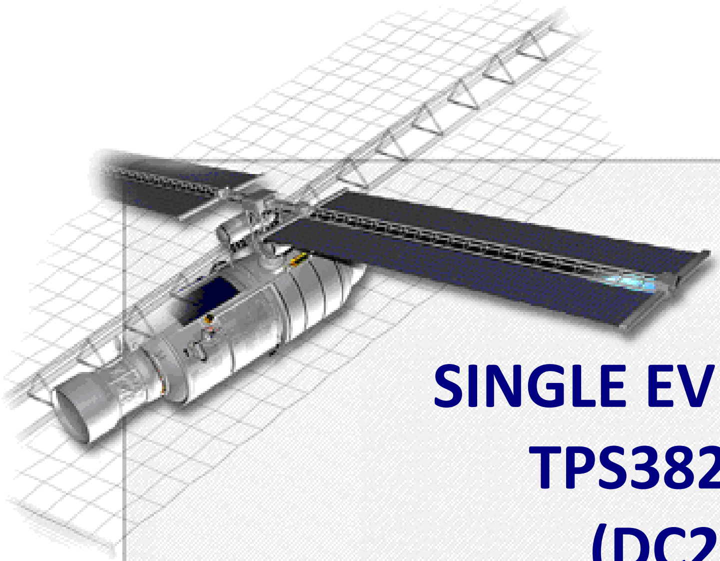
HEAVY ION TEST REPORT



SINGLE EVENT EFFECTS
TPS3820-33DBV
(DC2303+5)
TPS382x Voltage Monitor With Watchdog Timer
From
Texas Instruments

TRAD/TI/TPS3820-33DBV/DC2303+5/ESA/TA/2308		Labège, December 18th, 2023
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Abbreviations and acronyms

DUT	Device Under Test
ESA	European Space Agency
LET	Linear Energy Transfer
RADEF	RADiation Effects Facility (Jyväskylä, Finland)
SEE	Single Event Effect
SEFI	Single Event Functional Interrupt
SEL	Single Event Latch-up
SET	Single Event Transient
VASCO	VAcuum System for Californium Operation

Abstract

The main objective of this test was to evaluate the sensitivity of the TPS3820-33DBV, a Voltage Monitor with Watchdog Timer versus SEL, SET and SEFI.
The irradiation was performed at RADEF with a maximum LET of 56.8 MeV.cm²/mg.
The main conclusions are the following.

The SEL test was performed under SEL test conditions (see Table 6).

In SEL test configuration
SEL were observed with a minimum LET of 38.8 MeV.cm²/mg, Silver heavy ion.
No SEL was observed with a LET of 13.3 MeV.cm²/mg, Iron heavy ion.

An unprotected run was performed for a fluence of $3.71.10^5$ ions/cm² with a LET of 56.8 MeV.cm²/mg, Xenon heavy ion. The device was still functional after this run.

SET /RESET were observed with a minimum LET of 13.3 MeV.cm²/mg, Iron heavy ion.
No lower LET was tested during this test campaign.

No SEFI was observed with a LET of 56.8 MeV.cm²/mg, Xenon heavy ion.

1. Introduction

This report includes the test results of the heavy ion SEE test sequence carried out on the TPS3820-33DBV, a Voltage Monitor with Watchdog Timer from Texas Instruments, susceptible to show SEL induced by heavy ions.

This test was performed for ESA at RADEF. Irradiations were performed from October 27th, 2023 to October 28th, 2023. During this test campaign, 3 samples were irradiated.

2. Documents

2.1. Applicable documents

[AD1] Technical proposal: TRAD/P/ESA/AO17950/AR/131222 Rev 0 dated 13/11/2022
[AD2] Irradiation test plan: ITP/TRA/TI/TPS3820-33DBV/SOT23-5/TI/140923 Rev 0 dated 14/09/2023

2.2. Reference documents

[RD1] ESCC Basic specification No. 25100 Issue 2 of October 2014
[RD2] Datasheet: TPS3820 Voltage Monitor With Watchdog Timer, SLVS165N from Texas Instruments, dated Apr. 1998, revised Jul. 2022

3. Organization of activities

The devices were procured and delidded by TRAD. The testing board and testing software were developed by TRAD. Before the campaign the samples were checked-out and the test bench was validated with californium test at TRAD. The test campaign was performed by TRAD under ESA supervision. The next table summarizes the responsible entity for each activity involved in this project:

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 out	TRAD
5	Accelerator Test	TRAD/ESA
6	Test Report	TRAD

Table 1: Organization of activities

4. Parts information

4.1. Device description

The TPS382x family of supervisors provide circuit initialization and timing supervision, primarily for DSP and processor-based systems. During power on, RESET\ asserts when the supply voltage V_{DD} becomes greater than 1.1 V. Thereafter, the supply voltage supervisor monitors V_{DD} and keeps RESET\ active low as long as V_{DD} remains less than the threshold voltage, V_{IT-}. An internal timer delays the return of the output to the inactive state (high) to ensure proper system reset. The delay time, t_d, starts after V_{DD} has risen above the threshold voltage ($V_{IT-} + V_{HYS}$). When the supply voltage drops below the threshold voltage V_{IT-}, the output becomes active (low) again. No external components are required. All the devices of this family have a fixed-sense threshold voltage, V_{IT-}, set by an internal voltage divider. The TPS382x family also offers watchdog time out options of 200 ms (TPS3820) and 1.6 s (TPS3823, TPS3824, and TPS3828).

