Radiation Report

Single-Event Effects (SEE) Radiation Report of the TPS7H1301-SP

ABSTRACT

The purpose of this study is to characterize the single-event effects (SEE) performance due to heavy-ion irradiation of the TPS7H1301-SP. Heavy-ions with LET_{EFF} of 75MeV×cm^2/mg were used to irradiate six production devices and 4 pre-production devices. Flux of 6.98×10^4 to 1.35×10^{5}ions/cm^2/s and fluence of ≈10^{7}ions/cm^2 per run were used for the characterization. The results demonstrated that the TPS7H1301-SP is SEL-free up to *75*MeV×cm^2/mg at T=125°C and SEB/SEGR free up to 75MeV×cm^2/mg at T=25°C. SET transients performance for voltage excursions ≥|3%| from the nominal values of VOUT and CPOUT, voltage excursions ≥|5%| from the nominal value of VREF, and voltage excursions ≥20% from the nominal value of PG are discussed.

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1 Introduction

The TPS7H1301-SP is a radiation-hardened, charge pump voltage inverter with an integrated low dropout adjustable regulator. The device features an input voltage range of 3V to 6.3V, capable of providing an output current of 400mA with an adjustable output voltage range of -0.6V to -6V. The TPS7H1301-SP integrates several key functions such as:

- External compensation by incorporating direct error amp access via the STAB pin
- Internal switching frequency of 500kHz
- Typical quiescent current of 15mA and typical charge-pump resistance of 3.5Ω makes the TPS7H1301-SP ideal for:
  - Driving power amplifiers
  - DAC bias rails
  - Low noise negative voltage applications

The device is offered in a 14-pin CFP ceramic package. General device information and test conditions are listed in the overview information table. For more detailed technical specifications, user-guides, and application notes please go to device product page.

Table 1-1. Overview Information

DESCRIPTION(1)	DEVICE INFORMATION
TI Part Number	TPS7H1301-SP
Orderable Part Number	5962R2421501VXC
Device Function	Charge Pump Voltage Inverter
Technology	LBC7 (Linear BiCMOS 7)
Exposure Facility	Facility for Rare Istotope Beams, K500 Cyclotron (KSEE), Michigan State University (19.5MeV/nucleon) and Radiation Effects Facility, Cyclotron Institute, Texas A&M University (15MeV/nucleon)
Heavy Ion Fluence per Run	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 TPS7H1301-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 TPS7H1301-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 TPS7H1301-SP was tested for SEL at the maximum recommended operating conditions of VIN=6.3V and the maximum and minimum output voltages of -6V and -0.6V, respectively. The device was loaded with a Chroma 63600 E-Load in constant resistance (CR) mode to achieve a load of 75mA during the VIN=6.3V to VOUT=-6V bias case and a load of 400mA during the VIN=6.3V to VOUT=-0.6V bias case. A load of 75mA was chosen during the VIN=6.3V to VOUT=-6V bias case rather than the full 400mA load in order to maintain VIN to VOUT headroom. During testing of the 4 production devices, the TPS7H1301-SP did not exhibit any SEL with heavy-ions with LET_{EFF} = 75MeV·cm^2/mg at flux ≈10^{5}ions/cm^2/s, fluence of ≈10^{7}ions/cm^2, and a die temperature of 125°C.

The TPS7H1301-SP was evaluated for SEB/SEGR at the same maximum recommended bias conditions as SEL testing. 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. The device was also tested for SEB Off by disabling the device. During the SEB/SEGR testing, not a single current event was observed, demonstrating that the TPS7H1301-SP is SEB/SEGR-free up to LET_{EFF} = 75MeV·cm^2/mg at a flux of ≈10^{5}ions/cm^2/s, fluence of ≈10^{7}ions/cm^2, and a die temperature of ≈25°C.

The TPS7H1301-SP was characterized for SET at flux of ≈10^{5}ions/cm^2/s , fluence of ≈10^{7}ions/cm^2, and at room temperature. The device was characterized with VIN=5V, VOUT=-1.8V, and a load of 400mA for the "golden" configuration and V_{IN}=6V, VOUT=-5V, and a load of 150mA for the "silver" configuration. Heavy-ions with LET_{EFF} of 75MeV·cm^2/mg were used to characterize the transient performance. To see the SET results of the TPS7H1301-SP, please refer to Section 8.

3 Device and Test Board Information

The TPS7H1301-SP is packaged in a 14-pin CFP ceramic package as shown in Figure 3-1. The TPS7H1301EVM-CVAL was used to evaluate the performance and characteristics of the TPS7H1301-SP under heavy ion radiation. The evaluation module is shown in Figure 3-2. The schematics are shown in Figure 3-3. Table 3-1 shows the components updated on the TPS7H1301EVM-CVAL for this SEE test campaign.

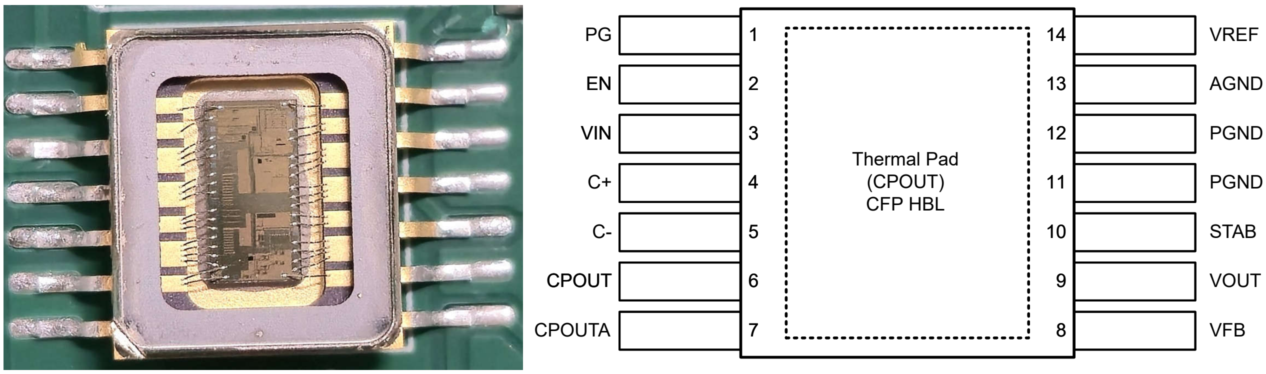

Figure 3-1. Photograph of Delidded TPS7H1301-SP [Left] and Pinout Diagram [Right]

