in two parts, with respect to reference or applicable documents:

- Runs were performed up to a fluence of 1.10^{7} cm^{-2} with only SEL monitoring. This configuration allowed to verify the latchup sensitivity of the device.
- Runs were performed up to a fluence of 1.10^{6} cm^{-2} for the SET, and SEFI detection. A latchup monitoring was used during these tests in order to protect the component. This configuration allowed to verify the SET and SEFI sensitivity of the device.

The test was terminated when the maximum fluence was reached or when about a hundred events were recorded.

6.1.2. SEL Test Principle

The test was performed at nominal operating voltage and ambient temperature.
TRAD has developed a fully integrated test bench to perform Single Event Latchup tests (SEL). The GUARD system (Graphical Universal Autorange Delatcher) allows the user to easily protect his device under test and perform SEL characterization.
The power supply is applied to the device under test through the GUARD system.
The threshold current of the GUARD system is set according to the nominal current. If the nominal current exceeds the threshold current, the GUARD system is triggered and the event is counted as an SEL. Then, the GUARD system sends a trigger command to the oscilloscope, maintains the power supply during a defined 'Time hold' and cuts it off during a defined 'Time cut'. Then, the power supply is restarted with the nominal current consumption.
At the end of each run, the test program reads the oscilloscope's "Local Scope Counter" which represents the total event count and downloads the recorded current waveforms to store them.

Figure 4 shows an example of the SEL detection.

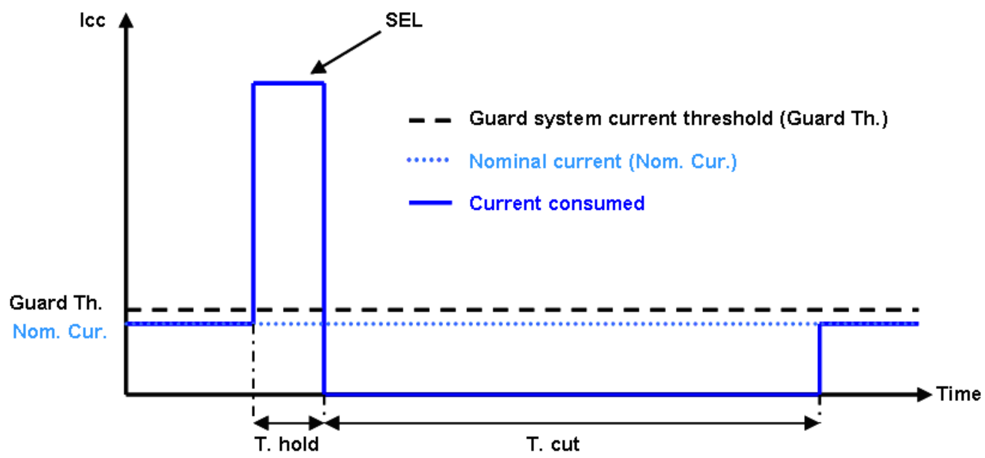


Figure 4: Common SEL characteristic.

6.1.3. SET and SEFI Test Principle

The GUARD system is always used on the component's power supply to detect SEL and to prevent the destruction of the device under test.
Single Event Transient is an event described by a voltage amplitude and a timing parameter.
To detect these events, the output voltage of the component is monitored.

A set of digital inputs: quarter, half and three-quarter of the input range is used to evaluate the least sensitive configuration. These configurations are respectively noted as SET_1, SET_2 and SET_3. For all these configurations, the DUT operates in "Transparent latch" mode, where no conversion clock is required at CE or CS input pins, thus allowing direct access to the DAC. The least sensitive configuration is then maintained for the remaining tests.

SET can be positive or negative. Two trigger thresholds (positive and negative) are used to detect the amplitude voltage due to SET. An SET is detected when the output device voltage becomes higher or lower than the positive trigger threshold or the negative trigger threshold respectively. During the test, the oscilloscope's internal counter is incremented at each detected SET and the waveform of each transient is stored.