4.2. Identification

Part designation	TPS3820-33DBV
Manufacturer	Texas Instruments
Part function	Voltage Monitor with Watchdog Timer

Table 2: Part identification

4.3. Procurement information

Package	SOT-23-5
Date code	2303+5
Lot code No.	3007704NFM
Number of tested parts	3 irradiated samples

Table 3: Part procurement information

4.4. Sample preparation

4 parts were delidded, no sample was damaged during this operation.
A functional test was performed on delidded samples to check that devices were not degraded by the delidding operation.
Among the 4 delidded samples available for the test campaign, 3 were irradiated and 1 was not used.

4.5. Sample pictures

4.5.1. External view

The Figure 1 shows an external view of the parts. Left and right components on the picture are respectively the top and the bottom views of the package.

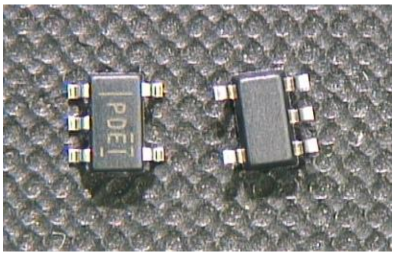

Figure 1: Picture of the package

4.5.2. Internal view

Figure 2 gives an overview of the die. Figure 3 presents a view of the internal marking observed on the die (indicated by a red rectangle on Figure 2).

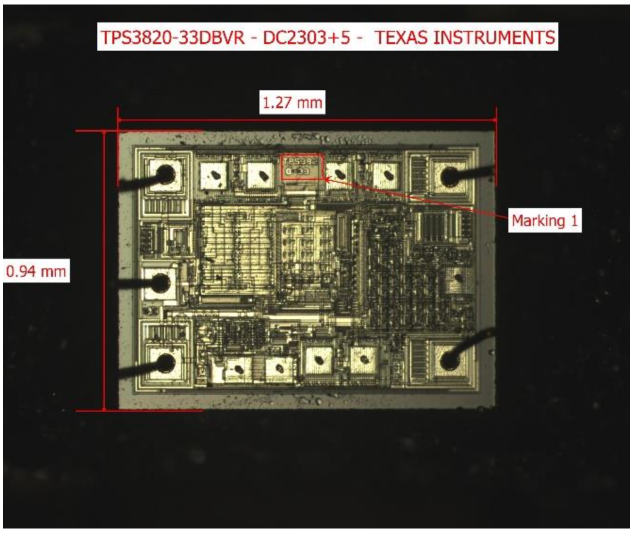

Figure 2: Picture of the internal overall view

Figure 3: Picture of the die markings

5. Dosimetry and irradiation facility

5.1. RADEF heavy ion test facility

The cyclotron used is a versatile, sector-focused accelerator for producing beams from hydrogen to xenon.

Heavy ion irradiations are 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 5 minutes of pumping, and venting takes also only a few minutes. Irradiations can also be performed in air, therefore the LET and the range is calculated according the distance between the collimator and the component.
The components can be fixed on a 25x25cm^2 aluminium plate which will be mounted on the linear movement apparatus inside the chamber. The DUT can be moved in the X and Y directions and also tilting is possible.

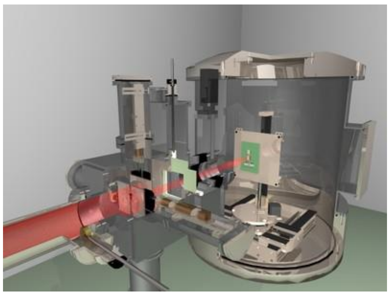
Figure 4: RADEF facility

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.

5.2. Dosimetry

To control and monitor the beam parameters, scintillation plastics connected to photomultiplier tubes are used as detectors. Four of such kinds of detectors are very close and placed around the edges of the beam. Detector can be moved to the front of the DUT and evaluate flux and homogeneity.
The spot size is 2 cm^2 and for special cases up to a diameter of 70 mm in vacuum. The Spot Homogeneity is ± 10 %

5.3. Beam characteristics

The beam flux is variable between a few particles s^{-1}cm^{-2} and 1.5E+4 s^{-1}cm^{-2} and is set depending on the device sensitivity. On special request, the users have the possibility to increase the flux up to 1E+6 s^{-1}cm^{-2}.
Characteristics of heavy ions available at RADEF during the test campaign are listed in Table 4 where heavy ions used for this test campaign are highlighted.
The tests on TPS3820-33DBV are performed in air, therefore the LET and range are calculated according to 50 µm of Kapton degrader (used only with Xenon heavy ion), and the distance between collimator and the component.