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

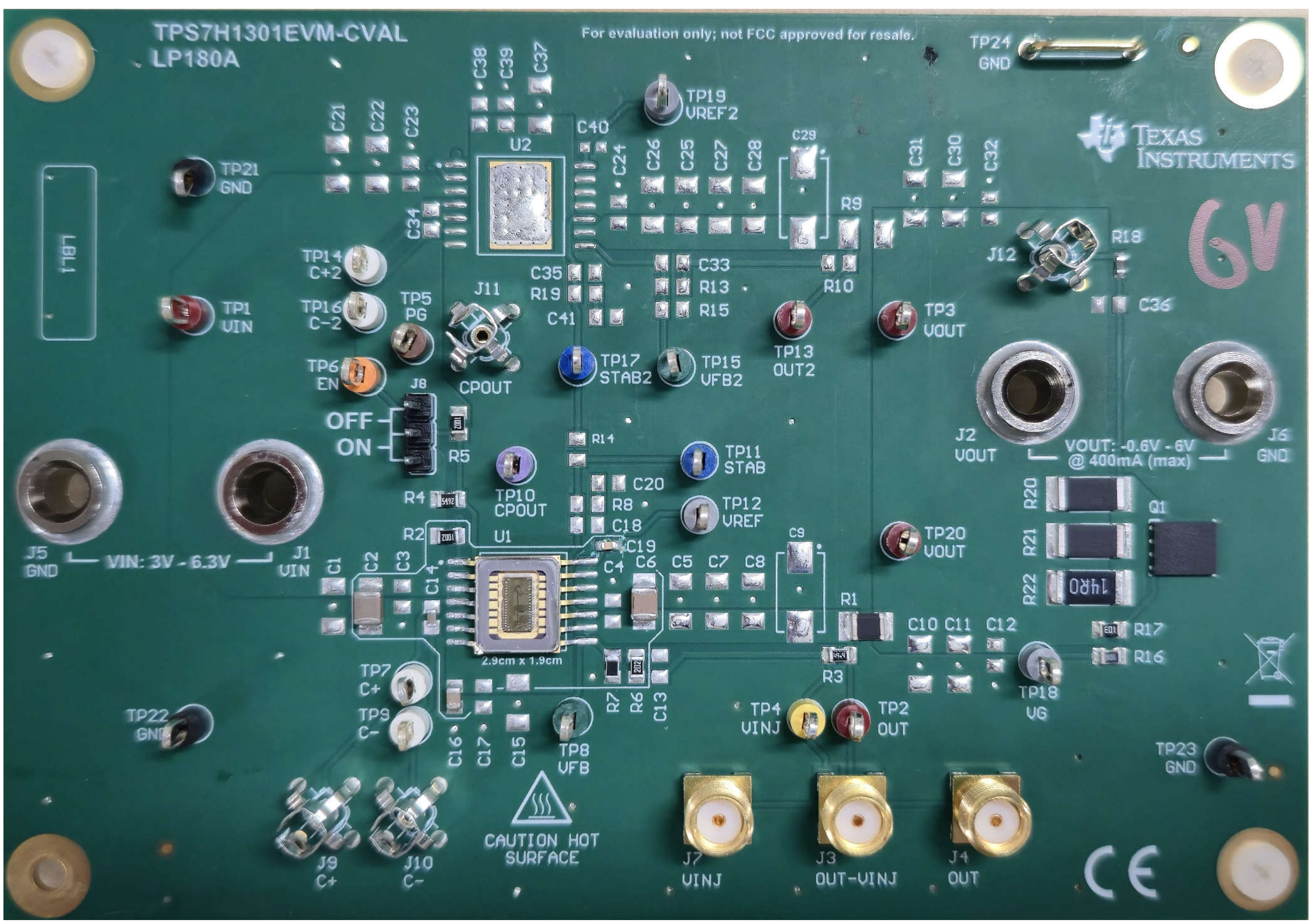

Figure 3-2. TPS7H1301-SP EVM Top View

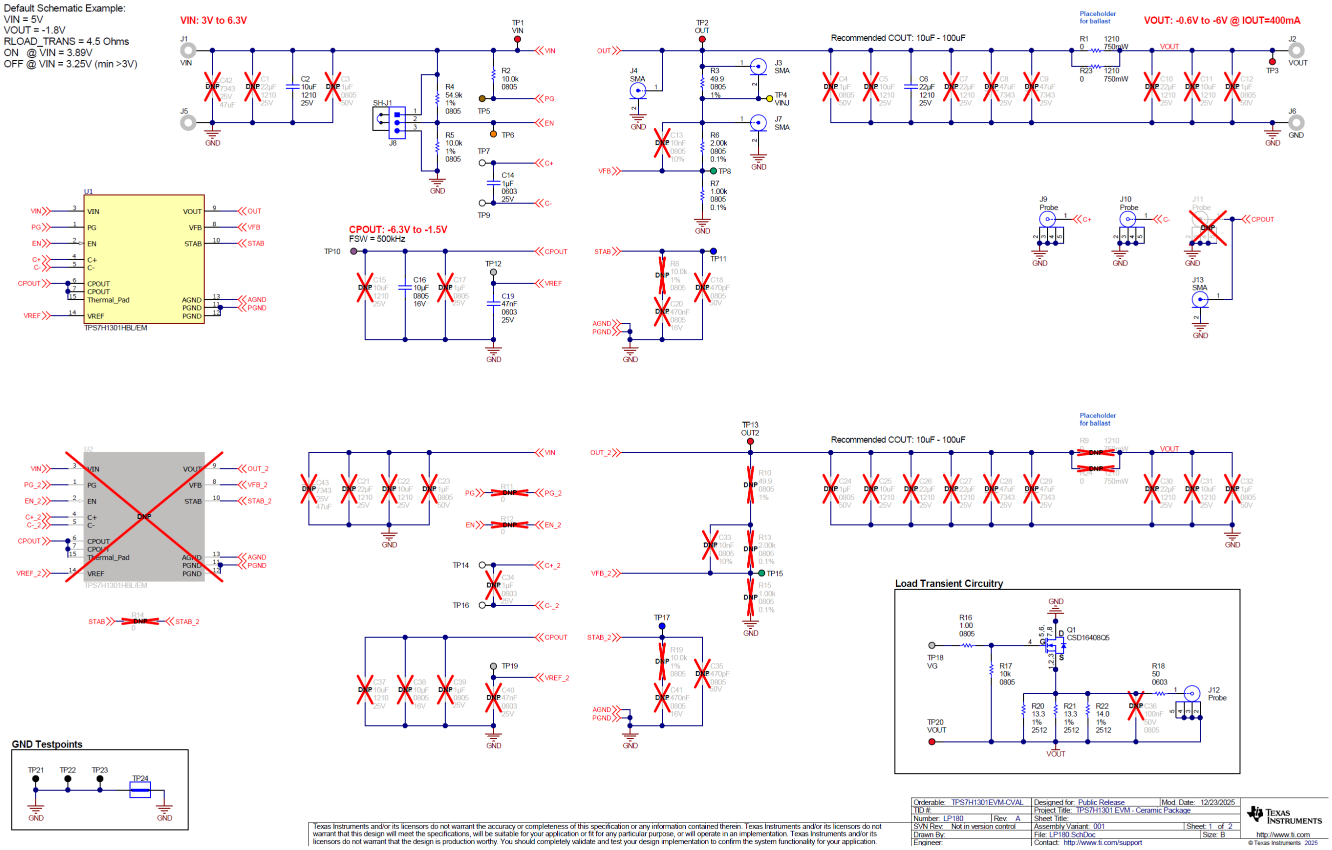

Figure 3-3. TPS7H1301-SP EVM Schematic

Table 3-1. TPS7H1301-SP Component Changes for SEE Testing

VOUT (V)	R6 (FB-Top)	R7 (FB-Bot)
-6	2kΩ	222Ω
-5	2kΩ	272Ω
-1.8	2kΩ	1kΩ
-0.6	2kΩ	Open

4 Irradiation Facility and Setup

The heavy-ion species used for the SEE studies on this product were provided and delivered by:

- Michigan State University (MSU) Facility for Rare Isotope Beams (FRIB) using a K500 superconducting cyclotron (KSEE) and an advanced electron cyclotron resonance (ECR) ion source. At the fluxes used, ion beams had good flux stability and high irradiation uniformity as the beam is collimated to a maximum of 40mm × 40mm square cross-sectional area for the in-air and vacuum scintillators. Uniformity is achieved by scattering on a Cu foil and then performing magnetic defocusing. The flux of the beam is regulated over a broad range spanning several orders of magnitude. For these studies, ion flux of ≈10^5ions/cm^2/s was used to provide heavy-ion fluences of ≈10^7ions/cm^2. The KSEE facility uses a beam port that has a 3-mil polyethylene naphthalate (PEN) window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 60mm for all runs.
- Texas A&M University (TAMU) Cyclotron Radiation Effects Facility using a K500 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 ≈10^5 ions/cm^2/s was used to provide heavy-ion fluences of ≈10^7ions/cm^2. The TAMU facility uses a beam port that has a 1-mil Aramica window to allow in-air testing while maintaining the vacuum within the particle accelerator. The in-air gap between the device and the ion beam port window was maintained at 40mm for all runs.

For the experiments conducted on this report, there was 2 ions were used, ^{169}Tm and ^{165}Ho. Both were used to obtain LET_{EFF} of 75MeV·cm^2/mg. The total kinetic energies for the ions were:

- ^{169}Tm = 3.295GeV (19.5MeV/nucleon)
  - Ion uniformity for these experiments was between 79.8% and 92%
- ^{165}Ho = 2.474GeV (15MeV/nucleon)
  - Ion uniformity for these experiments was 94%

Figure 4-1 shows the TPS7H1301EVM-CVAL evaluation module in front of the beam line at the KSEE facility.

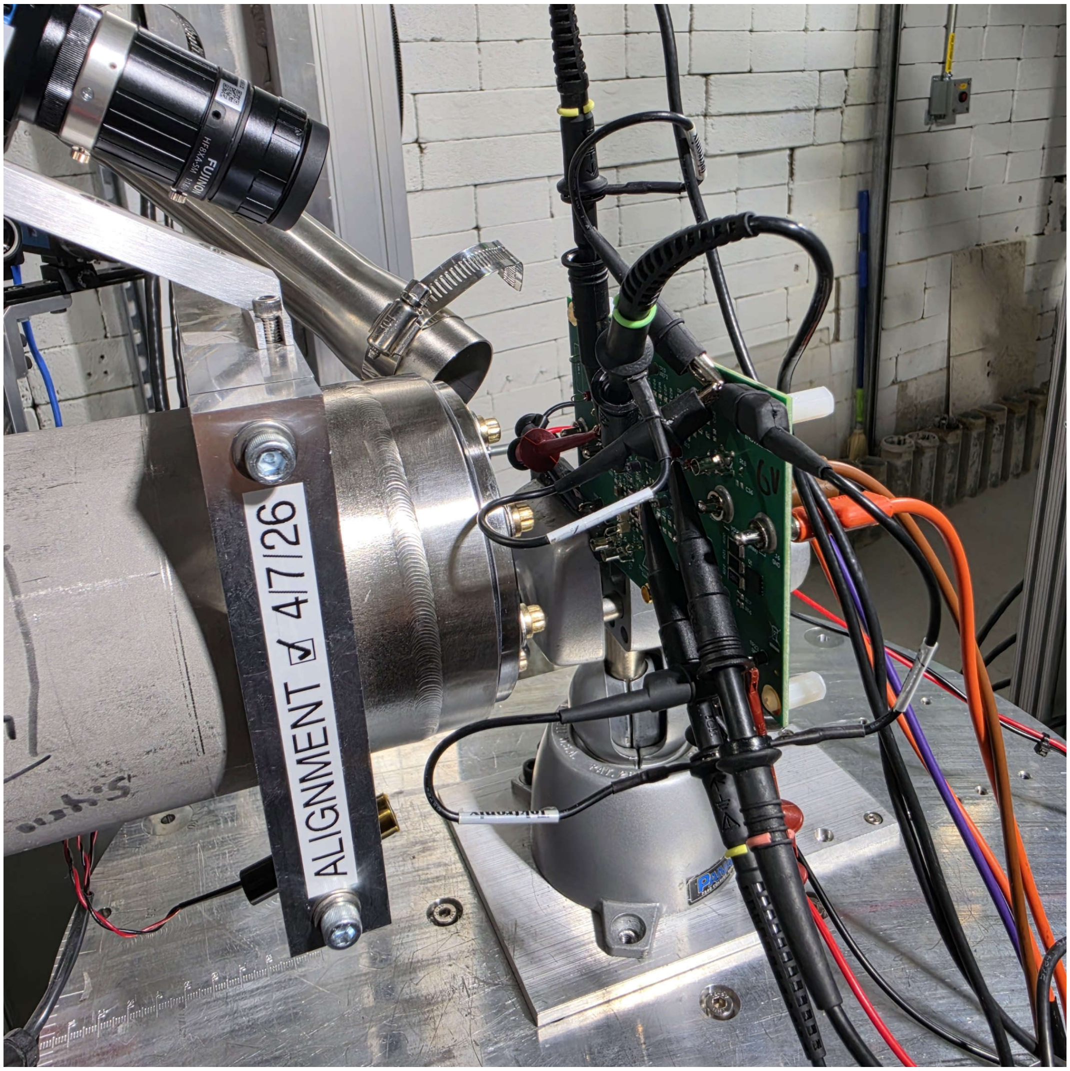

Figure 4-1. TPS7H1301-SP EVM in Front of the Heavy-Ion Beam Exit Port at the MSU FRIB KSEE Line