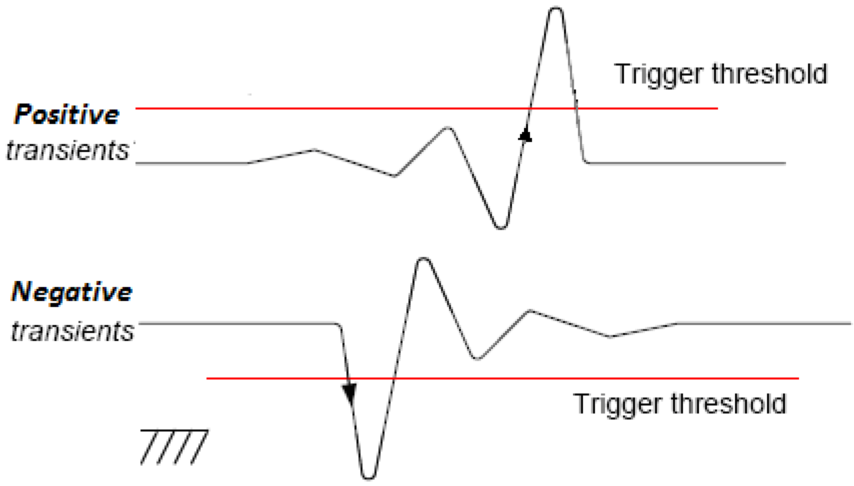


Figure 5: Positive and negative SET detection

The lower threshold for the SET detection is set to "Vout - 20 LSB" and the higher threshold is set to "Vout + 20 LSB".

A voltmeter is used to detect Single Event Functional Interrupt. In this case the lower threshold for the SEFI detection is set to "Vout - 10 LSB" and the higher threshold is set to "Vout + 10 LSB". A SEFI is taken into account if Vout stays out of these limits during more than 100ms. When a SEFI occurs the DAC is power cycled OFF-ON.

At the end of each run, the test program reads the oscilloscope's "Local Scope Counter" which represents the total event count and downloads the recorded current waveforms to store them.

6.2. Test bench description

6.2.1. Preparation of test hardware and program

TRAD has developed a specific test program and a specific motherboard to feed power supply to components.
The output of the DUT is visualized using an oscilloscope and curves are saved when an event occurs.
The test system is driven by a personal computer through a standard IEEE488 communication interface.
All signals are delivered and monitored by this equipment and SEE curves are saved in its memory.
At the end of each test run, data is transferred to the hard disk for storage. An overall description of the test system is given in Figure 6.
Before performing the heavy ion test, the whole system (delidded sample, test board and software) was assembled and tested by TRAD in V.A.S.C.O (Vacuum System for Californium Operation).

6.2.2. Test equipment identification

The tests were carried out with evaluation test boards developed by TRAD.

COMPUTER	PO-TE-097
REF. TEST BOARD	TRAD/CT1/I/AD558/DIL16/LS/1407
EQUIPMENT	ME-79, MI-60, GR-53, SM-92
TEST PROGRAM	AD558_TI_XXX1_SEL_V10.spf AD558_TI_XXX1_SEU_V20.spf