ION	Energy (MeV)	Range (µm(Si))	LET (MeV.cm²/mg)
$^{126}Xe^{44+}$	1446.48	105.71	56.8
$^{107}Ag^{37+}$	1714	158	38.8
$^{83}Kr^{29+}$	1358	185	24.5
$^{57}Fe^{20+}$	941	214	13.3
$^{40}Ar^{14+}$	657	264	7.2
$^{20}Ne^{7+}$	328	360	2.3
$^{17}O^{6+}$	284	481	1.5

Table 4: RADEF heavy ion list

6. Test procedure and setup

6.1. Test method

With respect to reference documents (see 2 Documents), runs were performed:

- Up to a fluence of 1E+7 cm^{-2} with SEL, SET and SEFI monitoring.

6.2. Test principle

6.2.1. SEL test principle

A SEL is a permanent event that results from the activation of a parasitic thyristor structure creating low impedance conduction path in the device. The consequent high current can potentially damage the device, possibly even leading to its destruction due to overcurrent. A power cycle is required to correct this situation.

GeV is a specific equipment developed by TRAD to protect the DUT and to perform SEL characterization. The power supply is applied to the DUT through GeV which protects the DUT against over consumption. Indeed, GeV continuously monitors and records the current. A programmable threshold current is set above the nominal operating value of the supply current. During irradiations, if the current consumption exceeds the threshold during a defined “hold time”, a SEL is counted and the DUT is switched off during a defined “off time”. Once the event is defused, the power supply is switched ON again with the nominal current consumption expected.

Figure 5 shows a common SEL characteristic, with and without the GeV system protection.

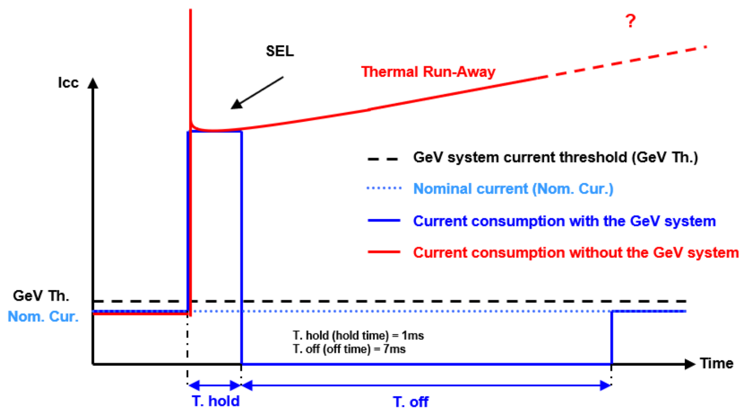

Figure 5: Common SEL characteristic

The SEL test was performed under SEL test conditions (see Table 6).
TRAD uses a dedicated system to heat and regulate the DUT temperature. The temperature is visualized and regulated from outside of the vacuum chamber during the irradiation.

6.2.2. SET test principle

A SET event is a temporary voltage excursion (voltage spike) at a node in a logic, or linear, integrated circuit, caused by a single energetic particle strike.

On static output signals, the SET can be a positive or negative amplitude variation. Two trigger thresholds (positive and negative) are used to detect the event when the monitored signal is out of the detection range (Figure 6). All SET are counted and their waveforms are recorded using an oscilloscope.

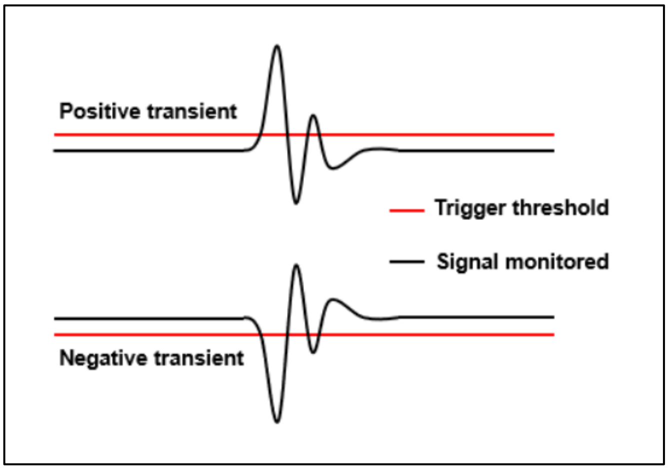

Figure 6: SET in static mode characteristic

SET were monitored on the /RESET pin during this test campaign and were triggered as downslopes front from 5.5V to 0V (see 9.5 for worst cases recorded).

