Radiation Report

TPS7H1111-SP Single-Event Effects (SEE)

TEXAS INSTRUMENTS

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H1111-SP. Heavy-ions with LET_{EFF} of 48 to 75 MeV·cm^2 /mg were used to irradiate 6 production devices. Flux of 10^4 to 10^5 ions/cm^2 ·s and fluence of 10^6 to 10^7 ions/cm^2 per run were used for the characterization. The results demonstrated that the TPS7H1111-SP is SEL-free up to 75 MeV·cm^2/mg at T = 125°C and SEB/SEGR free up to 75 MeV·cm^2/mg at T = 25°C. SET transients performance for output voltage excursions ≥ |3%| from the nominal voltage and PG < 0.5-V (Negative Edge) are presented and discussed. This report uses the QMLV TPS7H1111-SP device in a ceramic package. It is also applicable for the QMLP TPS7H1111-SP device in a plastic package which uses the same die as the QMLV device.

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1 Introduction

The TPS7H1111-SP is an ultra-low noise, high PSRR, low dropout (LDO) linear regulator optimized for powering RF (radio frequency) devices in a space environment. It is capable of sourcing up to 1.5A over a 0.85-V to 7-V input range with a 2.2-V to 14-V bias supply.

The high performance of the device limits power-supply generated phase noise and clock jitter, making this device ideal for powering high-performance ADCs, DACs, VCOs, PLLs, SerDes, and other RF components in satellites. For digital loads (such as FPGAs and DSPs) requiring low voltage operation, the exceptional accuracy and excellent transient performance ensure optimal system performance.

The device is offered in a 14-pin Ceramic package and 28-pin plastic package. General device information and test conditions are listed in Table 1-1. For more detailed technical specifications, user-guides, and application notes please go to TPS7H1111-SP product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H1111-SP
Orderable Number	5962R2120301VXC
Device Function	Ultra-Low Noise Low Dropout (LDO) Linear Regulator
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15 MeV/nucleon)
Heavy Ion Fluence per Run	1.00×10^6 – 1.00×10^7 ions/cm^2
Irradiation Temperature	25°C (for SEB/SEGR testing), 25°C (for SET testing), and 125°C (for SEL testing)

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2 Single-Event Effects (SEE)

The primary concern for the TPS7H1111-SP is the robustness against the destructive single-event effects (DSEE): single-event latch-up (SEL), single-event burnout (SEB), and single-event gate rupture (SEGR). In mixed technologies such as the BiCMOS process used on the TPS7H1111-SP, the CMOS circuitry introduces a potential for SEL susceptibility.

SEL can occur if excess current injection caused by the passage of an energetic ion is high enough to trigger the formation of a parasitic cross-coupled PNP and NPN bipolar structure (formed between the p-sub and n-well and n+ and p+ contacts) [1,2]. The parasitic bipolar structure initiated by a single-event creates a high-conductance path (inducing a steady-state current that is typically orders-of-magnitude higher than the normal operating current) between power and ground that persists (is “latched”) until power is removed, the device is reset, or until the device is destroyed by the high-current state. The TPS7H1111-SP was tested for SEL at the maximum recommended input voltage (V_{IN}) of 7V and the maximum recommended bias voltage (V_{BIAS}) of 14V. Two different output voltage (V_{OUT}) conditions were tested to achieve minimum, 0.4V, and maximum, 5.5V, operating conditions. The output loads varied depending on V_{OUT} with a load of 0.38 ohms, 1.05A, for the 0.4V output condition and 3.8 ohms, 1.5A, for the 5.5 output condition. The difference in output loads was based on device temperature and ensuring the device reached, but did not exceed 125°C. During testing of the 4 devices, the TPS7H1111-SP did not exhibit any SEL with heavy-ions with LET_{EFF} = 75 MeV·cm$^{\mathbf{2}}$ /mg at flux ≈10$^{\mathbf{5}}$ ions/cm^2 ·s, fluence of ≈10$^{\mathbf{7}}$ ions/cm$^{\mathbf{2}}$, and a die temperature of 125°C.

The TPS7H1111-SP was evaluated for SEB/SEGR at a maximum voltage of 14-V in the enabled and disabled mode. Because it has been shown that the MOSFET susceptibility to burnout decrement with temperature [5], the device was evaluated while operating under room temperatures. The device was tested with no external thermal control device. Different output loads were used in order to achieve the highest possible load without exceeding a temperature too high for valid SEB testing. A load of 4 ohms, 100mA, was used for the 0.4 output condition and a load of 3.8 ohms, 1.5A, was used for the 5.5 output condition. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H1111-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV·cm^2/mg at a flux of ≈10^5 ions/cm^2·s, fluences of ≈10^7 ions/cm^2, and a die temperature of ≈25°C.

The TPS7H1111-SP was characterized for SET at flux of 1.02 × 10^4 to 9.66 × 10^4 ions/cm^2·s, fluences of 1.00 × 10^6 to 1.05 × 10^6 ions/cm^2, and room temperature. The device was characterized at V_{IN} of 2.5-V and V_{BIAS} of 5, 12, and 14-V. Different V_{BIAS} conditions were used to test the TPS7H1111-SP in "golden configuration" (5-V)and "silver configuration" (12-V). Heavy-ions with LET_{EFF} of 48 to 75-MeV·cm^2/mg were used to characterize the transient performance. To see the SET results of the TPS7H1111-SP, please refer to Single-Event Transients (SET).

3 Device and Test Board Information

The TPS7H1111-SP is packaged in a 14-pin thermally-enhanced Ceramic package as shown in Figure 3-1. The TPS7H1111-SP evaluation module was used to evaluate the performance and characteristics of the TPS7H1111-SP under heavy ion radiation. The TPS7H1111-SP EVM (Evaluation Module) is shown in Figure 3-2. The EVM schematic is shown in Figure 3-3.

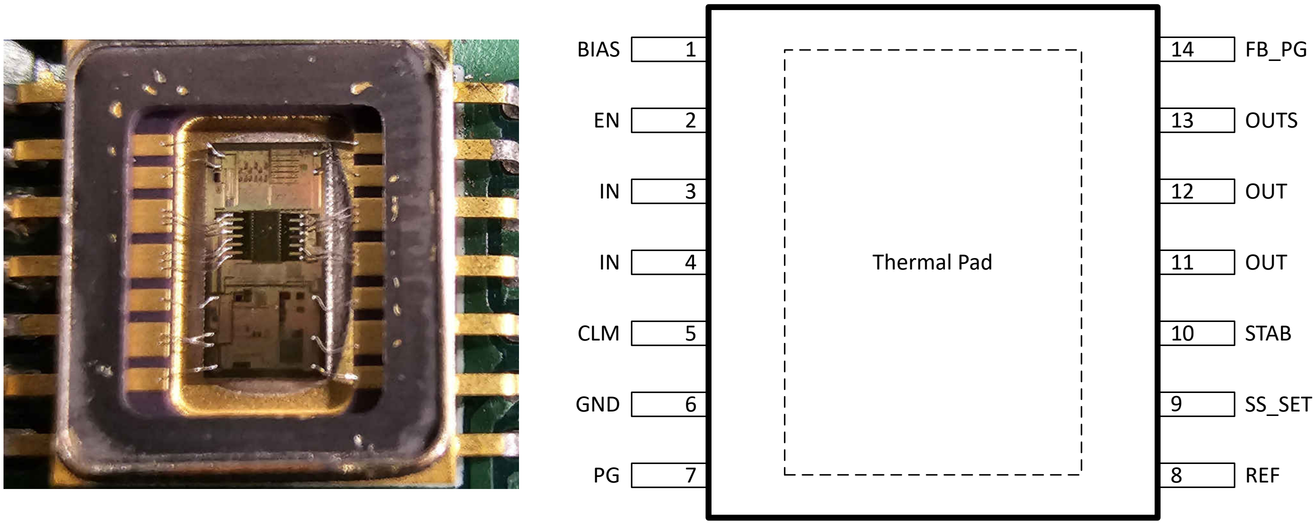

Figure 3-1. Photograph of Delidded TPS7H1111-SP [Left] and Pinout Diagram [Right]

Note: The package was delidded to reveal the die face for all heavy-ion testing.