6.2.3. Test Bench description

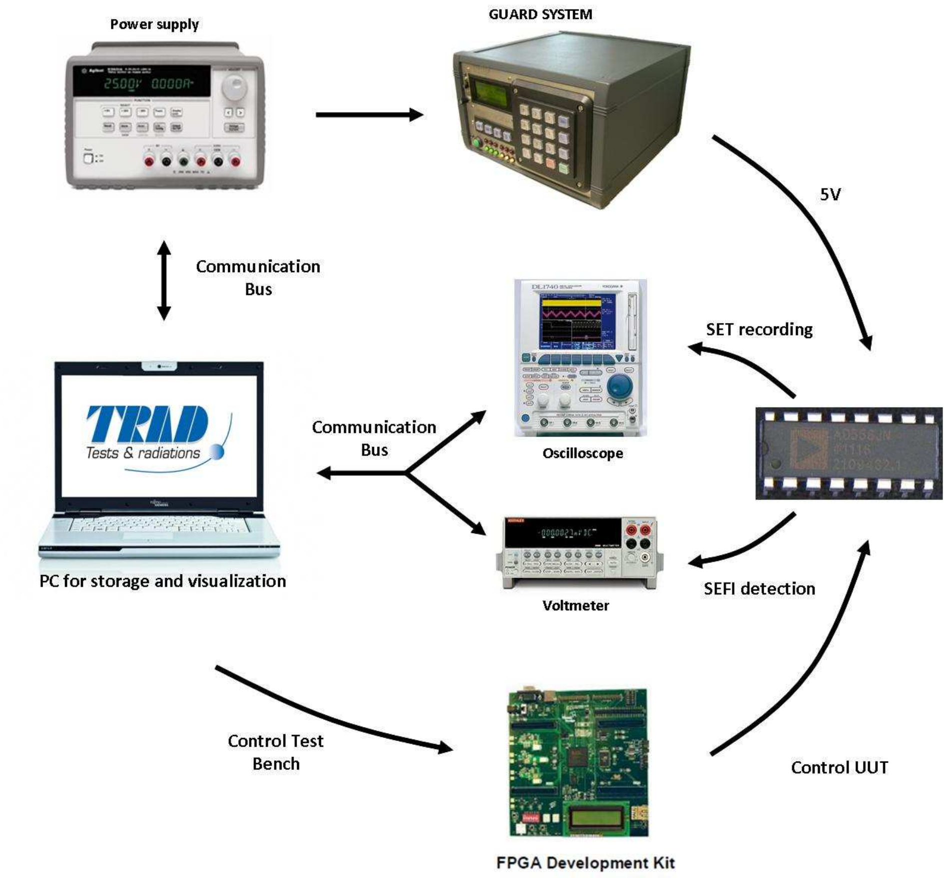


Figure 6: Test system description

6.2.4. Device setup and Test conditions

Trigger thresholds for SET test are defined in the following table:

Vcc	5V		
Configuration	SET_1	SET_2	SET_3
V_{out}	0.51	1.27	2.04
Positive trigger threshold	0.71	1.47	2.24
Negative trigger threshold	0.31	1.07	1.84

Table 4: static SET detection threshold

Trigger threshold for SEL test is defined in the following table:

Vcc	5V
$I_{nominal}$	15mA
$I_{threshold}$	20mA
T_{hold}	1ms
T_{cut}	7ms
Temperature	25°C