6.3. Test bench description

6.3.1. Test bench overview

Figure 7 provides a global view of the test bench. It is composed by:

- A computer to control the test equipment and to record the SEE.
- A test board to bias and operate the DUT (schematic is shown in Figure 10).
- A power supply for the DUT and auxiliary components.
- A GeV System to protect the DUT, detect and record SEL.
- An oscilloscope to detect and record SET.

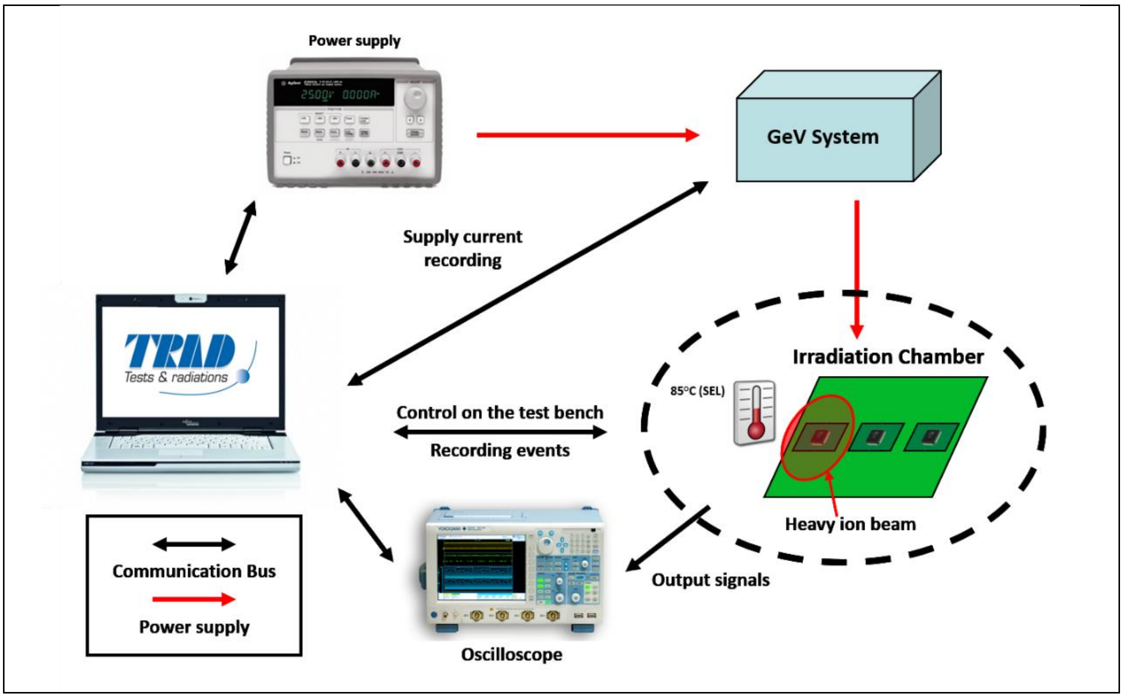

Figure 7: Test bench description

6.3.2. Validation of test hardware and program

Before performing the heavy ion test, the whole system (delidded sample, test board and software) was assembled and tested by TRAD in VASCO.

The VASCO is a vacuum chamber developed by TRAD in order to test the complete setup in vacuum with all cables length and electrical feedthroughs as used on the irradiation site.
The VASCO main characteristics are:
Chamber dimensions: 400x400x400mm, pressure 5.10^{-2} mbar.
Electrical feedthroughs available:
16 isolated BNC, 16 isolated SMA, 16 isolated SMB, 4 DB25, 3 HE10-40.
Other possibility on request

Validation runs are performed using Californium-252 source.
Californium-252 is a fissionable, transuranic radionuclide which decays by alpha particle emission with a half-life of 2.72 years.
The source emits alpha particles, fission fragments and fast neutrons. The fission fragments are used for SEE testing and these have a mean LET of 43 MeV.cm²/mg (Si) with 95% of the particles having LETs between 41 and 45 MeV.cm²/mg (Si). The mean range of the fission particles in silicon is 14.2µm.

Figure 8: VASCO picture

6.3.3. Heating system

TRAD has developed a specific heating system to heat and regulate the temperature of the DUT. Figure 9 shows a thermal image taken during the heating calibration of the DUT, the temperature of the die was set to 85°C as shown on the picture.