5 LET$_{EFF}$ and Range Calculation

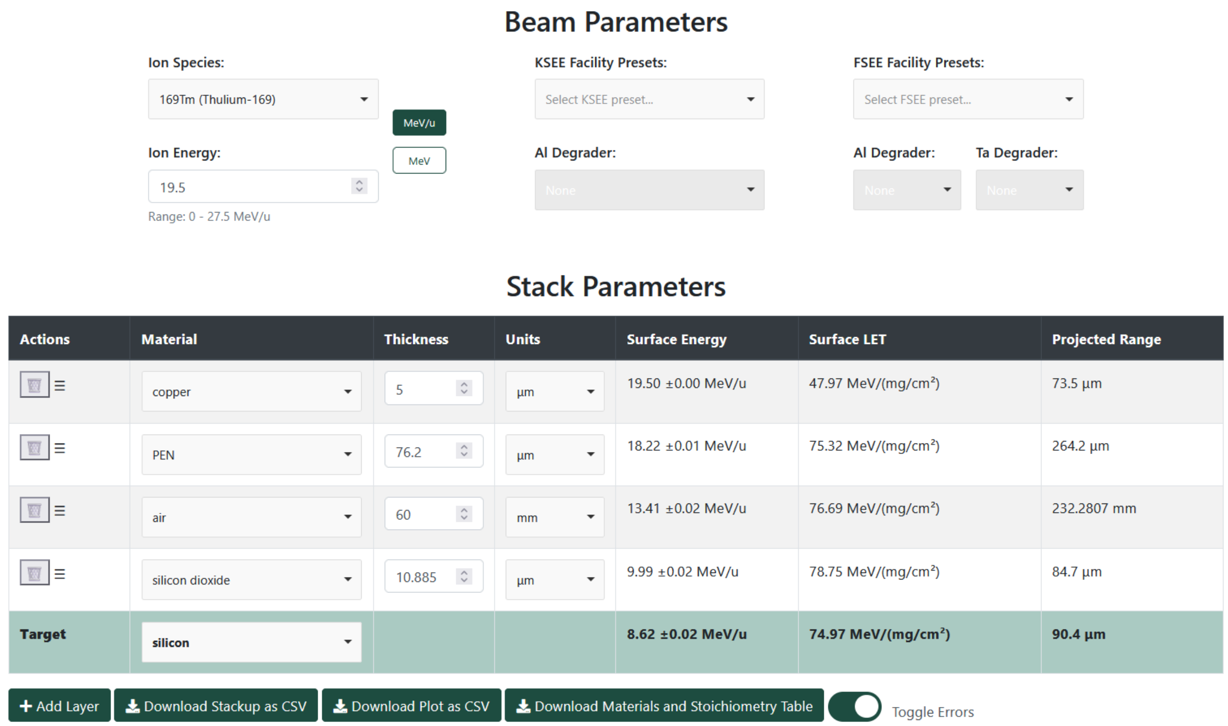

Figure 5-1. MSU Stack-up Calculator Used to Determine Key Ion Parameters

The TPS7H1301-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 10.885µm based on the nominal layer thickness.

Accounting for energy loss through the degrader, copper foil, beam port window, air gap, and the BEOL stack of the TPS7H1301-SP, the effective LET (LET$_{EFF}$) at the surface of the silicon substrate and the range was determined with:

- MSU Stack-Up Calculator (provided by MSU FRIB and based on latest SRIM-2013 [7] models)
- SEUSS 2024 software (provided by TAMU and based on the latest SRIM-2013 [7] models)

The results are shown in Table 5-1.

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

Facility	Beam Energy (MeV/ nucleon)	Ion Type	Degrader Steps (#)	Degrader Angle (°)	Copper Foil Width (µm)	Beam Port Window	Air Gap (mm)	Angle of Incidence	LET$_{EFF}$ (MeV·cm^2/ mg)	Range in Silicon (µm)
KSEE	19.5	^{169}Tm	-	-	5	3-mil PEN	60	0	74.97	90.4
TAMU	15	^{165}Ho	0	0	-	1-mil Aramica	40	0	75	97.2

6 Test Setup and Procedures

There were two input supplies used to power the TPS7H1301-SP which provided VIN and EN. The VIN for the device was provided via Ch. 3 of an N6705C power module and ranged from 5V to 6.3V for SEL, SEB/SEGR, and SET testing. The EN of the device was driven by an E36311A power supply and was either forced to 5V or 0V to enable or disable the device.

Table 6-1. TPS7H1301-SP SEE Testing Bias Conditions

Test Type	VIN (V)	EN (V)	VOUT (V)	IOUT (mA)
SEL (Max VOUT)	6.3	5	-6	75
SEB On (Max VOUT)	6.3	5	-6	75
SEL (Min VOUT)	6.3	5	-0.6	400
SEB On (Min VOUT)	6.3	5	-0.6	400
SEB Off	6.3	0	-	-
SET (Golden)	5	5	-1.8	400
SET (Silver)	6	5	-5	150

The primary signal monitored during testing were VOUT and CPOUT by using a PXIe-5172 triggering using a window trigger at |3%|. VREF was also monitored using a PXIe-5172 triggering on a window trigger at |5%|. The fourth signal monitored was PG using a PXIe-5172 with a edge-negative trigger at 20% lower than the nominal value of this signal. All of these signals were monitored and triggered on their own independent NI PXIe-5172 cards.

All equipment 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.

Table 6-2 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 TPS7H1301-SP.

Table 6-2. Equipment Settings and Parameters Used During the Open-Loop SEE Testing of the TPS7H1301-SP

PIN NAME	EQUIPMENT USED	CAPABILITY	COMPLIANCE	RANGE OF VALUES USED
VIN	N6705C (Ch #3)	60V, 17A	15A	5V, 6V, 6.3V
EN	E36311A (Ch #1)	6V, 5A	0.1A	0V, 5V
VOUT	PXIe-5172 (1)	100 MS/s	—	100 MS/s
CPOUT	PXIe-5172 (2)	100 MS/s	—	100 MS/s
VREF	PXIe-5172 (3)	100 MS/s	—	100 MS/s
PG	PXIe-5172 (4)	100 MS/s	—	100 MS/s

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 test facilities. During the heavy-ion testing, the LabVIEW control program powered up the TPS7H1301-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 window or edge 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.