Table 5: SEL detection threshold

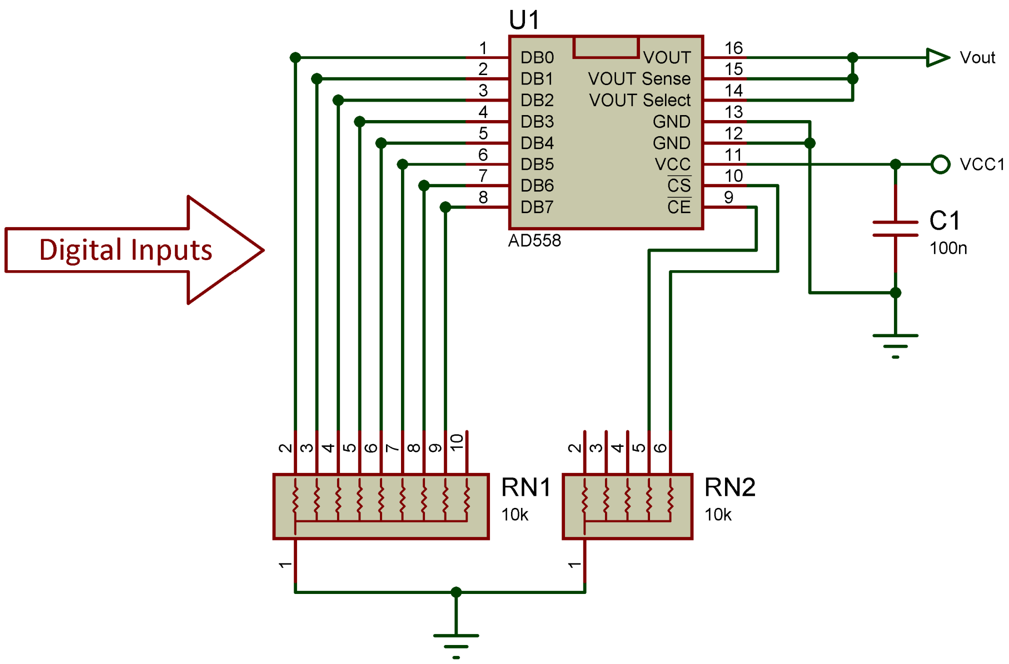


Figure 7: Test board schematic

7. Test Story

Test sequence, test and measurement conditions were nominal.

8. RESULTS

8.1. Summary of runs.

Runs performed during this campaign are summarized in the following table. Tests results are described in the following chapter.

AD558JNZ Vcc = 5V T= 25°C												LATCHUP		SEE			
Run	Part	Config	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	Vcc	Cross Section	SET	Cross Section	SEFI	Cross Section
High LET M/Q=5																	
1	1	SEL	124Xe 26+	420	37	67.7	8.61E+03	1163	1.00E+07	10.848	10.848	0	<1.00E-07	-	-	-	-
2	2	SEL	124Xe 26+	420	37	67.7	1.01E+04	996	1.00E+07	10.845	10.845	0	<1.00E-07	-	-	-	-
3	2	SET_2	124Xe 26+	420	37	67.7	1.03E+03	142	1.47E+05	0.159	11.004	0	<6.82E-06		<6.82E-06		-
4	2	SET_2	124Xe 26+	420	37	67.7	1.03E+03	86	8.86E+04	0.096	11.100	0	<1.13E-05	102	1.15E-03	0	<1.13E-05
5	2	SET_1	124Xe 26+	420	37	67.7	1.29E+03	778	1.00E+06	1.086	12.186	0	<1.00E-06	987	9.84E-04	0	<1.00E-06
6	2	SET_3	124Xe 26+	420	37	67.7	1.51E+03	52	7.88E+04	0.085	12.272	0	<1.27E-05	116	1.47E-03	0	<1.27E-05
7	1	SET_2	124Xe 26+	420	37	67.7	1.53E+03	93	1.42E+05	0.154	11.002	0	<7.03E-06	209	1.47E-03	0	<7.03E-06
8	1	SET_1	124Xe 26+	420	37	67.7	1.55E+03	646	1.00E+06	1.085	12.087	0	<1.00E-06	964	9.62E-04	0	<1.00E-06
9	1	SET_1	84 Kr 17+	305	39	40.4	1.54E+03	80	1.23E+05	0.080	12.167	0	<8.10E-06	101	8.18E-04	0	<8.10E-06
10	2	SET_1	84 Kr 17+	305	39	40.4	1.54E+03	90	1.38E+05	0.089	12.361	0	<7.23E-06	104	7.52E-04	0	<7.23E-06
High Range M/Q=3.3																	
11	4	SET_1	83 Kr 25+	756	92	32.6	1.53E+03	112	1.71E+05	0.089	0.089	0	<5.84E-06	113	6.60E-04	0	<5.84E-06
12	5	SET_1	83 Kr 25+	756	92	32.6	1.54E+03	71	1.09E+05	0.057	0.057	0	<1.00E-05	105	9.60E-04	0	<1.00E-05
13	6	SET_1	83 Kr 25+	756	92	32.6	1.50E+03	117	1.76E+05	0.092	0.092	0	<5.69E-06	103	5.86E-04	0	<5.69E-06
14	6	SET_1	40 Ar 12+	372	117	10.2	1.82E+03	231	4.20E+05	0.068	0.160	0	<2.38E-06	101	2.41E-04	0	<2.38E-06
15	4	SET_1	40 Ar 12+	372	117	10.2	2.23E+03	214	4.77E+05	0.078	0.167	0	<2.10E-06	100	2.10E-04	0	<2.10E-06
16	4	SET_1	13 C 4+	131	292	1.1	3.74E+03	269	1.01E+06	0.018	0.185	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06
17	6	SET_1	13 C 4+	131	292	1.1	5.17E+03	195	1.01E+06	0.018	0.178	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06
18	6	SET_1	22 Ne 7+	235	216	3	5.15E+03	196	1.01E+06	0.048	0.226	0	<1.00E-06	12	1.19E-05	0	<1.00E-06
19	4	SET_1	22 Ne 7+	235	216	3	5.14E+03	196	1.01E+06	0.048	0.233	0	<1.00E-06	14	1.39E-05	0	<1.00E-06
20	4	SET_1	58 Ni 18+	567	100	20.4	2.54E+03	59	1.50E+05	0.049	0.282	0	<6.67E-06	102	6.80E-04	0	<6.67E-06
21	6	SET_1	58 Ni 18+	567	100	20.4	2.50E+03	66	1.65E+05	0.054	0.280	0	<6.06E-06	101	6.12E-04	0	<6.06E-06