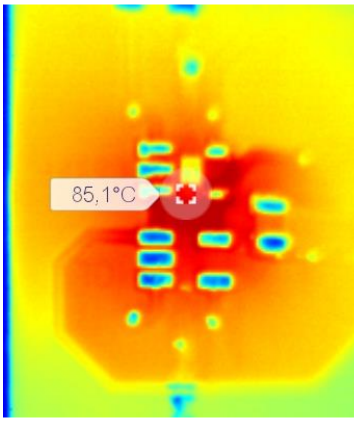

Figure 9: Thermal image of TPS3820-33DBV heated to 85°C

6.3.4. Test equipment identification

TEST BOARD	TRAD/TA1/I/TPS3820-33DBV/SOT-23/AA/2309
EQUIPMENT	SM-87; ME-70; ME-54; GeV-3
TEST PROGRAM	TPS3820-33DBV_I_2303+5_B-MTP_V1_SEL.spf

Table 5: Equipment identification

6.3.5. Test board description

The TRAD test board schematic referenced “TRAD/TA1/I/TPS3820-33DBV/SOT-23/AA/2309” is illustrated in Figure 10.

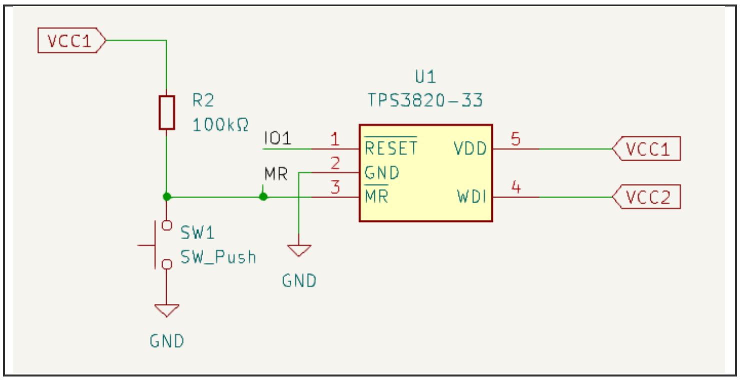

Figure 10: Test board schematic

6.3.6. Test conditions and event detection thresholds

SEL test

	VCC1	VCC2
Voltage	5.5 V	5 V / 1 kHz
$I_{nominal}$	8 mA	77 µA
$I_{threshold}$	16 mA	1000 mA
T_{hold}	1 ms	1 ms
$T_{cut\ off}$	7 ms	7 ms
Temperature	85°C	

Table 6: SEL test conditions and detection thresholds

7. Test story

No atypical behaviour during the test to report.

8. Non conformance

Test sequence, test and measurement conditions were nominal.

9. Results

In this chapter are presented the SEE test results.
First, test runs summary tables provides details of the runs performed during this campaign, their parameters and results.
Then, for each event type are given their corresponding LET threshold, cross section and worst cases when it is applicable.
On the cross section curves are plotted their corresponding error bars.
The following formulas is used to calculate these error bars. It can be found in ESCC Basic specification No. 25100.

$$\delta\sigma \times F = \sqrt{(\delta Nevents)^2 + (\mathrm{Nevents} \times \frac{\delta \mathrm{F}}{F})^2}$$

where :

- F is the fluence
- $\sigma = N_{events} / F$
- $\delta F/F$ is the uncertainty on the measured fluence (±10%).
- δN_{events} is the variance on the measured number of events.

Assuming that SEE events are random, the probability of events follows a Poisson distribution. The variance on the number of events is calculated from the chi-square distribution for a given confidence level. In this test report, we used a confidence level of 95%.

9.1. Test run summary

Run	Test configuration	Part	T° (°C)	Ion	Energy (MeV)	Eff. LET (MeV.cm²/mg)	Eff. Range (µm Si)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	SEL	SEL Cross Section (cm²)	SET /RESET	SET /RESET Cross Section (cm²)
1	SEL	2	85	Ag	1714	38.8	158.0	1.07E+04	932	1.00E+07	6.21	6.21	18	1.80E-06	-	-
1	SEL	3	85	Ag	1714	38.8	158.0	1.07E+04	932	1.00E+07	6.21	6.21	20	2.00E-06	-	-
2	SEL	2	85	Xe Kapton	1446.5	56.8	105.7	1.05E+04	569	6.00E+06	5.46	11.66	31	5.17E-06	>180*	
2	SEL	3	85	Xe Kapton	1446.5	56.8	105.7	1.05E+04	569	6.00E+06	5.46	11.66	34	5.67E-06	>180*	
3	Unprotected	2	85	Xe Kapton	1446.5	56.8	105.7	2.51E+03	148	3.71E+05	0.34	12.00	-	-	-	-
4	SEL	3	85	Fe	941	13.3	214.0	7.14E+03	1401	1.00E+07	2.13	13.79	0	<1.00E-07	13	1.30E-06
4	SEL	4	85	Fe	941	13.3	214.0	7.14E+03	1401	1.00E+07	2.13	2.13	0	<1.00E-07	13	1.30E-06
5	SEL	3	85	Fe	941	13.3	214.0	8.03E+03	62	4.98E+05	0.11	13.90	0	<2.01E-06	0	<2.01E-06
5	SEL	4	85	Fe	941	13.3	214.0	8.03E+03	62	4.98E+05	0.11	2.23	0	<2.01E-06	0	<2.01E-06

Table 7: TPS3820-33DBV test run table

SEE detailed results are described in the following sections.
*: More than 180 SET /RESET were observed, but not recorded over 180. Due to SEL occurrences, a too large number of events were seen with the oscilloscope but not recorded at the end of irradiation. Only 180 events were recorded for SET signatures.