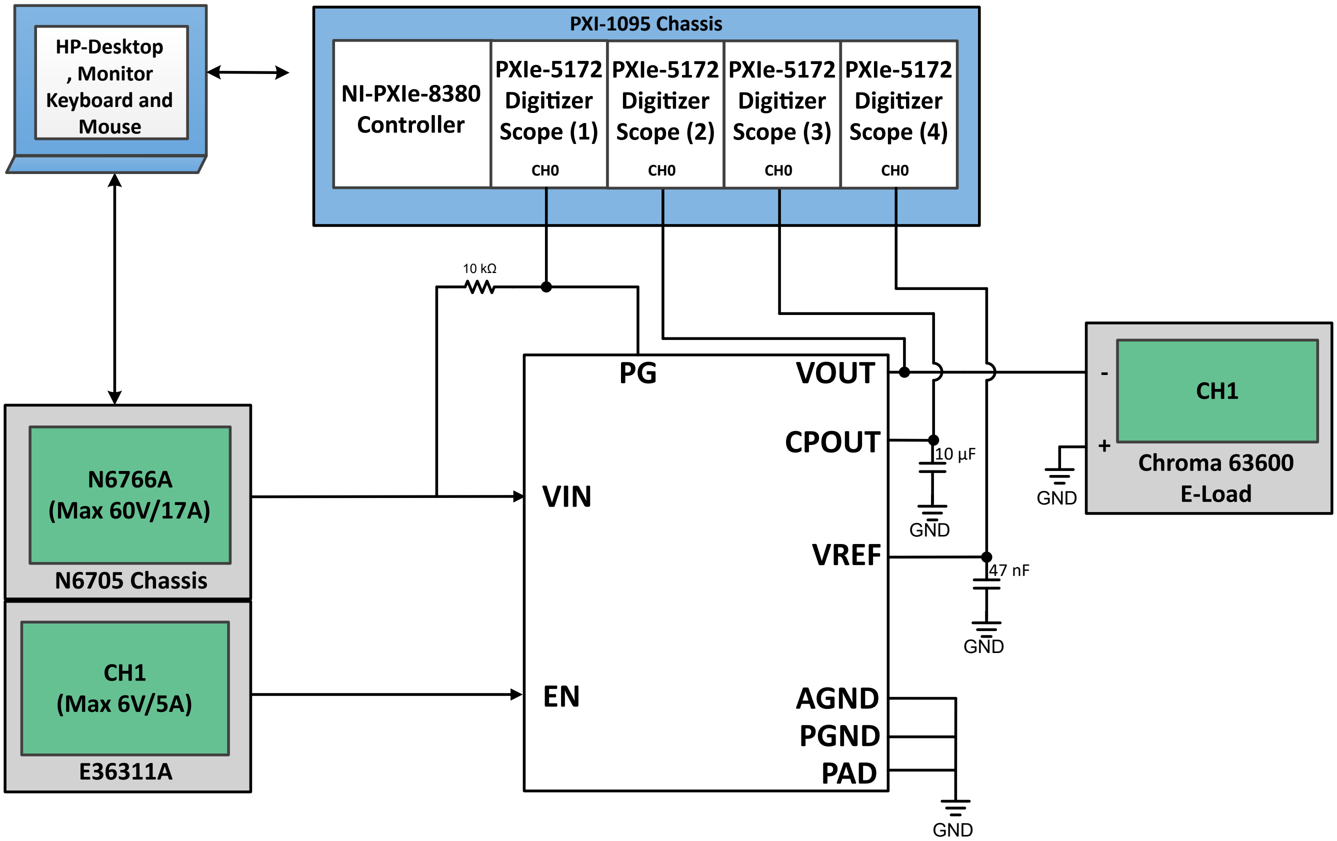

Figure 6-1. Block Diagram of the SEE Test Setup for the TPS7H1301-SP

7 Destructive Single-Event Effects (DSEE)

7.1 Single-Event Latch-up (SEL) Results

During the SEL testing the device was heated to 125°C by using PID controlled heat gun (MISTRAL 6 System (120V, 2400W)). The die temperature was verified using a standalone FLIR thermal camera prior to exposure to heavy ions at KSEE. The temperature of the die was constantly monitored during testing at TAMU through an IR camera integrated into the control loop to create closed-loop temperature control.

The species used for the SEL testing was ^{169}Tm at 19.5MeV/nucleon (KSEE) and ^{165}Ho at 15MeV/nucleon (TAMU). For both ions an angle of incidence of 0° was used to achieve a LET_{EFF} of ≈75MeV·cm^2/mg (for more details refer to Table 5-1). Flux of ≈10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was ≈2 minutes. The 4 production devices were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 6.3V and both min and max VOUT values of -0.6V and -6V, respectively. No SEL events were observed during all four runs, indicating that the TPS7H1301-SP is SEL-free up to 75MeV×cm^2/mg.Table 7-1 shows the SEL test conditions and results. Figure 7-1 and Figure 7-2 show a plot of the current versus time for runs 1 and 2, respectively.

Table 7-1. Summary of TPS7H1301-SP SEL Test Conditions and Results

Run #	Unit #	Facility	Production Type	Ion	LET_{EFF} (MeV×cm^2/mg)	Flux (ions/cm^2/s)	Fluence (ions/cm^2)	VIN (V)	VOUT (V)	IOUT (mA)	SEL (# Events)
1	1	KSEE	Final	^{169}Tm	75	1.17 x 10^5	1 x 10^7	6.3	-6	75	0
2	2	KSEE	Final	^{169}Tm	75	1.07 x 10^5	1 x 10^7	6.3	-0.6	400	0
3	3	KSEE	Final	^{169}Tm	75	1.11 x 10^5	1 x 10^7	6.3	-0.6	400	0
4	4	KSEE	Final	^{169}Tm	75	1.15 x 10^5	1 x 10^7	6.3	-6	75	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 at 125°C (4 × 10^7), the upper-bound cross-section (using a 95% confidence level) is calculated as:

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

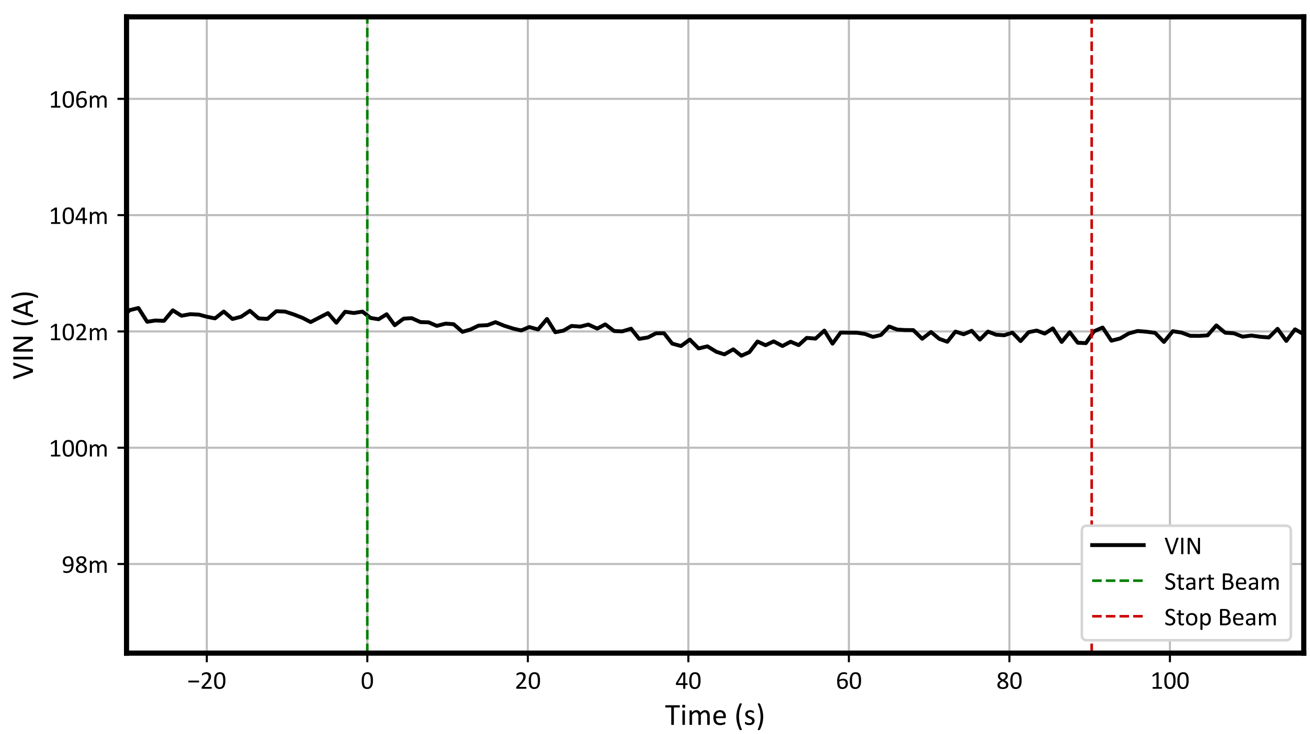

Figure 7-1. SEL Current versus Time for Run #1 at T = 125°C, VOUT=-6V, and IOUT=75mA

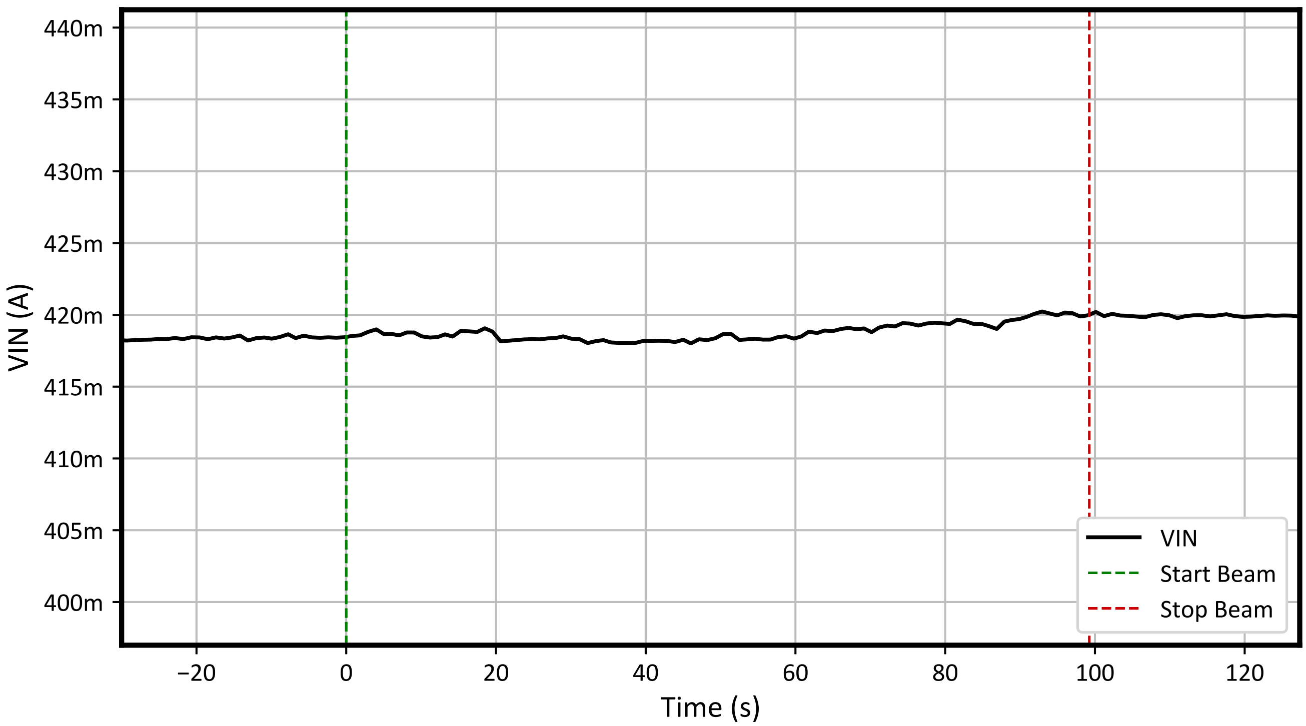

Figure 7-2. SEL Current versus Time for Run #2 at T = 125°C, VOUT=-0.6V, and IOUT=400mA