Figure 3-2. TPS7H1111-SP EVM Top View

TPS7H1111-SP EVM - Schematic

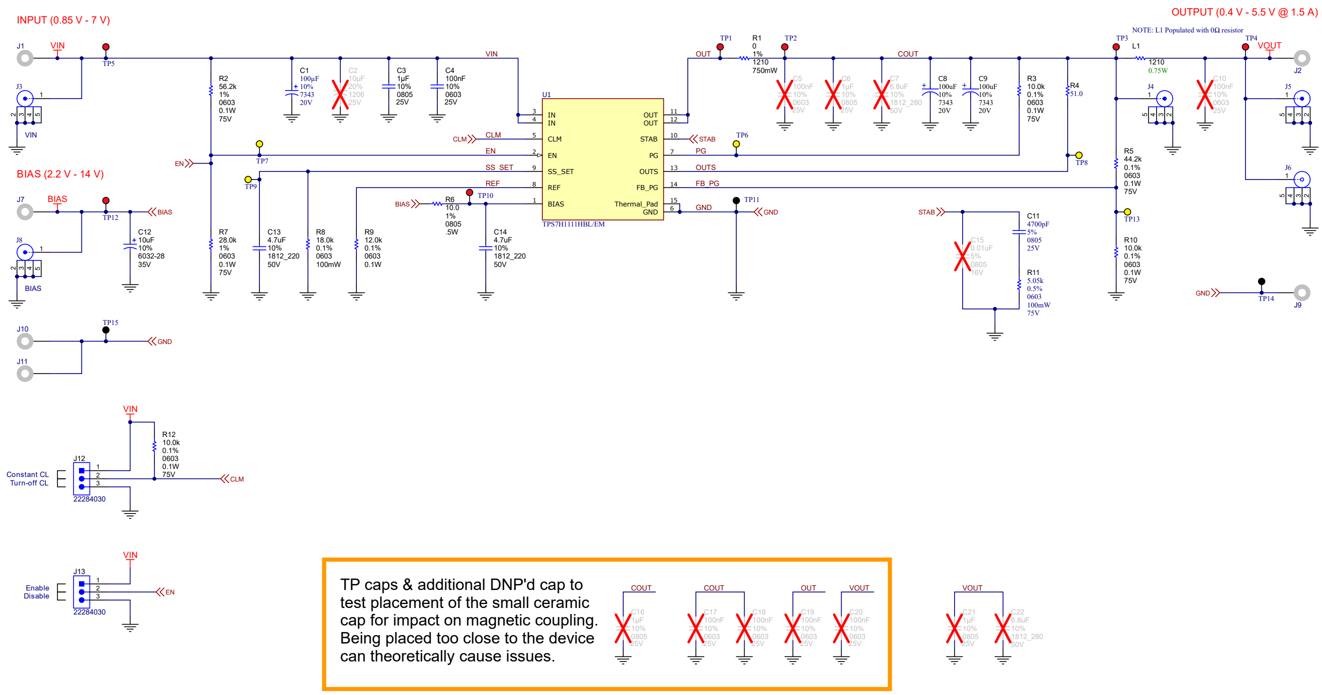

Figure 3-3. TPS7H1111-SP EVM Schematics

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by the TAMU Cyclotron Radiation Effects Facility using a superconducting cyclotron and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity over a 1-in diameter circular cross-sectional area for the in-air station. Uniformity is achieved by magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of 1.02×10^4 to 1.12×10^5 ions/cm^2·s were used to provide heavy-ion fluences of 1.00×10^6 to 1.00×10^7 ions/cm^2.

For the experiments conducted on this report, there were 2 ions used, ^{109}Ag and ^{165}Ho. ^{109}Ag was used to obtain LET_{EFF} of 48 and 60 MeV·cm^2/mg. ^{165}Ho was used to obtain LET_{EFF} of 75 MeV·cm^2/mg. The total kinetic energys for each of the ions were:

- ^{109}Ag = 1.634 GeV (15 MeV/nucleon)
  - Ion uniformity for these experiments was between 93 and 96%
- ^{165}Ho = 2.474 GeV (15 MeV/nucleon)
  - Ion uniformity for these experiments was between 95% and 96%

Figure 4-1 shows the TPS7H1111-SP EVM used for the data collection at the TAMU facility. Although not visible in this photo, the beam port has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the accelerator with only minor ion energy loss. The in-air gap between the device and the ion beam port window was maintained at 40 mm for all runs.

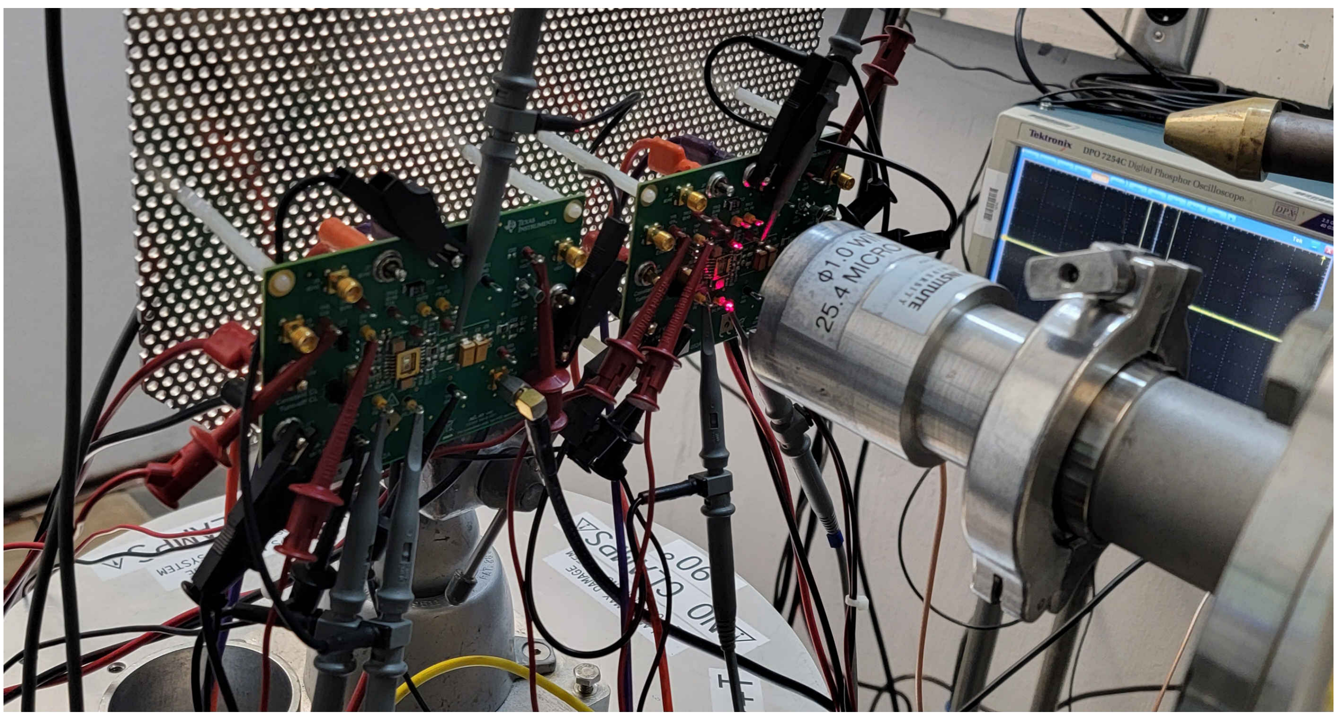

Figure 4-1. Photograph of the TPS7H1111-SP EVM in Front of the Heavy-Ion Beam Exit Port at the Texas A&M Cyclotron

5 Depth, Range, and LET$_{EFF}$ Calculation

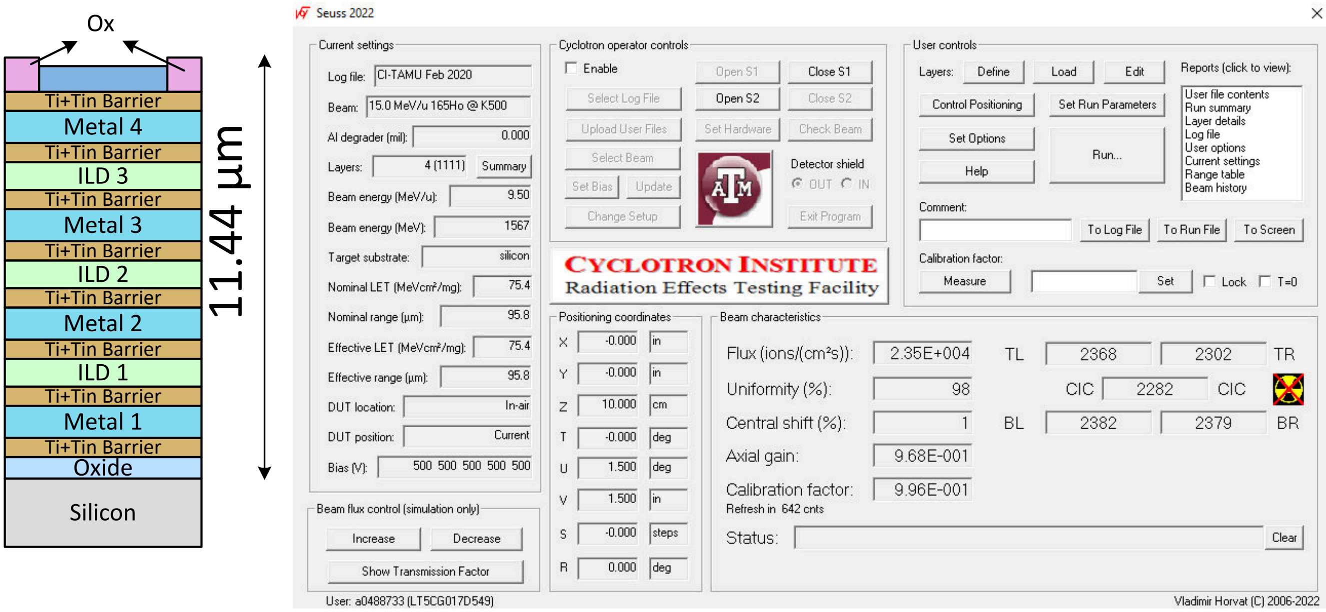

Figure 5-1. Generalized Cross-Section of the LBC7 Technology BEOL Stack on the TPS7H1111-SP [Left] and SEUSS 2020 Application Used to Determine Key Ion Parameters [Right]

The TPS7H1111-SP is fabricated in the TI Linear BiCMOS 250-nm process with a back-end-of-line (BEOL) stack consisting of 4 levels of standard thickness aluminum. The total stack height from the surface of the passivation to the silicon surface is 11.44 µm based on nominal layer thickness as shown in Figure 5-1. Accounting for energy loss through the 1-mil thick Aramica beam port window, the 40-mm air gap, and the BEOL stack over the TPS7H1111-SP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the depth was determined with the SEUSS 2020 Software (provided by the Texas A&M Cyclotron Institute and based on the latest SRIM-2013 [7] models). The results are shown in Ion LET$_{EFF}$, Depth, and Range in Silicon.