9.2. Cumulated dose table

Part No.	Cumulated Dose (krad)
2	12
3	13.9
4	2.23

Table 8: Cumulated dose table

9.3. SEL test results

9.3.1. SEL LET threshold

The SEL test was performed under SEL test conditions (see Table 6).

In SEL test configuration

SEL were observed with a minimum LET of 38.8 MeV.cm²/mg, Silver heavy ion.
No SEL was observed with a LET of 13.3 MeV.cm²/mg, Iron heavy ion.

9.3.2. SEL cross sections

Hereafter are shown the SEL cross section values for each tested component.

In SEL test configuration

	TPS3820-33DBV SEL Cross Section (cm²) in SEL test configuration								
LET Eff (MeV.cm²/mg)	Part No. 2			Part No. 3			Part No. 4		
	error (-)	cross section	error (+)	error (-)	cross section	error (+)	error (-)	cross section	error (+)
56.8	1.66E-06	5.17E-06	2.17E-06	1.74E-06	5.67E-06	2.25E-06	-	*Not tested*	-
38.8	7.33E-07	1.80E-06	1.04E-06	7.78E-07	2.00E-06	1.09E-06	-	*Not tested*	-
13.3	-	*Not tested*	-	0.00E+00	<1.00E-07	3.69E-07	0.00E+00	<1.00E-07	3.69E-07

Table 9: TPS3820-33DBV SEL cross section values in SEL test configuration

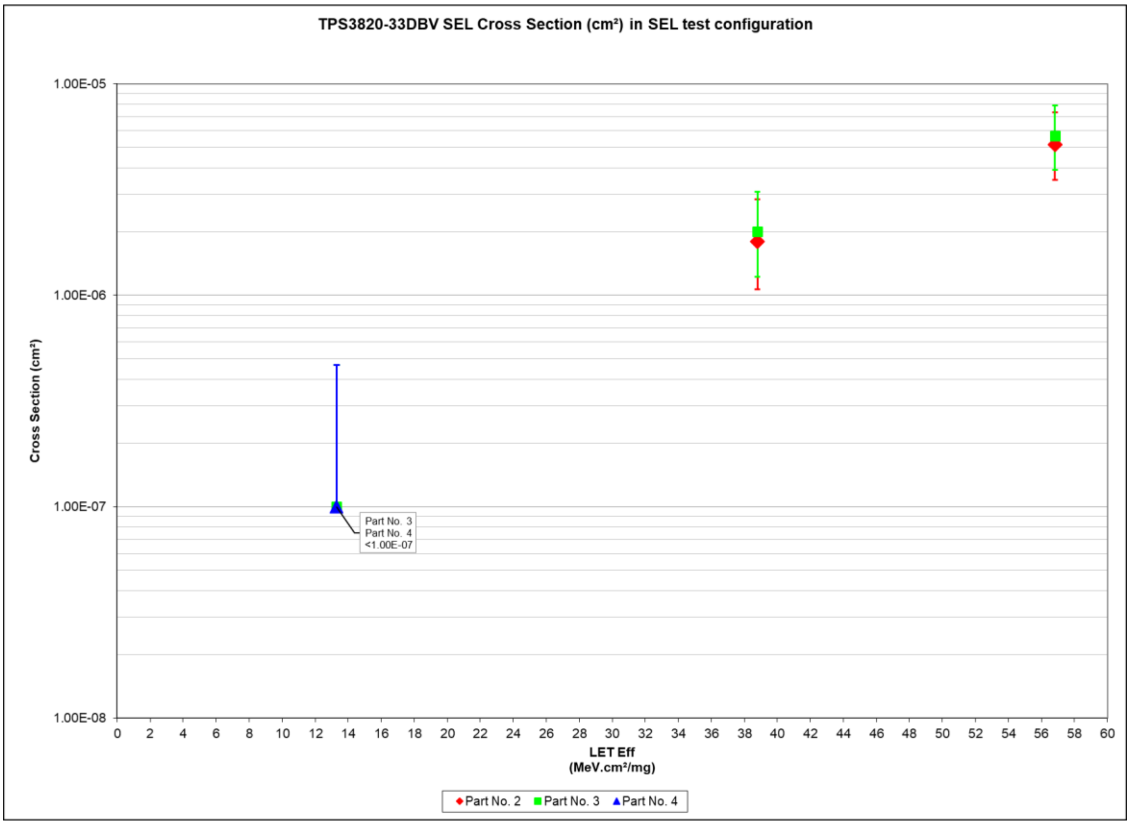

Figure 11: TPS3820-33DBV SEL cross section curve in SEL test configuration

9.3.3. SEL worst case

This section presents a selection of worst SEL observed during the test of the TPS3820-33DBV.