Table 6: AD558JNZ test results

No SEL or SEFI were detected during this test.
SET events were detected during this test.

8.2. SEL test results.

The SEL test was performed at 25°C.
No SEL was observed during this test under Xenon irradiation with a total fluence equal to 1E+7 cm^{-2} with a particle angle of 0° (LET = 67.7 MeV.cm²/mg and range = 37µm).

8.2.1. SEL Cross sections

LET ($MeV.cm^2.mg^{-1}$)	AD558JNZ SEL Cross Section (cm^2)	
	N°1	N°2
67.7	<1.00E-07	<1.00E-07

Table 7: AD558JNZ SEL cross section results

8.3. SEE tests results

The SEE test was performed at 25°C.

The three tested configurations did not present a difference of sensitivity at Xenon Heavy Ion, LET = 67.7 MeV.cm²/mg. Configuration SET_1 was selected to perform SET tests.

SETs were observed during the irradiation down to the Neon Heavy Ion (LET = 3 MeV.cm²/mg).

8.3.1. SET Cross sections

AD558JNZ SET_1 configuration SET Cross Section (cm^2)					
LET Eff ($MeV.cm^2.mg^{-1}$)	**SET**				
	N° 1	N° 2	N°4	N° 5	N° 6
67.7	9.62E-04	9.84E-04	-	-	-
40.4	8.18E-04	7.52E-04	-	-	-
32.6	-	-	6.60E-04	9.60E-04	5.86E-04
20.4	-	-	6.80E-04	-	6.12E-04
10.2	-	-	2.10E-04	-	2.41E-04
3	-	-	1.39E-05	-	1.19E-05
1.1	-	-	<1E-06	-	<1E-06

Table 8: AD558JNZ SET_1 configuration SET cross section results

The following figures present the cross section of the SET event on Vout on the AD558JNZ part on SET_1 configuration.
Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.00 $10^{-6}cm^{-2}$, value corresponding to one event at maximum fluence.
Error bars are calculated as described in the ESCC25100, using 95% confidence level and 10% fluence uncertainty.