Table 5-1. Ion LET$_{EFF}$, Depth, and Range in Silicon

ION TYPE	Beam Energy (MeV/nucleon)	ANGLE OF INCIDENCE	DEGRADER STEPS (#)	DEGRADER ANGLE	RANGE IN SILICON (µm)	LET$_{EFF}$ (MeV·cm^2/mg)
^{109}Ag	15	0	0	0	95.1	48
	15	30	0	0	69.8	60
^{165}Ho	15	0	0	0	97.2	75

6 Test Setup and Procedures

There were three input supplies used to power the TPS7H1111-SP which provided V_{IN}, V_{BIAS} and EN. The V_{IN} for the device was provided via Ch. 1 of an N6705C power module and ranged from 2.5V for SET to 7 V for SEL and SEB/SEGR. The V_{BIAS} for the device was provided by a National Instruments (NI) PXIe-4139 SMU and ranged from 5V to 14V depending on the type of test. The last input supply was Ch. 1 of an E36311A power supply and ranged from 0V for SEB Off to 2.5V for most SET testing and 5V for all DSEE testing.

The instrument used to load the TPS7H1111-SP was a Chroma E36300 E-Load that was used in Constant Resistance (CR) mode. The value of CR was adjusted depending on the type of test. For the SEB testing during the V_{OUT} = 0.4V case the CR value had to be set such that the load on the device would not heat the device too much in order to ensure the test would remain valid. For the SEL testing during the V_{OUT} = 0.4V case the CR value was set to achieve a load of 1A as this load provided the correct amount of device heating to achieve a die temperature of 125°C.

The primary signal monitored on the EVM was V_{OUT} and this was done using two instruments. The first was a NI PXIe-5172 Scope card which was set to trigger on a 3% window based on the nominal value of VOUT. The second was a TDS7404B with the same 3% window trigger based on its measured value of V_{OUT}. All SEB On, SEL, and SET testing used these conditions with only the SEB Off testing having different conditions. The conditions for SEB Off were a positive edge trigger at 0.5V which would check to see if the device ever incorrectly turned on while it was disabled.

All equipment other than the TDS7404B was controlled and monitored using a custom-developed LabVIEW™ program (PXI-RadTest) running on a HP-Z4™ desktop computer. The computer communicates with the PXI chassis via an MXI controller and NI PXIe-8381 remote control module. The TDS7404B was used using the manufacturer interface. The DPO was set to fast-frame for all SET's data collection.

Equipment Settings and Parameters Used During the SEE Testing of the TPS7H1111-SP shows the connections, limits, and compliance values used during the testing. Figure 6-1 shows a block diagram of the setup used for SEE testing of the TPS7H1111-SP.

Table 6-1. Equipment Settings and Parameters Used During the SEE Testing of the TPS7H1111-SP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
V_{IN}	N6705C (CH # 1)	20.4-V, 50-A	5-A	2.5 to 7-V
V_{Bias}	NI-PXIe 4139 (CH # 1)	±60-V, 3-A	3-A	5 to 14-V
EN	E36311A (CH # 1)	5-V,5-A	0.1-A	0-V, 5-V
V_{OUT}, PG	TDS7404B	40 GS/s	—	2.5 and 5 GS/s
V_{OUT}	PXIe-5172 (1)	100 MS/s	—	100 MS/s
PG	PXIe-5172 (2)	100 MS/s	—	100 MS/s
V_{OUT}	Chroma E36300 Load	80A	Low	—

All boards used for SEE testing were fully checked for functionality. Dry runs were also performed to ensure that the test system was stable under all bias and load conditions prior to being taken to the TAMU facility. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H1111-SP device and set the external sourcing and monitoring functions of the external equipment. After functionality and stability was confirmed, the beam shutter was opened to expose the device to the heavy-ion beam. The shutter remained open until the target fluence was achieved (determined by external detectors and counters). During irradiation, the NI scope cards continuously monitored the signals. When the output exceeded the pre-defined 3% window trigger, a data capture was initiated. No sudden increases in current were observed (outside of normal fluctuations) on any of the test runs and indicated that no SEL or SEB/SEGR events occurred during any of the tests.

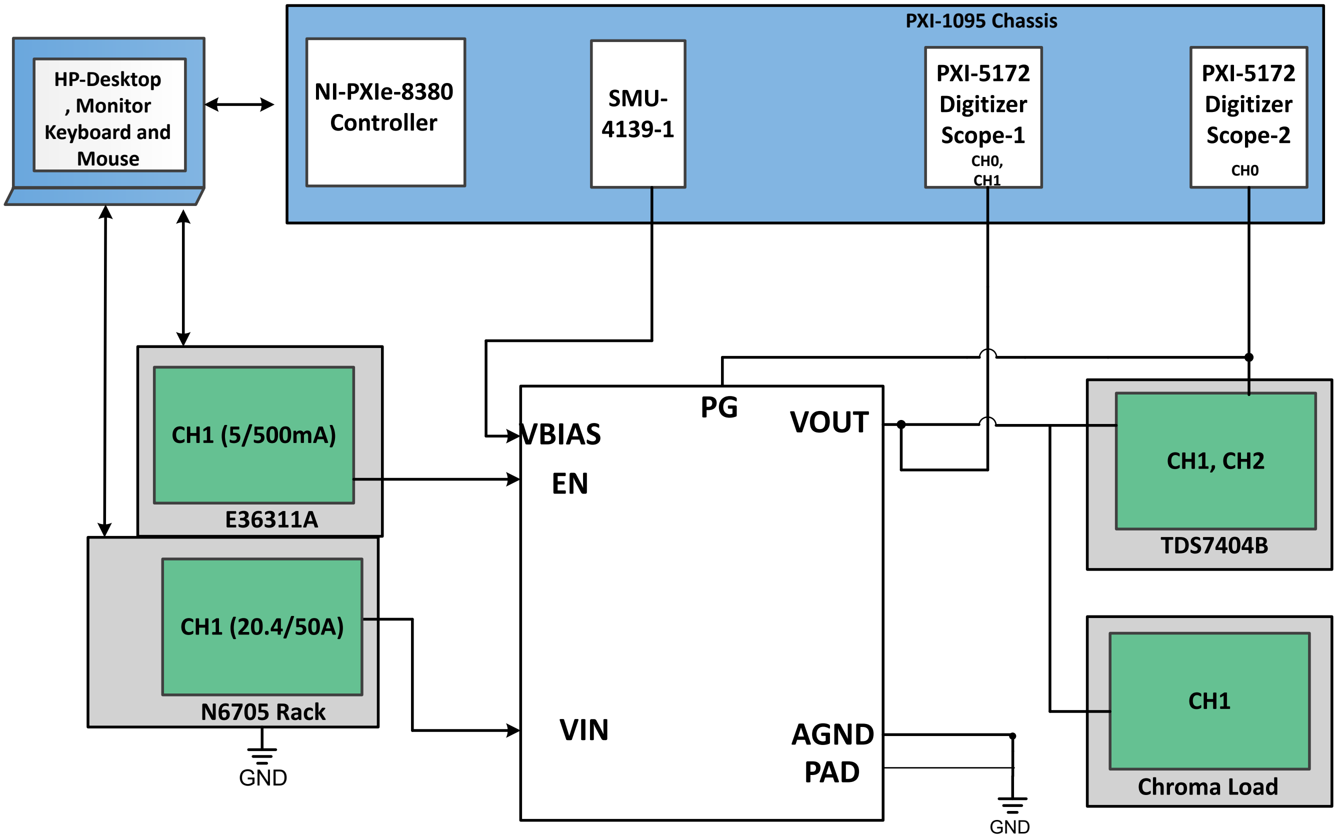

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H1111-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During the SEL tesing the device was heated to 125°C by using a Closed-Loop PID controlled heat gun (MISTRAL 6 System (120V, 2400W)). The temperature of the die was verified using thermal camera prior to exposure to heavy ions.

The species used for the SEL testing was Homium (^{165}Ho @ 15 MeV/nucleon). For the ^{165}Ho ion an angle of incedence of 0° was used to achieve an LET_{EFF} = 75 MeV·cm^2/mg (for more details refer to Ion LET_{EFF}, Depth, and Range in Silicon). The kinetic energy in the vacuum for this ions is 2.474 GeV. Flux of approximately 10^5 ions/cm^2·s and a fluence of approximately 10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was approximately 2 minutes. The four devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 7-V, the maximum recommended bias voltage of 14-V. Two different output conditions were tested, the minimum recommended output voltage of 0.4-V and the maximum recommended output voltage of 5.5-V. No SEL events were observed during all four runs, indicating that the TPS7H1111-SP is SEL-free up to 75 MeV·cm^2/mg. Table 7-1 shows the SEL test conditions and results. Figure 7-1 shows a plot of the current vs time for run # 1.