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 0V (using Ch #1 of a Keysight E36311A). 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 ^{169}Tm at 19.5 MeV/nucleon (KSEE) and ^{165}Ho at 15MeV/nucleon (TAMU). For both ions an angle of 0° was used to achieve a LET_{EFF} of ≈75MeV·cm^2/mg (for more details refer to Table 5-1). Flux of ≈10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 per run was used. Run duration to achieve this fluence was ≈2 minutes. The 4 production devices (same as used in SEL testing) were powered up and exposed to the heavy-ions using the maximum recommended input voltage of 6.3V and both min and max VOUT values of -0.6V and -6V, respectively. No SEB/SEGR current events were observed during the 8 runs, indicating that the TPS7H1301-SP is SEB/SEGR-free up to LET_{EFF} = 75MeV·cm^2/mg. Table 7-2 shows the SEB/SEGR test conditions and results.

Table 7-2. Summary of TPS7H1301-SP SEB/SEGR Test Conditions and Results

Run #	Unit #	Facility	Production Type	Ion	LET_{EFF} (MeV·cm^2/mg)	Flux (ions/cm^2/s)	Fluence (ions/cm^2)	Enabled Status	VIN (V)	VOUT (V)	IOUT (mA)	SEB (# Events)
5	1	KSEE	Final	^{169}Tm	75	1.35 x 10^5	9.99 x 10^6	EN	6.3	-6	75	0
6	1	KSEE	Final	^{169}Tm	75	1.07 x 10^5	9.99 x 10^6	DIS	6.3	-	-	0
7	2	KSEE	Final	^{169}Tm	75	1.05 x 10^5	1.00 x 10^7	EN	6.3	-0.6	400	0
8	2	KSEE	Final	^{169}Tm	75	1.16 x 10^5	1.00 x 10^7	DIS	6.3	-	-	0
9	3	KSEE	Final	^{169}Tm	75	1.14 x 10^5	1.00 x 10^7	EN	6.3	-0.6	400	0
10	3	KSEE	Final	^{169}Tm	75	1.16 x 10^5	1.00 x 10^7	DIS	6.3	-	-	0
11	4	KSEE	Final	^{169}Tm	75	1.16 x 10^5	1.00 x 10^7	EN	6.3	-6	75	0
12	4	KSEE	Final	^{169}Tm	75	1.15 x 10^5	1.00 x 10^7	DIS	6.3	-	-	0

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:

$\sigma_{SEB} \leq 4.61 \times 10^{-8}$ cm^2/device for LET_{EFF} = 75MeV·cm^2/mg and T = 25°C.

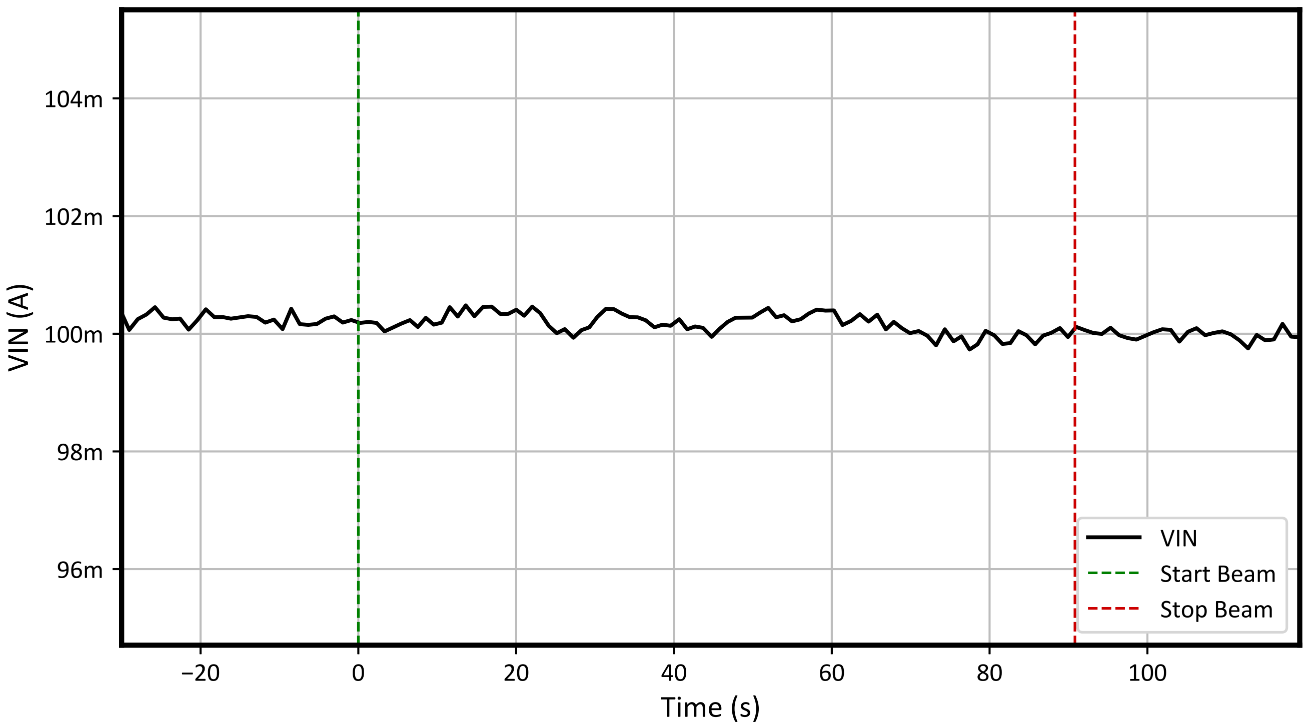

Figure 7-3. SEB On Current v. Time for Run #5 at T = 25°C, VOUT=-6V, and IOUT=75mA

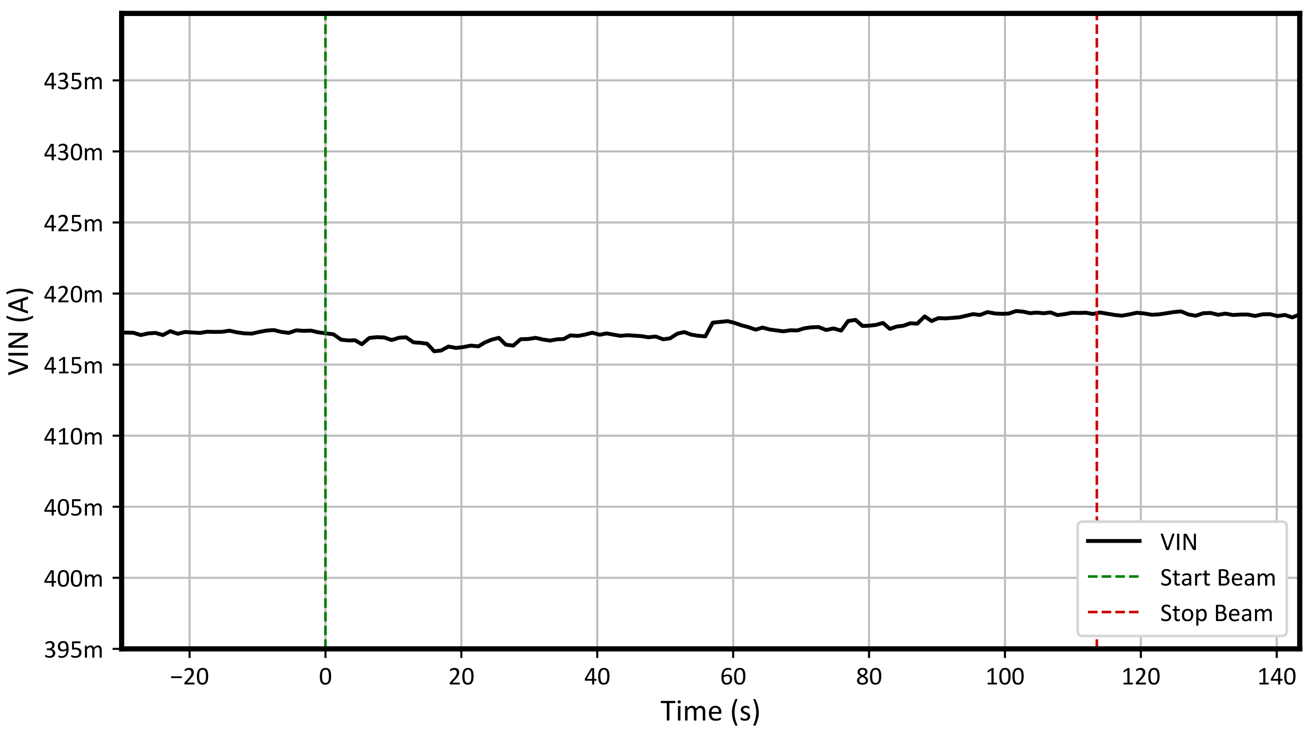

Figure 7-4. SEB On Current v. Time for Run #7 at T = 25°C, VOUT=-0.6V, and IOUT=400mA