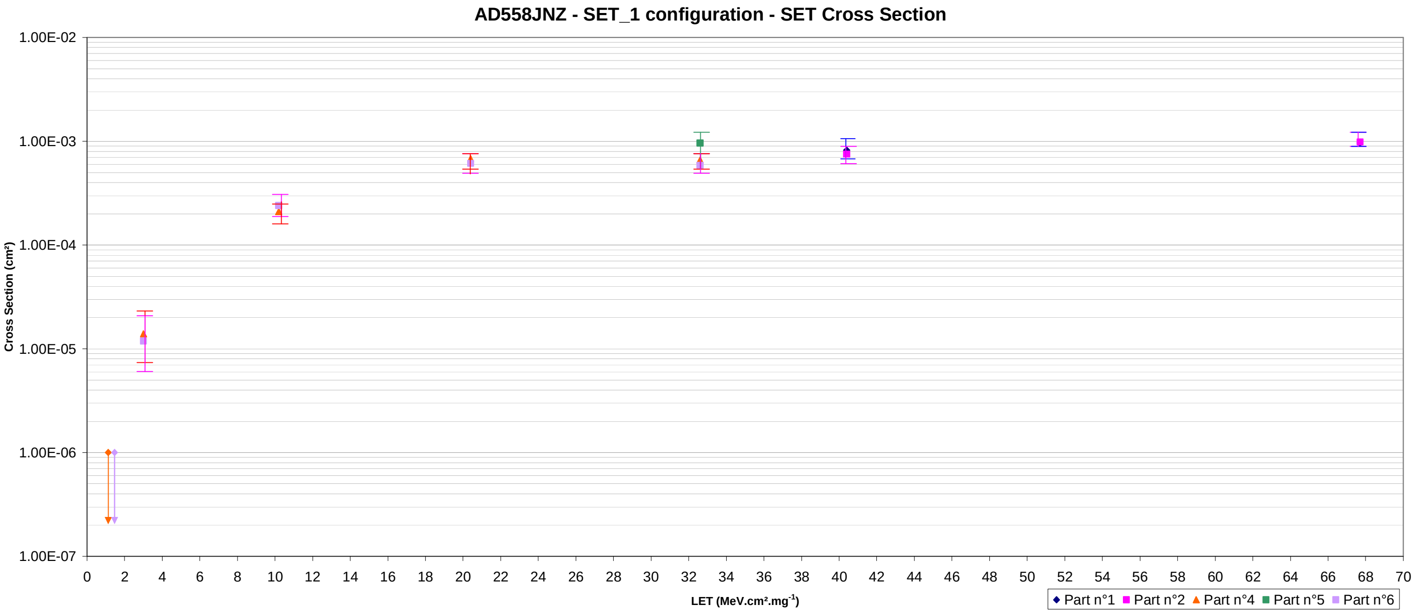


Figure 8: SET_1 configuration SET cross section curve for AD558JNZ

8.3.2. Worst Cases SET Observed

Three different types of SET were observed, positive SET, negative SET and double SET.
The worst positive SET case occurs on Part N°4 during run n°11 event n°71 (Kr, 32.6 MeV.cm²/mg).