Table 7-1. Summary of TPS7H1111-SP SEL Test Condition and Results

Run #	Unit #	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions·cm^2/mg)	Fluence (# ions)	V_{IN}	V_{BIAS}	V_{OUT}	I_{OUT} (A)	SEL (# Events)
1	1	^{165}Ho	75	9.60 x 10^4	1 x 10^7	7	14	5.5	1.5	0
2	2	^{165}Ho	75	1.07 x 10^5	1 x 10^7	7	14	5.5	1.5	0
3	3	^{165}Ho	75	9.64 x 10^4	1 x 10^7	7	14	0.4	1	0
4	4	^{165}Ho	75	9.34 x 10^4	1 x 10^7	7	14	0.4	1	0

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report and combining (or summing) the fluences of the four runs @ 125°C (4 × 10^7), the upper-bound cross-section (using a 95% confidece level) is calculated as:

$\sigma_{SEL} \leq 9.22 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75 MeV·cm^2/mg and T = 125°C.

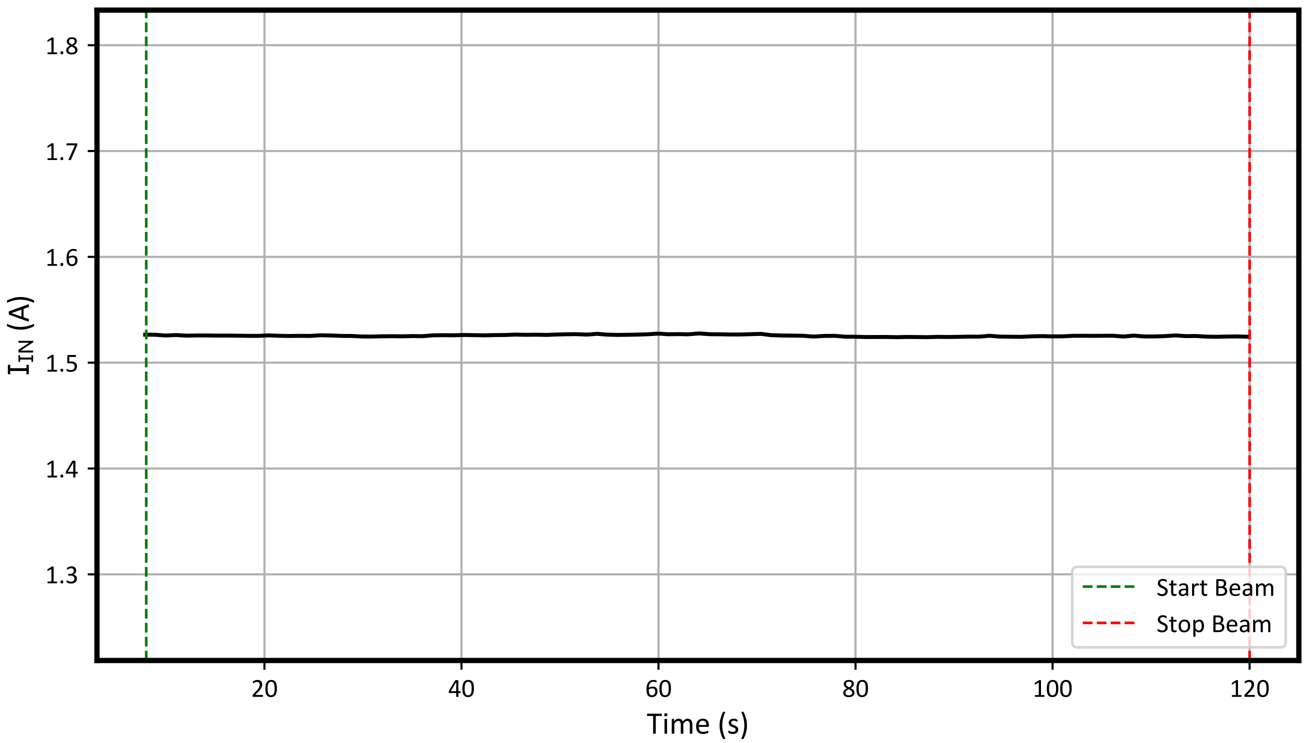

Figure 7-1. Current vs Time for Run # 1 of the TPS7H1111-SP at T = 125°C (V_{OUT} = 5.5-V)

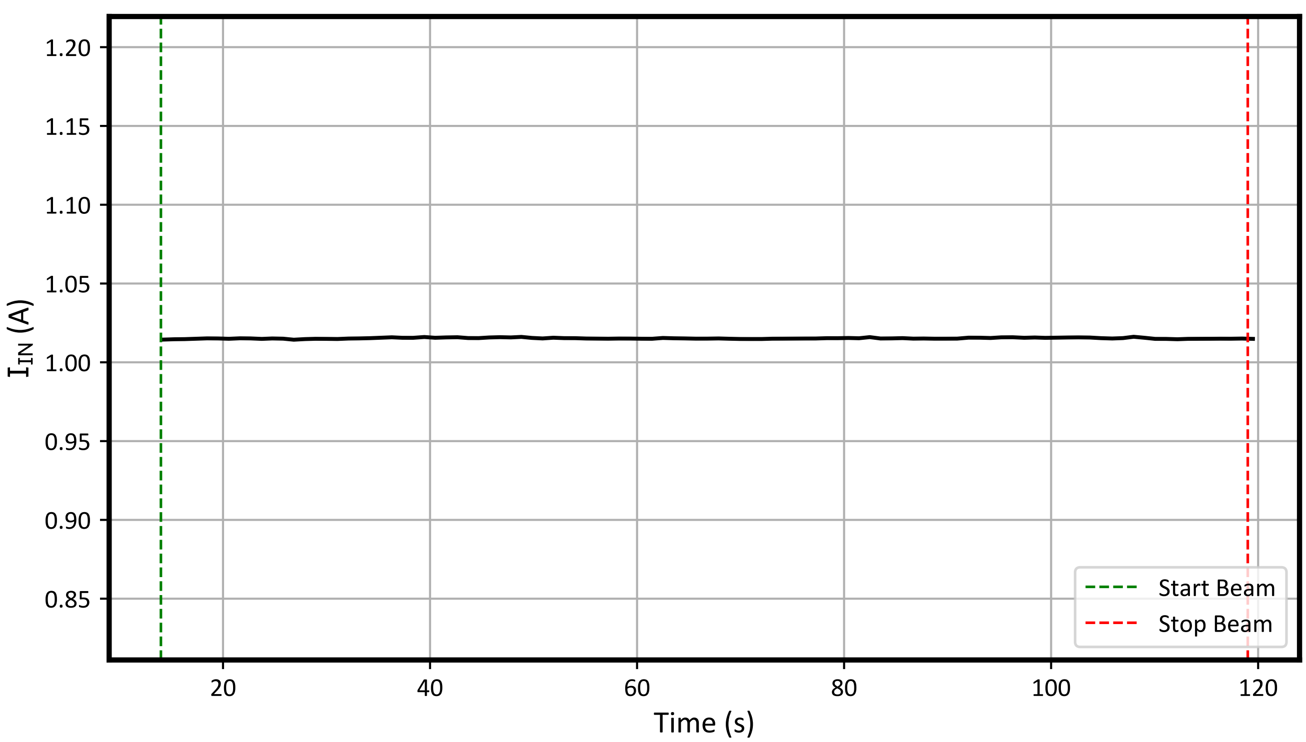

Figure 7-2. Current vs Time for Run #3 of the TPS7H1111-SP at T = 125°C (V_{OUT} = 0.4-V)

7.2 Single-Event Burnout (SEB) and Single-Event Gate Rupture (SEGR) Results

During the SEB/SEGR characterization, the device was tested at room temperature of approximately 25°C. The device was tested under both the enabled and disabled mode. For the SEB-OFF mode the device was disabled using the EN-pin by forcing 0-V (using CH # 1 of a E36311A Keysight PS). During the SEB/SEGR testing with the device enabled/disabled, not a single input current event was observed.

The species used for the SEB testing was Homium (^{165}Ho @ 15 MeV/nucleon). For the ^{165}Ho ion an angle of incedence of 0° was used to achieve an LET_{EFF} = 75 MeV·cm²/mg (for more details refer to Ion LET_{EFF}, Depth, and Range in Silicon). The kinetic energy in the vacuum for this ion is 2.474 GeV (15-MeV/amu line). Flux of approximately 10^5 ions/cm²·s and a fluence of approximately 10^7 ions/cm² was used for the run. Run duration to achieve this fluence was approximately 2 minutes. The four devices (same as used in SEL testing) were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 7-V, the maximum recommended bias voltage of 14-V. Two different output conditions were tested, the minimum recommended output voltage of 0.4-V and the maximum recommended output voltage of 5.5-V. No SEB/SEGR current events were observed during the 8 runs, indicating that the TPS7H1111-SP is SEB/SEGR-free up to LET_{EFF} = 75 MeV·cm²/mg and across the full electrical specifications. Summary of TPS7H1111-SP SEB/SEGR Test Condition and Results shows the SEB/SEGR test conditions and results.