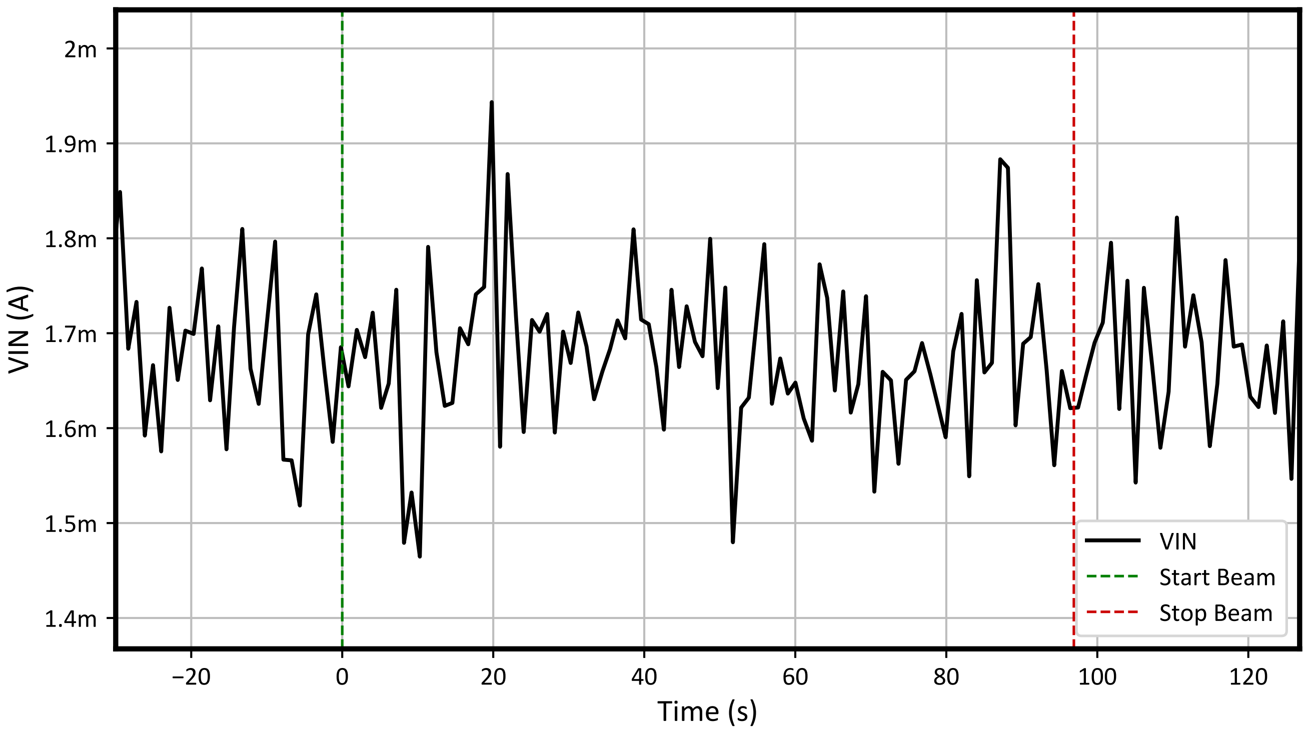

Figure 7-5. SEB Off Current v. Time for Run #6 at T = 25°C and VIN=6.3V

8 Single-Event Transients (SET)

SET are defined as heavy-ion induced transients on the VOUT, CPOUT, VREF, or PG signals of the TPS7H1301-SP. Testing was performed at room temperature (no external temperature control applied). The species used for the SET testing was ^{169}Tm at 19.5MeV/nucleon (KSEE) and ^{165}Ho at 15MeV/nucleon (TAMU) (for more details refer to Table 5-1). Flux of ≈10^5 ions/cm^2/s and a fluence of ≈10^7 ions/cm^2 per run were used for the SET characterization discussed.

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

Table 8-1. Scope Settings

Scope Model	Trigger Signal	Trigger Type	Trigger Value	Record Length	Sample Rate
PXIe-5172 (1)	VOUT	Window	±3%	10k	100MS/s
PXIe-5172 (2)	CPOUT	Window	±3%	10k	100MS/s
PXIe-5172 (3)	VREF	Window	±5%	10k	100MS/s
PXIe-5172 (4)	PG	Edge Negative	20%	10k	100MS/s

The primary signals monitored during testing were VOUT and CPOUT by using a PXIe-5172 triggering using a window trigger at |3%|. VREF was also monitored using a PXIe-5172 triggering on a window trigger at |5%|. The fourth signal monitored was PG using a PXIe-5172 with a edge-negative trigger at 20% lower than the nominal value of this signal. All of these signals were monitored and triggered on their own independent NI PXIe-5172 cards.

The SET results for 2 production and 4 pre-production devices are shown in Table 8-2. As there were no upsets on PG, there is high confidence that the TPS7H1301-SP is SEFI free and the recorded transient events on the other 3 signals indicate that this device has a very low upper-bound cross-section against SETs, as presented in Table 8-3.

Table 8-2. Summary of TPS7H1301-SP SET Test Conditions and Results

Run #	Unit #	Facility	Production Type	Ion	LET_{EFF} (MeV·cm²/mg)	Flux (ions/cm²/s)	Fluence (ions/cm²)	VIN (V)	VOUT (V)	IOUT (mA)	# VOUT ≥ |3%|	# CPOUT ≥ |3%|	# VREF ≥ |5%|	# PG ≥ 20%
13	5	KSEE	Final	^{169}Tm	75	1.22×10^5	1.00×10^7	6	-5	150	0	7	0	0
14	6	KSEE	Final	^{169}Tm	75	1.31×10^5	1.00×10^7	5	-1.8	400	3	81	3	0
15	7	KSEE	Pre	^{169}Tm	75	6.98×10^4	1.00×10^7	6	-5	150	0	10	0	0
16	8	KSEE	Pre	^{169}Tm	75	7.31×10^4	1.00×10^7	5	-1.8	400	2	-	0	0
17	9	TAMU	Pre	^{165}Ho	75	7.80×10^4	1.00×10^7	5	-1.8	400	0	-	0	0
18	10	TAMU	Pre	^{165}Ho	75	7.72×10^4	1.00×10^7	6	-5	150	0	3	0	0

Table 8-3. TPS7H1301-SP SET Cross-Sections

LET_{EFF} (MeV·cm²/mg)	Signal	VIN (V)	VOUT(V)	IOUT(A)	Fluence (ions/cm²)	# Transients	Upper-Bound Cross-Section (cm²)
75	VOUT	5	-1.8	400	3×10^7	5	3.89×10^{-7}
		6	-5	150	3×10^7	0	1.23×10^{-7}
	CPOUT	5	-1.8	400	1×10^7	81	1.01×10^{-5}
		6	-5	150	3×10^7	20	1.03×10^{-6}
	VREF	5	-1.8	400	3×10^7	3	2.92×10^{-7}
		6	-5	150	3×10^7	0	1.23×10^{-7}
	PG	5	-1.8	400	3×10^7	0	1.23×10^{-7}
		6	-5	150	3×10^7	0	1.23×10^{-7}