In SEL test configuration

Run No.	2
Part No.	3
Test configuration	SEL
Ion LET (MeV.cm²/mg)	56.8
Absolute amplitude	518 mA

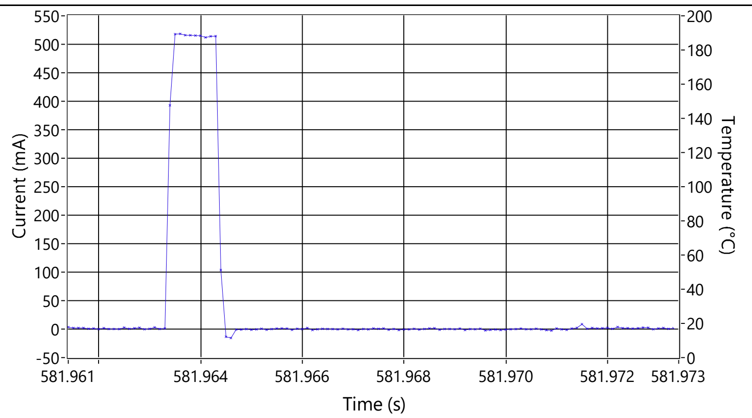

Figure 12: SEL biggest case amplitude

Run No.	2
Part No.	3
Test configuration	SEL
Ion LET (MeV.cm²/mg)	56.8
Absolute amplitude	293 mA

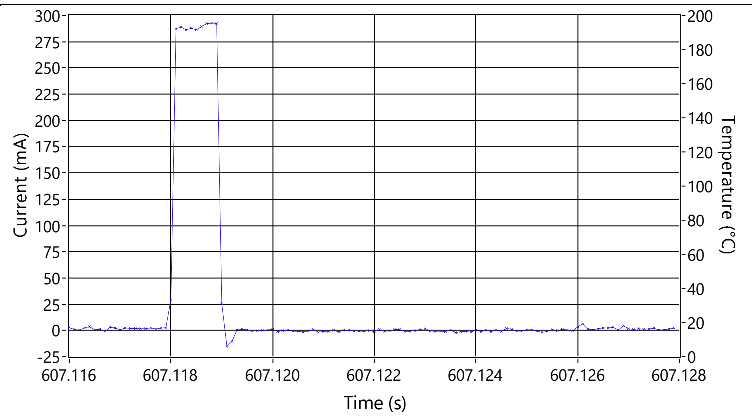

Figure 13: SEL smallest case amplitude

9.4. Unprotected run test results

This section presents the current consumption recorded on VDD during the unprotected run with a LET of 56.8 MeV.cm²/mg, Xenon heavy ion. The device was still functional after this run.

Run No.	3
Part No.	2
Test configuration	SEL
Ion LET (MeV.cm²/mg)	56.8
Max amplitude	354.1 mA

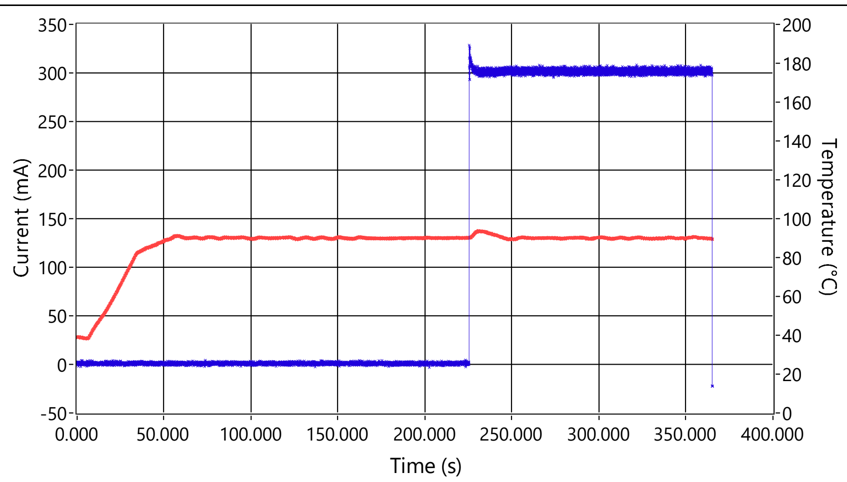

Figure 14: Unprotected run

9.5. SET /RESET worst case

This section presents the longest and the shortest duration of SET /RESET observed during the test of the TPS3820-33DBV.