Table 7-2. Summary of TPS7H1111-SP SEB/SEGR Test Condition and Results

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	ENABLED STATUS	V_{IN}	V_{BIAS}	V_{OUT}	I_{OUT} (mA)	SEB EVENT?
5	4	^{165}Ho	75	1.00 x 10^5	9.99 x 10^6	EN	7	14	0.4	100	No
6	4	^{165}Ho	75	1.03 x 10^5	9.99 x 10^6	DIS	7	14	0	0	No
7	3	^{165}Ho	75	1.12 x 10^5	1.00 x 10^7	EN	7	14	0.4	100	No
8	3	^{165}Ho	75	1.07 x 10^5	1.00 x 10^7	DIS	7	14	0	0	No
9	2	^{165}Ho	75	9.87 x 10^4	1.00 x 10^7	EN	7	14	5.5	100	No
10	2	^{165}Ho	75	1.00 x 10^5	1.00 x 10^7	DIS	7	14	0	0	No
11	1	^{165}Ho	75	1.00 x 10^5	1.00 x 10^7	EN	7	14	5.5	100	No
12	1	^{165}Ho	75	9.50 x 10^4	1.00 x 10^7	DIS	7	14	0	0	No

Using the MFTF method described in *Single-Event Effects (SEE) Confidence Interval Calculations* application report, the upper-bound cross-section (using a 95% confidence level) is calculated as:

$\sigma_{SEB} \leq 4.62 \times 10^{-8}$ cm²/device for LET_{EFF} = 75 MeV·cm²/mg and T = 25°C.

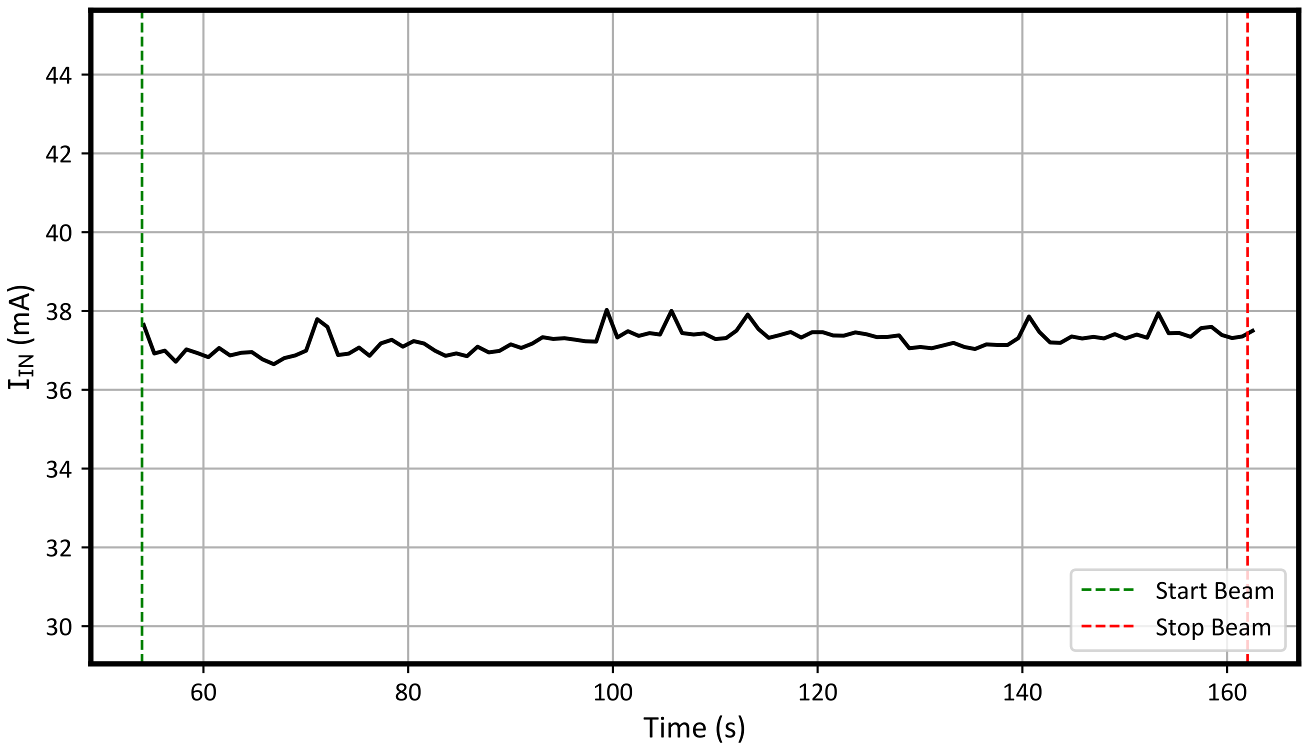

Figure 7-3. SEB On Run #5 (V_{OUT} = 0.4-V)

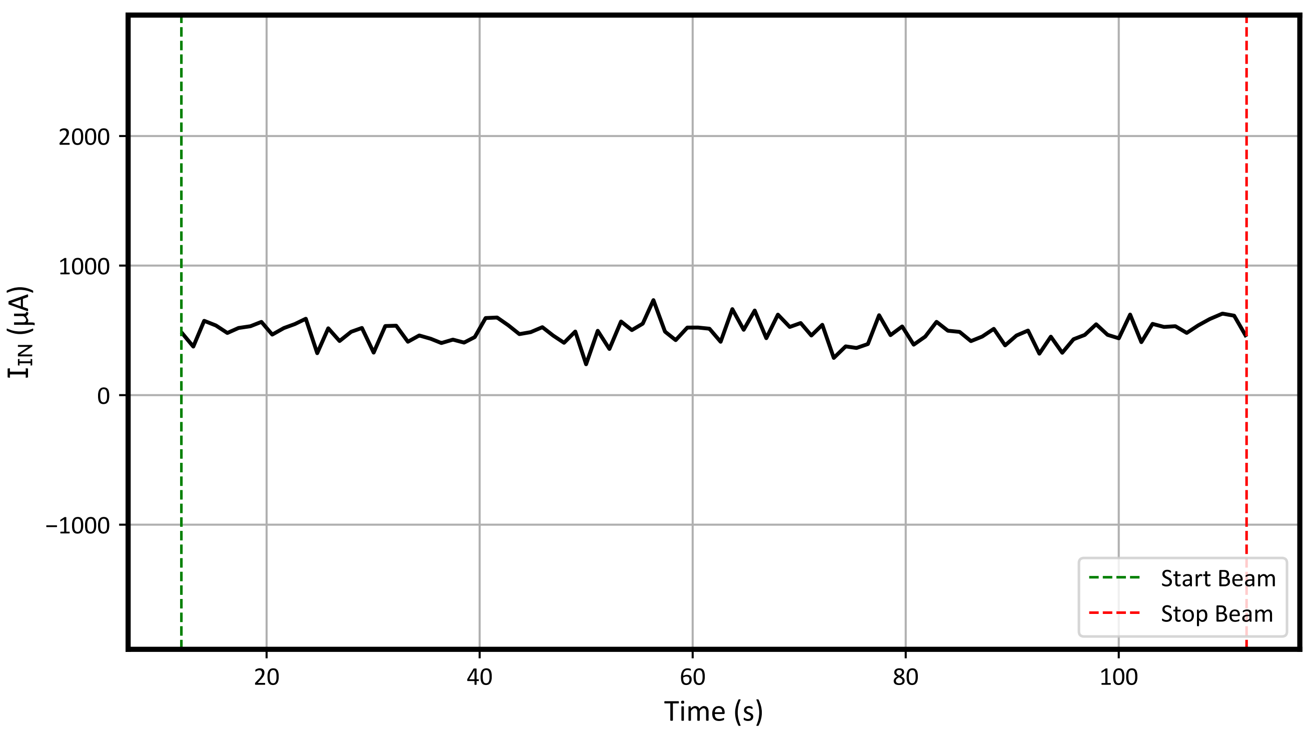

Figure 7-4. SEB Off Run #6 (V_{OUT} = 0-V)

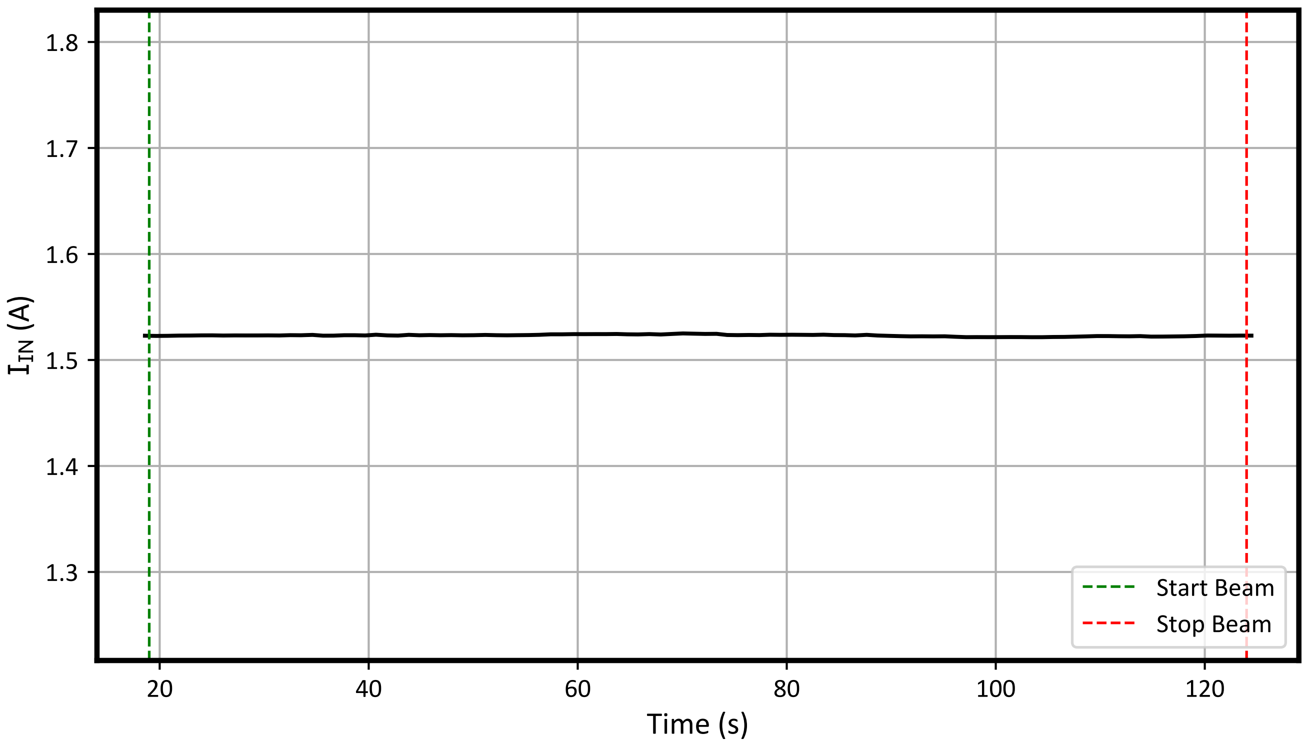

Figure 7-5. SEB On Run #9 (V_{OUT} = 5.5-V)