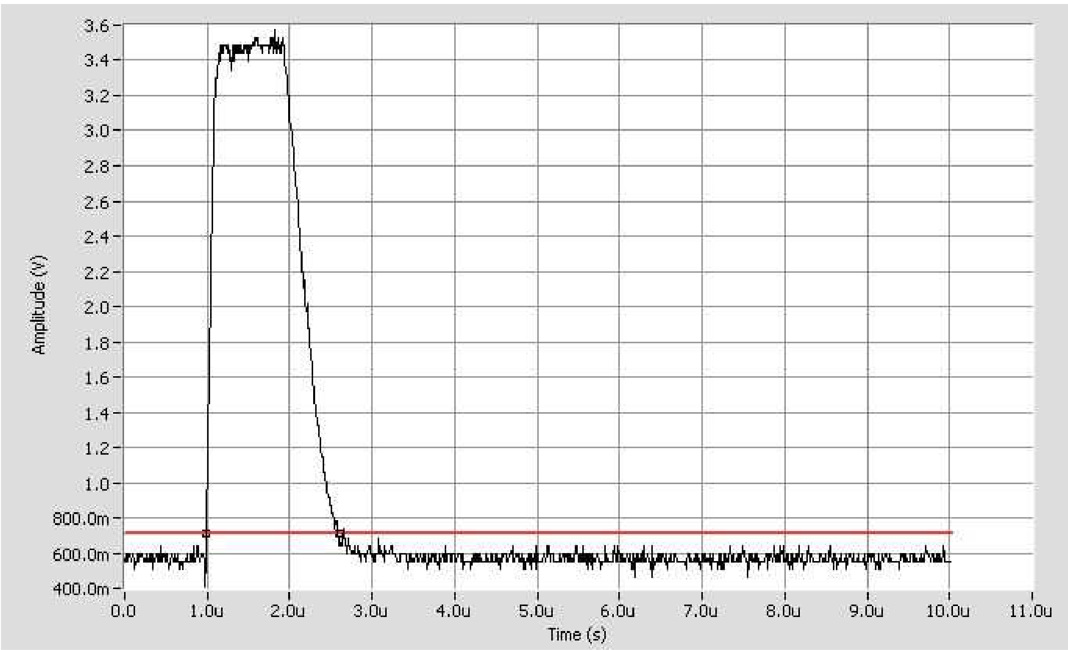


Figure 9: Positive SET curve, Heavy Ion $^{83}Kr^{25+}$ (LET: 32.6MeV.mg/cm²), Part 4, Run n°11, Event n°71

The worst negative SET case occurs on Part N°2 during run n°5 event n°643 (Xe, 67.7 MeV.cm²/mg).

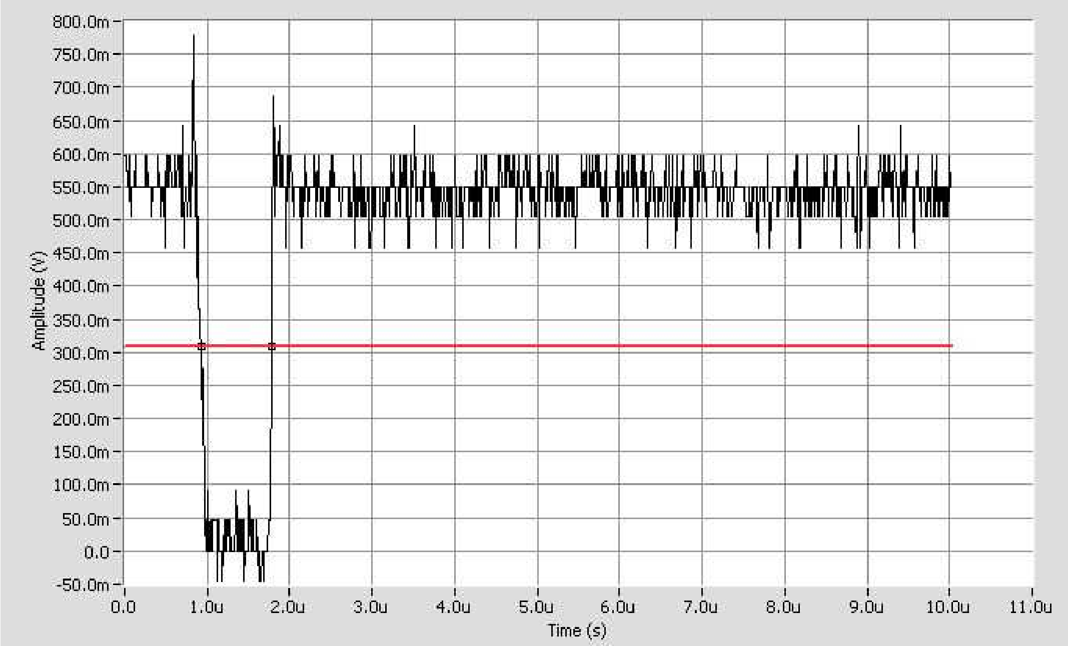


Figure 10: Negative SET curve, Heavy Ion $^{124}Xe^{26+}$ (LET: 67.7MeV.mg/cm²), Part 2, Run n°5, Event n°643

The worst double SET case occurs on Part N°2 during run n°5 event n°840 (Xe, 67.7 MeV.cm²/mg).