Run No.	2
Part No.	3
Test configuration	SEL
Ion LET (MeV.cm²/mg)	56.8
Duration	697 ms

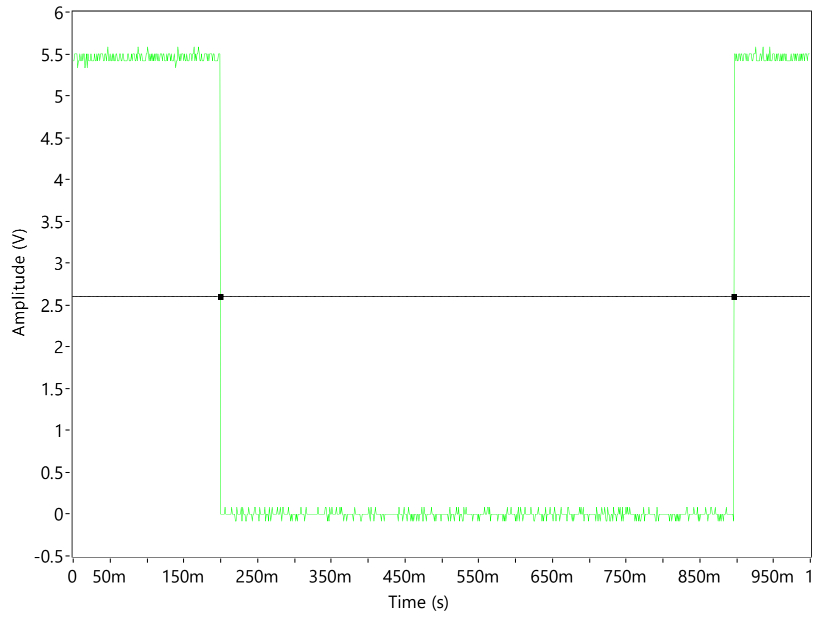

Figure 15: SET /RESET longest case duration

Run No.	2
Part No.	2
Test configuration	SEL
Ion LET (MeV.cm²/mg)	56.8
Duration	25 ms

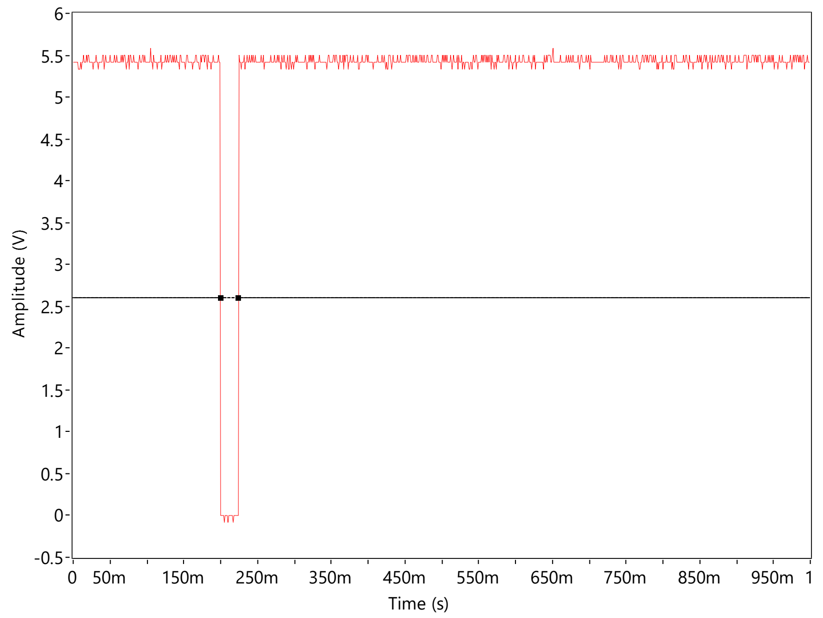

Figure 16: SET /RESET shortest case duration

10. Conclusion

The heavy ion test was performed on TPS3820-33DBV. The aim of the test was to evaluate the sensitivity of the device versus SEL.

The SEL test was performed under SEL test conditions (see Table 6).

In SEL test configuration
SEL were observed with a minimum LET of 38.8 MeV.cm²/mg, Silver heavy ion.
No SEL was observed with a LET of 13.3 MeV.cm²/mg, Iron heavy ion.

An unprotected run was performed for a fluence of $3.71.10^5$ ions/cm² with a LET of 56.8 MeV.cm²/mg, Xenon heavy ion. The device was still functional after this run.

SET /RESET were observed with a minimum LET of 13.3 MeV.cm²/mg, Iron heavy ion.
No lower LET was tested during this test campaign.

No SEFI was observed with a LET of 56.8 MeV.cm²/mg, Xenon heavy ion.