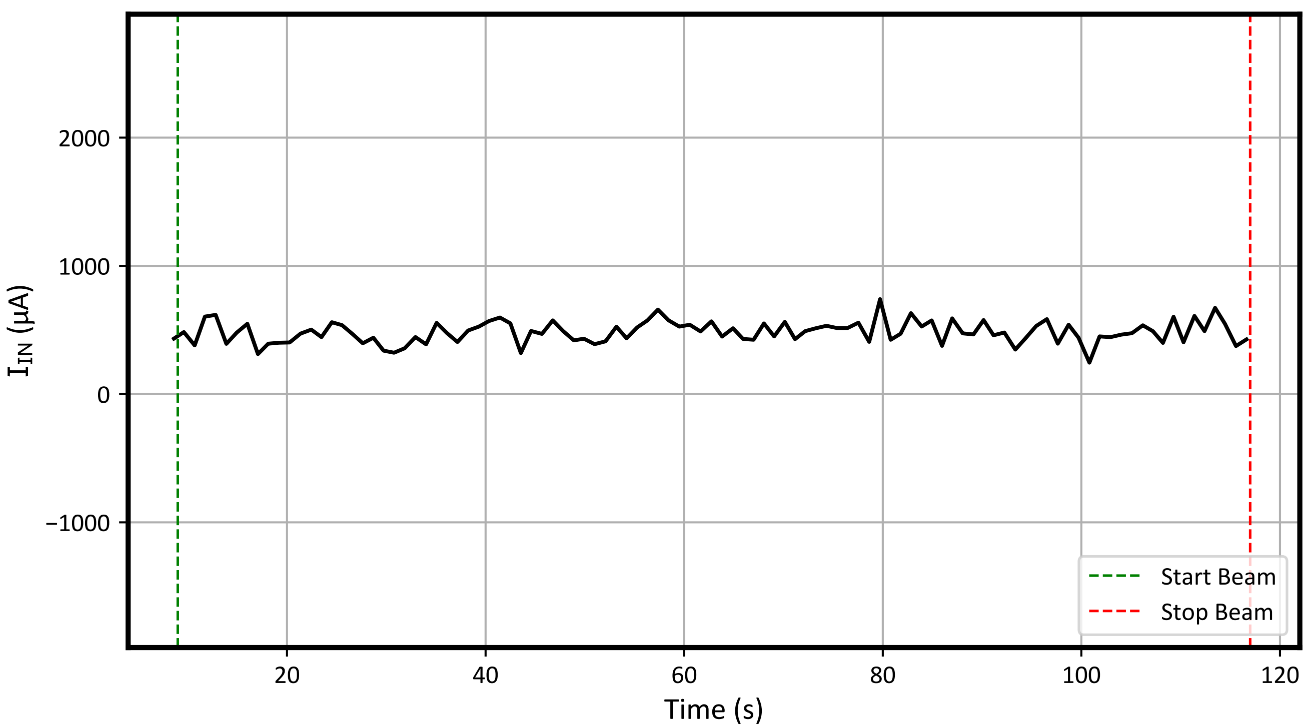

Figure 7-6. SEB Off Run #10 (V_{OUT} = 0-V)

8 Single-Event Transients (SET)

SET are defined as heavy-ion-induced transients upsets on the VOUT and PGof the TPS7H1111-SP.

Testing was performed at room temperature (no external temperature control applied). The heavy-ions species used for the SET testing were Silver (^{109}Ag),and Homium (^{165}Ho) for an LET_{EFF} = 48 to 75 MeV·cm^2/mg, for more details refer to Ion LET_{EFF}, Depth, and Range in Silicon. Flux of 1.02 x 10^4 to 9.66 x 10^4 ions/cm^2·s and a fluence of 1.00 x 10^6 to 1.00 x 10^7 ions/cm^2, per run were used for the SET's characterization discussed on this chapter.

SET testing was catagorized as:

1. Golden Config: V_{IN}=2.5-V (Nominal), V_{BIAS}=5-V (Nominal)
2. Silver Config: V_{IN}=2.5-V (Nominal), V_{BIAS}=12-V

Waveform size, sample rate, trigger type, value, and signal for all scopes used is presented on Table 8-1.

Table 8-1. Scope Settings

Note: Only one Signal was used as a trigger source at a time, this table just present all posible sources for a given scope, the same is valid for the trigger type. All percentage specified on the trigger value are deviation from the nominal value.

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
TDS7404B	V_{OUT}	Window	± 3 %	20µs/div	250MS/s
	PG	Edge/Negative	0.5-V		
PXIe-5172 (1)	V_{OUT}	Window	± 3 %	20k	100MS/s
PXIe-5172 (2)	PG	Edge/Negative	0.5-V	20k	100MS/s

V_{IN}=2.5-V (nominal) and V_{BIAS} = 5-V (nominal)

For the "golden configuration" of V_{IN} = 2.5-V and V_{BIAS} = 5-V with a V_{OUT} of 1.8-V two units were characterized from 75 MeV down to 48 MeV. ^{165}Ho was used to achieve LET_{EFF} = 75 MeV and ^{109}Ag was used to achieve LET_{EFF} = 60 and 48 MeV. A DPO and two PXIe-5172 scopes were used to monitor the V_{OUT} and PG signals of the TPS7H1111-SP with V_{OUT} triggering off a 3% window and PG triggering off a negative edge. The following tables summarize the results for the two units as well as the upper bound cross sections for V_{OUT}. A typical V_{OUT} transient is shown in the figure below, the figure shows that although the signal goes beyond the 3% window, the signal recovers back to nominal and the device continues to operate properly. As the summarization of results shows, the onset for the TPS7H1111-SP in "golden configuration" occurs at an LET_{EFF} of 60 MeV.

Table 8-2. Summary of TPS7H1111-SP SET Test Condition and Results V_{IN} = 2.5-V and V_{BIAS} = 5-V

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	V_{OUT} Capacitor	TDS7404B V_{OUT} # ≥ 3%	TDS7404B V_{OUT} # ≥ 5%	PXI 5172 PG #
13	5	^{165}Ho	75	8.91×10^4	1.00×10^7	2 x 100 µF	78	41	90
14	6	^{165}Ho	75	1.18×10^4	1.05×10^6	1 x 220 µF	21	4	0
15	5	^{109}Ag	60	1.13×10^4	1.00×10^6	2 x 100 µF	0	0	0
16	5	^{109}Ag	48	1.14×10^4	1.00×10^6	2 x 100 µF	0	0	0

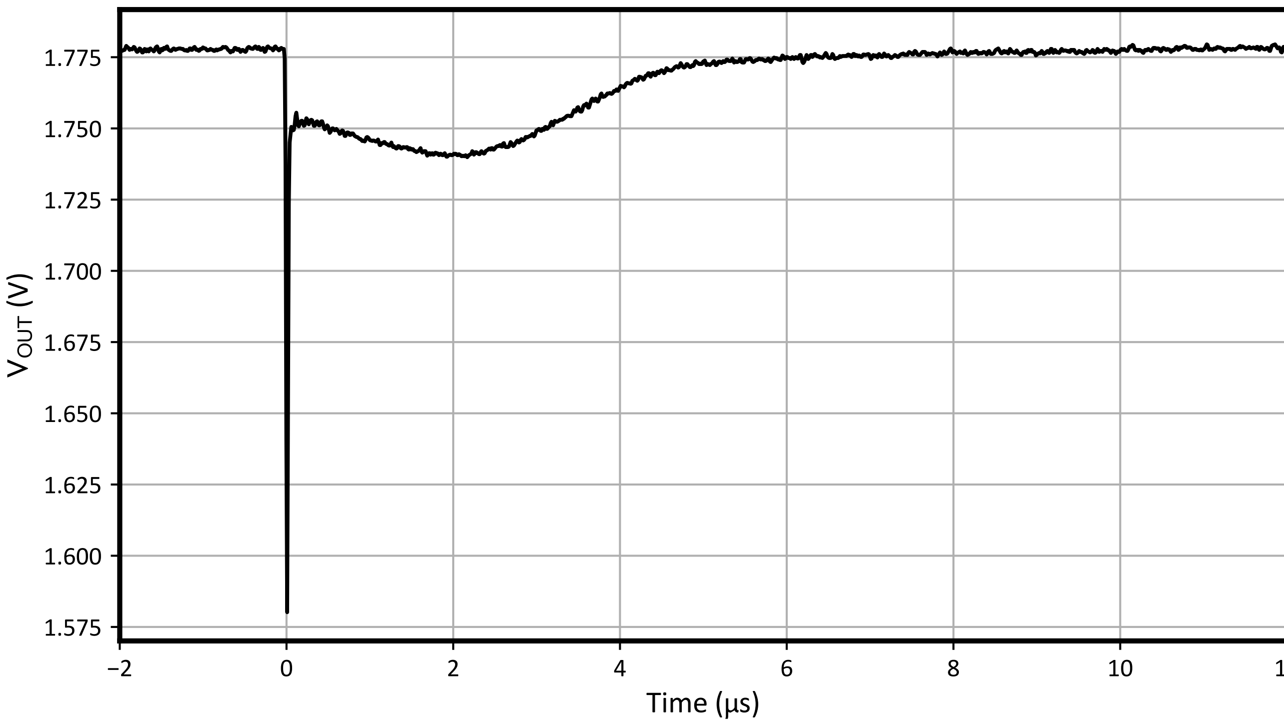

Figure 8-1. Worst-Case V_{OUT} Upset (Run # 13)