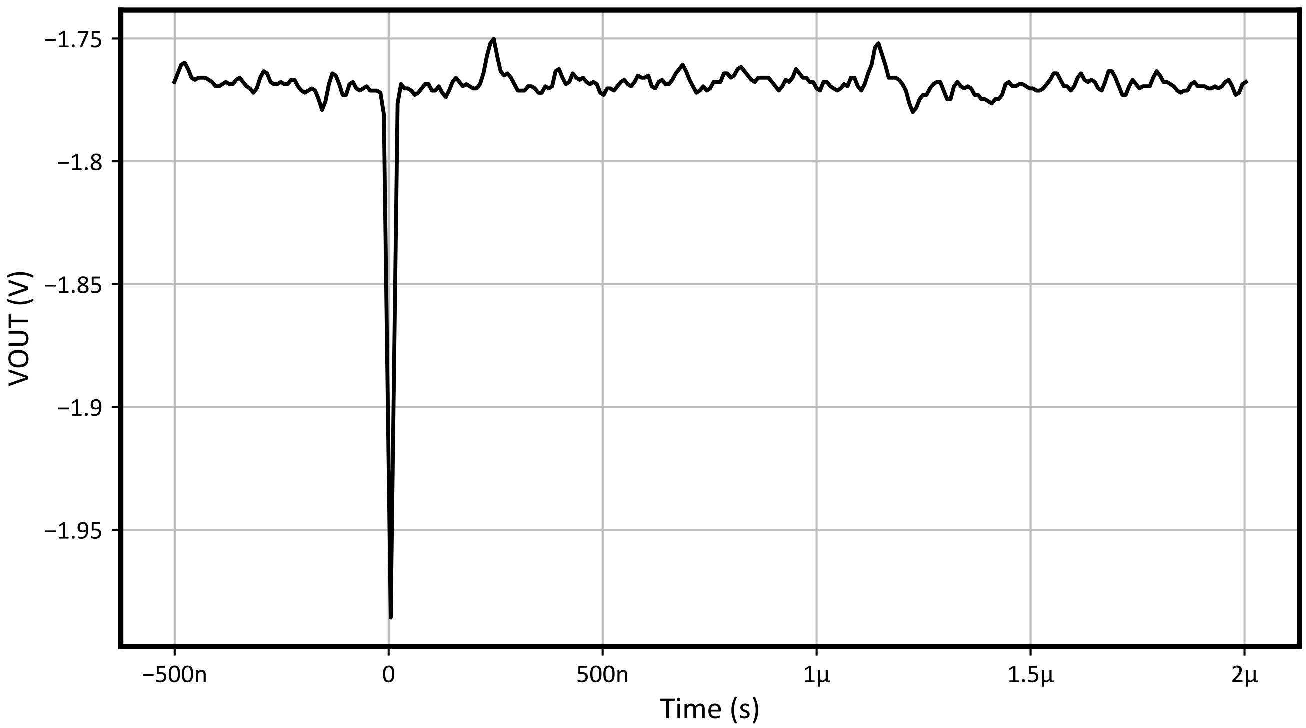

Figure 8-1. VOUT SET with VIN=5V, VOUT=-1.8V, IOUT=400mA

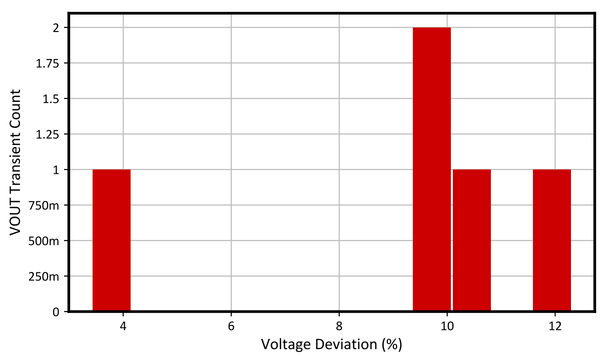

Figure 8-2. VOUT Voltage Deviation Histogram with VIN=5V, VOUT=-1.8V, IOUT=400mA

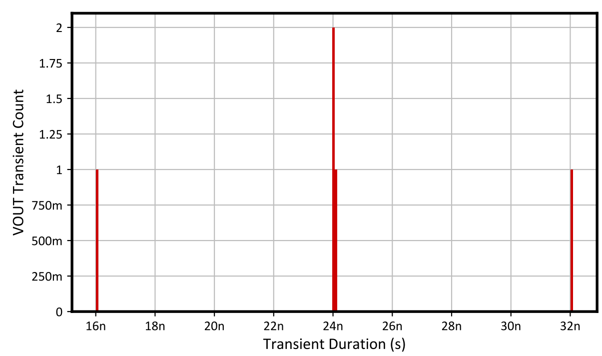

Figure 8-3. VOUT Transient Duration Histogram with VIN=5V, VOUT=-1.8V, IOUT=400mA

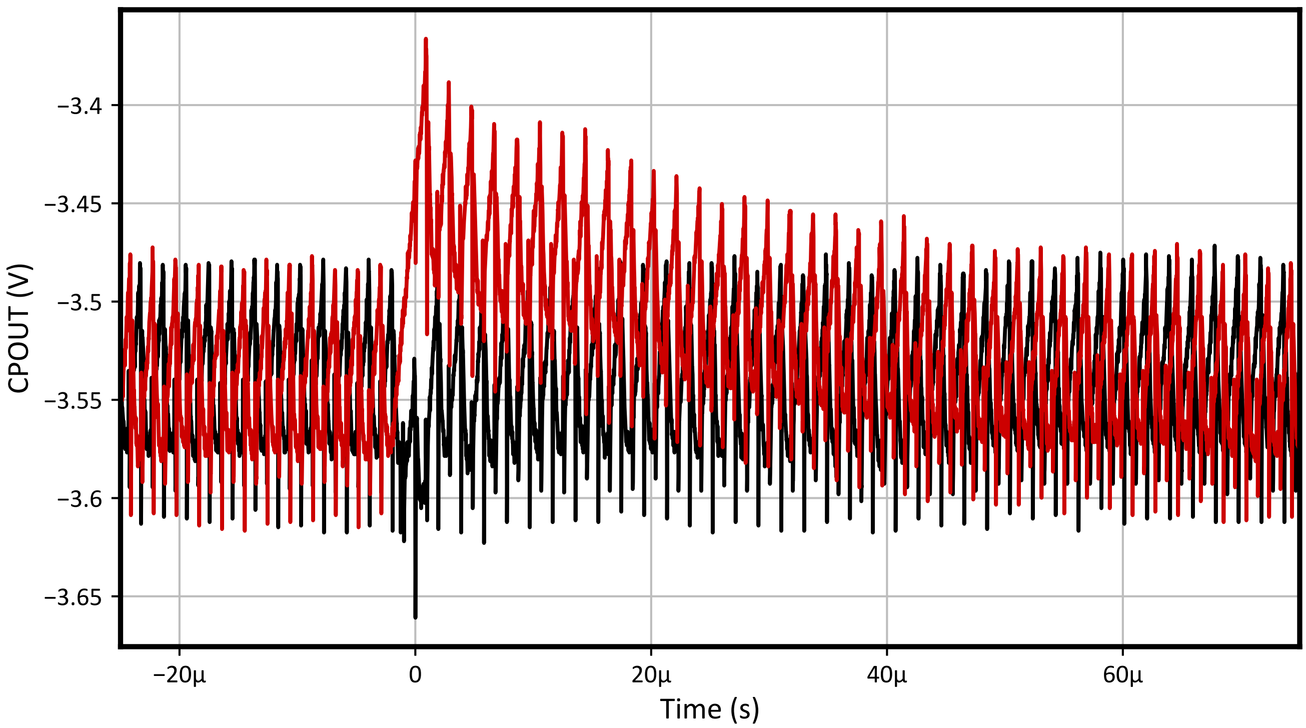

Figure 8-4. CPOUT SET with VIN=5V, VOUT=-1.8V, IOUT=400mA

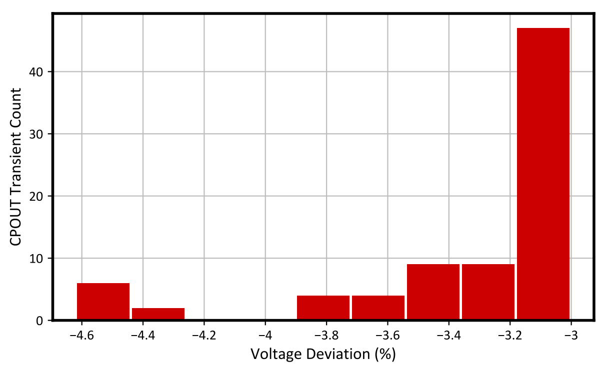

Figure 8-5. CPOUT Voltage Deviation Histogram with VIN=5V, VOUT=-1.8V, IOUT=400mA

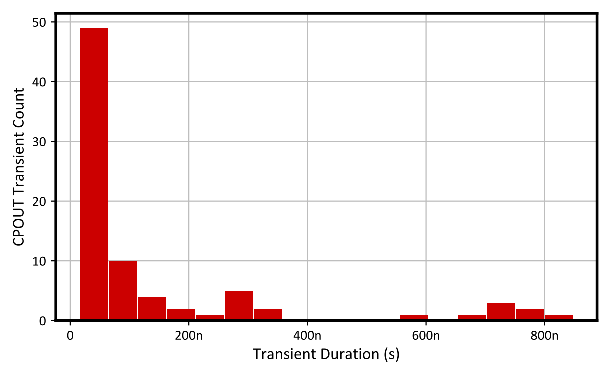

Figure 8-6. CPOUT Transient Duration Histogram with VIN=5V, VOUT=-1.8V, IOUT=400mA