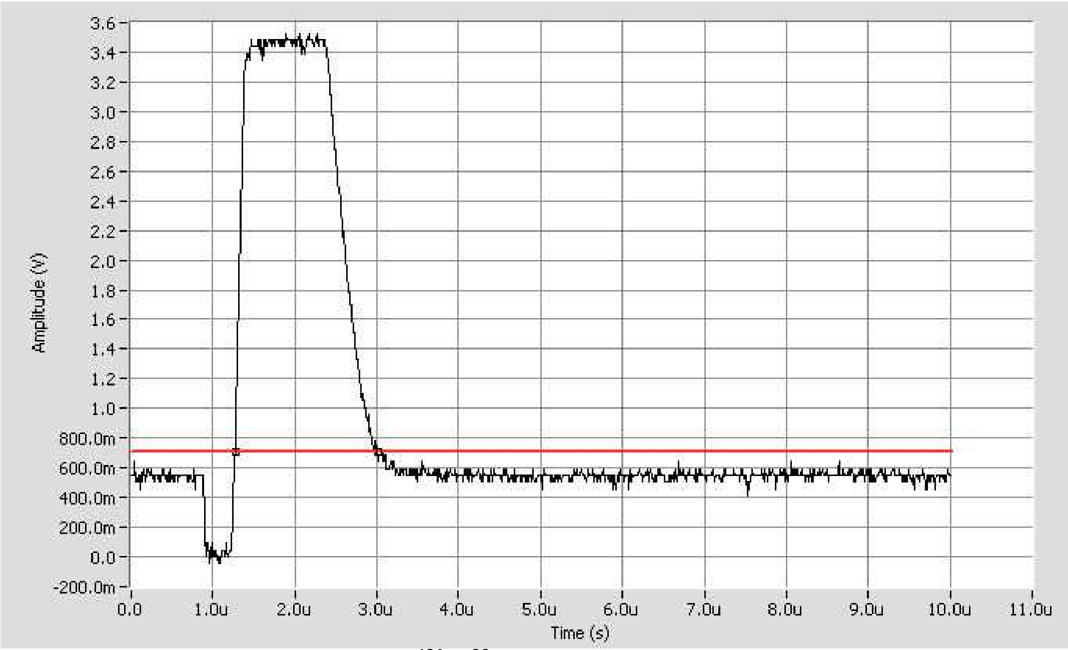


Figure 11: Double SET curve, Heavy Ion $^{124}Xe^{26+}$ (LET: 67.7MeV.mg/cm²), Part 2, Run n°5, Event n°840

8.4. SEFI test results.

The SEFI test was performed at 25°C.
No SEFI was observed during this test under Xenon irradiation with a total fluence equal to 1E+6 cm^{-2} with a particle angle of 0° (LET = 67.7 MeV.cm²/mg and range = 37µm).

8.4.1. SEFI Cross sections

LET ($MeV.cm^2.mg^{-1}$)	SEFI Cross Section (cm^2)	
	N°1	N°2
67.7	<1.00E-06	<1.00E-06

Table 9: AD558JNZ SEFI cross section results

9. Conclusion

Heavy ion tests were performed on AD558JNZ to evaluate the sensitivity of the device versus SEL, SET and SEFI. This test was performed as a part of a global study to evaluate the potential synergetic effects of TID on SEE sensitivity (ESTEC Contract No.4000111336/14/NL/SW). As a result, the development strategy for this test was not the characterization of the AD558JNZ itself, but the evolution of its SEE sensitivity after submission to TID. The results presented in this report were obtained before TID irradiation (0 krad).

No SELs were observed with the LET value of 67.7MeV.cm²/mg (Xenon heavy ions).

No SEFIs were observed with the LET value of 67.7MeV.cm²/mg (Xenon heavy ions).

SETs were observed on the AD558JNZ with a minimum LET of 3 MeV.cm²/mg (Neon heavy ions). No SET was detected with a LET of 1.1 MeV.cm²/mg (Carbon heavy ions).