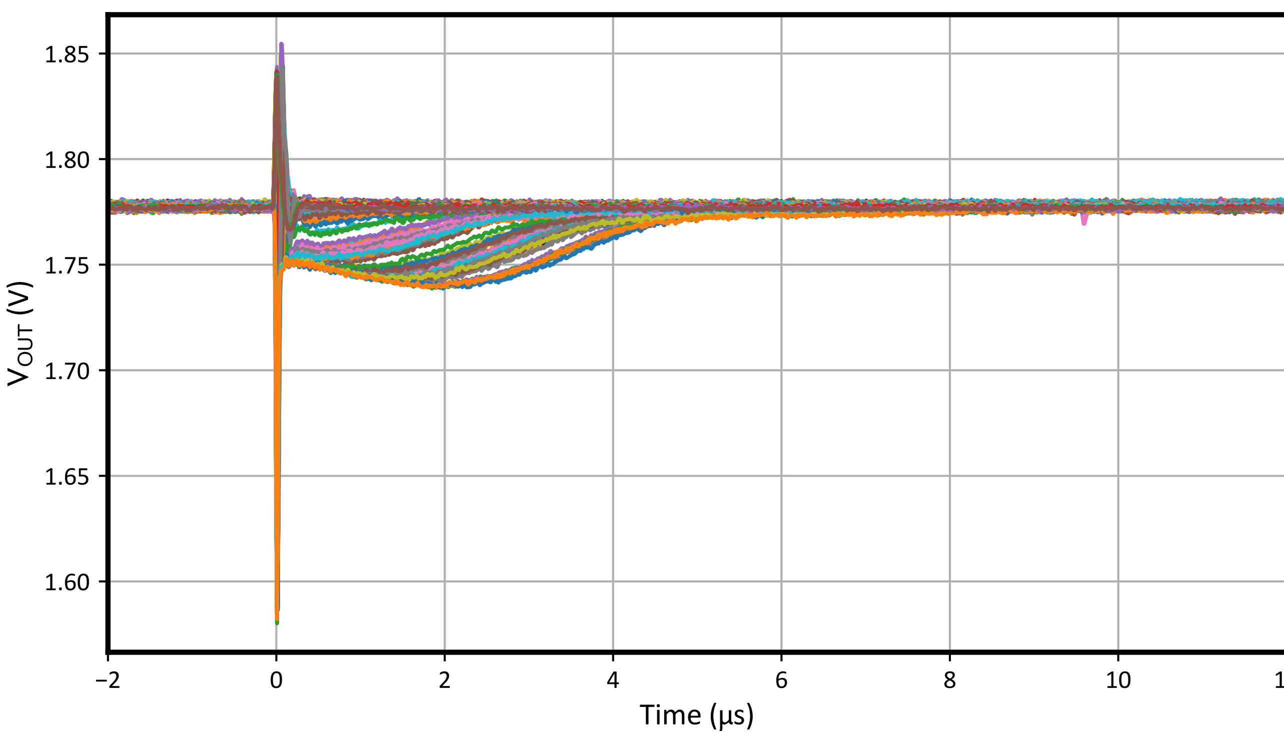

Figure 8-2. All V_{OUT} Upsets (Run # 13)

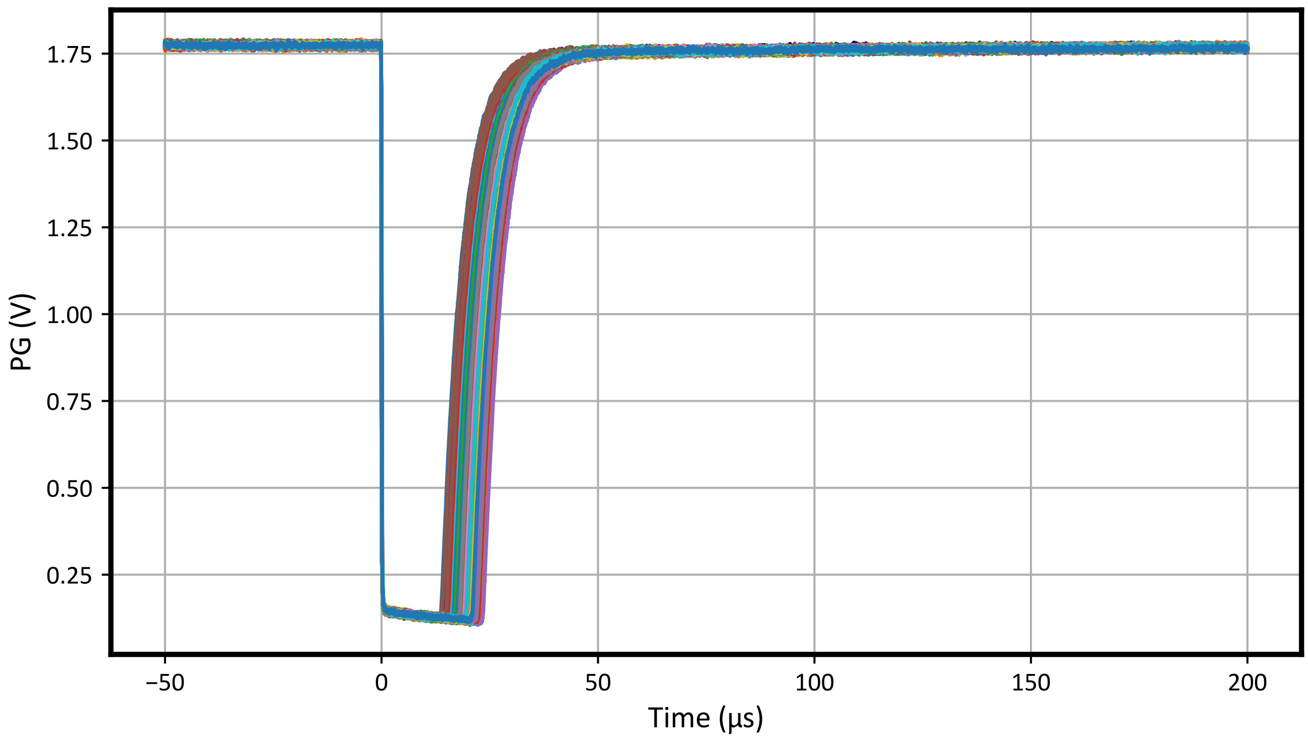

Figure 8-3. All PG Upsets (Run # 13)

V_{IN}=2.5-V (nominal) and V_{BIAS} = 12-V

Table 8-3. Summary of TPS7H1111-SP SET Test Condition and Results VIN = 2.5-V and V_{BIAS} = 12-V

RUN #	UNIT #	ION	LET_{EFF} (MeV·cm²/mg)	FLUX (ions·cm²/mg)	FLUENCE (# ions)	V_{OUT} Capacitor	TDS7404B V_{OUT} # ≥ 3%	TDS7404B V_{OUT} # ≥ 5%	PXI 5172 PG #
17	5	^{165}Ho	75	9.96×10^4	1.00×10^7	2 x 100 µF	140	78	175
18	6	^{165}Ho	75	1.17×10^4	1.00 x 10^6	1 x 220 µF	32	9	0
19	5	^{109}Ag	60	1.15×10^4	1.00 x 10^6	2 x 100 µF	5	3	0
20	5	^{109}Ag	48	1.12×10^4	1.00 x 10^6	2 x 100 µF	0	0	0
21	6	^{109}Ag	48	1.02 x 10^4	1.00 x 10^6	1 x 220 µF	0	0	0