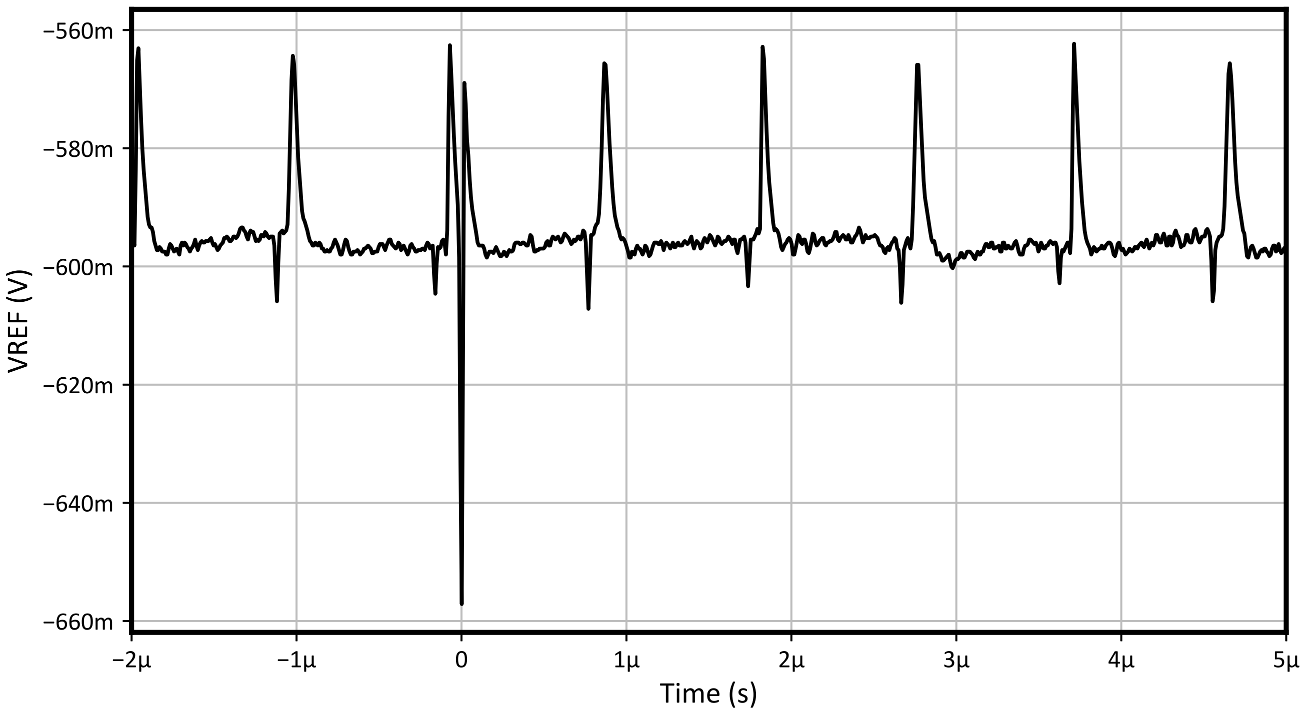

Figure 8-7. VREF SET with VIN=5V, VOUT=-1.8V, IOUT=400mA

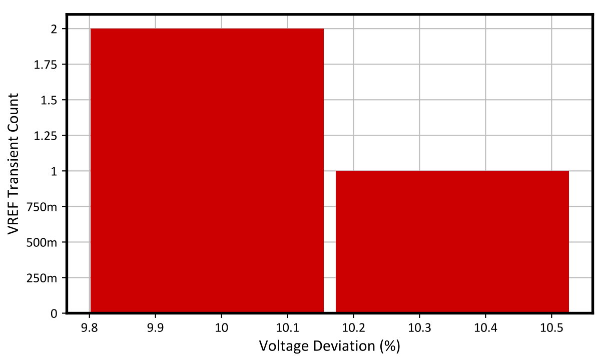

Figure 8-8. VREF Voltage Deviation Histogram with VIN=5V, VOUT=-1.8V, IOUT=400mA

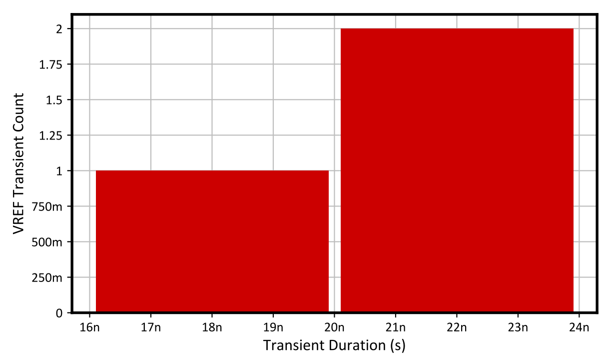

Figure 8-9. VREF Transient Duration Histogram with VIN=5V, VOUT=-1.8V, IOUT=400mA

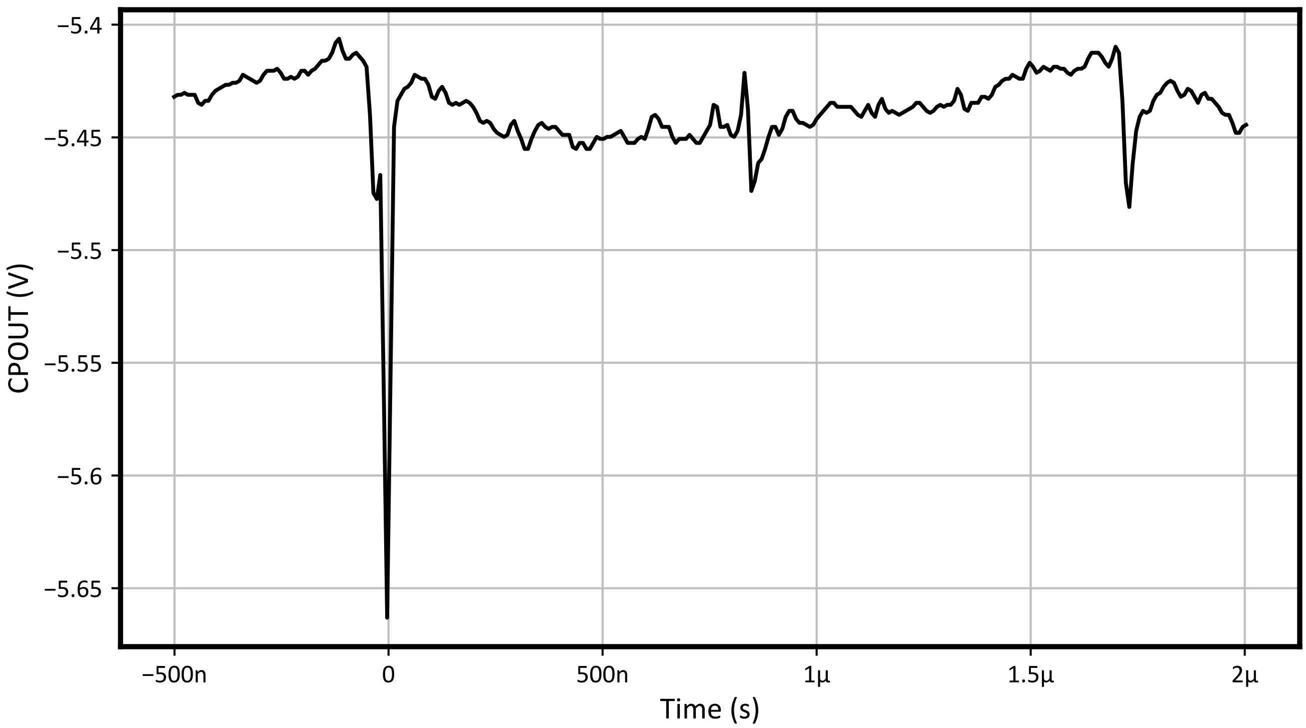

Figure 8-10. CPOUT SET with VIN=6V, VOUT=-5V, IOUT=150mA

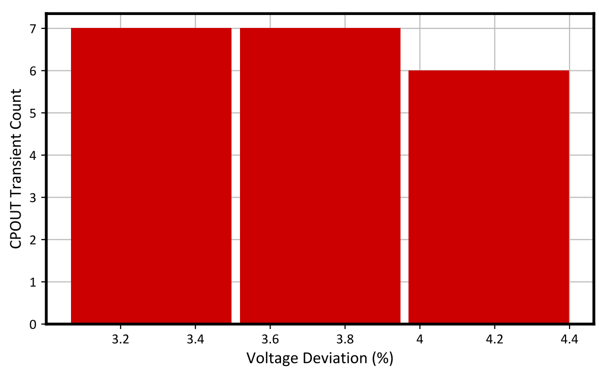

Figure 8-11. CPOUT Voltage Deviation Histogram with VIN=6V, VOUT=-5V, IOUT=150mA

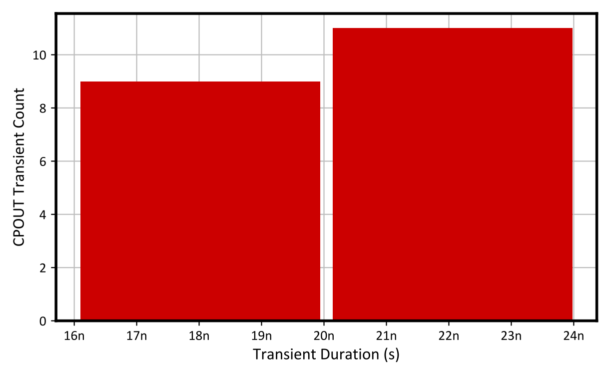

Figure 8-12. CPOUT Transient Duration Histogram with VIN=6V, VOUT=-5V, IOUT=150mA

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. **Note that this number is for reference since no SEL or SEB/SEGR events were observed.**

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}	2.41×10^{-4}	4.75×10^{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}	4.61×10^{-8}	2.89×10^{-12}	1.20×10^{-4}	9.49×10^{8}
GEO		1.77×10^{-4}		8.15×10^{-12}	3.40×10^{-4}	3.36×10^{8}

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 TPS7H1301-SP radiation-hardened, charge pump voltage inverter with an integrated low dropout adjustable regulator. Heavy-ions with LET_{EFF} = 75MeV·cm^2/mg were used for the SEE characterization campaign. Flux of ≈10^{5}ions/cm^2/s and fluences of ≈10^{7}ions/cm^2 per run were used for the characterization. The SEE results demonstrated that the TPS7H1301-SP is free of destructive SEL and SEB LET_{EFF} = 75MeV·cm^2/mg and across the full electrical specifications. Transients at LET_{EFF} = 75MeV·cm^2/mg were monitored and discussed and demonstrates this device is free of SEFI events at LET_{EFF} = 75MeV·cm^2/mg. CREME96-based worst week event-rate calculations for LEO(ISS) and GEO orbits for DSEE are presented for reference.

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