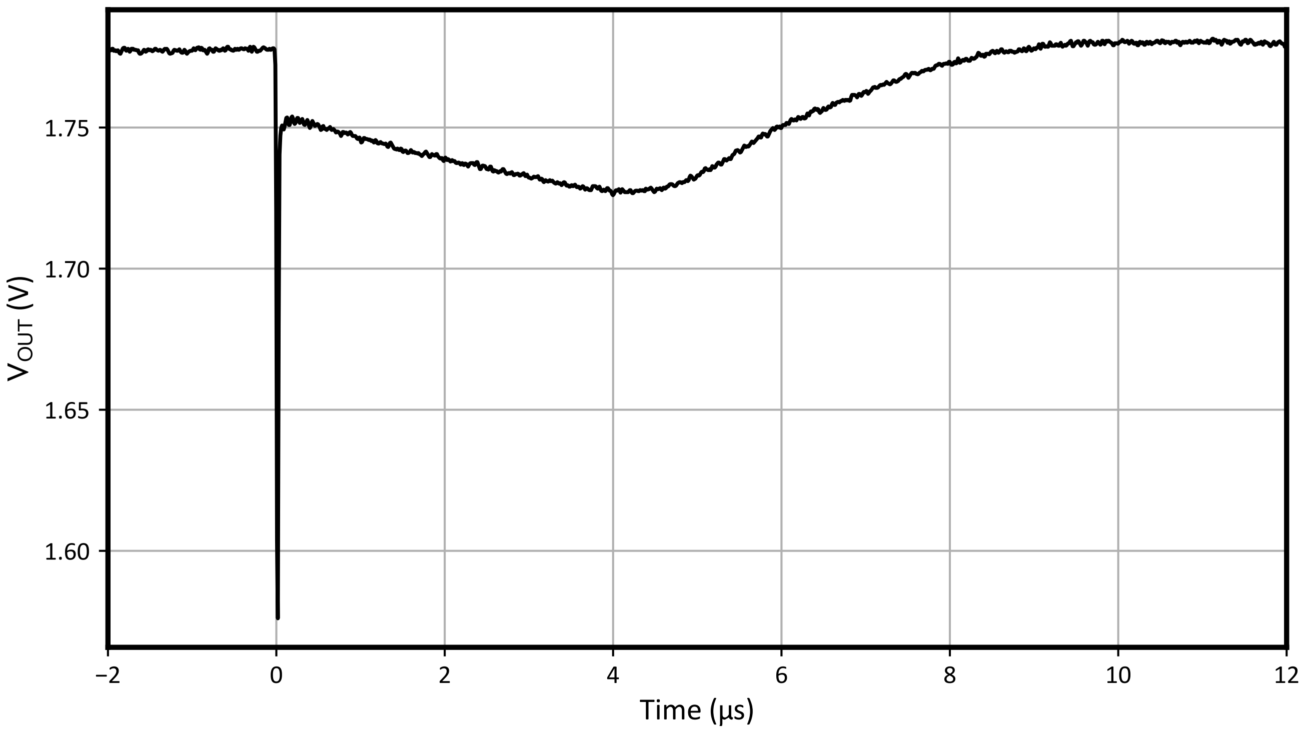

Figure 8-4. Worst-Case V_{OUT} Upset (Run # 17)

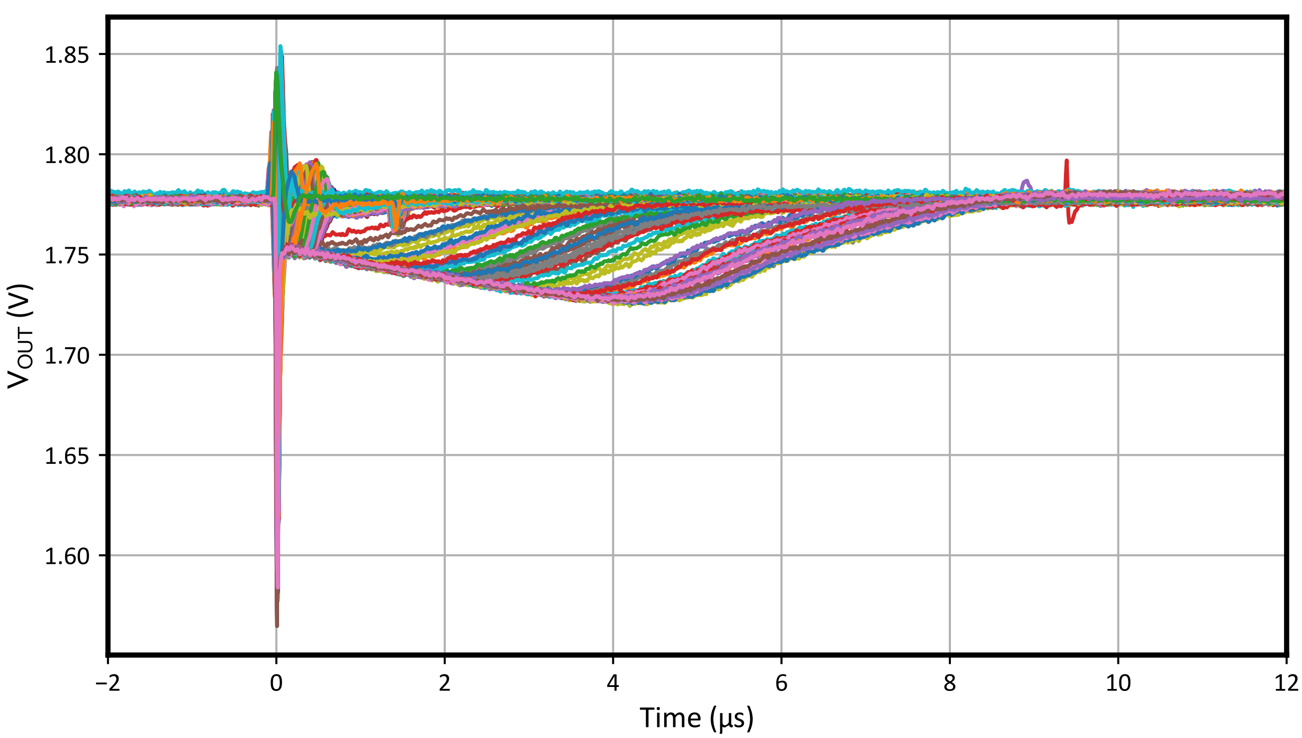

Figure 8-5. All V_{OUT} Upsets (Run # 17)

9 Event Rate Calculations

Event rates were calculated for LEO (ISS) and GEO environments by combining CREME96 orbital integral flux estimations and simplified SEE cross-sections according to methods described in *Heavy Ion Orbital Environment Single-Event Effects Estimations* application report. We assume a minimum shielding configuration of 100 mils (2.54 mm) of aluminum, and "worst-week" solar activity (this is similar to a 99% upper bound for the environment). Using the 95% upper-bounds for the SEL and the SEB/SEGR, the event rate calculation for the SEL and the SEB/SEGR is shown on Table 9-1 and Table 9-2, respectively. **It is important to note that this number is for reference since no SEL or SEB/SEGR events were observed.** SET orbit rate for V_{OUT} at V_{IN}=2.5-V and V_{BIAS} = 5 and 12-V is presented onSEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits.

Table 9-1. SEL Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.26×10^{-5}	9.22×10^{-8}	5.77×10^{-12}	2.40×10^{-4}	4.74×10^{8}
GEO		1.77×10^{-4}		1.63×10^{-11}	6.79×10^{-4}	1.68×10^{8}

Table 9-2. SEB/SEGR Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	75	6.26×10^{-5}	4.62×10^{-8}	2.89×10^{-12}	1.20×10^{-4}	9.47×10^{8}
GEO		1.77×10^{-4}		8.17×10^{-12}	3.40×10^{-4}	3.35×10^{8}

Table 9-3. SET (V_{IN}=2.5-V , V_{BIAS}= 5-V) Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	60	1.66×10^{-4}	1.09×10^{-5}	1.82×10^{-9}	7.58×10^{-2}	1.51×10^{6}
GEO		4.94×10^{-4}		5.39×10^{-9}	2.24×10^{-1}	5.09×10^{5}

Table 9-4. SET (V_{IN}=2.5-V , V_{BIAS}= 12-V) Event Rate Calculations for Worst-Week LEO and GEO Orbits

Orbit Type	Onset LET_{EFF} (MeV-cm^2/mg)	CREME96 Integral FLUX (/day/cm^2)	σSAT (cm^2)	Event Rate (/day)	Event Rate (FIT)	MTBE (Years)
LEO (ISS)	48	4.50×10^{-4}	1.81×10^{-5}	8.17×10^{-9}	3.41×10^{-1}	3.35×10^{5}
GEO		1.48×10^{-3}		2.68×10^{-8}	1.12×10^{0}	1.02×10^{5}

10 Summary

The purpose of this study was to characterize the effect of heavy-ion irradiation on the single-event effect (SEE) performance of the TPS7H1111-SP ultra-low noise, high PSRR, low dropout linear regulator (LDO). Heavy-ions with LET_{EFF} = 48 to 75 MeV·cm^2/mg were used for the SEE characterization campaign. Flux of ≈10^4 to 10^5 ions/cm^2 ·s and fluences of ≈10^6 to 10^7 ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H1111-SP is free of destructive SEL and SEB LET_{EFF} = 75 MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 48 to 75 MeV·cm^2 /mg on V_{OUT} are presented and discussed. CREME96-based worstweek event-rate calculations for LEO(ISS) and GEO orbits for the DSEE and SET (at V_{IN}=2.5-V and V_{BIAS}=5 and 12-V) are presented for reference.

A Total Ionizing Dose from SEE Experiments

The production TPS7H1111-SP is rated to a total ionizing dose (TID) of 100 krad(Si). In the course of the SEE testing, the heavy-ion exposures delivered ≈10 krad(Si) per 10^7 ions/cm^2 run. The cumulative TID exposure was controlled below 100krad (Si) per unit. All six TPS7H1111-SP devices used in the studies described in this report stayed within specification and were fully-functional after the heavy-ion SEE testing was completed.

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